Kingdom of Bhutan

Second National Communication to the UNFCCC

National Environment Commission
Royal Government of Bhutan

Kingdom of Bhutan

Second National Communication to the UNFCCC

National Environment Commission
Royal Government of Bhutan

This report is the Second National Communication from the Kingdom of Bhutan to the United Nations Framework Convention on Climate Change (UNFCCC).The report was prepared as an Enabling Activity funded by the Global Environment Facility through UNDP-Bhutan. A soft copy of this report and other supporting documents are available online at www.nec.gov.bt/climate/snc/

Second National Communication from Bhutan to the UNFCCC

Coordinated and Edited by:
Thinley Namgyel, SNC Coordinator, EMD, NECS
Sonam Dagay,CCU, EMD, NECS
Tshering Tashi, EMD, NECS
Sonam Lhaden Khandu, CCU, EMD, NECS
Karma Tshering, PCS, NECS

Cover Illustration:
Rajesh, VAST Bhutan

Published by:
National Environment Commission
Royal Government of Bhutan
PO Box 466, Thimphu, BHUTAN
Tel: +975-2-323384/324323 Fax: +975-2-323385
www.nec.gov.bt

ISBN #: 978-99936-865-0-7

Thimphu, BHUTAN, November 2011

Printed @ *Phama Printers and Publishers*

Contents

Glossary of Acronyms 1

Executive Summary 5

Chapter1: National Circumstances 13

1.1 Geographic profile 15

1.2 Climate 15

1.3 Biodiversity 15

1.4 Demography 17

1.5 Socio-economy 18

1.6 Governance 20

1.7 National Coordination Mechanism on Climate Change 21

Chapter 2: National Greenhouse Gas Inventory 23

2.1 Introduction 25

2.2 Methodology 25

2.3 Total GHG Emissions 25

2.4 GHG Emission Trends 26

2.5 Energy 27

2.6 Industrial Processes and Other Product Use 28

2.7 Agriculture 29

2.8 Land-Use Change and Forestry 30

2.9 Waste 30

2.10 Emissions of PFCs, HFCs, and SF_6 31

2.11 Uncertainty Assessment 31

Chapter 3: Mitigation Measures 35

3.1 Introduction 37

3.2 Current Mitigation measures 37

3.3 Energy 40

3.4 Industrial Processes 51

3.5 Agriculture 53

3.6 Land Use Change and Forestry 59

3.7 Waste Management ... 62
3.8 Priorities for International Support in Mitigation ... 63
Chapter 4: Vulnerability and Adaptation ... 65
4.1 Introduction ... 67
4.2 Climate Baseline and Scenarios ... 67
4.3 Water Resources ... 78
4.4 Agriculture ... 80
4.5. Forests and Biodiversity ... 84
4.6 Energy (Hydropower) ... 91
4.7 Human Health ... 96
4.8 Glaciers and GLOFs ... 99
4.9 Cross-cutting Issues ... 105
4.10 Adaptation Plan ... 106
Chapter 5: Other Information ... 125
5.1 Climate Change Awareness ... 127
5.2 Education and Capacity Building for Climate Change ... 128
5.3 Technology Needs Assessment ... 129
5.4 Recommendations to improve Climate Change Actions in Bhutan ... 129
Annexures ... 133
Annex I: Climate Change Committees, Task Forces & Workshop Participants ... 135
Annex II: References ... 145

Foreword

As a small least developed and land locked country in the Eastern Himalayas, Bhutan already faces significant challenges for development but climate change threaten the achievements in development made thus far. Recognising the seriousness of such challenges, Bhutan has committed to taking all necessary measures to address climate change. In 2009 at COP 15, the Royal Government delivered a declaration titled, "Declaration of the Kingdom of Bhutan- The Land of Gross National Happiness to Save our Planet" wherein we committed to "keep absorbing more carbon than we emit – and to maintain our country's status as a net sink for Green House Gases".

While adaptation to the adverse impacts of climate change remains a top priority, actions on mitigation have been taken to not only ensure that development choices are in line with our development philosophy of Gross National Happiness, but also to encourage others that bold actions are needed to combat climate change. To support our carbon neutral declaration our Economic Development Policy aims for "green growth" and a strategy for Bhutan to remain carbon neutral will be soon in place. With regards to adaptation, Bhutan is implementing one of the first projects under the National Adaptation Program of Action to reduce the risk of glacial lake outburst flood from one of 25 dangerous glacial lakes. Furthermore, considering the extreme vulnerability of mountainous areas, Bhutan will be hosting the "Climate Summit for a Living Himalayas- Bhutan 2011", between Bangladesh, Bhutan, India and Nepal in November 2011 to promote regional cooperation in adaptation to climate change in the Eastern Himalayas.

The Second National Communication from Bhutan to the UNFCCC elaborates the actions taken, and needed, to address emissions and adverse impacts of climate change in Bhutan. Greenhouse gas emissions from Bhutan are still a third of what our forests sequester, but emissions are growing due to progress in socio-economic development and a growing population. Mitigation measures that are already in place and options for further action are presented in this report. Vulnerability and adaptation assessment in the key sectors of water, agriculture, energy (hydropower), human health, and glaciers, highlight the high degree of vulnerability of the people of Bhutan to climate change. The adaptation actions needed to address the vulnerabilities and impacts have been identified but will require the support of the international community to ensure their implementation.

While the Second National Communication from Bhutan to the UN Framework Convention on Climate Change is being submitted as an obligation, the information contained herein will also inform all Bhutanese and our development partners. This report is the outcome of a long process of collaboration, capacity building and consultation led by the National Environment Commission among key stakeholder groups including line agencies, civil society organisations, the private sector, and experts from outside Bhutan. In this regard, I would like to thank all the individuals and organisations that have contributed to this important document and also all our partners who have been supporting Bhutan in its development efforts and in combating climate change.

Jigmi Y. Thinley

Prime Minister of the Kingdom of Bhutan

Chairman of National Environment Commission

Glossary of Acronyms

ABI	Association of Bhutanese Industries
ABTO	Association of Bhutanese Tour Operators
ANOVA	Analysis of variance
A-OGCM	Atmosphere-Ocean General Circulation Model
ATF	Aviation Turbine Fuel
AWS	Automatic Weather Station
BAFRA	Bhutan Agriculture and Food Regulatory Authority
BaO	Barium Oxide
BAP	Biodiversity Action Plan
BAU	Business-as-Usual
BCCI	Bhutan Chamber of Commerce and Industry
BHU	Basic Health Unit
BPC	Bhutan Power Corporation
BRT	Bus Rapid Transit
BT	Biotemperature
BTC	Bhutan Tourism Corporation
BTFEC	Bhutan Trust Fund for Environment and Conservation
CAB	Construction Association of Bhutan
CAN	Calcium Ammonium Nitrate
CaO	Calcium Oxide
CC	Climate Change
CCD	Climate Change Division
CCU	Climate Change Unit
CDM	Clean Development Mechanism
CFL	Compact Fluorescent Lamp
CH_4	Methane
CLSH	Climate Summit for a Living Himalayas
CNG	Compressed Natural Gas
CNR	College of Natural Resource
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CoRRB	Council of Renewable Natural Resource Research of Bhutan
CSLH	Climate Summit for Living Himalaya
CSO	Central Statistical Organization
CTEM	Cleaner Technology and Environmental Management
DAMC	Department of Agriculture Marketing Cooperatives
DDM	Department of Disaster Management
DGM	Department of Geology and Mines
DGPC	Druk Green Power Corporation
DLG	Department of Local Governance
DoA	Department of Agriculture
DoE	Department of Energy
DOFPS	Department of Forests and Park Services
DoI	Department of Industry
DoL	Department of Livestock
DoPH	Department of Public Health
DoT	Department of Trade
DRE	Department of Renewable Energy
DSSAT	Decision Support System for Agrotechnology Transfer
EA	Environment Assessmnet
ECHAM	European Center Hamburg Model
ECP	Environment Climate change and Poverty
EE	Energy-efficient
EIA	Environment Impact Assessment
EMD	Environment Monitoring Division
ESD	Environment Service Division
EU	European Union
FAO	Food and Agriculture Organization

FeMn	Ferro Manganese
FMU	Forest Management Unit
FYM	Farmyard Manure
GCMs	General Circulation Models
GDP	Gross Domestic Product
GEF	Global Environment Facility
Gg	Gigagram
GHG	Greenhouse Gas
GLOF	Glacial Lake Outburst Flood
GLS	Gray Leaf spot
GNH	Gross National Happiness
GNHC	Gross National Happiness Commission
GWh	Giga Watt Hour
Ha	Hectare
HadCM	Hadley Centre Coupled Model
HCFC	Hydrochloroflurocarbons
HFCs	Hydrofuorocarbons
HIG	High growth
HIGEE	High growth coupled with energy efficiency
HLZS	Holdridge Life Zone system
HMSD	Hydro Metrological Service Division
HST	Hydraulic Siphon Technique
ICIMOD	International Center for Integrated Mountain Development
ICS	Information Communication and Services
IEMMP	Integrated Energy Management Plan
INC	Initial National Communication
IPCC	Inter-governmental Panel on Climate Change
IWRM	Integrated Water Resources Management
JDWNRH	Jigme Dorji Wangchuck National Referral Hospital
JSP	Joint Support Program
kV	Kilovolt
kWh	Kilowatt -hour
kWh/m^2	Kilowatt-hour meter square
LCMP	Land Cover Mapping Project
LDO	Light Diesel Oil
LEAP	Long-range Energy Assessment Plan
LED	Light Emitting Diodes
LPG	Liquefied Petroleum Gas
LRT	Light Rail Transit
LUCF	Land Use Change and Forestry
m.a.s.l	Meter Above Sea Level
m^3/s	Cubic Meter per Second
MoAF	Ministry of Agriculture and Forests
MoE	Ministry of Education
MoEA	Ministry of Economic Affairs
MoHCA	Ministry of Home and Cultural Affairs
MoIC	Ministry of Information and Communication
MOP	Muriate of Potash
MoWHS	Ministry of Works and Human Settlement
MPIOM	Max Planck Institute for Meteorology
MSTCCC	Multi Sectoral Technical Committee on Climate Change
MSW	Municipal Solid Waste
MT	Metric Tonnes
MU	Mega Units
MW	Megawatts
N_2O	Nitrous Oxide
NAMAs	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Program of Action
NBC	National Biodiversity Center
NBS	Net Basin Supply
NCCC	National Climate Change Committee
NCD	Nature Conservation Division

NDRMF	National Disaster Risk Management Framework
NEC	National Environment Commission
NECS	National Environment Commission Secretariat
NGO	Non Governmental Organization
NLC	National Land Commission
NMVOC	Non Methane Volatile Organic Compound
NRDCL	Natural Resources Development Corporation Limited
NSB	National Statistical Bureau
NSSC	National Soil Service Center
NTG	National Thematic Group
ORC	Outreach Clinics
PFCs	Perfluorocarbons
PFM	Plasmodium Falciparum
PHED	Public Health Engineering Division
PPD	Policy Planning Division
PRECIS	Providing Regional Climates for Impact Studies
PV	Photo Voltaic
R&D	Research and Development
RDTC	Rural Development Training Center
REDD+	Reducing Emission from Deforestation and Forest Degradation
REMP	Rural Electrification Master Plan
REP	Renewable Energy Policy
RGoB	Royal Government of Bhutan
Rn	Rain
RNR	Renewable Natural Resources
RNR-RC	Renewable Natural Resource Research Center
RSPN	Royal Society for Protection of Nature
RSTA	Road Safety and Transport Authority
SF_6	Sulphur hexafluoride
SFC	SAARC Forestry Center
SFD	Social Forestry Division
SLM	Sustainable Land Management
SLMP	Sustainable Land Management Programme
SNC	Second National Communication
SNV	Stichting Nederlandse Vrijwilligers (Netherland Development Organization)
SRES	Special Report on Emission Scenarios
SSP	Single Super Phosphate
START-SEA	System for Analysis Research and Training - South East Asia
SVO	Straight Vegetable Oils
TCB	Tourism Council of Bhutan
tCO_2e	Tonnes of Carbon Dioxide Equivalent
TERI	The Energy and Resources Institute
TLB	Turcicum Leaf Blight
Tn	Minimum Temperature
TOE	Tonnes of Oil Equivalent
Tx	Maximum Temperature
UNCBD	United Nations Convention on Biological Diversity
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UWICE	Ugyen Wangchuck Institute for Conservation and Environment
V&A	Vulnerability and Adaptation
W/m^2	Watt per meter square
WB	World Bank
WCD	Wildlife Conservation Division
WCP	Wangchuck Centennial Park
WEAP	Water Evaluation and Planning
WHO	World Health Organization
WR	Water Resources
WWF	World Wildlife Fund

Executive Summary

National Circumstances

The Kingdom of Bhutan is a small country with a population of 695,822, covering an area of 38,394km^2 and landlocked between China to the north and India to the south. Located in the eastern Himalayas, the landscape is mountainous and rugged with elevations from 100m to 7000m and extremely challenging for development. The landscape is dominated by high forest (70.46%) along steep slopes with very little land available for agriculture (2.93%). The climate is heavily influenced by the monsoons with 70% of the precipitation falling during summer (June-September). Rainfall and water availability also differs spatially with most falling in the warm southern foothills and getting drier towards the cooler northern highland areas. The combination of geography, climate and high forest cover has resulted in extremely high biodiversity and Bhutan is home to many species that are globally endangered.

Bhutan is classified as a Least Developed Country with significant challenges for economic development due to its small population base, mountainous terrain and by being land locked. While its share of GDP has been dropping, agriculture is still the most significant socio-economic sector with 69% of the population dependent on this activity, mostly in subsistence farming. Hydropower is now the most significant sector accounting for over 21% of GDP and 45% of revenue. The economy has been growing at an average of 8.7% per year fuelled by growth in hydropower, construction, industries and services. Tourism is a significant source of convertible foreign exchange earnings.

Governance in Bhutan has undergone historic changes in the last few years. While reforms started as far back as the 1980s, His Majesty the Fourth King Jigme Singye Wangchuck introduced Constitutional Monarchy in 2008. The first democratic elections were held in 2008 when representations to both the National Assembly and National Council elected and a new government headed by Prime Minister Jigmi Y. Thinley was formed. The first Constitution of the kingdom was also adopted in 2008 and His Majesty Jigme Khesar Namgyel Wangchuck was enthroned as the Fifth King. His Holiness the Je Khenpo is the head of the Monastic Bodies.

Greenhouse Gas Inventory

Total greenhouse gas (GHG) emissions, excluding Landuse change and Forestry (LUCF), in 2000 were 1,559.56 Gg CO_2-equivalent, which includes 270.23 Gg CO_2-equivalent from energy; 237.76 Gg CO_2-equivalent from industrial processes; 1,005.30 Gg CO_2-equivalent from agriculture, and 46.27 Gg CO_2-equivalent from waste. CO_2 sequestration by the forestry and land use sector in 2000 amounted to 6,309.6 Gg. Total GHG emissions, including LUCF, are estimated to be -4,750.04 Gg CO2-equivalent, indicating that Bhutan is a net sink for GHG emissions.

Emission trends were also estimated for 1994-2009. Emissions have been growing mostly in the energy and industrial sector. Between the first GHG Inventory year of 1994 and the second inventory year of 2000, emissions from energy grew at 21.4% a year mostly due to transport and industry growth. Emissions from industrial processes grew at about 8.7% a year.

It should be noted that due to almost 100% use of hydropower for electricity and relatively low industrialisation in 2000, emissions were most significant from agriculture sector due to methane and nitrous oxide from livestock management.

Mitigation Measures

Current Actions

Current mitigation measures include major policies and actions. The most significant measure is the constitutional mandate for the country to maintain 60% of land under forest cover at all times. In 2009, the government made a pledge for Bhutan to remain carbon neutral where emissions do not exceed the sequestration capacity of forests and called on the international community to support this pledge. Current policy measures for mitigation include; expansion of installed hydropower capacity to 10,000 MW by 2020, electricity for all by 2013, incentives for energy saving devices and low emission vehicles, and various legislation for environmental protection. Programs in agriculture like sustainable land management, reduction of improved livestock management and promotion of organic agriculture also provide mitigation benefits. Forest policy and management actions through sustainable forest management, reforestation plans and efforts to reduce fuel wood consumption are significant actions in the LUCF sector. The Economic Development Policy 2010 also provides several measures to promote "green growth" in response to the government's commitment to carbon neutrality. A strategy for Bhutan to maintain carbon neutral status is under development and is expected by end of 2011.

Options for Energy

While hydroelectricity is an important energy source for industry, increasing energy efficiency in industry and adoption of cleaner technology and process optimisation are important measures that need support for mitigating further emissions. Options for the transport sector include promotion of alternative fuels, electric and hybrid technologies and mass transport options. Transport demand management including proper design of urban areas and promotion of non-motorised transport are also seen as important mitigation measures for transport sector. The residential sector can benefit from improved building designs, promotion of more efficient appliances, and switching to cleaner fuels and electricity. Promotion of renewable energy will be important not only for mitigation but also from energy security and adaptation perspectives because of the country's dependence on climate vulnerable hydropower and imported fossil fuels.

Options for Industry

Mitigation in industry is linked to measures discussed in energy efficiency and also in process optimisation. Different efficiency improvement technologies through promotion of cleaner technologies and management will be important to both increase efficiency and reduce emissions. Other possible measures include substitution of input materials where feasible. Carbon capture and offsets are other options but costs may be an issue.

Options for Agriculture

Options for livestock include improvements in livestock and grazing management to reduce enteric fermentation such as reduction of surplus population and improvement of breeds, pasture and fodder. Manure management and biogas production are measures that could result in improved farmer income and emission reduction, and could provide other benefits like reduced human wildlife conflict and improved forest regeneration. Improved soil fertility management through promotion of farm yard manure, upscaling of sustainable land management practices, increasing cropping intensity, and increasing the area under organic farming are feasible measures for the cropping sector. Changes in techniques for rice farming could provide mitigation benefits but threats from urban expansion and limited area available for cultivation may affect paddy cultivation and food security in Bhutan. Several measures such as sustainable land management and livestock management will increase resilience of communities through better land husbandry and forest conservation.

Options for LUCF

In the landuse change and forestry sector, implementation of measures to support existing policies will be required. Opportunities like REDD+ need to be aligned with the National Forest Inventory to make optimum use of limited resources of manpower and financing. Review of FMUs and implementation of interventions to improve management will be crucial to maintain sustainable production of timber. Expansion and promotion of community forestry which is already picking up rapidly will provide both mitigation and socio-economic benefits to local communities. Prevention and control of forest fires will become more important under a future climate of drier and warmer winters. Reforestation of degraded areas and plantation activities should continue to both promote carbon sequestration and control of soil erosion and land degradation. It should be noted that measure for mitigation in LUCF sector also interface with adaptation and biodiversity conservation through ecosystem resilience.

Options for Waste

With increasing population and affluence, waste management will be an important mitigation measure. Emissions from wastes can be reduced through promotion of the 3Rs (reduce, reuse and recycle), promoting of composting the high organic content in municipal waste, methane capture and incineration for energy. Measures in waste management will require promotion of public private partnership and provision of incentives as per existing policies and legislation.

Vulnerability and Adaptation Assessment

The challenge for development and vulnerability of mountainous countries to climate change is well established and recognised in both the Convention and IPCC Assessment Reports. The adaptive capacity of mountainous countries like Bhutan is also very low due the fragility of the ecosystem and high costs of delivering services in a rugged terrain.

Climate Scenarios

Data is extremely limited in Bhutan in terms of historical record or spatial coverage to provide adequate baseline assessment of climate. However an analysis of observed data from 2000-2009 shows an increasing trend for both maximum and minimum temperatures but no apparent trends in precipitation pattern.

Future periods were modelled using ECHAM5 and HadCM3Q0 A1B scenarios in PRECIS. As compared to the 1980-2009 period mean annual temperature is projected to increase by 0.8^{0}C to 1.0^{0}C in 2010-2039 and by 2.0^{0}C – 2.4^{0}C by 2040-2069. Summer temperatures may increase by up to 0.8^{0}C in 2010-2039 and by 2.1^{0}C in 2040-2069. Winter temperatures will see higher increases with projected increase of 1.2^{0}C by 2010-2039 and 2.8^{0}C by 2040-2069. Changes in mean annual precipitation is projected to increase 10% by 2010-2039, and 20% by 2040-2069 but with conditions getting wetter in the monsoon season and slightly drier in the winter season. These more extreme precipitation changes between seasons conform to the findings of the IPCC (2007) report for the Himalayan region of South-east Asia. The change in the amount and seasonality of precipitation will affect not only the energy/hydropower and domestic water sector of Bhutan, but also the water used for irrigation.

Extreme climate events are also becoming more frequent with episodes of high rainfall over short periods such as cyclone Aila in May 2009 which brought record rains and rivers to flood levels throughout the country so much so that flows in Punatsangchhu were higher than during the 1994 GLOF. In addition to flash floods and landslides, windstorms are also increasingly damaging property and crops.

Water resources

While at a gross level, Bhutan has one of the highest per capita availability of water, the distribution of this resource over the seasons and area is an issue. WEAP modelling also shows that water availability in the future under climate change will be adequate at a gross level (main rivers) in the Wang Chhu Basin despite increasing demand and evapo-transpiration. However, this provides a false sense of availability as all major rivers are at valley bottoms while settlements and agriculture depends on rain, springs or smaller streams and tributaries. There are increasing reports of drying water sources throughout the country which is already a current vulnerability and may get worse with drier and warmer winters in the future.

Agriculture

Agriculture is a significant contributor to GDP in Bhutan, accounting for more than 18.5 % of GDP in 2008 and with 69% of the population dependent on this sector. Agriculture is already vulnerable due to increasing episodes of extreme events like flash floods, hailstorms, windstorms, droughts, pests and diseases. The mountainous terrain and limited land availability also affect food security. For the regions used as case studies, namely Kanglung for maize, Bhur for rice and Phobjikha for potatoes, both the HadCM3Q0/AIB and ECHAM5/A1B climate models, when coupled with the DSSAT crop model, show slight to moderate decreases in maize and rice yields, but significant increases in potato yields in the future (2010-2039 and 2040-2069).

Forests and Biodiversity

Current threats to forests and biodiversity include direct pressures like urbanisation, industrialisation and other development and human activities, and indirect pressures like population growth, changing consumption patterns and climate change. For the forestry and biodiversity sector, both the HadCM3Q0/AIB and ECHAM5/A1B climate models, when coupled with the Holdridge Forest Classification System, show a general northward migration of the major forest classes of Bhutan in the future (2010-2039 and 2040-2069), with subtropical species invading the southern margins and alpine species decreasing on the northern margins. Climate change will accelerate and exacerbate threats to biodiversity through loss of species, spread of invasive, pests and diseases, increased risk of forest fire, loss of agro diversity and loss of livelihood, traditional knowledge and practices.

Energy

Hydropower is important for Bhutan as it is the major source of government's revenue and contributes 19% of GDP mainly through exports to India. Almost 100% of electricity consumed is from hydropower with biomass as the major source of primary energy in Bhutan. Fossil fuels are the energy sources for transport and industries. Threats to hydropower include glacial lake outburst floods, increased sedimentation from increased precipitation, disruption in flows from changing precipitation and deterioration of watersheds. Using Net Basin Supply (NBS) assessment with the HadCM3Q0/AIB and ECHAM5/A1B climate models show generally slightly increased potential flows (NBS) and hydropower production in the wet monsoon season and slightly decreased flows and hydropower production in the dry winter season.

Health

The health sector will be vulnerable to future (2010-2039 and 2040-2069) climate change. However, the analysis for the health sector is greatly compromised by the lack of sufficient observed data. However health of climate change on impacts will be determined by both climate change and non-climatic factors such as health care and the health condition of the population. Strengthening of public health systems is necessary with or without climate change; climate change makes this need even more critical and urgent. The threat to human health from climate change includes potential changes in water and vector borne diseases.

Glaciers and GLOF

Bhutan has 677 glaciers and 2674 glacial lakes. Glaciers in Bhutan are retreating rapidly by 8-10m/year for debris free glaciers and 30-40m/year for debris covered glaciers. Due to the rapid melting, 25 glacial lakes are considered potentially dangerous with the threat of glacial lake outburst floods (GLOFs). Based on rates of glacial retreat, temperature trends in the area and trends in GLOF in the region, threats from GLOF are expected to increase in the future. Bhutan has implemented GLOF risk mitigation measures at a couple of lakes but and options for adaptation will depend on site conditions.

Adaptation priorities

Bhutan lacks the resources for meeting most of its development needs let alone adaptation measures required to address the additional burdens to address the impacts of climate change. Adaptation priorities were prepared based on the V&A assessment in the SNC and has been aligned with the national process under the Climate Summit for a Living Himalayas – Bhutan 2011. Priority adaptation actions have been prepared for the sectors of Water and Climate Related Disasters, Agriculture, Energy, Forest and Biodiversity, Human Health, and for Glaciers and GLOF. Cross cutting issues among the sectors and stakeholder groups, estimated costs, time frames and implementation measures have also been considered in the preparation of the Adaptation Priorities for Bhutan. The major objectives of the adaptation actions are as follows;

Water Sector and Climate related disasters

- Conduct comprehensive water resources assessment to improve understanding of water resource availability, the effects of climate change to develop appropriate adaptation measures
- Increase resilience to the impacts of climate change on water resources
- Water Resources Management through adoption and implementation of IWRM and eco-efficiency by using river basin framework for planning
- Strengthening Climate observation and network for early warning and forecasting of extreme events understanding climate change
- Mainstream CC & WR into national plans and programmes.

Agriculture

- To identify and map highly vulnerable farming communities across the country
- To strengthen institutional capacity of research/extension of DoA and at district and geog levels
- To increase access to improved genetic resources resistant to a-biotic and biotic stresses
- To identify and promote potential crops for agriculture/farming diversification to reduce crop failures
- Increase access to improved irrigation systems
- Improve postharvest facilities to increase shelf life of food products
- Improve information management system of the sector.

Energy

- Measures to ensure energy security during lean season (due to projected shortfall of hydropower production in winter as a result of climate change)
- Diversify the energy supply mix to reduce dependence on hydropower which is threatened by climate change
- Measures to address demand side management especially for projected lean season power shortfall under climate change.

Forests and Biodiversity

- Establishing the baseline, understanding and monitoring the impacts of CC on the species and ecosystems in Bhutan
- Increase ecosystem resilience against climate change disruption through re-evaluation and strengthening of protected areas, and sustainable management of biodiversity use
- Address risk of species loss from climate change by strengthening species conservation and management program by taking into consideration climate change
- Measures to address increased threat from invasive species, pests and diseases under changing climate
- Develop and implement a comprehensive forest fire management program, taking into account drier and warmer winters
- Conserve agro-biodiversity to promote adaptation of crops and livestock to changing climatic conditions
- Measures to ensure sustainable use and management of biodiversity by local communities by taking into account threats from changing climate

- Develop sustainable local conservation financing mechanisms to reduce vulnerability and build adaptive of ecosystems and habitats
- Capacity Building for Biodiversity and Climate Change Resilience by strengthening relevant institutions, public awareness, and institutional arrangements and mainstreaming.

Health

- Ensure adequate drinking water during the dry period
- Control and reduce spread of vector borne diseases
- Build disaster response management preparedness
- To educate and enhance the level of awareness to cope with health risks of climate change
- Strengthening the surveillance, research, monitoring, review and supervisory system and feedback mechanism for climate related diseases
- Build and improve program and research capacity to monitor climate change impacts on human health
- Reduce nutritional impacts of climate change.

Glaciers and GLOF

1. Enhancing preparedness and understanding for GLOFs triggered by Climate Change
2. Implementation of risk reduction measures in potentially dangerous glacial lakes.

Other Information

Climate Change Awareness

A survey of various stakeholders including policy makers revealed a high level of awareness about climate change and most believe that the cause of climate change is human activities. There was agreement that climate change will negatively affect development activities in Bhutan and that proper adaptation measures are necessary. While there is general awareness, in depth knowledge about the subject is lacking especially on information specific to Bhutan. This gap in information on climate change, attributed to lack of funds and resources and the general lack of research in Bhutan, is identified as a barrier to effective adaptation planning.

Education and Capacity Building

An assessment of existing educational institutes revealed that some institutional capacity exist in terms of programmatic structures that is conducive to mainstreaming environment, poverty and climate change (ECP) in to training programmes. However systematic constraints include uncertainties about demand for such trainings, lack of recognition of programs and courses, lack of resources for teaching and knowledge, insufficient number of faculty members and inadequate coverage of relevant issues in existing curricula and modules. Several recommendations to address these concerns and to mainstream ECP have also been made through the Joint Sector Program in Bhutan, but implementation is yet to be funded.

Technology Needs Assessments

While several technologies have been identified within the mitigation and adaptation measures, a full assessment is now underway and is to be completed in 2012. The first technology needs assessment conducted in 2002 (agriculture, industries and meteorology) was limited by lack of guidelines and methodologies and has become out dated.

Recommendations for future work to address climate change

- A comprehensive national climate change strategy should be developed by taking into account, adaptation needs, mitigation measures and other related crosscutting issues.
- Climate change mainstreaming should be promoted in development plans and policies at all levels.

- Addressing climate change requires additional efforts on top of ongoing development activities, so financial support required should be emphasized as support needed for the additional burden of climate change.
- There needs to be better coordination among stakeholders led by NEC in cooperation with GNHC.
- Increased support is needed to promote research and capacity development for climate change to better inform preparation of adaptation and mitigation measures.
- The media and relevant NGOs, and government should educate the citizens and policy makers about climate change and actions required to address the impacts and causes.
- Climate change must be incorporated in to the education curriculum as the youth of today will have to face a future with a different climate.
- NEC should be given more authority to monitor better implementation of environment and climate policies.
- Future assessment of climate change should address human settlements (urban areas and infrastructure) and conduct mapping of vulnerable population.

Chapter One

National Circumstances

1.1 Geographic profile

The Kingdom of Bhutan with an area of 38,394km^2 is one of Asia's smallest nations. The country is situated on the southern slopes of the Eastern Himalayas and lies between 26^{0}45' N and 28^{0}10' N latitude and 88^{0}45' E and 92^{0}10' E longitude. Bhutan is landlocked between the Tibetan region of China in the north, and India to the east, south and west. The country is characterized by fragile mountainous ecosystem with elevations ranging from about 100m in the foothills to over 7500m towards the north all within a range 170 km from the northern to the southern border. The east-west dimension of the country measures around 300km. High, rugged mountains, glaciers and moraines, deep valleys and ravines and depressions earmarking watercourses, drainage basins and waterfalls characterize Bhutan's physical features.

The most dominant land cover is forests, making up 70.46% of the land area while shrubs account for 10.43%, cultivated agricultural land and meadows account for 2.93% and 4.10% respectively. Snow cover constitutes 7.44% while bare areas constitute 3.20%. Degraded areas, water bodies, built up areas, marshy areas and non-built up areas constitute less than 1% each (Figure 1.2).

1.2 Climate

The climate in Bhutan varies substantially from one Dzongkhag to another due to dramatic changes in the topography, elevation and altitude. Bhutan's location at the northern periphery of the tropical circulation is an important feature that determines the country's climate. Bhutan has three climatic zones:

- The southern belt is made up of the Himalayan foothills with an altitude ranging from under 200m to about 2000m. It has a typical subtropical climate characterized by high humidity and heavy rainfall. In this climatic zone, the temperature ranges from 150C to 300 C all year round.
- The central belt consists of the main rivers valleys with altitude ranging from about 2000m to 4000m and is characterized by cool winters, hot summers with moderate rainfall. The temperature ranges from 150 to 260 C during the monsoon season (June through September) and -40 to 150C during the winter season, and
- The high region in the north encompasses snowcapped peaks and alpine meadows above 4000m with cold winter and cool summers.

Around 70% of the precipitation in Bhutan is generated by the monsoons while pre-monsoon activities generate about 20% of the precipitation. The summer monsoons last from late June through late September. The annual precipitation ranges widely in various parts of the country. The northern region gets about 40mm of annual precipitation, mostly in the form of snow. The temperate central valley get a yearly average of about 1000mm of rainfall while the southern region gets about 1,500mm of rainfall annually (NSB 2007).

1.3 Biodiversity

Due to the high forest cover, the mountainous landscape and monsoonal seasons, the country's diverse ecosystems are reservoirs of a spectacular assortment of wild flora and fauna. Bhutan is ranked amongst the top ten countries with the highest species density in the world, and has the highest fraction of land in Protected Areas and the highest proportion of forest cover than any Asian country (NCD 2002). The country's protected area system is made up of five national parks, four wildlife sanctuaries and a strict nature reserve, altogether making up an area of 16,396.43 km^2 or 42.71 percent of the country's total area (NCD 2009).

Bhutanese flora is considered to be of immense scientific value not only due to the high level of diversity but also because of the relatively good state of preservation compared to other Himalayan regions (NCD 2002). About 5,603 species of vascular plants, including 369 species of orchids, 46 species of rhododendrons and

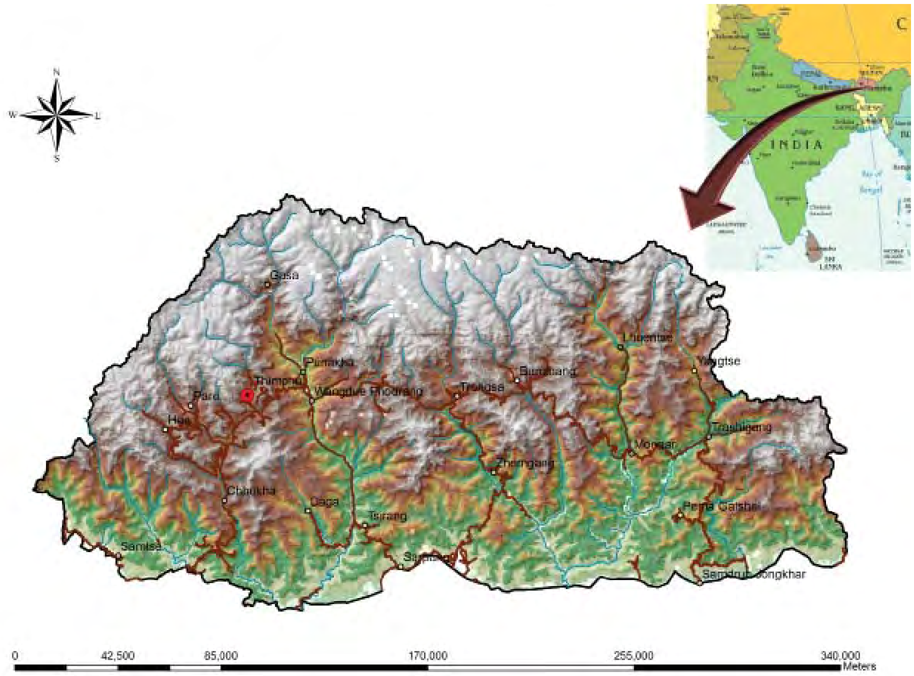

Figure 1.1: Bhutan and neighbouring countries

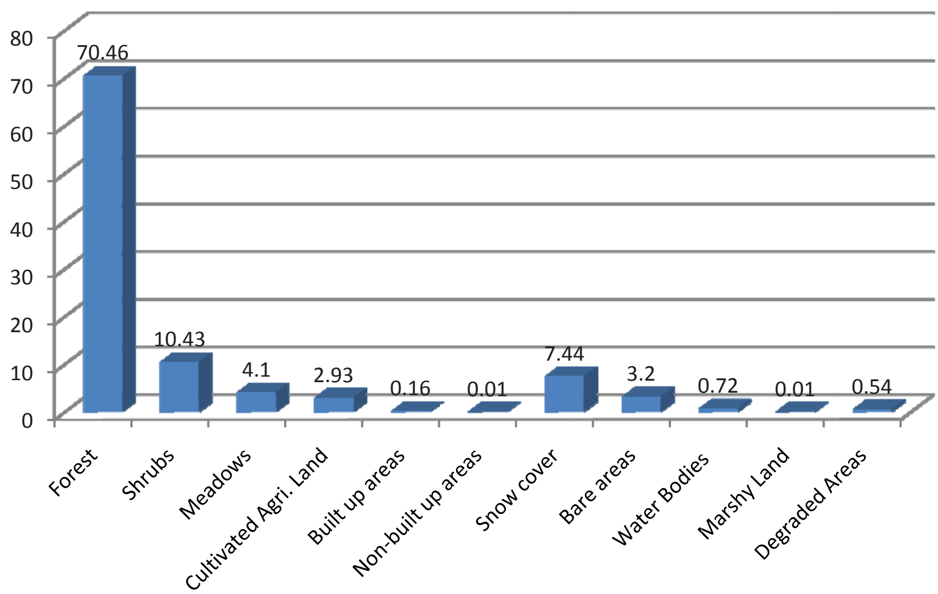

Figure 1.2: Land cover types of Bhutan (LCMP-2010)

105 endemics plant species have been recorded in Bhutan (NCD 2009). Close to 200 species of mammal are known to occur in Bhutan of which 27 are globally threatened species like the Royal Bengal tiger, Snow leopard, Red panda, Bhutan Takin and Golden langur among others (NCD 2009). 677 species of birds, of which 14 are globally threatened and ten restricted range bird species are found in the country. Other types of fauna are less studied but some 50 freshwater fish species are recorded in the country, 23 species of reptiles and amphibians were recorded in the Manas National Park and about 800 to 900 species of butterfly are expected to exist in Bhutan (NCD 2009).

In terms of domestic biodiversity, about 80 species of agricultural crops is grown in Bhutan including cereals such as rice, maize, barley, millet, wheat and buckwheat; fruits such as apple, orange, and pear; vegetables such as potato, bean, and cabbage; and spices such as chilli, cardamom, garlic, and ginger (NCD 2009). Several of the crop varieties represent adaptations to some of the highest agricultural lands in the world, with cultivation in the alpine agro-ecological zone extending up to 4,600 masl.

For example, while wheat is not an indigenous crop, varieties grown around Laya are adapted to higher altitudes and colder climatic conditions than wheat varieties in other parts of the world (NCD 2009). Livestock diversity in Bhutan basically consists of bovines, caprines, ovines, equines, avians, swines, canines and felines (NCD 2009).

1.4 Demography

With an estimated population of 695,822 in 2010, Bhutan is one of the least populated countries in Asia (Table 1.1). Population density is still very low at 18.1 persons per sq km but habitable area is restricted due to rugged terrain, snow and rocky areas and forests. When considering only cultivated land, human settlement areas (built up and non-built up) of the 2010 landcover assessment, population density in 2010 soars to nearly 585 persons per km^2.

The two key urban issues in Bhutan are the very rapid rates of urbanization and limited availability of serviced land (MoWHS 2008). The estimated average annual growth of urban population in Bhutan was 7.3 percent during 2000-2005 and as high as 12.6 percent in Thimphu, the capital of Bhutan (MoWHS 2008).

Since the establishment of health care facilities in Bhutan in 1962, there has been a continuous effort in improving the modern medical facilities. The Ministry of Health has a widespread network

Table1.1: Population statistics

	2000	2005	2010
Total Population	677,934	634,982	695,822
Male Population	342,324	333,595	363,383
Female Population	335,610	301,387	332,439
Population Density	14.6	16	18.1
Crude Birth Rate (per 1,000)	34.1	20	-
Crude Death Rate (per 1,000)	8.6	7	-
Natural rate of increase	2.5	1.3	-
Total Fertility Rate	4.7	2.6	-
Life Expectancy at Birth	-	66.25	-
Life Expectancy (Male)	-	65.65	-
Life Expectancy (Female)	-	66.85	-

Source: NSB 2006, 2010. *Note: Figures for 2000 are estimates from Health Survey 2000. 2005 figures based on Population and Housing Census of Bhutan 2005 and 2010 figures are projections.*

of health facilities, covering around 90% of the total population (NSB 2010). As of 2009, there are 31 hospitals, 181 Basic Health Units (BHU) and over 15 Extended Health Centers/Out Reach Clinics (ORC) providing health care services. General Health conditions in Bhutan are affected by low nutrition, poor sanitation, high prevalence of parasitic infections and contagious diseases. Acute Respiratory Infection continues to dominate entire morbidity situation (NSB 2007).

1.5 Socio-economy

Bhutan is categorised as a least developed country and its small population base, geographic size and being land locked pose significant challenges for development. Agriculture is still the dominant sector providing livelihood, income and employment to more than 69% percent of the total population. Bhutan is also rich in hydropower resources and the majority of electricity is exported to India. Fuelled by the development of hydropower, the industrial sector is developing rapidly. Tourism activities are also on the rise.

Socio-economic development in Bhutan is guided by the philosophy of Gross National Happiness (GNH) promulgated by His Majesty King Jigme Singye Wangchuck. In recent years, the philosophy of GNH has gained acceptance amongst global economists, academicians, social scientists and planners who are developing methods to use GNH as a development indicator to measure how sustainable and equitable development is. The GNH philosophy advocates that socio-economic development will lead to the prosperity and happiness of the general populace only if there is an equitable balance between the four pillars of: i) Good governance, ii) a pristine environment, iii) economic self-reliance and iv) the preservation and promotion of Bhutan's culture. To emphasize the importance of using GNH as the guiding philosophy for all plans and programs of the country, a GNH Commission was established in 2008 as the apex body for planning in Bhutan.

Between 2005 and 2010 the economy grew at an average of 8.7% per year with inflation largely contained within 7% over that period (GNHC 2011) and is fuelled mainly by investments in hydropower projects. Hydropower and construction together comprise one third of the economy while electricity has exceeded the agriculture sector in 2007 and 2010 constituting more than a fifth of the economy (Table 1.2). The service sector accounts for more than a third of Gross Domestic Product (GDP).

Agriculture

The renewable natural resources sector comprising of agriculture, livestock rearing and forestry accounted for almost a quarter of the total GDP in 2005 (NCD 2008) although its share of GDP has been declining due to growth in other sectors (Table 1.2). Although only 2.9% of the total land area is used for agriculture (NSSC 2010), more than 69% of Bhutan's population depends on agriculture for their livelihood.

Table 1.2: Economic Growth and GDP Aggregates

	2005	2006	2007	2008	2009	2010
Real GDP Growth	8.8%	6.9%	17.9%	4.7%	6.7%	8.1%*
GDP per capita (US$)	1,290	1,388	1,815	1,874	1,851	-
Electricity (% of GDP)	10.1%	13.1%	20.4%	21.1%	19.3%	21.8%*
Construction(% of GDP)	17.2%	14.8%	13.7%	11.4%	12.2%	15.1%*
Agriculture (% of GDP)	22.3%	21.4%	18.7%	18.4%	18.2%	14.5%*
Manufacture (%of GDP)	7.1%	7.6%	8.2%	8.4%	8.2%	8.7%*
Services (% of GDP)	41.7%	40.9%	37.3%	38.4%	39.8%	35.4%*
GDCF(% of GDP)	56.4%	45.6%	40%	30.6%*	35.4%*	39.6%*
GDS (% of GDP)	31.7%	33%	37.3%	40.2%*	40.5%*	40.4%*

Source: GNHC 2011

Therefore, a significant segment of the Bhutanese population is vulnerable to the impacts of climate change as crop irrigation is highly dependent on perennial streams and the monsoons. In addition, the rugged and steep terrain makes it difficult to both expand productions and market any surplus that may be produced. The main cash crops of the farmers (rice, potatoes, chillies, apples, maize and oranges) are all highly sensitive to water and temperature variations (DoA 2005). Dry land crops such as wheat, buckwheat, maize and barley are the major food source for the farmers; both for family consumption and for rearing livestock. Dry land crops are however entirely dependent on rainfall thus making the farmers even more vulnerable to climate hazards.

Energy

Bhutan's main export earnings are from hydropower generation and accounts for about 45% of the country's revenue. It is estimated that the country has the potential to generate up to 30,000MW of electricity, and the total installed capacity as of December 2010 was 1505.32 MW (NTG-Energy 2011). Much of the electricity is exported to India to generate income to finance development activities in the other sectors. In 2005, 1775MU[3] (approximately 67% of the total electricity generated) was exported to India. During the lean season (winter months), power is also imported from India. In 2005, 18.39MU was imported from India (DoE, 2005). Other sources of energy constitute coal, biomass, fossil fuels and other renewable energy sources. According to the Department of Geology and Mines, Bhutan has 1.96 million tonnes of coal reserves in the eastern part of the country in SamdrupJongkhar (DoE 2005). Biomass fuels from forests are the main energy source for a majority of households in both urban and rural areas of the country.

Transport

The transport system is a critical infrastructure for development. The transport system in Bhutan consists mainly of road and air transport services. Bhutan has a total length of 6920.14 Km (as of June 2010) of roads. This includes national highways, district roads, feeder roads, farm roads, urban roads, expressway, power tiller tracks, access road and forest roads (DOR, 2010). As of August 2011, there are 59,483 registered vehicles in Bhutan (RSTA2011). According to the Road Safety and Transport Authority (RSTA), the number of vehicles that is being registered in Bhutan is increasing at an average of 10% annually. Air transport was introduced in the beginning of the 1980s with links to neighbouring countries provided by the only national airline (Druk Air) with a fleet of two aircraft. Limited domestic air services are expected to begin in 2012.

Industries

Industrial development in Bhutan is constrained by many factors, including supply and access to raw materials, high transportation costs, small domestic market, lack of space and infrastructure, and shortage of skilled and semi-skilled human resources. The number of industrial license holders has increased steadily over the last decade, however most of the industrial establishments are small scale or cottage industries (Table 1.3). The mineral based industries are calcium carbide, ferro alloys and cement production. There are several units that mine dolomite, gypsum, limestone and coal. Wood-based industries comprise mainly of small sawmills, furniture making units, small traditional paper units, one particleboard factory, wood veneering and resin and turpentine harvesting. Agro-based industries consist of fruit processing and alcoholic beverage production units. Other manufacturing units produce local handicrafts and textiles.

Tourism

The tourism industry plays an important role in Bhutan's socio-economic development as the largest commercial source of convertible currency earnings. Bhutan's location, terrain and relative isolation have provided a strong comparative advantage for Bhutan as a special destination. Furthermore, the kingdom's reputation for conservation and its developmental philosophy of Gross National Happiness have all added to Bhutan's mystique, luring more and more tourists to Bhutan every year. The "High value, Low impact" policy has always guided tourism in

Bhutan. Under this policy, tourists are required to pay a sum of USD 200/day as tariff.

The sector also has significant potential for enhancing rural incomes and providing employment to the rising number of educated youth. Tourism in Bhutan began in 1974 through a government controlled agency, Bhutan Tourism Corporation. The BTC was privatized in 1991 opening the market up to other competitors. In 2008, there were 475 licensed tour operators (NSB 2010). In 2008 there were 27,636 tourist arrivals and the revenue generated in the tourism sector was over US$ 38 million (NSB 2010).

1.6 Governance

Governance in Bhutan has undergone historic changes in the last few years. While reforms started as far back as the 1980s, His Majesty, the Fourth King Jigme Singye Wangchuck dissolved the cabinet and devolved all executive authority and power to an elected Council of Ministers in 1998. He then introduced Constitutional Monarchy in 2008. The first democratic elections were held in 2008 when representations to both the National Assembly and National Council elected and a new government headed by Prime Minister Jigmi Y. Thinley was formed. The first Constitution of the kingdom was also adopted in 2008 and His Majesty Jigme Khesar Namgyel Wangchuck was enthroned as the Fifth King. His Holiness the Je Khenpo is the head of the Monastic Bodies.

At the national level, the nation is primarily governed through the Cabinet where the Cabinet Ministers are the heads of ministries. At the local level, Bhutan is administratively divided into 20 *Dzongkhags* (districts) governed by a district administrator or *Dzongda*. The Dzongkhags are sub-divided into small blocks or *geogs*. There are 205 *geogs* in the twenty Dzongkhags which are grouped under 47 constituencies.

The National Assembly (Gyelyong Tshogdu) consists of 47 members who are representatives from the 47 constituencies directly elected by the people of their respective constituencies. Their main functions are to enact, amend or repeal laws, endorse appointments of senior government officials and to approve the Five Year Plans and the national budget (NSB 2010). The National Assembly meets twice a year and the speaker may convene special sessions if necessary.

Table 1.3: Number of industrial establishments by sector, size and type 2005-2009

Industrial establishments	2005	2006	2007	2008	2009
Total number of industries	***17,257***	***24,505***	***26,261***	***28,073***	***30,317***
Industries by size					
Large scale	57	72	85	91	103
Medium scale	62	78	112	128	156
Small scale	678	1,660	1,815	2,064	2,330
Cottage scale	6,941	12,920	14,165	15,359	16,883
Other (Contract)	9,519	9,775	10,084	10,431	10,845
Industries by type					
Agro based	181	199	207	217	252
Forest based	414	470	517	574	651
Mineral based	80	91	110	144	163
Others	310	373	420	454	499
Contract	9,519	9,775	10,084	10,431	10,845
Services	6,753	13,597	14923	16,253	17,907

Source: NSB 2010

The National Council has 25 members, of which 20 are directly elected by the people from the 20 Dzongkhags and the other 5 are nominated by His Majesty the King of Bhutan. Their main functions are to review matters affecting the security and sovereignty of the country and to ensure that the government safeguards the interest of the nation and fulfills the aspirations of the people (NSB 2010). The National Council also meets twice a year and special sessions can be convened depending on the needs.

The Monastic Body comprises of the Central Monastic Body and the Rabdeys (District Monastic Bodies). The Monastic Body is the sole arbiter on religious matters and His Holiness the Je Khenpo is the head of the Monastic Body. The current strength of the Monastic Body is over 5000 registered gelongs (monks) and is financed by an annual subsidy from the Royal Government (NSB 2010).

1.7 National Coordination Mechanism on Climate Change

After Bhutan ratified the United Nations Framework Convention on Climate Change (UNFCCC) on 15 August 1995, the National Environment Commission Secretariat (NECS) became the national focal agency for climate change activities in the country. The National Environment Commission (NEC) chaired by the Prime Minister is designated as the National Climate Change Committee (NCCC).

In 2009, the NEC at its 27th Commission Meeting approved the formation of a national level task force, the Multi Sectoral Technical Committee on Climate Change (MSTCCC) to serve as a forum for coordinating all climate change related activities/ issues in the country. The meeting also approved the formation of a Climate Change Unit (CCU) at the NECS. Furthermore, in June 2011 the 32nd NEC approved the up-gradation of the CCU to a Climate Change Division at the NECS.

Chapter Two

National Greenhouse Gas Inventory

2.1 Introduction

This chapter presents the estimates of national anthropogenic greenhouse gas (GHG) emissions by sources and removals by sinks for the year 2000 for the Kingdom of Bhutan. The inventory includes five categories of emission sources: Energy; Industrial processes; Agriculture; Land use change and forestry (LUCF) and Waste. Trends in emissions of carbon dioxide (CO2), methane (CH4) and nitrogen oxide (N2O) are also estimated for 1994-2009.

2.2 Methodology

The methodology used to develop the inventory is based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* and the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Good Practice Guidance) and the *Good Practice Guidance for Land Use, Land-Use Change, and Forestry*, which further expanded upon the methodologies in the Revised 1996 IPCC Guidelines. Inventory worksheets were prepared using the M.S. Excel based software "Non-Annex I National Greenhouse Gas Inventory Software, Version 1.3.3" released by the UNFCCC.

The preparation of the GHG inventory was a consultative process among analysts within relevant sectors and agencies in Bhutan and coordinated by the National Environment Commission Secretariat (NECS). At the inception of the inventory process, a National GHG Inventory Team was formed and trained on the use of the Revised 1996 IPCC GHG Guidelines and UNFCCC Software. Subsequently the sectoral working groups of the inventory team collected activity data from national sources, other secondary sources, such as published research, statistical reports, and related studies as necessary. Emission factors were based on IPCC default values and conversion coefficients, and adjusted to reflect local conditions, where necessary and possible. Where actual data was not available, expert judgment by Bhutanese analysts was relied upon. A number of assumptions were made in the application of the IPCC methodology and default data, to the context of Bhutan.

Similarly, assumptions were made in order to justify the use of locally derived values, intended to represent the explicit local conditions of Bhutan. Throughout the process, the NECS and a consultant interacted with the thematic groups and reviewed and cross checked all assumptions and information collected locally to identify and resolve all open questions and issues. The NECS finalized the data values in the Inventory Spreadsheets and produced summary reports for the 2000 inventory year.

Details of the methodology are provided in the supporting document "Technical Basis for the Second Greenhouse Gas Inventory for

Table 2.1: Total GHG emissions in Bhutan, 2000

GHG Sources & Sinks	Total (CO2, CH4 and N2O), CO_2-equiv	GHG, Giga grams						
		CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1 Energy	270.23	260.31	0.38	0.01	1.76	9	1.30	0.96
2 Industrial Processes	237.76	237.76	0.0	0.0	0.0	0.0	1.69	0.1
3 Solvent & Other Product Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 Agriculture	1005.30	0.0	25.85	1.49	0.2	0.41	0.0	0.0
5 Land-Use Change & Forestry	-6,309.6	-6,309.6	0.0	0.0	0.0	0.0	0.0	0.0
6 Waste	46.27	0.0	2	0.01	0.0	0.0	0.0	0.0
Total GHG Emissions, excluding LUCF	1,559.56	498.07	28.23	1.51	1.78	9.41	4.7	1.05
Total GHG Emissions, including LUCF	**-4,750.04**	**-5,810.9**	**28.23**	**1.51**	**1.78**	**9.41**	**4.7**	**1.05**

Bhutan", Volume 1 (Technical notes on methods, assumptions and data sources) and Volume 2 (Spreadsheets of the inventory for year 2000)[1].

2.3 Total GHG Emissions

Table 2.1 presents total GHG emissions by sources and removals by sinks for the year 2000. Total GHG emissions, excluding LUCF, in 2000 were 1559.56Gg CO_2-equivalent, which includes 270.23 Gg CO_2-equivalent from energy; 237.76 Gg CO_2-equivalent from industrial processes; 1005.30 Gg CO_2-equivalent from agriculture, and 46.27 Gg CO_2-equivalent from waste. Emissions from perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfurs hexafluoride (SF6) in Bhutan are negligible as the products containing these gases are not produced in the country. CO_2 sequestration by the forestry and land use sector in 2000 amounted to 6,309.6 Gg. Total GHG emissions, including LUCF, are estimated to be -4,750.04 Gg CO2-equivalent, indicating that Bhutan is a net sink for GHG emissions.

2.4 GHG Emission Trends

Figure 2.1 presents the changes in total GHG emissions for 1994, base year for the Initial National Communication (INC), and 2000. The first stacked column represents emissions as reported for 1994 in the INC while the second stacked column represents emissions estimated the same year in the SNC. The dominant contribution of the LUCF sector is evident; GHG sequestration increases by nearly 80% as compared to the estimate in the INC and in 2000. However this is mainly attributed to different assumptions area comprising "managed forests". In the current inventory half of forest all protected areas is assumed to have human interventions (See section 2.8) but in the INC, all protected areas was excluded. However, estimate of net operable area has also changed since the INC and area under plantation/afforestation in 1994 was also lower.

Emissions excluding LUCF for the revised 1994 are higher at 1,413 Gg CO_2equivalent compared to 1,292 Gg CO_2equivalent in the INC; the differences are traced to omission of emissions from rice cultivation, omission of some coal types in industry and construction for energy, and different choices of emission factors for metal industries in the INC. Waste emissions were not estimated in the INC and the revised estimates for 1994. So comparing the revised 1994 estimates and estimates for 2000, total GHG emissions, excluding LUCF, have increased by about 10%, from 1,413 Gg CO_2 equivalent in 1994 to 1,560 Gg CO_2 equivalent in 2000. This increase is mainly due to increase in industrialization and rapid urbanization; Emissions from manufacturing industries increased from 154.27 Gg CO_2 equivalent to 237.76 Gg CO_2 equivalent, and emissions from energy combustion increased from 159.95 Gg CO_2 equivalent to 270.23 Gg CO_2 equivalent.

The emissions from agricultural sector are about 8.47% lower in 2000 from 1994 level which is due to lower N_2O emissions from agricultural soils. It should be noted that emissions from the agriculture sector is heavily influenced by the number of livestock. The contribution of GHG emissions from the waste sector is very small in 2000.

Figure 2.2 presents GHG emission trends for energy and industrial processes for the period 1994-2000. The time series data for the period 1994-1998 are unavailable for agriculture and waste. Forest cover data were available only for 1994 and 2000. Over the period of 1994-2000 GHG emissions from energy use have been growing by about 21.4% per year. This is primarily due to steep increase in energy use for road transport which nearly doubled, and manufacturing industries and construction, which increased by almost 8-fold. Also over this period, GHG emissions from industrial processes have been growing about 8.7% per year. These trends are consistent with the rapid growth in economic development in the country.

1 Copies of this document and all supporting documents published separately can also be downloaded from www.nec.gov.bt/climate/snc/

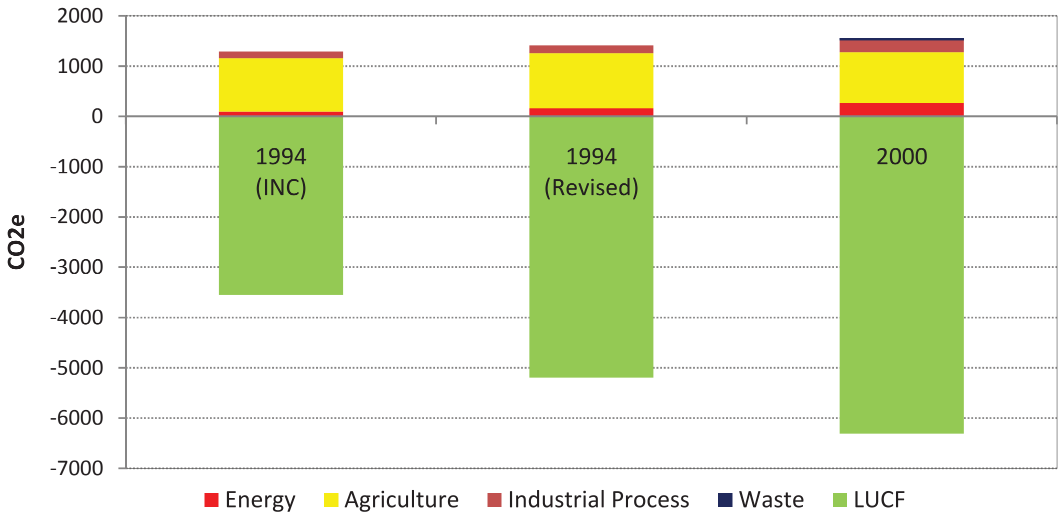

Figure 2.1: Total GHG emission trend, 1994 & 2000

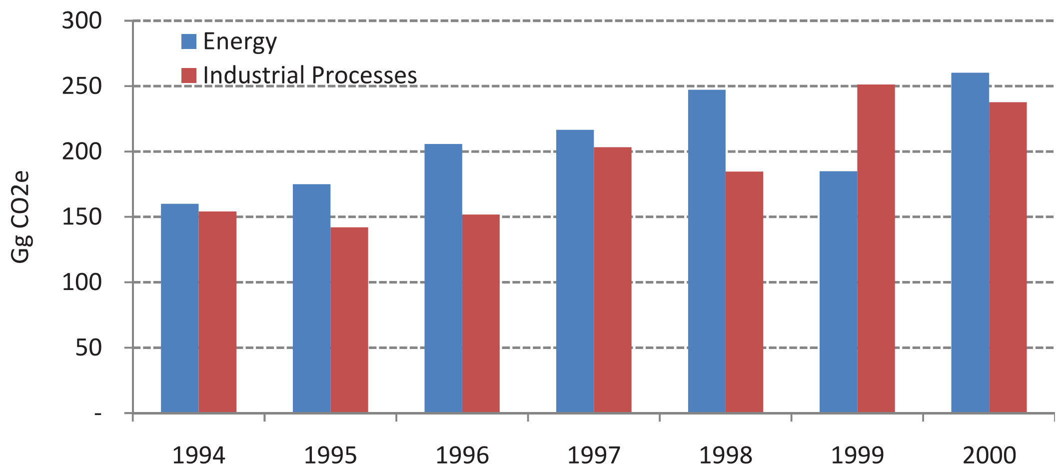

Figure 2.2: GHG emission trend for energy and industrial processes, 1994-2000

2.5 Energy

Table 2.2 summarizes GHG emissions associated with energy activity in 2000. The total GHG emissions from energy use were 270.23Gg CO_2-equivalent which represented about 17.33% of total national GHG emissions excluding LUCF. Activity data for energy use were based on the 2005 Bhutan Energy Data Directory as well as Bhutan Trade Statistics for the year 2000.

The majority of emissions from energy activities are from fossil fuel combustion. There were no oil and gas exploration activities, and low levels of mining activities that contribute to fugitive emissions. GHG emissions from fuel combustion are associated with the use of petroleum products that are imported from India - petrol and diesel are used mainly for road transport; kerosene and LPG are used in the commercial/institutional and residential sectors for cooking and space heating.

Figure 2.3 illustrates the breakdown in energy-related GHG emissions by activity-type in 2000. Transport sector account for about 45% of all energy-related emissions; followed by Manufacturing and construction sector at 42%. The share of GHG emissions from energy industries in the total GHG emissions excluding LUCF is less than 1%, as hydropower was and continues to be the main resource for electricity generation in Bhutan with negligible levels of diesel used in stand-by diesel generator. Biomass in the form of fuel wood is the main resource for rural residential energy requirements and amounts to nearly 60 Gg CO_2-equivalent of GHG emissions in 2000.

2.6 Industrial Processes and Other Product Use

Table 2.3 summarizes GHG emissions associated with industrial processes and products use in 2000. Industrial processes are the third largest emitter of anthropogenic GHG emissions in Bhutan, accounting for 237.76 Gg of CO_2–equivalent, or about 15.24% of total GHG CO_2–equivalent emissions in 2000. Activity data for the industrial sector was based on Bhutan Trade Statistics from the years 1999, 2000 and 2001; the national industrial license database; and surveys of nearly 60 individual industries. Mineral products (i.e., cement production) account

Table 2.2: GHG emissions from energy use, 2000 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
All energy emissions	**268.08**	**260.31**	**0.37**	**0.0**	**1.75**	**9**	**1.29**	**0.96**
A Fuel Combustion Activities	*270.23*	*260.3 1*	*0.38*	*0.01*	*1.75*	*9*	*1.29*	*.96*
1 Energy Industries	0.7	0.07	0.0	0.0	0.0	0.0	0.0	0.0
2 Manufacturing Industries & Construction	108.5	107.84	0.01	0.0	0.34	0.32	0.02	0.57
3 Transport	118.11	117.90	0.01	0.0	1.25	3.11	0.60	0.20
4 Other Sectors	41.64	34.50	0.34	0.0	0.16	5.57	0.67	0.19
B Fugitive Emissions from Fuels	*0.21*	*0.0*	*0.01*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
1 Solid Fuels	0.21	0.0	0.01	0.0	0.0	0.0	0.0	0.0
2 Oil and Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Memo Items	*61.93*	*61.93*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
International Bunkers	2.18	2.18	0.0	0.0	0.0	0.0	0.0	0.0
CO2 Emissions from Biomass	59.75	59.75	0.0	0.0	0.0	0.0	0.0	0.0

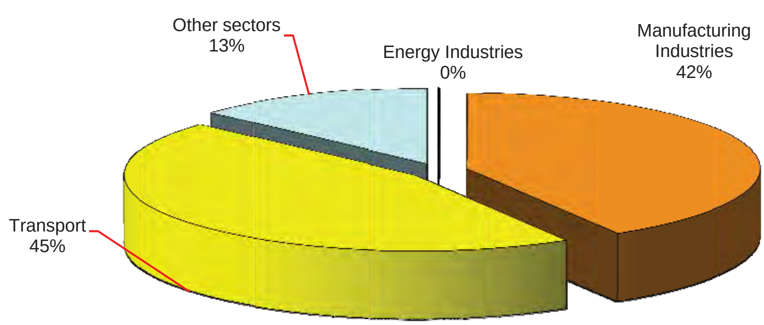

Figure2.3: Breakdown of GHG emissions associated with energy activities, 2000

Table 2.3: GHG emissions from industrial activity, 2000 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
All industry emissions	**237.76**	**237.76**	**0.0**	**0.0**	**0.0**	**0.0**	**1.69**	**1.0**
Industrial Processes	*237.76*	*237.76*	*0.0*	*0.0*	*0.0*	*0.0*	*1.69*	*0.10*
A Mineral Products	152.07	152.07	0.0	0.0	0.0	0.0	1.42	0.10
B Chemical Industry	18.47	18.47	0.0	0.0	0.0	0.0	0.0	0.0
C Metal Production	67.22	67.22	0.0	0.0	0.0	0.0	0.0	0.0
D Other Production	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.0
E Production of Halocarbons and Sulphur Hexafluoride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F Consumption of Halocarbons and Sulphur Hexafluoride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Solvent and Other Product Use	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
A Paint Application	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B Degreasing and Dry Cleaning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C Chemical Products, Manufacture and Processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

for the largest share of emissions, about 64%; followed by metal production (i.e., ferroalloys) at about 28.27% and emissions from the chemical industry (i.e., carbide production) at roughly 8%.

2.7 Agriculture

Table 2.4 summarizes GHG emissions associated with agricultural activity in 2000. Relative to overall total GHG emissions excluding LUCF, the GHG emissions of 1005.30 Gg CO_2-equivalent from agricultural activities constitute about 64.5% of total national GHG emissions. In 2000 over 70% of the population was reliant on subsistence agriculture. Therefore with a small industrial base and heavy reliance on hydropower, this high share of GHG emissions from agricultural activities is not surprising. Activity data was based on national livestock statistics and census information and expert judgment by specialists in the Department of Agriculture (Ministry of Agriculture). GHG emissions from the agriculture sector are largely from livestock used in subsistence farming.

The majority of emissions are associated with methane emissions from enteric fermentation (40%), followed by agricultural soils (about 37% and mainly from use of animal waste). Emissions from manure management of cattle, buffalo, swine, and other household livestock account for 17% of agricultural emissions. Rice cultivation accounts 6% of agricultural emissions. It is notable that due to absence of subsidies and preference for organic inputs by most farmers, synthetic fertilizers result in very minor emissions. Less than 2% of emission from agricultural soils is due to synthetic fertilizers with animal waste contributing 90% of emission from agricultural soils.

Table 2.4: GHG emissions from agricultural activity, 2000 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
All agriculture emissions	**1005.30**	**-**	**25.85**	**1.49**	**0.02**	**0.41**	**0.0**
A Enteric Fermentation	401.65	-	19.13	0.0	0.0	0.0	0.0
B Manure Management	169.80	-	3.80	0.29	0.0	0.0	0.0
C Rice Cultivation	61.15	-	2.91	0.0	0.0	0.0	0.0
D Agricultural Soils	372.10	-	0.0	1.20	0.0	0.0	0.0
E Prescribed Burning of Savannas	0.0	-	0.0	0.0	0.0	0.0	0.0
F Field Burning of Agricultural Residues	0.60	-	0.02	0.00	0.02	0.41	0.0

2.8 Land-Use Change and Forestry

Table 2.5 summarizes GHG emissions associated with land use, land-use change and forestry in 2000. The managed forests, forest plantations and the abandonment of managed lands sequestered 6,309.63 Gg CO_2-equivalent and is roughly four times the level of Bhutan's total GHG emissions excluding LUCF. Annual activity data were compiled from national forest reports which used a mixture of sources including annual forest resource and land cover assessments, GIS-based and RS-based land use/land cover mapping using Landsat satellite images from 1999-2000.

The prominence of carbon sequestration in the national GHG inventory reflects national policy that regards forests as crucial for the well-being of the Bhutanese population through its natural regulation of climatic, water, and flora/fauna resources to furnish essential needs such as wood, food, fodder and traditional remedies. The Constitution of the Kingdom of Bhutan also mandates that 60% of the country remain under forest cover for all times to come. Total managed forests accounted for about 14,054 square kilometres in Bhutan in 2000[2]. This total managed forest area is comprised of 8,124 square kilometers (58%) reserved for potential commercial management; 4,231 square kilometers (30%) of protected forests (representing 50% of total protected forest land); and 1,700 square kilometers (12%) of areas already being managed as forest management units (figure 2.4). It is important to note that virtually all forests in Bhutan have some form of

2. The area estimated as "managed forests" for this inventory is much more conservative when compared to the Forest Resources Assessment for Bhutan (FAO 2005) which estimated managed forests in Bhutan at 2,933,500 ha (modified natural + semi-natural + 50% of Primary or 2,543,000 + 184,000 + 0.5x413,000 ha).

Table 2.5: GHG emissions from LUCF activity, 2000 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO
All LUCF emissions	-6,309.6	-6309.6	0.0	0.0	0.0	0.0
A Changes in Forest and Other Woody Biomass Stocks	-5,988.0	-5,988.0	0.0	0.0	0.0	0.0
B Forest and Grassland Conversion	0.0	0.0	0.0	0.0	0.0	0.0
C Abandonment of Managed Lands	-321.63	-321.63	0.0	0.0	0.0	0.0
D CO2 Emissions and Removals from Soil	0.0	0.0	0.0	0.0	0.0	0.0
E Other	0.0	0.0	0.0	0.0	0.0	0.0

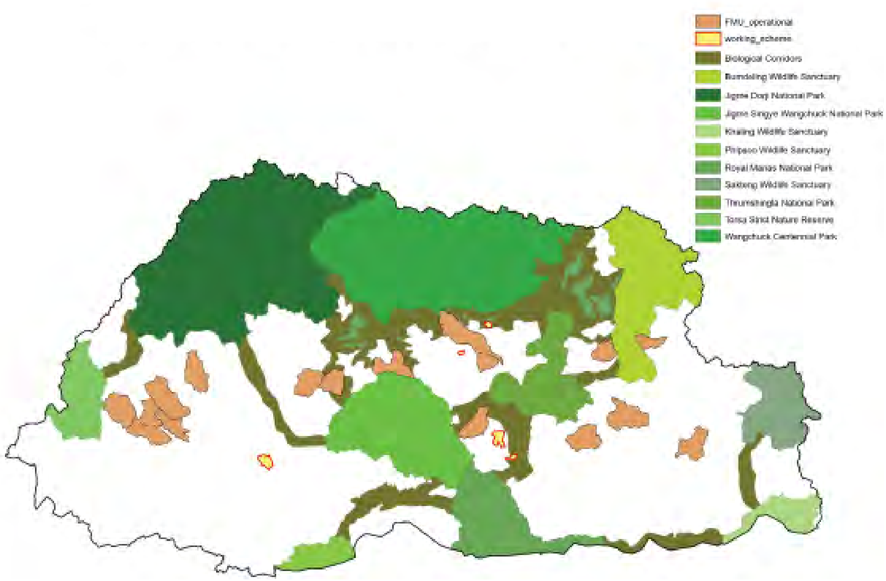

Figure 2.4: Forest management units and working schemes in Bhutan.

human intervention through biomass collection, livestock grazing, as well as timber harvesting for house construction, flag poles for religious and cultural uses, and cremation.

2.9 Waste

Table 2.6 summarizes GHG emissions associated with waste management activity in 2000. The GHG emissions from waste sector were 46.27 Gg CO_2-equivalent in 2000 and represented about 3% of total national GHG emissions excluding LUCF. Sources for waste management data included published literature on municipal solid waste management in Bhutan and results of the population and housing census, 2005. Emissions from waste management were not quantified in Bhutan's first national communication due to the lack of reliable data.

There are two main sources of GHG emissions within Bhutan's waste sector. Solid waste disposal on land accounted for 84% of total waste-related GHG emissions. Only 10 urban areas (i.e., Thimphu, Phuentsholing, Samtse, Paro, Gelephu, Damphu, Samdrupjongkhar, Bumthang, Trashigang, and Mongar) are included in the inventory as the remaining population emitted extremely low amounts of methane as a result of waste disposal. Domestic and commercial wastewater handling accounted for 16% of total waste-related GHG emissions. These emissions are associated with the only two cities in Bhutan that have centralized domestic and commercial sewage treatment facilities; Thimphu and Phuentsholing.

2.10 Emissions of PFCs, HFCs, and SF_6

According to the 1996 Revised IPCC Guidelines, the major emission sources of PFCs, HFCs, and SF_6 gases are from the following activities: replacement of ozone-depleting substances; HCFC-22 production; electric power transmission; production of primary aluminium; production of semiconductors; and production and processing of magnesium. Only the third activity (power transmission) occurs in Bhutan. PFCs and HFCs were not produced or imported/consumed as substitutes for ozone depleting substances in refrigeration and fire extinguishers because ozone-depleting substances were not banned in Bhutan over the 1998-2000 periods. The estimation of SF_6 emissions associated with electric power transmission proved to be a significant challenge due to data constraints and was assumed to be negligible.

2.11 Uncertainty Assessment

An uncertainty assessment was considered to be an essential element of the GHG emission inventory update to help prioritize efforts to improve the accuracy of future inventories. In Bhutan, uncertainties are associated with data access/constraints, potential unsuitability of generic emission factors, and an incomplete understanding of the processes associated with emissions. Some of the current estimates, such as those for CO_2 emissions from energy-related activities and cement processing, animal production, and commercial forest harvest are considered to have minimal uncertainty associated with them. For some other categories of emissions such as the extent of abandoned lands and water management techniques used in rice cultivation, however, a lack of information increases the uncertainty surrounding the estimates presented.

Table 2.7 summarizes the uncertainty assessment for the Bhutan GHG inventory. Based on expert judgment of specialists participating in the

Table 2.6: GHG emissions from waste management activity, 2000 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
All waste emissions	**46.27**	**0.00**	**2.00**	**0.01**	**0.00**	**0.00**	**0.00**
A Solid Waste Disposal on Land	38.90	0.00	1.85	0.00	0.00	0.00	0.00
B Wastewater Handling	7.38	0.00	0.15	0.01	0.00	0.00	0.00
C Waste Incineration	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D Other (please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

development of the inventory, the confidence in the results for each source/sink category was evaluated relative to the uncertainty associated with data quality and emission factor suitability. Less than 10% uncertainty was considered to be low; uncertainty between 10% and 50% was considered medium; and uncertainty greater than 50% was considered high.

Attention to two areas could help reduce uncertainty in Bhutan's GHG inventory. First, improving the accuracy of some emission factors to calculate emissions from a variety of sources is vital. Most of the emission factors correspond to IPCC default factors. However, as noted in the above table, there are numerous emission factor categories, particularly for agriculture LUCF, and waste, that are classified as having medium uncertainty (i.e., uncertainty between 10% and 50%). For example, the accuracy of current emission factors for enteric fermentation by animals at high altitude remains uncertain in the absence of local sampling and testing activities. Secondly, the availability of detailed activity data will support refinement of inventory estimates. Although methodologies have been used to estimate emissions for some sources, problems arose in obtaining activity data at a level of detail in which aggregate emission factors can be applied. Addressing these areas through additional capacity strengthening and development of dedicated observation networks will enhance the quality and accuracy of future emission inventories.

Table 2.7: Uncertainty assessment associated with the Bhutan GHG inventory, 2000

Sector	Activity	Uncertainty in		Confidence in Inventory results
		emission factor	data quality	
Energy	Public Electricity and Heat Production	Low	Low	High
	Non-Ferrous Metals	Low	Low	high
	Pulp,Paper and Print	Medium	medium	medium
	Domestic Aviation	Low	Low	high
	Road transport	Medium	medium	medium
	Residential	Low	medium	high
	Coal Mining	Low	Low	high
Industrial processes	Cement production	Low	Low	High
	Mineral product production/use	Medium	Low	High
	Carbide production	Low	Low	high
	Iron/steel production	Low	Low	high
	Pulp & paper production	Medium	medium	medium
	Alcoholic beverage production	Low	Low	high
	Bread/other food production	Medium	medium	medium
Agriculture	Domestic Livestock	Medium	Medium	Medium
	Rice Cultivation	High	High	Low
	Field Burning of Agri Residues	Low	Low	High
	Agricultural Soils	Medium	Medium	Medium
LUCF	Plantations – tropical	Medium	medium	medium
	Plantations- Temperate	Medium	medium	medium
	Managed forest area	High	medium	medium
	NonForest trees	Medium	Low	medium
	Commercial Harvests	Medium	Low	medium
	Total fuelwood consumption	Medium	High	low
	Rural timber	Medium	Low	medium
	Carbon Fraction	Medium	medium	medium
Waste	CH4 emissions from SWD sites	Medium	High	low
	CH4 emission from domestic/commercial wastewater	Medium	Medium	Medium
	N2O emissions from human waste	Low	Low	high

Chapter Three

Mitigation Measures

3.1 Introduction

3.1.1 Methodology

Having consulted with the various key stakeholders in public and private sectors, this chapter summarises the mitigation policies and measures that are being taken and can be taken in Bhutan to reduce GHG emissions. The current and future GHG trends along with the technical, financial, regulatory and institutional barriers and challenges are discussed.

Future trends from energy and industry sectors, the two sectors with growing emissions, are based on results of energy demand simulations using Long-range Energy Assessment Plan (LEAP) model as detailed in the Integrated Energy Management Plan (IEEMP) developed by the Department of Energy and TERI in 2010. The emission factors for each fuel types were used to convert the energy intensity data into potential GHG emissions. In the IEEMP the scenarios for the various sub-sectors were simulated for the base year of 2005 and projected for 2010, 2015 and 2020 under four scenarios (although in this chapter only 2020 data are considered):

- **Business-as-Usual scenario (BAU)** - In the absence of any technological or policy intervention, this scenario is termed as the most likely path of development. This scenario incorporates existing government plans and policies, an average real gross domestic product (GDP) growth rate of 7.7%

- **Energy-efficient scenario (EE)** - This scenario takes into account the specific energy efficiency measures spanning across all sectors. Efficiency improvements in existing devices and shifts to modern efficient technologies are basic characteristics and sectoral variables are assumed to grow as per the BAU rates.

- **High growth scenario (HIG)** - This scenario assumes a high GDP growth rate of 10% (uniform over the modeling time frame, 2005–20). The HIG scenario is characterized by a shift of the economy towards growth led by the industrial and service sector, with the latter dominating in terms of its contribution to GDP.

- **High growth coupled with energy efficiency (HIGEE)** - Finally, the HIGEE scenario combines a high GDP growth rate of 10% with high energy efficiency measures. This scenario is representative of the most optimistic scenario in terms of both economic growth and technological interventions.

3.1.2 GHG Emission Trends

The GHG emission trends for the energy, industrial process, agriculture and waste sectors are shown in Figure 3.1. As is evident, emissions from Bhutan are currently dominated by the agriculture sector but without clear trends in emission. However, with rapid economic development over the last few decades, there has been steady growth in emissions from energy consumption and industrial processes. Emissions from industrial processes increased from 142.14 Gg CO_2 to 237.76 GgCO_2 in 2000 to 505.03 GgCO_2 in 2009. Emissions from energy have also steadily increased from 175.22 Gg CO_2e in 1995 to 270.23 Gg CO_2e in 2000 to 500.87 Gg CO_2e in 2009.

3.2 Current Mitigation measures

In 2009, the government of Bhutan issued a declaration titled "Declaration of the Kingdom of Bhutan- The Land of Gross National Happiness to Save our Planet" Bhutan committed to "keep absorbing more carbon than we emit – and to maintain our country's status as a net sink for Green House Gasses". Keeping in line with this bold declaration, the Economic Development Policy of 2010 also states that "green growth" will be encouraged in promoting industrial and private sector development. The declaration also calls for the international community to support Bhutan in fulfilling this commitment. A strategy for Bhutan to maintain Carbon Neutrality is also under preparation and will be completed by end of 2011.

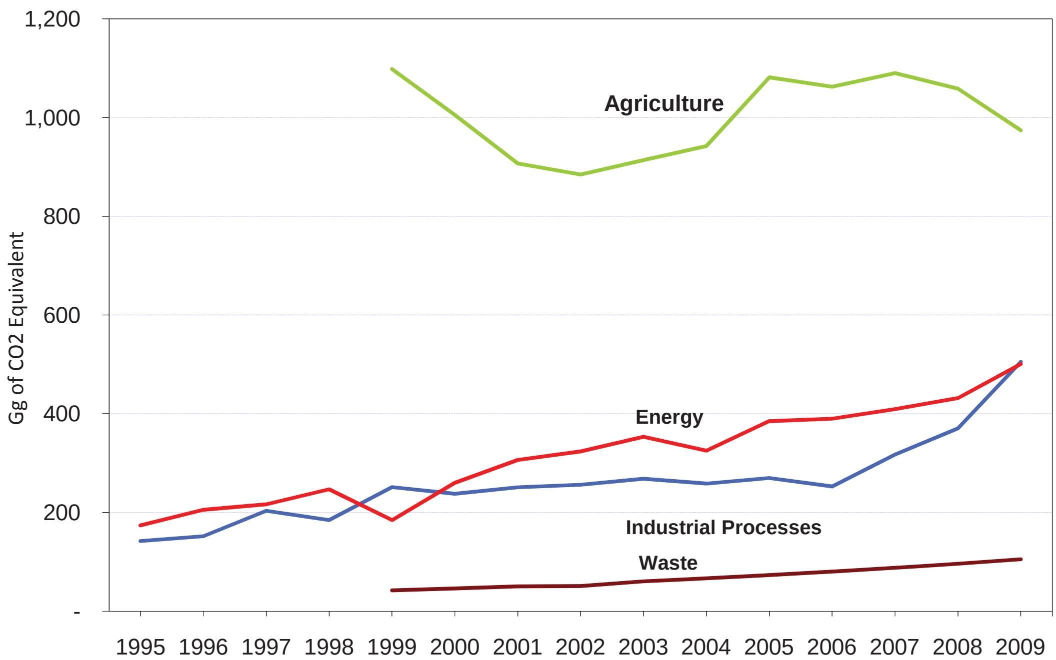

Figure 3.1: Trends in GHG emissions by sector in Bhutan

3.2.1 Energy

Hydropower potential in Bhutan is estimated at about 30,000 megawatts (MW). At the present, 1505.32 MW has been installed. The government has also set a goal to generate a total of 10,000 MW by 2020. Apart from being the main driver of socio-economic development in the country, hydropower is viewed as a clean source of energy and a means of reducing the country's dependence on traditional solid and liquid fuels.

Providing "Electricity for all" by 2013, through grid extension and other means like micro hydro and photo voltaic is an important goal that is on track.

Currently, there are two registered CDM projects in Bhutan. The first, 'E7 Bhutan Micro Hydro Power CDM project' (70kW installed capacity) has had 474 tCO_2e issued. The second is 'Dagachhu Hydropower Project', (114 MW) with crediting period starting in 2012 and anticipated CERs of 500,000 tCO_2e per year. Several other CDM projects (hydro and rural biogas) are also in the pipeline.

Several pilot domestic biogas has been installed with a potential to develop 20,000 domestic biogas digesters (40,000 to 80,000 tCO_2e). The initial target is for 1,500 units in the first 3 years and could be scaled up as programmatic CDM.

Pilot solar PV has been installed by the government and NGOs in several communities. There is a potential for 50,000 solar systems of 100 Wph with equivalent of 8,800 tCO_2e

Control of vehicle emission has been instituted through vehicle emission standards and improvement of fuel quality imported into the country. Tax incentives are also provided with progressive tax rates for larger vehicles and 0% duty for zero or low emission vehicles like electric cars and bicycles.

3.2.2 Industrial processes

After the enactment of the Environment Assessmnet Act 2000, industries and mines have accepted that environment impact assessments or enviroment codes of best practices for the 17 listed sectors in the EA Act 2000 are part of overall business planning and management. Two phases of Cleaner Technology and Environmental Management (CTEM) support were provided to industries in the last decade. The first phase covered awareness, capacity building and piloting of CTEM projects. The second phase from 2004 focused on cleaner production guidelines for the steel, ferro-silicon, cement, food, wood industries and the mining sector and also an environmental management plan for Pasakha industrial estate. These industries representing the largest number of industrial activities in the country are taking measures to institutionalise CTEM and also understand that reduced waste improves bottomline.

The Association of Bhutanese Industries has established an information cell to disseminate CTEM information to members. However, industries also face challenges in terms of resources for wider adoption of CTEM.

3.2.3 Agriculture

The government is promoting "Zero Grazing Policy" to make the best use of animal waste. This shall be complemented with biogas project to generate energy and reduce dependence on fossil fuels, electricity, and forest in small homesteads. The feed and fodder program shall ensure the provision of better feeds that will have reduced GHG emission from animals and improved productivity.

Under the *GEF-WB* funded Sustainable Land Management Programme (SLMP) participatory Sustainable Land Management is currently active in Trashigang, Chukha and Zhemgang and provides support to nine *geogs* in these three *Dzongkhags*. Activities are also underway for mainstreaming socio-economy and prevention of rangeland degradation by nomads of Haa in Western Bhutan. The SLM practices being developed in the following three sectors are:

- Agriculture - support for land management through demonstration of vegetative and non-vegetative on-farm soil conservation measures. Measures include hedgerow using fodder species, which serve as important source of fodder for livestock. Farm soil conservation, creations of plantation crops is also supported.
- Livestock – Improved breed and livestock management practices are promoted and supported to reduce the number of stray and unproductive cattle in order to ultimately reduce number of livestock population grazing free in the forest.
- Forestry - the project supports establishment of community and private forestry and reforestation program that are of direct benefits to the farmers.

The *UNDP/GEF* supported Sustainable Land Management Programme is helping various communities in Dagana Dzongkhag to combat land degradation and secure sustainable farmland for future generations. This is part of a bigger project promoting SLM practices in Dagana, Sarpang, Samtse, Bumthang and Trongsa. A community group comprised of members from all households has been formed to initiate this joint effort in combating land degradation and securing sustainable farmland for future generations. Apart from terracing, contour bunding and building check dams to control soil erosion, sustainable agricultural practices through participatory SLM approaches is also promoted. To meet the demand for fuel wood, fodder and fruit trees, the project supported a nursery on private land voluntarily contributed by the community leaders.

GEF Small Grants Program in the area of climate change mitigation, projects include promotion of renewable energy technologies by removing barriers and reducing implementation costs.

3.2.4 Land Use Change and Forestry

The constitution of Bhutan mandates that 60% of the country shall remain under forest cover. In line with this the National Forest Policy (2008) states its goal that "*Bhutan's forest resources and biodiversity are managed sustainably and* *equitably to produce a wide range of social, economic and environmental goods and services for the optimal benefit of all citizens while still maintaining 60% of the land under forest, thereby contributing to Gross National Happiness".* Currently 74.46% of the land or 27,052.9km^2 is forested. The 2nd GHG Inventory estimates that 6309Gg of CO_2 was sequestered in 2000.

Bhutan has one of the highest proportions of area under protected areas in the world with five national parks, four wildlife sanctuaries and a strict nature reserve, altogether making up an area of 16,396.43 km^2 or 42.71 percent of the country's total area(NCD 2009).

The forest policy mandates that timber production is for domestic demand only and commercial logging is limited to forest management units and very small concession areas, rural timber demand is met through timber marking. There are a total of 18 FMUs in operation with scientific silvicultural management plans. The operational and planned FMUs collectively cover a total forest area of 238,633 hectares. This figure translates to roughly eight percent of the total forest area and 48 percent of the total forest area manageable for timber production.

Shifting cultivation (*tseri*) which was practiced in the eastern region of the country is now illegal and other farming methods are promoted.

As a national programme, reforestation of degraded and barren forest lands was the earliest conservation initiative in Bhutan. As early as 1947, the first forest plantation was established, 11 years prior to the DoF coming into being. Since then, reforestation has been carried out on more than 21,500 ha. Reforestation has been a regular feature in all the Five Year Plans and has been carried out at the rate of about 2,400 ha per Five Year Plan.

Since the reinitiation of a program on community forestry from 2001, 313 community forest units covering 36,649 ha of forest land were established (as of June 2011) (SFD 2011).

3.2.5 Waste

Waste Prevention and Management Act 2009 came into force with the principles of Reduce, Reuse and Recycle and allows for penalties and incentives. Public Private Partnership models for waste management including recycling and composting has also been initiated.

3.3 Energy

Due to rapid economic growth over the last few decades, GHG emissions in the energy sector increased significantly from 175Gg CO_2e in 1995 to 260.31 Gg CO_2e in 2000 and 500.87 Gg CO_2ein 2009. This large increase was mainly due to increasing energy emissions from transportation and industries (Figure 3.2). Emissions from the residential sector are fairly constant. As almost all energy produced in Bhutan is from fuelwood or hydropower, and GHG emissions from energy industries (backup generators) are less than 1% of the national emissions.

3.3.1 Energy situation in Bhutan

The energy needs of the Bhutanese economy can be categorized in the following manner: resources for electricity generation; fuels and resources for transport which is dependent on import of petrol and diesel and jet fuel; and fuels to meet heat and mechanical energy demand of the industrial, commercial, and residential sectors (excluding electricity). Bhutan is endowed with rich water resources, along with abundant biomass reserves. Both these resources are being exploited in a sustainable manner to fulfil the energy needs of the people whilst making sure that GHG emissions are managed sustainably.

Recognizing the importance of energy for poverty alleviation, the Royal Government has been taking several measures to accomplish its ambitious goal of 'electricity for all by 2020'

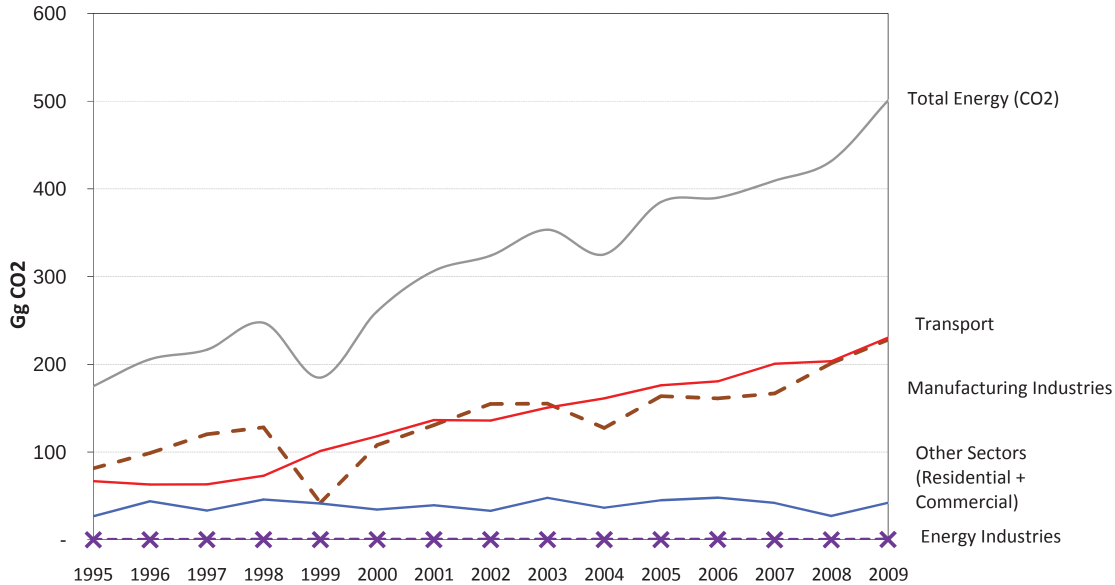

Figure 3.2: GHG emissions for the Energy sub-sector (1995 to 2008)

of the Vision 2020 document, and revised the target year to 2013. The Rural Electrification Master Plan (REMP) 2005, provides a road map to achieve 100% electrification by 2013. While, per capita energy and electricity supply are still way below the world average, in a regional context, Bhutan emerges as the leading country, both in terms of total primary energy supply as well as electricity supply per capita per year.

3.3.2 Policy and regulatory framework

The draft policy for the energy sector has two major objectives of i) emphasis on power exports to strengthen the economy and ii) Supply of reliable, low carbon, environment-friendly, and affordable power for all citizens. Accelerated hydropower development has been identified as an option for achieving these objectives. Given a dispersed population and complex terrain, achieving "electricity for all" would require major financial resources for grid extension. The critical policy issues in the power sector are (1) accelerating development of the hydropower sector by attracting investments including carbon finance and assuring reliable supply, considering the seasonal variations in supply; and (2) extending the grid to supply affordable power to all, without affecting economic viability in the power sector. The Economic Development Policy 2010 provides for upto 15% income tax rebate for industries that have undertaken environmentally friendly technological upgrades beyond what is required by law.

Renewable Energy

Renewable and non-conventional energy sources like solar, wind, biomass, and municipal solid waste can be harnessed for clean power generation and help towards reducing national GHG emissions. These sources would diversify the power portfolio, which presently consists mainly of the hydropower. The proposed Renewable Energy Policy will help to reduce national carbon emissions by developing alternative energy resources for both electrical power and thermal energy generation through export of electricity to India. The draft policy aims to:

- Reduce heavy dependence on hydropower.
- Augment electricity supply or reduce demand during winter season so as to meet the challenge of low hydroelectricity production due to lower water flows in rivers.
- Reduce the use of fossil fuels in the transport sector.

- Introduce environment-friendly and locally available fuels/energy resources to meet demand for energy, especially in remote and dispersed locations.

Diversification of the energy mix through renewable energy is both a mitigation and adaptation measure as the existing seasonal shortage of hydropower in the winter is projected to get worse under future climate change (see Chapter 4). Diversification of energy supply can be utilized to both avoid use of fossil fuels for energy generation and also for energy security under climate change. Such measures could include storage type hydro plants that can also increase water supply rather than just relying on run-of-river hydropower schemes. Such multi-purpose hydropower plants can also prevent flooding and provide water for drinking and irrigation. An overview of some of the potential renewable energy (other than hydro) is presented below.

a. Bioenergy

Biomass largely consists of unrefined fuels that are used in a traditional way, such as solid biomass used in traditional cook stoves for cooking, water heating, and space heating. "Modern bioenergy" is used after their conversion into more efficient energy carriers with higher calorific value (such as pellets, briquettes, bio-diesel, and biogas) and/ or are used in the efficient equipment (such as improved cook stoves and gasifiers). Liquid biofuels such as straight vegetable oils (SVO) and bio-diesel are currently being explored as alternatives to petroleum fuels, especially for the transport sector. In Bhutan, these fuels will have limited role due to limited land available for cultivation.

b. Biomass-based power generation

Biomass-based power generation – either through direct combustion or through gasification– is an established technology worldwide. Biomass-based power generation can supplement the power generation capacity for continuous power generation: **i) Off-grid power generation using biomass** - Locally available biomass in decentralized power generation using biomass gasifiers where producer gas is used for various applications, including power generation. **ii) Thermal applications of biomass -** Current biomass appliance/technology used for heating and cooking in residential and institutional sectors can be upgraded to modern efficient biomass technologies like gasifier and briquetting for thermal applications. and **iii) Pelletization -** Pellets produced from various raw materials like agro-waste, sawdust, and pine needles are easy to handle and transport, and advanced automatic pellet stoves and space heaters have made pellets simple and efficient to use.

c. Wind energy

While Bhutan has good wind potential, the development of wind farms is constrained by various issues, as outlined in the IEMMP: **i) Infrastructure development -** Typically, wind machines of large capacities are installed on 50–80m towers, and wind generator blades are typically 20–30m long but current road infrastructure may not be adequate to transport such blades and heavy machinery; **ii) Public opinion** - There is concern that large wind machines may spoil the aesthetic and natural beauty of the landscape, and that they may also be harmful for endangered birds such as White bellied herons especially in Punakha and Wangdi valley and other areas where black necked cranes are found and **iii) Small wind machines and water pumping wind mills -** Small wind machines (less than 100 kW) and mechanical wind pumps to generate electricity or water pumping for irrigation and drinking could be installed in isolated locations for scattered households, and could be coupled with solar photovoltaic power plants in hybrid mode to generate electricity for small villages.

d. Solar energy

The solar energy resource in the southern part of the country is about 4.0 kWh/m^2 and about 5.0 kWh/m^2 per day at high altitudes in the northern part of Bhutan (NREL, 2009). Some suitable areas are located near transmission lines and have potential for on grid connection. Assessments using satellite imaging show some areas with moderate (300-400 W/m^2) to excellent (500-600 W/m^2) potential in several valleys throughout the country but these data will need further ground data validation. Solar photovoltaic technologies are expensive but can be considered as an alternative for electricity production.

Grid-connected solar photovoltaic plants of few hundred kilowatt capacities are generally cheaper. Currently, solar photovoltaic power generation costs are in the range Nu 15–30/ kWh, depending on the site, technology, and size of the plant. These costs are, thus, very high compared to hydropower unless the cost of grid extension as well as low capacity utilization of this infrastructure is also taken into account.

e. Geothermal energy

Geothermal energy is the heat energy available in the core of the earth. Several hot springs (*tsachhus*) are known to exist in Bhutan in northern Bhutan at Gasa, Punakha, upper Trongsa, Bumthang, and Lhunetse dzongkhags and in southern Bhutan at Rongkhola and Bhurkhola. These are traditionally used for bathing, as the water is believed to have medicinal and healing properties.

3.3.3 Energy demand in the manufacturing and construction sector

Spurred by the lowest electricity tariffs in the region there has been a rapid growth in industrial activities in the past few decades (see Chapter 1). The industrial sector as a whole consumed about 25.5% of total energy in the country and 64.7% of total electricity (DoE 2005). Other fuels that are used in the sector include coal, furnace oil, kerosene, light diesel oil (LDO), and fuelwood. Though the industrial sector in Bhutan has many small and medium scale industries, energy consumption in the industrial sector is dominated by few large energy-intensive industries. Electricity consumers are categorized in three groups: (i) Low voltage consumers (230 volts and 415 volts) are mostly the residential and commercial sectors and a number of small-scale industries; (ii) Medium voltage consumers (6.6 kV, 11 kV, and 33 kV) are medium-scale and some small-scale industries, and (iii) High voltage consumers (66 kV and above) are heavy, power-intensive industries.

For energy projections, analysis has been done separately for both energy intensive and non-energy-intensive industries under the IEMMP. However, detailed data was available only for six major operating units which are classified as energy intensive industries (Bhutan Ferro Alloys Ltd, Bhutan Calcium Carbide Ltd, Penden Cement Authority Ltd, Druk Cement Company Ltd, Druk Iron and Steel Ltd, and Bhutan Steels Ltd). All other remaining industries are classified as non-energy intensive industries. In 2005, these six energy intensive industries consumed close to 90% of the total sectoral energy consumption and 62% of the country's electricity consumption. Being powered by hydropower, the GHG emissions are relatively low and the products are for export with India as the main international market. Energy equivalent of petroleum products use is 9,000 tonnes of oil equivalent (TOE), while that of electricity is 33,000 TOE. In the following sections, the existing energy consumption patterns (energy intensities), technologies used in energy-intensive units, and the potential for energy conservation are discussed.

Emissions from energy use in manufacturing industries grew by from 81.42 Gg CO_2 in 1995 to 107.84GgCO_2e in 2000 to 228.10 GgCO_2e in 2009 (Figure 3.2). Potential future GHG emissions trends were simulated using data generated through LEAP assessment in the IEMMP (DoE 2010). Each fuel was converted to potential GHG emissions with appropriate emission factor. The energy supply and demand scenarios for the various sub-sectors from 2005 to 2020 were simulated under four scenarios as described in section 3.1.1. As mentioned earlier, these energy-intensive industries mostly consume electricity and coal and future demand for these inputs by energy-intensive industries is presented in Figures 3.3.

a. Electricity

The 2005 total electricity consumption by energy-intensive industries is 377 million kWh (GWh) and is expected to reach 2,192 million kWh by 2020 under the BAU scenario. Being of hydro source, the GHG emission is insignificant. However, if a grid emission factor of 1.004 is used (based on the East Indian Grid EF as used in the two registered CDM hydro projects), then the 5.8 times increase in electricity consumption will lead to an extra 1,824 $GgCO_2e$ from the base of 379 to 2,201 $GgCO_2e$. Electricity saving potential is close to 10% under the EE scenario, which can lead to reduced consumption to 1,994 million kWh with a saving of 2 million tCO_2e. Based on the present export tariff, exports of saved electricity (@ 200 million kWh) can fetch foreign revenue close to approximately Nu 400 million (USD 888,889). Under the HIG scenario total electricity consumption by energy-intensive industries will go up to 2,782 million kWh by 2020 and an emission of 2,793 $GgCO_2e$. This estimate is mainly based on the assumption that all types of new industries (including carbon intensive industries) will be allowed. The saving potential under the HIG scenario is about 210 million kWh and a GHG saving of 211 $GgCO_2e$.

b. Coal

Bhutan's coal import in 2005 was estimated at 124,000 tonnes and emitted 290 $GgCO_2e$. Cement industry was the largest consumer, with consumption close to 58,000 tonnes. With the expansion in existing plant capacities and new industries, the demand is estimated to rise to 586,000 tonnes by the end of 2020 and emit 1,370 $GgCO_2e$ (a 4.7 folds increase). Improved demand side management could help to reduce total coal consumption by 21% to 450,000 tonnes approximately and save 302 $GgCO_2e$. Coal consumption under the HIG and HIGEE scenarios is assumed to be same as that under the BAU and EE scenarios, since most of the additional proposed industries assumed to be established under the HIG scenario are not likely to use coal.

c. Wood

Total consumption of wood in non-energy-intensive industries in 2005 was 50,000 tonnes and emitted 60 Gg CO_2e. Under the BAU scenario, total demand is expected to reach 175,000 tonnes emitting 22 Gg CO_2e, an increase of 2.6 folds. Demand side management can help achieve an efficiency of 20% over baseline estimates equivalent to 5 $GgCO_2e$, reducing consumption to 140,000 tonnes and 250,000 tonnes in the EE and HIGEE scenarios, respectively. At HIGEE, GHG emissions would have increased to 31 $GgCO_2e$ showing a 5 folds increase.

3.3.4. Mitigation measures in the industrial sector

The opportunities for GHG mitigation in industry are some what different from those in other sectors (transport and building) because the greatest increases in the efficiency of energy and

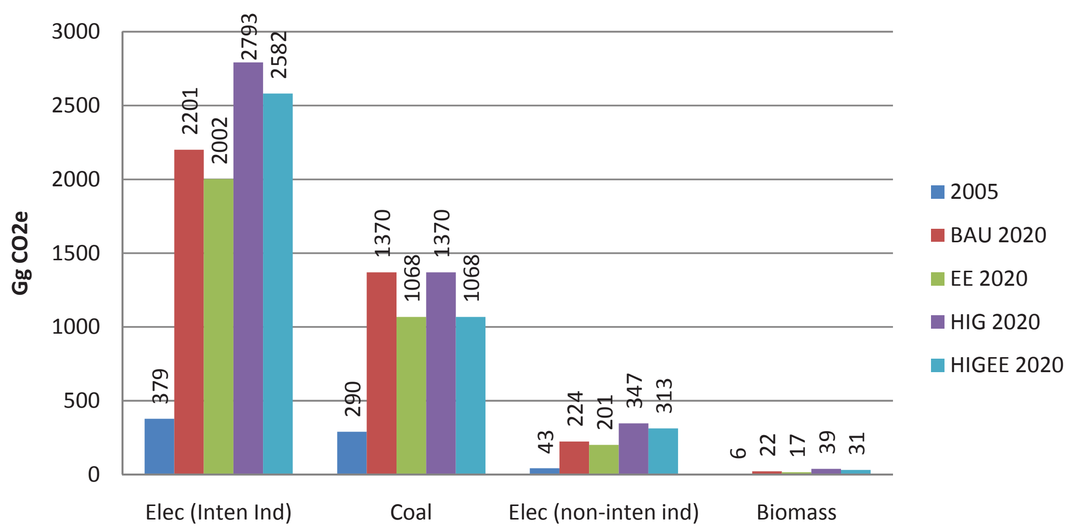

Figure 3.3: GHG emissions for the Industrial sector (2005 and 2020)

materials use often come not from direct efforts to reduce consumption, but rather from pursuing other goals such as improved product quality and lower production costs. Industry is also different in that, firms usually have an incentive to improve efficiency in order to reduce costs and maintain their profitability. Furthermore, the Economic Development Policy 2010 provides upto 15% income tax rebate for industries that implement environmentally friendly technological upgrades beyond what is required by law. Some of the recommended options for energy efficiency in industries are discussed below.

a. Small- and medium-scale industries

The main aim of this strategy is to improve energy efficiency and reduce energy consumption as well as pollution and GHG emissions in the small and medium-scale industries. The LEAP analysis has shown that implementing these measures will save approximately 10% of electricity in future. The DoE has established an energy laboratory under the IEMMP project. The laboratory facilities and the infrastructure available with the Department of Industry on Training and Capacity Building can be used to develop training and energy audit programmes for small-scale industries.

b. Ferro alloy industry

In 2000, 17237.02 tons of Ferro alloys production emitted 67.22 GgCO_2. It is observed that the ferro alloy industry is one of the most energy intensive industries in Bhutan and accounts for more than one-third of the domestic electric consumption. So, even a small saving can indeed make a significant difference to total electricity scenario for Bhutan. In 2005, the largest ferro alloy plant in Bhutan is the Bhutan Ferro Alloys Ltd (BFAL). However, as large number of applications for establishment of such units have been received and is presently only limited by power availability in the winter. Energy-efficient technologies would need to be used extensively.

c. Cement industry

In addition to being a heavy user of electricity, the cement industry is also the biggest consumer of coal in Bhutan. In 2000, 293994.67 tons of clinkers production emitted 152.07 Gg CO_2. Dungsam Cement Project is expected to be operational by end of 2011 and will produce 1 million tons of clinker annually adding three times more CO_2 emissions annually from this industry.

Process optimization, load management, and operational improvement can lead to significant energy saving, and although it involves marginal financial investment, it is found to have encouraging results in energy saving. These include the following: Plugging of leakages in kiln and pre-heater circuit, raw mill, and coal mill circuits; Reducing idle running; Installing improved insulating bricks/blocks in kilns and pre-heaters; Utilizing hot exit gases in an efficient manner; Optimizing cooler operation; Optimum loading of grinding media/grinding mill optimization; Rationalizing compressed air utilization; Redesigning of raw mix; Installing capacitor banks for power factor improvement; Replacing over-rated motors with optimally rated motors; Optimizing kiln operation; Changing from flat belt to V-belt.

d. Iron and steel industry

As of 2009 there were 7 iron and steel industries in Bhutan with some specializing in iron re-rolling, while others in the iron and steel making. Emissions from iron and steel industry along with ferro alloys have increased significantly since 2006 and surpassed emissions from cement industry (Figure 3.6).

Demand side management in industries is effectively done by adopting energy efficiency measures and promoting energy-efficient technologies. The energy audits carried out during the IEMMP project have shown that the industries have the potential to save energy and reduction in GHG emissions.

3.3.5 Energy Demand in Transport Sector

The transport sector in Bhutan is characterized by the dominance of road and air transport. Being a mountainous country, rivers generally do not run very deep, and use of waterways for transport is non-existent. In some places, ropeways are being used for the transportation of logs and other materials. However, foot trails, ponies and yaks are still widely used in Bhutan and especially where road connectivity is lacking.

International aviation from Bhutan is limited to the Druk Air, the national carrier, which operates two Airbus A319s, and supplemented by one turboprop aircraft on lease. Limited domestic air services with turboprop planes is planned to begin by 2011. Nevertheless the transport sector is one of the significant sectors with emissions in Bhutan. Emissions from transport have grown consistently from 66.81Gg CO_2in 1995 to 230.36 Gg CO_2 in 2009 (Figure 3.2).

Diesel, gasoline, and ATF are the main fuels consumed in the transport sector. Alternative fuels like compressed natural gas (CNG) and LPG are not used for transportation in Bhutan. Of the three major transportation fuels imported in Bhutan, diesel has the largest share.

The import of petrol has gone up more than three times over the period 1995–2005, while that of diesel has risen 2.5 times during the same period. The number of vehicles is growing at 9-10% per annum and the consumption of petroleum products for surface transport is likely to grow 3 times the current level of petroleum product consumption by 2020 (RSTA 2007). Besides the rising cost of petrol and diesel, complete dependence of the transport sector on imported fuels is a concern from the energy security perspective.

Diesel

In the IEMPP, diesel consumption in 2005 is reported to be 53878 kilolitres (equivalent of 144.46 Gg CO_2) and is expected to reach 191,100 kilolitres in the BAU scenario (3.7 folds increase to 507 Gg CO_2) and 284,000 kilolitres in the HIG scenario (751 GgoCO2e). Energy-efficient diesel engines can reduce the consumption of diesel by about 10% to 171,694 kilolitres and 256,178 kilolitres under the EE and HIGEE scenarios, respectively (Figure 3.4). This will provide a saving of between 50 to 76 $GgCO_2$ for both scenarios.

Aviation turbine fuel

In the BAU scenario, it is predicted that a total import of 3,495 kilolitres of ATF will be required and emit 9 GgCO2e, while in the HIG, the import demand can reach as high as 5,074 kilolitres by 2020 to give an emission of 13 GgCO2e.

Petrol

Volume of petrol imports is estimated at 13,775 kilolitres and an emission of 31.96 $GgCO_2$ in 2005. Projections from LEAP peg the total import demand at 51,673 kilolitres in the BAU scenario and emit 120 $GgCO_2$ in 2020, while in the HIG scenario, the total demand is expected to be 78,402 kilolitres with an emission of 183 $GgCO_2$. Efficiency improvement of 14% for petrol-driven engines can reduce the consumption to 44,439 kilolitres and 67,426 kilolitres, respectively, in the EE and HIGEE scenarios, respectively. This will give a saving of between 17 and 23 GgCO2e with improved efficient petrol vehicles.

3.3.6 Mitigation options for transport sector

Some of the management strategies explored in the Surface Transport Master Plan for Bhutan also provide options for mitigation options for the transport sector and are discussed below.

a. Improving efficiency of petrol and diesel vehicles through standards

The import of old and second hand cars is prohibited in Bhutan and so far prevented the dumping of old and inefficient vehicles in the country which can increase GHG emissions. Vehicle emission standards have also been established and import duties removed for spare parts that are essential in engine exhaust control. Other measure taken include the check on quality of fuel imported after vehicle emissions monitoring revealed that fuel quality was one of the major causes of vehicular pollution in Bhutan. Vehicle emissions standard and type standards (Euro and Bharat Standards) are to be reviewed periodically and made more stringent to encourage efficiency and reduce local air pollution. Increasing capacity of workshops and mechanics in vehicle maintenance and drivers will also be essential as improved eco-driving methods

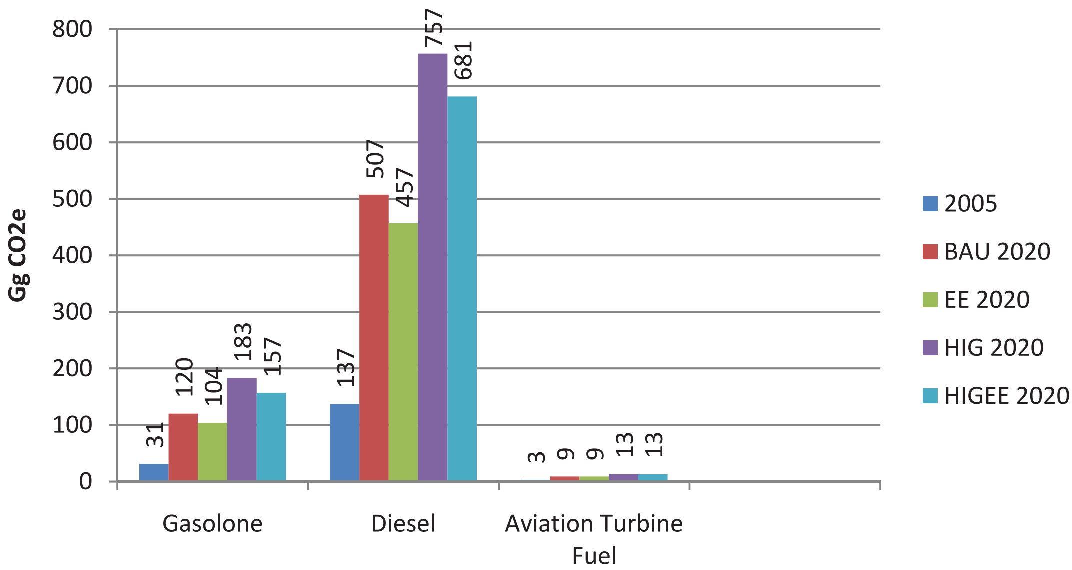

Figure 3.4: GHG emissions for the Transport sub-sector (2005 and 2020

and improved maintenance regimes has been demonstrated to show improved fuel efficiency and emission reductions (NEC/ADB 2011).

b. Introduction of vehicles running on alternative fuel

Vehicles running on alternative fuels are becoming reality in many countries often with less or practically zero pollutants. Options explored for reducing transport emissions in Bhutan as discussed below.

Compressed natural gas

Use of CNG as a safe, clean and cheaper fuel for transport will reduce GHG emissions and also other pollutants. However, CNG filling stations are more complex than regular fuel stations as high pressure, high cost of compressors, storage and dispensers are involved. The roll out of CNG infrastructure for Bhutan is estimated at Nu 15-20million. However, lack of reserves, infrastructure and difficult terrain may be barriers.

Liquefied petroleum gas

LPG is deemed superior to petrol and diesel in terms of vehicular emissions. Typically, exhaust emissions of vehicles running on LPG comprise 75% less carbon monoxide, 85% less hydrocarbons, 40% less nitrous oxide, and result in 87% less ozone depletion as compared to vehicles running on petrol. However, LPG would have to be imported and also compete for domestic uses for cooking.

Biofuels

Bio-fuel is an efficient, environment friendly and 100% natural energy alternative to petroleum based fuels. Ethanol and bio-diesel can be used with a certain percent of blending in petrol and diesel vehicles respectively and can reduce emissions and improve urban air quality. While the feasibility and land requirements for production of biofuels in Bhutan have not been done, potential sources for ethanol and biodiesel are discussed. Ethanol is obtained by fermentation and distillation of molasses, a bi-product of sugar industry. Other possible raw materials are corn, rice straw and potato. Ethanol can be used in petrol vehicle with 5-10% of blending to conserve petrol. The existing infrastructure used for supply of petrol fuel can be used. Bio-diesel can be produced from various plants (seeds) such as Sunflower, Rapeseed, Jatropha and Karanja and a host of other plants such as Mohua, Palm and

Soyabean. Jatropha appears to be most suitable for plantation on under stocked forestlands, farmer's field boundaries to provide protective hedge, fallow lands, public lands along highways, etc.

c. Electric vehicles

With abundant and cheap hydroelectricity, use of electricity for mass transport and electric/hybrid vehicles for personal transport are viable options for Bhutan in medium term. Hybrid and electric vehicles are now being developed by many major automobile manufacturers worldwide. Tax incentives are already provided for purchase of electric vehicles. Further policy measures could be explored to encourage greater use through small scale assembly of electric cars, battery swaps and maintenance in the country.

d. Mass transit options

Options for mass transit such as electric trolley busses and light rail transit are also being explored through the Bhutan Urban Transport Systems Project as alternative transport systems. Mass transportation systems must be promoted to tackle congestion and air pollution in the major urban areas of Bhutan.

Electric Trolley Bus

Electric trolley buses with motors powered by electricity from overhead wires and rubber-tyres, are more energy efficient, quieter, operate better on hills, require less maintenance, and longer lasting than motor buses. Cheap hydropower in Bhutan is an advantage for this type of transport. However, trolley buses will be restricted to lines with a high-enough frequency of service as infrastructure costs are high.

Light RailTransit

Light Rail Transit (LRT) as Urban Rail Transit typically uses less massive equipments and infrastructure than rapid transit systems. LRTs can either run along the streets or share space with road traffic or along their own right-of-way separated from road traffic. Light rail may not be feasible due to high infrastructure costs and limited space for dedicated lines.

Bus Rapid Transits

Among the transport options considered, Bus Rapid Transit (BRT) is the most viable and flexible option. These buses running on dedicated lanes or by providing priority on roads could be powered by electricity and the need to create an electric bus trolley line will not be necessary. The management of batteries by establishing a national infrastructure network for charging and loading batteries will have to be built.

e. Transport Demand Management

Transport Demand Management is seen as a new paradigm in transport management. Demand management measures could reduce GHG emissions and at the same time reduce congestion and provide other local benefits. Some of the options are discussed as follows:

Promotion of Non Motorized Transport

Cycling has zero emissions and is a healthy practice and is growing among urban dwellers particularly in Thimphu. Adequate and user friendly infrastructure must be created for bicyclists. Walking is another very healthy option. Many people in the urban as well as rural Bhutan still walk long distances. Yet, pedestrians remain invisible in the maze of motorized traffic that choke the roads and walk in extremely unsafe and hostile conditions. Cities must build pedestrian friendly infrastructure instead of building more roads. Some portion of road space must be dedicated for pedestrians.

Integration of Land Use and Transport Planning

While land use and transport are intricately linked to each other, land use planning has been done in isolation without considering transport and travel needs of city dwellers. Urban planners need to distinguish between moving people and goods from moving vehicles. Providing easy access to education, employment, and shopping and entertainment opportunities is what transport systems must provide. Predicting traffic growth and providing infrastructure has been proven unsuccessful in many cities worldwide and Bhutan must learn from the mistakes. Co-ordination issues between various agencies involved in transport must be addressed through restructuring institutional set ups and other reforms. All these measures should focus on the need to reduce travel.

Car pooling and car sharing practices

A growing trend of single occupancy driving is observed in almost all the urban centres. Such habits are highly unsustainable and un-economical. Car pooling and car sharing practices will help improve energy efficiency, ease traffic congestions and reduce GHG emissions.

Parking Management

Car ownership is growing at a very high rate (9-10% per annum) but without enough space for parking. This leads to reduced accessibility and mobility especially in city centres. Proper parking management policies impacts share of transport mode, supports local economic development, earns revenue, improves road safety and influences car ownership. Limited parking space should be better managed through pricing.

Road Pricing and Congestion charging

Road pricing would not only re-orient travel to off-peak periods but would also reduce total demand for travel itself.

3.3.6 Residential sector energy demands

Biomass in the form of fuel wood is the main resource for rural residential energy requirements and emitted about 41.64Gg CO_2-equivalent in 2000. The residential sector accounts for 48.7% of the total energy consumption, making it a highest energy consumer. The sector's 91% demand is met by biomass, and the remaining 9% is accounted for by fuels like LPG, electricity, and kerosene. In the residential sector, energy is mainly used for cooking (66% of the total residential energy share) and fodder cooking (26%). There is a significant difference in the energy consumption patterns between the rural and urban areas. While rural households primarily depend on firewood, the urban households rely more on electricity and petroleum fuels.

Electricity

Demand for electricity during 2005 in the residential sector was 80.2 million kWh and is expected to reach 175 million kWh by 2020, under the BAU scenario, whereas in the HIG scenario, the demand can be as high as 253 million kWh (Figure 3.5). Energy-saving measures can help reduce electricity consumption by 27%. No significant GHG emissions are expected from the use of hydro-electricity.

Fuelwood

The demand in 2005 for fuelwood is 490,000 tonnes which emitted 59 Gg $CO_2$and is highly skewed towards rural households that account for 95% of the total residential usage. Fuel switching is expected, and as a result, fuelwood usage will come down to 294,000 tonnes in the BAU scenario (Figure 3.5) to give a saving of 24 Gg CO_2 (60% saving). In the HIG scenario, due to the faster switching to cleaner fuels like LPG and electricity, the consumption could come down to 150,000 tonnes and a further saving of 41 Gg CO_2 (70%) from 2005 baseline. Demand side management, particularly in household cooking, can help achieve an efficiency level of 30% (saving of 10 Gg CO_2e).

Liquefied petroleum gas

The consumption of LPG is found to be on the lower side compared to other fuels but is expected to increase by 2.4 times the present consumption of 2,900 tonnes to give an increase in emissions of 11 Gg CO_2 (2.76 tCO_2/t LPG). In the HIG scenario, consumption could reach 9,000 tonnes and emit an extra 17 Gg CO_2 over the base year of 2005 (Figure 3.5). Achievable efficiency improvement is 5%, as the devices in use do not have a scope for improvement, which can lead to reduction in consumption, with the figures in the EE and HIGEE scenarios being 6,200 and 8,800 tonnes, respectively. The savings are less significant at 1 Gg CO_2.

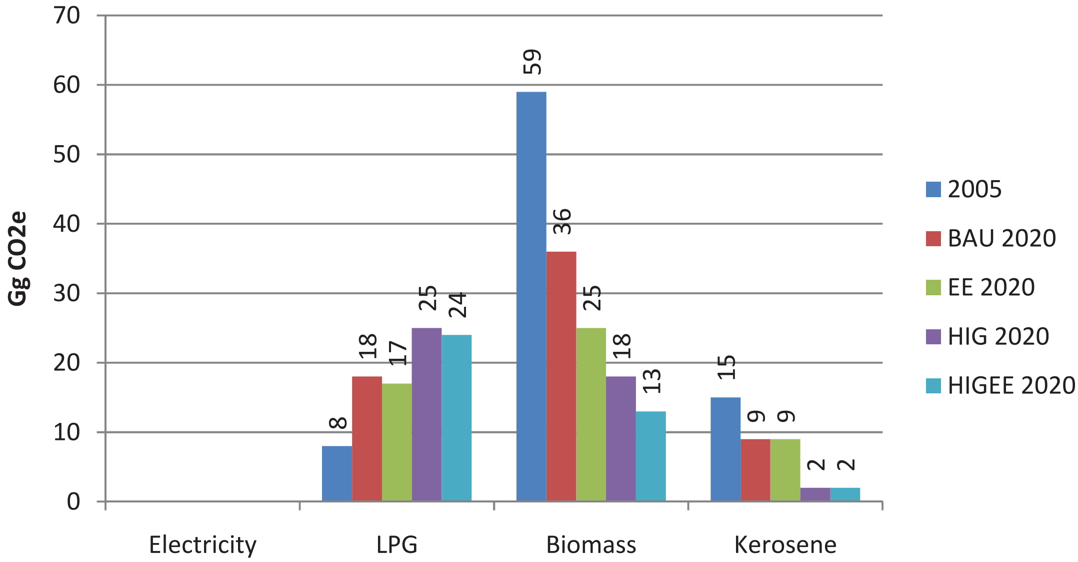

Figure 3.5: GHG emissions for the Residential sub-sector (2005 and 2020)

Kerosene

Kerosene consumption is dominant in rural households vis-à-vis urban households, with the total kerosene consumption in 2005 being 6,400 kilolitres to give a GHG emission of 15 Gg CO_2 (2.4 $kgCO_2e/l$). With rural electrification, kerosene consumption is expected to come down to 3,890 kilolitres with a GHG saving of 6 Gg CO_2 in the BAU and EE scenarios and to 640 kilolitres in the HIG and HIGEE scenarios (Figure 3.5). This will give a saving of 13 Gg CO_2 over the base in 2005.

3.3.7 Mitigation options in residential sector

The residential sector mainly consumes fuelwood, kerosene, liquefied petroleum gas (LPG), and electricity. As discussed earlier, fuelwood accounts for more than 90% of the sector's energy demand, and at the same time, fuelwood devices are hardly 10%–15% efficient. Fuelwood is mainly used for cooking, space heating, and lighting. Similarly, kerosene is the most widely used fuel for lighting purpose in the residential sector.

Improvement in the overall efficiency

In the residential sector, improvement in the overall efficiency of the appliances used for cooking, space heating, and lighting will reduce fuel consumption and GHG emissions. The strategies for the improvement in the overall efficiency in the fuel and energy consumption are as follows.

- Promotion of improved cook stove to reduce GHG emissions and fuelwood consumption for cooking and space heating in rural households.
- Use of improved cook stoves for fodder cooking. About 26% of the energy consumed in the residential sector is used for fodder cooking in rural areas. Such cooking is done using firewood in traditional three-stone cook stoves. Improvements in efficiency or alternative fuels could reduce emissions.
- Promotion of CFLs, LED lamps, and other energy-efficient lighting fixtures in electrified areas.

Bhutanese households commonly use incandescent electric bulbs for lighting. Replacement of these bulbs with CFLs can save as much as 80% of electricity used for lighting. Apart from CFLs, new types of efficient tube lights and lighting systems based on light-emitting diodes (LED) are also available in the market. The Royal Government could enter into time bound exclusive distribution contracts with leading lighting companies to switch the nation from incandescent electric bulbs to use of CFL and LED. Exclusivity should allow for procurement at lower cost CFL/LED lights by consumers and free use by the company of its collaboration with the country in its advertisements for a greener planet.

Use of modern fuel and renewable energy sources

Promotion of efficient LPG stoves- Use of LPG as cooking fuel is common in urban areas. However, in rural areas, LPG is still not a preferred fuel due to: (i) High cost mainly from transportation cost; (ii) limited availability and (iii) difficulty in transporting it to the households. Replacing fuelwood with LPG and efficient use ofLPG by introducing efficient LPG cook stoves can help to reduce local GHG emissions.

Use of briquettes and pellets for space heating- Briquettes made from saw dusts are now available in Thimphu region, and mainly supplied through briquetting plant set up by the Natural Resources Development Corporation Ltd. (NRDCL). Promoting such plants at other places can reduce both wood waste and emissions.

Promotion of solar lanterns and home lighting systems in un-electrified areas-Reducing the use of imported kerosene will reduce emissions along with indoor pollution and provide improved lighting to rural unelectrified households. Though all households will eventually be covered under accelerated rural electrification programme, an immediate and intermediate solution can be providing solar lighting systems and solar lanterns.

Promotion of solar water heating systems - Water heating is another end use application in Bhutan, which consumes a lot of energy. Water is heated mostly in kitchen or by using *bukharis*. Solar water heating systems have proved their effectiveness in saving electricity and other fuels that are used for heating water.

Promotion of use of electricity for cooking- Use of LPG or kerosene incurs an outflow of money, as it has to be imported. A viable means is to promote the use of electricity for cooking by families. Reliable electricity supply is essential to encourage switch over and low lifeline rates to cover basic cost of running such appliances.

Development of energy efficient housings/ buildings

Energy consumption for lighting and space heating and GHG emissions can be reduced by using suitably designed houses and buildings. Eco-friendly housing designed to reduce heat loss and use daylight for internal lighting is effective in reducing the energy consumption for space heating and lighting. Energy-efficient building designs can be introduced initially for new housing complexes being developed by government agencies. Initially external expert agencies can be involved in developing designs and simultaneously followed by organizing capacity building training courses for architects and builders. An industry manufacturing insulation materials, windows, doors and other construction materials and products for improving energy efficiency in homes must be promoted through a preferential public procurement policy. The Royal Government must lead by mandating that all its construction must be green and energy efficient and any space it plans to rent must be energy efficient.

3.4 Industrial Processes

The industrial sector is dominated by a small number of cements, chemical, ferro alloys, steel rolling mills, carbide, agro processing and forest and wood based plants like furniture, medium density fibre board and ply wood. As shown in Figure 3.6, the GHG emissions in the industrial sector increased from 142.14 Gg CO_2 in 1995 to GgCO_2 to 505.03 GgCO_2 in 2009. Emissions from the mineral sub-sector, dominated by cement production increased from 75 GgCO_2 in 1995 to 189 GgCO_2 in 2009. The chemical sub-sector accounted by one plant has been steady at around 20 Gg of CO_2 over the same periods. The metal industry showed the most growth in GHG emissions in the last several years from 46 GgCO_2 in 1995 to 297 GgCO_2 in 2009.

As the industrial and service sectors will continue to make significant contribution to GDP in Bhutan, GHG emissions projection were estimated using the growth rate for the energy demand of the manufacturing and construction sector as given in IEMMP. The growth rate for the energy demand for the manufacturing and construction sectors from the base year of 2005 to 2020 under the BAU is 4.7 times and under the HIG scenario is 4.76 times. Hence, the GHG emissions for the whole industrial sector (mineral, chemical and metal) would have increased from 269.86 GgCO_2e to 1,279 GgCO_2e in 2020 under both BAU and HIG (Table 3.1).

3.4.1 Mineral sector

The main sources of carbon dioxide in cement manufacturing are combustion of fossil fuel and limestone calcinations. Approximately, half of the CO_2 emitted by the cement industry originates from the fuel and half from the calcinations that will convert raw materials into clinker. Applying different efficiency improvement technologies is a good option especially at GHG reduction target up to 12%. Beyond that reduction target, fuel switching should be applied to achieve a reduction target such as 25%. At reduction target higher than 25%, carbon capture technology should be applied and efficiency improvement technologies are no more a good mitigation option. The cost of production increases dramatically when the reduction target is beyond 25%. This is expected since carbon capture technology is the most expansive selected technology.

In 2000, 293994.67 tons of cement clinkers were produced which emitted 152.07 Gg CO_2. As the demand for cement increase, the GHG emissions would increase from 170.49 GgCO2e in 2005 to 812.6 GgCO_2e under BAU and 822.6 GgCO_2e under HIG scenarios if no intervention is introduced. If non-energy related improvement could be introduced for cement processing to reduce emission by a conservative 20% then this would give a saving of 163 GgCO_2e over BAU and HIG scenarios.

3.4.2 Chemical sector

Chemical products (i.e., carbide production) account for the least emissions with only about 7% in 2000 (18.47 GgCO_2e) and 21.47 GgCO_2e in 2005. Under BAU scenario with no intervention, the emission will increase to 101 GgCO_2e and with promotion of better processes, a further reduction of 22% is feasible to give a saving of 20 GgCO_2e.

3.4.3 Metal sector

In 2000, 17237.02 t of ferro alloys production emitted 67.22 Gg CO_2 and account for 28.27% of

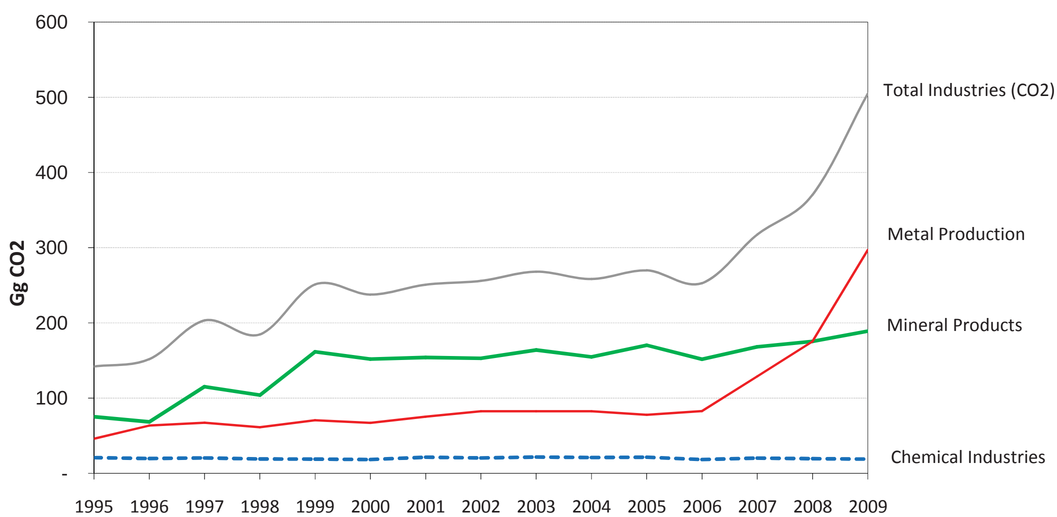

Figure 3.6: GHG emissions for the Industrial processes sub-sector (1995 to 2008)

Table 3.1: Industrial GHG trends from 2005 to 2020

Greenhouse Gas Source ($GgCO_2e$)	2005	2020	2020
		BAU	HIG
Industrial Processes	269.86.	1279.9	1295.6
A Mineral Products	170.49	812.6	822.6
B Chemical Industry	21.5	101.0	102.2
C Metal Production	77.9	366.3	370.8
D Other Production	0.0	0.0	0.0
E Production of Halocarbons and Sulphur Hexafluoride	0.0	0.0	0.0
F Consumption of Halocarbons and Sulphur Hexafluoride	0.0	0.0	0.0
G Other (please specify)	0.0	0.0	0.0
Percentage increase from 2000 to 2020		4.70	4.76

the industrial emissions. As the demand for ferro alloys increases, the GHG emissions are estimated to grow to 366.3 Gg CO_2 under the BAU scenario in 2020. With further improvement in the industrial process, a 20% reduction in GHG emission is envisaged to give a saving of 74 Gg CO_2.

For producing low phosphorus (less than 0.20%) ferro-manganese, calcium oxide/barium oxide (CaO/BaO)-based flux is recommended for the dephosphorization of liquid high carbon Fe–Mn. But the melt will have to be desiliconized to less than 0.20% Si before dephosphorization. Injection of Ca–Si cored wire in the melt can reduce phosphorus in liquid ferro-manganese to less than 0.15%. Laboratory investigations have been completed for optimizing parameters such as composition of the reagent, amount to be added, effect of variation in silicon contents, treatment temperature, and treatment time. It is worth mentioning that for 0.10% decrease in phosphorus, the premium obtained is around Ngultrum 500 per tonne of ferro-manganese. The use of partially burnt coal as a partial substitute to coke needs to be looked into and tried in actual practice, as it is expected to increase the charge resistance.

3.5 Agriculture

The Renewable Natural Resources (RNR) sector comprising of agriculture proper, livestock and forestry remains the largest and single most sector of the Bhutanese economy and with 69% of the population dependent on this sector, mainly through subsistence farming. The share of agriculture in gross domestic product (GDP) is estimated to have decreased from 42.7% in 1990 to 35.9% in 2000 and 18.2% in 2009 (CSO 2000 and NSB 2010). However, the relative decline is more indicative of growth in the industrial and construction sector including major hydropower projects.

Data for emissions in the agriculture sector are available from 1999 to 2009 which has shown little changes. This is not surprising given the limited land area available for cultivation where only 2.93% of the country (1,124km2) is cultivated land (LCMP 2010) and changes in emission from year to year closely mirrors livestock population. As is evident from figure 3.7 the most significant source of emissions in this sector are enteric fermentation (40% in 2000) and agricultural soils (37% in 2000), followed by manure management (17% in 2000) and rice cultivation (6% in 2000). Emission from field burning of agricultural residues is negligible. The emissions from enteric fermentation, agricultural soils and manure management are due to livestock rearing by subsistence farmers as described in Chapter 2 and in the following sections.

3.5.1 Sources of Agricultural GHG

a. Nitrous oxide emissions

Nitrous oxide emissions from the agriculture sector are mainly from handling of livestock manure either from animal waste left on soils or through manure management (Figure 3.8). Farmyard manure (FYM) and artificial chemical fertilizers are two main sources of plant nutrients used by farmers in Bhutan but FYM continues to be the single most important source of plant nutrient with at least 139,000 mt applied to cereals and horticultural crops in year 2000 (RNR Statistics 2000). Farmers greatly value their livestock for manure production as well as milk and milk products (Chettri, 2003). Additional nutrients are added to manure with the lavish use of litter from the forest. Farmers also practice tethering cattle in the field.

N_2O emissions from application of synthetic fertilisers account for only about 37.02 % of total CO_2e emissions from agricultural sector in 2000. This is to be expected given that fertiliser use in Bhutan is one of the lowest in Asia: only about 4.3 kg of plant nutrient per ha of cultivated land. Unlike FYM, chemical fertilizers are mainly restricted to crops with higher returns such as paddy, potato, chilli and tree crops such as apples and oranges. Close to 30 percent of households reported to have used chemical fertilizers amounting to 1,800 MT. Urea, suphala and SSP comprise bulk of the amount used although MoP, CAN, bone meal and borax are also applied in minor quantities. In the main rice growing valleys, the adoption rate of fertiliser is about 30%. Of all fertiliser distributed in the country (about 13,000 tons annually), 20-30% is applied on rice (Chettri, 2003). Given the low levels of fertiliser use, the improved and increased use of fertilisers has great potential to boost production in Bhutan but this will increase GHG emissions.

b. Methane emissions

Combined with the relatively small area under paddy cultivation (19070.38Ha in 2000), and the absence of deep water cultivation, methane emissions from rice cultivation accounted for only about 6% of total agricultural emissions (Figure 3.7). Methane emission is mainly from livestock rearing through enteric fermentation. Emission from manure management is similar to emissions from rice cultivation (Figure 3.9).

Livestock sub-sector is essential for farm households for income source, draft power, and diet for inhabitants. Cattle husbandry is a major activity in livestock rearing in Bhutan (table 3.2) and statistics show that ruminants (cattle, yaks, dairy cattle, goats) and poultry showed slight increase in population from 2000 to 2009 while those of buffaloes, horses, pigs and sheep showed slight decline. In addition to cattle, poultry and pigs are also kept in small numbers by nearly every household. Poultry are kept for egg production and rarely reared for meat. The intensity in the production of milk and milk-products is determined by access to market which range from commercial holdings to homestead for own consumption. In most rural areas, standards

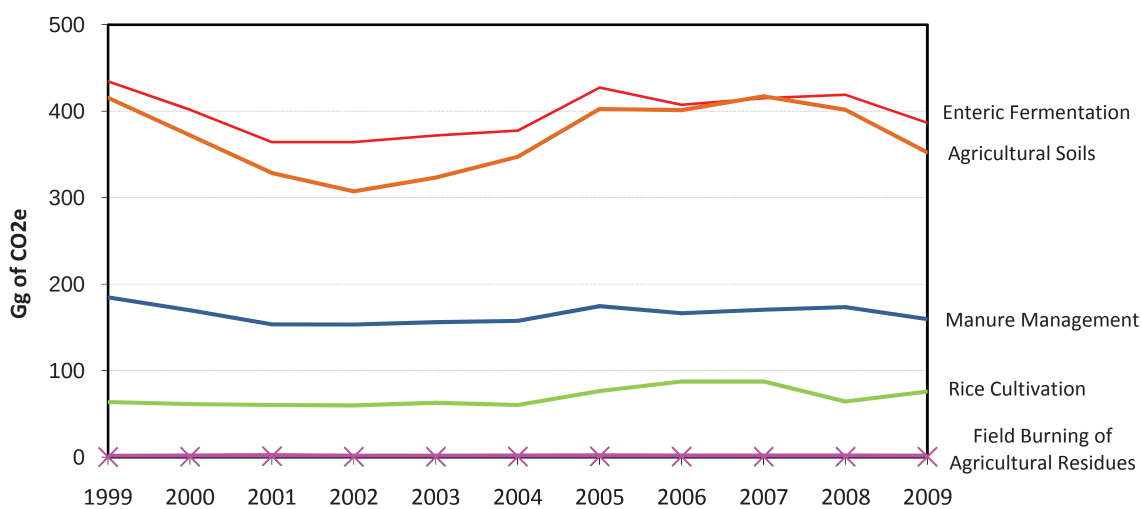

Figure 3.7: Emissions from the Agriculture sector (2000 to 2009)

of husbandry and disease control, as well as the lack of adequate availability of suitable feed are constraints to increasing milk yield, despite the government's effort to replace traditional breeds of cows by high yielding, improved breeds. Local supply of milk, butter and cheese thus meets a small proportion of the market need in urban areas. Efforts to establish milk cooperatives have not been very successful. The requirement for meat and livestock products in Bhutan is thus met largely by imports from India.

The government has been encouraging farmers to plant pasture on government leased land but due to labour shortage some managed pastures has been abandoned and became degraded and the invasive and less nutritious weeds have taken over. Free grazing, migratory and over grazing has led to land degradation as the vegetation has less opportunity to recover from constant grazing. Eventually the productivity of the grass or pasture land will decline and lead to abandonment and barrenness.

3.4.2 Mitigation Options for the Agricultural Sector

Given the declining contribution of the agriculture and forestry sector to GDP and with increasing pressures on agricultural land from urbanization and farm labour shortages, it is unlikely that the GHG emission from this sector will increase in the future. The promotion of sustainable land management practices will help to reduce GHG emissions in land base economic activities. Livestock continues to be an important part of the agricultural system in the Bhutanese context and policies and programs in this sector will be an important component of mitigation efforts.

a. Livestock Management

Emissions of CH_4 from enteric fermentation in ruminant and non-ruminant animals are dependent on the animal's digestive system and the amount and type of feed consumed. Emissions of CH_4 from domestic ruminant animals can be reduced as producers use improved grazing systems with higher quality forage, since animals grazing on poor quality rangelands produce more CH_4 per unit of feed consumed. Confined feeding operations utilizing balanced rations that properly manage digestion of high energy feeds can also reduce direct emissions, but can increase indirect emissions from feed production and transportation. Means to improve Livestock and Grazing Management to reduce Enteric Fermentation are:

i. Develop and implement livestock management to reduce surplus livestock population:

- Revise taxation scheme on the basis of livestock holding in adult equivalents to discourage the rearing of unsustainable numbers of livestock;
- Enhance livestock sterilization service through

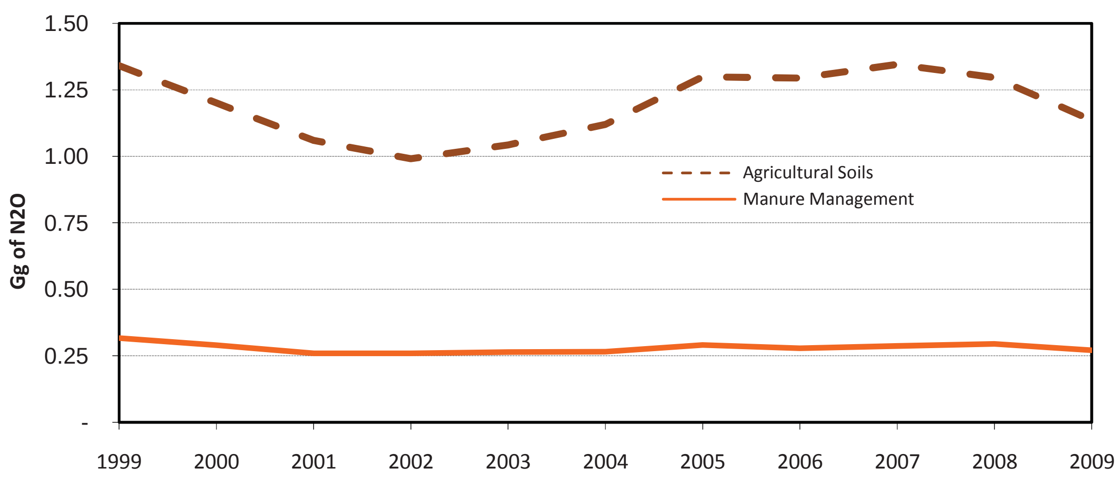

Figure 3.8 Emissions of N_2O from Agriculture

better coverage, including mobile units;

- Improve yak and cattle breed through selection of superior bulls from local population on the basis of pedigree and/or progeny performance, distribution of bulls from other areas to introduce new blood lines and reduce inbreeding and artificial insemination with imported semen.

ii. Develop and implement improved pasture and fodder management to increase and improve forage reproductive capacity and quality and reduce grazing pressure on forests:

- Establish farmers' cooperatives that will among other things oversee proper utilization of forage resources through monitoring of stock numbers, grazing duration and grazing time, nutrient management, and shrub and weed control;
- Conduct studies on forage competition between wild ungulates and domestic cattle and yak to aid planning and implementation of sound grazing management interventions where forage competition is most severe;
- Establish hay meadows with high-yielding fodder legumes and grasses under high nutrient supply condition to reduce grazing pressure on forests;
- Introduce controlled burning or mechanical

Table 3.2: Livestock population (Livestock Statistics, DOL)

Year	Cattle	Yak	Buffalo	Horse	Pig	Sheep	Goat	Poultry
1999	344,595	39,604	1,790	31,255	52,264	24,840	36,007	293,633
2000	320,509	34,928	1,800	27,887	41,401	22,880	31,328	230,723
2001	287,052	38,892	1,777	21,588	40,829	22,199	22,950	184,874
2002	294,787	31,223	1,754	21,511	40,088	20,099	24,071	191,931
2003	293,990	38,274	1,731	23,448	38,548	24,515	22,950	165,708
2004	295,922	41,328	1,754	24,692	35,255	20,803	23,850	195,286
2005	338,847	45,538	1,731	24,608	28,161	17,612	20,507	189,269
2006	312,063	52,911	1,683	20,127	25,743	15,084	22,207	182,776
2007	319,899	51,500	1,551	20,967	26,966	12,415	28,300	200,629
2008	325,628	48,400	1,023	22,837	27,501	13,283	39,099	208,213
2009	307,013	38,690	955	18,237	22,184	12,296	38,618	248,118

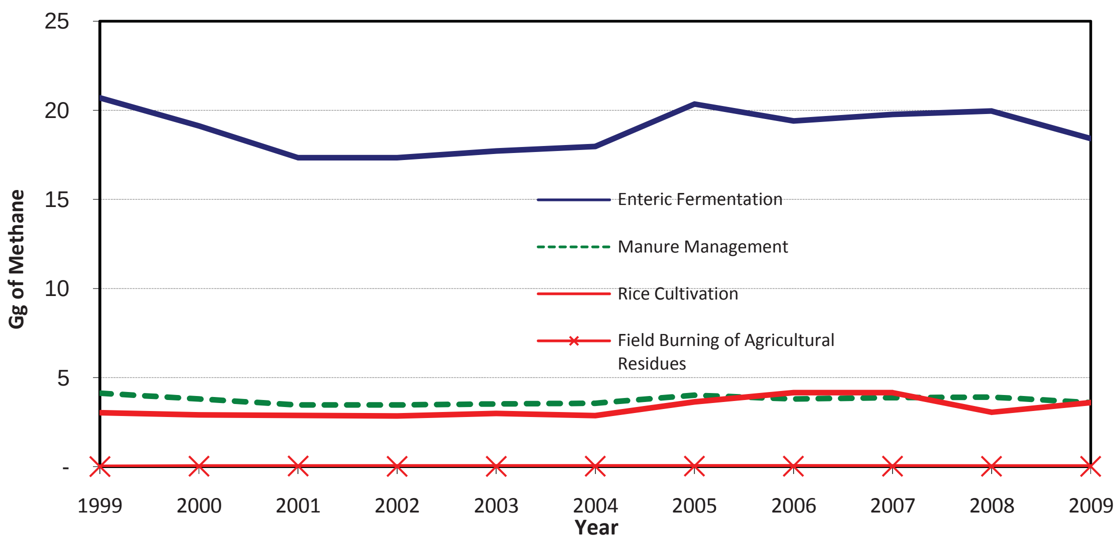

Figure 3.9 Emissions of CH_4 from Agriculture

clearing of shrubs followed by reseeding with selected species and protection from grazing based on applied research and extension;

- Establish community and homestead forests of species with high forage and soil conservation values, and preferably with other ethno-botanical values using participatory strategies with local people. This will necessitate establishment of forest nurseries, where such nurseries do not exist.

iii. Develop and implement pasture management on leased forest lands:

- Identify barren and/or degraded forest lands that can be potentially leased for pasture management as per the provision of the Land Act of Bhutan 2007;
- Prepare and implement management plans for pasture development on leased barren/degraded forest lands on a pilot scale, starting with 1-2 sites in each dzongkhag.

b. Manure and Biogas

The keeping of livestock in pen or stall as a cut and carry system for integration into a cropping farm system will provide protein, milk and food crop security. The livestock provides farm security and the manure from the livestock could be converted into clean biogas through anaerobic digester for cooking and lighting. Furthermore the digested organic sludge and slurry are a good source of organic fertilizer which can be used in rice, cereal or fruit tree. Human wastes could also be connected to the digester to provide extra biogas and clean sanitation. Biogas feasibility assessments (SNV 2010) found that up to 20,000 potential domestic digesters could be developed in the warmer parts of Bhutan and each digester could reduce 2 to 4 tCO_2e per annum depending on whether non renewable biomass is used in the baseline calculation. During first 3 years, around 1,500 plants could be installed, leading to maximally 3,000 tCO_2e per year after 3 years. A program to identify and to mitigate the technical, financial and regulatory barriers for the scaling up of domestic biogas is currently being developed by the Department of Livestock in collaboration with the Department of Energy.

Other measures that can reduce fugitive emissions include:

- Increasing the digestibility of forage and feeds;
- Adopting a good manure nutrient management plan;
- Understanding of crop fertilizer needs;
- Soil testing to establish nutrient requirement;
- Use of organic manure as a nutrient source;
- Timing of manure application: Controlled-release fertilizers, nitrification inhibitors, the timing of nitrogen application, and water management should lead to improvements in nitrogen use efficiency and further limit N2O formation;
- Determine amount of manure produced;
- Application of compost;
- Mineral additions to compost and Improve Moisture and aeration.

c. Agriculture Sector (Crops): Mitigation Measures

Agriculture is an important sector in Bhutan that engages over 69 % of the population and provides employment to over 55 % of the total population (see – Bhutan Climate Summit on Food Security and Climate Change). The arable land suited for farming is around 2.93 % of the total geographical area, and more than 60 % of arable land is under dry land cultivation (NSSC, 2010). The main source of plant nutrients to produce food comes from the application of 3 to 5 tons of farmyard manure, and around 9 kg of plant nutrients from chemical fertilizersper hectare of land (Norbu, 2008). The use of plant protection chemicals such as insecticides and fungicides has decreased over the years while use of the herbicides in paddy and potato fields increased. The distribution of chemicals for crop production recorded during the 2007-2008 report of the department of agriculture showed 3057.8 t of inorganic fertilizers and around 16 t of plant protection chemicals (DoA, 2009). Through intensification and diversification of farming systems, the sector intends to achieve more than 50 to 60 % self sufficiency in rice, increase annual income of farming households to Nu 35,000, and encourage more farming households to practice organic farming (10th plan document, 2008). The key to meet these targets, and help to mitigate climate change is through a number of interventions highlighted: Promotion of integrated Soil Fertility Management; Sustainable land Management (SLM); Increasing Cropping Intensity; and Organic Farming.

d. Promotion of Integrated Soil Fertility Management

Farmers in Bhutan use crop residues, forest litter and animal manures to produce farm yard manure (FYM). FYM is a mixture of these organic materials and serves as the main source of plant nutrients for all types of crop production. The application rates reported varied from 3 -5 t/ha, and the percent of N, P and K in FYM dry matter was 1.6 %, 0.8 % and 2.9 % respectively in one of the studies conducted (RNR-RC, Bajo, 2000). Because of the year in and year out application of this input, the soil organic matter build up in most of the cultivated soils ranges between 2 to 4 %. This traditional practice of FYM application to farm land has been helping to store carbon in soils in the form of soil organic matter for generations. This traditional process also helps to reduce emissions of methane or nitrogenous oxide gas from manure since FYM is not in slurry form and is being collected and piled on regular intervals. With increasing farm labor shortage to produce FYM coupled with the introduction of chemical fertilizers is likely to reduce soil organic matter content in the long run. There is, however, a huge potential to promote integrated soil fertility management principles (combination of improved management of organic residues, chemical fertilizers and use green legumes) to reduce GHG emissions from these sources - manures and chemical fertilizers.

e. Up Scaling Sustainable Land Management (SLM) Technologies

Sustainable land management is one of the best measures available to mitigate climate change in the Bhutanese farming landscape. The national land management campaign in 2005 promoted SLM technologies across the diverse farming systems (DoA, 2005). Hedge rows of grasses and tree species were introduced along the sloping farming land to reduce soil erosion, diversify income sources and sequester carbon. Through GEF, UNDP and World Bank support, these activities were promoted from wet humid tropics to cool temperate pilot sites. The farmers have taken up these technologies on their farms as well as on the community lands. Most of these degraded forest or grazing land was brought under improved management systems. The SLM/WB_GEF project reported that about 2400 ha of degraded/vulnerable lands are brought under improved land management practices; and another 2563 *tseri* (shifting cultivation) lands are brought under permanent cultivation. Although SLM benefits are long term, with continued advocacy and educations, more farmers are coming forward to take up these technologies. This is also a promising area where land degradation, biodiversity and climate change focal area activities potentially converge.

f. Increasing Cropping Intensity

There is no scope to expand arable land to increase food production. The only possible way out is through intensification and diversification. For example, farmers living around wet sub-tropical to dry sub-tropical zones can harvest three crops in a season: potato- maize followed by buckwheat or millets/wheat. Growing more crops in a year would mean capturing more carbon dioxide from atmosphere. There is a potential to increase cropping intensity from around 120 to over 200 % in some of the selected agro-ecological zones there by reducing fallow period. Shifting cultivation or *tseri* is another form of land use to grow cereal crops, but now it has been discouraged since crop yield per unit area appeared to be very low, and damage to environment is high through removal of vegetation cover and burning. Incentives are provided to farmers to convert them into permanent cultivation such as orchards or agro-forestry systems. Promotion of enabling environment to grow more crops in a year, and bring barren areas under permanent cultivation is another potential to increase food production, reduce emission of GHG, and carbon sequestration.

g. Increasing Area under Organic Farming

Farming in Bhutan revolves around recycling of organic residues for plant nutrients and crop rotation practices to reduce pest and disease infestations. The land holding is small (less than 1.5 ha) and because of economic reasons, many farmers do not invest in inputs like chemicals to increase production. In many ways, there is scope to increase production guided by organic farming principles if right sites and crops are selected. For these reasons the government is seeking to expand Bhutan's total area under organic cultivation to create "Brand Bhutan" envisioned under the Economic Development Policy. The organic farming framework is in place and currently the master plan/strategic plans are being developed. But there is always tension between the desire to promote low carbon organic farming and the need to increase food production and food security using high input intensive systems.

The spread of pest and diseases are low in most of these farming communities because of geographical isolation of one farming community from another. The buildup of soil organic matter is going to be high since plant nutrients are supplied through recycling of organic residues. Biological control of pest and diseases, crop rotation practices and the use of local resistant land races are going to demand less energy to produce organic food. There is also a high demand for organic produce in the local tourism industry and neighbouring cities of India. For environment, economic and health reasons, organic farming has drawn a lot attention from politicians, planners and researchers. They know that this farming practice can reduce emission of green house gases, sequester carbon and increase income for small holders.

h. Reducing methane emission from rice fields

Feasible mitigation strategies that have been verified to significantly reduce methane emission from rice fields are temporary midseason aeration of the soil, using fermented instead of fresh organic manure, applying sulfate containing fertilizer, and planting/breeding rice cultivars with low emission capacity (Chettri, 2003). Developing direct seeding techniques to augment transplanting are potential future options that could help to reduce methane emissions. However with increasing threats to paddy fields from increasing urban sprawl and farm labour shortage, unless there are major changes in policy and incentives, increase in rice cultivation is not expected.

3.6 Land Use Change and Forestry

The prominence of carbon sequestration in the national GHG inventory reflects national policy that regards forests as crucial for the well-being of the Bhutanese population. The great foresight and leadership has allowed much of Bhutan's natural environment and biodiversity to be in pristine state. Bhutan has been dubbed as a conservation centrepiece of the Eastern Himalayas, a region known to be one of the global biodiversity hotspots. The 6,309.6 Gg of CO_2 sequestered through managed forests, forest plantations and the abandonment of managed lands is roughly four times the level of Bhutan's overall anthropogenic GHG emissions (see Chapter 2).

3.6.1 Forest Resources and threats

According to the Land Cover Assessment 2010, 70.46% of Bhutan is forested. Of this, 12.9%, roughly 413,000 hectares, is classified as primary forest. There are 10 formally protected areas covering nearly 43% of the land area. An additional nearly 9% of the land area has been declared as biological corridors connecting the protected areas. With the addition of conservation areas, about 51% of the country's area is under some form of conservation management.

It is estimated that 236,700 ha of forests are degraded; the annual rate of degradation is estimated to be 0.5 per cent and the main causes are:

- Shifting cultivation (tseri) is prevalent in the eastern region of the country. Shifting cultivation, if properly carried out, does not cause major degradation. However, shortened fallow periods, clearing land on steep gradients and forest fires resulting from slash-and-burn cultivation are among the factors contributing to degradation. Slash-and-burn cultivation is now illegal as per the forest and nature conservation legislation.
- Fire is one of the biggest threats to the forests in Bhutan. The amount and distribution pattern of rain affects the fire situation to a great extent in Bhutan. The peak season for forest fires in Bhutan is from January to March. The causes are; (I) burning of agricultural debris (40%), (II) burning of trees to prepare grazing areas for livestock (30%), (III) camps, picnics and cooking fires (25%), and (IV) discarded cigarettes (5%).
- Rapid urbanization is also placing increased demands on the forests for timber and fuelwood. Despite the fact that logging is not allowed without an approved management plan, tree marking for bona fide house construction is practiced in most of the government reserved forests.

3.6.2 Legal and institutional setting

The Constitution of the Kingdom of Bhutan adopted in 2008 is one of the key legal mandates for forest management in the country as it mandates that 60% of the country remain under forest cover for all times to come. The Constitution also mandates the responsibilities of all citizens to safeguard the natural environment for the benefit of present and future generations.

The key legislation governing forest management is the "Forest and Nature Conservation Act, 1995" with the following objectives: i) To ensure an adequate supply of basic forest products to meet the needs of the population with due recognition of the multiple responsibilities for forest resources and their sustainable management and use; ii) To provide for the special legal protection from fires; and protection of flora and fauna, listing twenty-three wild animals and seven plants as totally protected species and iii) To lay down regulations for the extraction of firewood.

The Land Act of Bhutan 2007 is another important legislation with major implications for forest management. In the context of REDD+, one of the important implications is Chapter 6 which confirms that trees, either naturally grown or planted, in registered land shall belong to the landowner.

A revised National Forest Policy is now in the final stages of Government endorsement. Its goal explicitly states that, "*Bhutan's forest resources and biodiversity are managed sustainably and equitably to produce a wide range of social, economic and environmental goods and services for the optimal benefit of all citizens while still maintaining 60% of the land under forest, thereby contributing to Gross National Happiness."* The Policy establishes six broad objectives that must be pursued within a planning framework that integrates environmental and economic/ commercial outcomes. These are:

- Sustainably produce economic and environmental goods and services to meet the long term needs of society through active and sustainable management of Bhutan's forests;
- Maintain species persistence and ensure long term sustainability of Bhutan's biodiversity, ecosystem services and natural habitats through a network of protected areas;
- Bhutan's forested watersheds actively managed to achieve sustainable rural livelihoods and to produce a reliable supply of high quality water for domestic use, irrigation and hydro power production;
- Rural communities able to meet the majority of their timber demands from their own community forests, and derive economic benefits from the sustainable management of their forests through sale of forest products

and services;

- An economically viable and efficient forest based industry and
- Organizational and institutional reforms carried out and managerial, technical and administrative capacity developed to implement strategies and achieve all policy objectives.

3.6.3. Mitigation Options for LUCF

a. Reduction Emission from Deforestation and Forest Degradation (REDD +)

Bhutan will need support to address the various capacity gaps in becoming ready to implement REDD+. The government in collaboration with WWF Living Himalayas Initiative and other partners has initiated REDD+ capacity building and aim to further integrate national level baseline carbon estimation within the current national forest inventory. Ensuring that the design of the National Forest Inventory is suitable for biomass and carbon assessment would allow substantial capacity to be developed. A coordinated implementation of the forest inventory and monitoring would be essential to make efficient use of limited resources of manpower and financing.

b. Sustainable Forest Management

Strengthening the protection and management of forests to enhance carbon sinks for sustainable production and utilization of forest resources will be crucial in ensuring the maintenance of Bhutan's carbon sink. Some recommendations in the Bhutan Biodiversity Plan (NBC 2009) include the following actions:

- Assessment of old FMUs, particularly in wood deficit dzongkhags, for sustainable production and utilization of forest resources with some protection and enrichment planting;
- Develop capacity of territorial forestry divisions to effectively implement planning guidelines for management of forest areas outside the FMU system;
- Implement the planning guidelines in at least one forest area in each territorial forestry division and evaluate the applicability and effectiveness of the guidelines;
- Evaluation of the effectiveness of FMUs in the context of environmental sustainability and socio-economic development for enhancing FMU planning and management.

c. Expansion of Community Forests

The primary objective of Community Forestry is to improve local forest conditions through community management whilst enhancing socio-economic benefits to the local communities in terms of increased access to timber, fuelwood, fodder and non-wood forest products. As of June 2011, 313 community forest unit covering 36,649 ha of forest land was established.

Prevention and Control of Forest Fires

In spite of stringent legislation and regular public awareness programmes, forest fires are a recurrent and widespread phenomenon. 526 incidents of forest fire, affecting nearly 70,000 hectares of forest was recorded, between 1999/2000 and 2007/08 (NCD 2009). Prevention and control of forest fire, like forest management, is both an adaptation and mitigation measure. The risk of forest fire is expected to increase with drier winters under a future climate (See chapter 4) and is also identified as a priority activity in Bhutan's NAPA. The approaches for forest fire management will require both, research, awareness campaigns and capacity building for both government agencies and community organizations.

e. Reforestation

As a national programme, reforestation of degraded and barren forest lands was the earliest conservation initiative in Bhutan. As early as 1947, the first forest plantation was established, 11 years prior to the DoF coming into being. Since then, reforestation has been carried out on more than 21,500 ha as. The end of 9th FYP. (Table 3.3). Continued reforestation of degraded and burnt forest lands will be essential for management of forests for both reducing risk of erosion and landslides from degraded areas as well as for sequestration.

3.7 Waste Management

Greenhouse gas emissions from wastes in Bhutan were estimated for two sources; Solid waste disposal on land (84% of total waste-related emissions in 2000) and domestic and commercial wastewater handling (16% in 2000). Data was not available for industrial waste handling. Due to relatively low level of urbanization and infrastructure solid waste mostly estimated from 10 urban areas (Thimphu, Phuentsholing, Samtse, Paro, Gelephu, Damphu, Samdrupjongkhar, Bumthang, Trashigang, and Mongar). However most of the emissions can be attributed to the two cities of Thimphu and Phuentsholing. In 2000, GHG emissions from the waste sector in Bhutan only accounted for 2.9% of the total national emission. Emissions in waste sector are a function of consumption rate and population and emissions have been increasing steadily, especially from solid waste management (Figure 3.11).

3.7.1 Options for managing waste emissions

The waste management system in Bhutan is guided by the Waste Prevention and Management Act of Bhutan, 2009 and is based on three guiding principles: i) Precautionary principle ii) Polluter pays principle and iii) Principle of 3 Rs and Waste Minimization Hierarchy. It also has provisions to provide incentives for reduction and management of wastes.

a. Reducing residential, commercial and industrial wastes through the 3R to reduce, reuse and recycle waste

Given the high eco-literacy in the country, a 3R campaign to reduce, reuse and recycle waste would be the cost effective mitigation option for Bhutan. Such campaigns have already started in the schools and schools are encouraged to reduce their non biodegradable waste through green school initiatives. Catching the children young to instill such values will yield long term dividends who in turn can convince their parents and friends to care for the environment. Several private entrepreneurs have emerged recently in waste management, and incentive provisions in the Waste Prevention and Management Act should

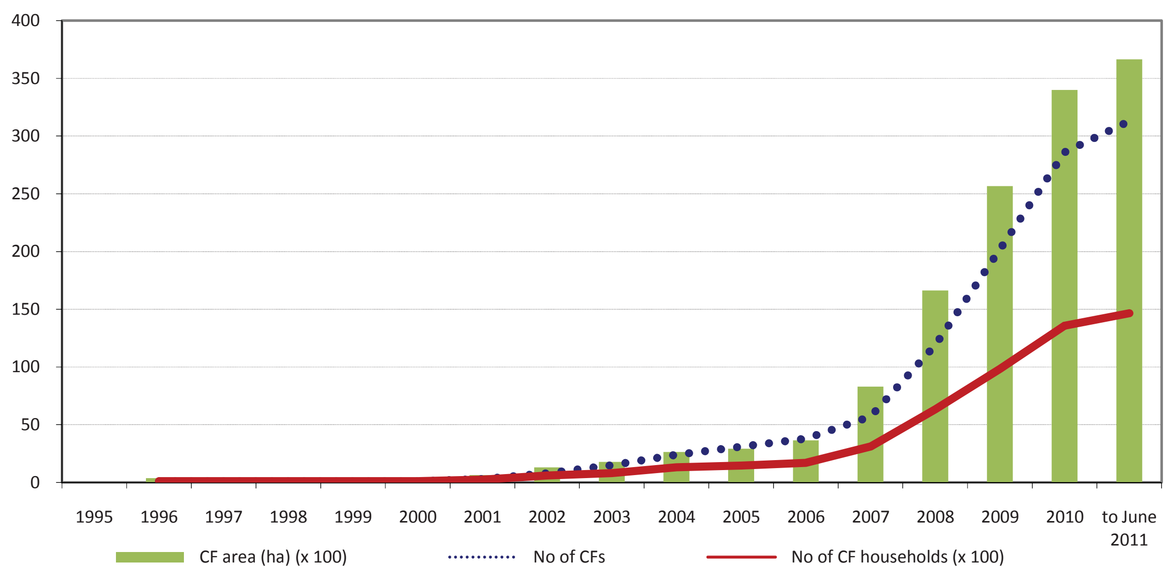

Figure 3.10: Community forests in Bhutan (SFD 2011)

be used to encourage efficient waste reduction and management. Public Private Partnership models are already being explored and must be encouraged.

b. Composting

In view of the high organic content (>50%) of the MSW, there is opportunity to convert this into good compost. Composting will help to reduce the waste volume. Manual or automatic segregation needs to be developed to make this system viable and Thimphu municipality has started a composting program to reduce solid waste volumes.

c. Incineration

Mitigation measure to curb solid waste emission could involve the capturing of methane from landfill sites for electricity generation, incineration for energy recovery or recycling to reduce the wastes volume. Although emission technology and standard from incineration plants has improved, there is still opposition to this concept for fear of dioxin and furan emission from plastic combustion.

d. Energy from waste – methane capture

With increasing population, the safe disposal and management of the solid waste and associated methane emissions pose a constant challenge. Thimphu and Phuentsholing alone generate about 37 tonnes and 25 tonnes of solid waste, respectively, daily, containing a lot of organic matter (DOE 2005). If this waste can be used for the generation of energy (electricity or thermal energy), besides augmenting the energy supply per se, it would take care of waste management as well. The IEMMP reported that Bhutan has the potential to sustain over 3MW of power generation capacity through waste. A biomethanation system of capacity 1 tonne/day could be set up in Thimphu as a demonstration plant, treating its organic waste, including that generated from hotels and vegetable market.

3.8 Priorities for International Support in Mitigation

As a least-developed country, Bhutan's capacity to contribute to global mitigation efforts is limited by a number of constraints. Bhutan lacks both the public and private-sector funds to invest in mitigation efforts to remain carbon neutral. Limited technological capacity and human resources are also significant constraints for Bhutan. Bhutan's potential to contribute to global mitigation efforts will not be realized without greater support from the international community. This includes not

Table 3.3: Reforestation in Bhutan (from NCD 2009)

	Plantation Area (hectare)
Before 1st Five Year Plan	822
1st Five Year Plan (1961 - 66)	932
2nd Five Year Plan (1967 - 72)	1,278
3rd Five Year Plan (1972 - 77)	3,525
4th Five Year Plan (1977 - 82)	1,743
5th Five Year Plan (1982 - 87)	2,199
6th Five Year Plan (1987 - 92)	4,498
7th Five Year Plan (1992 - 97)	2,525
8th Five Year Plan (1997 - 2002)	1,916
9th Five Year Plan (2002 - 07)	2,078
Total	21,516

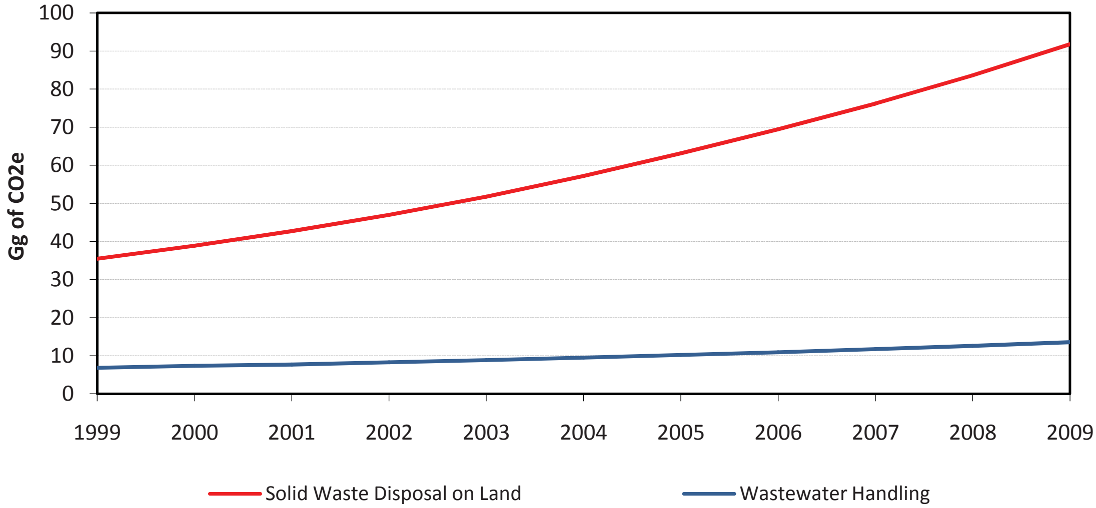

Figure 3.11: Emissions from waste Management

only financial support, but also for the transfer of proven technology and help with capacity development initiatives and the strengthening of the institutional and legal framework.

A strategy to guide Bhutan towards fulfilling the commitment made in 2009 to ensure that emissions do not exceed the capacity of its forests to sequester carbon is under development and is expected to be completed by end of 2011. This strategy will be part of Bhutan's NAMA. However, some of the key mitigation initiatives that would enhance Bhutan's capacity have been identified as mitigation options within the preceding sections.

Chapter Four

Vulnerability and Adaptation

4.1 Introduction

The vulnerability of countries with mountainous ecosystems to the adverse effects of climate change is well recognised. The UNFCCC identifies countries with mountainous ecosystems as among the most vulnerable in Article 4.8 and also its preamble. The Intergovernmental Panel on Climate Change (IPCC) in its Second, Third and Fourth Assessment Reports indicate that mountainous countries such as Bhutan are likely to be among the most vulnerable to the adverse impacts of climate change. The IPCC and other similar reports point to a number of vulnerabilities that mountainous countries face in regards to climate change and variability, including their size and limited resource base, vulnerability to existing weather events such as heavy monsoonal rainfall, dry-season drought, tropical storms such as cyclones, and restricted economic opportunities that are being exacerbated by globalization and trade barriers. Though, relatively small in size (38,394 km^2) and population (projected population of 708,265 people in 2011), there is more than ample space but rugged terrain, limited economic resources and poor soils and limited land for cultivation (1,124km^2) make for difficult economic and living conditions. In fact, the various IPCC reports claim that adaptive capacity of human systems is generally limited in mountainous developing countries, such as in Bhutan, and vulnerability high. Furthermore, one of the most important consequences of climate change, especially mountainous countries with glaciers, is climate-driven glacial melt and Glacial Lake Outburst Floods (GLOF), which in turn can severely impact upon inland waters and ecosystems and infrastructure well into the future.

In this chapter, the key vulnerabilities and adaptation needs for Bhutan are presented for the following sectors: water resources, forests and biodiversity, agriculture, energy, human health and glaciers. Cross-linkages between sectors where overlap occurs are also addressed. Furthermore, policy frameworks, plans, policies and institutional frameworks and resources for developing and implementing adaptation strategies and measures in response to climate change are also addressed.

This chapter was prepared through a process involving a combination of technical assessments by several teams of experts (refer Annex I) specifically for the Second National Communication, outputs of other ongoing assessments in Bhutan, and several rounds of consultations with stakeholders and experts to provide inputs for the assessments and review the findings. The general methodology used in the V&A is provided in the following sections but the main technical assessment is fully presented in a separate document "V&A Assessment for Bhutan's Second National Communication: Technical Report" published separately[3]. The V&A process for the SNC also built upon a separate process, namely, the preparation of national thematic papers for the "Climate Summit for a Living Himalayas-Bhutan 2011[4]" and used the same members in the V&A Task force to ensure synergy in developing the adaptation priorities for Bhutan.

4.2 Climate Baseline and Scenarios

Bhutan has very limited meteorological records both in terms of area and historical coverage. A limited data set of reliable observed data at the Dzongkhag (district) level is available from 23 Class A and Class C stations for maximum and minimum temperature and rainfall, from 1996-2008 for most stations (13 years) and a few stations cover the

3 Soft copies of this report and the full technical V&A assessment, supporting maps and data are available online at www.nec.gov.bt/climate/snc/

4 The Climate Summit for a Living Himalayas-Bhutan 2011 is a sub-regional effort for common adaptation needs of the nations and communities around the southern slopes of the Eastern Himalayas, namely; Bangladesh, Bhutan, India and Nepal. The Summit is scheduled for 19 November 2011 in Thimphu, Bhutan and will culminate in a regional roadmap to address adaptation along the themes of Biodiversity, Energy Security, Food Security and Water Resources. More information is available at www.bhutanclimatesummit.org.bt

period 1994-2008 (15 years). Most of the stations are located along the southern border and in the middle latitudes of the country. There is no record of snowfall and records of solar radiation and wind have been started only in the last couple of years at a few stations. Even in the more reliable records there are gaps in data (missing data) in several cases.

However, an analysis of data from a few selected automated meteorological stations of the four representative eco-floristic zones of Bhutan from 2000-2009 is available in the National Thematic Paper on Biodiversity for the Climate Summit for a Living Himalaya- Bhutan 2011. The results of this analysis show a trend of rising mean summer and winter temperature (Figure 4.2.1). Due to the short time-series annual rise in temperature was not quantified. There was no detectable trend in patterns of precipitation for the 2000-2009 period (Figure 4.2.2). There was no snow cover and snow fall data available for analysis.

For climate change impacts studies, the normal convention is to use 30-year time slices. So for the current or control climate scenario, on account of data availability problems, the 1980-2009 period from the PRECIS simulations is used. These simulated data sets for the 1980-2009 period were cross-checked for consistency and accuracy against observed station data that cover the period 1994/96-2008 (NEC/START-SEA, 2011). For the future scenarios, two time slices are used, namely a short term time period (2010-2039) and a long term time period (2040-2069). These future short term (2010-2039) and long term (2040-2069) scenarios of daily maximum and minimum air temperature, daily precipitation and daily solar radiation, at minimum, were prepared using the PRECIS regional climate model (NEC/START-SEA 2011). The downscaled climate change scenarios (22km resolution) prepared in PRECIS was piloted by two GCMs, namely the German ECHAM5 A1B and the British HadCM3Q0 A1B covering the period 1979-2069.

This section deals with the trends in mean annual and seasonal temperature (^{0}C) and mean annual

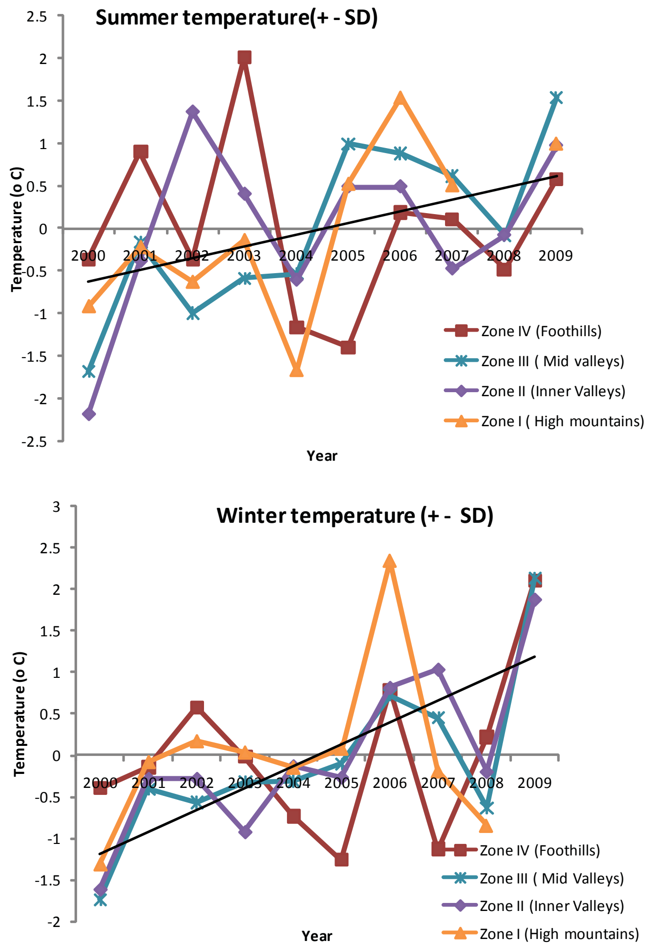

Fig.4.2.1: Observed mean summer and winter temperature. Source: National Thematic Paper on Biodiversity

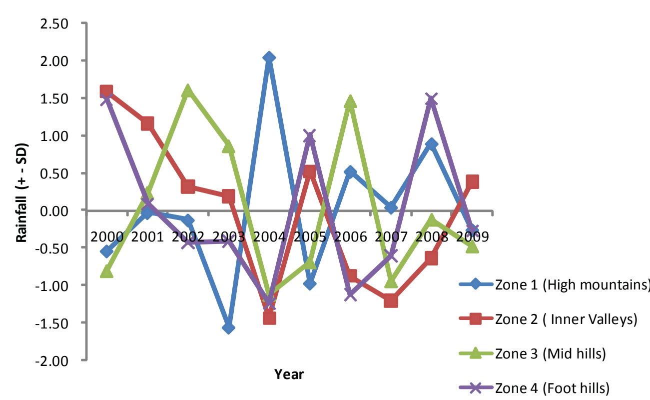

Figure 4.2.2: Rainfall trends from 2000 to 2009. Source: National Thematic Paper on Biodiversity

and seasonal precipitation/rainfall (mm) for the entire surface area of Bhutan for the period 1980-2069, using simulations from the downscaled (22 x 22 km grid network) HadCM3Q0 and ECHAM5 climate models. Due to a lack of adequate data for the control/observed period (1980-2009) trends are based on simulated outputs as described above.

4.2.1. Mean Annual and Seasonal Air Temperature Trends (^{0}C):1980-2069

The annual trends in annual mean temperature between 1980 and 2069 are shown in Figure 4.2.3. Both the downscaled HadCM3Q0 and ECHAM5 climate model outputs of air temperature show a progressive and steady increase in air temperature from 1980 to 2069. However, there is a difference of ~ 1.5^0 C, between the downscaled HadCM3Q0 and ECHAM5 simulations, the HadCM3Q0 simulations being higher. This may well be due to the way the two models vary certain parameters such as corrections for elevation, Bhutan being largely a mountainous country. The HadCM3Q0 simulations show an increase of 3.5^0 C by 2069 (from ~ 13.5^0 C in 1980) to ~ 17.0^0 C in 2069) and ECHAM5 simulations show a similar magnitude of temperature increase of 3.5^0 C (from 12.0^0 C to ~ 15.5^0 C).

The seasonal trends in monsoon/summer mean temperature between 1980 and 2069 show similar trends (Figure 4.2.4) with a steady increase from 1980 to 2069 under both HadCM3Q0 and ECHAM5. Again, there is a difference of ~ 1.5^0 C, between the downscaled HadCM3Q0 and ECHAM5 simulations, the HadCM3Q0 simulations being higher. Under HadCM3Q0 temperature during the monsoon wet season increases by ~ 3.0^0 C (from ~ 19.5^0 C in 1980 to ~ 22.5^0 C in 2069) and ECHAM5 also shows a similar change of ~ 3.0^{0}C (from ~ 17.5^0 C in 1980 to ~ 20.5^0 C in 2069).

Mean temperature for winter between 1980 and 2069 also show similar trends (Figure 4.2.5) with both the HadCM3Q0 and ECHAM5 showing a progressive and steady increase in air temperature from 1980 to 2069. There is a difference of less than 1.0 ^{0} C between the downscaled HadCM3Q0 and ECHAM5 simulations, the HadCM3Q0 simulations again being higher. Under HadCM3Q0, temperature during the winter increases by about 4.0^0 C (from ~ 6.75^0 C in 1980 to ~ 10.75^0 C in 2069). ECHAM5 simulations also show a steady increase of temperature during the dry winter season, increasing by 3.5^0 C (from ~ 6.5^0 C in 1980 to ~ 10.0^0 C in 2069).

Both the downscaled HadCM3Q0 and ECHAM5 climate models project slightly higher temperature increases in the winter, similar to those for South-East Asia, from ensemble model simulations in Fourth Assessment Report of the IPCC).

4.2.2. Mean Annual and Seasonal Total Precipitation Trends (mm)

The annual trends in annual mean total precipitation between 1980 and 2069, based on down-scaled simulations of both the HadCM3Q0 and ECHAM5 climate models are shown in Figure 4.2.6. Both climate models show a progressive and steady increase in precipitation from 1980 to 2069. While there is a difference of ~ 100 mm/year between the downscaled HadCM3Q0 and ECHAM5 simulations, both show steady increases in precipitation. ECHAM5 shows a steady increase of ~ 600mm/year in precipitation/rainfall (from ~ 2,000 mm/year in 1980 to ~ 2,600 mm/year in 2069), and HadCM3Q0 simulations shows an increase of ~500mm/year in annual precipitation/rainfall, (from ~ 1,900 mm/year to ~ 2,400 mm/year).

The seasonal trends in mean total seasonal precipitation during the monsoon from 1980 and 2069 are shown in Figure 4.2.7. Both climate model outputs for monsoonal season precipitation/rainfall show a progressive and steady increase in precipitation from 1980 to 2069. There is a difference of ~ 200mm between the downscaled HadCM3Q0 and ECHAM5 simulations but both show steady increase in monsoon precipitation.

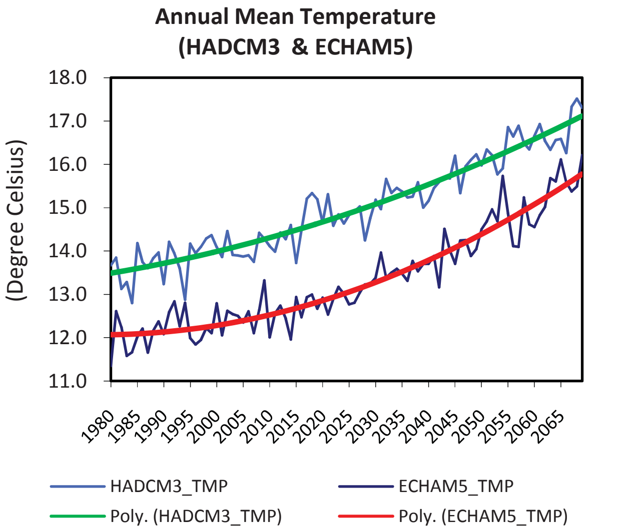

Figure 4.2.3: Annual trends of annual mean air temperature (^{0}C) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios

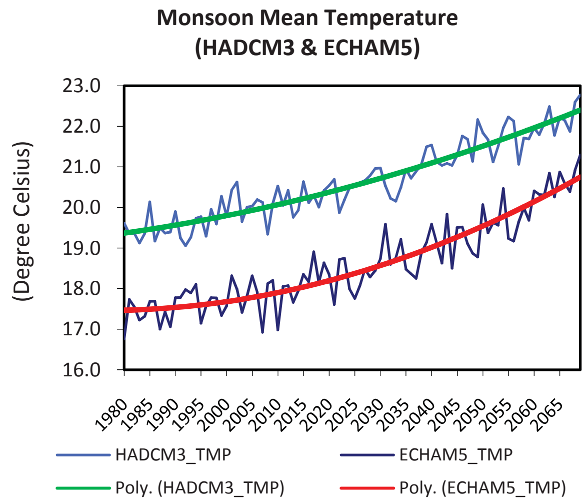

Figure 4.2.4: Annual trends of seasonal/monsoonal mean air temperature (^{0}C) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios

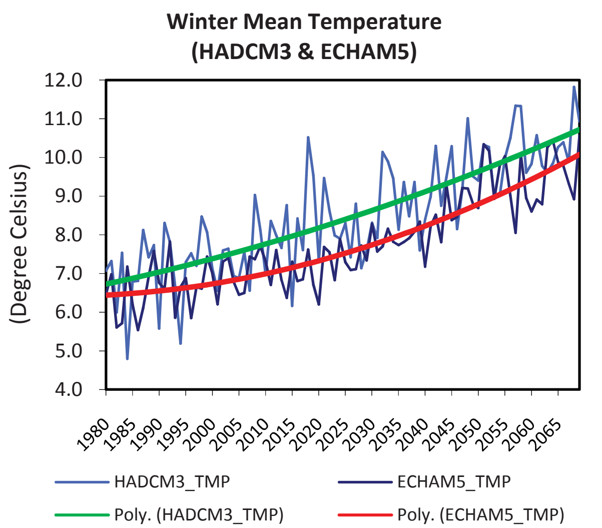

Figure 4.2.5: Annual trends of seasonal/winter-dry mean air temperature (^{0}C) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios

Under ECHAM5 precipitation/rainfall during the monsoon increases ~ 450 mm/year (from ~ 1,300 mm/monsoon season in 1980 to ~ 1,750 mm/monsoon season in 2069). HadCM3Q0 simulations show an increase of seasonal precipitation/rainfall of ~350mm/year (from ~ 1,150 mm/year to ~1,500 mm/year).

The seasonal trends in the mean total seasonal precipitation for winter between 1980 and 2069 are shown in Figure 4.2.8. Both the downscaled HadCM3Q0 and ECHAM5 climate model outputs of winter/dry season precipitation/rainfall now show, at first, a progressive and steady decrease in precipitation from 1980 to ~ 2020 followed by a steady and progressive increase from ~ 2020 to 2069. Also, there is now a difference of ~ 100 mm/winter season between the downscaled HadCM3Q0 and ECHAM5 simulations, the HadCM3Q0 simulations now being slightly higher, especially towards 2069. The ECHAM5 simulations therefore show a stable or even slight decrease of precipitation/rainfall, hovering around ~ 75 mm/winter season from 1980 to 2069. On the other hand, the HadCM3Q0 simulations also show a steady slight decrease of seasonal precipitation/rainfall, decreasing from ~ 130 mm/winter to ~120 mm/winter, before increasing again slightly from the 2020s then reaching ~ 140 mm/winter by 2069.

On the whole these changes in winter seasonal precipitation are similar to those for the Himalayan region of South-East Asia, from ensemble model simulations in the latest IPCC Report (IPCC, Vol. 1, 2007).

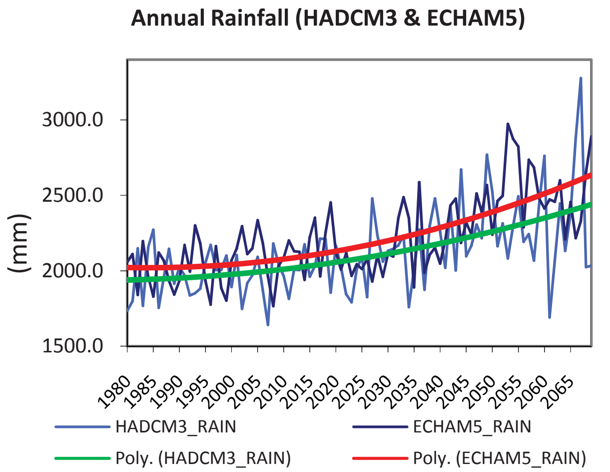

Figure 4.2.6: Annual trends of mean total annual precipitation (mm) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios

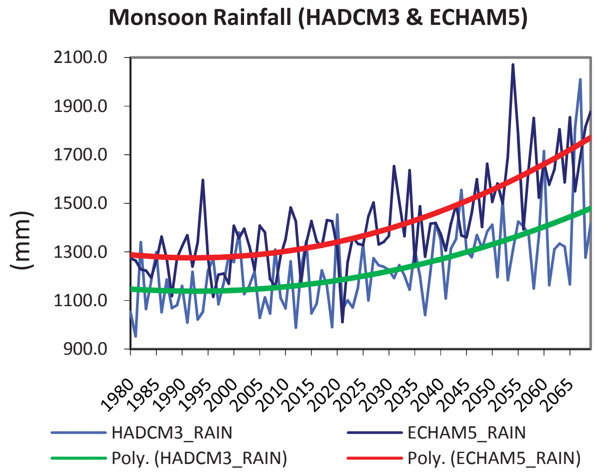

Figure 4.2.7: Annual trends of seasonal/monsoonal total precipitation (mm) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios t).

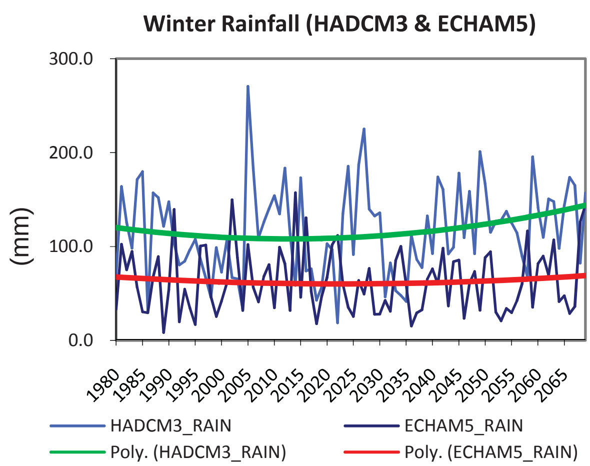

Figure 4.2.8: Annual trends of seasonal/winter-dry total precipitation (mm) from 1980 to 2069 for Bhutan according to the PRECIS downscaled HadCM3Q0 and ECHAM5 scenarios

4.2.3. Climate Scenarios: Air Temperature and Rainfall Changes by District

The spatial patterns of changes in temperature and precipitation/rainfall according to District from 1980 to 2069 are described in this section. The time slices and scenarios are the same as described previously. These maps together with a description of the changes in temperature and rainfall on an annual and seasonal basis for the three time periods and the two climate scenarios are to be found in the Technical V&A Report (2011).

4.2.3 a. Summary of Temperature Changes by Districts

Simulated/observed temperatures for the current (1980-2009) and future time periods (2010-2039 and 2040-2069) simulated with HadCM3Q0/ A1B are presented in table 4.2.1 and simulated/ observed temperatures for current (1980-2009) and future time periods (2010-2039 and 2040-2069) simulated with ECHAM5/A1B are presented in table 4.2.2. The changes in temperatures are presented spatially in figure 4.2.9.

4.2.3 b. Summary of Precipitation Changes

Simulated/observed precipitation for the current (1980-2009) and future time periods (2010-2039 and 2040-2069) simulated with HadCM3Q0/ A1B are presented in table 4.2.3 and simulated/ observed precipitation for current (1980-2009) and future time periods (2010-2039 and 2040-2069) simulated with ECHAM5/A1B are presented in table 4.2.4. The changes in precipitation are also presented spatially in figure 4.2.10.

4.2.4. Summary of Climate Scenarios

It transpires from the preceding sections that, compared to the current (1980-2009) climate, by 2010-2039 the mean annual temperature will increase by ~ 0.8 ^{0}C (ECHAM5/A1B scenario) to ~ 1.0 ^{0}C (HadCM3Q0/A1B scenario). Also, HadCM3Q0/A1B scenario projects a slightly higher increase in mean winter seasonal temperature (~ 1.2 ^{0}C) and a slightly lower increase in mean monsoon seasonal temperature (~ 0.8 ^{0}C) for the period 2010-2039. On the other hand, there is little or no difference between the annual and seasonal (monsoon and winter) temperature changes for the period 2010-2039, according to the ECHAM5/A1B scenario.

On the other hand, by 2040-2069 mean annual temperature will increase by ~ 2.0 ^{0}C (ECHAM5/A1B) to ~ 2.4 ^{0}C (HadCM3Q0/A1B). Again, the HadCM3Q0/A1B scenario projects a slightly higher increase in mean winter seasonal temperature (~ 2.8 ^{0}C) and a slightly lower increase in mean monsoon seasonal temperature (~ 2.1 ^{0}C) for the period 2040-2069. But there is little or no difference between the annual and seasonal (monsoon and winter) temperature changes for the period 2040-2069, according to the ECHAM5/A1B scenario.

As for changes in mean annual precipitation both the HadCM3Q0/A1B and ECHAM5/A1B project a slight increase in mean total annual precipitation of ~ 6% in the 2010-2039 period. On a seasonal basis there is a slight decrease in winter precipitation (~2%) and increase between 4-8% in the monsoon season for the period 2010-2039.

Finally, for the 2040-2069 period, the HadCM3Q0/A1B projects a moderate increase in mean total annual precipitation of ~ 21 %, but with generally higher increases in the monsoon season compared to the winter season for Bhutan on the whole (11%). Similarly, the ECHAM5/A1B scenario also projects an increase in mean total annual precipitation of ~ 25 % for the 2040-2069 period, also with generally higher increases in the monsoon season compared to the winter season for all Dzongkhags together.

Therefore, for changes in precipitation both the HadCM3Q0/A1B and ECHAM5/A1B scenarios project moderate increases in mean total annual rainfall for the 2040-2069 period, but with conditions getting wetter in the wet monsoon season and drier in the dry winter season. These more extreme precipitation changes between seasons conform to the findings of the IPCC (2007) report for the Himalayan region of South-east Asia.

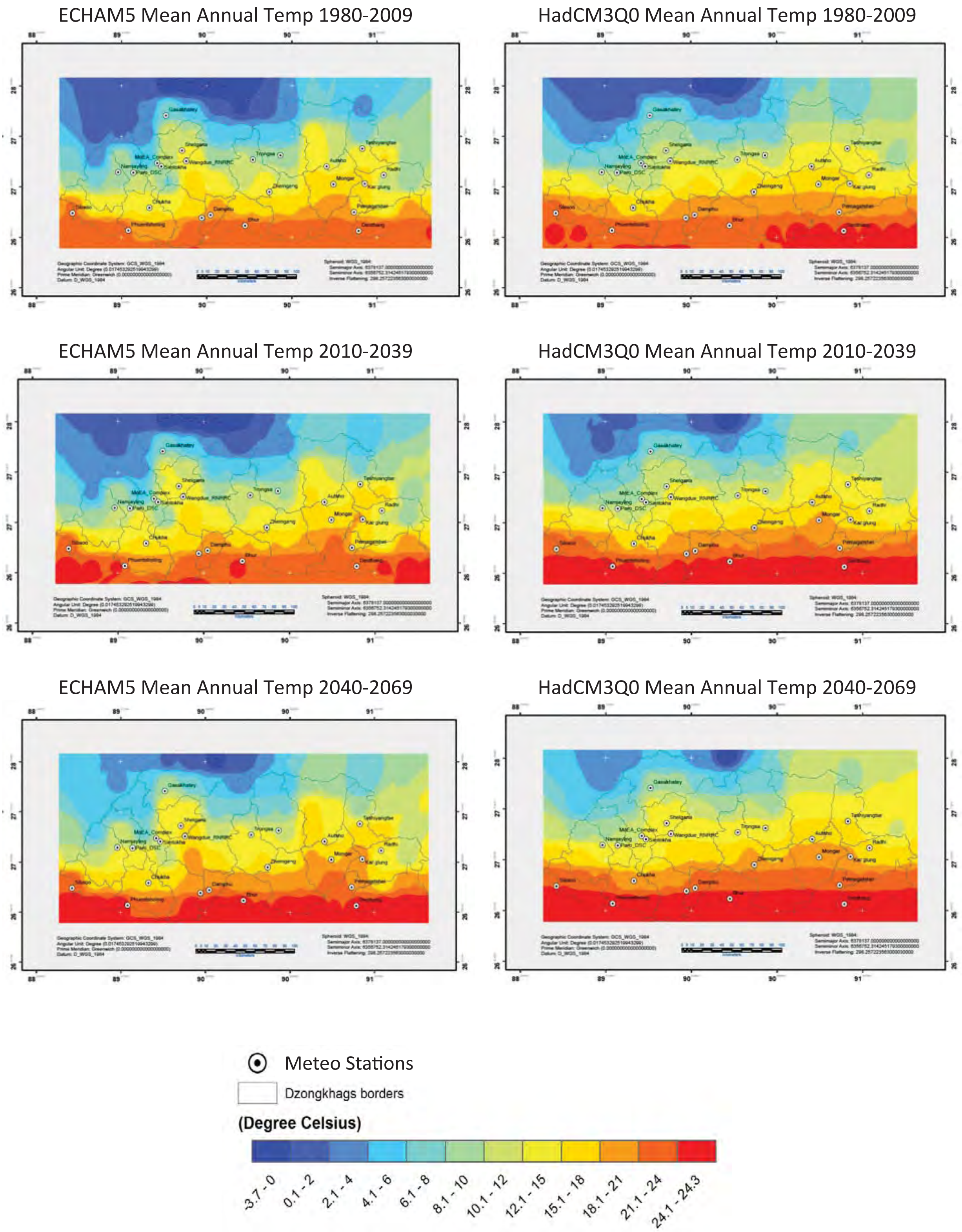

Figure 4.2.9 Maps showing changes in Mean Annual temperature under ECHAM5 and HadCM3Q0 scenarios.

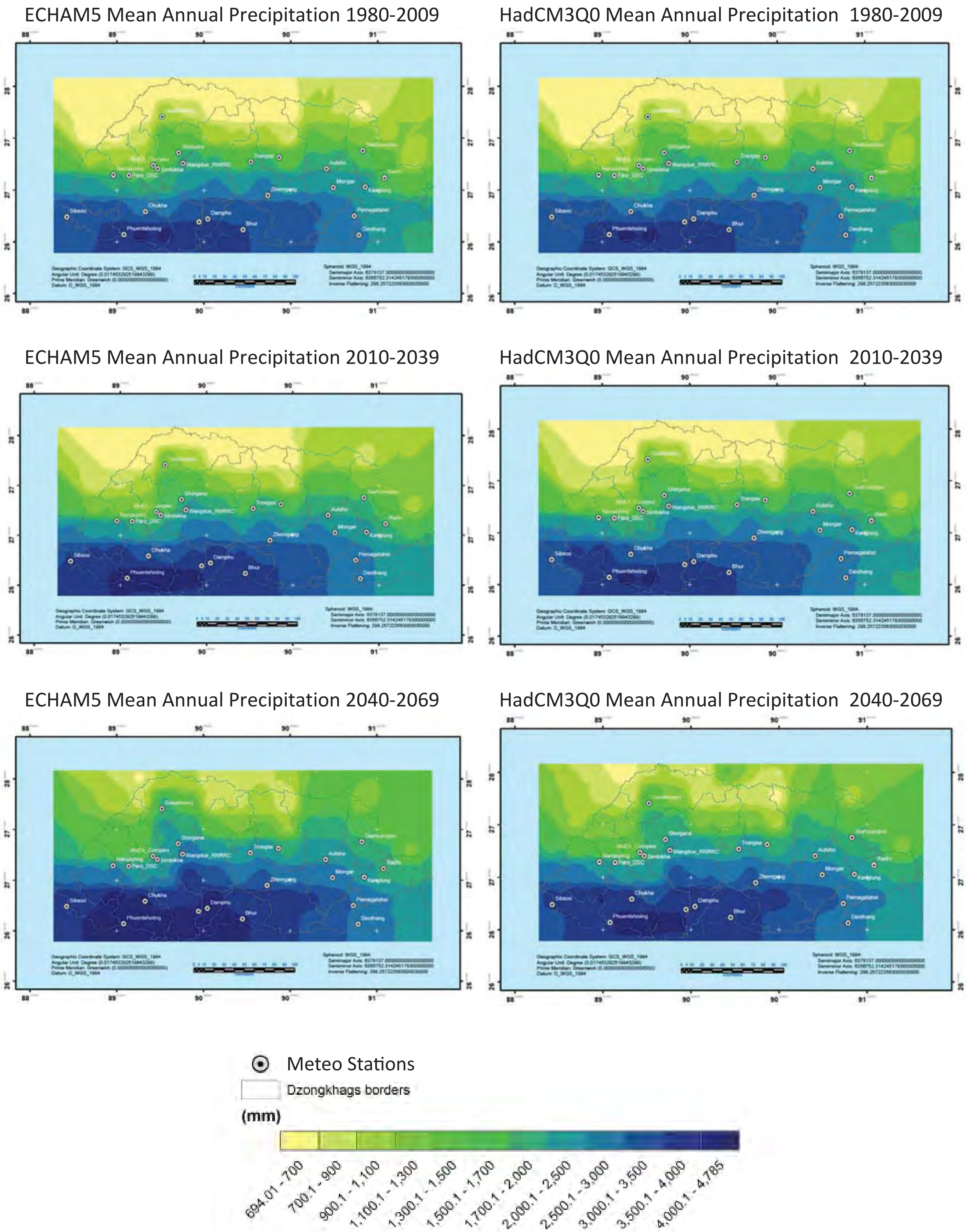

Figure 4.2.10 Maps showing changes in Mean Annual precipitation under ECHAM5 and HadCM3Q0 scenarios

Table 4.2.1: Summary of Temperature Changes (^0C) by Dzongkhags for the periods 1985-2010, 2010-2040 and 2040-2069 according to the downscaled HadCM3Q0 scenario.

	1980-2009			2010-2039			2040-2069		
Dzongkhag/District	**Mean Annual Temp (0C)**	**Mean Monsoo n Temp (^0C)**	**Mean Winter Temp (^0C)**	**Mean Annual Temp (^0C) Change**	**Mean Monsoon Temp (^0C) Change**	**Mean Winter Temp (^0C) Change**	**Mean Annual Temp (^0C) Change**	**Mean Monsoon Temp (^0C) Change**	**Mean Winter Temp (^0C) Change**
Bumthang	8.3	15.2	0.6	1.1	0.9	1.3	2.6	2.2	2.8
Chhukha	19.5	24.2	13.7	1.0	0.8	1.2	2.3	1.9	2.8
Dagana	19.3	24.1	13.4	1.0	0.8	1.2	2.4	1.9	2.8
Gasa	3.9	11.7	-4.2	1.2	0.9	1.4	2.7	2.4	2.8
Haa	12.6	18.9	5.2	1.1	0.8	1.3	2.5	2.1	2.9
Lhuentse	10.3	17.1	2.8	1.0	0.8	1.2	2.5	2.1	2.9
Monggar	17.5	22.6	11.6	0.9	0.8	1.0	2.3	1.9	2.7
Paro	7.6	14.8	-0.2	1.2	0.9	1.4	2.6	2.3	2.8
Pemagatshel	22.2	26.7	16.8	0.9	0.8	1.0	2.3	1.9	2.7
Punakha	10.0	16.7	2.5	1.0	0.8	1.1	2.5	2.2	2.7
Samdrupjongkhar	22.0	26.4	16.8	1.0	0.8	1.1	2.3	1.9	2.7
Samtse	21.1	25.5	15.4	1.0	0.8	1.1	2.3	1.8	2.7
Sarpang	21.8	26.2	16.4	0.9	0.8	1.1	2.3	1.8	2.6
Thimphu	7.0	13.9	-0.3	1.1	0.9	1.4	2.6	2.3	2.7
Trashigang	15.1	20.5	8.8	1.0	0.8	1.1	2.4	1.9	2.7
Trongsa	12.9	18.8	6.1	1.0	0.8	1.1	2.3	2.0	2.6
Tsirang	20.7	25.4	15.0	0.9	0.8	1.0	2.3	1.9	2.6
Wangduephodrang	10.6	17.0	3.2	1.0	0.8	1.2	2.5	2.1	2.7
Yangtse	11.4	17.7	4.5	1.0	0.8	1.1	2.4	2.1	2.8
Zhemgang	20.4	25.0	14.9	0.9	0.8	1.1	2.3	1.9	2.6

Table 4.2.2: Summary of Temperature Changes (^0C) by Dzongkhags for the periods 1985-2010, 2010-2040 and 2040-2069 according to the downscaled ECHAM5 scenario.

	1985-2010			2010-2039			2040-2069		
Dzongkhag/District	**Mean Annual Temp (^0C)**	**Mean Monsoon Temp (^0C)**	**Mean Winter Temp (^0C)**	**Mean Annual Temp (^0C) Change**	**Mean Monsoon Temp (^0C) Change**	**Mean Winter Temp (^0C) Change**	**Mean Annual Temp (^0C) Change**	**Mean Monsoon Temp (^0C) Change**	**Mean Winter Temp (^0C) Change**
Bumthang	6.5	12.7	0.0	0.8	0.8	0.6	2.6	2.3	2.1
Chhukha	16.8	21.1	11.9	0.7	0.7	0.7	2.3	2.0	2.0
Dagana	17.6	22.0	12.7	0.8	0.7	0.8	2.3	2.0	2.0
Gasa	2.7	9.5	-4.1	0.8	0.8	0.5	2.8	2.5	2.2
Haa	8.9	14.5	3.0	0.8	0.7	0.7	2.5	2.2	2.0
Lhuentse	9.5	15.6	3.3	0.8	0.8	0.7	2.5	2.2	2.1
Monggar	16.6	21.5	11.2	0.8	0.7	0.7	2.3	2.1	2.0
Paro	7.3	13.2	1.2	0.8	0.9	0.6	2.8	2.5	2.1
Pemagatshel	20.5	24.8	15.5	0.8	0.7	0.8	2.3	2.1	2.1
Punakha	11.1	16.7	5.2	0.7	0.7	0.5	2.5	2.3	1.9
Samdrupjongkhar	19.9	24.5	14.8	0.8	0.7	0.8	2.2	2.0	2.1
Samtse	18.4	22.7	13.5	0.7	0.6	0.8	2.3	2.0	2.1
Sarpang	19.8	24.0	15.0	0.8	0.7	0.8	2.2	2.0	2.0
Thimphu	5.7	11.9	-0.8	0.7	0.8	0.5	2.7	2.5	2.0
Trashigang	12.5	18.0	6.8	0.8	0.7	0.7	2.3	2.1	2.0
Trongsa	10.7	16.3	4.8	0.7	0.7	0.6	2.3	2.1	1.9
Tsirang	19.4	23.6	14.6	0.8	0.7	0.8	2.3	2.0	2.0
Wangduephodrang	9.3	15.1	3.3	0.8	0.8	0.6	2.4	2.2	2.0
Yangtse	10.1	16.0	3.9	0.7	0.8	0.7	2.4	2.2	2.0
Zhemgang	18.1	22.6	12.9	0.8	0.7	0.7	2.2	2.1	2.0

Table 4.2.3: Summary of Precipitation Changes (mm) by Dzongkhags for the periods 1985-2010, 2010-2040 and 2040-2069 according to the downscaled HadCM3Q0 scenario.

	1985-2010			2010-2039			2040-2069		
Dzongkhag/District	Mean Annual Precip. (mm)	Mean Monsoon Precip. (mm)	Mean Winter Precip. (mm)	Mean Annual Precip. Change (mm)	Mean Monsoon Precip. Change (mm)	Mean Winter Precip. Change (mm)	Mean Annual Precip. Change (mm)	Mean Monsoon Precip. Change (mm)	Mean Winter Precip. Change (mm)
Bumthang	1117.7	668.8	59.8	125.3	71.6	-0.3	355.1	244.8	26.1
Chhukha	3397.7	1978.5	164.6	119.7	-2.5	-7.4	421.5	244.9	38.4
Dagana	3290.8	2012.1	152.8	67.6	-29.9	-11.2	351.8	183.3	20.0
Gasa	678.8	471.1	6.8	134.1	91.4	1.6	403.0	326.5	9.5
Haa	2084.9	1271.1	98.3	200.2	79.7	-2.7	480.1	272.5	42.5
Lhuentse	1224.3	692.2	81.2	87.8	42.6	0.1	355.9	236.9	35.5
Monggar	2431.7	1379.4	174.2	60.3	-2.5	-11.5	325.7	183.3	12.1
Paro	1226.3	860.5	24.3	124.0	48.9	3.6	381.8	252.7	22.5
Pemagatshel	2713.7	1369.0	209.5	58.2	-21.4	-13.7	260.1	109.8	13.2
Punakha	1422.3	954.0	37.6	136.5	84.3	3.1	412.5	344.5	16.2
Samdrupjongkhar	2187.1	1097.5	170.8	77.1	-3.1	-15.3	262.1	99.6	17.1
Samtse	3280.5	1942.2	178.1	158.8	37.3	-18.0	308.9	155.4	27.2
Sarpang	3394.1	1829.7	213.8	22.1	-53.2	-11.3	232.0	114.4	14.1
Thimphu	1112.9	848.5	14.8	112.4	58.0	2.2	365.0	292.1	11.1
Trashigang	1776.3	931.2	144.5	122.9	46.1	-11.7	345.2	161.3	24.5
Trongsa	1988.4	1151.8	148.2	125.9	66.0	-13.5	450.5	316.3	28.4
Tsirang	3480.6	2028.9	195.8	23.3	-59.6	-20.5	318.6	198.6	5.6
Wangduephodrang	1673.6	1060.9	85.8	123.5	73.8	-6.5	389.4	280.5	21.2
Yangtse	1296.8	713.2	101.4	72.6	19.3	1.2	328.1	176.2	41.4
Zhemgang	2969.2	1591.7	215.6	78.1	-2.9	-14.9	307.4	168.1	11.2

Table 4.2.: Summary of Precipitation Changes (mm) by Dzongkhags for the periods 1985-2010, 2010-2040 and 2040-2069 according to the downscaled ECHAM5 scenario.

	Observed: 1985-2010			ECHAM5/A1B: 2010-2039			ECHAM5/A1B: 2040-2069		
Dzongkhag/District	Mean Annual Precip. (mm)	Mean Monsoon Precip. (mm)	Mean Winter Precip. (mm)	Mean Annual Precip. Change (mm)	Mean Monsoon Precip. Change (mm)	Mean Winter Precip. Change (mm)	Mean Annual Precip. Change (mm)	Mean Monsoon Precip. Change (mm)	Mean Winter Precip. Change (mm)
Bumthang	1160.0	739.9	44	89.2	77.4	1.9	392.9	292.1	9.4
Chhukha	3536.6	2204.4	78	233.0	188.0	-4.9	671.0	481.7	3.0
Dagana	3413.2	2179.0	73	144.2	133.8	-5.3	555.0	391.7	3.6
Gasa	701.2	475.0	11	116.0	94.3	3.4	495.1	391.0	8.6
Haa	2144.9	1405.3	59	165.2	137.7	0.4	551.1	390.2	11.3
Lhuentse	1277.1	795.7	57	78.3	67.1	2.5	408.1	300.0	11.7
Monggar	2527.2	1539.6	100	36.2	49.0	-9.3	286.7	187.0	-7.8
Paro	1280.4	893.4	21	141.3	112.1	1.6	492.0	375.6	10.8
Pemagatshel	2809.8	1597.5	108	27.9	54.1	-16.4	263.1	162.5	-10.5
Punakha	1483.6	967.9	44	107.5	99.2	2.8	559.0	438.6	12.5
Samdrupjongkhar	2243.7	1296.2	85	30.0	47.3	-11.9	270.5	181.4	-9.6
Samtse	3393.7	2211.9	82	191.5	164.2	-5.4	483.7	342.3	-7.6
Sarpang	3512.5	2082.7	108	100.6	106.4	-17.3	412.3	284.6	-4.4
Thimphu	1173.6	844.9	16	122.0	114.5	1.2	491.8	403.6	7.1
Trashigang	1822.6	1069.9	81	51.3	47.1	-4.0	292.3	201.1	-3.6
Trongsa	2062.3	1297.4	94	96.7	94.3	-2.4	457.5	354.1	0.0
Tsirang	3598.8	2248.7	95	100.7	104.1	-12.8	507.0	362.0	-3.5
Wangduephodrang	1740.9	1144.4	66	119.0	111.1	1.5	524.9	407.1	7.2
Yangtse	1347.2	827.6	67	65.7	46.5	2.5	333.1	223.6	5.6
Zhemgang	3073.9	1816.0	116	94.9	100.2	-14.7	390.4	264.8	-10.1

4.2.5 Extreme Climate Events

While the data records are not adequate, in recent years, extreme events have been reported with increasing frequency and intensity. In 2004, flash floods in the 6 eastern Dzongkhags killed 9 people, washed away 29 houses, damaged 107 houses and destroyed 664 acres of wet and dry farm loads (NDRMF 2006). In May 2009, cyclone Aila originating in the Bay of Bengal caused one of the worst climatic disasters in Bhutan. Record breaking rainfall was recorded around the country and up to 76 mm fell in a 24 hour period for Thimphu (HMSD 2009). All major rivers more than doubled in size and the flows in the Punatsangchhu exceeded the volumes of the 1994 GLOF (figure 4.2.11). The floods were the worst experienced by people in over 40 years and caused the loss of 12 lives, damage to agriculture, roads, bridges, schools, hydro projects, and other infrastructure. Numerous landslides were also triggered at various locations cutting off communities and affected areas. In 2010, landslides and flash floods damaged more than 2000 acres of agricultural land affecting 4165 households and damaged farm roads and irrigation channels affecting 529 households, 40 acres of pastureland were washed away and over a thousand livestock killed (DoA, MoAF 2011 & Livestock disaster 2009-2010, DoL, MoAF). While there are no records of wind speed or intensity in Bhutan, the occurrence of windstorms and damages have been recorded in the national newspaper (from 1994) and incidents of windstorms have been recorded every year. However, the severity and frequency of windstorms in Bhutan have increased over the past few years with hundreds of houses being destroyed and agricultural crops being flattened. Successive windstorms in the spring of 2011 affected sixteen of Bhutan's twenty districts (Dzongkhags) and according to the damage assessment report of the Department of Disaster Management, 2,424 rural homes, 81 religious structures, 57 schools, 21 health centers and 13 other government institutions were damaged across the affected districts.

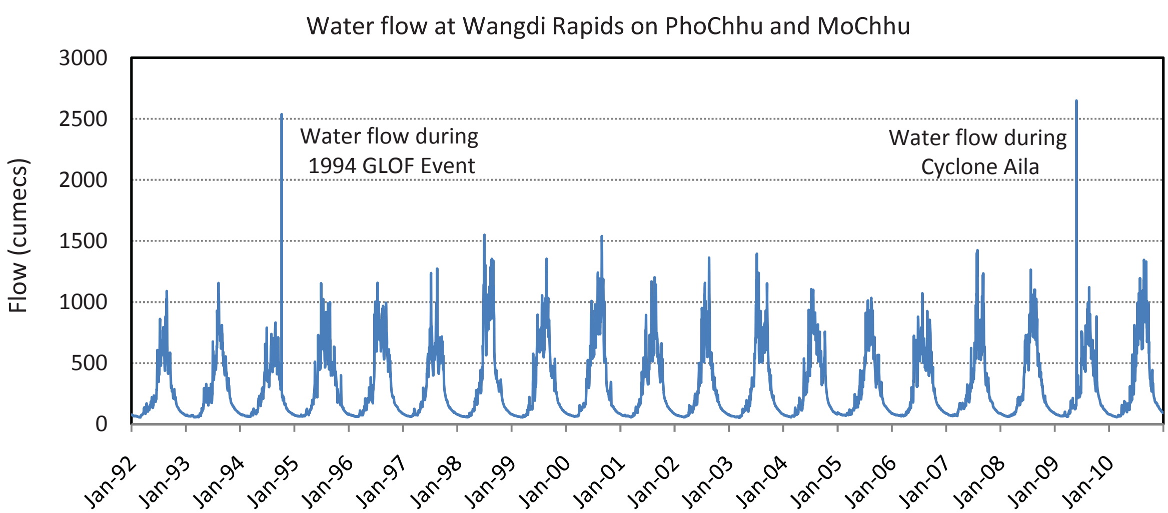

Figure 4.2.11: Water volumes on the Puntsang Chhu river at the Wangdi Rapids gauging station showing flows during 1994 GLOF and Cyclone Aila. Data source: Hydromet Services Division, Dept of Energy, MOEA

4.3 Water Resources

Bhutan has four major river systems with numerous tributaries streams and natural lakes which are dependent mainly on glaciers, snow, forests and seasonal rainfall. The Amo Chhu (Toorsa), the Wang Chhu (Raidak), the Punatsang Chhu (Sunkosh) and the Drangme Chhu (Manas) are Bhutan's four major rivers all of which drain into the Brahmaputra River in India. Nyera Ama Chu, Jomotshangkha Chhu and Shaar Chhu form smaller river basins. All the river systems originate within the country except three rivers viz. Amo Chhu, Gongri and Kuri Chhu all of which originate in the southern part of the Tibetan Plateau.

Water is of vital importance to the economy and people of Bhutan. Water has always been vital to agriculture but with economic growth, other sectors, mainly hydro power, industry and tourism are leaning more heavily on water resources. While the rivers provide potential for hydropower, the main rivers are generally at the bottom of valleys, irrigated agriculture is limited to areas adjacent to small perennial streams above the main rivers. On a macro scale the availability of water seems very high (109,000 m^3 per capita) but this provides a false sense of water security as the major sources for drinking and irrigation are mainly from local springs, streams and minor east-west tributaries. The main rivers are generally located at the bottom of valleys or deep gorges and ravines where accessibility remains a daunting challenge. Water flow measuring stations are also located only on main rivers for hydro power planning purposes and measurements do not exist for the smaller springs, streams and tributaries on which the majority of population depends.

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 (NTG Water, 2011). Surveys of local perceptions have reported that people have observed winter flows to be lower than normal in the past 10-20 years (NTG Biodiversity 2011, WWF & WCP 2011). 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.

4.3.1 WEAP Assessment of Water Resources

For the V&A Assessment of water, WEAP (Water Evaluation and Planning) software package was selected. Due to time and scope of the project, the case study approach was used within the Wang Chhu River Basin. The area covered includes, Thimphu District/Dzongkhag, (Thimphu Chhu River) Haa Dzongkhag (Haa Chhu), Paro District (Paro Chhu) in the upper part of the basin and Chukha District/Dzongkhag in the lower part of the Basin (Figure 4.3.1). The climate scenarios are the same as described in the previous section for the baseline (1980-2009) and future periods (2010-2039 and 2040-2069). The water demand and supply scenarios were based on the Water Resources Management Plan (DoE 2003) with 2002 as current accounts year (the most recent year with reliable data) and 2003-2009 as the reference period. Water Demand sites were considered for Thimphu (Municipal and Industry), Paro (Rural and Livestock), Irrigated Land (Agriculture Land). Stream flow data for Paro and Chimakothi were used. For the 2 future periods, water demand was modified by applying a population growth rate for both Thimphu (7.0% and Paro regions (1.3%) and an increase in the amount of irrigated areas. The water year method was used to integrate climate scenarios in the model. The full assessment is described in the Technical Report for the V&A available separately as described before.

Figure 4.3.1: Schematic model showing the three demand sites (Thimphu, Paro and Agriland) and the two main rivers (Pacchu and Wangchhu).

In summary, the main findings of the WEAP analysis for water resources in Bhutan are that:

1) There is an increase in water demand in the future (Municipal, Rural and Irrigation)

2) Agriculture will continue to demand more water than the other two sectors (municipal and industry)

3) Water demand for all 3 sites will be satisfied according to the both HadCM3Q0 and ECHAM5 climate scenarios coupled with WEAP for both future periods (2010-2039 and 2040-2069), but with increasing pressure on water resources.

The results of the analyses show no major negative impacts of climate change on water coverage for the three case study sites. However the assessment for WEAP is based on total water flows in the main rivers. As described previously in this section, the majority of population depends on water from springs and smaller streams for drinking water and irrigation. There are increasing reports of such sources of water drying out affecting villages and communities in several Dzongkhags even for their basic drinking water necessities. Several acres of land in most Dzongkhags left without cultivation is also attributed to the shortage of water in the recent years. The NEC is in the process of conducting a rapid survey to assess the historical trend of water fluctuation in various villages and on the various uses of water in the local communities.

4.3.2 Adaptation for Water Resources Sector

Due to the increasing demands for water and also localised vulnerabilities already reported from many parts of Bhutan adaptation measures will be necessary for both efficient use of water and also dealing with the impacts of climate change on water resources.

Other projections indicate that by the 2050s, access to freshwater in Asia will decrease, as well as increasing extremes of dry and wet periods (IPCC 2007). 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 (see Section 4.5), as a result of increased evaporation, and runoff increase with high rainfall events and waste overflows, both of which will degrade water quality. 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. 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.

In light of such projected impacts and lack of information in the country on the status of water security, one of the urgent activities needed for both resource management and adaptation to climate change is baseline assessment of water resources. In Bhutan there has been no comprehensive study of the water sources, their historical trend, and inventory on the use of the water for various purposes. Such assessments and other adaptation priorities and issues for water security in Bhutan are described in the section on the Adaptation Plan (Section 4.9).

4.4 Agriculture

Traditionally agriculture has been the mainstay of the Bhutanese economy. In 2008, the agricultural sector contributed 18.5 percent to Bhutan's GDP. Its share has been gradually declining over the years as energy (hydro power), industry and tourism have recently become more important. However, 69% of the Bhutanese population still depends on the agriculture sector which is mostly subsistence in nature and farmers engage in both land and animal husbandry. Due to the mountainous terrain, land available for cultivation is limited and only 2.93% of the country (1,124km^2) is cultivated. Furthermore, farming is a challenge because of low soil fertility, poor infrastructure, small landholding size and occurrence of natural disasters like floods, and the mountainous terrain, all of which make the activity labour-intensive. Despite the limited area, Bhutan's agricultural diversity in the agro-ecological zones is quite varied and covers a range of climatic zones (Table 4.4.1).

The main crops in Bhutan are rice, maize, wheat, potatoes, buckwheat, barley and millet. Socioeconomically, rice, maize and potato are the three most important crops in Bhutan. Rice is the staple food of the Bhutanese people, closely followed by maize. Potato is an important cash crop of communities living at higher elevations. Rice is grown mainly in the western region, in Thimphu, Paro, Punakha and Wangdue districts and the Southern districts of Samdrupjongkhar, Sarpang, Tsirang and Samtse followed by notable areas in Lhuentse, Trashiyangtse and Trashigang in the East. Total cultivated rice area is estimated at 19,410 hectares and represents 74 percent of all farming households. Production of rice on a commercial scale is limited – total paddy cultivation is limited to 19,410 hectares – due largely to a shortage of arable land and farm labor, low cropping intensity, inadequate irrigation and crop losses to pests and especially, wild animals.

Maize is grown all over the country, but is more popular in the Eastern region. About 45 percent of the total maize production comes from the six eastern districts of Trashigang, Samdrupjhongkhar, Pemagatshel, Trashiyangtse, Monggar and Lhuntse. Maize constitutes 49 percent of the national food basket and represents 42 percent of the cultivated area. Potato is the most important cash crop in Bhutan. Around 27,745 households, located mostly at mid and high elevations such as Phobjekha in the Wangdue Phodrang district, are dependent on potato production for a significant portion of their livelihood. While self-sufficient in maize, barley, millet, and buckwheat, Bhutan is only 50 percent self-sufficient in rice and 30 percent in wheat. In total the country is around 60 percent self-sufficient in cereals. Other key crops which are exported are potatoes, spices (mainly cardamom), and fruits such as oranges and apples. However, exports of vegetables are gaining importance especially during the summer months.

4.4.1 Current vulnerability of agriculture sector

Some of the observed symptoms of climate change impacts on agriculture in Bhutan are loss of crops to unusual outbreaks of pests and diseases, erratic rainfalls, windstorms, droughts and flash floods/ landslides that are increasing annually. In 1996, farmers in the high altitude areas lost between 80% to 90% of rice to rice blast epidemic. 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.

Most of the farmers are totally dependenton the monsoons for irrigation. The late arrival of the monsoons can lead to drought while excessive monsoon rains cause natural disasters such as floods and landslides. Such extreme climatic events also put rural communities at increased risk as many remain disconnected in largely scattered settlements in the most challenging geographic conditions. Reports of damages from extreme climatic events have also been increasing in recent years. In 2008, more than 320 households were affected by severe windstorms. The heavy summer monsoon rainfall of 2004 caused heavy landslides in the east and damaged 39 irrigation channels, affected 161 acres of wetlands and 503 acres of dry land. In terms of food items, 350 million tonnes of maize, 126 million tonnes of paddy, and 2000 citrus trees were damaged. Transportation remained disrupted for many days in most of the eastern and southern Dzongkhags during the period affecting food distribution systems (NTG- Food Security, 2011). 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, chili, buckwheat and others (Draft Revised NAPA, 2011).

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.

4.4.2 Vulnerability Assessment for Agriculture using DSSAT

For the agriculture sector, the chosen methodology is to couple the outputs (daily maximum and minimum temperature, rainfall, solar radiation) of the downscaled regional model (PRECIS) data with a crop model (DSSAT: Decision Support System for Agrotechnology Transfer) to examine potential crop yield changes for the three major crops, namely rice, maize and potatoes. This approach requires climate and crop data at the local and daily scales, as well as soil information at the

Table 4.4.1 Agro-ecological zones of Bhutan

Agro-ecological Zone	Altitude (m.a.sl)	Rainfall (mm/annum)	Farming Systems, major crops and agriculture produce
Alpine	3,600 – 4,600	<650	Semi-nomadic people, yak herding, dairy products, barley, buckwheat, mustard and vegetables.
Cool Temperate	2,600 – 3,600	650 – 850	Yaks, cattle, sheep & horses, dairy products, barley, wheat & potatoes on dryland, buckwheat & mustard under shifting cultivation.
Warm Temperate	1,800 – 2,600	650 – 850	Rice on irrigated land, double cropped with wheat and mustard, barley and potatoes on dryland, temperate fruit trees, vegetables, cattle for draft and manure, some machinery and fertilizers used.
Dry Sub-tropical	1,200 – 1,800	850 – 1,200	Maize, rice, millet, pulses, fruit trees and vegetables, wild lemon grass, cattle, pigs and poultry.
Wet Sub-tropical	150 – 600	2,500 – 5,500	Humid zones – irrigated rice rotated with mustard, wheat, pulses and vegetables, tropical fruit trees.

Source: Ministry of Agriculture

site level. As in the water sector, the case studies approach is used to demonstrate the vulnerability of the agricultural sector to climate change. For the case studies, Bhur Gewog is selected for rice, Kanglung Gewog for maize and Phobjikha Gewog for potatoes. To this end, observed and simulated downscaled PRECIS data of daily maximum and minimum air temperature, solar radiation and rainfall for each district listed above for both the current (1980-2009) and future climates (2010-2039 and 2040-2069) are used to evaluate future potential crop yield changes.

The full assessment using DSSAT is described in the separate technical document but the methodology is summarized as follows. DSSAT was calibrated for each crop using local data and simulations run to evaluate the impacts of climate change on the water-limited yields, namely yields limited by climate, soil features, crop characteristics and management and soil water, of rice (Bhur) maize (Kanglung), and potatoes (Phobjikha). CO_2 fertilization was also considered with CO_2 level fixed at 344 ppm for the current climate (1980-2009) and for the future climates, impacts were simulated by both ignoring and integrating the fertilization effect of ambient CO_2 (429 ppm CO_2 in 2010-2039, and 522 ppm CO_2 for the 2040-2069 period). Yield changes between the current (1980-2009) and future (2010-2039 and 2040-2069) climates were used to anticipate yields changes and socio-economic impacts of climate change for the selected crops and locations.

Crop Yield Changes

Summaries of the year by year yield and yield changes (kg/ha) derived by coupling DSSAT with the two climate change scenarios, namely HadCM3Q0 and ECHAM5, for the current observed/simulated period (1980-2009) and the two future periods (2010-3039 and 2040-2069) are presented in Tables 4.4.2 and 4.4.3 for maize in the Kanglung Gewog, in Tables 4.4.4 and 4.4.5 for rice in the Bhur Gewog, and in Tables 4.4.6 and 4.4.7 for potato in the Phobjikha Gewog. Also shown are the average yields (kg/ha) for each period and the change (%) in yields for each period.

Figure 4.4.2: Agro-ecological zones of Bhutan and case study sites

Maize: Kanglung

According to the HadCM3Q0/A1B scenario, maize yields are expected to decrease for the two future periods (2010-2039 and 2040-2069). But according to the ECHAM5/A1B scenario, maize yields are expected to decrease for the future period 2010-2039, but then increase in the 2040-2069 future period (Tables 4.4.2 and 4.4.3). Decreases in maize yields under climate change scenarios, as observed elsewhere, are normally attributed to water deficits and acceleration in maturation (Singh et al, 1998; Brassard and Singh, 2007; 2008).

Rice: Bhur

According to the HadCM3Q0/A1B scenario, rice yields are expected to decrease slightly for the 2010-2039 period but the increase dramatically for the 2040-2069 period. However, according to the ECHAM5/A1B scenario, rice yields are expected to decrease for the two future periods, namely, 2010-2039 and 2040-2069 (Tables 4.4.4 and 4.4.5). It should however be noted that DSSAT is highly influenced by solar radiation and water availability and from 2053 onwards to 2069 solar radiation and to a lesser extent, rainfall, in HadCM3Q0 increases sharply and this causes more vigorous growth and eliminates any water deficits. Other contributing factors may have been that the increase in temperatures brought thermal conditions closer to optimal and extended the grain filling period for the rice cultivar in this region. On the other hand, the decreases in rice yields under the ECHAM5 climate change scenario, may well be attributed to continuing water deficits and acceleration in maturation, as observed elsewhere, (Singh et al, 1998; Brassard and Singh, 2007; 2008).

Potato: Phobjikha

Under both ECHAM5 and HadCM3Q0, potato yields increased in future periods and with a further boost in yields due to CO_2 fertilization (Tables 4.4.6 and 4.4.7). It seems then that the increase in temperatures for the 2010-2030 and 2040-2069 periods brought temperatures closer to optimal for the potato cultivar in the Phobjikha region in Wangdue district.

4.4.3 Adaptation for Agriculture

It is obvious from the preceding discussions that with climate change and increasing CO_2 levels agricultural crop yields are expected to change. The potential for future decline in yields under climate change such as in rice and maize would call for adaptation measures such as; change in crop cultivars, change in location of cultivation sites, and improvements in water and pest management. For crops like potato the changing climate may allow for agricultural production of potato on a larger scale in the future. Adaptation and policy options should be implemented to take advantage of potential positive impacts

Table 4.4.2: Summary of Mean Yield changes for maize for Kanglung Gewog with CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	4509	3972	-12	3696	-18
ECHAM5	4923	4454	-10	4756	-3

Table 4.4.3: Summary of Mean Yield changes for maize for Kanglung Gewog without CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	4509	3900	-14	3583	-21
ECHAM5	4923	4374	-11	4606	-7

by; adjusting the mix of crops to allow for more potato production, and securing export markets for increased potato production.

However, climate change will affect not only the physical aspect of the farming environment in the form of crop losses but also other dimensions like land degradation, distribution systems and prices of the essential commodities as discussed in the observation of current vulnerabilities. In the difficult geographic setting where rural settlements are scattered over a rugged mountainous terrain, extreme events due to climate change will also increase risks and impacts. In terms of adaption options, the solution not only lies in increasing the yield and productivity of agricultural crops and improved efficiency in irrigation through increased investment in research and development in the agriculture sector, but also ensuring proper food distribution systems and pricing mechanisms. The adaptation priorities and measures for agriculture have thus been formulated to ensure food security under climate change as detailed in the section 4.9 on Adaptation Action.

4.5. Forests and Biodiversity

As described in the Chapter 1 on National Circumstances, Bhutan is heavily forested with diverse ecosystems and has rich and globally significant levels of biodiversity. Most ecosystems are substantially intact with only a few areas impacted by anthropogenic activities. The total land area under forest cover (excluding shrubs) is 27,052.9 sq.km, or 70.46 percent of the country

Table 4.4.4: Summary of Mean Yield changes for rice for Bhur Gewog with CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	1334	1222	-8	2394	79
ECHAM5	1965	1730	-12	1461	-26

Table4.4.5: Summary of Mean Yield changes for rice for Bhur Gewog without CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	1334	1222	-8	2298	72
ECHAM5	1965	1730	-12	1442	-27

Table 4.4.6: Summary of Mean Yield changes for Potato for Phobjikha Gewog with CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	12516	14401	15	15641	25
ECHAM5	6294	9476	51	12383	97

Table 4.4.7: Mean Yield changes for Potato for Phobjikha Gewog without CO_2 fertilizing effect

Climate Model	1980-2009	2010-2039		2040-2069	
	Yields (kg/ha)	Yields (kg/ha)	Yield Change (%)	Yields (kg/ha)	Yield Change (%)
HadCM3Q0	12516	13991	12	14898	19
ECHAM5	6294	9020	43	11494	83

(NSSC, LCMP, 2010). The interaction of topography, climate and human use has resulted in a complex pattern of vegetation and habitat types. The three major vegetation zones of Bhutan are: the Alpine zone (above 4000m); Temperate zone (2000 to 4000m), which includes the major conifer/broadleaf forests; and the Subtropical Zone (150 to 2000m), characterized by tropical/subtropical vegetation.

The broadleaf forests (62.43 %) and the mixed conifer forest (22.69%) form the dominant forest types (Figure 4.5.1).These diverse ecosystems harbour a spectacular assortment biodiversity with a recorded total of 5,603 species of angiosperms and gymnosperms, close to 200 species of mammals and 678 species of birds, recorded to date (see Chapter 1 and the Technical V&A document for more details).

In Bhutan, the importance of biodiversity is highlighted by the country's unique social, cultural, economic and physiographic conditions. Reverence for nature and all beings is fundamental to Buddhism, which plays a predominant role in the lives and culture of the Bhutanese people. From the ecological standpoint, the country's inherently fragile geologic conditions, rugged mountain terrain and high precipitation levels necessitate conservation and sustainable use of natural resources to mitigate natural disasters such as landslides and flash floods. Furthermore, the forests of Bhutan have an immensely important role in carbon sequestration and alleviating the impacts of climate change (Ministry of Agriculture, RGOB, 2009).

Due to such traditional and ecological reasons, biodiversity and forest conservation is embedded in the policies of the Royal Government. The Constitution of Bhutan mandates the maintenance of at least 60% of the land under forest cover and ensures the rights and responsibilities for every Bhutanese as a "trustee of the Kingdom's natural resources for the benefit of present and future generation" (See Chapter 1 for details). Environmental conservation is also one of the four pillars of the development philosophy of "Gross National Happiness" that guides development planning in Bhutan. Bhutan also became a party to the United Nations Convention on Biological Diversity) in 1995.

4.5.1 Current Threats to Biodiversity

Conservation and sustainable use of biodiversity are becoming increasingly challenging in Bhutan as the country opens up to meet new development needs of a growing and modernizing population. There are both direct and indirect causes affecting biodiversity in Bhutan.

The direct causes affecting biodiversity in Bhutan are forest harvesting for housing and construction and fuelwood; wood-based industries; infrastructure development; livestock grazing of pastures and forests, forest fires, human-wildlife conflicts and poaching, land use change and conversion, urbanization, mining and quarrying, infrastructure development, invasive species, hydropower and industrial development (BAP, 2009).

The indirect causes affecting biodiversity in Bhutan are a growing population, poverty, changing consumption trends and market forces. The new threat is from climate change It is already known from global experiences that climate change leads to ecosystem changes such as, phenological shifts, altitudinal and latitudinal range shifts and upward migration of species, colonization by new species, extinction of certain species, epidermis burning of vegetation, shifts in species occurrence and habitat changes for plants, birds and mammals and upward shift of cultivation and grazing activities (Herzog et al., 2011).

While there is a general lack of resources and capacity to conduct studies on climate change and biodiversity in Bhutan, a survey of people's observations and perceptions in 2010 is one of the first attempts in this regard (NTG Biodiversity, 2011). The survey conducted across four broad eco-floristic zones in the country showed people's understanding of climate change and its impacts on biodiversity was poor in general, highlighting their vulnerability to the impacts of climate change. However, the survey reported changes in a number of animal species across all the eco-floristic zones with an observed increase in the population of animals such as the blue sheep, wild boar, takin, snow leopard, bear, and birds such as the laughing thrush, blood pheasant and monal pheasant. Some of the animals observed to decline in population were the musk deer, barking deer, wild fox, leopard and tiger, and birds such as the eagle, hornbill, cuckoo, vulture and common crow etc. While such changes in populations may not necessarily be attributed to climate change there are notable changes being observed. For example there are reports of Himalayan black bear sightings during the hibernation season, leading to conflicts with farmers in rural areas.

In terms of plants, changes in flowering time across the different eco-floristic zones has been reported with *Rhododendron spp., Magnolia sp., Rosa sp., Juglans sp., Populus sp., Michelia doltsopa, Prunus sp., Erythrina sp., Daubanga sp., Bombax sp.,* all flowering earlier (up to a month) compared to 10 to 20 years ago.The same survey also reported a significant increase in the diversity of invasive species such as *Mikania micarantha., Parthenium spp.,* and reported *outbreaks* of bark beetle in spruce forests, increased incidence of mistletoe infestation, and moisture–stress related problems in blue pine forests. In terms of agro-biodiversity, while the correlations to climate change is yet to be ascertained, the survey reported a high incidence of pests and diseases in crops such as ants in potatoes, trunk borer (in rice and wheat), and fruit fly, and diseases like Citrus greening, Turcicum Leaf Blight (TLB) and Gray Leaf spot (GLS) in maize.

4.5.2 Assessment of Changes in Forests and Biodiversity

For the forestry and biodiversity sector, the Holdridge Life Zone Classification is used to evaluate the potential impacts of climate change on shifts and changes of the major forest zones of Bhutan. According to the Holdridge system forest eco-climatic zones are characterized by a series of hexagons, each representing a particular forest type, fitted into a triangle whose axes represent climate variables, namely mean annual biotemperature (BT: ^{0}C), mean total annual

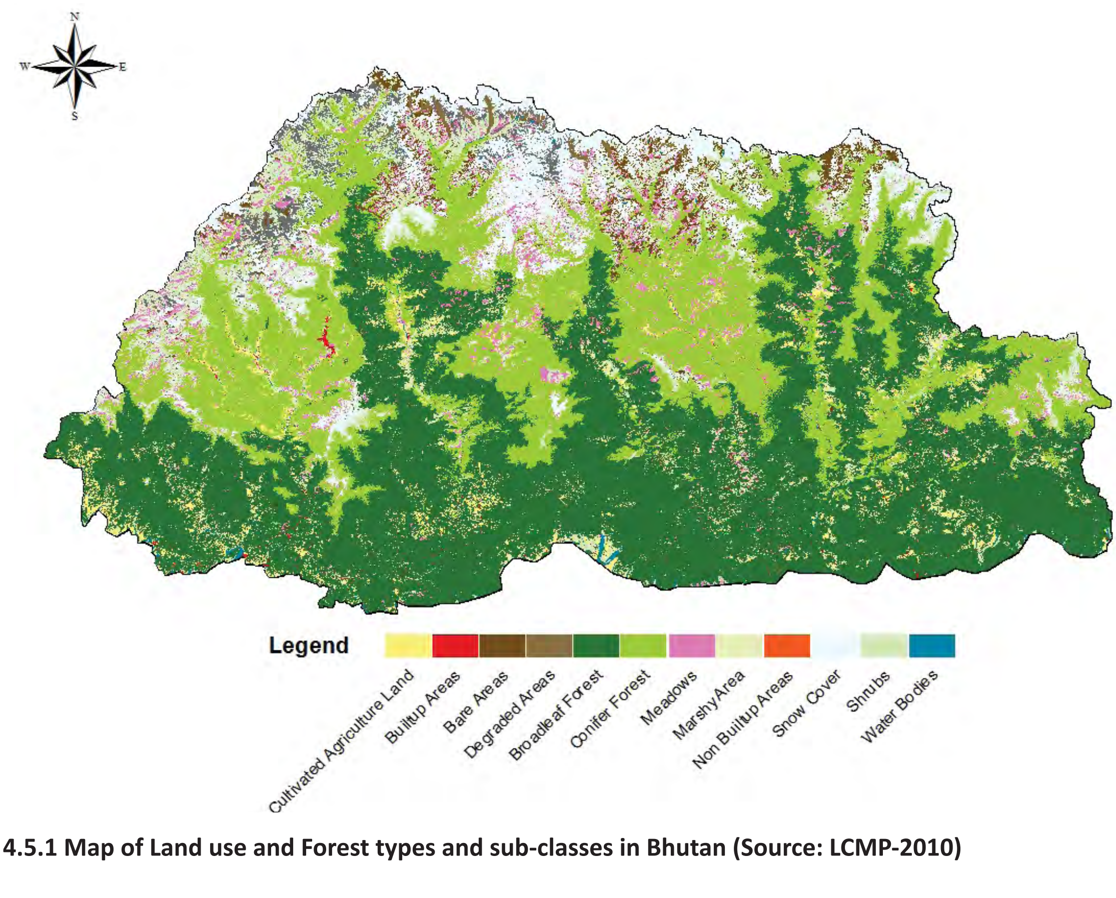

Figure 4.5.1 Map of Land use and Forest types and sub-classes in Bhutan (Source: LCMP-2010)

precipitation (PA: mm) and a ratio, derived from BT and PA, representing potential evapotranspiration (REP) (Holdridge, 1947; Emmanuel and Shugart, 1986): Several studies (ex. Singh et al, 1987) have demonstrated that the Holdridge Life Zone system provides an excellent tool to evaluate the impacts of climate change on the migration of forest zones, especially in a mountainous environment like Bhutan. The details of the Holdridge Forest Classification methodology and the assessment for the V&A can be found in the Technical V&A Report. The method involves BT, PA and REP derived from climate data which are then used to create the major forest zones for the whole of Bhutan using the Holdridge Life Zone system for the control/simulated (HadCM3Q0/A1B and ECHAM5/A1B) period (1980-2009). This zonation is then calibrated and tuned against maps (using ArcGIS 9.3), based on land cover maps of the current major forest zones in Bhutan. Thereafter the process of creating the Holdridge Life Zone classification is repeated for the whole of Bhutan, using the two future scenarios climate information extracted from the PRECIS downscaledHadCM3Q0/A1B and ECHAM5/A1B climate scenarios (2010-2039 and 2040-2069).

4.5.3 Potential Changes in Simulated Forest Area using Holdridge Classification

The results of the assessment in potential change in forest area using the Holdridge classification are presented in Table 4.5.1 and Figure 4.5.2. The results show the strong zonal pattern in distribution of major forest classes of Bhutan under both scenarios and a general northward/upslope migration of forests in the future. Such movement of forests in other parts of the Himalaya have already been recorded and similar forest shifts under future climate is also anticipated (WWF & WCP 2011).

Changes under HadCM3Q0/A1B

When comparing forest area from 1980-2009 to 2010-2039 period, there is net northward migration of all major forest classes (Table 4.5.1 and Figure 4.5.2). Tropical Dry forests move northwards and occupy a fair portion (increase of 232 %) of the southern fringes, Subtropical Dry forests increase in area (27 %) and Tropical Wet forests show little change. With this northward migration of major forest classes some forest classes undergo a decrease in area: Subtropical Rain (-55 %); Montane Rain (-100 %); Montane Dry (-29 %); Alpine (-26 %) and Nival (-75 %). By the 2040-2069 period forests continue to move northward. The tropical Dry forests move further northwards and occupy a good portion (increase of 291 %) of the southern fringes, Subtropical Dry forests further increase in area (37 %) and Tropical Wet forests show little change. With this continued northward migration of the major forest classes, some forest classes undergo a further decrease in area: Subtropical Rain (-58 %); Montane Rain (-100 %); Montane Dry (-53 %); Alpine (-85 %) and Nival disappears (-100 %).

Changes under ECHAM5

Similar results are also seen under ECHAM5/A1B climate scenarios. By the 2010-2039 period there is a net northward migration of all the major forest classes (Table 4.5.1 and Figure 4.5.2). Tropical Dry forests move northwards and occupy a fair portion (increase of 493 Km^2) of the southern fringes, Subtropical Rain forests increase in area (68 %), Subtropical Dry forests increase in area (36 %) and Tropical Wet forests show little change. Again, with this northward migration of the major forest classes, some forest classes undergo a decrease in area: Montane Rain (-3 %); Montane Wet (-5 %); Montane Dry (-55 %); Alpine (-24 %) and Nival (-32 %). By the 2040-2069 period, tropical Dry and Tropical Wet forests on the southern fringes move further northwards and increase in area (Tropical Dry: 2,223 Km^2 and Tropical Wet: 1,534 Km^2). Subtropical Wet (2 %) and Subtropical Dry (10 %) also increase in area. Again, with this continued northward migration of the major forest classes some forest classes undergo a further decrease in area: Montane Rain (-24 %); Montane Wet (-11 %); Montane Dry (-88 %); Sub Alpine (- 16 %); Alpine (-71 %) and Nival (-83 %).

4.5.4 Forest Area Changes: Compared to real forest areas

The preceding section focused on forest areas generated entirely by the Holdridge forest classification system. The actual forest cover types were also compared and changes simulated for future periods. Firstly actual forest category areas from the 2010 Land Cover Classification of Bhutan (NSSC 2011) were compared against Holdridge classification in the current period (1980-2009) and then changes applied in forest category areas according to HadCM3Q0 and ECHAM5 to derive future (2010-2039 and 2040-2069) forest acreages in relation to the actual forest category areas for the current period. The full details of this assessment can be found in the Technical V&A Report. The summary of changes in actual forest types is presented in Table 4.5.2. In general, according to the Holdridge Forest Classification System, the Broadleaf and Conifer and Chir Pine forest categories would increase in area at the expense of the other forest classes.

4.5.5 Impacts and Adaptation: Forestry and Biodiversity

The preceding section examined the expected shifts in the distribution of the major forest zones. These shifts in the pattern of land cover would have further indirect impacts on the habitats of many flora and fauna and also the integrity of ecosystem services.

Changes in distribution of fauna

In view of the fact that the major forest zones are expected to shift northwards with climate change, faunal and avifaunal species that are tied to climate and land cover would also be expected to migrate northwards. For instance, elephants that are now mostly concentrated

Table 4.4.1: Spatial distribution of vegetation for Bhutan according to the Holdridge Forest Classification System using the PRECIS-downscaled HadCM3Q0and ECHAM5 model climate outputs

FOREST CATEGORY	HadCM3Q0					ECHAM5				
	Simulated Area (Km^2) (1980-2009)	Simulated Area (Km^2) (2010-2039)	Difference (%) (2010-2039)-(1980-2009	Simulated Area (Km^2) (2040-2069)	Difference (%) (2040-2069)-(1980-2009	Simulated Area (Km^2) (1980-2009)	Simulated Area (Km^2) (2010-2039)	Difference (%) (2010-2039)-(1980-2009	Simulated Area (Km^2) (2040-2069)	Difference (%) (2040-2069)-(1980-2009
NIVAL	809	203	-75	0	-100	2065	1406	-32	358	-83
ALPINE	1279	942	-26	186	-85	2530	1922	-24	742	-71
SUBALPINE	3463	3169	-8	2049	-41	4351	4348	0	3672	-16
MONTANE DRY	3312	2343	-29	1569	-53	759	338	-55	90	-88
MONTANE WET	9775	9181	-6	8206	-16	9698	9217	-5	8596	-11
MONTANE RAIN	39	0	-100	0	-100	2373	2300	-3	1804	-24
SUBTROPICAL DRY	4398	5578	27	6009	37	2783	3780	36	3060	10
SUBTROPICAL WET	18523	17176	-7	18842	2	17744	17874	1	18140	2
SUBTROPICAL RAIN	338	153	-55	143	-58	915	1541	68	2998	228
TROPICAL DRY	1283	4262	232	5020	291	0	493	N/A	2223	N/A
TROPICAL WET	0	211	N/A	1190	N/A	0	0	N/A	1534	N/A

Note: Due to the fact that PRECIS-downscaled grid boxes extended beyond the borders of Bhutan, the total forest area of the country will exceed the total area of the country

Table 4.5.2: Summary of actual forest types (km^2) according to the Holdridge Forest Classification System using the PRECIS-downscaled HadCM3Q0 model climate outputs

	Time Periods	Broad Leaf & Conifer	Blue Pine Forest	Chir Pine Forest	Fir Conifer Forest	Mixed Conifer	Meadows	Shrubs
HADCM3Q0	1989-2009	351.63	859.16	1,203.16	2,060.61	6,857.84	1,754.69	4,665.17
	2010-2039	347.54	812	1,190.61	1,804.51	6,676.23	1,581.00	4,299.27
	2040-2069	356.82	745.66	1,273.72	1,467.38	6,390.42	1,282.28	3,664.22
ECHAM5	1989-2009	351.63	859.16	1,203.16	2,060.61	6,857.84	1,754.69	4,665.17
	2010-2039	367.74	824.03	1,282.03	1,879.84	6,705.95	1,607.84	4,335.57
	2040-2069	328.73	758.95	1,231.89	1,461.59	5,989.79	1,241.18	3,502.58

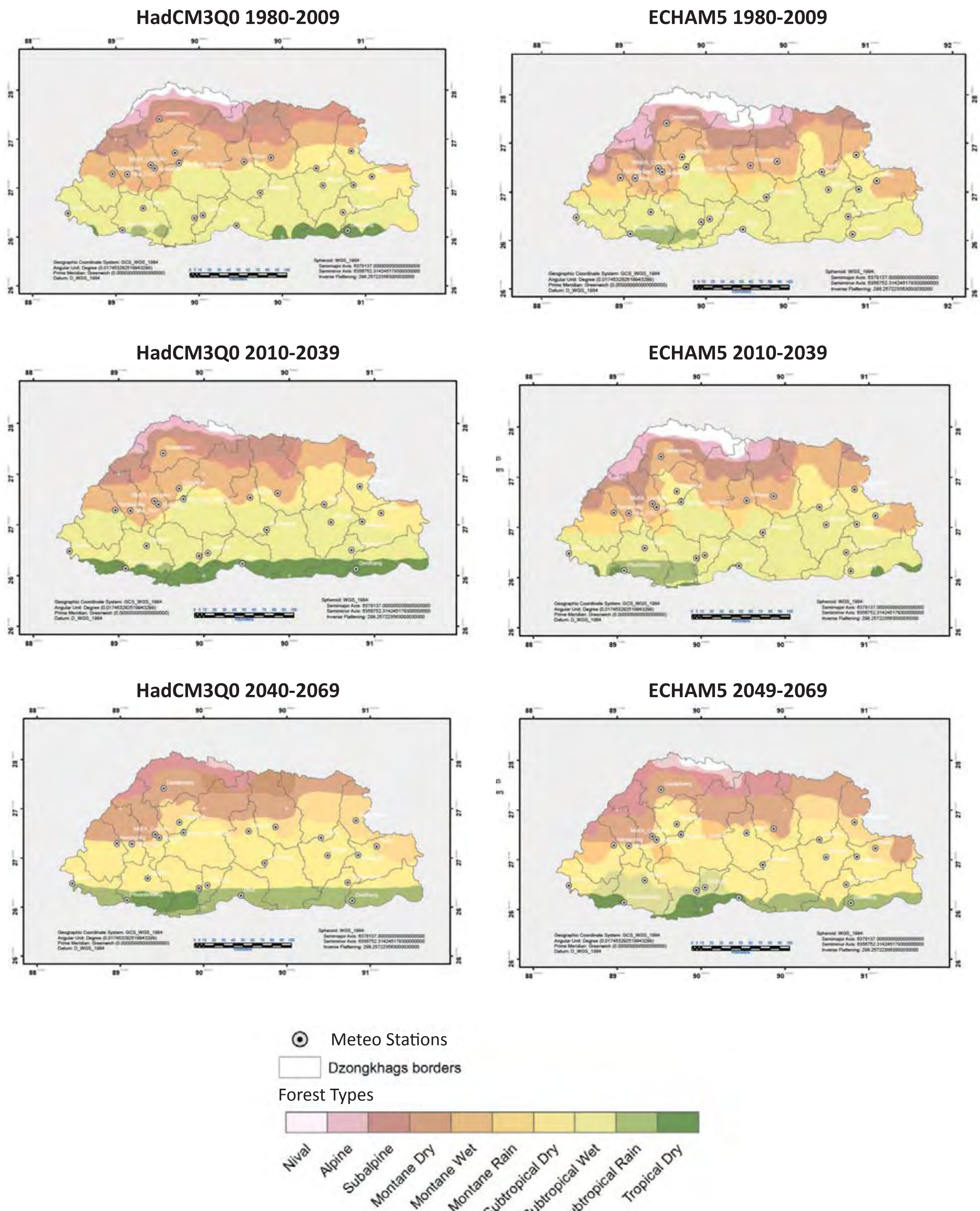

Figure 4.5.2 Maps of forest zones according to the Holdridge Forest Classification System using the PRECIS-downscaled HadCM3Q0and ECHAM5 model climate outputs

in the Subtropical Rain and Tropical Dry forests on the southern fringes of Bhutan may migrate northwards towards the interior. Tigers that are today mostly found in the southern two thirds of Bhutan may in the future be found in riverine habitats spread across Bhutan. Birds commonly found in southern and central parts of Bhutan under the current climate (e.g. migratory water birds, and hornbills), are likely to move to higher altitudes in the future.

Loss of species

Many of the species in Bhutan are already at risk of extinction due to pressures arising from natural processes and human activities. Climate change will further exacerbate these pressures especially for threatened and vulnerable species (Gitay et al, 2002). According to the IPCC AR4 (2007), up to 30 percent of the higher plant and animal species are likely to be at an increased risk of extinction if global average temperature increase exceeds 1.5 to 2.5 degree Celsius over the present temperature (Campbell et al, 2009, NTG - Biodiversity, 2011). The further changes from northward migration of habitats especially threaten mountain-top and location restricted species. A study by WWF and Wangchuck Centennial Park (2011) on the vulnerability in Wangchuck Centennial Park indicates considerable loss of habitats for the snow leopard (an endangered top predator of alpine areas) under future climate. Endangered and globally significant birds with restricted habitats like Black Necked Crane and White bellied Heron would likely be at additional risk.

Increased establishment of invasive species

The threat to biodiversity due to alien invasive species is considered only second to that of habitat loss. Climate change will expedite the colonization of some areas by invasive species in both terrestrial as well as fresh water ecosystems, which will have severe ramifications on native species (Campbell et al, 2009, CBD, 2009 National Paper on Biodiversity, 2011). In Bhutan, Survey 2010 reported a significant increase in the diversity of invasive species such as *Mikania micarantha., Parthenium spp., Opuntia spp., Eupatorium ordoratum, Lantana camara, Commelina, Galinsoga* and *Phyllanthus* (NTG - Biodiversity, 2011). The northward migration of such species can also be expected in light of the northward migration of forest types in the future under a changing climate.

Increased risk of forest fire

Forest fires are considered to be one of the key threats to coniferous forests in the country with 526 incidents of forest fire, affecting over 70,000 ha of forest between 1999/2000 to 2007/2008 (BAP, 2009). While most fires in Bhutan are caused by human activity, the rising temperature and long spells of drought due to climate change are likely to increase the risk of forest fires resulting in further reduction and degradation of forest resources. Such examples include the fires in the winter of 1998/99 which was characterized by a prolonged spell of dry (snow-less) weather with forest fire incidents even in places without a known history of forest fires (BAP, 2009 and NTG - Biodiversity, 2011). Forest fires in Bhutan mostly occur in Blue pine and Chir pine zones, and the results of the Holdridge classification indicate that it is these forest types that are likely to increase in area.

Loss of agro-biodiversity

Agricultural biodiversity plays a crucial role for adapting to altered climatic conditions through genetic variability of crops and livestock species which can be bred to better adapt to climate change impacts. It is widely accepted that genetic diversity is important both in its own right and in determining resilience of species to impacts of climate change and other pressures. The introduction of modern crop varieties and breeds has led to the erosion of genetic diversity (Fowler and Mooney, 1990) with estimates that 75% of the genetic diversity of agricultural crops has been lost since the beginning of the twentieth century (FAO, 1997). Now climate change poses additional threat to agricultural biodiversity by increasing genetic erosion of landraces and threatening wild species, including crop wild relatives (Jarvis et al., 2008). Climate change will also bring new and enhanced demand for genetic resources. National and international breeding programmes are already targeting new varieties of crops for adaptation to future climatic stresses (NTG - Biodiversity, 2011).

Increased incidences of pests and diseases

Recent moderate warming has been linked to improved forests productivity, but these gains are expected to be offset by the effects of increasing drought, fire and insect outbreaks as a result of further warming (Campbell et al, 2009). Survey 2010 results showed that the productivity of *Abies densa*, *Pinus wallichiana, Quercus glauca and Quercus griffithii* forests suffered set-backs due to periodic diebacks and insect attacks (NTG-Biodiversity, 2011) and that pests and diseases in forests and agriculture had increased over the years in general. There were outbreaks of bark beetle in spruce forests, increased incidence of mistletoe infestation, and moisture–stress related problems in blue pine forests. It is likely that with rising temperature and erratic dry and moist periods, intensity and incidences of diseases and pests will increase. In less than 16 years (1992-2008), five incidences of pine die-backs were observed (1994, 1999, 2001, 2003 & 2008) along the Paachu-Wangchu valley. Research indicates that pine die-back was strongly correlated with higher temperature and lower rainfall during the die-back incidences in the area (Wangda et al. 2009 and NTG - Biodiversity, 2011).

Loss of livelihood, traditional knowledge and practices ("Biocultural" loss)

The Bhutanese have always lived in harmony with nature and have used biodiversity for many purposes such as fuel-wood, food, fibre, shelter, medicine, household implements, and handicrafts among others. Traditional practices are also closely linked to biodiversity. For example, the use of "*Dru Na Gu"* (nine important food crops) in offerings and rituals signifies the sacred role of biodiversity in culture and traditions. If climate and land-use change lead to losses in biodiversity, including loss of habitats, the livelihoods of local communities will be adversely affected. Destruction of vegetation as a result of heavy grazing or exposure of soil could encourage the establishment of southerly weedy species under a warmer climate leading to adverse impacts on native biodiversity and local livelihoods (Gitay et al, 2002). Loss of alpine habitat from encroachment could lead to the loss of *Ophiocordyceps sinensis* and other high value medicinal plants which will have significant impacts on the livelihoods of high altitude pastoral communities (NTG - Biodiversity, 2011).

4.5.6 Adaptation Options

The Adaptation measures for the Forest and Biodiversity Sector are presented in Section 4.9. The measures have been prepared considering the global significance of the biodiversity in Bhutan, the potential impacts from climate change, gaps in baseline information and the lack of capacity and resources in monitoring impacts from climate change.

4.6 Energy (Hydropower)

The primary energy resource in Bhutan is biomass (wood) followed by hydropower. Fuel wood dominates the primary energy at 56.8% of total primary energy supply with electricity at 15.7%, 19% from petroleum fuels and coal at 8% (DoE 2010). Fossil fuels used in Bhutan and which are imported include petrol, diesel, LPG, kerosene and aviation turbine fuel. Small deposits of sub-bituminous coal are found in south eastern Bhutan. Solar energy is harnessed as a part of the rural electrification programme for lighting homes, as a source for powering telecommunication equipment and in heating water for some institutions. The feasibility of tapping wind energy is being explored and presently data are being collected.

However, hydropower is considered the backbone of the Bhutanese economy and contributes about 45% of the national revenue and constitutes about 19% of the country's GDP. The rugged mountainous terrain and swift flowing rivers have made Bhutan a natural haven for hydro power with an estimated potential for 30,000

MW out of which 23,765 MW has been found to be techno-economically feasible. The total installed capacity as of December 2010 was 1505.32 MW. The government has also set an ambitious programme to install a minimum of 10,000 MW generating capacity by 2020 through 10 hydropower projects under the "accelerated hydropower development programme". Of these 10 projects, Punatsangchhu-I (1200 MW), Punatsangchhu-II (990 MW) and Mangdechhu (720 MW) are under construction while the rest are in the various stages of detailed feasibility studies, and implementation.

With almost total dependency on hydropower for electricity and hopes for the sector to be the major source of economic growth and future source of revenues for development activities, Bhutan has become most vulnerable to climate change. While the country is endowed with abundant water resources, any change in flow regimes will have a direct impact on ensuring energy security. The issues of concern in the hydropower sector are 1) predicting future flows, 2) managing hydropower systems for potential future flows, 3) reservoir sedimentation, 4) floods including flash floods and GLOFs, 5) increasing glacier retreat and less snow cover, 6) erratic rainfall patterns (NTG-Energy, 2011).

On the other hand, as biomass is the primary energy source of energy with almost 91% of residential consumption being met by biomass (DoE 2010). The biomass reserves (forests) are impacted by frequent rains and flood resulting in heavy erosion and landslides which in turn reduces the capacity of the catchment to retain water and affects the growth of vegetation.

Current vulnerabilities in the energy/hydropower sector as identified in Bhutan's NAPA (NEC 2006 & 2011 draft) include:

- Threats to hydropower systems from Glacial Lake Outburst Floods
- Temporal & 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
- Reduced ability of catchment areas to retain water/increased runoffs with enhanced soil erosion (deterioration of environment).

4.6.1 Vulnerability Assessment of Energy Sector

Given the socio-economic significance of hydropower, the vulnerability assessment of the energy sector focused on hydropower. It is well known that the hydro generating capacities of drainage basins are closely linked to the discharge rates (m^3/s) of the river systems so the Net Basin Supply (NBS) concept is used for this assessment (see Singh 1987). NBS essentially represents the potential flow or discharge taking into account the supply of moisture by precipitation and the loss of moisture via evapotranspiration on a monthly basis. Details on the NBS methodology and the full assessment are available in the Technical Report. The case study approach is utilized for the assessment for Chukha (336 MW) and Tala Hydro-electric (1020 MW) projects on the Wangchhu River (Figure 4.6.1) and the Puna Tsang Chhu I & II hydro-electric projects (1200 MW & 990 MW respectively) which are currently under construction along the Punatsangchhu river (Figure 4.6.2). NBS (m^3/s) and potential hydro-generating capacity for the chosen river basins are calculated for the control period (1980-2009) and for the two future time slices (2010-2039 and 2040-2069), using outputs from the HadCM3Q0/A1B and ECHAM5/A1B in order to evaluate the vulnerability of the energy sector of Bhutan to climate change.

4.6.2 Summary of NBS (Potential Discharge/Flow) Changes

The results of the changes in NBS (potential flow) for the Wangchu and Punatsangchhu basins for the future periods (2010-2039 and 2040-2069) according to the HadCM3Q0/A1B and ECHAM5/A1B downscaled scenarios are presented below and summarised in figures 3.5.3 and 4.6.4.

Figure 4.6.1: Wangchhu Basin and Chukha and Tala Hydropower Dam sites

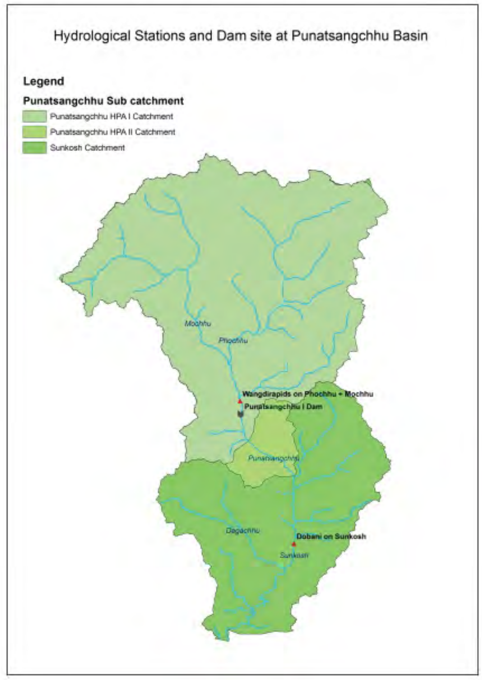

Figure 4.6.2: Mochhu and Phochhu Basins and Punatsangchhu (HPA I and HPA II) Hydropower dam sites

4.6.2a Chukha (Wangchu Basin)

According to HadCM3Q0 for the 2010-2039 period NBS at Chukha is expected to decrease (-2% to -14%) in the dry winter months (December to March), but to increase by up to 56 % (October) to 58 % (May) during the monsoon season. On average NBS is expected to increase by 26 % and for the 2040-2069 period, NBS is expected to generally decrease (-2 % to -18 %) in the dry winter months (November to February), but to increase by up to 63 % (May) to 99 % (October) during the monsoon season. Again, on average NBS is expected to increase by 34 %.

According to ECHAM5 scenario in the 2010-2039 period, NBS at Chukha is expected to decrease (-1 % to -37 %) in the dry winter months (October to March), but to increase by up to 64 % (April) during the monsoon season (May to September). On average NBS is also expected to increase by 26 %. However, for the 2040-2069 period, NBS is expected to generally decrease (-9 % to -15 %) in the dry winter months (December to March), but to increase by up to 112 % (October) during the monsoon season. But, on average NBS is expected to increase by 77 % according to the ECHAM5 scenario.

4.6.2b Tala (Wangchu Basin)

According to HadCM3Q0 in the 2010-2039 period, NBS at the Tala is expected to decrease (-2 % to -14 %) in the dry winter months (December to March), but to increase by up to 56 % (October) during the monsoon season (April to November). On average NBS is again expected to increase by 26 %. For the 2040-2069 period, NBS at the Tala is expected to generally decrease (-3 % to -18 %) in the dry winter months (November to February), but to again increase by up to 99 % (October) during the monsoon season. On average NBS is expected to increase by 82 % according to the HadCM3Q0 scenario.

Under ECHAM5 scenario in the 2010-2039 period NBS at the Tala is expected to generally decrease (-1 % to -37 %) in the dry winter months (October to March), but to increase by up to 64 % (April) during the monsoon season (May to September). On average NBS is also expected to increase by 23%. For the 2040-2069 period NBS at the Tala is expected to generally decrease (-9 % to -15 %) in the dry winter months (December to March), but to increase by up to 112 % (October) during the monsoon season. But, on average NBS is expected to increase by 77 % according to the ECHAM5 scenario.

4.6.2c Punatsangchhu Hydro Project I (Punatsangchhu Basin)

Under the HadCM3Q0 scenario, in the 2010-2039 period, NBS at Punatsangchhu Hydropower Project-I site is expected to decrease (-2 % to -11 %) in the dry winter months (December to April), but to increase very significantly by up to 223 % (May) during the monsoon season (May to November). On average NBS is expected to increase significantly by 90 %. As for the 2040-2069 period, NBS is expected to decrease even further (-3 % to -20 %) in the dry winter months (November to April), but to increase significantly by up to 186 % (May) during the monsoon season. Again, on average NBS is now expected to increase by a phenomenal 247 %.

According to ECHAM5in the 2010-2039 period, NBS for Punatsangchhu I is expected to decrease (-1 % to -20 %) in the dry winter months (December to March and May), accompanied by a significant decrease in October (-74 %) but to increase by up to 17 % to 27 % during the monsoon season (April, then June to September). On average NBS is expected to increase very significantly by 172 %. But for the 2040-2069 period, NBS at the Puna-1 site is expected to decrease even further (-8 % to -14 %) in the dry winter months (December to April), but to increase significantly by up to 393 % (October) during the monsoon season (April to October). Again, on average NBS is expected to increase significantly by 247%.

4.6.2d Punatsangchhu Hydro Project II (Punatsangchhu Basin)

As for the Punatsangchhu-II hydropower site, changes in NBS under ECHAM5 in the 2010-2039 period is expected to decrease (-2 % to -11 %) in the dry winter months (December to April), but

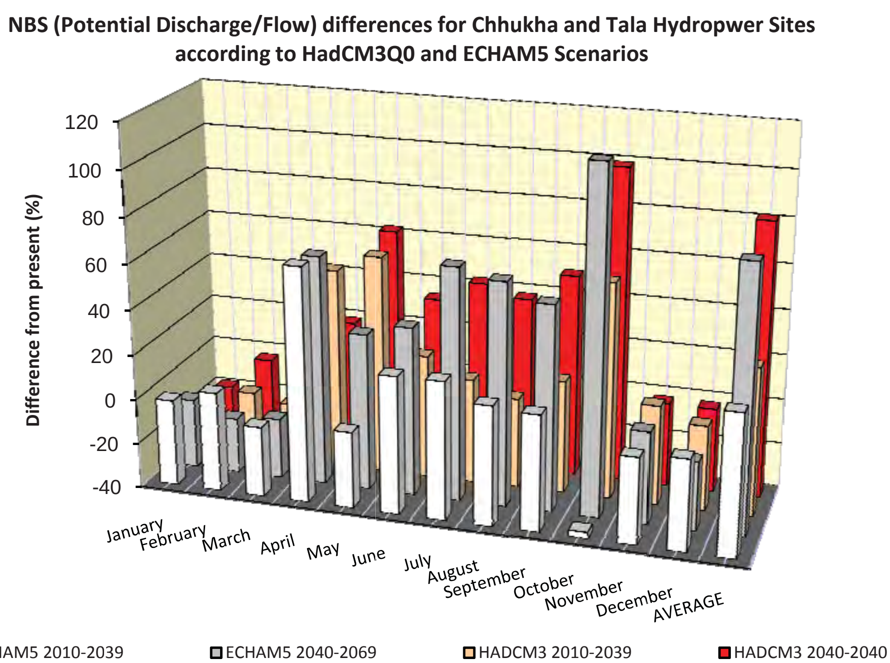

Figure 4.6.3: Average monthly and average (of all twelve months) NBS (potential discharge/flow) changes (%) for the Chukha and Tala hydropower sites in the Wangchu basin according to the HadCM3Q0 and ECHAM5 scenarios.

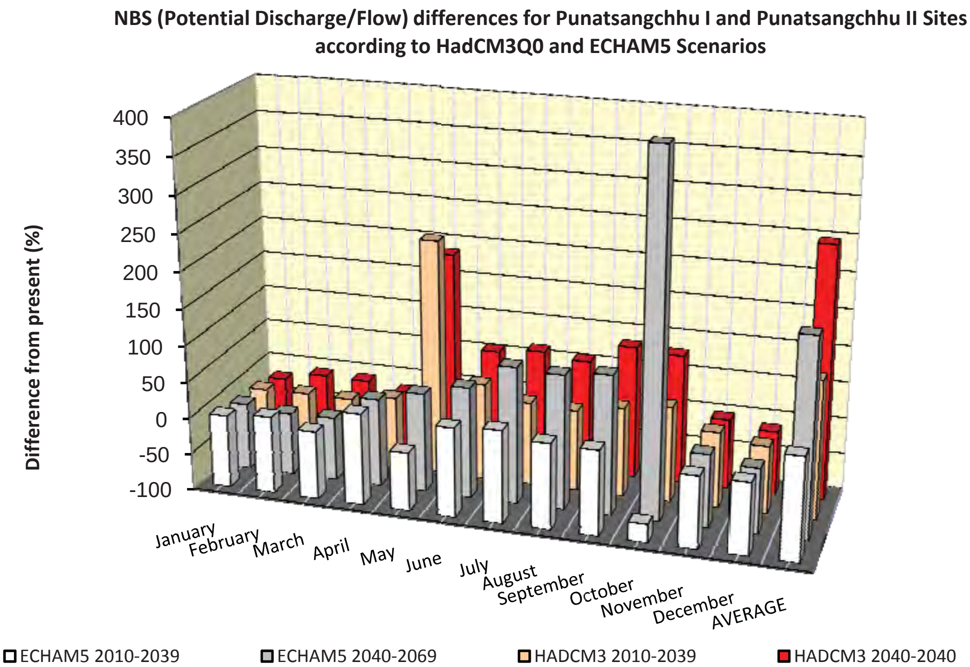

Figure 4.6.4: Average monthly and average (of all twelve months) NBS (potential discharge/flow) changes (%) for the Puna-1 and Puna-11 hydropower sites in the Punatsangchhu basin according to the HadCM3Q0 and ECHAM5 scenarios.

to increase significantly to 223 % (May) during the monsoon season (May to November). On average NBS is expected to increase significantly by 90 %. However, for the 2040-2069 period, NBS is expected to decrease even further (-3 % to -20 %) in the dry winter months (November to April), but to increase very significantly by up to 186 % (May) during the monsoon season (May to October). Again, on average, NBS is now expected to increase very significantly by 247 %.

According to the ECHAM5 scenario in the 2010-2039 period, NBS at Punatsangchhu-II site is expected to again decrease, but up to -74 % (October) in the dry winter months (October to December and March), but to increase moderately by 17 % to 27 % during the monsoon season (April, then June to September). On average NBS is expected to increase significantly by 41 %. But for the 2040-2069 period, NBS is expected to decrease generally and even further (-8 % to -14 %) in the dry winter months (December to March), but to again increase significantly by up to 393 % (October) during the monsoon season (April to October). Again, on average NBS is now expected to increase significantly by 172 %.

4.6.3 Summary for Hydropower Vulnerability

It transpires from the above that, in general, NBS in the Wangchu and Punatsangchhu basins will decrease moderately in the dry winter months (~November to April), but would increase significantly in the wet monsoonal months (~May to October) according to both the HadCM3 and ECHAM5 scenarios. As a matter of fact the ECHAM5 scenario projects more extreme seasonal changes. The Chukha and Tala hydropower sites in the Wangchu basin are more or less the same which is to be expected given the proximity of these two sites. Similarly, the potential changes in NBS for Punatsangchhu-I and Punatsangchhu-II hydropower sites in the Punatsangchhu basin are more or less the same given the proximity of these two sites.

Furthermore, a recent study on: 'Climate change impacts on the flow regimes of rivers in Bhutan and possible consequences for hydropower development' using the ECHAM5/MPIOM A-OGCM, forced by the SRES A2 and B1 GHG scenarios and downscaled to a 0.5 degree grid for the Hindu Kush-Himalayan region and coupled to a spatially distributed hydrological model was conducted by the Norwegian Water Resources and Energy Directorate for describing hydrological processes including glacier mass balance, snow storage, subsurface water storage and streamflow and their impacts on hydropower generation (Beldring, S. (Editor) 2011). Historical or present climate was represented by a control period 1981-2010, while future climate for the projection periods 2021-2050 and 2071-2100 were considered.

The results of this study, which corroborates with this study, showed that the change in mean annual discharge available for hydropower production from 1981-2010 to 2021-2050 varies between 13 % decrease and 7 % increase for all catchments and both climate scenarios. The change in mean annual discharge available for hydropower production from 1981-2010 to 2071-2100 is influenced by reduced contribution to streamflow from glacier ice melt (Beldring, S. (Editor) 2011).

Since, there is the possibility of reduced river flows there is the risk of reduced hydropower potential and loss of revenues, especially during the dry winter months.

4.6.4 Adaptation for Energy Sector

Given the heavy dependence of Bhutan on the hydropower sector, the findings of the vulnerability assessment necessitate major adaptation measures for the energy sector. Such measures would need to consider the current run-of-river hydropower schemes to capture water for the lean season, diversification of energy sources and other policies to increase energy efficiency. Furthermore, given the fact that emissions from Bhutan are almost negligible due to dependence on hydropower and forest biomass (See Chapters 2 and 3), measures to promote energy efficiency and diversification in Bhutan will have to be considered as adaptation rather than mitigation measures. The adaptation priorities for energy security are presented in Section 4.9.

4.7 Human Health

The health of millions of people is impacted upon each year by the acute and long-term effects of climate. Climate change is expected to exacerbate this condition. The basic requirements for good health are clean air and water, sufficient food and adequate shelter and each of these conditions are very likely to be affected by future climate changes. Climate change also brings new challenges to the control of infectious diseases. Many of the major killers are highly sensitive to temperature and rainfall, including cholera and diarrhoeal diseases, as well as vector borne diseases including malaria, dengue and schistosomiasis (WHO, 2010). Malaria and dengue fever, two diseases linked to climate change, have become major public health problems in countries such as Bhutan in the recent past. *Plasmodium falciparum* (PFM), one of the species that causes malaria, is the main infectious agent transmitted.

4.7.1 Statistical Analysis of Climate Sensitive Diseases

For the health sector, the case study approach is utilized on the two most populous municipalities, namely the capital city of Thimphu and the border town of Phuentsholing to the south, adjacent to India. In order to evaluate the impacts of climate change on human health in Bhutan, epidemiological data on the types of diseases and mortality rates is utilized. The data for the Thimphu region consisted of an agglomeration of data from a number of Hospitals and Public Health Centers, including JDWNR hospital, Gidakom hospital, Lungtenphu Army hospital, Dechhencholing BHU I, Motithang Sat. Clinic, Jungshina Sat. Clinic, RBP Clinic and Chamgang. In the case of Phuntsholing, data was obtained for only the Phuntsholing hospital. Because of data limitation, dengue was treated for the whole of Bhutan. However, it must be cautioned that people from the surrounding rural populations of both Thimphu and Phuntsholing visit the health centers and hospitals in these urban centers, so that the incidence of diseases reflect not only the two towns but also the nearby rural population. Using multiple regression and analysis of variance (ANOVA) statistics, numerical relationships between number of cases of each disease, except dengue, on a monthly and yearly basis, and climate parameters, namely maximum (Tx) and minimum (Tn) and rainfall (Rn) temperature for the control (2003-2009) period are developed.

The results of the statistical analysis are presented in Tables 4.7.1, 4.7.2 and 4.7.3. These statistical relationships between climate and the incidence of diseases were then used to assess number of cases reported rates for the future periods (2010-2039 and 2040-2069) by substituting the pertinent climate changes, namely air temperature (Tx and Tn) and precipitation (Rn) and the statistical relationships developed for the control period.

The potential health sector impacts using the statistical relationships, but applied to the future changes (2010-2039 and 2040-2069) in climate parameters, namely maximum and minimum air temperature and rainfall, derived from two climate scenarios (HadCM3Q0/A1B and ECHAM5/A1B) and how they would affect the incidence of future diseases for the municipalities of Thimphu and Phuentsholing are detailed in the Technical V&A Report (2011).

4.7.2 Assessment of Sensitive Malaria Zones

With malaria as one of the important vector borne diseases, especially in the southern lower elevation regions of Bhutan, an assessment was also conducted to assess how the sensitive zones of malaria may be impacted by climate change in the future (2010-2039 and 2040-2069). It is evident from Figure 4.7.1 that the highest incidence of malaria cases are highest in the warmer and wetter southern Dzongkhags of Samste, Chhukha, Sarpang, Zhemgang, Monggar, Pemagatshel, Trashigang and Samdrupjongkhar. It is assumed that biting mosquitoes and the probability of malaria transmission rates are highest at optimal temperatures between 14.5 and 15 ^{0} C (P. vivax strain) and between 16 and 19 ^{0} C (P. falciparum strain) and rainfall exceeding 45 mm/month. Since, there is no discrimination between the P. vivax strain and the P. falciparum strain the optimal temperature range is taken to be 14.5 and 19 ^{0} C.

According to the HadCM3Q0-A1B scenario for the period 2010-2039 (see Technical V&A Report, section 2) these optimal climate conditions occur mainly in the wet monsoonal season (June to September) and now extends to the Chhukha, Dagana, Punakha, Monggar, Pemagatshel, Samdrupjongkhar, Samste, Sarpang, Trashigang, Tsirang and Zhemgang, districts for optimal temperature, whereas the condition of optimal rainfall is met in all districts. For the 2040-2069 period, in addition to the districts identified for the 2010-2039 period above, Haa and Trongsa districts also now meet the requirements of optimal temperature and rainfall conditions for mosquitoes and the likelihood of malaria incidence.

Similarly, according to the ECHAM5-A1B scenario for the period 2010-2039 (see Technical V&A Report, section 2), optimal climate conditions occur mainly in the wet monsoonal season (June to September) and now extends to the Chhukha, Dagana, Haa, Lhuentse, Punakha, Monggar, Pemagatshel, Samdrupjongkhar, Samste, Sarpang, Trashigang, Tsirang and Zhemgang, districts for optimal temperature, whereas the condition of optimal rainfall is met in all districts. For the 2040-2069 period, the same districts identified for the 2010-2039 period above, also meet the requirements of optimal temperature and rainfall conditions for mosquitoes and the likelihood of malaria incidence.

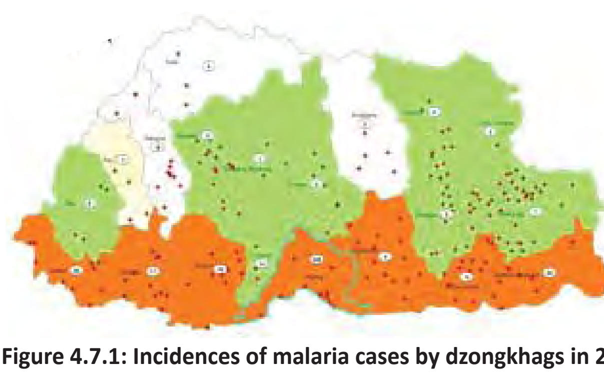

Figure 4.7.1: Incidences of malaria cases by dzongkhags in 2010

Table 4.7.1: Statistical relationships between the climate variables (Tx, Tn and Rn) and diseases for the Thimphu region for the control period (2003-2009) using the HadCM3Q0 and ECHAM5 data.

Disease	HadCM3Q0 Correlation (R^2)	ECHAM5 Correlation (R^2)	Remarks
Cholera	0.40	0.47	Moderate
Diarrhoea	0.85	0.81	Significant
Dysentery	0.82	0.93	Significant
PFM	0.56	0.21	Weak to Very Weak
Other Malaria	0.34	0.20	Weak to Very Weak
Typhoid	0.15	0.12	Very weak

Table 4.7.2: Statistical relationships between the climate variables (Tx, Tn and Rn) and diseases for the Phuentsholing region for the control period (2003-2009) using the HadCM3Q0 and ECHAM5 data.

Disease	HadCM3Q0 Correlation (R^2)	ECHAM5 Correlation (R^2)	Remarks
Cholera	0.47	0.48	Moderate
Diarrhoea	0.44	0.50	Moderate
Dysentery	0.51	0.29	Moderate to Weak
PFM	0.66	0.64	Significant
Other Malaria	0.24	0.23	Weak to Very Weak
Typhoid	0.30	0.22	Weak

Table 4.7.3: Statistical relationships between the climate variables (Tx, Tn and Rn) and diseases for the whole of Bhutan region for the control period (2004-2009) using the HadCM3Q0 and ECHAM5 data.

Disease	HadCM3Q0 Correlation (R^2)	ECHAM5 Correlation (R^2)	Remarks
Dengue	0.82	0.04	Significant to Very weak

Studies have also shown that there is a link between ENSO events and the incidence of Malaria. But apart from data problems to do such an analysis, the health care interventions have controlled this disease in Bhutan.

4.7.3. Summary of Health Impacts

On the whole, the significant health impacts of climate change for Bhutan would be slight increases or no change in the number of cases of Cholera and PFM and moderate to significant increases in the incidence of Diarrhoea, Dysentery, Other Malaria and Typhoid for both the Thimphu and Phuntsholing regions according to the HadCM3Q0 and ECHAM5 scenarios. For Dengue, only the ECHAM5 scenario projects moderate (2010-2039) to significant (2040-2069) increases in the incidence of this disease for the whole of Bhutan, unlike the HadCM3Q0 scenario that projects significant decreases. These changes in the incidence of the various diseases are most likely linked to the increasing temperatures (~ 1^0C in 2010-2039 and ~ 2^0C in 2040-2069) and slight increases in precipitation (5% to 10 %) across Bhutan. But, based on studies elsewhere (IPCC, 2007) it would appear that the ECHAM5 scenario would be more plausible. However, it must be cautioned that apart from the uncertainties in the climate scenarios (HadCM3Q0 and ECHAM5) there is the issue of limited data sets on diseases. So these results should be interpreted with caution. Finally, other issues indirectly related to climate such as GLOFs and landslides, will also affect the health status and mortality rates of the Bhutanese people.

4.7.4. Adaptation: Health Sector

The global public health community has a wealth of experience in protecting people from climate sensitive hazards. Many of the necessary preventive actions to deal with the additional risks of climate change are already clear (IPCC, 2007;

Gatrell et al., 2009: Leary et al, 2008; Martens, 1996; Lindsay and Birley, 1996). Widening the coverage of proven, effective health interventions will be critical to the global effort to adapt to climate change. As a matter of fact health impacts of climate change will be determined by both climate change and non-climatic factors such as health care and the health condition of the population (WHO, 2010).

The adaptation options for the health sector is elaborated in Section 4.9 and will include considerations existing capacity to understand and monitor health impacts of climate change in Bhutan; current and future incidence of diseases; control of vectors (mosquitoes) for diseases (malaria, dengue), education and awareness and improved health care and access.

4.8 Glaciers and GLOFs

High mountainous countries like Bhutan are home to large numbers of a variety of mountain glaciers. Glacial Lake Outburst Flood (GLOF) takes place in heavily glacierized mountain regions and are triggered by natural forces such as heavy rains, landslides and avalanches and earthquakes. This leads to an overspill of water from the glacial lakes, a sudden increase in drainage and an outbreak of the glacial lake resulting in floods that have the capacity to cause widespread damages to entire communities located downstream, impacting their lives, livelihoods, socio-economic assets and other development infrastructure in the mountain regions. The main causes or triggers of GLOFs can be classified into several categories (Vuichard and Zimmerman, 1986; Leber and Hausler, 1998):

- An outbreak of lakes dammed by a glacier, or the outbreak of ponded melt-water from beneath or within a glacier system;
- Overspill of lakes frontal to a glacier that have been dammed by landslides;
- The sudden drainage of ephemeral lakes dammed landslides, rockfalls or by snow or ice avalanches that have blocked the main channel of a river;
- Surge wave caused by mass movements due to seismotectonic events;
- Intense seepage and piping as a result of a rise of the lake water level.

There are a total of 677 glaciers known to exist in the Bhutan Himalayas, which cover an area of 1,317 km^2 with approximately 127 km^3 of ice reserves and occur above the elevation of 4000 m above mean sea level. Of the six types of glaciers in the Bhutan Himalayas, mountain glaciers are the most common (ICIMOD and UNEP, 2002; UNDP/EU, 2008). These glaciers feed water into 2,674 glacial lakes formed due to the retreating processes of the glaciers. Bhutan has been described as being prone to dangerous GLOFs (Watanabe and Rothacher, 1996).

Using the distance of the lake from the glacier as a parameter to judge the potential danger of the lake likely to lead to GLOFs, i.e. closer the lake to the glacier, the higher the probability of a GLOF event; there are 174 lakes that are within a distance of less than 50 m. And out of these lakes, 25 have been identified as most dangerous (ICIMOD and UNEP, 2002). Among the identified potentially dangerous lakes, three lakes are in the Chamkhar Chu Basin, one is in the Kuri Chu Basin, seven are in the Mangde Chu Basin, five are in the Mo Chu Basin and eight are in the Pho Chu Basin (Figure 4.7.1) (ICIMOD; UNEP, 2002; UNDP/EU, 2008).

Studies (Kaser et al, 2006 and Lemke et al, 2007) have evaluated glacier mass balances for several mountainous regions including the Asia High Mountains. For Asia High Mountains, which includes the Hindu Kush Himalayas of Northern Bhutan, the decrease in glacier mass balance between 1960 and 2003 is ~ 10 meters of water equivalent, which translates into a rate of ~ 0.25 meters/year. Further studies on the cumulative frequency of GLOF events in Nepal, Bhutan and Tibet show a progressive increase from 1940 to 2000, approaching a total of ~ 35 GLOF events by 2000 (Richardson and Reynolds, 2000). This would translate into close to one GLOF event every two years and even greater recently, given the non-linearity of the increase in recent years (Richardson and Reynolds, 2000).

Of greatest concern are the 9 lakes in Pho Chu Basin where there have been four GLOF incidents in recent times. The most serious GLOFs along Pho Chu River occurred in 1958 and 1994. The "*unexpected*" Lugge Tsho GLOF of 1994 caused damage to Punakha Dzong, houses, bridges, agricultural land, and the loss of *21 lives* (UNDP/ EU, 2008) (Tables 4.8.1 and 4.8.2). Following the Lugge Tsho outburst, the Royal Government implemented risk mitigation measures in Raphstreng Tsho in between 1996 and 1998 by lowering the lake level by 4m. However the risk still remains high due to the new threat from adjoining Thorthormi Tsho which is rapidly increasing in size and the moraine wall separating the two lakes is decreasing in size.

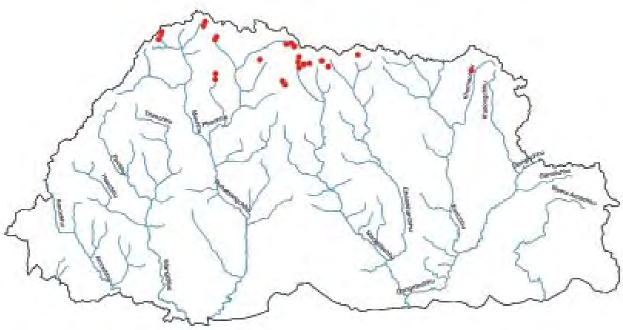

Figure 4.8.1: Potentially Dangerous GLOF in Northern Bhutan and the Pho Chu Sub-Basin

Some of the vulnerabilities from glacial retreat and GLOF identified in Bhutan's NAPA include;

- Loss of lives and livelihoods through impacts on agricultural lands and people from GLOF
- Loss and damage to essential infrastructure such as hydropower systems (generation plants, transmission and distribution infrastructure), industrial estates/ infrastructures, human settlements, historical and cultural monuments, roads, bridges and communications infrastructure
- Reduction of water resources (possible shortages/variations for downstream uses in agriculture and hydropower) due to receding glaciers.

The NAPA also identified "Artificial Lowering of Thorthormi Lake", "GLOF Hazard Zoning" and

Table 4.8.1: List of known GLOF events in Bhutan (Source: Mool et al, 2001; Bajracharya, 2008; ICOMOD, 2010)

Date	River basin	Lake	Cause of GLOF
1957	Pho Chu	Tarina Tso	Not Known
1960	Pho Chu	Unnamed	Not Known
1960?	Chamkhar Chu	Bachamancha Tso	Not Known
7 Oct. 94	Pho Chu	Luggye Tso	Moraine collapse

Table 4.8.2: Summary of glaciers, glacial lakes, and lakes identified as potentially dangerous in selected parts of Bhutan (Source: Karma et al, 2008; ICIMOD, 2010).

River basin	Glaciers			Glacial lakes		
	Number	Area (sq.km)	Ice reserves (cu.km)	Number	Area (sq.km)	Potentially dangerous
Amo Chu	0	0	0.00	71	1.83	0
Wang Chu	36	49	3.55	221	6.47	0
Puna Tsang Chu	272	503	43.27	980	35.08	13
Manas Chu	310	377	28.77	1383	55.51	11
Nyera Ama Chu	0	0	0.00	9	0.07	0
Northern basins	59	388	51.72	10	7.81	0
Total	**677**	**1317**	**127.31**	**2674**	**196.77**	**24**

Note: The Thorthormi Lake was not detected during this desk assessment and has since been added due to ground conditions of rapidly growing supra glacial lakes, and diminishing moraine wall adjoining the Raptsthreng Lake, the total now stands at 25 potentially dangerous lakes.

"Installation of Early Warning System in the Pho Chhu Basin" as 3 of the 9 prioritised NAPA project. Currently Bhutan is implementing one of the first NAPA projects to address these three priorities under the LDC Fund and entitled "*Reducing Climate Change-induced Risks and Vulnerabilities from Glacial Lake Outburst Floods in the Punakha-Wangdi and Chamkhar Valleys".* The project aims to (1) Artificially lower water levels in Thorthormi Lake by 5 meters, (2) Increase capacity for disaster risk management in affected valleys and (3) Installing Technical Early Warning System for glacial lake outburst floods.

The Department of Geology and Mines is currently collaborating with several international researchers to assess the trends in glacial retreat and the risk of GLOF with on ground research to improve on the assessments which have so far been based on remote sensing and desktop analysis. With temperatures rising even further and faster in the coming decades, it is expected that the risk and threat of GLOF events will increase in the years to come.

4.8.1 Assessment of Trends in Glacial Retreat and GLOF

In order to assess the impacts of climate change on GLOF events, daily data available for Lunana station located in the head waters of the Pho Chu basis, the area most susceptible to GLOF events was first analyzed. It is well established that the greatest amount of glacier retreat, responsible for rising lake waters and subsequent overflow, occurs during the warmer months when a combination of increased temperature and rainfall lead to loss of glacier mass balance.

For the years where data is available (2003-2003), the half-hourly data for the warmer months (May to October) was averaged. However, even for these months where data was most complete, there were gaps for some years (2005, 2006, 2007, 2008 and 2009) of which data was missing for 2006 and 2008 (Table 4.8.3). In spite of these data problems, the seasonal (May – October) temperatures and the temperature change relative to the first year of data availability, namely 2003 was calculated (Table 4.8.3 and Figure 4.8.2). Based on this limited data set the average yearly change in temperature, for the months considered, was estimated to be 0.6 ^{0}C/year. The glacier retreat rates (30 - 40 m per year for Debris cover glacier - and 8-10 m per year for Debris free glacier) provided by the Department of Geology and Mines (Karma Toeb) was used and the mid-point value in each case was chosen (35m/year for debris covered glaciers and 9 m/year for debris free glacier).

Based on the average temperature change, namely 0.6 ^{0}C/year, and the glacier retreat rates for debris covered glacier (35 m/year) and debris free glaciers (9m/year), future projected changes in glacier retreat rates was estimated by comparing temperature changes for the future periods (2010-2039 and 2040-2069) relative to the current (1980-2009) for the HadCM3Q0 and ECHAM 5 for the grid box closest to Lunana and the area of active GLOF events (28.18 ^{0} N latitude and 90.4 ^{0} E longitude). The results presented in Tables 4.8.4 and 4.8.5 show that based on warm season temperature changes alone, temperatures in the area are projected to increase by 0.49^{0} C (ECHAM5) to 1.23^{0} C (HadCM3Q0) for the period 2010-2039 and by 1.34^{0} C (ECHAM5) to 2.88^{0} C (HadCM3Q0) for the period 2040-2069. These temperatures changes would lead to glacier retreat rates of 78.2 m (ECHAM5) to 168.0 m (HadCM3Q0) for the period 2010-2039 for debris covered glaciers and of 20.1 m (ECHAM5) to 43.2 m (HadCM3Q0) for the period 2040-2069 for debris free glaciers. Based on the trends in GLOF events in Nepal, Bhutan and Tibet (Richardson and Reynolds 2000) this would translate into more frequent GLOF events by 2010-2039 and even more frequent by 2040-2069, especially in regards to the HadCM3Q0 scenario.

In addition to air temperature, changes in the type and amount of precipitation would lead to further melting of glaciers in the upper Himalayan regions of Bhutan. According to both the HadCM3Q0/A1B and ECHAM5/A1B models projections for the two future periods, namely 2010-2039 and 2040-2069, precipitation, with more and more falling as rain, is expected to increase more significantly in

Table 4.8.3: Summary of Data for warm season months (May-October) for Lunana station (2003-2009) (Data source: DGM 2011)

Year	Months Considered	Temperature (^{0} C)	Temp Change re 2003 (^{0} C)	Remarks
2003	May-October	4.61	-	6 months
2004	May-October	4.83	0.2	6 months
2005	May-September	7.68	3.07	5 months
2006	Missing	7.35	2.74	Interpolated
2007	July-October	7.01	2.4	4 months
2008	Missing	7.62	3.01	Interpolated
2009	July-October	8.22	3.61	4 months
Average Temperature Change			0.6 ^{0}C/year	

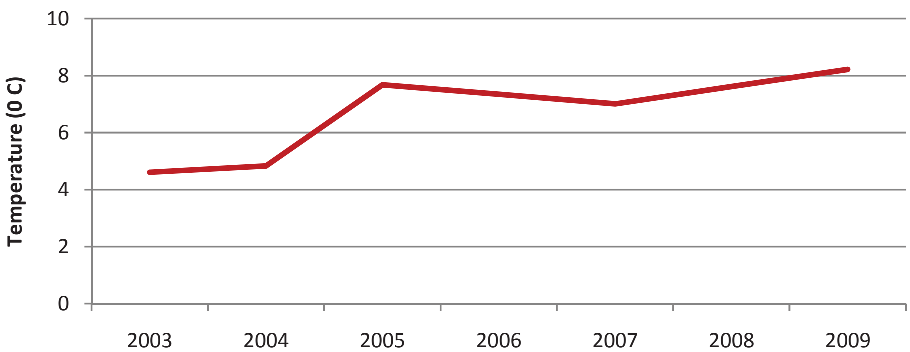

Figure 4.8.2: Temperature change for warm season months (May-October) for Lunana station (2003-2009).

the northern regions of Bhutan (Gasa, Bumthang, Thimphu, Paro and Haa) (See Section 4.1). The combined influences of increasing temperature and rainfall would therefore accelerate the melting of Himalayan glaciers near and within northern Bhutan and this would very likely lead to an increase in the frequency and intensity of GLOF events.

Furthermore, a recent study on 'Climate change impacts on the flow regimes of rivers in Bhutan and possible consequences for hydropower development' (Beldring, S. Ed. 2011) using the ECHAM5/MPIOM, A-OGCM (SRES A2 and B1) taking into account glacial mass balance, snow storage, subsurface water storage and stream flow indicated that the change in mean annual discharge available for hydropower production from 1981-2010 to 2021-2050 varies between 13 % decrease and 7 % increase for all catchments and both climate scenarios. The change in mean annual discharge available for hydropower production from 1981-2010 to 2071-2100 is influenced by reduced contribution to stream flow from glacier ice melt.

4.8.2 Adaptation for GLOFS

Due to the history of GLOF in Bhutan, several adaptation measures have already been under taken in recent times as described previously in this section. The Royal Government, particularly the Department of Geology and Mines, has initiated numerous structural measures to reduce the possibility of future GLOF incidents. Measures such as draining of lake levels, installation of early warning systems and building river protection embankments have been initiated. In parallel, the Department of Disaster Management of the Ministry of Home and Cultural Affairs is spearheading the National Disaster Risk Management Framework which proposes an institutional framework at three different levels - national, Dzongkhag (district) and Dungkhag/ Gewog/Thromde (local administration) levels -to discharge responsibilities in both pre-disaster as well as the post-disaster phases.Following the 1994 Lugge Tsho GLOF the Government of Bhutan promptly started further structural GLOF mitigation initiatives and response measures to avoid similar catastrophic incidents in the future. Following up on preliminary studies of the dangerous glacial lakes in Pho Chu, a series of short-term and long-term measures were recommended (ICIMOD and UNEP, 2002; Watanabe and Rothacher, 1996 and Hausler and Leber, 1998).

While the priority actions for adaptation to GLOF and glacial retreat is presented in section 4.9 a discussion on the various adaptation measures to GLOF is warranted since the chosen methods will depend on particular conditions at site, costs and other information that will arise during detailed assessments. A brief discussion of various recommended measures is presented below:

The Short-term Measures recommended were:

- Unloading the crown of the landslide near the Tshopda Tsho outlet and constructing gabiontoe walls on either banks of Pho Chu;
- Lowering the outlet of Thorthormi Tsho by 10 m in stages to reduce the hydrostatic pressure;
- Restoring the original section of the morainic barrier of Raphstreng Tsho washed away by the 1994 flood; and
- Lowering the level of Raphstreng Tsho by 20m to reduce the volume by 38%.

The Long-Term Measures recommended were:

- Construction of check dams, river draining dykes and other energy dissipation measures downstream;
- Stabilization of slopes by plantations;
- Detailed monitoring of glacial lakes;
- Establishment of seismic stations to record earthquakes in the Lunana area; and
- Establishment of meteorological station in the lake area to record micro-climatic variations.

Furthermore, Grabs and Hanisch (1993) prescribed a series of structural methods to lower the water level in the glacier lakes to prevent the outburst of GLOF-prone lakes, and the most common techniques recommended were:

- Artificial deepening of the natural spillway;
- Blasting the moraine dam;
- Inclined drilling through the moraine dam; and
- Driving a tunnel from an adjacent deeper lying valley.

Grabs and Hanisch (1993), however, cautioned that the above methods and techniques “suffer from unpredictable risks” and suggested that the Hydraulic Siphon Technique (HST) as best suited for the harsh Himalayan conditions in addition to being affordable. Basically HST, which can be adapted to the specific conditions of the Himalayas, can lower lake water levels in the magnitude of 5 m by taking advantage of the difference of a hydraulic potential between the inlet and the outlet water filled pipe to a deeper lying outlet.

The non-structural mitigation measures include (UNDP/EU, 2008):

At a National level:

- Strengthen legislative and institutional frameworks;
- Devising of simpler response mechanisms;
- Allocation of sufficient funds; and
- Build disaster risk management capacity.

Community and local levels:

- Strengthen awareness and preparedness measures;
- Initiate an effective flood insurance scheme;
- Build a disaster resilient community;
- Strengthen community bond;

- Initiate practice drills and first-aid training; and
- Acknowledge and advocate spatial relocation issues.

Furthermore, the Government of Bhutan, in recent years, has recognized the importance of developing a comprehensive disaster risk reduction strategy that minimizes the impact of both natural and man-made catastrophes (MoHCA, 2006). Towards this end, and spearheaded by a newly created Disaster Management Department of the Ministry of Home and Cultural Affairs, a National Disaster Risk Management Framework was developed in 2006 with a vision to reduce disaster risks for a 'safe' and 'happy' Bhutan. The National Disaster Risk Management Framework essentially comprises of the following seven components:

- Institutional, Legislative and Policy Frameworks: To establish an appropriate institutional and legislative framework defining the mandates and inter-relationships of various organizations across sectors and administrative levels.
- Hazard, Vulnerability and Risk Assessment: To identify the probability of occurrence of various hazards in a specified future time period, as well as the intensity and area of impacts.
- Early Warning Systems: To generate advance warnings and thus improve capacity of decision makers to take required action prior to the occurrence of a disaster.
- Disaster Preparedness Plans: To prepare multi-hazard disaster preparedness and response plans at national, Dzongkhag, Dungkhag (sub-division of district) Geog and Thromde (township) levels to ensure requisite levels of preparedness and functioning of sectoral response plans.
- Mitigation and integration of disaster risk reduction in development sectors.
- Public Awareness and Education: To establish partnerships with media and community organizations for dissemination of disaster risk management agenda and incorporation of the same in education curricula to promote a people-centric approach to mitigate disaster risks.
- Capacity Development: To create a cadre of trained and skilled professional and disaster management practitioners with requisite knowledge and capacity to initiate and implement disaster risk management programs.

Table 4.8.4: Warm season (May-October) average maximum temperature-based glacier retreat for Debris- covered glaciers for future HadCM3Q0 ans ECHAM5 scenarios (2010-2039 and 2040-2069) relative to the 1980-2009 scenario in Northern Bhutan.

Model	Tx (^{0}C) 1980-2009	Tx (^{0}C) 2010-2039	Δ Tx (^{0}C) 2010-2039	Retreat (m) 2010-2039	Tx (^{0}C) 2040-2069	Δ Tx (^{0}C) 2040-2069	Retreat (m) 2040-2069
HadCM3Q0	9.96	11.19	1.23	71.8	12.84	2.88	168.0
ECHAM5	8.89	9.38	0.49	28.6	10.23	1.34	78.2

Table 4.8.5: Warm season (May-October) average maximum temperature-based glacier retreat for Debris- free glaciers for future HadCM3Q0 ans ECHAM5 scenarios (2010-2039 and 2040-2069) relative to the 1980-2009 scenario in Northern Bhutan

Model	Tx (^{0}C) 1980-2009	Tx (^{0}C) 2010-2039	Δ Tx (^{0}C) 2010-2039	Retreat (m) 2010-2039	Tx (^{0}C) 2040-2069	Δ Tx (^{0}C) 2040-2069	Retreat (m) 2040-2069
HadCM3Q0	9.96	11.19	1.23	18.45	12.84	2.88	43.2
ECHAM5	8.89	9.38	0.49	7.4	10.23	1.34	20.1

The Government of Bhutan has also elevated GLOF to the position of "among the most serious natural hazard potentials in the country" and specifically seeks to achieve the following expected outputs pertaining to GLOF within the overall context of the National Disaster Risk Management Framework (UNDP/EU, 2008):

- Develop hazard zonation maps for all major geological hazards;
- Establish GLOF monitoring systems, web enabled databases and capacity for voice and data traffic; and
- Develop and implement hazard-specific mitigation measures.

4.9. Cross-cutting Issues

It is expected that climate change impacts and vulnerabilities will not occur in isolation. Non-climate factors, linkages between sectors, as for instance the link between glaciers and GLOFs and water resources and energy production and the subsequent impacts on agriculture and human health and settlements should also be taken into consideration (Leary et al., 2008a; 2008b). Examining the various adaptation actions proposed within the different sectors in the V&A assessment (Section 4.10.2), it is evident that there are many cross linkages and that adaptation would need to be implemented in a coordinated and integrated manner. In this regard, a matrix was prepared to determine the linkages between the different sectors in this assessment (Table 4.9.1) It is evident that water resources, whether through rainfall or irrigation is vital for agricultural production, for maintaining forest land and wetlands, for ensuring sufficient river flows for hydropower production and sufficient and good quality water for human health. On the other hand, melting glaciers and GLOFs are instrumental in enhancing water resources maintaining river flows, although they may be hazardous for human health. Agriculture is vital for ensuring food security in Bhutan. So the cross-linkages with climate change and water resources and human health are evident. Also, in the case of agroforestry, which is very important in rural Bhutan, the link with the forestry and biodiversity sector is significant. Forestry and biodiversity are also subject to the vagaries of climate change. But they also play a key role enhancing the filtration and storage of water resources, not to mention their role in agroforestry.

However, forests are the home of a number of wild animals such as elephants and wild hogs, and

Table 4.9.1: Cross-linkages between the targeted sectors

SECTORS	Climate Change	Water Resources	Agriculture	Forests and Biodiversity	Energy Production	Glaciers and GLOFs	Human Health
Climate Change	-	XXX	XXX	XX	XX	XXX	XX
Water Resources	XXX	-	XXX	XX	XXX	XX	XX
Agriculture	XXX	XXX	-	XXX	X	XX	XX
Forestry and Biodiversity	XX	XX	XXX	-	XX	XX	X
Energy Production	XX	XXX	X	XX	-	XX	X
Glaciers and GLOFs	XXX	XX	XX	XX	XX	-	XX
Human Health	XX	XX	XX	X	X	XX	-

X: Little Impact *XX: Significant Impact* *XXX: Very Significant Impact* these are very disastrous to agriculture in Bhutan: the human-wildlife conflict. Finally glaciers and GLOFs, although they contribute to maintaining river flows for energy production via hydropower and to irrigation water for agriculture in Bhutan, they can sometimes be detrimental to human health, causing loss of life through excessive flooding. It is therefore very evident that climate change would intricately cross-link with other key sectors of Bhutan, namely the water resources, agriculture, forestry and biodiversity, energy, glaciers and GLOF and human health.

4.10 Adaptation Plan

The adaptation priorities are presented by sector in this section along with objectives, indicative time frame, scope of coverage, lead agencies and other cross-cutting sectors and issues. Costs of some of the adaptation activities have also been roughly estimated. The adaptation measures were prepared in a consultative manner, over several rounds of discussions, taking into consideration the outcomes of the Vulnerability and Adaptation Assessment as described in this chapter, the national thematic papers prepared for the Climate Summit for a Living Himalayas-Bhutan 2011 (CSLH) and outcomes of other assessments and projects, and also the adaptation options identified in Bhutan's National Adaptation Programme of Action.

Since the CSLH -Bhutan 2011 will result in a national adaptation road map as a part of the Regional Framework of Action for Climate Adaptation in the Eastern Himalayas (Bangladesh, Bhutan, India and Nepal) to be adopted in November 2011, it was essential to ensure synergies with that process. Towards this end, members of the four Thematic Group for the CLSH (Biodiversity, Energy Security, Food Security and Water Resources), upon completion of their task of preparing the national thematic papers continued as members of the SNC V&A Task Force. Human Health and Glaciers & GLOF were two additional sectors for the SNC V&A Task Force. Consequently the adaptation actions identified in this section is aligned with the activities within the CLSH process.

4.10.1 Implementation Arrangements for Adaptation

Currently Bhutan lacks financing and capacity even for regular baseline development activities and research on climate observation and vulnerability assessment, let along additional adaptation activities. Therefore the implementation of adaptation priorities will be heavily dependent on availability of financing.

With regards to implementation arrangements, it is recommended that at a national level the NEC as the national focal agency for climate change, in consultation with the GNHC as the national planning agency, shall coordinate national V&A and adaptation planning including monitoring the progress in implementation of adaptation activities. However sectors and stakeholders shall implement adaptation priorities and actions within their own sectoral plans and programs. The role of local communities, local governance and civil society organisations will also be crucial to ensure that adaptation measures are implemented to benefit the most vulnerable communities

Coordination of crosscutting and overlapping issues can be facilitated through the Multisectoral Technical Committee on Climate Change (MSTCCC). Such an arrangement can also facilitate synergies with other relevant activities. It will also be essential to maintain close consultation between NEC and the Secretariat for the Climate Summit for a Living Himalayas – Bhutan 2011 to ensure synergy in building national resilience to climate change from two different but related processes.

With regards to implementation within sectors, several sector specific recommendations are identified as follows:

Water

- Set-up of present institutions are adequate
- Better collaborations are required both within agencies and with the local governments/ gewogs, and water user associations
- Need to establish Independent Water

Authority as per Water Act

- Capacity building required.

Energy

- Each sectoral adaptation action will be implemented by the identified agency in the sectoral plan.
- For Energy issues, there is a need for either an independent Ministry to address the overall energy issues or an Energy Board comprising members from different relevant agencies.

Forest and Biodiversity

- MoAF will be the main implementing agency for adaptation in the forestry and biodiversity sector.
- Relevant institutions will be mandated by MoAF to implement priority actions under the national action plan.
- A nodal agency should be identified to coordinate and monitor the implementation of adaptation activities within the agriculture and forestry sector. The nodal agency shall also link with relevant agencies/NGOs within and outside Bhutan.

Health

- Research institutes should be encouraged to conduct more research on health and climate change.
- A National Integrated Database bank to cover all aspects of climate related data should be established to facilitate health sector concerns.

Agriculture

- Institutionally, food security needs to be addressed across all sectors and not just the Ministry of Agriculture and Forest
- Increase investment on SLM technologies to combat land degradation arising due to climate change
- Increase investment on Research institutions to increase the capacity to develop climate resilient technologies
- Institute pest and disease surveillance system
- Strengthen and improve information management system.

Glaciers and GLOF

- National Environment Commission and other major stakeholders shall coordinate at the national level
- Dzongkhags and communities implement and coordinate at the local level.

4.10.2 Adaptation Priorities by Sector

Table 4.10.1: Adaptation Priorities for Water Sector and Climate Related Disasters

Objectives	Activities	Estimated Cost (m$)	Level of Activity	Time Frame	Lead Agencies	Cross-cutting sectors	Potential Barriers	Policy/Actions to reduce barriers
Conduct comprehensive water resources assessment to improve understanding of water resource availability, the effects of climate change to develop appropriate adaptation measures	Survey, mapping and assessment of quality and quantity of water sources for various uses along with analysis of hydro-meteorological patterns	10	National	Short	NEC in collaboration with other agencies	Hydro-met, Watershed Management	Finance and Manpower (number and quality/ climatologist/analysts)	Proper Coordination,
	Study Climate Trends in Bhutan through analysis of observed meteorological data, ground verification and case studies		National	Short	Dept of Hydromet Services	NEC, Watershed Management, Research Institutes	Finance, capacity	Installation of state of art weather observation stations; and analysis and use of past data
	Analysis of glacial and seasonal snow covers to assess the contribution of snow melt to water flow of Bhutanese rivers		National	Short	Ministry of Economic Affairs (Geology and Mines, Hydro-met & Energy)	Hydro-met, Geology and Mines and Disaster Management	Finance, accessibility and climate, no communication, lack of equipment and qualified staff	Installation of weather stations in high altitude and Glacier mass balance monitoring and study in Bhutan
Increase resilience to the impacts of climate change on water resources	Vulnerability assessment of Climate Change on Water Resources through hydrologic modeling and analysis	35	Local and regional	Short	NEC	Hydro-met, Health, Agri, Geology and Mines	Lack of capacity, Good quality long time series hydro-meteorological data and other such and soil data, lad use data and DEM etc.	Use of ongoing climate modeling PRECIS and other relevant hydrological models such as HBV and other

Objectives	**Activities**	**Estimated Cost (m$)**	**Level of Activity**	**Time Frame**	**Lead Agencies**	**Cross-cutting sectors**	**Potential Barriers**	**Policy/Actions to reduce barriers**
	Installation of GLOF technical early warning systems with associated awareness-raising		National/ basin level	Short	Dept of Hydro-met Services	Geology and Mines and Disaster Management	Finance and lack of in house technical capacity, No. reliable communication system	Use the experience of ongoing GLOF EWS set up in Puntsangchhu basin (Phochhu) and Regional experience
	Build impoundments to store water for use during lean season (multi-purpose)		National	Medium – Long term	Ministry of Works & Human Settlements, Ministry of Agriculture	Health, NEC, Energy	Finance and Terrain	Global/Regional experience
	Implement proper land use planning in watershed areas, reforestation in degraded areas, protection of wetlands, spread of greenbelt and implement policy measures to help conserve watersheds.		National	Long term	Dept of Forest and Park Services	Agri, Energy, Forests, Works & Human Settlement	Urbanization, migration, logging and Finance	The protection of water sources and catchment areas as accorded in all environmental legislations
	Study vulnerability of landslides and flood prone areas and implement prioritized projects focusing on roads and agriculture land		National	Short - Long term	Dept of Geology and Mines	Geology and Mines, Agri, Roads, transport Authority, Hydro-met	Lack of information, Finance	Road Act, EFRC guidelines, technical competency, EA Act 2000
Water Resources Management through adoption and implementation of	Improvement of irrigation systems (lining, better maintenance) to reduce water loss & promote water use efficient irrigation technologies for ensuring water availability for farming	20	National	Short - Long term	Dept of Agriculture	Agriculture	Finance, Awareness	Regional experiences

Objectives	Activities	Estimated Cost (m$)	Level of Activity	Time Frame	Lead Agencies	Cross-cutting sectors	Potential Barriers	Policy/Actions to reduce barriers
IWRM and eco-efficiency by using river basin framework for planning	Rainwater Harvesting to supplement water supply schemes in both rural and urban areas for domestic water use		National	Short - Long term	Ministry of Works and Human Settlements, Ministry of Health	Agriculture and NEC	Awareness, Policy	Regional experiences
	Water Demand Management through use of Water Safety Planning tool, eco-efficient fixtures, eco- sanitation, reducing losses, metering and water reuse.		National	Short - Long term	Ministry of Works and Human Settlements, Ministry of Health	All	Awareness, monitoring, Finance and no/low tariff	NEPA, Tax incentives
Strengthening Climate observation and network for early warning and forecasting of extreme events understanding climate change	Extension of meteorological stations in the northern highlands with snow gauging and necessary analysis	5	National	Short	Department of Hydro-met Services	NEC, geology and mines. Agri and forest depts,	Finance and Manpower (number and quality) Limited or not access to communication	
	Establishment of Early Warning Systems and up-gradation of the weather forecasting center for better forecasting and information dissemination		National	Short	Department of Hydro-met Services	NEC, geology and mines. Agri and forest depts,	Finance and Manpower (number and quality) No access to upper air observation data, global and regional NWP products, Non availability of suitable weather forecasting	Establish WMO GTS connection to Bhutan, Establish dense network of Automatic Weather Stations with real time communication .

Objectives	Activities	Estimated Cost (m$)	Level of Activity	Time Frame	Lead Agencies	Cross-cutting sectors	Potential Barriers	Policy/Actions to reduce barriers
							model for mountainous country , No real time data hydro-meteorological network	
Mainstream CC & WR into national plans and programmes	Review/revisit existing tools & guidelines to address water and CC in national and local development plans &programmes	5	National and local	Short term	NEC	GNHC and Local Governance	Lack of capacity across the sectors in mainstreaming CC into plans	Whole-of-government capacity building on CC mainstreaming on-going. CC mainstreaming guideline both at policy and plan levels available.
	Strengthen local capacity & community engagement in incorporating & implementing water and CC adaptation activities		National and local	Short - Long term	Dept of Local Governance, GNHC	NEC, GNHC	None	Capacity dev. need assessment for local governments in terms of environment and climate change available
	Integrate existing & emerging knowledge on water and CC into water management plans & development programs to ensure climate proofing		National	Short - Long term	NEC	Whole government	Uncoordinated	Water Act, NEPA

Table 4.10.2: Adaptation Priorities for Agriculture Sector

Objectives	Activities	Estimated Cost (m$)	Lead Agencies	Level of Activity	Time Frame	Cross Cutting	Potential barriers	Actions to reduce barriers
To identify and map highly vulnerable farming communities across the country	Secure high resolution maps to identify sites Consult and map sites in consultation with dzongkhag administration Produce maps with clear identification of vulnerable communities	2.000	DoA	National/Regional	2012 – 2017	Disaster	Finance	Mobilise fund
To strengthen institutional capacity of research/extension of DOA and DYT/GYT of Dzongkhag administrations	Train researchers and extension staff through seminars/workshops on climate change impacts on the agriculture sector. Focus training to selected researchers and Dzongkhag agriculture staff on short courses on adaptation measures in agriculture Educate and create awareness on building resilience to climate change for the local leaders and farmers	1.500	DoA/MoAF	National/Regional/Local	2012 – 1017	Disaster	Finance	Mobilise fund
To increase access to improved genetic resources resistant to a-biotic and biotic stresses.	Evaluate, screen, demonstrate and promote crop and fodders varieties resistant to drought and diseases in research centres	2.500	DoA/DoL	Rgional/Local	2012 – 2017	Biodiversity	Technology Genetic materials	Exchange of technology Exchange of genetic materials

Objectives	Activities	Estimated Cost (m$)	Lead Agencies	Level of Activity	Time Frame	Cross Cutting	Potential barriers	Actions to reduce barriers
	and to the farming communities						Finance	Mobilise fund
To identify and promote potential crops for agriculture/farming diversification to reduce crop failures	Promote and increase production of minor cereals (buckwheat, millets, barley etc) through awareness and value addition Introduce maize/oat second crops for feed and fodder development Promote highly nutritious vegetables in remote and vulnerable communities	1.500	DoA/DoL	Regional/Loca	2012 – 2017	Biodiversity	Lack of awareness Lack of technology (agro-processing) Financial resources	Create awareness amongst the communities on minor cereals Secure technology for value addition and processing Mobilize fund
Increase access to improved irrigation systems	Improve existing irrigation channels to reduce water losses Explore alternative irrigation technologies like drip, sprinkle Introduced water harvest technologies to make water available for off-season vegetables	3.000	DoA/DoE	Local	2012 – 2017	Water	Technology Institutional Capacity finance	Secure technology Strengthen institutional capacity Mobiles fund
Improve postharvest facilities to increase shelf life of food products	Improve existing grain storage facilities Construct cold storage facilities to store highly perishable agriculture	1.000	DoA/FCB	Regional/Local	2012 – 2017	Disaster	Fund	Mobilize fund

Objectives	Activities	Estimated Cost (m$)	Lead Agencies	Level of Activity	Time Frame	Cross Cutting	Potential barriers	Actions to reduce barriers
	produce Introduce zero-energy storage facilities at community level for seed storage							
Improve information management system of the sector	Develop/institutionalize pest and disease surveillance in different agro-ecological for crops and animals Improve collection and synthesis of agro-metrological data Predict/forest weekly rainfall pattern with department metrological for agro-climatic Increase access to IT among extension staff of remote areas.	3.000	DoA/DoE	National/Regional/Local	2012 – 2017	Disaster	Technology Finance	Secure technology (IT infrastructure) Fund

Table 4.10.3: Adaptation Priorities for Energy Sector

Objectives	Activities	Estimated Cost	Level of Activity	Time Frame	Lead Agencies	Cross Cutting Sectors	Potential Barriers
Measures to ensure energy security during lean season (due to projected shortfall of hydropower production in winter as a result of climate change)	Hydropower (Immediate actions) Feasibility studies and DPR for development of Storage, small and medium Hydro power plants	Not estimated	National	Short term	Ministry of Economic Affairs	Water, Agriculture, Forestry	Financial Constraint
	Hydropower (Medium Term Actions) Pre- Construction of Storage, small and medium Hydro power plants	Not estimated	National	Medium Term	Ministry of Economic Affairs	Water , Agriculture, Forestry	Financial Constraint
	Hydropower (Long Term Actions) Construction and Commissioning of Storage, small and medium Hydro power plants	Not estimated	National	Long Term	Ministry of Economic Affairs	Water, Agriculture, Forestry, Concerned Communities	Financial Constraint
Diversify the energy supply mix to reduce dependence on hydropower which is threatened by climate change	Renewable energy Development (Short Term Actions) (Solar, Wind, Biogas, Biomass, etc.): Capacity Building, Rules and Regulations for RE Development, Establishment of RE Lab for research, testing and certification , RE Resource Assessment, Master Plan development, Awareness Campaigns	Not estimated	National	Short term	Department of Renewable Energy, MoAF (Biogas/ biomass)	Livestock, Agriculture, Ministry of Finance, Forestry, Business Sector	Financial constraint, Lack of Technical, Competency, Insufficient attractive incentives (financing,etc), Limited Market
	Renewable energy Development (Medium Term Actions) (Solar, Wind, Biogas, Biomass, etc.): Pilot Project, Awareness Programs, Testing and Certification	Not estimated	National	Medium Term	Department of Renewable Energy, MoAF (Biogas/ biomass)	Livestock, Agriculture, Ministry of Finance, Forestry, Business Sector	Capital Intensive, Lack of appropriate technology
	Renewable energy Development (long term actions): (Solar, Wind, Biogas, Biomass, etc.): - Mega Solar PV Project for Grid integration. - Integration of Wind, Solar, small/micro Hydro and Biomass systems. -Advanced Renewable Energy Research and Development (Bio-hydrogen, etc.). - Institutions and Policies for competitive biomass energy programmes. - Work for multiple biomass generation products (gas, liquid, electricity).	Not estimated	National	Long Term	Department of Renewable Energy Ministry of Agriculture & Forests (Biogas/biomass)	Livestock, Agriculture Ministry of Finance, Forestry, Business Sector	Need for clear cut policies, regulations and incentives

Objectives	Activities	Estimated Cost	Level of Activity	Time Frame	Lead Agencies	Cross Cutting Sectors	Potential Barriers
Measures to address demand side management especially for projectected lean season power shortfall under climate change	Energy Efficiency (immediate to short term actions): - Awareness and Institutional Capacity building - Feasibility studies, Review and formulation of labeling and standardization of energy efficient appliances - Policy formulation, rules and regulations, subsidies etc for energy efficiency measures -Development of Building codes Development/certification of energy efficient standards and codes for industries - Energy Auditing of existing energy intensive industries	Not estimated	National	Short term	Ministry of Economic Affairs in collaboration with Ministry of Works & Human Settlement	Construction Industry, Industrial Sector, Transport Sector, - Residential sector, Agriculture, Commercial sector	Lack of technology and technical capacity, Lack of integration between different sectors, Lack of attractive incentives
	Energy Efficiency (Medium Term Action): Design of Energy efficient buildings - Pilot/Demonstration Projects(Energy efficient building, Improved Cook Stoves, efficient lighting systems etc) - Adoption and implementation of energy efficient labeling and appliance standards - Implementation of Demand side management - Promotion of energy efficient equipment and technologies in industrial sector	Not estimated	National	Medium Term	Ministry of Economic Affairs in collaboration with Ministry of Works & Human Settlement	Construction Industry, Industrial Sector, Transport Sector, Residential sector, Agriculture, Commercial sector	Lack of technology and technical capacity, Lack of integration between different sectors, Lack of attractive incentives
	Energy Efficiency (Long Term Actions): Design of Energy efficient buildings Stoves, efficient lighting systems etc) - Scaling up of energy efficient project activities - Adoption and implementation of energy efficient labeling and appliance standards	Not estimated	National	Long Term	Ministry of Economic Affairs in collaboration with Ministry of Works & Human Settlement	Construction Industry, Industrial Sector, Transport Sector, Residential sector, Agriculture, Commercial sector	

Table 4.10.4: Adaptation Priorities for Forest and Biodiversity Sector

Objectives	Adaptation Options	Lead agency	Estimated cost ($)	Level of activity (Vulnerable Ecological Systems)	Period
Conduct comprehensive assessment to adequately monitor and understand the impacts of CC on the flora & fauna and ecosystems in Bhutan	Standardization of Forest Type, Classification & Ecological Zones	DoFPs, DoL, NBC, UWICE, RCs, NGOs	100,000	All forest types, Biological Corridor and Thematic Areas	Medium Term
	Assess and Monitor Spatial Distribution of CC Vulnerable Species	DoFPs, DoL, NBC, UWICE, RCs, NGOs	300,000	All forest types, Biological Corridor and Thematic Areas	Short Term
	Guidelines/protocols for smart green infrastructure development within PAS in place.	PPD-MoAF, DoFPs, NEC, GNHC, MoWHs	100,000	All forest types, Biological Corridor and Thematic Areas	Short Term
Increase ecosystem resilience against climate change disruption through re-evaluation and strengthening of protected areas, and sustainable management of biodiversity use	Protected Areas & Biological Corridors reviewed for functionality and efficacy.	DoFPs	100,000	All	Medium Term
	Protected areas and biological corridors fully operationalized.	DoFPs	4,000,000	All	Medium Term
	Valuation of key ecosystem services conducted	DoFPs, DoL, NEC, NGOs	100,000	All	Short Term
	Revised forest management planning guidelines and codes of practice inclusive of biodiversity, ecosystem services and changing climate in place	DoFPs, PPD, GNHC, NBC	50,000	All	Short Term
	Percent of forest cover under community/private/agro-forestry/plantation programs increased.	DoFPs, DoA	20,0000	All	Medium Term
	Chainsaw users, saw millers and loggers trained and certified in improved timber harvesting and processing methods and techniques.	DoFPs, NRDCL	50,000	All	Short Term
	Environmentally friendly wood/timber treatment plants established.	DoFPS, NRDCL, WBI	1,000,000	All	Short Term
	Post harvest facilities for prioritized NWFPs established.	DoFPs, DoA	600,000	All	
	Natural products developed from NWFP's to improve rural incomes and reduce vulnerability	DoFPs, DoA, NGO, NBC, DAMC	200,000	All	Medium term
Address risk of species loss	Habitat for prioritized species (e.g: tiger, snow leopard, white	DoFPs, DoL, NGOs,	4,000,000	All	Long Term

Objectives	Adaptation Options	Lead agency	Estimated cost ($)	Level of activity (Vulnerable Ecological Systems)	Period
from climate change by strengthening species conservation and management program by taking into consideration climate change.	bellied heron, Rufous-necked hornbill, Golden Mahseer, Snow Trout, etc) conserved and viable population maintained.	NBC			
Measures to address increased threat from invasive species due to a changing climate on natural and agro-ecological systems	Management strategies for invasive species in place.	NBC, BAFRA, DoFPS, DoL, DoA	100,000	SubTropical& Temperate	Medium Term
	Regulatory guidelines and protocols for entry and introduction of alien species in place.	NBC, BAFRA, DoFPs, PPD, DoL, DoA	60,000	SubTropical& Temperate	Medium Term
Develop and implement a comprehensive forest fire management program, taking into account drier and warmer winters.	Fire ecology research under different ecosystems /tree species that are fast growing and more resistant to fire damages conducted	DoFPS, CoRRB, RDCs	300,000	Temperate & Alpine	Medium to Long Term
	Fire volunteer groups trained and strengthened.	DoFPs	100,000	Temperate & Alpine	Short Term
	National fire management strategy developed and program strengthened.	DoFPs, PPD	300,000	Temperate & Alpine	Short Term
	Fire hydrants established.	DoFPs	600,000	Temperate & Alpine	Medium Term
	Post forest fire rehabilitation program in place	DoFPs	150,000	Temperate & Alpine	Medium Term
Conserve agro-biodiversity to promote adaptation of crops and livestock to changing climatic conditions.	Genetic diversity of major crops and livestock breeds assessed.	NBC, DoA, DoL, CoRRB, RDCs	200,000	All	Medium Term
	Habitats of wild crop relatives and important agriculture landscapes conserved.	NBC, DoFPs, CoRRB, RDCs, DoA	100,000	All	Medium Term
	Important traditional crop varieties and livestock breeds conserved *in-situ*.	NBC, CoRRB, RDCs, DoA, DoL	1,000,000	All	Medium Term
	Community seed banks established in selected areas.	NBC, DoA,RDCs	75,000	All	Medium Term
To control and manage increased incidences of pests and diseases under changing	Management strategies for prioritized pests and diseases in place.	DoFPs, NBC, CoRRB, RDCs, DoA, DoL	150,000	All	Medium Term

Objectives	Adaptation Options	Lead agency	Estimated cost ($)	Level of activity (Vulnerable Ecological Systems)	Period
climate					
Measures to ensure sustainable use and management of biodiversity by local communities by taking into account threats from changing climate.	Local communities trained in genetic diversity management and sustainable use of NWFPs.	NBC, DAMC, CoRRB, RDCs, DoA, DoL	300,000	All	Short term
	Local perspective and traditional knowledge on climate change assessed and incorporated into adaptation plans.	NBC, DoA,DoL	50,000	All	Medium Term
	Crop and livestock insurance scheme established and Wildlife Endowment Fund Strengthened	DoFPs, DoL, DoA, LG	1,400,000	All	Long Term
	Community based nature tourism strengthened.	DoFPs, TCB, ABTO, DoL	300,000	All	Medium Term
Develop sustainable local conservation financing mechanisms to reduce vulnerability and build adaptive of ecosystems and habitats.	Core fund of BTFEC strengthened for Biodiversity and climate change with a dedicated window for climate change. *(All donor funds for climate change channeled into BTFEC climate change funding window)*	NEC, BTFEC, MoAF,GNHC		All	Short term
	National REDD+ strategy plan developed and implemented.	MoAF, DoFPS(lead)	1000,000	All	Medium Term
	PES up-scaled and institutionalized	NEC, DoF, NBC, DoL, DoA, CoRRB, RDCs	100,000	All	Medium Term
	Access and Benefit sharing fund strengthened through successful collaborations in bioprospecting.	NBC	100,000	All	Medium Term
Strengthen adaptive capacity of relevant stakeholders in forest and biodiversity sector	National pest and disease laboratories strengthened.	DoA, DoFPs, DoL, CoRRB, BAFRA	200,000	All	Medium Term
	Cryopreservation and molecular characterization facilities strengthened	NBC	300,000	All	Medium Term
	National Bioprospecting laboratory upgraded	NBC	200,000	All	Medium Term
	Meteorological stations along different eco-floristic zones established.	DoFPs	200,000	All	Short Term
	Strengthen National Carbon and Biomass Assessment Process	NEC, DoFPs	500,000	All	Medium Term
	National technical capacity on biodiversity and Climate Change strengthened in the following fields: remote sensing, GIS, climatology, taxonomy, forestry statistics, pest and diseases surveillance, identification and management, genetic resources	ALL	1,000,000	All	Medium Term

Objectives	Adaptation Options	Lead agency	Estimated cost ($)	Level of activity (Vulnerable Ecological Systems)	Period
	conservation, etc.)				
To enhance public understanding and awareness on biodiversity and climate change	Educational materials on biodiversity and climate change developed.	NEC, DoFPs, NBC,CoRRB, DoE	50,000	All	Short Term
	Mass education and awareness programs at all levels conducted.	NEC, DoFPs, NBC,CoRRB, DoE	200,000	All	Short Term
	Biodiversity and climate change information integrated into biodiversity portal.	NBC, ICS	100,000	All	Short Term
Strengthen existing institutional arrangements for biodiversity conservation to effectively address climate change issues.	Institutional mandates and functions reviewed and realigned Annual coordination meetings instituted Coordination institute identified Biennium reports on the implementation of the action plans	GNHC,MoAF,NEC	85,000	All	Short Term
	Biodiversity and climate change included in school and university curricula.	NEC, DoFPs, DoA, DoL, NBC, MoE, UWICE, RUB	50,000	All	Medium Term
Mainstream climate change into relevant policies, plans and processes for biodiversity conservation and utlisation.	Biodiversity and CC factored in policy/ policy scanning tools/planning guidelines.	MoAF, NEC, GNHC	50,000	All	Short - Medium Term
	Climate change policy developed	Coordinated by NEC	100,000	All	Short - Medium Term
	Biodiversity and CC incorporated into national and local development plans, and EIA	MoAF, NEC, GNHC	200,000	All	Short - Medium Term

BAFRA= Bhutan Agriculture and Food Regulatory Authority (MOAF), CORRB= Council for RNR Research of Bhutan (MOAF), DOA= Dept of Agriculture (MOAF), DAMC = Dept of Agriculture Marketing and Cooperatives (MOAF), DOE= Dept of Education (MOE), DOFPS = Dept of Forest and Park Services (MOAF), DOL= Dept of Livestock (MOAF), GNHC = Gross National Happiness Commission, ICS= Information and Communication Services (MOAF), MOAF= Ministry of Agriculture and Forests, MOEA= Ministry of Economic Affairs, MOE= Ministry of Education, MOWHS = Ministry of Works and Human Settlements, NBC= National Biodiversity Center(MOAF), NEC= National Environment Commission, NGOs = Non Governmental Organisations, NRDCL = Natural Resources Development Corporation (MOAF), PPD= Policy and Planning Division (MOAF), RDC= Research and Development Centers (MOAF), RUB= Royal University of Bhutan, UWICE= Ugyen Wangchuck Institute for Conservation and Environment (MOAF), WBI = Wood Based Industries,

Table 4.10.5: Adaptation Priorities for Health Sector

Objectives	Activities	Estimated Cost	Lead Agencies	Level	Time frame	Cross-Cutting	Potential Barriers	Actions to remove barriers
Ensure safe drinking water to reduce water borne diseases.	Increase number of/Protect existing water sources (for RWS) and water treatment plants.	Not Estimated	Ministry of Health (PHED), Municipalities,MoWHS	Local but nation wide	Short Medium and Long Term	Water & Forest	Land access problem, may not get suitable plot to set up water treatment plant.	Local Area Plans should have adequate provision for WTP (NLC, MoWHS, Local Governments)
	Monitor safe drinking water	Not estimated	MOH (PHL, PHED)	Local but nation wide	Short, medium and long	Water	Technical capacity Resources and barriers.	Build capacity
Ensure adequate drinking during the dry period	Adopt Rainwater harvesting system and water pumping technologies. Explore other alternative technologies.	Not Estimated	Ministry of Health (PHED), Municipalities.	Local but nation wide	Short Medium and Long Term	Water & Forest	Resources	Capacity building
Control and reduce the vector borne diseases	Control of vector growth (Stagnant water control measures and sanitation improvements)	Not Estimated	Ministry of Health	Local/ Regional but nation wide	Short Medium and Long Term	Water Agriculture	Geographical area constraints Human resource constraints	Monitoring
	Regular cleaning and awareness on reduction of breeding sites where mosquito vector is abundant	Not Estimated	Ministry of Health (VDCP, Env Health), Local Govt. (village health worker), Media.	Local but nation wide	Short Medium and Long Term	City Corporation	Low response (turn up may be poor due to ignorance, time, interest) Geographical area constraints	Incentives (eg. Basic tools/equipments) to increase the participants for awareness program. Monitoring &supervision
Disaster management Preparedness	Strengtheningthe existing Emergency Medical Services - Effective implementation of Health Sector contingency plan.	Not Estimated	Emergency Medical Services, Dept. of Medical Services, MoH Dept of Disaster Management,	Local/ regional	Short Medium and Long Term		Lack of coordination, Resource and technical constraint	-Identify clear roles/responsibilities, -Awareness Professional training

Objectives	Activities	Estimated Cost	Lead Agencies	Level	Time frame	Cross-Cutting	Potential Barriers	Actions to remove barriers
			Local communities, Armed Force					
To educate and enhance the level of awareness to cope with health risks by being better prepared	Strengthen awareness of climate relevance to health amongst national policy makers/general population	Not Estimated	Ministry of Health, National Environment Commission	National	Short Medium and Long Term	Media, Education	Low response	-Increase awareness programs to target policy makers, general population and education sector.
Strengthening the surveillance, research, monitoring, review and supervisory system and feedback for climate related diseases.	Set up and develop comprehensive early warning system and response system for vector borne disease.	Not Estimated	Ministry of Health & (Env. Health/VBDCP) Dept of Hydromet Services	Local/ regional	Short Medium and Long Term	Water	Technical knowledge Technology Lack of Coordination	-Capacity building, -Improve coordination between stakeholders.
	Establish epidemiological information on Climate Sensitive Diseases (CSD) to detect diseases trends overtime and evaluate current strategy.	Not Estimated	Ministry of Health (Env. Health/VBDCP, Research unit) Dept of Hydromet Services	Local but nationwide	Short Medium and Long Term		Inadequate data collection & reporting	Assess the existing national surveillance and response -Monitor and supervise
Build and improve program and research capacity to monitor and study climate change impacts on human health	Build capacity to effectively manage and evaluate future activities for health outcomes of climate change.	Not Estimated	Ministry of Health	National	Medium	Water, Disaster Management	Lack of resources/fund.	Mobilize fund and build capacity.
Reduce nutritional effects due to climate change	Establish link between climate change and nutritional effects.	Not estimated	MoH (Nutrition Program, Env. Health & Research)	Local but national	Long term	Agriculture	Lack of data, Lack of expertise to interpret and establish link	-Capacity building -Improve coordination
	Community based training on prevention and management of malnutrition and food safety.				Medium term			

Table 4.10.6: Adaptation Priorities for Glaciers and GLOF

Objective s	Activities	Estimated Cost (m$)	Lead Agencies	Level	Time frame	Cross-Cutting	Potential Barriers	Actions to reduce barriers
Enhancing preparedness and understanding for GLOFs triggered by Climate Change	Study of other dangerous lakes at the headwaters of Amo Chhu, Kuri-Gongri Chhu, Mangdi Chhu, Kholong Chhu, Mangdechu	Not estimated	Dept of Geology and Mines	Local to national	Short term	Research Water coordination	Technology Finance Physical Knowledge Capacity	Further collaborative efforts among the sectors concerned towards implementing the adaptive measures. Crop and livestock insurance schemes National Forestry Management Policy SLMP Water Act National Disaster Management Act- to facilitate smooth implementation.
	Initiate the Glacier Mass Balance monitoring and research study in Bhutan	Not estimated	Dept of Geology and Mines	Local to national	Short – Long term	Research		
	Establish more automatic weather stations (AWS) in high altitude including snow measurements as there is no data from high altitude	Not estimated	Department of Hydromet Services,	Local to national	Short term	Meteorology & Climate Observation		
	Detailed monitoring of Glacial lakes.	Not estimated	Dept of Geology and Mines	Local to national	Medium – long term	Disaster Management		
	Hazard zonation maps and demarcation. Creation of awareness on GLOFs	Not estimated	Dept of Geology and Mines, Dept of Disaster Management, Relevant Districts	Local to national	Short term	Disaster Management, Education, Media		
Implementation of risk reduction measures in potentially dangerous glacial lakes	Measures to reduce risk of GLOF from 25 other dangerous lakes (lowering, siphoning, storage, barriers etc).	Not estimated	Dept of Geology and Mines	Local to national		Lessons from Thorthormi,an d other countries		
	Installation of early warning system for all affected downstream valleys and disaster preparedness	Not estimated	Department of Hydromet Services, Dept of Disaster Management	Local to national		Disasater Media, District Groups		
	Construction of protection wall along the river banks to protect the existing settlements and community infrastructure	Not estimated	MOWHS, DDM, Others	Local to national		Water, Forests, Communities		

Chapter Five

Other Information

5.1 Climate Change Awareness

A study was undertaken to access the level of climate change awareness of the policy makers and other stakeholders and to provide necessary recommendations for the policy makers related to planning and climate change. In this process, many policy documents and reports related to completed and ongoing climate change activities were reviewed. The full report of this study is published separately[5]. Most of the reports reviewed highlighted the need for climate change awareness and capacity building. The NAPA and the actions identified for mitigation (chapter 3) and adaptation (Chapter 4) also identify several needs for increasing awareness and capacity building.

A survey was also conducted as part of the study to assess the awareness of the various stakeholders, at the institutional and policy making levels (See full report for details). The key findings were as follows:

- The majority of the policy makers are aware of climate change issues. A majority (94.6 % of respondents) agreed that climate change was important and must be considered while developing any kind of plans and policies. They also felt that they should be accountable for any plans and policies executed under their leadership if there were any resulting negative environmental impacts contributing to climate change.

- The survey showed that all the respondents have heard of 'climate change' before the interview. Similarly, all respondents believe that the climate change is a reality (with 70.9% strongly agreeing). The respondents felt that climate change is affecting the lives of Bhutanese people and they don't believe that climate change is a natural phenomenon.

- The Bhutanese planners and policy makers are aware about climate change. They believe that climate change has impacts on people's health and feel that Bhutan must have climate change adaptation programmes.

- Respondents suggested the need of awareness programmes on climate change in schools, institutes, and public. 92.7% agreed on the need for awareness programmes, 94.5% agreed that Bhutan should initiate adaptation programmes, and 85.4% disagreed that 'climate change has no impacts on health', meaning they know that it has impacts on human health.

- 81.8 % of the respondents disagree with the statement, 'climate change will not have any effects on our developmental projects/ activities' and that adopt proper plans and policies should be adopted to minimize the impacts.

- The respondents have greater concerns regarding future effects of climate change in Bhutan. A majority of 70.9% of the respondents was of the view that it was important to worry and think about future climate change impacts. The majority of respondents rated 'glacial lake outburst flood' as the possible future impact of climate change.

The study summarized that currently, planners and policy makers of Bhutan are aware of what climate change means in general. Almost all the respondents have an idea and basic knowledge of what climate change is indicating that the numerous awareness activities in the country and media have helped create climate change awareness. They were able to broadly identify the main causes of climate change, the possible future impacts on Bhutan, and what they should do to minimize its impacts. They are also aware of the impacts of developmental activities and projects.

However, while planners and policy makers are aware about climate change issues in general there seems to be a lack of in-depth technical knowledge on climate change. This can be attributed to the lack of research and information

5 The full report including review of reports of other projects and assessments and the survey on awareness on climate change in Bhutan is available online at www.nec.gov.bt/snc/

regarding climate change in Bhutan till recently. The lack of funds and technological resources for a small developing country like Bhutan is another problem since it limits the extent of research carried out in climate change. However, there are few people like environmental officers and planners in the technical divisions of government ministries and agencies who have technical capacity about climate change issues. However, lack of technical capacity or in-depth knowledge in dealing with climate change and its effects can act as barriers to actually develop appropriate adaptation programmes and implementing them.

5.2 Education and Capacity Building for Climate Change

A report commissioned by the NEC for the Joint Support Program on Capacity Development for Mainstreaming Environment, Climate Change and Poverty Concerns in Policies, Plans and Programs (JSP, 2011) assessed the existing capacity situation and various proposed capacity development actions for strengthening capacity for in-country training in the area of Environment Climate and Poverty (ECP) mainstreaming. The assessment covered eleven institutes, namely the College of Natural Resources, College of Science and Technology, Gaeddu College of Business Studies, Institute for Management studies, Paro College of Education, Royal Institute of Management, Royal Thimphu College, Sherubtse College, Ugyen Wangchuck Institute for Conservation and Environment, Jigme Namgyal Polytechnic and Samtse College of Education.

The assessment found that institutional capacities exist in the form of favorable programmatic structures of the environmental institutes to infuse ECP mainstreaming training, good institutional partnerships with international institutes, existence of courses and modules that offer substantial scope to embed ECP mainstreaming elements, very good training infrastructure and facilities, and good location of the institutes in relation to their training/ educational programs.

However, systemic capacity constraints include market uncertainties for training courses customized for ECP mainstreaming especially if similar courses are offered by a number of institutes, lack of recognition of short training courses in career advancement, and lack of mechanism for coordination between in-country training institutes. Capacity constraints at the institutional level include inadequate coverage and focus on ECP mainstreaming in existing curricula and modules, lack of teaching and knowledge resources for ECP mainstreaming, insufficient number of Bhutanese faculty members for teaching ECP mainstreaming, intermittent staff turnover, and lack of institutional partnerships with reputed overseas institutes in the area of ECP mainstreaming. A few institutes currently lack recognized accreditation/ certification system. At the individual level, existing faculty members have very limited specialization training in subjects related to ECP mainstreaming.

As a result of the assessment several capacity building priorities to address ECP were proposed as follow:

- Development of coordination mechanism to foster inter-institutional collaboration and synergy for training in the area of ECP mainstreaming;
- Advocacy of ECP mainstreaming in the context of the policy for GNH-infused learning;
- Review and enhancement of existing curricula/ modules to build in or enhance ECP mainstreaming elements;
- Development of new courses, such as those been envisioned by institutes such as the College of Natural Resources and College of Science and Technology, with special attention to ECP mainstreaming topics;
- Development of teaching aids/materials and knowledge for ECP mainstreaming training depending upon the design of revised/ newly developed curricula and modules;
- Development and conduct of customized

short training courses addressing specific ECP mainstreaming topics on a pilot basis with the dual objectives of providing hands-on training experience to faculty members and of developing knowledge and skills on specific ECP mainstreaming approaches and tools among certain target groups;

- Development of partnerships with overseas institutes with expertise in ECP mainstreaming;
- Development of knowledge and skills of the faculty members in the various institutes, through an in-country training workshop on ECP mainstreaming in the short-term for orientation and general understanding about the subject followed by specialization courses (short-term intensive courses and Postgraduate diploma or Masters degree courses) in the medium-term for advanced knowledge and skills in ECP mainstreaming topics.

5.3 Technology Needs Assessment

After the completion of the Initial National Communication in 2000, a Technology Needs Assessment was undertaken with top up funding from GEF/UNDP. The assessment at that time was conducted without any guidance on methodologies or adequate information, and without any follow up for implementation. The needs assessment was conducted for Agriculture, Cleaner Production in Industries and Strengthening of Meteorological Network. A new Technology Needs Assessment is currently being implemented by NEC with support from UNEP and GEF Funding. This assessment will build on the work in the second national communication, the NAPA, Carbon Neutral Strategy (expected end of 2011) and will also prepare prioritized projects for both adaptation and mitigation along with an implementation plan by June 2012.

5.4 Recommendations to improve Climate Change Actions in Bhutan

During the survey, consultations and review of reports on climate change programs and activities, several recommendations to enhance awareness, capacity building and mainstreaming of climate change in Bhutan were suggested. The key recommendations are summarized below.

a. Comprehensive climate change strategy should be developed

While several separate assessments and action plans like the SNC, NAPA, National Road Map for the Climate Summit, Technology Needs Assessment and Carbon Neutral Strategy are ready or being prepared there is a need for a comprehensive and cohesive national climate change strategy. The separate assessments mentioned now provide a sound grounding to inform the development of a national climate change strategy that targets both Adaptation and Mitigation. The strategy should also cover related actions required such as, policies and actions, incentives and measures, capacity building, research, awareness and education, technology needs etc. Such a strategy can inform policy and decision makers, implementers at national and local levels and also potential donor partners engaged in climate change activities in Bhutan.

b. Research and capacity development on climate change

NEC can coordinate support for research and capacity development, with all relevant institutions including developing capacity of technical staff and awareness at the local government level as well as the tertiary education and civil society. Research proposals and small studies on climate change in Bhutan should be funded. Technical staff and decision makers in the most relevant line ministries, commissions and governing bodies can be trained further. The networking of educational institutes should be promoted, especially the higher education sector, to share research and data related to climate change and its impacts.

c. Better coordination among stakeholders and donors

A drawback is the weak coordination and linkages amongst stakeholders within the country as well as within the donor agencies. In the area of climate change, NEC could take a lead role for donor coordination, in cooperation with the GNHC. This would be in-line with the recommendations of the "2005 Good Governance Plus" exercise to establish inter-agency coordination mechanisms to minimise duplications. While the MSTCCC has been established for this purpose, support is needed to increase capacity to better understand climate change and mainstreaming issues for effective coordination.

d. Mainstreaming Climate Change

Climate Change mainstreaming should be promoted in development plans and policies at all levels. This is important to ensure that development activities are implemented keeping in mind potential impacts of climate change or potential impact on the national policy to remain carbon neutral. Such mainstreaming efforts should be no-regret options that provide local benefits and additional costs should be supported by climate change financing. However, greater support for understanding mainstreaming of climate change, along with other issues of environment, poverty and gender needs to be provided through capacity building and demonstration projects.

e. Climate Financing Options

It is a given that actions to address climate change will require additional financing on top of regular development activities that are already being pursued. It is recommended that options of securing climate change finance from the various emerging funding sources be explored. The financing options and strategy should be aligned with a national climate change strategy and the comparative advantages of the sources and local needs and priorities should be considered as the emerging funds will be a mix of public and market based mechanisms, grants or loans and may be channelled through multilateral or bilateral sources.

f. Media and Awareness

The media and conservationists should educate citizens on climate change and hold policymakers accountable for policies that have a negative impact on the environment. There must be more climate change related reports and information made available to the public. Policy makers should be informed on climate change issues and be accountable for the environmental impact of any initiatives executed under their leadership, be it hydropower projects, large scale farming, or industrial development.

g. Climate Change in Education Curriculum

Climate change can be incorporated as a subject at the earliest possible. The youth of today will become the policy makers of tomorrow and need to be informed adequately about the science and issues surrounding climate change. NEC should take a lead role in creating awareness in schools. RSPN in collaboration with NEC can develop environmental education programs for the general public and school children. NEC and RSPN can develop a curriculum with the Ministry of Education to create awareness at the school level.

h. NEC should be given more authority

NEC is the apex environmental agency in Bhutan but it does not have the power or authority to override decisions made by the ministries or government as a whole. NEC should have authority to be able to ensure better implementation of all policies and to ensure that defaulters are punished.

i. More investment towards R&D in climate change

There is a need to reorient research plans and programs to seek policy and financial support to prepare for the changing local environment. There is a need to increase budget allocation, improve research facilities and equip researchers with technical know-how to address issues of food, water, and energy security and climate change and impacts on local resources like forests and biodiversity. A research fund can be created for financing long term climate change research and development.

j. Vulnerability and Adaptation of Human settlements and infrastructure

Given the changes in demography and growth in urban areas and investments in public infrastructure, it is recommended that future V&A assessments should cover human settlements, critical infrastructure and mapping of vulnerable populations and areas. This may be taken up in the third national communication or other activities. Mapping vulnerable areas and populations will help mainstream climate change by providing information to planners at different levels including local levels for making appropriate plans and programs and prioritising interventions. This exercise should build another efforts including assessment of the state of the environment reports at national and local levels, and other vulnerability mapping exercises such as the different hazard mappings under the NAPA implementation program.

Annexures

Annexures

Annex I: Climate Change Committees, Task Forces & Workshop Participants

National Climate Change Committee/National Environment Commission

H.E Jigmi Y. Thinley	Hon'ble Prime Minister, Chair
H.E Yeshey Zimba	Hon'ble Minister, Ministry of Works and Human Settlements
H.E Khandu Wangchuk	Hon'ble Minister, Ministry of Economic Affairs
H.E Dr. Pema Gyamtsho	Hon'ble Minister, Ministry of Agriculture and Forests and Minister-in-Charge, NECS
H.E. Paljor J. Dorji	Special Adviser to NEC
Dr. Ugyen Tshewang	Secretary, NECS, Member Secretary
Ugyen Tenzin	Chairman, Parliamentary Committee for Environment, National Assembly
Dr. Lam Dorji	Executive Director, Royal Society for the Protection of Nature
Dr. Pema Choephyel	Director, Bhutan Trust Fund for Environment Conservation

Multi Sectoral Technical Committee on Climate Change

Dr. Ugyen Tshewang	Secretary, NECS, Chair
Mr. Thinley Namgyel	Head, CCU/EMD, NECS, Member secretary
Mrs. Peldon Tshering	Head, Policy Coordination services, NECS
Mr. Wangchuk Namgay	Sr. Planning Officer, GNHC
Mr. Karma Dupchu	Head, Hydromet Services Division, Department of Energy, MOEA
Mr. Karma P Dorji	Executive Engineer, PCD, Department of Energy, MOEA
Mr. Sangay Dorji	Sr. Environment Officer, Department of Industry, MOEA
Ms. Pema Deki	Geologist, Department of Geology & Mines, MOEA
Mr. Chhimi Rinzin	Offtg. Chief Agriculture Officer , Department of Agriculture, MOAF
Dr. Tashi Dorji	Chief Livestock Officer, Department of Livestock, MOAF
Mr. Jamyang Phuntshok	Head, Water & Climate Section, WMD, Department of Forest, MOAF
Mr. Kado Zangpo	Chief Planning Officer, PPD, Ministry of Health
Ms. Daw Zam	Dy. Chief Environment Officer, DUDES, MOWHS
Mr. Sonam Dendup	Planning Officer, Ministry of Information & Communication
Ms. Sonam Deki	Program Officer, Department of Disaster Management, MOHCA
Mr. Kinzang	Chief International Organization Division , Ministry of Foreign Affairs
Mr. Dago Tshering	Environment Education Officer, Royal Society for the Protection of Nature
Ms. Chime P. Wangdi	General Secretary, Tarayana Foundation
Mr. Letho	General Secretary, Association of Bhutanese Industries, BCCI

National Greenhouse Gas Inventory Team

Energy

Mr. Karma Pemba	RSTA, MOIC *(Working group Leader)*
Mr. Sonam Gyeltshen	National Statistical Bureau
Mr. Karma Dupchu	Department of Energy, MoEA
Ms. Tashi Chuki Wangdi	Environment Unit, MOEA
Mr. Karma Tshewang	Dept of Energy, MoEA

Industrial Processes

Mr. Karchen Dorji	Environment Unit, MoEA
Mr. Chandra B. Chettri	BCCI
Ms. Tashi Chuki Wangdi	Environment Unit, MoEA
Ms. Deki Gyamtsho	RRCO, MoF, Paro
Ms. Choden	Dept. of Roads, MoWHS
Ms. Peldon Tshering	NEC *(Working group Leader)*
Mr. Karma L. Rapten	UNDP-Bhutan
Mr. Tshewang Dorji	NEC

Agriculture

Mr. Isaac Lepcha	NFFP, Bumthang, MoA
Ms. Sonam Deki	DMD, MoHCA
Ms. Kinley Dem	Agromet Section, CORRB, MoA
Ms. Yeshey Dema	NSSC, MoA *(Working group Leader)*

LUCF

Mr. Sonam Dhargay	National Land Commission
Mr. Karma Jigme	DoF, MoA
Mr. Krishna B. Rai	Bhutan Power Corporation
Mr. Chukey Wangchuk	BTFEC *(Working group Leader)*
Mr. Ngawang Gyeltshen	National Biodiversity Center
Mr. Langa Tshering	Tala Hydroelectric Project
Mr. Dungkar Dukpa	PPD, MoWHS

Waste

Mr. Yeshey Penjor	NEC *(Working group Leader)*
Mr. Dago Tshering	RSPN
Mr. Gyembo Dorji	Dept. of Public Health, Ministry of Health

Mr. Gyaltshen Dukpa	Thimphu City Corporation
Mr. Pema Gyelpo	Tarayana Foundation
Ms. Dawa Zangmo	CDB, MoWHS
Mr. Thinley Namgyel	NEC
Mr. Rinzin Namgay	NEC

National Vulnerability and Adaptation Task Force for SNC

Agriculture

Dr. Thinlay	Plant Protection Specialist, NPPC, MoAF
Ganesh B Chettri	Agri.specialist- DoA
Mahesh Ghimirey	Rice specialist, RDC-Bajo (Germplasm)
Tirtha Katwal	Principal Research Officer, RDC- Wengkhar
Dr. Tashi Dorji	CLO, Dept of Livestock Livestock, MoAF
Chhimi Rinzin	CAO, DoA, MoA

Glaciers & GLOF

Karma Toep	Chief Glaciologist, Department of Geology and Mines, MoEA
Tshering Wangchuk	Asst. Program Officer, Department of Disaster Management, MoHCA
Sonam Dagay	Asst. Environment Officer, Climate Change Unit NEC
Sonam Dagay	National Land Commission
Mr. Wangchuk Namgay	Sr. Planning Officer, GNHC
Mr. Letho	General Secretary, Association of Bhutanese Industries

Energy

Tashi Dorji,	Chief Engineer, Planning and Coordination Division, DoE, MoEA
Karma P. Dorji	EE, Planning and Coordination Division, DoE, MoEA
Mewang Gyeltshen	Head, Renewable Energy Division, Department of Energy, MoEA
Karma Pemba	Head, Transport Development Division, RSTA, MoIC
Tashi Pem	Dy. Executive Engineer, Dept of Energy
Thinley	Asst. manager (CDM), Druk Green Power Corporation

Forests & Biodiversity

Kinley Tshering,	CFO, Forest Resources Development Division, DoFPS, MoAF
Chado Tshering	SAARC Forestry Center
Dr. Pema Wangda	RNR-Research and Development Center-Yusipang
Dr. Lungten	Council for RNR Research of Bhutan, MoAF
Sangay Dema	National Biodiversity Center

Ugen Dorji	MAP& Spices Program, Horticulture Division, DoA, MoAF
Sherab	Ugen Wangchuck Institute for Conservation and Environment
Karma Jigme	Nature Conservation Division, DoFPS, MoAF
Dorji	Program Officer, BTFEC

Human Health

Sonam Chophel	Sr. Program Officer, Ministry of Health
Rada Dukpa	Asst. Program Officer, Ministry of Health
Dr Meenakshi Rai	Head, Community Outreach Unit, RENEW
Dago Tshering	RSPN
Sonam Lhaden Khandu	NEC

Water

G Karma Chhopel	Head, Water resources Coordination Division, NEC
Kunzang	Legal Services, NEC
Ichharam Dulal	UISD, DUDES, MoWHS
Karma Tshering	Watershed Management Division, DoFS, MoAF
Ugyen Rinzin	PHED, DoPH, MoH
Karma Tshethar	DoA, MoAF
Karma Dupchu	Hydromet Services Division, DoE, MoEA
Chukey Wangchuk	Sr. Program Officer, BTFEC

Participants for GHG Mitigation Assessment Workshop

Anne Erica Larsen, Project Analyst, UNDP, Bhutan

Bikash Tirwa, Chemist, Lhaki Cement

Chimi Zangmo, Druk Holding and Investments

Choden, Assistant Engineer, DoR, MoWHS

Chukey Wangchuk, Chief Program Officer, BTFEC

Dago Tshering, Environment Education Officer, RSPN

Daw Zam, Dy. Chief Environment Officer, MoWHS

Dr. Karma Tenzin, Country Coordinator, GEF Small Grant Program,UNDP, Bhutan

G K. Chhopel, Head, WRCD, NEC

Janchub Dema, EQS Technician , NEC

K. N. Ghimeray, Social Forestry DoFPS, MoAF,

Kamal Ghalley, USD Enterprise, Thimphu

Karchung Dukpa, Chemist, KK Steel

Karma C. Nyedrup, Environmental Analyst, NEC

Karma Dupchu, Head, HMSD, DOE, MOEA

Karma L. Rapten, Head, Energy Environment and Disaster Management Unit, UNDP, Bhutan

Kezang Yangden, Forest Officer, FRDD, DoFPS, MOAF

Kinley Dem, Forest Officer, DoFPS, MoAF

Kinzang, Chief, International Organization Division, Ministry of Foreign Affairs

Krishna B. Rai, Environment Officer, BPC

M. Ghimiray, RNR Research Center, Bajo

Matt Addison, TA, ADB, NEC

N. K. Sharma, ADB-TA Project NEC

Narayan Pradhan, General Manager, NRDCL.

Pema Gyalpo, Finance Officer, Tarayana Foundation

Phurba Lhendup, Program Officer, WWF

S R. Gurung, Focal Person, Ugyen Ferro Alloy Ltd.

Samdrup, Environment Focal Person, PCAL

Sangay Dorji, Head, Environment Unit, MoEA

Sherab Wangchuk, Asst Program Officer, MoAF

Sonam Choden, Forest Officer, WMD, DoFPS, MoAF

Sonam Dargay, Asst. Environment Officer, NEC

Sonam Dendup, Sr. Program Officer, MoIC

Sonam Dhargay, Dy. Chief ICT Officer, *NLC*

Sonam Tobgay, RSTA, MoIC

Tandi Dolma, Focal Person, Druk Iron and Steel

Tashi Wangdi, Manager, Bhutan Ferro and Alloy Ltd.

Thinley Namgyel, Head, EMD, NEC

Tshering Dorji, Statistical Officer, PPD, Ministry of Finance

Tshering Tashi, Communication Office, NEC

Tshering Zam, Department of Agriculture, MoAF

Tshewang Dorji, Environment Officer, NEC

Ugyen Dorji, Proprietor, Yangki Automobile

Yeshey Penjor, Head, ESD, NEC

Yeshi Dorji, Program Officer, BCCI

Participants for Vulnerability & Adaptation Training and Consultation Workshop

Anne E. Larsen, Project Analyst, UNDP Bhutan

Chencho G. Dorjee, Program Analyst, UNCDF, Bhutan

Chhimi Rinzin, Chief Agriculture Officer, Department of Agriculture, MoAF

Chukey Wangchuk, Chief Program Officer, BTFEC

Dago Tshering, Environment Education Officer, RSPN

Dechen Lham, EQS Technician, National Environment Commission

Thinley, Druk Green Power Corporation ,

Dorji, Program Officer, BTFEC

G. K. Chhopel, Head, Water Resource Coordination Division, NEC

Ichharam Dulal, Chief Engineer, Department of Urban Development and Engineering Service, MoWHS

Karl Schultz, Climate Change Economist, NEC/ADB Capacity Building Project, NEC

Karma Dupchu, Head, Hydromet Service Division, Department of Energy, MoEA

Karma Jigme, Forest Officer, Department of Forest and Park Services, MoAF

Karma P. Dorji, Executive Engineer, Department of Energy, MoEA

Karma Tenzin, Livestock Officer, Department of Livestock, MoAF

Karma Toeb, Chief Glaciologist, Department of Geology and Mines, MoEA

Karma Tshering, Chief HMO, Watershed Management Division, MoAF

Karma Tshethar, Executive Engineer, Department of Agriculture, MoAF

Kunzang, Legal Officer, NEC

Letho, General Secretary, Association of Bhutanese Industries

Nim Dem, Civil Engineer, Rural Electrification Division, Department of Energy, MoEA

Passang Dema, EQS Technician, NEC

Phuntsho, GIS Officer, Forest Resource Development Division, Department of Forests and Park Services, MoAF

Rada Dukpa, Asst. Program Officer, Department of Public Health, Ministry of Health

Sangay Dema, Dy. Chief Biodiversity Officer, National Biodiversity Center, MoAF

Sonam Dagay, Asst. Environment Officer, National Environment Commission

Sonam Dhargay, Dy. Chief Information Officer, National Land Commission

Sonam L. Khandu, Environment Officer, NEC

Tashi Dorji, Chief Engineer, Policy Coordination Division, Department of Energy, MoEA

Tashi Pem, Engineer, Department of Energy, MoEA

Thinley Namgyel, Head, EMD, NEC

Tshering Tashi, Communication Officer, NEC

Tshering Wangchuk, Program Officer, Department of Disaster Management, MoHCA

Tshewang Dorji, Sr. Environment Officer, NEC

Tshewang Lhamo, Program Officer, NEC

Ugyen Dorji, Sr. Horticulture Division, Horticulture Division, Department of Agriculture and Forests, MoAF

Ugyen Rinzin, Executive Engineer, Public Health Engineering Division, Ministry of Health

Yeshey Penjor, Climate Change Policy Specialist, UNDP, Bhutan

Participants for 2nd Consultation Workshop on Vulnerability and Adaptation

Chado Tshering, CEO, SFC, DOFPS, MoAF

Cheku Dukpa, General Secretary, CAB

Chhimi Dorji, Dy. Executive Engineer, HMSD, MOEA

Chhimi Dorji, Executive Engineer , HMSD, MoEA

Chukey Wangchuk, CPO, BTFEC

Dr. Tashi Dorji, Chief Livestock Officer, DoL, MoAF

Dr. Tashi Yangzom, Prog. Director, NSB, MoAF

G. Karma Chhopel, Head, WRCD, NEC

Ichharam Dulal, Specialist, DUDES, MoWHS

Jigme Nidup, Sr. Environment Officer, NEC

Jigme Zangmo, AQS Technician, NEC

Karma Jigme, Forest Officer, Wildlife Conservation Division, MoAF

Karma Pembak, Dy. Chief Transport Officer, RSTA, MoIC

Karma Tenzin, Livestock Officer, DoL, MoAF

Karma Tshering, Program Officer , NEC

Karma Tshethar, Executive Engineer , DoA, MOAF

Kinley Tshering, Chief Forest Officer , FRDD, MoAF

Krishna B. Rai, Environment Officer, BPC

Kritika Neopaney, Environment Officer , Druk Holding Investment Infra

Kunzang Choden, Sr. Research Officer , CORRB, MoAF

Kunzang, Legal Officer,NEC

Letho, General Secretary,ABI

Lobzang Dorji, Chief Environment Officer, PHPA

M B Monger, Chief Engineer , DoR, MOWHS

Mewang Gyeltshen, Chief Engineer,DOE, MoEA

Mewang Gyeltshen, Chief Engineer, DOE, MoEA

Pema Gyelpo, Finance Officer , Tarayana Foundation

Pema Thinley, Program Officer, PPD, MoAF

Pema Wangda, RDC, Yusipang

Rada Dukpa, Asst. Program Officer, MoH

Riamsara Kuyakana, UWICE

Rinchen Namgyel, Asst. Engineer, DGPC

Sangay Dorji, Sr. Environment Officer, PHPA

Sangay Dorji, Sr. Lecturer, Sherubtse College

Sanjay Gurung, Environment Focal Person, Druk Ferro and Alloy

Sonam Dagay, Asst. Environment Officer , NEC

Sonam Dendup, Sr. Program Officer, MoIC

Sonam Dhargay, Dy. Chief ICT Officer, National Land Commission

Sonam L. Khandu, Sr. Environment Officer, NEC

Tashi Pem, DY. Executive Engineer, DoE, MoEA

Tashi Wangdi, Manager, Bhutan Ferro and Alloy Ltd.

Thinley Namgyel, Head, EMD, NEC

Thinley Pelden, Asst. program Officer, DDM, MOHCA

Thinley Wangdi, UWICE

Tshering Tashi, Communication Officer, NEC

Tshering Tashi (sr), Environment Specialist, NEC

Ugyen Rinzin, Executive Engineer, Public Health Engineering Division, Ministry of Health

Ugyen Wangda, Head, Geological Survey of Bhutan, DGM, MoEA

Participants for Final Consultation of Second National Communication

Sangay Khandu, Secretary, National Land Commission

Dr, Ugyen Tshewang, Secretary, National Environment Commission

Tshewang Tandin, Director General, Department of School Education, Ministry of Education

Dr. Ugeyn Dophu, Director, Department of Public Health, Ministry of Health

Chencho Norbu, Director, Department of Agriculture, Ministry of Agriculture and Forests

Chime P. Wangdi, Secretary General, Tarayana

Dr. Tashi Dorji, Chief Livestock Officer, Department of Livestock, , Ministry of Agriculture and Forests

Karma Dupchu, Head, Hydromet Service Division, Department of Energy, Ministry of Economic Affairs

Peldon Tshering, Chief, Policy Planning Services, National Environment Commission

Thinley Namgyel, Head, Climate Change Division, National Environment Commission

Ichharam Dulal, Specialist, Department of Urban Development and Engineering Services, Ministry of Works and Human Settlement

Yeshey Penjor, Climate change Policy Specialist, UNDP, Bhutan

Thinley Namgay, Chief Engineer, Road Safety and Transport Authority, Ministry of Information and Communication

Dago Tshering, Education Officer, Royal Society for Protection of Nature

Thuji Pem, Program Officer, Tourism Council of Bhutan

M B Monger, Department of Roads, Ministry of Works and Human Settlement

Chhimi Rinzin, Department of Agriculture, Ministry of Agriculture and Forests

Karma P. Dorji, Executive Engineer, Department of Energy, Ministry of Economic Affairs

Karchen Dorji, Environment Unit, Ministry of Economic Affairs

Sonam Tashi, Offtg, Chief Progaram Officer, PPD, Ministry of Economic Affairs

Tshering Tashi, Communication Officer, National Environment Commission

Sonam Dagay, Asst. Environment Officer, National Environment Commission

Wangchu Namgay, Sr. Program Officer, Gross National Happiness Commission

Tashi Wangmo, Department of Urban Development and Engineering Services, Ministry of Works and Human Settlement

Karma Tshering, Program Officer, National Environment Commission

Samten Wangdi, Engg. Geologist, Department of Geology and Mines, Ministry of Economic Affairs

Experts and Reviewers

Climate Modeling for Bhutan using PRECIS

START-SEA Team

Dr. Annond Snidvongs, Director, START Regional Office, SEA, Bangkok

Mr. Viriya Laung Aram,START Regional Office, SEA, Bangkok

Mr. Suppakon Chinvanno, Affiliated Researcher, START Regional Office, SEA, Bangkok

Mr. Watcharapong Noimuni, Asst. Researcher, START Regional Office, SEA, Bangkok

Bhutan Team

Mr. Thinley Namgyel, Head, EMD/CCD, SNC Project Manager

Mr. Tshering Tashi, Communication Officer, EMD

Mr. Sonam Dagay, SNC Project Asst.

Ms. Dechen Wangmo, Asst. Engineer I, GIS Unit, DoE, MoEA

Ms. Wangmo, Asst. Engineer I, GIS Unit, DoE, MoEA

National Circumstances (Chapter 1)

Consultant

Nedup Tshering, Sonam Consultancy, Thimphu,

Reviewers

Tshewang Lhamo, Environment Officer, NEC

Kezang Wangmo, Intern, NEC

Sonam Lhaden Khandu, Sr. Program Officer, NEC

Thinley Namgyel, Head, EMD, NEC

Sonam Dagay, Asst. Environment Officer, NEC

Tshering Tashi, Communication Officer, NEC

Greenhouse Gas Inventory (Chapter 2)

GHG Inventory Consultant & Trainer

Bill Dougherty, SEI-US Boston, USA

Reviewers

Thinley Namgyel, Head, EMD, NEC

Sonam Dagay, Asst. Environment Officer, NEC

Rinzin Namgay, Data Manager, NEC

Jigme, Bonn, UNFCCC, Germany

Mitigation Assessment (Chapter 3)

Mitigation Consultant

Dr. Jason Yapp, Caleb Group, UK, Mitigation Consultant

Emission trends team

Thinley Namgyel, Head, EMD, NEC

Sonam Dagay, Asst. Environment Officer, NEC

Rinzin Namgay, Data Manager, NEC

Reviewers

NCSP, UNDP, New York

MSTCCC Members

Thinley Namgyel, Head, EMD, NEC

Sonam Dagay, Asst. Environment Officer, NEC

Tshering Tashi, Communication Officer, NEC

Chencho Norbu, Director, DoA, MoAF

Sonam Tashi, PPD, MoEA

Vulnerability and Adaptation (Chapter 4)

V&A Assessment Consultants

Mr. Bhawan Singh, Climate Change, International Solutions, Canada, Lead V&A Consultant

*Dr. Abderrahman El Fouladi,*Consultant (Climate, Forestry and Energy)

*Dr. Kénel Délusca,*Consultant (Water Resources and Agriculture)

*Mr. Robert Cissokho,*Consultant (Human Health)

Reviewers

V&A Task Force

Multi Sectoral Technical Committee on Climate Change

National Communication Support Program, UNDP, New York

Thinley Namgyel, Head, EMD, NEC,

Tshering Tashi, Communication Officer, NEC

Sonam Dagay, Asst. Environment Officer, NEC

Other information (Chapter 5)

Climate change awareness surveyors

Phuntsho Wangmo, RIM Trainee

Dorji Nidup, RIM Trainee

Reviewers

Thinley Namgyel, NEC

Mr. Karma Tshering, NEC

Tshering Tashi, CO NEC

Second National Communication Project Board

Dr. Ugyen Tshewang,	Secretary, NEC, Chairman
Bakhodir Burkhanov,	Dy. RR, UNDP,
Wangchuk Namgay,	Sr. PO, GNHC
Peldon Tshering,	Head, PPS, NEC
Karma Chhopel,	Head, HMSD, MoEA
Karma Dupchu,	Head, HMSD, MoEA
Karma L. Rapten,	Unit Head, EEDM, UNDP
Rinzin Dorji,	Sr. PO, MoAF
Thinley Namgyel,	SNC Project Coordinator, Member Secretary
Karma Tshering,	P.O. NEC Alternate SNC Project Coordinator

Second National Communication Project Management Team

Thinley Namgyel,	Project Manager, Second National Communication
Karma Tshering,	Alternate Project Manager and V&A Coordinator, SNC
Sonam Dagay,	Project Assistant, SNC
Kunzang Dema,	SNC Project Accountant
Tshewang Rinchen,	Administration
Tshering Tashi,	GIS and Workshop Coordinator
Sonam L. Khandu,	Project Manager, National Adaptation Program of Action

Maps

Dr. Abderrahman El Fouladi, Canada

Tshering Tashi,	Communication Officer NEC

Annex II: References

Chapter 1: National Circumstances

Ageta, Y.; Naito, N.; Nakawo, M.; Fujita, K.; Shakar, K.; Pokhrel, A.P.; Wangda, D. (2001) 'Study Project on the Recent Rapid Shrinkage of Summer Accumulation Type Glaciers in the Himalayas, 1997-1999'. In *Bull. Glacial. Research*, vol.18 pp.45-49.

Department of Agriculture 2005, Agriculture Statistics 2005 – Volume 1, Ministry of Agriculture 2005, Royal Government of Bhutan, Thimphu

Department of Agriculture 2005, Agriculture Statistics 2005 – Volume 2, Ministry of Agriculture, Royal Government of Bhutan, Thimphu

Department of Energy 2005, Bhutan – Energy Data Directory 2005, Ministry of Trade & Industry, Royal Government of Bhutan, Thimphu

Department of Roads 2011, Information on Road Network (Spread sheet provided by DoR on September 2011), Ministry of Works and Human Settlement, Royal Government of Bhutan

Gross National Happiness Commission 2011, Eleventh Round Table Meeting- Turning Vision into Reality: The Development Challenges Confronting Bhutan, GNHC, Royal Government of Bhutan, Thimphu

Karma, Ageta, Y., Naito, N., Iwata, S.&Yabuki, H. 2003, 'Glacier distribution in the Himalaya and glacier shrinkage from 1963 to 1993 in Bhutan Himalayas',*Bulletin of Glaciological Research*, v.20, p.29-40.

Ministry of Health 2007, Annual Health Bulletin 2007 – A window to Health Sector Programme – Safer Water=Safer Health, MoH, Royal Government of Bhutan, Thimphu

Ministry of Home and Cultural Affairs 2006, *National Disaster Risk Management Framework – Reducing disaster risks for a safe and happy Bhutan,* Disaster Management Division (DMD), Department of Local Governance, MoHCA, Royal Government of Bhutan, Thimphu

Ministry of Works and Human Settlement 2008, Bhutan National Urbanization Strategy (BNUS) , MoWHS, Royal Government of Bhutan, Thimphu

National Environment Commission Secretariat, September 2000, REPORT – Bhutan's National Capacity Self Assessment for Global Environmental management and Action Plan, NEC, Thimphu

National Environment Commission Secretariat 2000, Initial National Communication, NECS, Thimphu

National Environment Commission Secretariat 2008, Bhutan Environment Outlook, NECS, Thimphu

National Soil Service Center (NSSC) & Policy and Planning Division 2010, *Bhutan Land Cover Assessment (LCMP 2010)*, Ministry of Agriculture and Forest, Royal Government of Bhutan, Thimphu

National Statistics Bureau December 2005, Statistical Yearbook of Bhutan 2005, NSB, Royal Government of Bhutan, Thimphu

National Statistics Bureau December 2007, Statistical Yearbook of Bhutan 2007, NSB, Royal Government of Bhutan, Thimphu

National Statistics Bureau December 2010, Statistical Yearbook of Bhutan 2006, NSB, Royal Government of Bhutan, Thimphu

Nature Conservation Division 2002, Biodiversity Action Plan for Bhutan 2002, Ministry of Agriculture, Royal Government of Bhutan, Thimphu

Nature Conservation Division 2009, Biodiversity Action Plan for Bhutan 2009, NCD, Ministry of Agriculture, Royal Government of Bhutan, Thimphu

NTG-Energy 2011, National Thematic Group for Energy, National Road Map for Energy Security 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas-Bhutan 2011

Chapter 2: GHG Inventory

Agricultural statistics, 2000; MoA

Bhutan Energy Data Directory 2005

Bhutan Trade Statistics (1998,1999,2000)

Conference Proceedings of the National Conference on Solid Waste Management (DUDES, 2008) Ministry of Work & Human Settlement

Department of Forestry, MoA, RGoB, Annual Report – 2007.

Dhittal, D.B., Forest Resources Assessment (FRA), RGOB/FAO 2005

FAO, 1990- FRA 2000, Forest Resources of Bhutan-Country Reports.

Fertilizer data from Druk Seed Corporation, Paro Bhutan.

Industrial License Database, Ministry of Economic Affairs as of July 2008

IPCC Good Practice Guidelines for LULUCF.

K.J. Temphel & H.J.J. Beukeboom, June 2006, Community Forestry Contributes to the National and Millennium Development Goals without Compromising the Forestry Policy,

Livestock Statistics 2007

MoA, RGoB, Master Plan for Forestry Development, 30 November 1991.

MoA, RGoB. Renewable-Natural Resources (RNR) Journal 2000,

Natural Resources Development Corporation Limited, Information Booklet – 2007.

Penjor, Y., (2007). Enhancing Municipal Solid Waste Management with 3Rs Option in Thimphu, Bhutan.

POL Section, Department of Trade, Ministry of Economic Affairs

PPD, MoA, RGoB, Bhutan Land Cover Assessment 2005 – Summary.

PPD, MoA, RGoB, Land Use and Land Cover Atlas of Bhutan – 1997.

Rice in Bhutan – A Source Book, 2008, CoRRB, MoA (Pp. 19).

RNR Census 2000

RNR Census 2002

Statistical Yearbook of Bhutan 2000, CSO, Planning Commission

Survey data from individual industries

Survey of Energy Usage in Industries by Energy Working Group, GHG Inventory Task Force of the Second National Communication Project, December 2008.

Ugen P. Norbu, Report on Fuelwood consumption in Bhutan – 2000, A study for Bhutan Trust Fund for Environmental Conservation

W. Schindele, Altusried, Forest Resources Potential Assessment (FRPA) for Bhutan. RGOB/FAO March 2004

Chapter 3: Mitigation Assessment

Chettri,G.B. 2003. Climate Change Adaptation Technology Needs Assessment: Agriculture Sector.

DOE 2005, Energy Data Directory, Department of Energy,Ministry of Economic Affairs and The Energy Research Institute

DOE 2010, Integrated Energy Management Master Plan for Bhutan, Department of Energy,Ministry of Economic Affairs and The Energy Research Institute

Dhittal, D.B., Forest Resources Assessment (FRA), RGOB/FAO 2005

DOA, 2005, Field Report # 2006/01- Land Management Campaign.

DOA, 2009. Highlights from 2007 to 2008, Department of Agriculture, June 2009.

Fertilizer data from Druk Seed Corporation, Paro Bhutan.

DOL 2007, Livestock Statistics 2007, Department of Livestock, Ministry of Agriculture and Forests

MoA, RGoB, Master Plan for Forestry Development, 30 November 1991.

MoA, RGoB, Renewable-Natural Resources (RNR) Journal 2000,

Natural Resources Development Corporation Limited, Information Booklet – 2007

Nature Conservation Division 2009, Biodiversity Action Plan for Bhutan 2009, NCD, Ministry of Agriculture, Royal Government of Bhutan, Thimphu

NEC/ADB, 2011, NEC ADB TA to Build Capacity of NEC in Climate Change – Transport Mitigation Report

Norbu, C. 2008. Inorganic Fertilizer Distribution trend in Bhutan-After Privatization. In Journal of RNR Bhutan,Vol 4. No.1.

LCMP 2010, Bhutan Land Cover Assessment 2010, Land Cover Mapping Project, National Soil Services Center and Policy and Planning Division, Ministry of Agriculture and Forests,

PPD, MoA, RGoB, Bhutan Land Cover Assessment 2005 – Summary

RGOB 10thFive Year Plan Document, 2008

Rice in Bhutan – A Source Book, 2008, CoRRB, MoA

RNR Census 2000, Ministry of Agriculture and Forests, Royal Government of Bhutan

RNR Census 2002, Ministry of Agriculture and Forests, Royal Government of Bhutan

RNR-RC,Bajo. 2000. Effects of farm yard manure, fertilizers and green manuring in rice-wheat system in Bhutan- results from a long term experiment. Technical Paper. 34pp.

Road Safety and Transport authority, Surface Transport Master Plan for Bhutan 2007

W. Schindele, Altusried, Forest Resources Potential Assessment (FRPA) for Bhutan. RGOB/ FAO March 2004

Chapter 4: Vulnerability and Adaptation

Climate Scenarios

B. Singh, A. El Fouladi, K. Délusca and R. Cissokho (2011). Technical Report on the V&A Chapter of the Second National Communications of Bhutan. Vol. 1, 262 p.

IPCC (1990). First Assessment Report (FAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (1995). Second Assessment Report (SAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (2001). Third Assessment Report (TAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (2007). Climate Change 2007: Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

NTG-Biodiversity 2011, National Thematic Group for Biodiversity, National Road Map for Biodiversity Persistence and Climate Change 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas-Bhutan 2011

Pope, V., M.L. Gallani, P.R. Rowntree, R.A. Stratton, (2000). The impact of new physical parameterizations in the Hadley Centre climate model: HadAM3. *Clim. Dyn.*, 16, 123-146.

Roeckner, E., R. Brokopf, M. Esch, M. Giorgetta, S. Hagemann, L. Kornblueh, E. Manzini, U. Schlese, and U. Schulzweida, Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model, J. Climate, 19, 3771-3791, 2006.

Water Resources

NEC 2006, National Adaptation Programme of Action for Bhutan

NTG-Water 2011, National Thematic Group Water, National Thematic Paper for Securing the Natural Freshwater Systems of the Bhutan Himalayas - Climate Change and Adaptation measures on Water Resources in Bhutan 2012-2021- Bhutan 2011

IPCC, Climate Change 2007—Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the FAR of the IPCC. (Cambridge University Press, New York, 2007)

Palmer, M. A., Reidy Liermann, C. A., Nilsson, C., Florke, M., Alcamo, J., *et al.* (2008). Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment* 6, 81–89. doi:10.1890/060148

Securing the Natural Freshwater Systems of the Bhutan Himalayas (November, 2011). Climate Change and Adaptation measures on Water Resources in Bhutan, 45 p.

Water Resources Management Plan (WRMP) (2003) Final Report. Volumes A to D4.

Agriculture

NEC 2006, National Adaptation Programme of Action for Bhutan

NTG-Food Security 2011, National Thematic Group for Food Security, National Road Map for Energy Security 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas- Bhutan 2011

Hoogenboom G, Wilkens PW, Thornton PK, Jones JW, Hunt LA, Imamura DT (1999) Decision support system for agrotechnology transfer V3.5. p. 1-36. In Hoogenboom G, Wilkens PW, Tsuji GY (eds.) DSSAT version 4, University of Hawaii, Honolulu, HI (ISBN 1-886684-04-9).

Forests and Biodiversity

Biodiversity Action Plan (BAP), 2009. Ministry of Agriculture, Royal Government of Bhutan.

Campbell, A., Kapos, V., Scharlemann, J.P.W., Bubb, P., Chenery, A., Coad,L., Dickson, B., Doswald, N., Khan, M.S.I., Kershaw, F., and Rashid, M., 2009. *Review of literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation.* Secretariat of the Convention on Biological Diversity, Montreal. Technical Series No.42.

NTG-Biodiversity 2011, National Thematic Group for Biodiversity, National Road Map for Biodiversity Persistence and Climate Change 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas- Bhutan 2011

Convention on Biological Diversity (CBD) Secretariat, 2009. *Connecting Biodiversity and Climate change mitigation and adaptation*; Report of the 2nd Adhoc Technical Expert Group on Biodiversity and Climate change, Montreal, Technical Series No. 41.

Emmanuel. W.R. and H.H. Shugart (1986). The Holdridge life-zone classification: climate change and the distribution of terrestrial ecosystems. Climatic Change.

FAO. 1997. The state of the World's Plant Genetic Resources for Food and Agriculture, Rome, Italy, FAO.510 pp.

Fowler, C & Mooney, P., 1990. The threatened Gene: Food politics and the loss of genetic diversity. Cambridge, UK. Lutworth Press.

Gitay, H., Suarez A., Watson, R.T., Dokken, D.J., (eds.), 2002. Intergovernmental Panel on Climate Change, Technical paper V.

Herzog, Sebastian K., Rodney Martínez, Peter M. Jørgensen, Holm Tiessen (Eds.) (2011). Climate Change and Biodiversity in the Tropical Andes .Inter-American Institute for Global Change Research (IAI) and ScientificCommittee on Problems of the Environment (SCOPE), 348 pp.

Holdridge, L.R. (1947). Determination of world plant formations from simple climatic data. Science, Vol. 105: 367-368.

IPCC 2007. Climate Change 2007: Synthesis Report.

Jarvis, A., Lane,A., & Hijmans, R., 2008. The effect of climate change on crop wild relatives. Agr.

Ecosyst. Environ., 126; 13-23.

Ministry of Agriculture, Royal Government of Bhutan (2009). Bhutan-Biodiversity Action Plan 2009, 95 pp.

National Paper on Biodiversity Persistence and Climate Change (2011). RGOB, 49 p.

Wangda, P. & Ohsawa, M. 2010.*Temperature and humidity as determinants of thetransition from dry pine to humid cloud forests in the Bhutan Himalaya*. In L. A. Bruijnzeel *et al.* ed. Tropical Montane Cloud Forests: International Hydrology Series, Cambridge University Press. 156-163.

WWF & WCP, 2011, *Climate Change Vulnerability Assessment of Wangchuck Centennial Park, Bhutan*, WWF Bhutan and Wangchuck Centennial Park Bhutan

Energy

NEC 2006, National Adaptation Programme of Action for Bhutan

NTG-Energy 2011, National Thematic Group for Energy, National Road Map for Energy Security 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas-Bhutan 2011

SINGH, B. and R. TAILLEFER (1986). The effect of synoptic-scale advection on the performance of the Priestley-Taylor evaporation formula. Boundary Layer Meteorology, Vol. 36, p. 267-282.

SINGH, B. (1987). The impacts of CO_2-induced climate change on hydro-electric generation potential in the James Bay Territory of Québec. IAHS Publication, No 168, p. 403-418.

Health

Climate Change and Adaptation. Earthscan, London, UK, 384 p.

Gatrell, Anthony C. and Elliot, Susan J. (2009). Geographies of Health: an introduction, 2nd Ed., Wiley-Blackwell, Chichester, West Sussex, UK, 282 p.

Haines, A., McMichael A.J. and Epstein P.R. (2000). Environment and health: 2. Global change and health. Canadian Medical Association Journal, 163, 729-734.

Heslop-Thomas, C., Baily, W., Amarakoon, D., Chen, A., Rawlins, S., Chadee, D.D., Crosbourne, R., Owino, A., Polson, K., Rhoden, C., Stennet, R. and Taylor, M. (2008). Vulnerability to Dengue Fever in Jamaica. In: Leary N., Conde, C., Kulkarni J., Nyong, A. and Pulhin, J. (Eds.) (2009). Climate Change and Vulnerability. Earthscan, UK, 431 p.

Initial National Communication (2002) of Bhutan (INC), 175 p.

IPCC (2007). Climate Change 2007: Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

Leary N., Adejuwon A., Barros V., Burton I., Kulkarni J. and Lasco R. (Eds.) (2008b). Climate Change and Adaptation. Earthscan, London, UK, 384 p.

Leary N., Conde C., Kulkarni J., Nyong A. and Pulhin J. (Eds.) (2008a). Climate Change and Vulnerability. Earthscan, London, UK, 431 p.

Lindsay S. W. Birley, M.H. (1996). Climate change and malaria transmission. Annals of Tropical medicine and Parasitology, 90, 573-588.

Martens, P. (1996). Health and Climate Change; modeling the impacts of global warming and ozone depletion, Earthscan Publication, London, UK.

World Health Organization (2010) www.who.int.

Glaciers and GLOF

Bajracharya, S.R., P.K. Mool and B.R. Shrestha (2008). Global Climate Change and Melting of Himalayan Glaciers. In: Ranade, P.S. (Ed.). Melting Glaciers and Rising Sea Levels: impacts and implications, Hyderabad: ICFAI University Press, pp 28-46.

Beldring, Stein (Editor) (2011). Climate change impacts on the flow regimes of rivers in Bhutan and possible consequences for hydropower development. Norwegian Water Resources and Energy Directorate, Report no. 4 – 2011, 156 p.

ICIMOD and UNEP (2002). Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods Monitoring and Early Warning Systems in the Hindu Kush - Himalayan Region: Bhutan.

Ives, J.D.,R. B. Shrestha and P. K. Mool (2010). Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment. ICIMOD Report, 66 p.

Ministry of Home and Cultural Affairs (MOHCA) (2006). National Disaster Risk Management

Framework: Reducing Disaster Risks for a Safe and Happy Bhutan, Royal Government of Bhutan.

Grabs, W. E. and J. Hanisch (1992). Objectives and Prevention Methods for Glacier Lake Outburst Snow and Glacier Hydrology (Proceedings of the Kathmandu Symposium). Kathmandu, Nepal, IAHS.

Kaltenborn, B.P., C. Nellemann and I. I. Vistnes (Eds.) (2010). High Mountain Glaciers and Climate Change: challenges to human livelihoods and adaptation. UNEP Report, 56 p.

Hausler, H. and D. Leber (1998). Raphstreng Tsho Outburst Flood Mitigatory Project (Lunana,

Northwestern Bhutan): Phase I. Vienna, Austria, Institute of Geology, University of Vienna: 33.

ICIMOD and EU (2007). The Snake and the River Don’t Run Straight: Local Knowledge on Disaster Preparedness in the Eastern Terai of Nepal.

Karma, T, K.S. Ghalley and U. Thinley (2008). Hazard zonation for glacier lake outburst flood along Punatshang Chu from Khuruthang to Thamoyzinkha. (Y. Dorgi, Ed), DGM-NCAP Project (Oct 2006- May 2008).

Leber, D., H. Hauesler, et al. (2002). GLOF Mitigation Project.

Richardson, S.D. and Reynolds, J.M. 2000. An overview of glacial hazards in the Himalayas. Quaternary International, 65-66, 31-47.

UNDP and EU (2008). An Analysis of Socio-economic Impact and risk Mitigation and Preparedness Measures of GLOF Events in Bhutan: a Case Study of Samdingkha, 62 p.

Vuichard, D. and M. Zimmerman (1986). The Langmoche Flash-Flood, Khumbu Himal, Nepal.

Mountain Research and Development 6(1): 5.

Watanabe, T., J. D. Ives, *et al*. (1994). “Rapid Growth of a Glacial Lake in Khumbu Himal, Himalaya: Prospects for a Catastrophic Flood.” Mountain Research and Development 14(4): 11.

Watanabe, T. and D. Rothacher (1996). Lugge Tsho Glacial Lake Outburst Flood, Bhutan Himalaya. Mountain Research and Development 16(1): 5.

Cross-cutting Issues

Gatrell, Anthony C. and Elliot, Susan J. (2009). Geographies of Health: an introduction, 2nd Ed., Wiley-Blackwell, Chichester, West Sussex, UK, 282 p.

Haines, A., McMichael A.J. and Epstein P.R. (2000). Environment and health: 2. Global change and health. Canadian Medical Association Journal, 163, 729-734.

IPCC (2007). Climate Change 2007: Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (2001). Third Assessment Report (TAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (1995). Second Assessment Report (SAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

IPCC (1990). First Assessment Report (FAR): Working Group Reports – Vol. 1; Vol. 2 and Vol. 3.

Leary N., Conde C., Kulkarni J., Nyong A. and Pulhin J. (Eds.) (2008a). Climate Change and Vulnerability. Earthscan, London, UK, 431 p.

Leary N., Adejuwon A., Barros V., Burton I., Kulkarni J. and Lasco R. (Eds.) (2008b). Climate Change and Adaptation. Earthscan, London, UK, 384 p.

Lindsay S. W. Birley, M.H. (1996). Climate change and malaria transmission. Annals of Tropical medicine and Parasitology, 90, 573-588.

Martens, P. (1996). Health and Climate Change;

modeling the impacts of global warming and ozone depletion, Earthscan Publication, London, UK.

World Health Organization (2010). http://www.who.int.

Chapter 5: Other Information

Capacity Development for Gross National Happiness, A Vision for Local Government in Bhutan. Discussion Paper – June 2010

Capacity Development Technical Assistance (CDTA) December 2009. Kingdom of Bhutan: Capacity Building of the National Environment Commission in Climate Change

Climate Change Screening of Danish Development Cooperation with Bhutan Danida, June 2008

GHG Inventory 2000, Bhutan National Greenhouse Gas Project

JSP 2011, "Capacity Development Assessment of Training and Educational Institutes in the Area of Environment-Climate Change-Poverty Mainstreaming", Joint Support Program on Capacity Development for Mainstreaming Environment, Climate Change and Poverty Concerns in Policies, Plans and Programs,

NTG-Biodiversity 2011, National Thematic Group for Biodiversity, National Road Map for Biodiversity Persistence and Climate Change 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas-Bhutan 2011

NTG-Energy 2011, National Thematic Group for Energy, National Road Map for Energy Security 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas-Bhutan 2011

NTG-Food Security 2011, National Thematic Group for Food Security, National Road Map for Energy Security 2012-2021- Bhutan, National Thematic Paper for the Climate Summit for a Living Himalayas- Bhutan 2011 (draft)

NTG-Water 2011,National Thematic Group Water, National Thematic Paper for Securing the Natural Freshwater Systems of the Bhutan Himalayas-Climate Change and Adaptation measures on Water Resources in Bhutan 2012-2021- Bhutan 2011

Royal Government of Bhutan, 2000 Initial National Communication under the UNFCC, November 2000

National Environment Commission
Royal Government of Bhutan
P.O. Box 466, Thimphu, Bhutan
www.nec.gov.bt

ISBN : 978-99936-865-0-7