Integrated Energy Management Master Plan for Bhutan

Prepared for
Department of Energy
Ministry of Economic Affairs
Royal Government of Bhutan

teri
The Energy and Resources Institute

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The Energy and Resources Institute

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Contents

List of tables

CHAPTER 5

CHAPTER 6

ANNEXURE 3.1

ANNEXURE 3.2

ANNEXURE 3.3

ANNEXURE 4.1

ANNEXURE 4.2

ANNEXURE 4.3

ANNEXURE 4.4

ANNEXURE 4.5

ANNEXURE 7.1

List of figures

CHAPTER 2

CHAPTER 3

CHAPTER 5

CHAPTER 6

CHAPTER 7

ANNEXURE 4.3

ANNEXURE 4.4

ANNEXURE 4.5

ANNEXURE 7.1

List of boxes

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List of abbreviations and acronyms

°C	degree Celsius
ADB	Asian Development Bank
AMC	Agriculture Machinery Centre
ASTRA	Application of Science and Technology to Rural Areas
ATF	aviation transport fuel
BAU	business-as-usual scenario
BCCL	Bhutan Calcium Carbide Ltd
BDFC	Bhutan Development Finance Corporation
BEA	Bhutan Electricity Authority
BEE	Bureau of Energy Efficiency
BFAL	Bhutan Ferro Alloys Ltd
BIMSTEC	Bay of Bengal Initiative for Multi-sectoral Technical and Economic Cooperation
Bioenergy	biomass energy
BOOT	build, operate, own, and transfer
BPC	Bhutan Power Corporation
BSL	Bhutan Steels Ltd
BTF	Bhutan Trust Fund
BTU	British thermal unit
CaO/BaO	calcium oxide/barium oxide
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CFLs	compact fluorescent lamp
CH_4	methane
CHP	combined heat and power
CITES	Convention on International Trade in Endangered Species
CLACC	climate change
CNG	compressed natural gas
CO	carbon monoxide
DCCL	Druk Cement Company Ltd
DGPC	Druk Green Power Corporation
DHI	Druk Holding and Investments Ltd
DISL	Druk Iron and Steel Plant
DoE	Department of Energy
DPRs	detailed project reports
DPT	Druk Phuensum Tshogpa
DRI	direct reduced iron
DSM	demand side management
DST	Department of Science and Technology
DYT	Dzongkhag Yargay Tshochung
EAF	electric arc furnace
ECBC	Energy Conservation Building Code
ECOs	energy conservation opportunities
EdL	Electricite du Laos
EE	energy efficient
ER	equivalence ratio
ESCO	energy service company
ESMAP	Energy Sector Management Assistance Programme
FAO	Food and Agriculture Organisation
FDCL	Forest Development Corporation Ltd
FDI	foreign direct investment
FNCA	Forest and Nature Conservation Act
FO	furnace oil
FYP	Five-year Plan
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GI	galvanized iron
$GJ/h.m^2$	Gigajoule per hour per metre square

GLCs	government-linked companies
GLOF	glacier lake outburst flood
GNH	Gross National Happiness
GoI	Government of India
GoL	Government of Laos
GWh	gigawatt-hours
GWP	Global Warming Potential
GYT	Gewog Yargay Tshochung
HBI	hot briquetted iron
HDR	hot dry rock
HHV	high heating value
HIG	high growth
HIGEE	high growth coupled with energy efficiency
HMSD	Hydro-Met Service Division
HSD	high speed diesel
IC	internal combustion
ICIMOD	International Center for Integrated Mountain Development
IDC	Industrial Development Centre
IDD	inverted downdraft
IEA	International Energy Agency
IEMMP	Integrated Energy Management Master Plan
IIED	International Institute for Environment and Development
IISc	Indian Institute of Science
IIT Delhi	Indian Institute of Technology, Delhi
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
KEVA	Kathmandu Electric Vehicle Alliance
kJ	kilojoules
kl	kilolitre
kV	kilovolt
KVIC	Khadi and Village Industries Commission
kW	kilowatt
kWh	kiowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LDCs	least developed countries
LDO	light diesel oil
LEAP	long-range energy alternatives planning
LED	light-emitting diodes
LHV	low heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCA	multiple criteria analysis
MDGs	Millennium Development Goals
MHV	medium heating value
MJ	megajoule
MJ/Nm^3	megajoule per Newton cubic metre
MnO	manganese oxide
MNRE	Ministry of New and Renewable Energy
MoA	Ministry of Agriculture
MoEA	Ministry of Economic Affairs
MoEF	Ministry of Environment and Forests
MoIC	Ministry of Information and Communications
msl	mean sea level
MT	million tonnes
MU	million unit
MW	megawatt
NAPA	National Adaptation Programme of Action
NATCOM	National Communication
NBP	National Biogas Programme
NCCBM	National Council for Cement and Building Materials
NEC	National Environment Commission
NGOs	non-governmental organizations
NHB	National Housing Board
NHPC	National Hydro Power Corporation

NRDC	Natural Resources Development Corporation
NSB	National Statistical Bureau
Nu	Ngultrum
O&M	operation and maintenance
OoCC	Office of the Census Commissioner
PAH	polycyclic aromatic hydrocarbons
PCAL	Penden Cement Authority Ltd
PCD	Planning and Coordination Division
PIC	products of incomplete combustion
PLF	plant load factor
PMT	per metric tonne
PV	photovoltaic
R&D	research and development
RED	Renewable Energy Department
REMP	Rural Electrification Master Plan
REs	renewable energies
RESCOM	Rural Energy Service Concession Model
RET	renewable energy technology
RGoB	Royal Government of Bhutan
RNR	renewable natural resource
RPM	revolution per minute
Rs	rupees
RSPN	Royal Society for Protection of Nature
RSTA	Road Safety and Transport Authority
SAARC	South Asian Association for Regional Cooperation
SED	Sustainable Energy Department
SPV	solar photovoltaic
SQCA	Standards and Quality Control Authority
SVO	straight vegetable oils
SWERA	Solar and Wind Energy Resource Assessment
tCO_2	tonnes carbon dioxide
TERI	The Energy and Resources Institute
TOE	tonnes of oil equivalent
TSP	total suspended particulates
TV	television
UN	United Nations
UNCCD	UN Convention on Combating Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	United States dollar
VOC	volatile organic compound
WB	World Bank
WEF	World Economic Forum
WRMP	Water Resource Management Plan
WWF	World Wildlife Fund

Conversion factors

Electricity:

1 MU = $1*10^6$ kWh
1 MWh = 1000 kWh

Energy:

1 calorie = 0.003968321 BTU
1 calorie = 4.1868 joules
1 calorie = 0.000001163 kWh
1 kilocalorie = 1000 calories
1 kilocalorie = 0.001163 kWh
1 kilojoule = 0.0002777778 kWh
1 TOE = 41.868 GJ
1 TOE = 11.630 MWh
1 TOE = 10.0 giga-calories
1 TOE = 308 gallons
1 kWh = 3412.142 BTU

Technical terms used in the report

TOE = tonnes of oil equivalent
kWh = kilowatt-hour
MU = million units
kcal = kilocalorie
m^2 = square metre
MT = million tonnes
kl = kilolitre
TOE/capita/year = tonnes of oil equivalent per capita per year
kWh/capita/year = kilowatt hour per capita per year
kWh/hh/annum = kilowatt hour per household per annum
kg/hh/annum = kilogram per household per annum
lit/hh/annum = litre per household per annum
kV = kilovolts
MW = Megawatt
GWh = Gigawatt-hour
Nu/unit = Ngultrum per unit
$Nm^3/h\ m^2$ = Newton metre cube per hour per metre square

Fuels energy conversion factors

1 kl ATF = 0.836 TOE
1 tonnes of briquette = 0.32 TOE
1 tonnes of coal = 0.282 TOE
1 kl of diesel = 0.899 TOE
1 kWh = 0.0000857 TOE
1 kl of furnace oil = 0.989 TOE
1 tonnes of fuelwood = 0.32 TOE
1 kl of kerosene = 0.882 TOE
1 kl of light diesel oil = 0.911 TOE
1 tonnes of LPG = 1.13 TOE
1 kl of petrol = 0.815 TOE

CHAPTER 1

Introduction

BACKGROUND

Under the Ninth Five-year Plan (2002–08), the Department of Energy (DoE), Ministry of Economic Affairs (formerly Ministry of Trade and Industry), undertook a study to prepare an Integrated Energy Management Master Plan (IEMMP) for Bhutan. This was a Government of India assisted study for which The Energy and Resources Institute (TERI), New Delhi, was appointed as a consultant.

In the first phase of the study, *Bhutan Energy Data Directory 2005* was published, which covered, for the first time, the energy demand and supply balance for 2005 and potential of energy resources. It also reviewed the status of the energy sector, including the institutional arrangements. The Data Directory included the survey of the residential sector and energy audits of major industries.

This report, second in the series, analyses a wide range of issues, which mainly relate to the energy sector of Bhutan. This report presents the objectives of the study, approach and methodology, future outlook of the energy sector till 2020, demand and supply analyses, impacts of energy on economy, and interdependence of development and energy. Various laws/regulations have also been analysed, along with assessment of social impacts of supplying energy to rural areas.

PROJECT OBJECTIVE AND METHODOLOGY

The objective of the IEMMP is to develop an all-encompassing framework, which would give a holistic overview of the demand and supply scenarios, along with recommending strategies (up to 2020) for the sustainable supply of energy for the socio-economic development of the kingdom, both at the rural and urban levels. This integrated approach provides various policy options, in line with the current policies and *Vision 2020*, for future development of the kingdom.

'Gross National Happiness is more important than Gross National Product'

His Majesty King Jigme Singye Wangchuck, 1972

The overall objective of the 'Gross National Happiness' is based on four widely accepted sustainable development principles, as listed below.

1 Equitable socio-economic development
2 Conservation of the natural environment
3 Promotion of cultural heritage
4 Establishment of good governance

PROJECT PLANNING

The project began on 1 January 2005 and was carried out in three phases.

1. Phase I (January 2005 to May 2006)
2. Phase II (June 2006 to December 2006)
3. Phase III (January 2007 to December 2009)

Phase I

The objective of Phase I was to prepare an energy database and energy balance for the country. Activities undertaken under this phase included the following.

- Sectoral energy consumption studies, which covered the following sectors.
  - Domestic
  - Commercial establishments and institutions
  - Industry
  - Agriculture
  - Transport

- Energy resources and supply assessment, covering the following.
  - Fossil fuels
  - Renewables (hydro, solar, wind, and biomass)
  - Electricity
- Energy conservation studies for industries and buildings
- Design and setting up of energy efficiency laboratory
- Technology assessment of appliances and gadgets
- Preparation of energy balance
- Stakeholder consultations and conducting workshops

Phase I also covered the following major initiatives and activities.

- Household energy survey of 5496 households
- Energy audits of three major industries and buildings
- Assessment of solar and wind resources by using secondary data
- Extensive consultations with stakeholders

Deliverables included the following.

- Energy database and energy balance
- Energy laboratory and resource centre

Phase II

The objective of Phase II was to develop an energy profile for the country in terms of supply options (present and future) and demand forecast.

Activities under this phase included energy modelling, preparing energy profile, and conducting stakeholder workshops.

Deliverables included the following.

- Preparing an energy atlas
- Preparing an energy accounting model for the kingdom, along with various energy scenarios for the period 2007–20.

Phase III

The objective of Phase III was recommending policies and strategies that would steer the energy sector and the economy, at large, towards optimal use of energy resources linked to appropriate energy technologies.

Activities undertaken included the following.

- Preparing IEMMP
- Submitting a draft report
- Conducting stakeholders' workshop
- Preparing a final report

The deliverables were as follows.

- Perspective planning for the energy sector
- Preparing an energy management information system

STRUCTURE OF THE REPORT

The report is structured in such a way that it presents the comprehensive analysis of all the sectors, both from supply as well as demand sides. Chapter 2 covers the overall energy scenario. Demand and supply projection scenarios and their analyses are covered in Chapter 3. Chapter 4 discusses the strategies recommended for energy efficiency and energy resource demand management. Chapter 5 gives a detailed analysis of the energy resources and supply side options, especially for the promotion of hydropower and utilization of renewable energy, including supply side issues and strategies for augmenting energy supply for energy security. Chapter 6 discusses the overall approach to IEMMP and practices and also presents policy recommendations and discussions on overarching issues in the context of development process.

CHAPTER 2

Energy sector – an overview

BACKGROUND INFORMATION ON BHUTAN

Bhutan is a landlocked country situated between India and China in the fragile eastern Himalayas. Its population as per Census 2005 is 634 982.

Bhutan covers an area of 38 394 km^2, roughly spread 140 km north to south and 275 km east to west. The altitude varies from 100 m above the mean sea level (msl) in the southern tropical region to 7550 above the msl in the northern alpine region. The country is blessed with natural forests and is one of the 10 biodiversity hotspots notified by the United Nations (UN). The country receives fair amount of rainfall, varying from 500 mm in the north to 5000 mm in the south. Situated in high altitude Himalayas, Bhutan has 667 glaciers and 2674 glacier lakes,[1] which feed four major rivers and their tributaries, making the country rich in hydropower resources. These geographical features, landlocked condition, and unique environment pose unique challenges and opportunities for Bhutan as it pursues the development of its economy sector.

After centuries of isolation, Bhutan opened its economy in 1950s and started following a path of sustainable and cautious development, popularly known as the 'middle path' of development. So far, it has followed the path of development sustainably, causing minimum damage to the environment and ecology.

Planned development started in 1961 when the first Five-year Plan was implemented with the help of the Government of India. Right from the first Five-year Plan (1961–66) till the Ninth Five-year Plan (2002–08),[2] the country has seen planned and steady economic development and has gone through substantial transformation.

Indo-Bhutan bilateral relationship plays an important role in the development of Bhutanese economy. India and Bhutan have had trade relations for centuries, and the ties grew stronger after the Independence of India in 1947. The historic India–Bhutan Treaty of 1949 laid the foundation for Indo-Bhutan relations. The power sector, along with the health and education sectors, is among the major sectors in which India has made significant contributions in terms of investment, capacity building, and technology transfer.

BHUTAN'S GROSS DOMESTIC PRODUCT

The growth rate of the gross domestic product (GDP, % per year) of the country, from 2003 to 2008, is presented in Table 1.

Table 1

GROWTH RATE OF GROSS DOMESTIC PRODUCT (GDP)

	Contributions to growth (supply) (%)					
	GDP	Agriculture	Electricity and water	Construction	Other industries	Services
2003	9.0	0.6	1.9	2.2	0.5	3.8
2004	7.0	0.5	0.8	1.0	0.4	4.3
2005	6.6	0.3	0.4	0.5	0.4	5.3
2006	6.4	0.3	2.5	-1.0	0.5	4.1
2007	14.1	0.2	10.7	-0.4	0.7	2.6
2008	11.5	0.4	7.2	0.0	0.8	3.2

[1] Details available at <http://www.un.org/Pubs/chronicle/2002/issue3/ +0302p48_glacial_lakes_flood_threat.html>, last accessed on 10 May 2007.

[2] The Ninth Plan period was extended to 2008 by the Royal Government of Bhutan.

DEVELOPMENT AND CHARACTERISTICS OF BHUTAN'S ENERGY SECTOR

Power sector development

Electricity was introduced for the first time in Bhutan in 1964 when the first diesel generator sets were installed at Pheuntsholing and Samtse. This was followed by the development of hydropower, and the first hydropower plant with a capacity of 360 kW was commissioned in 1967 to supply electricity to the capital town of Thimphu. The power sector got a boost in 1988 when Chukha Hydropower Plant with a capacity of 336 MW was commissioned. With the commissioning of Chukha Hydropower Plant, Bhutan started exporting electricity to India, earnings of which started funding its socio-economic development. Today, about 45% of its export earnings are through the export of electricity, and this earning has also been instrumental in the development of infrastructure like roads, hospitals, and school, besides providing impetus to industrial development.

Another major milestone in hydropower development was achieved in 2007 when Tala Hydropower Plant with a capacity of 1020 MW was fully commissioned.

Bhutan's economic growth is closely related to the development of its power sector. The phased commissioning of the Tala Power Project in 2006 boosted the GDP growth sharply in 2007. The growth was slightly less in 2008, which was due to high base effect.

Electricity supply and consumption trends

Some salient features of Bhutan's electricity sector are summarized below.

- Power generation in the country in 2005 was 2521.25 MU, while 18.39 MU of electricity was imported. Of the total electricity generated, 1793.76 MU of electricity was exported and 745.88 MU was consumed in the country.
- Of the total electricity consumed in the country, 619 MU of power was sold and 112.43 MU of the electricity was lost within the system. The balance met the auxiliary power requirement in the power plants.
- Peak demand in 2005 was 120 MW.
- Industries are the largest consumer of electricity in the country. In 2005, the sector consumed 419 MU (65% of the total consumption) of electricity.
- Institutional and commercial sectors consumed 118.88 MU (18.76 % of the total consumption) of electricity.
- The residential sector consumed 89 MU of electricity in 2005 (14.5% of total consumption).
- The agriculture and transport sectors consume negligible amount of electricity.

Electricity constituted 15.7% of the total energy supply in the country during 2005.

Figure 1 shows the electricity consumption in different Dzongkhags in 2005.

Fuelwood

The main source of primary energy in Bhutan is fuelwood obtained from forests. The country consumed 724 597 tonnes of fuelwood during 2005, which accounted for 56.8% of the total primary energy supply. In addition to fuelwood, other biomass fuels, which are being used in small quantities, include briquettes made from saw dust and agriculture residue.

Petroleum fuels

About 19% of the total energy is met from imported petroleum fuels like diesel, petrol, kerosene, liquefied petroleum gas (LPG), furnace oil, aviation turbine fuel, light diesel oil (LDO), and so on. Diesel and petrol feature amongst the top imports in the country on import value basis. In 2005, 51 460 kilolitres of diesel was imported against the import of 13 879 kilolitres of petrol. In addition, during the same year, 12 545 kilolitres of kerosene and 4472 million tonnes (MT) of LPG were imported. Figures 2 and 3 show trends in the import of petroleum fuels.

Coal

Coal meets 8% of the energy demand in the country. It is mostly used in the industrial sector. The total coal consumption in the country during 2005 was 97 509 tonnes. The total coal mined

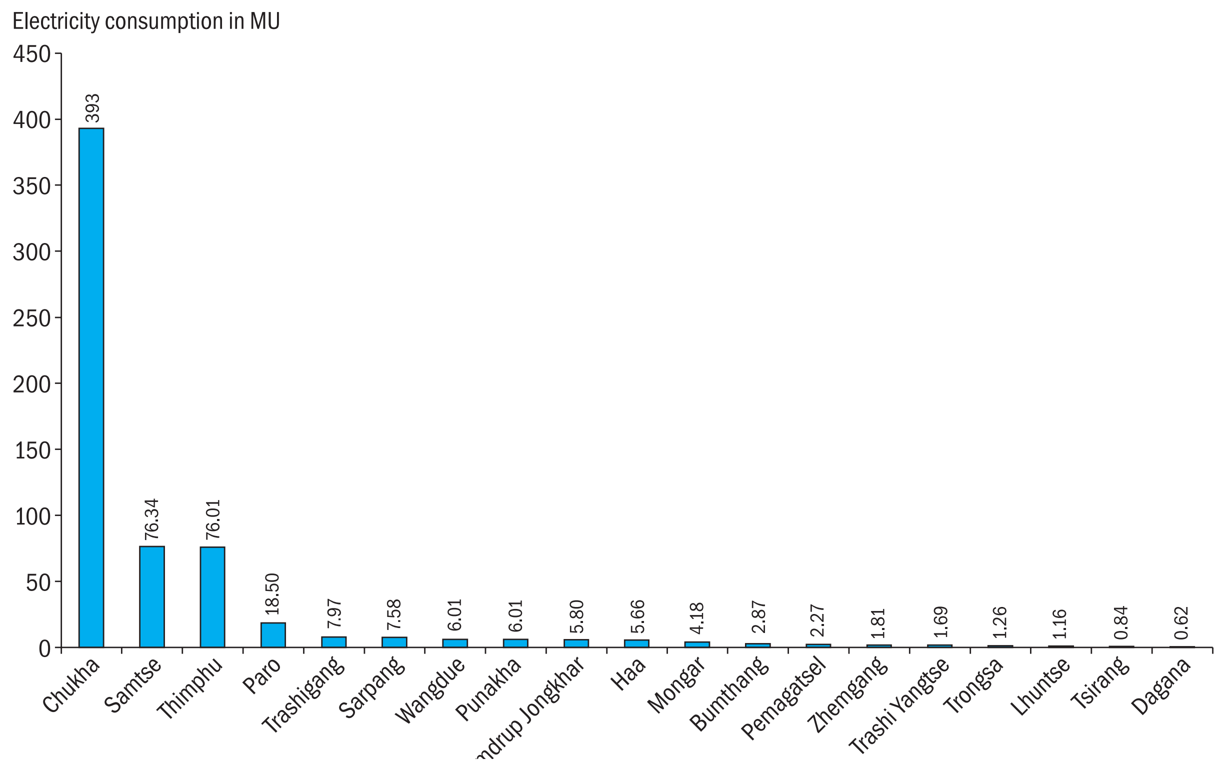


FIGURE 1 ELECTRICITY CONSUMPTION IN 2005, BY DZONGKHAG

from local coal mines was 85 279 tonnes, while 60 607 tonnes of coal was imported in the same year. Bhutan also exported 48 377 tonnes of coal in 2005.

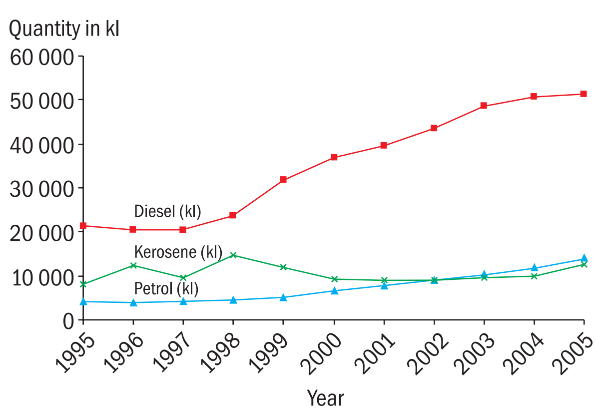


FIGURE 2 TRENDS IN IMPORTS OF DIESEL, PETROL, AND KEROSENE

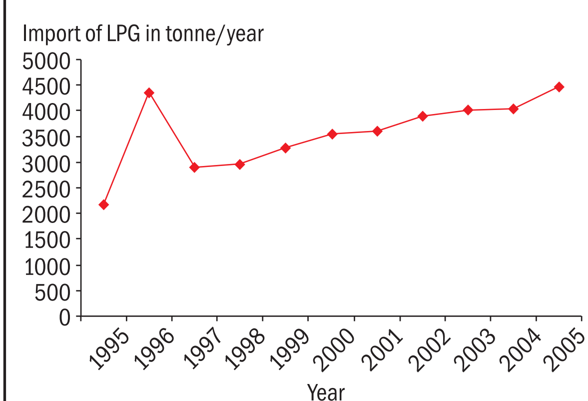


FIGURE 3 TRENDS IN THE IMPORT OF LIQUEFIED PETROLEUM GAS

SECTORAL ENERGY CONSUMPTION

The sectoral energy consumption for 2005 is shown in Figure 4.

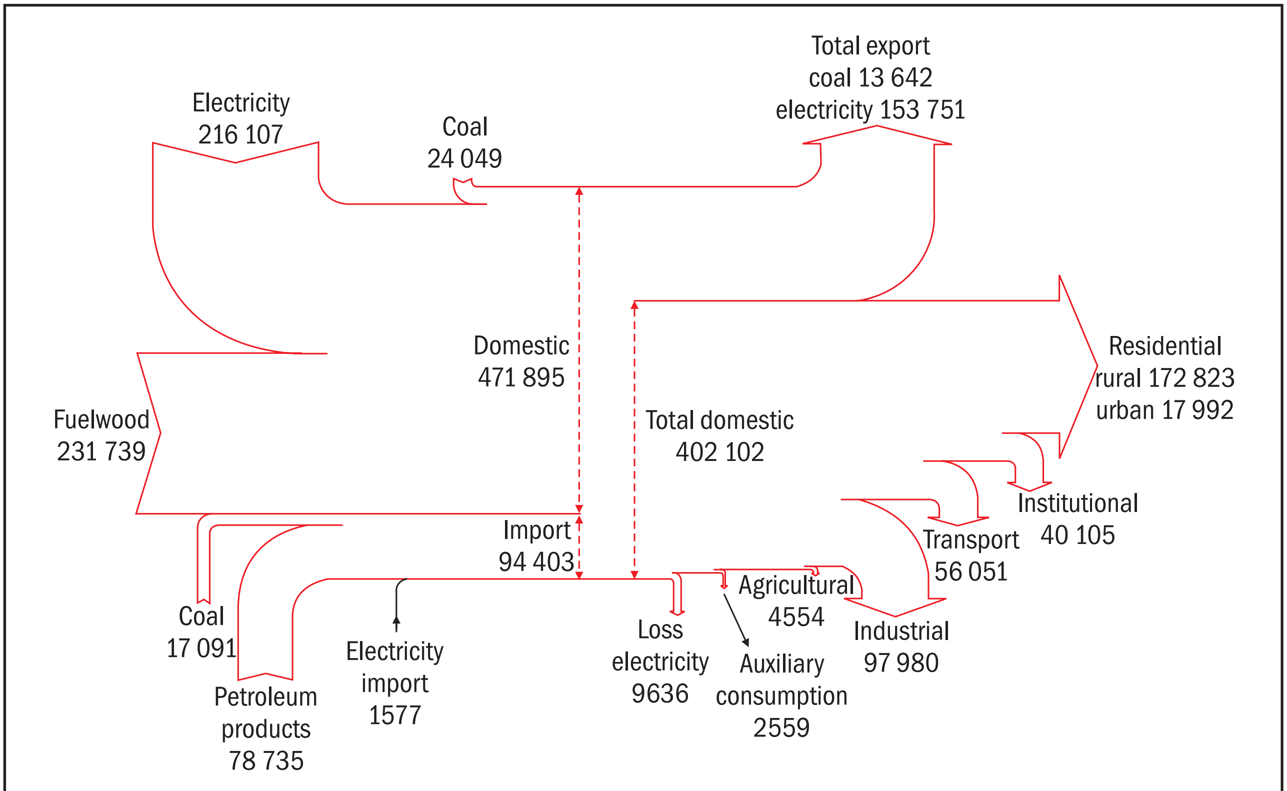


FIGURE 4 SANKY DIAGRAM FOR BHUTAN ENERGY SECTOR (2005) [5]

Residential sector

Population distribution

Bhutan's population of 634 982 (Census 2005) is distributed in 20 Dzongkhags. About 69% of this population lives in rural areas and 31% lives in urban areas. Seventy-five per cent of this population is concentrated in nine Dzongkhags, of which six are in the western region, two in the central region, and only one in the eastern region. Figure 5 shows the distribution of population, by Dzongkhag.

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),[4] which is followed by 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.

Figure 6 shows energy consumption in the residential sector, by Dzongkhag.

Electrification status

As per the 2005 statistics, the country has 126 115 households, of which 38 311 households are urban households and the remaining 87 804 households are rural households. Of these, 36 923 urban households (96.4%) and 35 140 rural households (40%) were electrified, as of 2005.

The Royal Government of Bhutan (RGoB) is pursuing rural electrification, with one of the objectives being reducing fuelwood consumption. These rural households consumed 89 MU of electricity in 2005, which was 14.6% of the total electricity consumption during the same period.

[3] All units are in TOE.

[4] It should be noted here that in a large number of households, same device is used for both cooking and space heating, making it difficult to apportion fuel use between the two end uses; in such a case, fuel use is apportioned to cooking.

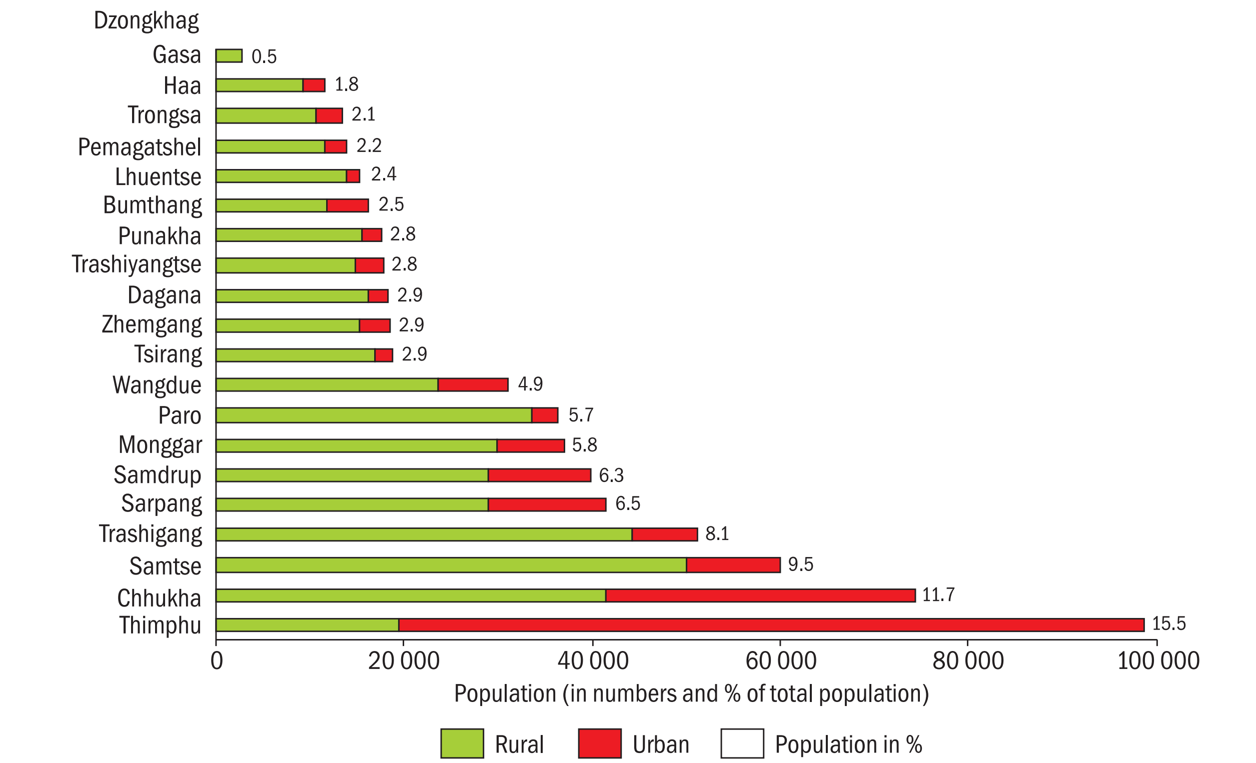


FIGURE 5 DISTRIBUTION OF POPULATION IN BHUTAN (2005)

In the Ninth Five-year Plan, as of June 2007, 15 148 households have been electrified. In the Tenth Five-year Plan (2008–13), a total of 43 951 rural unelectrified households will be electrified, thereby resulting in 100% rural electrification.

Fuels and energy resources used in the residential sector

The residential sector uses fuelwood, LPG, electricity, and kerosene as major fuels. The energy consumption in the residential sector in Bhutan is dominated by high consumption of fuelwood and relatively low use of modern fuels like LPG. Additionally, briquettes for space heating are being increasingly used in urban areas. On the other hand, solar photovoltaic (PV) systems have been set up in remote areas for lighting purpose.

Major fuel-consuming activities in the residential sector are as follows.

- Cooking
- Lighting
- Space heating (many times this is done with the device that is used for cooking)
- Fodder cooking in rural areas

Fodder cooking is treated separately at the end of this section.

Energy consumption for 2005, by fuel and end use, as estimated by the survey of 5450 households, carried out in Bhutan under the IEMMP project, is discussed subsequently.

Consumption analysis, by fuel

Fuelwood

While the choice of the fuel depends on the availability of fuels and their costs, fuelwood is the most commonly used fuel in Bhutan and constitutes about 90% of the energy used in the residential sector.

Rural areas have higher percentage of population (69%), which is allowed to collect fuelwood free of royalty, as per the policy of the RGoB. Rural areas are also the largest consumers of fuelwood. A total of 69 013 households use fuelwood as the main source of cooking fuel (Census 2005).

Fuelwood is collected mostly by women, and survey indicates that on an average, one person month per year is spent in collecting fuelwood. A survey of household energy consumption carried

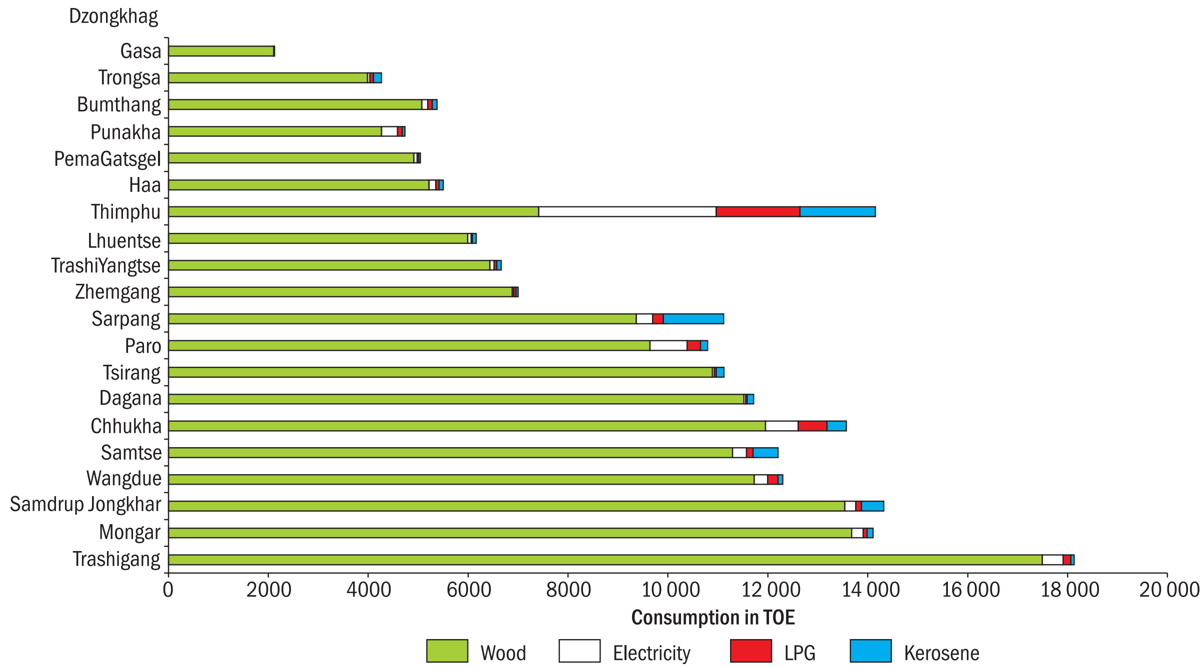


FIGURE 6 ENERGY CONSUMPTION PATTERN IN THE RESIDENTIAL SECTOR, BY DZONGKHAG

out by TERI under the IEMMP project has found that the per capita fuelwood consumption in the residential sector is about 0.78 tonne per annum, accounting for 68% of the total fuelwood consumption in the country.

Cooking and space heating are many times carried out by using same device, which is commonly called *bukhari*. It uses fuelwood as fuel. In urban areas, special types of *bukharis* are used for space heating and water heating.

Fuelwood consumption, by Dzongkhag, is presented in Table 2.

The table shows that Dzongkhags like Trashigang, Mongar, S'Jongkhar, Wangdue and Dagana, Samtse, and Chukha together account for about 50% of the fuelwood consumed in the residential sector. These areas can be targeted for implementing special programmes meant to reduce fuelwood consumption.

Electricity

In electrified areas, electricity is the preferred fuel for cooking, lighting, and space heating applications.

It is interesting to note that of the 72 063 electrified households in Bhutan, 31 510 urban households and 25 105 rural households (78.6%) use electricity as the main fuel for lighting and cooking (Census 2005). This shows that one of the objectives of rural electrification – to reduce fuelwood consumption – has been achieved successfully. Studies have also shown that there is about 25% reduction in fuelwood consumption in electrified households in rural areas.

Cookers and water boilers (or electric kettles) are the major cooking equipment used for cooking in these households. Besides, these electrified households use electric heaters, refrigerators, washing machines, and infotainment gadgets like TV, music players, and computers. The IEMMP survey has come up with the fact that electricity is mainly consumed for cooking, space heating, and water heating applications in the colder areas. Electric heaters used for space heating vary in type and quality.

Kerosene

Kerosene is the third most preferred fuel in the residential sector in Bhutan, after fuelwood and electricity. In 2005, the residential sector consumed 12 545 kilolitres of kerosene (50% of the total kerosene used in the country).

Table 2

FUELWOOD CONSUMPTION (TONNES), BY DZONGKHAG

	Rural					Urban					Total				
Dzongkhag	Cooking	Space heating	Fodder cooking	Lighting	Total	Cooking	Space heating	Fodder cooking	Lighting	Total	Cooking	Space heating	Fodder cooking	Lighting	Total
Bumthang	7 541	2 255	2 800	0	12 596	801	2 454	0	0	3 255	8 342	4 709	2 800	0	15 851
Chukha	20 595	4 184	10 186	0	23 965	1 896	491	0	0	2 387	22 491	4 675	10 186	0	37 352
Dagana	26 284	0	9 445	0	35 729	155	114	0	0	269	26 739	114	3 445	0	35 998
Gasa	3 955	312	2 315	0	6 582	0	0	0	0	0	3 955	312	2 315	0	6 582
Haa	4 225	5 908	4 938	0	15 071	142	1 092	0	0	1 233	4 367	7 000	4 938	0	16 304
Lhuentse	12 430	0	5 904	0	18 335	63	324	0	0	387	12 494	324	5 904	0	18 722
Mongar	34 743	0	8 010	0	42 753	0	0	0	0	0	34 742	0	8 010	0	42 753
Paro	10 794	1 389	17 033	0	29 216	27	883	0	0	910	10 821	2 272	17 033	0	30 126
PemaGatsgel	12 252	0	3 105	0	15 357	0	0	0	0	0	12 252	0	3 105	0	15 357
Punakha	9 439	0	3 886	0	13 324	0	0	0	0	0	9 439	0	3 886	0	13 324
Samdrup Jongkhar	28 907	0	13 425	0	42 332	0	0	0	0	0	28 907	0	13 425	0	42 332
Samtse	26 405	0	8 895	0	35 300	0	0	0	0	0	36 405	0	8 895	0	35 300
Sarpang	21 252	0	8 027	0	29 278	0	0	0	0	0	21 252	0	8 027	0	29 278
Thimphu	6 439	469	8 331	0	15 240	1 623	6 292	0	0	7 915	8 062	6 761	8 331	0	23 154
Trashigang	39 665	30	13 017	0	52 711	267	1 697	0	0	1 964	39 932	1 726	13 017	0	54 675
Trashi Yangtse	15 543	182	3 987	0	19 712	208	175	0	0	384	15 751	357	3 987	0	20 096
Trongsa	9 186	0	2 862	0	12 048	131	279	0	0	319	19 209	334	14 479	0	34 022
Tsirang	19 150	74	14 479	0	33 702	60	260	0	0	319	19 209	334	14 479	0	34 022
Wangdue	20 157	7 567	8 929	0	36 652	0	0	0	0	0	20 157	7 567	8 929	0	36 652
Zhemgang	14 507	230	6 187	0	20 923	160	413	0	0	573	14 667	643	6 183	0	21 497
Total	343 469	22 600	155 760	0	521 829	5 533	14 472	0	0	20 006	349 003	37 072	155 760	0	541 834

According to Census 2005, about 45 068 rural households (36% of the total households and 51.3% of rural households) and 996 urban households (2.8% of the urban households) still use kerosene as the main fuel for lighting. The total number of households that use kerosene as the main fuel for cooking is 11 342. Use of kerosene for space heating is not very common, although in urban areas of Thimphu, space heaters based on kerosene are available. Because of the adverse health impacts of using kerosene for lighting, low-cost wick lamps that are commonly used for lighting need to be discouraged. Accordingly, measures are proposed to reduce the use of kerosene for lighting.

Liquefied petroleum gas

LPG is mostly used for cooking in the urban areas of the country. In 2005, total LPG consumption in the residential sector was 3522 tonnes, of which 2613 tonnes (74%) was consumed in the urban sector.

LPG is supplied to Bhutan at concessional rates. However, the selling price is dependent on transport costs, and hence, landed costs are substantially higher in rural areas. Moreover, often users have to carry LPG cylinders manually due to the non-connectivity by road/lack of road infrastructure, and this is one of the reasons for the less penetration of LPG in rural areas. It was found that LPG is the least preferred fuel in rural houses that are not accessible by motorable roads.

Use of LPG for applications other than cooking was not noticed during the survey. LPG cook stoves used in the country vary widely in make and quality.

End-use devices efficiencies

Efficiencies of the end-use devices used as cooking appliances vary significantly, as shown in Table 3. These impact the amount of fuel used for getting similar amount of useful energy.

As shown in Table 4, useful energy delivered using different fuels, after considering the end-use device efficiency, also varies considerably.

It can be seen that to get the same amount of useful energy, 1 kWh of electricity replaces 1.74 kg of fuelwood, whereas 1 kg of LPG replaces 14.7 kg of fuelwood.

Table 3

THERMAL EFFICIENCY OF SELECT COOKING DEVICES THAT USE DIFFERENT FUELS

Fuel/stove	*Device*	*Efficiency* (%)
Electricity	Rice cooker	78–94
Biogas	Biogas stove	55
Liquefied petroleum gas (LPG)	LPG stove	60
Kerosene	Wick stove Pressure stove	36 40
Biomass	Traditional stove	8–18
Biomass	Improved stove	20–35

Source: Bhutan Energy Data Directory, 2005

Table 4

USEFUL ENERGY DELIVERED USING DIFFERENT FUELS

Fuel	*Calorific value* (kcal/kg)	*End-use device efficiency* (%)	*Useful energy delivered* (kcal)
Fuelwood	3500	12	420
Electricity	860	85	731
Liquefied petroleum gas	11 000	55	6050

Industrial sector

The development path followed by Bhutan has led to a spurt in industrial activities in the past few decades. 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. The industrial sector is driven by the fact that Bhutan has lowest electricity tariffs in the region, thus, making electricity-intensive industries profitable. Most industries are located in the southern Dzongkhag of Chukha, Samtse, Sarpang, and Thimphu, which are closer to the Indian border and also to Chukha Hydropower Plant.

Three large industries, namely, Bhutan Calcium and Carbide Ltd, Penden Cement Authority Ltd, and Bhutan Ferro Alloys Ltd, are the major consumers of energy in Bhutan. These industries are also the major consumers of electricity in the country. In 2005, they together consumed 334 MU of electricity, which is 81% of the total electricity consumed in the industrial sector.

The industrial sector consumes 25.5% of the total energy and is the largest consumer of electricity in the country. In 2005, the sector consumed 410 MU of electricity (about 64.7% of the total electricity consumed in the country). Other fuels that are used in the sector include coal, furnace oil, kerosene, LDO, and fuelwood.

Growth rate of value added in the industry (% per year) from 1994 to 2004 is given in Table 5.

Sectoral share of GDP (% per year) in various sectors is given in Table 6.

Table 6

SECTORAL SHARE OF GROSS DOMESTIC PRODUCT (% PER YEAR)

Year	*Agriculture*	*Industry*	*Services*
1980	56.7	12.2	31.1
2000	32.5	32.4	35.1
2001	49.4	5.0	45.6
2002	31.7	34.9	33.4
2003	31.0	35.1	33.9

Source *Asian Development Outlook, 2005*

Transport sector

The transport sector in Bhutan is characterized by the dominance of road and air transport. Being a hilly country, rivers generally do not run very deep, and hence, the use of waterways for transport is negligible. In some places, ropeways are being used for the transportation of logs and other materials.

Motorization trends in Bhutan

Bhutan has experienced high levels of motorization in the recent years. The motor vehicle fleet has more than doubled in the last decade (1997–2007), with the number of registered motor vehicles rising from 13 584 at the end of 1997 to 30 733 vehicles by the end of March 2006. Thus, the number of registered motor vehicles has exhibited an average annual growth rate of 10.4% during this period.

Energy consumption in the transport sector accounts for 13.7% of the total energy consumption. The energy is used in the transport sector for mainly road transport, which uses diesel and petrol. In 2005, the sector used about 48 703 kilolitres of diesel and 13 879 kilolitres of petrol. About 1145 kilolitres of the aviation turbine fuel was consumed during the same period. The country is fully dependent on transport fuel imports, and the imports are showing a rapid upward trend. 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.

Besides the rising cost of petrol and diesel, complete dependence of the transport sector on these imported fuels is an area of concern for future, from the energy security perspective.

Commercial and institutional sector

Energy consumption by the commercial and institutional sector, consisting of commercial establishments, such as shops and hotels, and institutional establishments, such as monasteries, government offices, schools, hospitals, and so on, accounts for 10.2% of the total energy consumption. The sector is also an important electricity consuming sector, consuming 119 MU in 2005, which is about 18.75% of the total electricity consumption in the country. Besides electricity, fuelwood, along with LPG and kerosene, is also widely used.

Table 5

GROWTH RATE OF VALUE ADDED IN THE INDUSTRY

Year	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*
Growth rate (% per year)	13.9	17.0	5.8	3.5	8.5	12.2	3.9	13.7	17.9	7.3	9.6

Source *Asian Development Outlook, 2005*

Tourism industry

Tourism is Bhutan's third largest contributor to economy, after electricity and industry. This sector is showing rapid growth, with substantial increase in the number of tourists in the past few years. Arrival of tourists in Bhutan, by year, is shown in Figure 7.

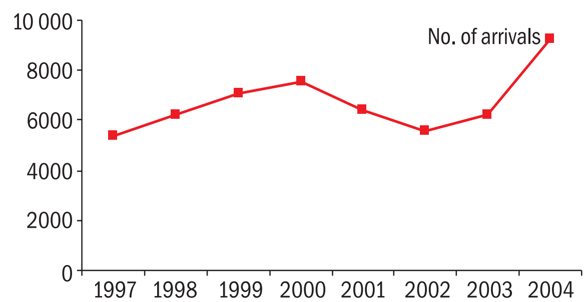


FIGURE 7 ANNUAL ARRIVALS IN BHUTAN

Source *DoT (2005)*

Agriculture sector

Traditionally, Bhutanese agriculture comprised subsistence farming, and rural households were self-sufficient in food production. Bhutan's agricultural sector, which employs about 79% of the population but has only about 7% of the land under cultivation, is driven substantially by the non-commercial energy in the form of human labour and animal power.

Agriculture activities are constrained in the region, which is mostly mountainous. Because of the mountainous terrain, it is difficult to have large farmlands and mechanized farming. Besides, large tracts of land are under forests and reserved parks. Lack of access to market, absence of approach roads from farms to marketplace, and lack of storage and post-harvest processing facilities are also some of the constraints faced by the agriculture sector. Recent years have seen improvement in these facilities, and agriculture is slowly shifting towards growing horticulture crops and cultivating cash crops like potato, rice, and so on. Cold storage facilities have been created at Paro (close to airport) and Phuentsholing for storing apples and oranges before exporting them. Export of fruits and potatoes has shown an increasing trend in the recent years.

Energy use in the agriculture sector

The agriculture sector is mainly dependent on human and animal power. However, with recent developments, the sector is increasingly using state-of-the-art energy resources.

Electricity in the agriculture sector is mainly used for pumping. The sector consumed about 0.8 MU of electricity in 2005, which is about 0.13% of the total electricity consumption of the country in 2005. Other fuels used in the sector include diesel (about 544 kilolitres) for power tillers, which are multipurpose devices for farmers. Subsidized power tillers are supplied by the Ministry of Agriculture. However, power tillers are predominantly used in few Dzongkhags only (Table 7).

Cardamom drying, oil extraction, and rice milling are some of the other activities that use energy resources for post-harvest processing. Overall, commercial and modern energy resources do not find much use in the agriculture sector compared to other sectors. Their use is likely to remain low in future too, as agriculture is constrained by natural factors such as mountainous terrain. With only 7% of the land under cultivation and rising demand for land for other uses such as industries and urban settlements, agriculture is likely to continue to be at the same level as today.

Energy situation in Bhutan in the regional context

The per capita energy and electricity supply are still way below the world average (Table 8). However, in a regional context, Bhutan emerges as the leading country in South Asia, both in terms of total primary energy supply as well as electricity supply per capita per year.

SUMMARY OF MAJOR ISSUES FOR INTEGRATED ENERGY PLANNING

- Heavy dependence of the residential sector on fuelwood would be a cause of concern in the years to come. Experience shows that because of electrification, fuelwood consumption reduces by about 30%–35%.

Table 7

NUMBER OF FARM MACHINERY SUPPLIED TO VARIOUS DZONGKHAGS (FROM 1983 TO MARCH 2005)

Dzongkhag	*Tractor*	*Power tillers*	*Power chain saw*	*Water pump*	*Power sprayers*	*Paddy transplanter*	*Power thresher*	*Total*
Thimphu	49	201	41	54	57	2	26	430
Paro	66	436	28	83	32	34	82	761
Haa	2	58	1	0	0	0	7	68
Chukha	8	23	45	3	0	0	0	79
Samtse	4	24	6	1	1	0	1	37
Punakha	5	226	2	33	0	8	29	303
Gasa	0	24	0	0	0	0	0	24
Wangdue	14	209	23	27	5	4	17	299
Tsirang	0	37	0	3	2	0	6	48
Dagana	0	22	0	2	0	0	0	24
Bumthang	21	134	12	0	2	1	11	181
Trongsa	5	95	4	0	0	0	0	104
Zhemgang	1	30	0	0	0	0	0	31
Sarpang	6	88	1	1	2	0	5	103
Lhuntse	1	10	3	2	0	0	0	16
Mongar	6	23	7	2	0	0	0	38
Trashigang	12	29	13	4	1	2	1	62
Yangtse	4	10	1	0	0	1	0	16
Peragatshel	4	31	0	1	0	1	1	38
S/Jongkhar	5	7	8	0	0	0	3	23
Total	213	1717	195	216	102	53	189	2685

Table 8

COMPARISON OF PER CAPITA ENERGY AND ELECTRICITY SUPPLY

	Per capita energy supply (TOE/capita/year)	*Per capita electricity supply* (kWh/capita/year)
Bangladesh	0.16	140
Bhutan	0.63	1174
India	0.53	457
Myanmar	0.28	104
Nepal	0.34	69
Pakistan	0.49	425
Sri Lanka	0.49	345
World	1.77	2516

Source *IEA (2006)*

- The pattern of energy consumption by the industrial sector would play a major role in energy management.
- Rapidly growing transport sector is entirely dependent on imported fossil fuels, and fuel consumption in this sector is a cause for concern mainly due to its impact on balance of trade and likely increase in pollution in the urban area.
- The commercial sector is showing substantial growth potential and is the third largest consumer of energy.
- The agriculture sector consumes relatively less commercial energy.

CHAPTER 3

Energy scenarios for Bhutan 2020

MODELLING DEMAND–SUPPLY SCENARIOS

Energy is one of the major drivers of economic growth. Bhutan, one of the smallest economies based on agriculture and forestry, is expected to experience rapid economic growth and development in future, and the country's requirements for energy and supporting infrastructure would increase as well. In view of this, an integrated assessment of energy demand was carried out, along with determining the possible energy pathways and their impacts on infrastructure requirements.

DEMAND ANALYSIS USING LEAP

The energy demand projections have been carried out for a period up to 2020 for the residential, industrial, commercial and institutional, and transport sectors. The Long-range Energy Alternatives Planning model, or LEAP, is a scenario-based energy–environment modelling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, and price, among other factors. LEAP is useful in projecting energy supply and demand situations in order to provide a glimpse of future patterns, identifying potential problems, and assessing the likely impacts of energy policies. LEAP can assist in examining a wide variety of projects, programmes, technologies, and other energy initiatives, and arriving at strategies that best address environmental and energy problems. The main advantages of LEAP are its flexibility and ease-of-use, which allow decision-makers to move rapidly from policy ideas to policy analysis, without having to resort to more complex models.

LEAP model projections have been made under four different scenarios for electricity, biomass, coal, liquefied petroleum gas (LPG), petrol, diesel, kerosene, and aviation turbine fuel (ATF).

DEFINING SCENARIOS

Energy scenarios are frameworks for analysing future energy perspectives, including various combinations of technology options and interventions. Scenarios help to visualize how the future is going to unfold under different assumptions. They are particularly helpful in investigating alternative future developments and their implications. Scenarios can be based on assumptions that are compatible with sustainable development goals like improved efficiencies, adoption of advanced energy supply technologies with low environmental impacts, and efficient use of natural resources. To have a look at the relative position of an economy, scenarios can also be based on different economic growth trajectories.

In the context of building scenarios for projecting energy demand for Bhutan, the following four scenarios have been considered.

- Business-as-usual scenario, or BAU
- Energy-efficient scenario, or EE
- High growth scenario, or HIG
- High growth coupled with energy efficiency, or HIGEE

The subsequent sections briefly define the broad characteristics of the four scenarios. Detailed explanation of the assumptions for different sectors is outlined in the later part of the analysis.

Business-as-usual scenario

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. In the BAU scenario, an average real gross domestic product (GDP) growth rate of 7.7% (uniform over the entire modelling frame, that is, between 2005 and 2020) has been considered. Sectoral variables grow with historical trends, and the specific energy consumption of different sectoral activities remains at its current levels (2005).

Energy-efficient scenario

This scenario takes into account the specific energy efficiency measures spanning across all sectors. These measures are expected to be adopted uniformly across all sectors from 2008/09. Efficiency improvements in existing devices and shifts to modern efficient technologies are the basic characteristics of this scenario. The sectoral variables are assumed to grow as per the BAU rates.

High growth scenario

This scenario assumes a high GDP growth rate of 10% (uniform over the modelling time frame, 2005–20) compared to the GDP growth rate of 7.7% assumed in the BAU scenario. The HIG scenario is characterized by a shift of the economy towards the growth led by the industrial and service sector, with the latter dominating in terms of its contribution to GDP. Specific energy consumption figures for different sectors remain at the BAU levels, wherein the total energy consumption for different fuels under different sectors is much higher due to higher growth of the sectoral variables.

High growth coupled with energy efficiency scenario

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, steering the economy towards the most energy-efficient path.

ENERGY DEMAND PROJECTIONS, BY SECTOR

Residential sector

The energy demand projections for the residential sector under different scenarios have been made for urban and rural households that use four different categories of fuel: (1) electricity, (2) LPG, (3) fuelwood, and (4) kerosene.

While Bhutan is aiming at 100% rural electrification by 2013, till electricity extends to all rural areas, lighting, cooking, and heating will continue to be primarily dependent on fuelwood. The distribution of households by fuel type is presented in Table 1.

Table 1

PERCENTAGE OF HOUSEHOLDS USING DIFFERENT FUELS (2004/05)

	Percentage of urban households	*Percentage of rural households*	*Percentage to total households*
Electricity			
Cooking	82.2	28.5	44.89
Lighting	96.4	40.0	57.2
Liquefied petroleum gas			
Cooking	77.1	20.3	37.56
Fuelwood			
Cooking + space heating	9.90	75.28	54.72
Kerosene			
Cooking	9.54	8.75	8.90
Lighting	2.6	51.3	36.52

The pattern of using fuels is not same in rural and urban areas. Urban households depend less on kerosene and fuelwood due to relatively high usage of electricity and LPG. In rural areas, a considerable proportion of the households still depends on traditional fuels due to non/less availability of modern cleaner fuels.

The total consumption of these fuels, by and large, depends on the growth rate of the sectoral variables, the intensity of their use, the future penetration rate of devices/modern fuels, and their usage pattern among different categories of households. Table 2 gives the assumptions under various scenarios for determining the major sectoral variables.

The energy demand projection for the domestic sector is confined to regular households only, although the census divides the households into regular, institutional, and transient. This is due to the fact that the household break-up by activities and fuel type is available only for regular households. According to Population and Housing Census of Bhutan 2005, a total of 126 115 regular households have been recorded in Bhutan. They account for 91% of the total resident population (634 982) and 86.3% of the total population (resident plus floating) of Bhutan. The average weighted household size is estimated to be 4.6. One year before the census, the natural growth rate of population was found to be 1.3%. This data is assumed to remain constant over the modelling time frame under all scenarios. The projected population up to 2020, based on the above details, is given in Annexure 3.1. Rural electrification, which at present stands at 40%, is assumed to take place uniformly across all the scenarios, according to the plans laid down in the Rural Electrification Master Plan (REMP); urban and rural electrification is expected to reach the 100% level by the end of the Tenth Five-year Plan (the current target is also to achieve 100% rural electrification by the end of the Tenth Five-year Plan). As far as the distribution of households in rural and urban areas is concerned, Census 2005 reports that 30.4% of the total population lives in urban areas and the rest 69.6% lives in rural areas. Given the historical trend of urban migration (prior to 2000), *Vision 2020* predicts that urban population will equal rural population by the end of 2020, which also holds true for the BAU and EE scenarios. However, in the other two scenarios

Table 2

ASSUMPTIONS FOR SECTORAL VARIABLES FOR ESTIMATING ENERGY DEMAND IN RESIDENTIAL SECTOR

Variables	*BAU scenario*	*EE scenario*	*HIG scenario*	*HIGEE scenario*
Analysis based on regular resident households	Yes	Yes	Yes	Yes
Annual population growth rate for regular resident households	1.3% (Census 2005)	1.3% (Census 2005)	1.3% (Census 2005)	1.3% (census 2005)
Household size				
Rural	4.7	4.7	4.7	4.7
Urban	4.3	4.3	4.3	4.3
Urban–rural population ratio	Urban population = rural population by 2020 (*Vision 2020*)	Urban population = rural population by 2020 (*Vision 2020*)	Urban population = 65% of total regular resident population (based on recent migration trends during 2000–05)	Urban population = 65% of total regular resident population (based on recent migration trends during 2000–05)
Rural electrification	According to Accelerated Rural Electrification Programme – end of the Tenth Five-year Plan	According to Accelerated Rural Electrification Programme – end of the Tenth Five-year Plan	According to Accelerated Rural Electrification Programme – end of the Tenth Five-year Plan	According to Accelerated Rural Electrification Programme – end of the Tenth Five-year Plan
Urban electrification	End of the Tenth Five-year Plan	End of the Tenth Five-year Plan	End of the Tenth Five-year Plan	End of the Tenth Five-year Plan

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency

(HIG and HIGEE), the recent migration pattern has been taken into account (2000–05 and then annualized), which shows that by 2020, about 65% of the total population will live in urban areas.

The pattern and type of fuel usage are not uniform across different categories of households and are found to vary significantly. The usage is largely governed by the availability and paying capacities of the households. With economic growth and access to cleaner fuels, the usage pattern is assumed to change significantly, especially in the HIG scenario. Table 3 shows how the usage pattern is expected to change across households and scenarios.

With complete electrification envisaged for rural and urban areas by 2013, almost all the households will be using electricity. According to TERI survey, electricity in urban areas is used for lighting, cooking, space heating, washing, refrigeration, and for other infotainment devices like TV and radio. On the other hand, in rural households, the usage is confined to lighting, cooking, and for running television and radios. The usages of these devices across economies by the rural and urban households have been obtained from the Bhutan Census Report.

Improvement in road conditions, increased per capita income, and the need to switch to cleaner fuels could well lead to a 100% penetration of LPG in rural and urban households in the HIG scenario. However, in the baseline and EE scenarios, it is assumed that by 2020, penetration would reach a maximum of 88.5%, based on a simple average of the existing and the HIG percentages. Kerosene consumption in the HIG and HIGEE scenarios is assumed to come down to 0% because of faster switching to cleaner fuels, with 4.65% being the 'end-of-model' period value under the BAU and EE scenarios (simple average). As evident from Table 3, fuelwood is being used by 10% of the urban households. With access to modern fuels, this dependence is assumed to come down to 5% by 2020 under the BAU and EE scenarios and to 1% in the extreme scenarios.

Fuelwood and kerosene, which at present are consumed by more than 50% of the regular households, are later to be replaced by electricity and LPG. Kerosene usage will experience a steep fall in the HIG scenario, where the percentage usage will come down to 10% by 2020 as against 51% in 2005. Fuelwood usage will drop to 30% in the HIG scenario as against 40% in the BAU and EE scenarios. The use of LPG, which is at present used by only 20.3% of the households, is assumed to reach 35% in the BAU and EE scenarios and 50% in the HIG and HIGEE scenarios. The energy

Table 3

FUEL USE PATTERN, BY RURAL AND URBAN HOUSEHOLDS (%)

	BAU		EE		HIG		HIGEE	
	2005	2020	2005	2020	2005	2020	2005	2020
Urban								
Electricity	96.4	100	96.4	100	96.4	100	96.4	100
Liquefied petroleum gas (LPG)	77.1	88.5	77.1	88.55	77.1	100	77.1	100
Fuelwood	10	5.5	10	5.5	10	1	10	1
Kerosene	9.3	4.65	9.3	4.65	9.3	0	9.3	0
Rural								
Electricity	40.1	100	40.1	100	40.1	100	40.1	100
LPG	20.3	35	20.3	35	20.3	50	20.3	50
Fuelwood	75	40	75	40	75	30	75	30
Kerosene	51	30.5	51	30.5	51	10	51	10

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency

intensities (consumption of fuels per household) for the above-mentioned fuels by end-use devices and scenarios are presented in Table 4.

Energy demand for the residential sector

The residential sector consumes about 49% of the total energy consumed in the economy, the largest amongst all sectoral shares. The relatively high energy consumption is on account of the

Table 4

ENERGY INTENSITIES BY END USE AND FUEL TYPE

		BAU	*EE*[a]	*Percentage improvement*	*Source*
Urban households					
Electricity	Lighting (kWh/hh/annum)	324	86.4	73	<http://www.eartheasy.com/live_energyeff_lighting.htm>
	Cooking and heating (kWh/hh/annum)	1256	1141.07	9	<http://www.clasponline.org/productsummary.php?country=China&product=Rice%20Cooker>
	Washing machine (kWh/hh/annum)[b]	150	150	0	
	Refrigerators (kWh/hh/annum)[b]	416	416	0	
	TV (kWh/hh/annum)[b]	152	152	0	
	VCD/DVD/tapes (kWh/hh/annum)[b]	21.66	21.66	0	
LPG	Cooking (kg/hh/annum)	88.3	84.09	5	<http://www.mahaurja.com/pdf/TipDS.pdf>
Fuelwood	Cooking + space heating (kg/hh/annum)	4336	2955	32	<http://web.mit.edu/d-lab/DlabIII06/study-stove-shastri.pdf>
Kerosene	Cooking (litre/hh/annum)	22	22	0	
	Lighting (litre/hh/annum)	119	119	0	
Rural households					
Electricity	Lighting (kWh/hh/annum)	341	90.33	74	http://www.eartheasy.com/live_energyeff_lighting.htm
	Cooking and others (kWh/hh/annum)	533	510.34	4	http://www.clasponline.org/productsummary.php?country=China&product=Rice%20Cooker
	TV (kWh/hh/annum)[b]	152	152	0	
	VCD/DVD/tapes (kWh/hh/annum)b	21.66	21.66	0	
LPG	Cooking (kg/hh/annum)	41	39	5	http://www.mahaurja.com/pdf/TipDS.pdf
Fuelwood	Cooking + space heating + fodder cooking (kg/hh/annum)	9359	6720 by 2008 and 5519 by 2020	41	http://www.ias.ac.in/currsci/oct102004/926.pdf
Kerosene	Cooking (L/hh/annum)	146	146	0	
	Lighting (L/hh/annum)	30	30	0	

[a] Efficiency applicable from 2008, [b] DoE, Bhutan; LPG – liquefied petroleum gas

Source *TERI primary survey (IEMMP project)* significant dependence of the sector on fuelwood. Fuelwood share in the total energy basket in 2005 was 92%. The share of electricity was 4%, while that for LPG and kerosene, it was close to 2.5% and 1.5%, respectively. The demand for different types of fuels under four scenarios is given in Figures 1–4. The focus of the proposed sustainable development strategy would be on reducing fuelwood share in the residential sector. This can be achieved by the (1) introduction of high efficiency cook stoves and (2) switching to modern fuels like LPG, electricity, and renewable energy like solar cooking, biogas-based cooking, and home heating systems.

Energy demand in the residential sector, by fuel

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. Energy-saving measures can help reduce electricity consumption by 27%.

Fuelwood

The present demand for fuelwood is 490 000 tonnes, which 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.

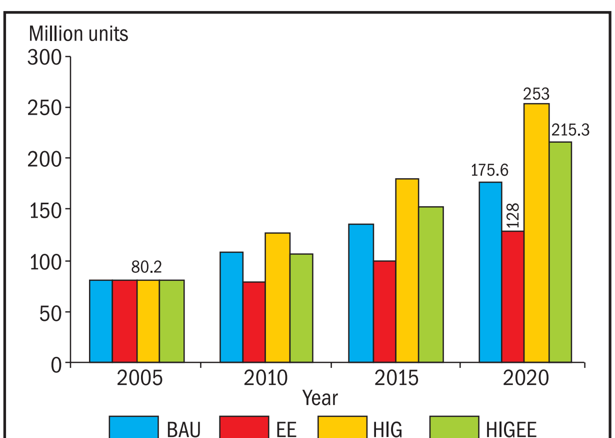


FIGURE 1 ELECTRICITY DEMAND

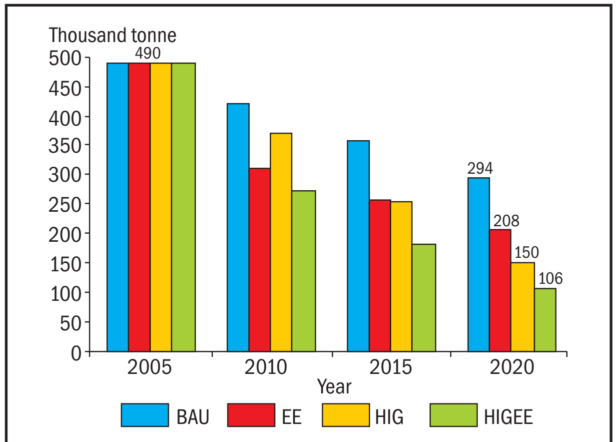


FIGURE 2 FUELWOOD DEMAND

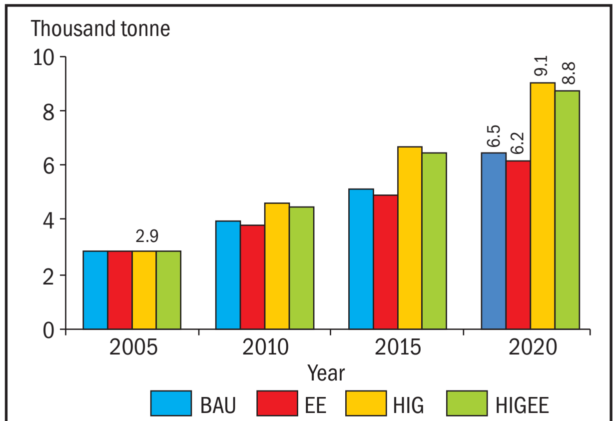


FIGURE 3 LPG DEMAND

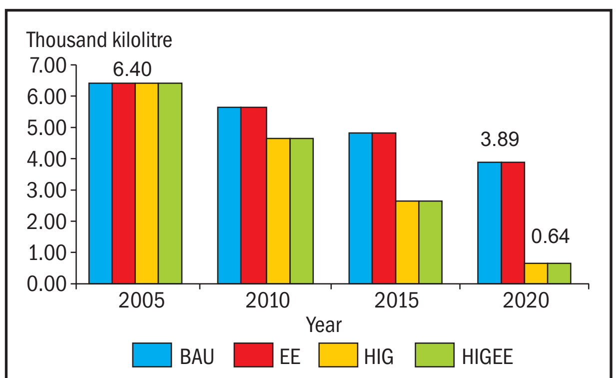


FIGURE 4 KEROSENE DEMAND

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. Demand side management, particularly in household cooking, can help achieve an efficiency level of 30%.

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 2900 tonnes.

In the HIG scenario, consumption could reach 9000 tonnes. Achievable efficiency improvement is 5%, as the devices in use do not have a scope for improvement, which can lead to the reduction in the consumption, with the figures in the EE and HIGEE scenarios being 6200 and 8800 tonnes, respectively.

Kerosene

Kerosene consumption is dominant in rural households vis-à-vis urban households, with the total kerosene consumption in 2005 being 6400 kilolitres.

With rural electrification, kerosene consumption is expected to come down to 3890 kiloliters in the BAU and EE scenarios and to 640 kilolitres in the HIG and HIGEE scenarios.

Industrial sector

Till 1998, the industrial sector in Bhutan played a limited role in the country's economic development. The sectoral (secondary sector) GDP to country's total GDP was close to 30% (between 1990 and 1998). Thereafter, the sectoral contribution improved, and between 1999 and 2002, the sectoral share increased from 36.5% to 38%. However, after 2002, it experienced a declining trend, reaching as low as 35% in 2004.

In Bhutan, industries are broadly classified under three categories: (1) private, (2) joint ventures, and (3) public. The number of private sector units has grown considerably between 2000 and 2004. From 5678 in 1999, the private sector units increased to 15 489 by 2004. The joint and public sectors did not experience much of a change in the number of establishments during the said period. Joint sectors increased from 5 to 15 units, with closing down of some of the existing ones, while the public sector grew marginally at 17 units between 1999 and 2004. Table 5 shows the trend in the number of industries under the three categories.

Recent data shows an increasing trend for private sector industries. Private sector industries grew from 15 489 in 2004 to 24 417 in 2006, an increase of 57% in two years. Notably, the large-scale industries grew from 47 in 2004 to 72 in 2006. Substantial growth can be noticed in small-scale industries, which ranged from 628 in 2004 to 1660 in 2006, logging more than 160% growth in two years.

Table 5

GROWTH IN INDUSTRIES UNDER THREE CATEGORIES

Year	Private	Joint ventures	Public
1999	5 678	5	33
2000	8 959	23	43
2001	12 807	24	47
2002	13 833	24	47
2003	14 627	15	50
2004	15 489	15	50
2005	17 181	15	61
2006	24 417	11	77

Source *Bhutan Statistical Yearbook, 2007*

Within the industrial sector, the manufacturing and mining industries play a crucial role in determining the present and future energy demand. According to the MoEA (Ministry of Economic Affairs) estimates for 2004, a total of 874 units existed under the mining and manufacturing industries, of which 858 were completely under the private sector. The rest 16 were under joint and public sector undertakings. Table 6 shows the growth in the number of units under the production and manufacturing category (between 2002 and 2004).

Table 6

GROWTH IN THE NUMBER OF PRODUCTION AND MANUFACTURING UNITS

Year	Private	Joint	Public
2002	570	6	10
2003	712	6	12
2004	858	5	11
2005	967	5	13
2006	1113	5	15

Source *Statistical Yearbook of Bhutan, 2007*

Within the industrial sector, the construction activities have been the major contributor to growth and contributed between 13% and 18% of the GDP. The manufacturing sector has accounted for around 8%–9% of the GDP, while the electricity, water, and gas sectors have been close to 10% of the GDP (Figure 5).

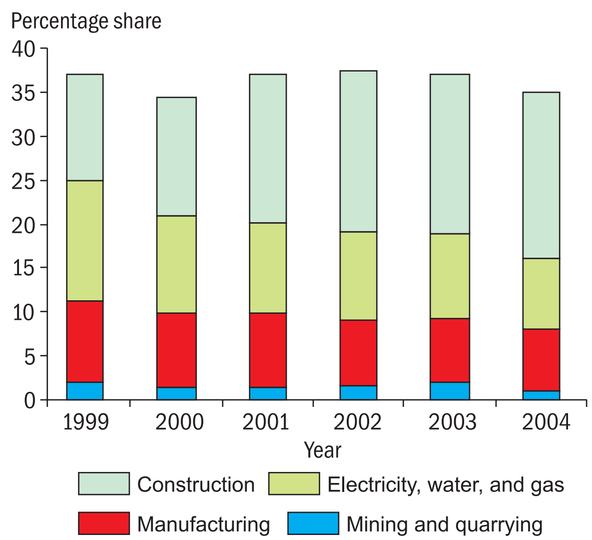


FIGURE 5 INDUSTRIAL GDP AS A PERCENTAGE SHARE TO TOTAL GDP

Source *Statistical yearbook of Bhutan (2005), National Statistics Bureau, RGoB, Bhutan*

Categorization of industries for energy projections

In Bhutan, the Bhutan Power Corporation (BPC) categorizes electricity consumers under the three following heads.

1 Low voltage consumers (230 volts and 415 volts)
2 Medium voltage consumers (6.6 kV, 11 kV, and 33 kV)
3 High voltage consumers (66 kV and above)

The low voltage consumers are mostly from the residential and commercial sectors and a number of small-scale industries. Medium-scale and some small-scale industries come under the medium voltage category. Finally, heavy, power-intensive industries come under the high voltage category. As per the records of the BPC (2005), altogether there are three high voltage industries, which consume 56% of the total electricity, followed by 22 medium voltage industries consuming 8%, and 122 low voltage industries consuming roughly about 3% of the total electricity. As far as the energy projection for the sector is concerned, analysis has been done separately for both energy-intensive and non-energy-intensive industries.

Given the above complexities, the criterion used to identify energy-intensive industries is the share of fuel cost to total cost of production. Based on the figures published in the Census of Manufacturing Industries 2001, the average share of energy expenditure to total was estimated at the sectoral level. The relative position of the industries (whether energy intensive or not) is classified based on the fact whether the share of the cost of fuel to total cost of production exceeds the economy's average. Data related to fuel and total costs was not available for the iron and steel plant. As a result, the data for the same has been assumed to be similar to that of the Indian industry for 2000. The value obtained for the industry was found to be 0.17, which is above the average value calculated for Bhutan (0.055). Table 7 shows the list of industries, which can be categorized as energy intensive.

Table 7

INDUSTRIES UNDER ENERGY-INTENSIVE CATEGORY

Industries	*Ratio of fuel purchased/total cost of production*
Cement	0.2828
Dolomite crushing	0.2682
Gypsum mining	0.2568
Marble mining	0.2127
Rice mill	0.2084
Stone crushing	0.1841
Ferro alloys	0.1102
Salt iodization	0.1059
Candle factory	0.0988
Nursery plantation	0.0892
Plaster of Paris	0.0890
Oil mill	0.0868
Dolomite powder	0.0793
Rosin and turpentine	0.0702

However, the detailed plant-level data could only be obtained for the following six major operating units.

1 Bhutan Ferro Alloys Ltd, or BFAL
2 Bhutan Calcium Carbide Ltd, or BCCL
3 Penden Cement Authority Ltd, or PCAL
4 Druk Cement Company Ltd, or DCCL
5 Druk Iron and Steel Ltd, or DISL
6 Bhutan Steels Ltd, or BSL

The rest are classified under the category of non-energy-intensive industries. These industries are further classified as: (1) existing and (2) upcoming units. 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 in detail.

Energy-intensive industries

Of the six industries listed above, the first three are listed under the high voltage category consumers, while the rest are under the medium voltage category. In 2005, these six industries consumed electricity equivalent to 377 million kWh (close to 90% of the total sectoral electricity consumption of 420 million kWh and 62% of the country's electricity consumption of 615 million kWh).

The energy-intensive industries indicated above are export oriented, with India as their major international market. The geographical pattern of the sales of four energy-intensive industries is presented in Table 8.

Table 8

SALES OF PRODUCTS OF POWER-INTENSIVE INDUSTRIES

Industry	*1993* (million Nu)	*1996* (million Nu)	*1999* (million Nu)	*2002* (million Nu)	*2004* (million Nu)
BFAL					
Exports to India		497.14	534.73	643.16	712.85
Exports to other countries		0	0	0	24.19
Sales within Bhutan		0	0	0	11.15
Total sales		497.14	534.73	643.16	748.19
PCAL					
Exports to India	95.92	124.2	433.67	258.15	265.14
Exports to other countries	2.1	0.27	0	0	0
Sales within Bhutan	15.73	85.06	250.78	556.12	586.69
Total sales	113.75	209.53	684.45	814.27	851.83
BCCL					
Exports to India	355.58	542.59	546.76	704.73	714.67
Exports to other countries	0.55	0	0	0	0
Sales within Bhutan	0.69	18.62	22.56	2.78	16.92
Total sales	356.82	561.21	569.32	707.51	731.59
DISL					
Exports to India					26 802
Exports to other countries					0
Sales within Bhutan					0
Total sales					26 802

BFAL – Bhutan Ferro Alloys Ltd; BCCL – Bhutan Calcium Carbide Ltd; PCAL– Penden Cement Authority Ltd; DISL – Druk Iron and Steel Ltd

Source *UNDP (2005); Bhutan Trade Statistics (2005)*

PCAL, the largest cement plant in Bhutan, caters to Bhutan, with 70% of its sales in the domestic market due to the demand from under construction hydropower project. This domestic demand is likely to taper off in the coming years with the completion of the Tala Hydel Power Project. This can, to some extent, affect the business of the plant, and if no substantial demand is generated, the plant has to depend on the market of neighbouring countries, especially Nepal, Bangladesh, and India. Notwithstanding increasing liberalization of these economies, there is a possibility of having to cope with greater competition. For example, there were concerns that calcium carbide exports from China were driving down the price of calcium carbide in India, thereby posing a threat to Bhutan's calcium carbide exports. This implies that the cement and other industries have to improve their production efficiency to remain competitive internationally.

According to the list provided by the BPC, a total of 55 industries (Annexure 3.2) have been given license to operate in Bhutan and are expected to come on stream between 2008 and 2009. Of these 55 industries, nine industries fall under ferro-alloy category, two under steel rolling, four under steel ingots, and one each is categorized under cement and magnesium metal. The production capacities of the existing energy-intensive industries and the upcoming ones are indicated in Table 9.

These industries mostly consume electricity as fuel in production. Significant coal usage is found in cement plants. As far as the consumption of petroleum products is concerned, industries are found to consume high speed diesel (HSD), furnace oil (FO), and light diesel oil (LDO). Of the total industrial consumption of HSD (10 120 kilolitres) in 2004, energy-intensive industries consumed 1000 kilolitres, approximately 10% of the total industrial usage. A considerable amount of FO (93% of the total industrial use) is also used. However, the usage of LDO is low compared to total industrial usage, which is approximately 3%. Compared to these fuels, electricity is used extensively in these very industries.

Table 9

PRODUCTION OF EXISTING AND UPCOMING ENERGY-INTENSIVE UNITS

Industries	BAU		EE		HIG		HIGEE		Comments
	2005	2020	2005	2020	2005	2020	2005	2020	
Bhutan Ferro Alloys Ltd	27 600	45 300	27 600	45 300	27 600	45 300	27 600	45 300	Increased production from 2006, as reported
Bhutan Calcium Carbide Ltd	22 000	39 280	22 000	39 280	22 000	39 280	22 000	39 280	Increased production from 2007, as reported in energy audit
Penden Cement	272 075	285 600	272 075	285 600	272 075	285 600	272 075	285 600	Increased production from 2008, as reported
Druk Cement	23 725	23 725	23 725	23 725	23 725	23 725	23 725	23 725	
Bhutan Steels	17 200	27 500	17 200	27 500	17 200	27 500	17 200	27 500	Increased production from 2006, as reported
Druk Iron and Steel Plant	29 200	36 000	29 200	36 000	29 200	36 000	29 200	36 000	Increased production from 2006, as reported
Upcoming ferro-alloys	0	87 200	0	87 200	0	87 200	0	87 200	Increased production from 2008, as reported
Upcoming steel plants	0	300 000	0	300 000	0	300 000	0	300 000	Increased production from 2008, as reported
Cement	0	1 000 000	0	1 000 000	0	1 000 000	0	1 000 000	Increased production from 2009, as reported
Upcoming other metal industries	0	69 500	0	69 500	0	69 500	0	69 500	Increased production from 2008, as reported

Energy equivalent of petroleum products use is 9000 tonnes of oil equivalent (TOE), while that of electricity is 33 000 TOE. The specific electricity consumption (electricity per tonne of finished output) for these industries is presented in Table 10.

Energy demand for different fuels by energy-intensive industries

As mentioned earlier, these energy-intensive industries mostly consume electricity and coal. The demand for these inputs by energy-intensive industries is presented in Figures 6 and 7.

Electricity

The present total electricity consumption by energy-intensive industries is 377 million kWh and is expected to reach 2192 million kWh by 2020 under the BAU scenario.

Electricity saving potential is close to 10%, which can lead to reduced consumption to the tune of 1994 million kWh. Going by the present export tariff, exports of saved electricity (@ 200 million kWh) can fetch foreign revenue close to Nu 400 million approximately (Figure 6).

Total electricity consumption by energy-intensive industries will go up to 2782 million kWh by 2020 under the HIG scenario. This estimate is mainly based on the assumption that all types of new industries will be allowed. The saving potential under this scenario is about 210 million kWh.

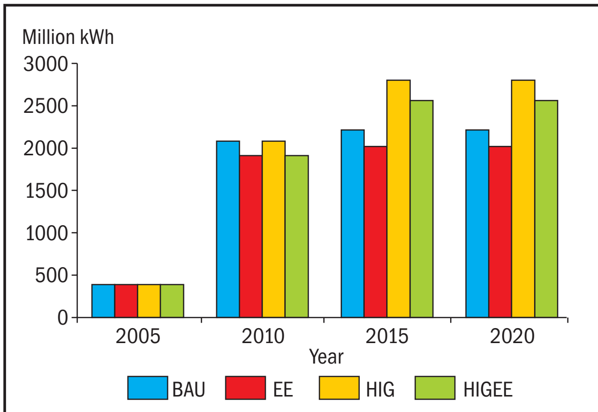


FIGURE 6 ELECTRICITY DEMAND IN ENERGY-INTENSIVE INDUSTRIES

Table 10

SPECIFIC ELECTRICITY CONSUMPTION

	Electricity consumption (kWh/tonne)				
	BAU	*EE*[a]	*HIG*	*HIGEE*[a]	
Bhutan Ferro Alloys Ltd	6824	6500	6824	6500	Efficiency value based on best application of Norwegian technology in Indian market
Bhutan Calcium Carbide Ltd	4500	4375	4500	4375	Efficiency value based on energy audit of TERI
Penden Cement	184.1	88	184.1	88	Five-stage pre-heater pre-calcinator (National Council for Cement and Building Materials [NCCBM])
Druk Cement	116	88	116	88	Five-stage pre-heater pre-calcinator (NCCBM)
Bhutan Steels	735	662	735	662	Based on 10% motor efficiency (Energy Handbook of TERI)
Druk Iron and Steel Plant	800	650	800	650	Based on efficiency improvement measures for electric arc furnace (EAF)-based steel plants (LBNL)
Upcoming ferro-alloys	9000[b]	8500[b]	9000[b]	8500[b]	Efficiency value based on best application of Norwegian technology in Indian market
Upcoming steel plants	728[b]	650[b]	728[b]	650[b]	Based on efficiency improvement measures for EAF-based steel plants (LBNL)
Cement	157[b]	88[b]	157[b]	88[b]	Five-stage pre-heater pre-calcinator (NCCBM)
Upcoming other metal industries	4659[b]	4659[b]	4659[b]	4659[b]	

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency
[a] Energy saving from 2008, [b] Weighted average

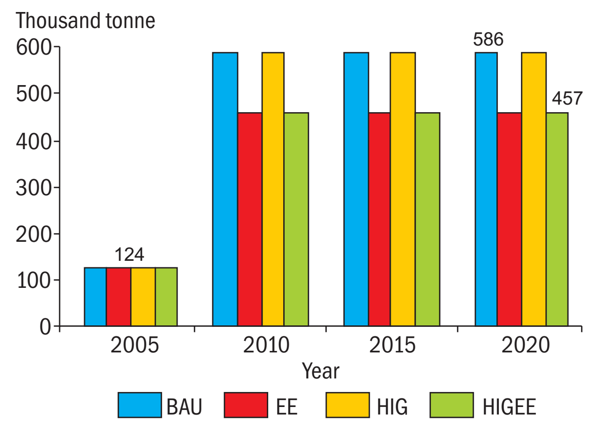


FIGURE 7 DEMAND FOR COAL IN INDUSTRIES

Coal

Bhutan's coal import in 2005 was estimated at 124 000 tonnes. Cement industry was the largest consumer, with consumption close to 58 000 tonnes. With the expansion in existing plant capacities and setting up of new industries, the demand is estimated to rise to 586 000 tonnes by the end of 2020 (Figure 7).

Demand side management can help reduce total coal consumption by 21%, that is, to 450 000 tonnes approximately (Figure 7). 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.

Energy demand for different fuels by non-energy-intensive industries

In 2004, a total of 864 non-energy-intensive industries existed in Bhutan. Because of the unavailability of data for 2005, the annual average growth rate (between 2000 and 2004) was used to arrive at the 2005 figure on the number of non-energy-intensive industries, the number of which was pegged at 980. Under the baseline scenario, the total number of industries is expected to reach the 3500 mark, on the assumption that the average annual growth rate remains at 9%, the annual growth rate for these industries between 1990 and 2004. In the HIG scenario, the number of operating industry is expected to reach 6300 by 2020, on the assumption that the average annual growth rate is 14%, which the industry experienced between 2000 and 2004. Table 11 presents the assumptions for estimating the number of industries and the energy intensities (energy consumption per establishment) under four different scenarios.

In addition to normal growth of the existing industries, 38 new licenses have also been awarded. Majority of these industries are into agro-based food products, silk fabric, and marble slabs. Approximately, 26 MW power has been allocated, and these units are expected to consume 65 million kWh per annum. Based on these figures, the average electricity consumption per unit is calculated to be 1.7 million kWh. However, with proper efficiency measures, the consumption per unit can come

Table 11

ASSUMPTIONS FOR ENERGY DEMAND ESTIMATION FOR NON-ENERGY-INTENSIVE INDUSTRIES

	BAU	EE	HIG	HIGEE
Growth in establishments	Grows annually @ of 9%, based on annual average growth rate between 1990 and 2004	Grows annually @ 9%, based on annual average growth rate between 1990 and 2005	Grows annually @ 9% till 2007 and @ 14% from 2008	Grows annually @ 9% till 2007 and @ 14% from 2009
Electricity consumption per unit (kWh/establishment)	43 877	39 489 (operational from 2008, with 10% efficiency in motors)	43 877	39 489 (from 2008 with 10% efficiency in motors)
Wood consumption (kg/establishment)	38 189	30 551 (operational from 2008 assuming improvement in efficiency of 20%)	38 189	30 551 (operational from 2008, assuming 20% improvement in the efficiency)

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency

down to 1.5 million kWh. The projected electricity and wood demand is presented in Figures 8 and 9.

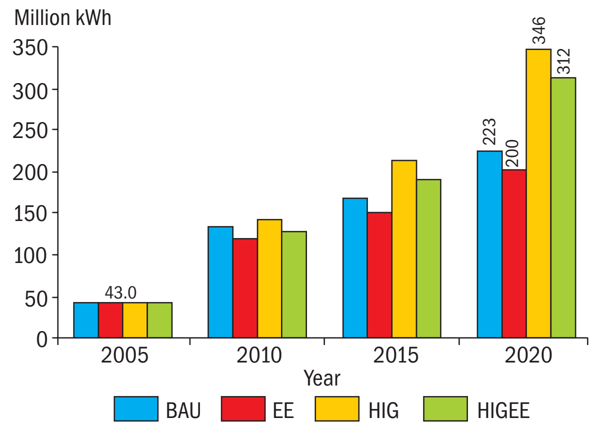


FIGURE 8 ELECTRICITY DEMAND IN NON-ENERGY-INTENSIVE INDUSTRIES

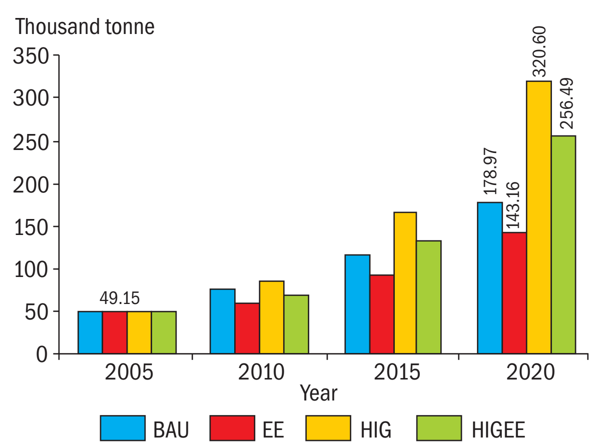


FIGURE 9 DEMAND FOR WOOD IN NON-ENERGY-INTENSIVE INDUSTRIES

Electricity

The total electricity demand in 2005 was found to be 43 million kWh, which is slated to rise sharply to 132 million kWh by 2010 and 223 MU by 2020 under the BAU scenario, while in the HIG scenario, the demand will be 346 MU by 2020.

Energy saving potential for this sector is close to 10%, which can help reduce consumption by 20 MU and 34 MU for the EE and HIGEE scenarios, respectively.

Wood

At present, the total consumption of wood in non-energy-intensive industries stands at 50 000 tonnes. Under the BAU scenario, total demand is expected to reach 175 000 tonnes.

Demand side management can help achieve an efficiency of 20% over baseline estimates, reducing consumption to 140 000 tonnes and 250 000 tonnes in the EE and HIGEE scenarios, respectively.

Commercial and institutional sector

The commercial and institutional sector has been divided into four sub-sectors. These are as follows.

1 Tourism
2 Commercial establishments (complexes, including shops and restaurants)
3 Institutions
4 Bulk energy consumers like defence

In the subsequent sections, each sector, its growth, the present and future energy intensities, and the energy saving potential are discussed in detail. Finally, energy demand for the sector, by fuel, is presented.

Tourism

Tourism can have a substantial impact on Bhutan's economic sector. Furthermore, tourism is the second largest foreign currency earner and the most important contributor in terms of free convertible currency (Strategy Document, Department of Tourism, 2005). There has been a considerable growth in the inflow of international tourists in the recent past. The total international arrival at the end of 1996 was estimated to be 5137, and by 2006, the total inflow reached an all time high of 17 342. Figure 10 presents the tourist inflow in Bhutan between 1996 and 2005.

As per the latest records, Bhutan has more than 175 hotels with more than 4000 beds. Average duration of stay per tourist in Bhutan has been estimated to be approximately 10 days. As far as the consumption of energy by these international tourists is concerned, the typical energy basket includes electricity, LPG, and petroleum products.

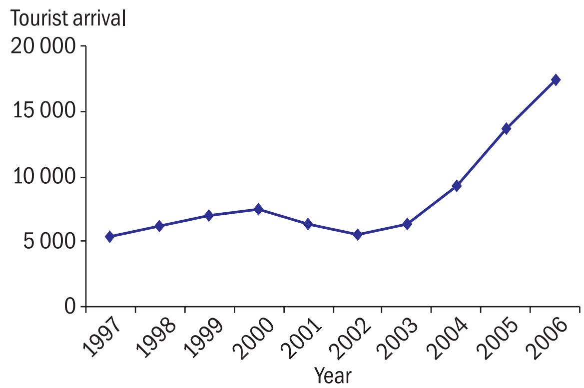


FIGURE 10 INFLOW OF FOREIGN (PAID TOURISTS) IN BHUTAN

Source Department of Tourism, RGoB (2005); Statistical Yearbook of Bhutan (2007)

While the consumption of electricity and LPG is discussed in this section, petroleum consumption is dealt with separately in the section on the transport sector.

Based on a rapid appraisal survey in three hotels in Thimphu, the electricity and LPG consumption per capita was estimated. Table 12 describes in detail the assumptions made in regard to the number of tourists expected to visit Bhutan, their energy consumption under different scenarios, and the saving potential.

The estimation of the number of tourists between 2005 and 2020 under the BAU and EE scenarios is based on the annual average influx of foreign tourists in Bhutan between 1991 and 2004. The average influx rate obtained was approximately 15%. Based on this estimate, the total number of tourists visiting Bhutan by 2020 under the two scenarios is expected to be 110 900. However, the influx rate has changed significantly over the past five years. In 2001, the number of foreign tourists visiting Bhutan was 6395, which increased to 13 626 by 2005, marking an annual average growth rate of 21%. Based on this growth rate, the final figure for 2020 is 237 800. Each tourist is estimated to consume about 261 kWh of electricity and 6.21 kg of LPG. Use of energy-efficient lighting and heating can reduce electricity consumption by 30%. As a result, the electricity intensity (electricity usage per tourist) can come down to 183 kWh. As far as LPG consumption is concerned, there may not be a far-reaching improvement, as even the existing LPG cook stoves are highly energy efficient. However, some research studies suggest that efficiency can be improved further by regular cleaning of stoves, using materials that have high heat conductivity for cooking, and so on. The efficiency attainable is 5% of the existing stoves, thus resulting in the reduction of the per capita consumption to 5.8 kg of LPG.

Commercial complexes, including hotels and restaurants

With increasing per capita disposable income and the government's policy to promote tourism in Bhutan, the commercial sector as a whole has experienced a healthy growth rate between 2000 and 2005, which is pegged at 16%. The growth in retail and hotel/restaurant industry is presented in Table 13.

Table 12

GROWTH IN TOURIST AND ENERGY INTENSITIES

	BAU		EE		HIG		HIGEE	
	2005	*2020*	*2005*	*2020*	*2005*	*2020*	*2005*	*2020*
Number of tourists	13 626	110 900	13 626	110 900	13 626	237 800	13 626	237 800
Per capita electricity consumption (kWh)	261	261	261	183	261	261	261	183
Per capita liquefied petroleum gas consumption (kg)	6.21	6.21	6.21	5.8	6.21	6.21	6.21	5.8

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency

Table 13

GROWTH RATE IN THE COMMERCIAL SECTOR (%)

	2000	2001	2002	2003	2004	2005
Wholesale and retail trade	23.63	16.62	19.94	11.68	18.51	15
Hotels and restaurants	0.41	26.53	3.23	11.84	21.91	18.53

Source *National Accounts Statistics Report 2000–05*

The commercial sector contributed about 4% to the total GDP in 2000. With sustained high growth, the sector's total contribution has almost doubled in a span of five years. The number of establishments, too, has grown during the same period. As per the records of the BPC, 5431 establishments existed in 2003. Based on the available data, the average growth rate of 7% (growth between 2000 and 2005) has been used to arrive at the 2005 figure, which is pegged at 6090 (Table 14). Based on this rate, the total number of such establishments can reach 16 460 by 2020. On the other hand, a high growth rate of 10% can raise the number to 24 900.

The data on the total electricity supplied to the commercial sector has been obtained from the BPC. The average annual electricity consumption was estimated at 3645 kWh. Given the energy saving potential of 30% by switching to efficient lighting and space heating, the specific electricity consumption can come down to 2551 kWh. The figures pertaining to the consumption of LPG and wood have been derived from energy balance figures. Consumption of LPG has been calculated to be 141 kg per unit and that of fuelwood 1384 kg. Energy intensities under the EE and HIGEE scenarios for these two fuels are 1107 kg and 1384 kg, respectively.

Institutions

Institutions include government buildings, monasteries, educational buildings, and hospitals. Institutional constructions did not experience a major surge between 1999 and 2003. In 1998, the total number of institutions (based on BPC estimates) was 1578, which reached 2539 by 2003. Since figures for 2005 were not available, the base year number was estimated using the growth rate of 12%, which the sub-sector experienced between 1999 and 2003. For this sub-sector, the growth in the number of institutions between 2005 and 2020 has been kept at 12% for all the scenarios. Based on the BPC supply figures, the electricity consumption per institution was found to be 8033 kWh per annum. Moreover, energy balance figures suggest that the wood consumption per institution was 20 282 kg per establishment. In the EE scenario, the consumption of electricity and firewood reduces to 5623 kWh and 16 266 kg, respectively.

Bulk

The growth in the bulk consumers has also been pretty moderate between 1998 and 2003, for which figures have been made available by the BPC.

Table 14

GROWTH IN COMMERCIAL ESTABLISHMENTS AND ENERGY INTENSITIES

	BAU		EE		HIG		HIGEE	
	2005	2020	2005	2020	2005	2020	2005	2020
Number of shops/restaurants/commercial outlets	6090	16 463	6090	16 463	6090	24 900	6090	24 900
Electricity consumption per establishment (kWh)	3645	3 645	3645	2 551	3645	3 645	3645	2 551
LPG consumption per establishment (kg)	141	141	141	134	141	141	141	134
Fuelwood consumption per establishment (kg)	1384	1 384	1384	1 107	1384	1 384	1384	1 107

BAU – business-as-usual; EE – energy-efficient; HIG – high growth scenario; HIGEE – high growth coupled with energy efficiency

The total number of consumers has increased from 250 to 364 during the same period, with an average annual growth rate of 9.7%. This gives us a figure of 439 consumers by 2005. Between 2005 and 2020, the growth was constant at 9.7% across all scenarios. The electricity consumption per consumer was 138 246 kWh. In the scenarios that incorporate demand side management, the consumption is expected to come down to 96 772 kWh.

Energy demand by commercial sector, by fuel

Energy demand for the commercial and institutional sector, by fuel, is presented in Figures 11–13.

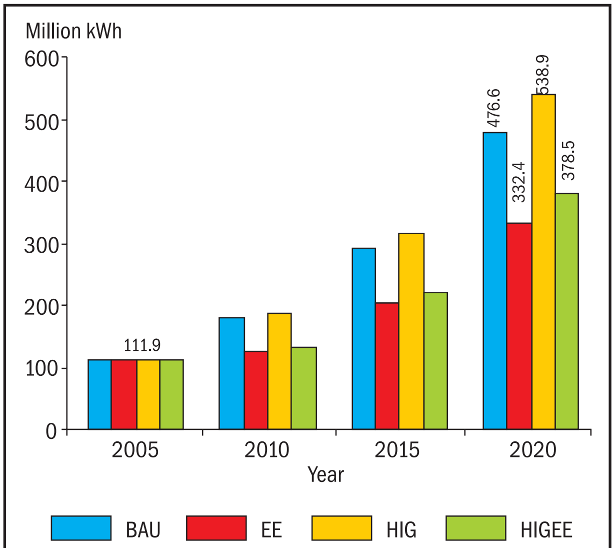


FIGURE 11 ELECTRICITY DEMAND

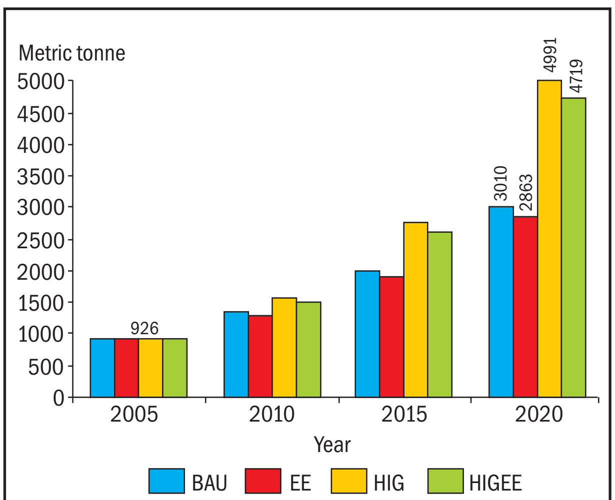


FIGURE 12 LPG DEMAND

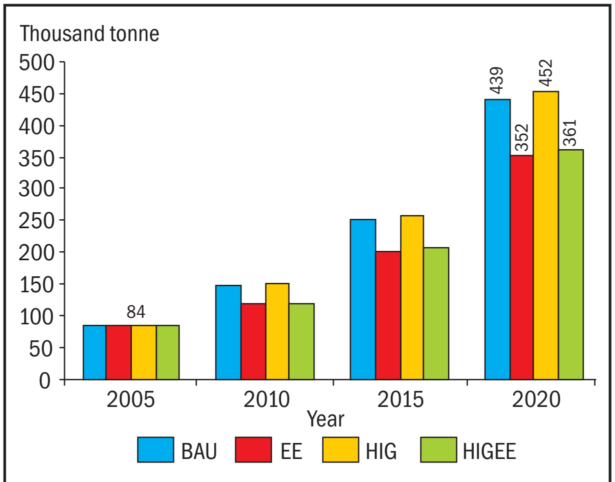


FIGURE 13 FUELWOOD DEMAND

Electricity

The electricity demand is expected to rise to 477 million kWh under the BAU scenario, while in the HIG scenario, it can be as high as 539 million kWh.

Energy efficiency can lead to 30% savings, with the consumption coming down to 332 million kWh and 378 million kWh under the EE and HIGEE scenarios, respectively.

LPG

Estimate shows that LPG consumption was 926 tonnes in 2005, and it is expected to reach 3010 tonnes and 5000 tonnes under the BAU and HIG scenarios, respectively, by 2020.

Fuelwood

Fuelwood consumption is likely to increase from 140 000 tonnes to 534 000 tonnes and 584 000 tonnes by 2020, under the BAU and HIG scenarios, respectively.

Transport sector

Bhutan's transport sector comprises road and air transport. According to the *Bhutan Statistical Yearbook*, till June 2005, the total length of roads was 4392 km, which served a total land area of 38 394 km^2 and catered to a total population of 672 425 (Bhutan Census 2005). This gives a road density of 0.114 km/km^2 and 6.53 km/1000 inhabitants.

Surface transport (road transport) is the dominant mode of passenger and freight movement for both inter- and intra-city movement in Bhutan. Furthermore, the absence of domestic air network linking different cities/towns and the lack of alternative/competing transportation modes have made the road-based transportation modes the preferred modes for transportation. With the growth in the construction sector, transport, storage, and communication have contributed significantly to the GDP. In 2000, the share of the sector to total GDP was 8.8%, which increased to 10.6% at the end of 2005. The sectoral growth rate in 2000 was found to be 10%, which significantly increased to 16.5% in 2005. The growth rate of the transport sector and its contribution to GDP, by year, are presented in Figure 14.

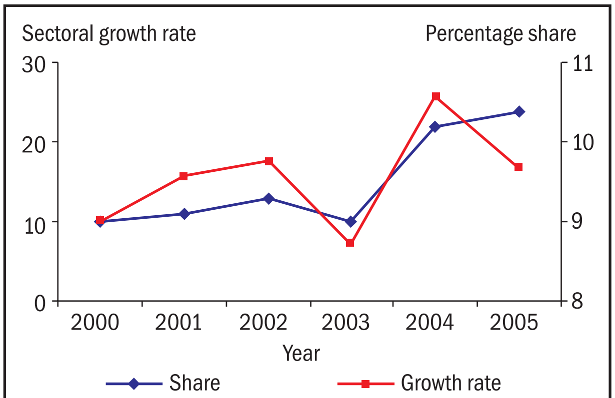


FIGURE 14 TRANSPORT, STORAGE, AND COMMUNICATION, PERCENTAGE SHARE AND GROWTH RATE

Source National Accounts Statistics 2000–05

Vehicular growth in Bhutan

There has been a significant increase in the number of vehicles registered in Bhutan since 2000. The trend in the registered motor vehicles during the period 2000–04 is presented in Table 15.

As shown in Table 15, the number of registered motor vehicles has shown a consistently upward trend between 2000 and 2004. The number of motor vehicles increased by 1.4 times, that is, from 19 463 vehicles in 2000 to 26 760 in 2004, an average annual growth rate of 8%. The rate of increase in vehicle registration has been 8.2%. This gives a total of 40 vehicles registered per 1000 population. The road transport system in Bhutan is characterized by the heterogeneity of motor vehicles in terms of the fuel consumed and the end-use purpose served by each category of motor vehicles. The import of various categories of vehicles, along with their fuel type, is presented in Figures 15 and 16.

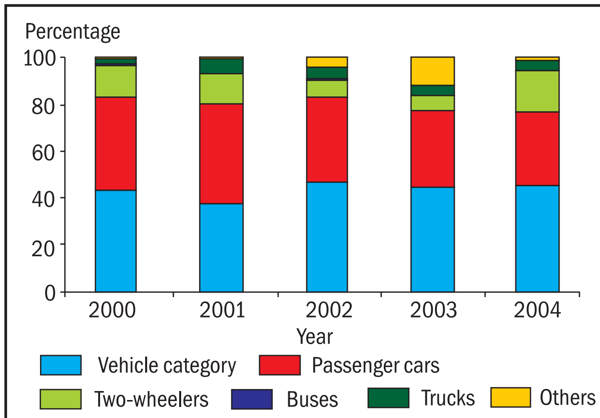


FIGURE 15 IMPORT OF MOTOR VEHICLES

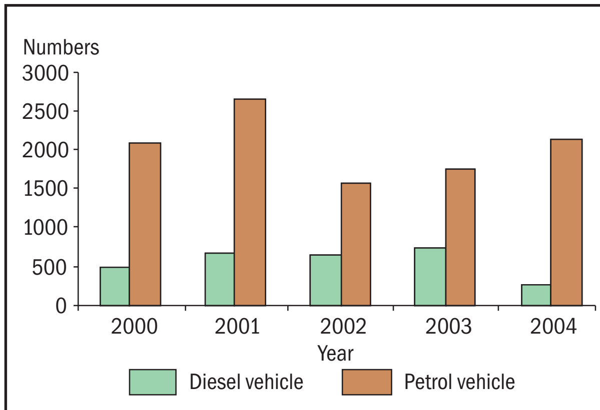


FIGURE 16 VEHICLE CATEGORY, BY FUEL TYPE

Source Various issues of Trade Statistics, Ministry of Finance, Royal Government of Bhutan

Energy consumption in the transport sector

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. The economy meets its entire energy demand through imports from India. Figure 17 gives the trends in the quantity of imported fuels consumed in the transport sector.

Table 15

NUMBER OF REGISTERED VEHICLES, BY TYPE AND REGION (2000–04)

Year	Region	Heavy vehicles	Medium vehicles	Light vehicles	Two-wheeler	Taxi	Earth movers	Others	Total
2000	Total	2062	NA	7 438	7793	770	NA	1400	19 463
	Thimphu	410	NA	4 865	4599	548	NA	537	10 959
	Gelephu	102	NA	274	604	11	NA	108	1 099
	Phuentsholing	1348	NA	1 971	1894	210	NA	633	6 056
	Samdrup Jongkhar	202	NA	328	696	1	NA	122	1 349
2001	Total	2853	697	8 905	8165	1188	408	268	22 484
	Thimphu	472	389	5 821	4789	810	109	145	12 535
	Gelephu	100	33	359	631	17	14	70	1 224
	Phuentsholing	2068	241	2 399	2003	356	244	-	7 311
	Samdrup Jongkhar	213	24	326	742	5	41	53	1 404
2002	Total	2747	770	10 071	8371	1423	464	614	24 460
	Thimphu	553	411	6 691	5160	1013	135	427	14 390
	Gelephu	96	46	383	627	18	14	89	1 273
	Phuentsholing	1923	261	2 653	1837	379	267	17	7 337
	Samdrup Jongkhar	175	52	344	747	13	48	81	1 460
2003	Total	4841	308	11 428	7507	1560	321	388	26 353
	Thimphu	2654	0	7 586	4540	1079	0	134	15 993
	Gelephu	85	49	332	628	441	10	138	1 683
	Phuentsholing	1915	230	3 144	1608	21	272	17	7 207
	Samdrup Jongkhar	187	29	366	731	39	39	99	1 490
2004	Total	4345	NA	12 638	7707	1682	NA	388	26 760
	Thimphu	1386	NA	8 424	4660	1171	NA	134	15 641
	Gelephu	149	NA	380	639	24	NA	138	1 192
	Phuentsholing	2524	NA	3 438	1657	468	NA	17	8 087
	Samdrup Jongkhar	286	NA	396	751	19	NA	99	1 452

Source *Bhutan Statistical yearbook (2004)*

Of the three major transportation fuels imported in Bhutan, diesel has the largest share—in 2005, it was close to 78% (51 440 kilolitres), followed by petrol at 20% (13 755 kilolitres) and ATF close to 2% (1200 kilolitres). The average annual growth rate of the demand for petrol has been greater than that of diesel. Between 1996 and 2005, the annual growth rate of petrol was 15.3% and that of diesel, 12%. The sustained growth in demand for diesel has been because of the construction sector. Construction of three major hydel power projects, that is, Kurichu, Basochhu, and Tala, between 1996 and 2005, has contributed to the increased diesel consumption (increased transportation of materials) in a major way. Again, the growing economy, with increased per capita income and stable inflation, has led to the growth in private transport vehicles, thus leading to increased petrol consumption. As far as the ATF import is concerned, till 2004, the demand grew at a very low rate. Increase in international tourists, coupled with the opening of new routes, has led to a sudden spurt in the demand for ATF. The growth rate for 2005 was 7.5% as against an average of 6.8%.

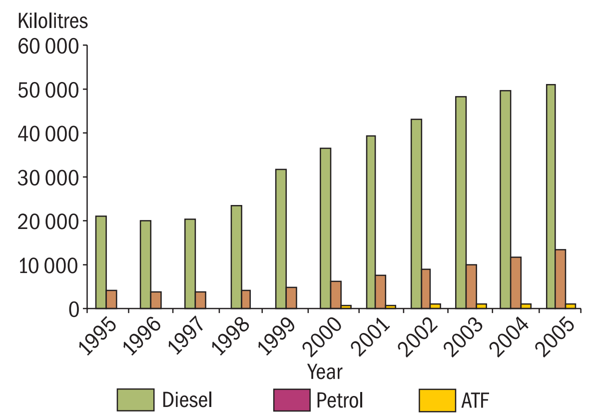


FIGURE 17 TRENDS IN THE QUANTITY OF IMPORTED FUELS CONSUMED IN THE TRANSPORT SECTOR

Source *Various issues of Trade Statistics, Ministry of Finance, Royal Government of Bhutan*

Demand projections for different categories of transport fuels (diesel, petrol, and ATF) have been made based on the bivariate regression analysis of fuel imports and GDP. The regression forms used are as follows.

- Diesel import (litres) = $\alpha1 + \beta1$GDPconstant 2000 (Ngultrum) + e1
- Petrol import (litres) = $\alpha2 + \beta2$GDPconstant 2000 (Ngultrum) + e2
- ATF import (litres) = $\alpha3 + \beta3$GDPconstant 2000 (Ngultrum) + e3

where e1, e2, and e3 are the random error components of the above regression equations. Based on the least square method, some parameters were estimated, which are presented in Table 16.

It is observed from Table 16 that when the GDP increases by Nu 1 million, the consumption of diesel, petrol, and ATF increases by 2.49, 0.711, and 0.043 kilolitres, respectively. Using this estimate, the future demand for these petroleum products is estimated based on the assumption that the average annual real GDP growth rate is 7.3%, the average growth rate obtained from 2000–05 estimate (National Statistics Bureau 2005). In the HIG scenario, the average growth rate considered is 10%, which the economy achieved in 2002 (9.99%). Based on recent research, there is a significant scope for improving fuel efficiencies, especially for the vehicles running on petrol and diesel. As far as the vehicle category is concerned, light motor vehicles can achieve an efficiency of 14.3% over the existing levels, and heavy vehicles can achieve an efficiency up to 11.3%. Fuel efficiencies for different categories of vehicles are presented in Table 17.

Table 16

PARAMETER ESTIMATES

	Unstd coefficient	*t*	*Sigma*
Diesel			
_const	-17 020.6	-4.182	0.002
GDP	2.490	13.143	0.000
Petrol			
_const	-7494.327	-8.484	0.000
GDP	0.711	17.239	0.000
ATF			
_const	-4.090	-0.021	0.984
GDP	0.043	5.397	0.000

Table 17

FUEL EFFICIENCY FOR DIFFERENT CATEGORIES OF VEHICLES

Vehicle type	*Existing efficiency* (km/l)	*Projected efficiency* (km/l)	*Percentage improvement*
Gasoline car	12	13.72	14.27
Diesel car	11	13	18.21
Diesel big bus	3.6	3.83	6.36
Diesel light-duty truck	8.5	9.52	12
Diesel heavy truck	3.7	4	8.12

Source *Bose (2005)*

Diesel car has the highest scope for efficiency improvement (18.21%), while heavy diesel buses have the least scope (6.36%). Based on these assumptions of growth and efficiencies, the demand for petroleum products for Bhutan has been estimated till 2020 under four different scenarios. Figures 18–20 present the projected demand for different transport fuels under four scenarios.

Diesel

- Diesel consumption in 2005 has been reported to be 51 440 kilolitres and is expected to reach 191 100 kilolitres in the BAU scenario as against 284 000 kilolitres in the HIG scenario.
- Energy-efficient diesel engines can reduce the consumption of diesel to 171 694 kilolitres and 256 178 kilolitres under the EE and HIGEE scenarios, respectively.

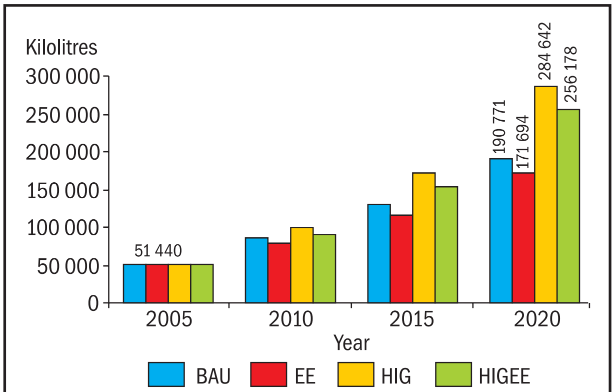


FIGURE 18 DEMAND FOR DIESEL

Petrol

- Like diesel, petrol is also imported from India, with the volume of imports estimated at 13 775 kilolitres in 2005. Projections from LEAP peg the total import demand at 51 673 kilolitres in the BAU scenario in 2020, while in the HIG scenario, the total demand is expected to be 78 402 kilolitres.
- 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.

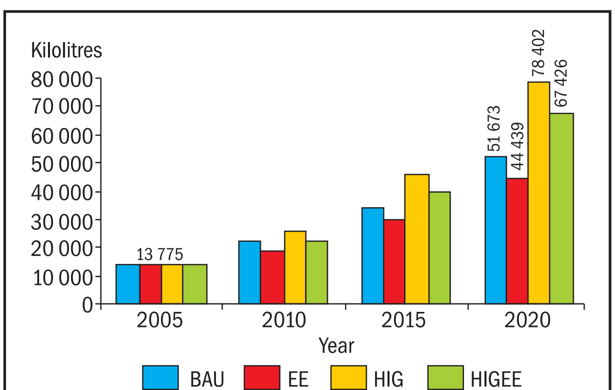


FIGURE 19 DEMAND FOR PETROL

Aviation turbine fuel

- In the BAU scenario, it is predicted that a total import of 3495 kilolitres of ATF will be required, while in the HIG, the import demand can reach as high as 5074 kilolitres by 2020.

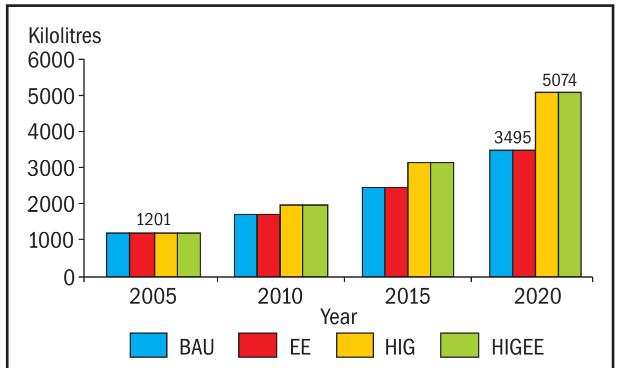


FIGURE 20 DEMAND FOR AVIATION TURBINE FUEL

TOTAL ENERGY DEMAND PROJECTIONS

The above analysis shows projected demand, by sector, under various growth scenarios. The total energy demand in thousand TOE for 2010, 2015, and 2020 is shown in Figure 21. The energy demand projections, by fuel, from 2005 to 2020 in different scenarios are given in Annexure 3.3.

Energy consumption in TOE, by fuel, for the same time period, under various scenarios, is shown in Figures 22 to 33. It is clear from the figures that if proper strategies are devised and implemented, Bhutan can develop sustainably in

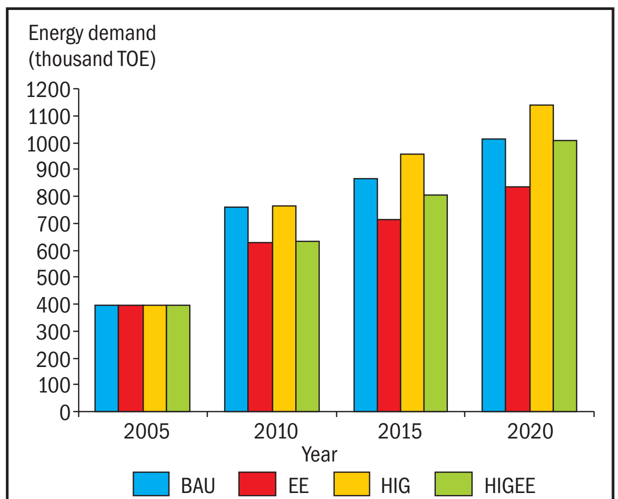


FIGURE 21 PROJECTED TOTAL ENERGY DEMAND IN THOUSAND TOE, UP TO 2020

future. Dependence of the residential sector on fuelwood is alarming, but with strategic planning, this dependency can be reduced to minimum by 2020. Similarly, kerosene consumption in the residential and commercial sectors is another major problem from sustainability and safety points of view (pollution-related health hazards). This problem, if tackled properly, can reduce kerosene consumption in these two sectors substantially.

The following chapter suggests various strategies for the implementation of suitable schemes in the country.

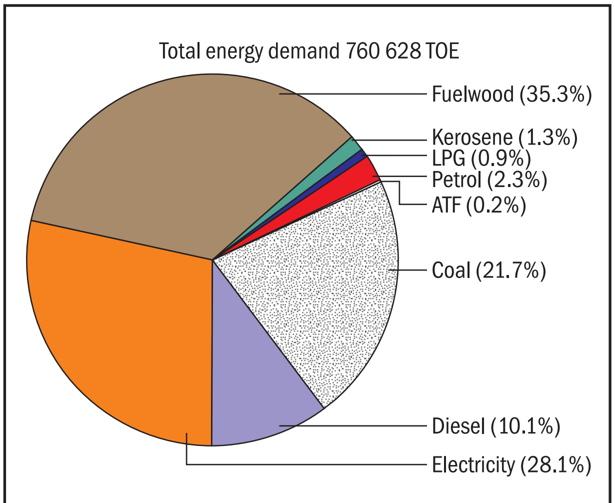


FIGURE 22 ENERGY CONSUMPTION IN BHUTAN BY 2010 IN BAU SCENARIO, BY FUEL

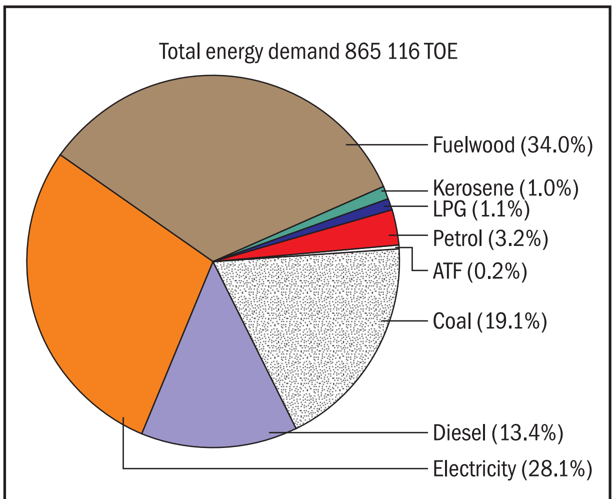


FIGURE 23 ENERGY CONSUMPTION IN BHUTAN BY 2015 IN BAU SCENARIO, BY FUEL

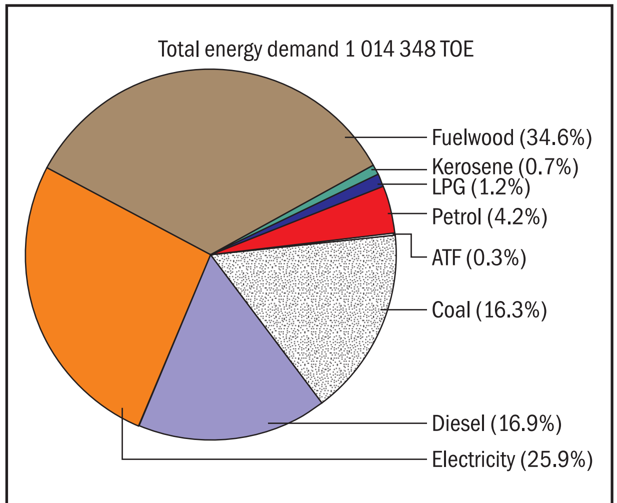


FIGURE 24 ENERGY CONSUMPTION IN BHUTAN BY 2020 IN BAU SCENARIO, BY FUEL

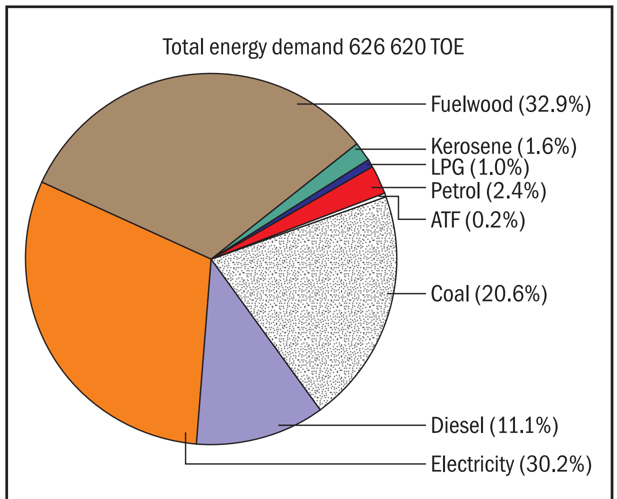


FIGURE 25 ENERGY CONSUMPTION IN BHUTAN BY 2010 IN EE SCENARIO, BY FUEL

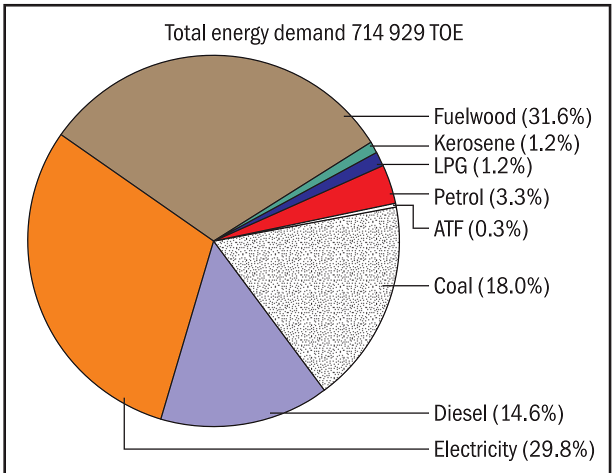


FIGURE 26 ENERGY CONSUMPTION IN BHUTAN BY 2015 IN EE SCENARIO, BY FUEL

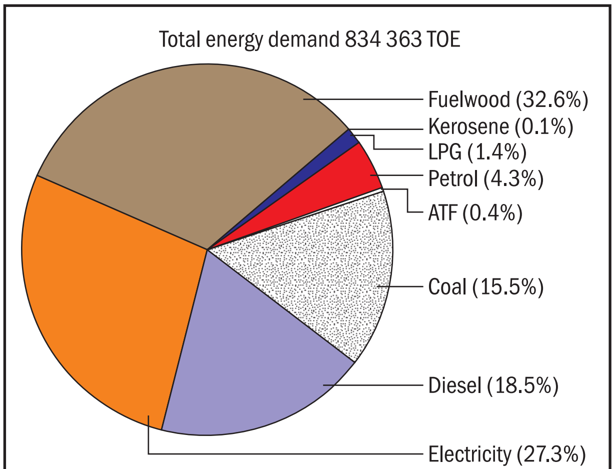


FIGURE 27 ENERGY CONSUMPTION IN BHUTAN BY 2020 IN EE SCENARIO, BY FUEL

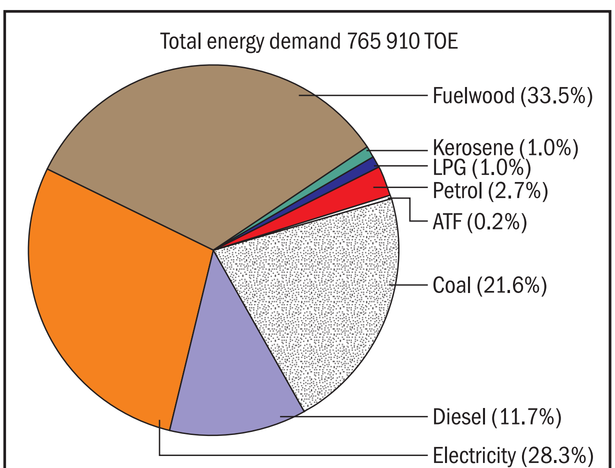


FIGURE 28 ENERGY CONSUMPTION IN BHUTAN BY 2010 IN HIG SCENARIO, BY FUEL

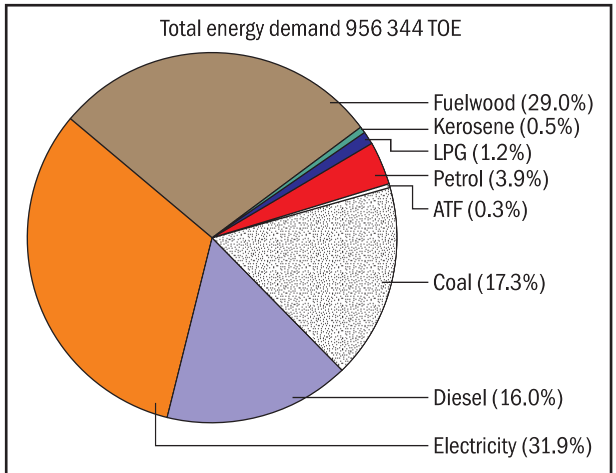


FIGURE 29 ENERGY CONSUMPTION IN BHUTAN BY 2015 IN HIG SCENARIO, BY FUEL

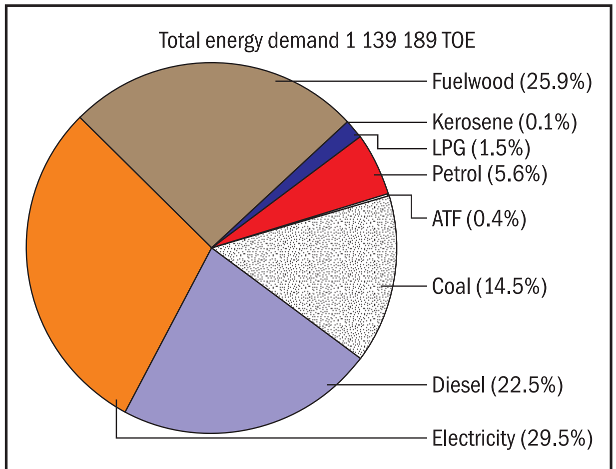


FIGURE 30 ENERGY CONSUMPTION IN BHUTAN BY 2020 IN HIG SCENARIO, BY FUEL

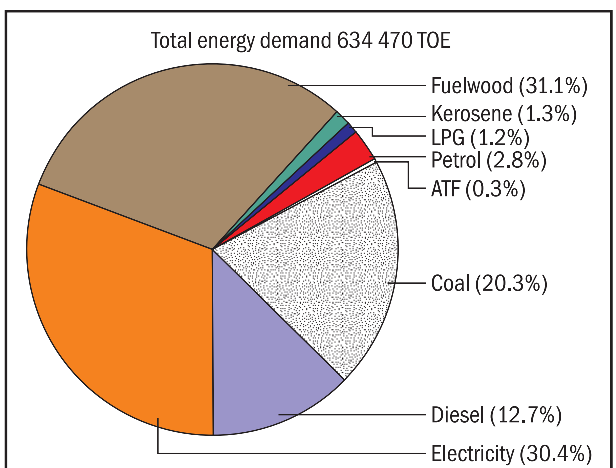


FIGURE 31 ENERGY CONSUMPTION IN BHUTAN BY 2010 IN HIGEE SCENARIO, BY FUEL

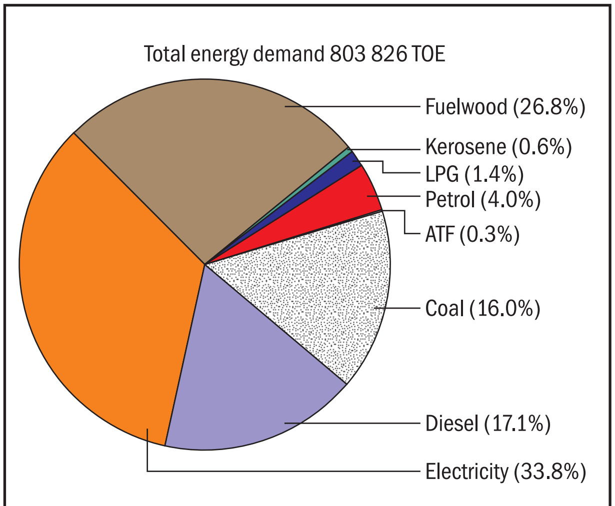


FIGURE 32 ENERGY CONSUMPTION IN BHUTAN BY 2015 IN HIGEE SCENARIO, BY FUEL

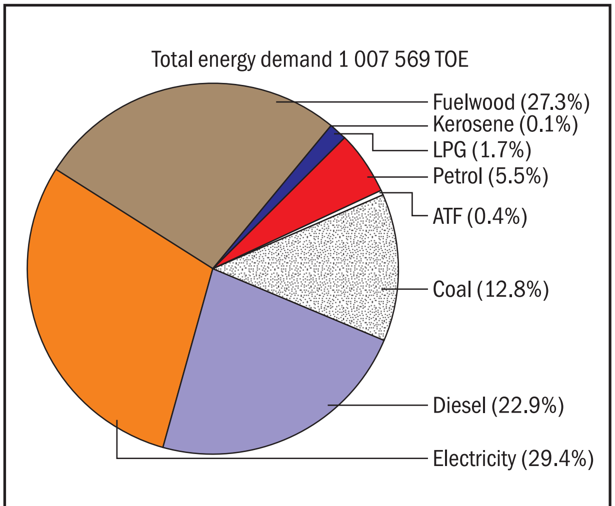


FIGURE 33 ENERGY CONSUMPTION IN BHUTAN BY 2020 IN HIGEE SCENARIO, BY FUEL

CHAPTER 4

Energy supply options for Bhutan

INTRODUCTION

The role of energy is crucial for any country that is traversing the rapid development path. It is an established fact that with the provision of energy, the quality of life improves considerably—education standards improve, along with health and hygiene, particularly that of women and children who otherwise spend considerable time in collecting fuels. An Asian Development Bank (ADB) study (2003) revealed that increased access to electricity raised the incomes of the Bhutanese people, lessened the extent of health burden, and positively contributed to improved education levels.

The Royal Government of Bhutan (RGoB) recognizes the importance of energy and has been taking several measures to accomplish its ambitious goal of 'electricity for all by 2020', now revised to 2013 with the Druk Phuensum Tshogpa (DPT) Government in power. Bhutan is endowed with rich water resources, along with abundant biomass reserves, both being key energy sources for fulfilling the country's energy needs. Both these resources are being exploited in a sustainable manner to fulfil the energy needs of the people. The government has formulated Rural Electrification Master Plan (REMP) 2005, which provides a road map to achieve 100% electrification in the country within the stipulated time frame.

As explained earlier, the energy needs of the Bhutanese economy can be categorized in the following manner.

- Resources for electricity generation
- Fuels and resources for the transport sector, which is currently completely dependent on fossil fuels (petrol and diesel)
- Fuels to meet heat and mechanical energy demand of the industrial, commercial, and residential sectors (excluding electricity)

This chapter covers the supply side options to meet the demand, including various renewable energy options for sustainable supply of energy.

THE POLICY AND REGULATORY FRAMEWORK FOR THE POWER SECTOR

The policy for the power sector is in the draft stage; however, the policy and planning of the power sector in Bhutan have two major objectives.

1 Emphasis on power exports to strengthen the economy
2 Supply of reliable, environment-friendly, and affordable power for all citizens

The overall policy and regulatory interventions are guided by these two broad objectives. The accelerated hydropower development has been identified as an option for achieving these objectives. The Ninth and the Tenth Five-year Plans indicate the policy direction for this sector.

To ensure reliable and affordable supply of electricity, the policy measures include allocating 15% of annual energy generated from all large hydropower plants for domestic consumption at a nominal rate of 0.3 Nu/unit. This is applicable for the power plants owned by the government or its entities.

For the supply of safe and reliable power, the Bhutan Electricity Authority (BEA) has put in process a transparent methodology for determining tariffs for power generation and consumption for different user categories. The policy is working towards gradually removing subsidy being provided to high voltage and medium voltage consumers by 2011. As for others, primarily the residential sector, the power would be supplied at subsidized rates as a social obligation so as to ensure socio-economic development.

Given dispersed population and the complex terrain, the electricity supply to all would require major financial resources for grid extension.

Thus, the critical policy issues in the power sector are (1) accelerating development of the hydropower sector by attracting investments 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.

A range of options to address these issues is as follows.

- Accelerated development of large hydropower plants
- Development of medium hydropower plants in independent power producer (IPP) mode
- Promotion of medium hydropower plants for captive use in industries
- Enhancement of power capacity of a firm by diversifying the electricity supply options, mainly through renewable energy sources (other than hydropower).

These would be dealt with in detail subsequently.

POWER SECTOR DEVELOPMENT

The power sector in Bhutan is synonymous with the hydropower sector, with more than 99% of electricity being generated by the hydropower sector. The hydropower sector has been the main driver of the Bhutanese economy, and through revenue earnings from the sale of electricity, it has spurred country's socio-economic development. At present, the sector accounts for about 22% of gross domestic product (GDP), with 40% contribution towards the total national revenue generation. The latter figure would have been reached 60% with the commissioning of Tala Hydropower Plant in 2007, but it is still about 40% because of the rapid growth in other sectors.

The hydropower potential of the techno-economically feasible sites is estimated to be about 23 760 MW, of which thus far only 1.6% has been developed (Table 1). With the commissioning of Tala Hydropower Project (1020 MW), the total installed capacity has risen to 1488 MW, and the mean annual generation is now about 7412 gigawatt-hours (GWh).

Table 1

CAPACITIES AND GENERATION OF MAJOR HYDROPOWER PLANTS IN BHUTAN

	Chukha	*Kurichu*	*Basochhu I*	*Basochhu II*	*Tala*
Installed capacity (MW)	336	60	24	40	1020
Firm capacity (MW)	67	24	5	10	168
Mean annual generation (GWh)	1860	400	105	186	4865
• Firm energy (GWh) • Seasonal energy (GWh)	587 1263	210 190	44 62	88 98	1472 3393

Source *WRMP (2004)*

While the hydropower sector is the propeller of the Bhutan's economy, to ensure that hydropower development does not take place in a haphazard manner but proceeds on the basis of careful identification of most promising sites, the RGoB updated the Power System Master Plan (PSMP) of 1993 for the period 1990–2010 to cover partially the period 2003–22 in its Water Resource Management Plan (WRMP) 2004. The WRMP 2004 screened hydropower projects on the basis of technical and economic criteria to select most promising projects, which were then subjected to Multiple Criteria Analysis (MCA)[1] for the eventual adoption in the WRMP.

[1] MCA facilitates comparison of projects that may have different types of impacts of highly varying magnitude. The variables are grouped under four key criteria, representing important objectives of the Government of Bhutan: technical, economic, social, and environmental.

The WRMP 2004 identified 78 potential run-of-the-river projects in Bhutan for hydropower development, with capacity above 10 MW, and estimated that if 25 of the 78 sites were developed, the installed capacity would be around 16 435 MW. Based on the screening of the projects, six potential projects were selected for implementation during the Power Master Plan period of 2003–22. The details of these are provided in Table 2.

Table 2

DETAILS OF SELECTED POTENTIAL MAJOR HYDROPOWER PROJECTS

Project	*Installed capacity (MW)*	*Estimated investment (million US dollars)[a]*	*Construction period*
Punatsangchhu I	1002	861	2007-11
Mangdechhu	670	588	2009-13
Punatsangchhu II	992	875	2011-15
Chamkharchhu I	671	547	2014-19
Chamkharchhu II	568	407	2018-22
Kholongchhu	486	383	2020-23
	4389	3661	

[a]2003 prices, inclusive of the cost of transmission to India, exclusive of interest during construction

Source *WRMP (2004)*

While there exists considerable hydropower potential in Bhutan, there are several constraints in fully exploiting this potential, encompassing technical, financial, environmental, and market limitations. One unique characteristic of the Bhutanese power sector is its complete dependence on hydropower and run-of-the-river type plants. Also, there is an issue of energy security due to overdependence on hydropower.

The run-of-the-river-type plants are environmentally benign and have lower cost of power generation compared to the other renewable energy resources; however, this has rendered the development of power plants in any other sector – renewable or conventional – commercially unviable and unattractive.

Seasonal variation in electricity production

Bhutan has been exploiting its vast hydropower potential in a sustainable manner, with the existing plants being run-of-the-river schemes as opposed to storage-based plants. While the run-of-the-river schemes ensure relatively benign use of environmental resources, the biggest challenge posed by them is their inability to operate at full capacity in the lean season when the river flow remains low. This is particularly true in winter months when the demand is at the peak without secure sources of energy supply.

With the commissioning of Tala Hydropower Plant, 288 MW of firm power (power available in the lean season) is available. Currently, the peak demand is about 211 MW, and as per the demand projections, it would rise to about 500 MW in near future (2012), if all the sanctioned industries become operational. The Department of Energy (DoE) plans to tackle this shortage in the following ways.

- Licenses to new ferro alloy industries will be given only after taking a long-term and holistic view of (1) the peak power demand in the country and (2) firm power availability.
- In case of shortage of power, priority will be given to the residential and institutional sectors.
- The Bhutan Power Corporation will regulate the allotment of power to industries.
- Power plant output will be augmented using better water management techniques to boost production during peak hours.
- Efficient management of hydropower plants will be undertaken.

Financing of hydropower projects

The issue of raising capital to invest in the additional power generation is a big challenge for Bhutan, which does not have an international credit rating. As seen in Table 2, for the six potential power plants, determined by the WRMP (2004), an investment of about $3660 million is required, which translates into capital expenditure of $183 million per year.

Mobilization of the resources of this magnitude, however, remains a critical issue, given the limited domestic resources and the current problems in attracting private sector to invest in the hydropower sector.

Though the Government of India has been expressing interest in financing the hydropower sector in Bhutan and has also committed to purchase extra power, the question is to what extent can Bhutan expect such financing options from India (Table 3). According to the WRMP, a number of factors would eventually determine the availability of international financing for hydropower development in Bhutan. The major challenge for hydropower funding is devising packages with debt servicing and maturities. Often, the potential imbalance between revenue and debt service, along with the level of risk involved in the project, prevents investors from financing large hydropower projects.

The most important factor with respect to the above is the size of the schemes—given the large size of hydropower schemes, financing is difficult. It is suggested that to overcome this problem, a public–private model, together with the backing of an international lending agency, could be considered. Besides the size, securing finance rests on the prospects of achieving a return on the capital, which should be sufficient to cover the level of risk involved. One such type of model that can be considered is the build, operate, own, and transfer (BOOT) model, which could be backed by the international lending agencies (Box 1).

Given that the investment in large hydropower projects is not readily forthcoming, it remains important from the energy security perspective that plants of small or medium capacities, typically about 100 MW capacity each, are planned and established. These plants should be promoted in eastern Dzongkhags, which are underdeveloped and where power outages are very common.

To accelerate the development of the hydropower sector in Bhutan, Hydropower Policy, 2008, has been finalized, although it is yet to be notified. Besides, a holding company called the Druk Green Power Corporation (DGPC) has been established to allow for optimal utilization of resources and enhance capacity building. It would also serve as an investment arm of the government, which would invest in future hydropower projects.

For an accelerated development of the hydropower sector, case studies have been evaluated to assess various proposed/feasible power plants under different financing options under IPP and captive power plant mode. These case studies are discussed in subsequent sections.

Development of large hydropower plants

Till now, the development of large power plants in Bhutan was financed through a mix of loans and grants. For accelerated development, other means of developing large hydropower plants would be required. Hydropower plants on IPP mode can also be developed with the help of public and

Table 3

FINANCIAL CHARACTERISTICS, BY PLANT

Plant	*Year of commissioning*	*Financial support option*	*Source of finance*
Chukha	1988	60% of grant and 40% loan financing model, with an interest rate of 5% per annum and a repayment term of 24 years	India
Kurichu	2002	60% of grant and 40% loan financing model, with an interest rate of 10.75% and repayment period of 12 years	India
Basochhu I	2001	The loan amount was to be repaid in equal instalments over 30 years	Austria
Basochhu II	2005	The loan amount was to be repaid at an interest rate of 2.78%, with repayment period of 15 years, along with a commitment fee of 0.15% and a management fee of 0.25% of the total loan payable in four instalments	Austria
Tala	2007	40% of grant and 60% loan financing model, with an interest rate of 9% per annum and 12 years of repayment	India

BOX 1

BUILD, OPERATE, OWN, AND TRANSFER MODEL

A build, own, operate, and transfer, or BOOT, model is a funding model that involves a single organization or period of time and then transferring this ownership across to an agreed party. The BOOT schemes are increasingly becoming a popular means of financing large-scale infrastructure development such as roads, bridges, and hydro dams in Australia and developing countries. An example in this respect is the 210 MW Theun-Hinboun Hydropower Project in Lao PDR, which developed in joint venture between the Government of Laos (GoL) and the private sector. The Laos government's state-owned electricity utility, Electricité du Laos (EdL), owns 60% of the project and the investment in the project is largely financed by a loan of $60 million from the Asian Development Bank (ADB). The ownership of the remaining 40% share of the project is split equally between the Thai company MDX Lao and Nordic Hydropower, a partnership organization owned by the Swedish government public utility. The total cost of the project is $240 million. It is being financed and developed as a BOOT venture that would see the project transferred back to the government in 30 years. The Theun-Hinboun Power Company, or THPC, is running this joint venture project.

Source *<http://www.mekong.es.usyd.edu.au/publications/briefs/ mekong_ brief3.pdf>, last accessed on 21 April 2007*

private partnerships or foreign direct investment (FDI). The private investment as well as FDI would depend on the viability of the projects as well as policies and regulations in the power sector. The viability of these plants will, in turn, depend on their cost of generation. A financial analysis to estimate the generation cost for such power plant was carried out using lifecycle cost approach, as explained subsequently. Since the revenue of these IPP would be in Ngultrum or in Indian rupees, an arrangement could be worked out for the import of the required equipment from India.

Large hydropower projects are developed primarily for exporting power to India, with certain percentage of power reserved for domestic consumption.

Case study I: Cost–benefit analysis for Chamkarchu Power Plant as independent power producer

An analysis was carried out for the Chamkarchu Hydropower Plant, one of the seven identified hydropower plants in the master plan, to check the financial viability of large power plants as IPP with the present policy. The analysis is summarized as follows.

Capacity	670 MW
Capital cost	Nu 37 520 million based on hydropower projects proposed under Government of India financing/collaboration
Loan	70% @ 9% interest rate
Equity	30%
Return on equity	15%
Construction period	6 years
Life	30 years
Net annual generation	3207 GWh
Operation and maintenance cost	1.5% of capital cost
Export of power	85%
Export price	2.00 Nu/unit
Wheeling charges for export	0.125 Nu/unit
15% domestic power supply at	0.30 Nu/unit

The analysis was carried out by estimating the cost of generation as per the 'tariff estimation methodology' issued by the BEA. The details of the analysis are given in Annexure 4.1. The analysis shows that the cost of generation is Nu 1.73/kWh. The implementation of the present policy of reserving 15% generation for domestic consumption at Nu 0.3/kWh and export of rest of power at Nu 2.0/kWh shows that the generation is financially viable, with return on equity more than 15%. Thus, the present policy of promoting large hydropower plants that export power and also provide power for domestic consumption at subsidized rate can be continued. If there are major changes in the financing terms, then the strategy may have to be reworked, that is, the rate at which power is sold for domestic use would have to be adjusted to make the projects viable. The analysis carried out was on completely commercial basis, that is, without any grant. With economic viability of the large hydropower plants, that is, they continue exporting power to India, these power plants can also be developed on IPP or FDI mode. Another option is developing these plants on BOOT mode. As explained earlier, equipment imports could be facilitated from India to take care of hard currency issue.

Development of medium-capacity hydropower plants

In addition to large-capacity plants, there exists large potential for medium-capacity (up to 100 MW) hydropower plants. The Power Systems Master Plan has identified about 36 plants of capacity up to 100 MW, as shown in Table 4.

An analysis of the small- and medium-sized hydropower plants was carried out to examine the viability of promoting such plants in IPP mode with private sector investments and as captive hydropower plant for energy-intensive industries.

Case study II: Medium-sized hydropower plant development as independent power producer

This analysis is based on typical design parameters for the feasible sites and costs, which are estimated based on Indian experience for similar capacity plants in similar Himalayan region.

The detailed calculations are given in Annexure 4.1.

Table 4

MEDIUM-CAPACITY POWER PLANTS IDENTIFIED IN THE POWER SYSTEM MASTER PLAN

River	*Identified capacity* (MW)
Pachhu	77
Samchhu	71
Churchhu/Chechhu	45
Thimphuchhu	57
Chari/Thimphuchhu	76
Parochhu	85
Haachhu	17
Bemengchhu	14
Piping	55
Sichhu	78
Tang/Pechhu	85
Tang/Pechhu	78
Cherchhu	25
Dagachhu	79
Samachhu	16
Rimjigangchhu	24
Krissa	32
Burgongchhu	69
Burgongchhu	70
Ghijam/Lirigang	53
Chamkharchhu	97
Shergarchhu	27
Rimjigangchhu	46
Thampochhu	95
Bambuchhu	22
Nayurgangchhu	24
Gobarichhu	43
Sherichhu	36
Gamrichhu	64
Gamrichhu	79
Gamrichhu	80
Gamrichhu/Yemkhari	81
Kholongchhu	94
Jaldhaka	19
Mao/Aie	83
Dhansiri	73
Total	2069

The major assumptions are as follows.

Capacity	100 MW
Capital cost	Nu 60 million/MW
Loan	70% @ 9% interest rate
Equity	30%
Return on equity	14%
Construction period	2 years
Life	30 years
Net annual generation	482 GWh
Operation and maintenance cost	2% of capital cost @ 2% annual escalation
Export price	Nu 2.00/unit
Wheeling charges for export	Nu 0.12/unit

The cost of generation, estimated as per the BEA methodology for tariff estimation, for medium-capacity hydropower power projects works out to be about Nu 1.68/kWh, since the capital as well as operation and maintenance (O&M) costs per megawatt of installed capacity for these plants are higher than the large hydropower plants. With the present domestic tariff, it will not be viable for the IPP to sell 15% power for domestic use at Nu 0.3/kWh. In that case, the sale price for the rest 85% becomes higher than the export price to get 14% return on equity. The IPPs can sell up to 10% of power at 0.3 Nu/kWh for domestic consumption and sell/export the rest of power at export rate to get 14% return on equity.

Thus, the IPPs would be viable with this model, that is, domestic sale of 10% generation at Nu 0.3/kWh and rest exported/sold at export price.

This analysis assumes 9% interest rate. Any upward change in the interest rate would affect the viability of the medium-capacity power plants. For example, the analysis with 12% interest rate shows that the generation cost reaches about Nu 1.86. With this generation cost, it would not be viable for the IPP to sell any power at subsidized rate of Nu 0.3 /kWh.

These power plants can be studied, primarily, for the expected capital cost and annual generation, and can be offered to the private sector developers with private investment (domestic or foreign), since the total investments (about Nu 60 million per MW) are not very large, and the private sector can look at the option of establishing such plant.

Case study III: Development of medium-capacity hydropower plants in captive mode

The medium-capacity hydropower plants could also be used for captive generation by industries. Private sector companies interested in setting up energy-intensive industry would look at these medium-sized plants as captive power generation units to ensure enough power supply round the year. This scenario was analysed for medium-capacity hydropower plants. The assumptions are same as in the case of the analysis of medium-capacity power plants. The analysis shows that the cost of generation is higher for medium-capacity hydropower plants in full commercial mode, that is, without any capital grants. The cost of generation is about Nu 1.88/kWh, which is higher than the present tariff paid by the industry. Thus, it would not be viable for industries to invest in medium-capacity hydropower plants for captive generation. However, as the cost of generation is lower than the export price, the medium-capacity hydropower plants should be promoted as captive power plants by providing capital grant or subsidy. The capital subsidy would make the generation cost comparable to the present high voltage tariff. In such a scenario, if the industries invest in captive generation, then equivalent power would be available for exports. A sensitivity analysis shows that the capital grant of 40% of project cost brings the generation cost down to Nu 1.2/kWh, which is the present tariff for industry. Thus, with generation costs comparable with present high voltage tariff, the industries could become interested in setting up captive small hydropower units. Further, as the cost of generation includes 14% return on equity, making additional investment in captive generation by the industry is also a viable option. Table 5 shows the cost of generation at different levels of subsidy. Detailed calculations are given in Annexure 4.1.

Table 5

COST OF GENERATION AT DIFFERENT LEVELS OF SUBSIDY

Capital grant (%)	*Cost of generation (with 15% return on equity)* (Nu/kWh)	*Rate of return on capital grant*
5	1.78	
10	1.69	55
15	1.60	36
25	1.41	21
35	1.22	15
40	1.17	13

From the government's perspective, by providing, say, 35% grant, the benefit would be in terms of having surplus energy, which could be exported at a price of Nu 1.85–2/kWh. Thus, against the expenditure of 35% grant, there is additional income through higher exports. A conservative estimate shows about 40% rate of return through export of power against 35% expenditure as subsidy for captive plants. Here the assumption is that any amount of energy can be exported at any point of time at fixed export rate. This is possible since the Government of India has agreed to buy power up to 10 000-MW capacity under the umbrella agreement.

Seasonal variation, energy security, and power plant development

As all hydropower plants in Bhutan are 'run-of-the-river' type, the power generation has a very high seasonal variation. In winter season, hydropower generation drops to almost 20% of its installed capacity. Thus, there is a critical issue of availability of firm power. After commissioning of Tala Hydropower Plant, the available firm power has reached about 253 MW. Based on the projected energy demand by the WRMP (2004), it must be noted that in case no new hydropower plants are developed soon after Tala, the peak supply capacity in winter months will fall short of projected peak power requirements. In such a situation, Bhutan would have to resort to power cuts or power imports from India, which would impact the country's export earnings from electricity sale. Further, whether India has surplus power to export to Bhutan will be another issue, as India itself is a power-deficit country. To address this issue, the Bhutan Power Corporation, along with the Department of Energy (DoE), is regulating the allotment of power to industries. The licensing to the industries has been done considering the availability of firm power. This policy deals with the demand side management. On the supply side, the options for augmenting power generation, more importantly, the firm power availability, are accelerated development of large as well as small hydropower plants. As large power plants have longer time of construction, development of small- and medium-capacity hydropower plants may be undertaken. The private/foreign participation may be encouraged, as discussed in the earlier section. Since the run-of-the-river hydropower plants will have seasonal variations, there would be limited improvement in the availability of firm power. The options for improving the firm power, therefore, could include the following.

- Development of storage-based hydropower plants
- Development of power generation from renewable energy sources

Case study IV: Development of reservoir hydropower plants

Given high hydropower potential, there is a possibility of developing reservoir-based hydropower plant in Bhutan. The DoE is considering developing the Sankosh Hydropower Project in reservoir mode. However, the capital investment required for reservoir hydropower plants is higher than the run-of-the-river plants, and thus, the cost of generation is also higher. An analysis was carried out to study the economic viability of the Sankosh Hydropower Plant under present policies and export price. The results of the analysis are as follows.

Medium-sized (@100-MW capacity) plants can be promoted through IPP or captive power plant. This will not only help increase power exports but also reduce firm power availability problem and improve speed of industrialization.

Capital cost	Nu 139 197 million (based on the hydropower projects proposed under Government of India financing/collaboration)
Loan	70% @ 9% interest rate
Equity	30%
Return on equity	14%
Construction period	6 years
Life	25 years
Net annual generation	6918 MWh
O&M cost	2% of capital cost
Export price	2.00 Nu/unit
Wheeling charges for export	0.2 Nu/unit

The cost of generation, estimated as per the BEA methodology for tariff estimation, for reservoir hydropower projects works out to be about 1.56 Nu/kWh, since the capital and O&M costs are higher than those of large hydropower plants. As a result, the generation cost is higher. With the higher generation cost and the policy of reserving 15% of generation for domestic consumption at 0.30 Nu/unit, the storage hydropower plants may not be economically viable. To make them viable, the limit for the sale of power at Nu 0.3/units may have to be reduced. This is desirable, as such power plants would provide much needed firm power in winter months. The analysis is done without any grant component; if any grant is made available, the generation cost would reduce accordingly.

At this stage, it is appropriate to look at the other renewable energy options for power generation to reduce dependence on hydropower.

Development of pump storage schemes

Pumped storage hydroelectricity is a type of hydroelectric power generation used for load balancing. In a pumped storage plant, the energy is stored in the form of water, pumped from a lower elevation reservoir to higher elevation. This is an effective way of storing energy during the periods of off-peak electricity demand. This would help in addressing the issue of lean periods when in normal course, hydropower generation is quite low.

Typically, in a pumped storage plant, approximately 75%–85% of the electrical energy used to pump water in the elevated reservoir is regained. This system can respond very fast to load fluctuations.

In the context of Bhutan, which generates almost all electricity as hydropower, pumped storage schemes or storage dam schemes would be ideal schemes for grid energy storage. Barring industrial loads, the demand for electricity fluctuates a great deal during the 24-hour cycle, and effectively designed pumped storage system can help in conserving energy.

POWER GENERATION USING RENEWABLE ENERGY

In Bhutan, renewable and non-conventional energy sources like solar, wind, biomass, and municipal solid waste can be harnessed for power generation. The power generation through these sources would provide diversity in the power portfolio, which presently consists mainly of the hydro resources. The power generation from biomass could be a viable option, given high forest cover in Bhutan. Sources like sun and wind could also supplement power generation. These technologies could also be used for decentralized power generation. Given the resource availability, the option for generating power from biomass in a centralized mode and using wind and solar photovoltaics in off-grid mode could be explored. Similarly, utilizing municipal solid waste for energy generation can also help in addressing issues related to viable disposal and management of ever-increasing solid waste in Bhutan's urban centres. A detailed analysis of renewable energy options for power generation is provided in the subsequent sections.

Alternatives to hydropower

It is advisable to enhance the diversity of resources for electricity generation, and since the next major hydropower plant of the country, Punatsangchu I, would be operational only in 2015, it is essential to look at the options to augment the current power generation capacity by promoting and exploring other renewables such as biomass, solar, and wind.

Under the proposed strategy to develop other energy resources for both electrical power and thermal energy generation, an analysis of other renewable, non-conventional, and fossil fuel resources has been carried out. This analysis aims at giving a holistic view of the energy resources and supply position. The overall objectives are as follows.

- To reduce heavy dependence on hydropower (more than 99% of the electricity produced in the country is hydropower).
- To 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.
- To reduce the use of fossil fuels in the transport sector.
- To introduce environment-friendly and locally available fuels/energy resources to meet demand for energy, especially in remote and dispersed locations.

BIOENERGY

Bioenergy (biomass energy) refers to the use of plant and other organic materials to provide desired forms of energy and energy services such as heat, light/electricity, and motive power. Bioenergy has been a primary source of energy since human civilizations discovered fire. Even today, bioenergy accounts for about 11% of the world's total primary energy supply of 420 exajoules (EJ) a year (ESMAP 2005). Forest-based biomass has been the main source of energy in Bhutan for many centuries. Abundantly and freely available biomass has become the natural choice for fuel for the rural population of Bhutan.

Bioenergy has been reviewed briefly in the following sections so as to develop a deeper understanding of this form of energy. Some bioenergy-related issues are also highlighted (Box 2).

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.

In recent times, biomass fuels are increasingly 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). This usage is collectively termed as 'modern' bioenergy.

The modern bioenergy has been playing small but increasingly significant role in recent times. It assumes greater significance in several countries and economic sectors, especially in well-forested countries with large forestry-based industries and/or the countries with cold winters and large space heating demands (ESMAP 2005). For example, in Finland and Sweden, modern bioenergy accounts for 33%–36% of total energy used by the industry sector, of which 11%–12% of energy is used for electricity generation, combined heat and power (CHP) generation, and district heating (IEA 2002, 2003a). Interest in modern bioenergy has been increasing worldwide. It is increasingly occupying centrestage in renewable energy plans and policies, especially in the developing countries, because of myriad practical, social, and economic advantages that it offers.

Modern bioenergy offers five major advantages over fossil and/or other renewable energy resources.

1. It is a widely available resource.
2. Bioenergy is essentially stored energy and is available all the times.
3. Bioenergy can be converted to all major energy forms like electricity, liquid fuels or gaseous fuels for use in stationary as well as transport applications.
4. It does not contribute to greenhouse gas concentrations. Apart from being 'carbon neutral', it also contributes to habitat preservation, watershed protection, and soil conservation.
5. Modern bioenergy is widely thought to play a key role in promoting rural development (UNDP 1995). In developing countries like Bhutan, bioenergy can form a basis for rural employment and income generation, thus helping curb migration from rural to urban areas.

BOX 2

BIOENERGY-RELATED ISSUES

Bioenergy has its own limitations. Bioenegry activities are labour-, land-, and resource-intensive. Bioenergy activities directly affect communities. Most importantly, supply side activities set bioenergy apart from other renewable energy resources that are freely available. In contrast, bioenergy resources must be grown, harvested, gathered, and transported to the energy conversion plant, sometimes from large number of dispersed suppliers. These must be stored, dried, and/or processed – chopped or pelletized – for using them as biofuel (Energy Sector Management Assistance Program [ESMAP] 2005). While supply chain activities can bring substantial benefits in the form of local employment and income, they may also raise serous problems like competitive land use and labour system, which form the backbone of rural economies. This necessitates the need for evaluating the impacts of bioenergy project on rural employment and the environment. The risk to existing biomass-dependent social groups or activities should also be taken into account.

The ESMAP study has identified seven main areas of particular importance to bioenergy project development, as listed below.

1 *Resource competition* Most biofuels have other uses as well. So, biofuels may face price competition. Competition with nonmonetized traditional biomass supplies that provide essential 'survival' energy is common and must be dealt with at early stages of project planning.
2 *Land competition* Energy plantation may compete for land with other plantations or other uses.
3 *Land intensity* Bioenergy plants are highly land intensive. For example, they typically require roughly 100 times more land than solar photovoltaics to produce same amount of electricity. This physically limits the feasibility of bioenergy systems.
4 Labour intensity
5 *Handling requirements* Bioenergy fuels are relatively bulky and need infrastructure to handle.
6 *Environmental concerns* Biomass systems, if not well designed, can have adverse impacts on soil quality, water resources, biodiversity, and landscape.
7 Supply uncertainty and risks

Use of liquid biofuels

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. However, in case of Bhutan, these fuels will have limited role to play due to limited land available for cultivation. In Bhutan, only about 7% of the land is under cultivation. The rest of the land has forest cover. Wasteland constitutes a very small area, and hence, bio-oil-bearing plantation for bio-diesel production will have direct conflict with food security and agriculture production.

Biomass fuels,[2] primarily sourced from forests, play a vital role in the economy of Bhutan, as they are the main energy source for a large number of rural enterprises, apart from majority of households in the rural and urban areas of the country. The country consumed about 724 000 tonnes of firewood during 2005, which accounted for almost 57% of the total primary energy supply. With the sustainable yield for timber and fuelwood estimated at 1 565 540 tonnes/year, biomass would continue to remain an important source of energy for Bhutan.

Biomass-based power generation

Biomass-based power generation – either through direct combustion or through gasification route – is an established technology worldwide. Further, with the hydropower generation being seasonal in Bhutan, biomass-based power generation can provide an option to increase the power generation capacity for continuous power generation. Besides, biomass used for power generation can contribute

[2] The term biomass generally refers to the renewable organic matter that originates from living organisms, for example, wood, agricultural residues, animal manure, so on.

to fuel diversity. Therefore, it is suggested that a 5-MW biomass-based power plant be installed as a demonstration plant. Based on the operation of this demonstration plant, the DoE can further plan for additional biomass-based power generation. The proposed 5-MW biomass-based power plant can be supported by energy plantation to ensure sustainable fuel supply. A detailed techno-economic analysis of such a plant is presented in Annexure 4.2. Salient features of 5-MW biomass-based power plant are as follows.

Capital cost	Nu 225 million
Fuel consumption	2 kg/kWh
Biomass required	15 000 tonnes/year
Electricity production	30.66 MU/year

Off-grid power generation using biomass

The small-scale biomass gasifier is an established technology, wherein the producer gas produced in the gasifier can be used for various applications, including power generation. The locally available biomass can be used for decentralized power generation using biomass gasifiers. These biomass-gasifier-based power plants can be deployed in remote off-grid locations. It is suggested that five biomass-gasifier-based decentralized power plants for rural electrification be established as demonstration projects on priority. Typically, these plants have capacities ranging from 5 kW to 100 kW and can be established for supplying grid-quality power for a village or groups of villages.

Gasifier-based grid power generation (5–100 kW)	
Capital cost	Nu 0.1 million/kW
Fuel consumption	1.6 kg/kWh

Thermal applications of biomass

Biomass is currently used for heating and cooking purposes in the residential and institutional sectors. The present biomass appliance/technology can be changed to modern efficient biomass technologies like gasifier and briquetting for thermal applications. Biomass gasifiers can be used for larger thermal applications like institutional cooking, while the biomass/saw dust briquettes can be used with efficient heating devices. A description of the biomass densification technology is given in Annexure 4.3, and biomass gasification technologies and their thermal applications are briefly discussed in Annexure 4.4.

The success of the sawdust briquetting plant operated by the Forest Development Corporation Ltd (FDCL) indicates the potential for the use of biomass/saw dust briquettes for thermal applications. In this regard, the DoE can develop a programme for sawdust and biomass briquetting in the Tenth Plan. The small-sized sawdust briquetting in combination with individual sawmills could immediately go onstream. This programme can include the promotion of efficient cooking/heating appliances.

Pelletization

Pelletization is now a well-established technology in Europe. Pellets are produced from various raw materials like agro-waste, sawdust, and pine needles. Pellets are easy to handle and transport, and advanced automatic pellet stoves and space heaters have made pellets simple and efficient to use. The Renewable Energy Division of the DoE can take up a feasibility study on adopting pellet technology in Bhutan. With vast areas under pine and other forests, pellet manufacturing from forest waste can substantially reduce the demand for fuelwood for space heating in both urban and rural areas.

Similarly, demonstration of biomass gasifier for thermal application like institutional cooking, cardamom drying, and lemon grass oil extraction can be taken up in the Tenth Plan.

Wind energy

Wind-based electricity generation is now a well-developed commercialized technology. Worldwide, wind energy is increasingly being utilized. Bhutan does have good wind potential; however, the development of wind farms is still constrained by various issues, as discussed subsequently.

Infrastructure development

Road and power evacuation infrastructure is yet to be developed. Typically, wind machines of large capacities are installed on 50–80-m-high tower, and wind generator blades are typically 20–30 m long. Current road infrastructure may not be adequate to transport these blades and heavy machinery.

Public opinion about wind machines

During the discussions with officials and policy-makers, it was found that there were certain reservations on the installation of large wind machines due to the concerns about natural beauty for which Bhutan is famous.

Small wind machines and water pumping wind mills

Bhutan, thus, can explore small wind machines of capacity less than 100 kW and mechanical wind pumps to generate electricity in isolated locations for scattered households and can use water pumping mills for providing water for irrigation and drinking. A detailed technology write-up on small wind machines is presented in Annexure 4.5.

Small wind machines can also be coupled with solar photovoltaic power plants in hybrid mode to generate electricity for small villages. These isolated and distributed power generation technologies can play an important role in reducing time and cost of extending infrastructure to supply electricity to far-flung areas. These minigrids can be connected to main grid, once the grid is established.

Solar energy

Bhutan has reasonably good solar energy potential. Although detailed time series ground measurement data is not yet available, the solar energy resources quantified at various places and solar energy resource map developed for the region under Solar and Wind Energy Resource Assessment (SWERA) project of the United Nations Environment Programme (UNEP) have shown a resource potential of 4.5–5 kWh/m^2 in various locations.

Solar energy can be exploited in various ways, but two major ways to use solar energy in Bhutan are as follows.

> ***Solar PV wafer and cell production unit***
> *Solar PV wafers, which are used to produce solar cells, are produced from raw silica/sand using energy-intensive process mostly using electricity. Since Bhutan has cheap and renewable hydro energy in abundance, use of hydro energy for manufacturing solar PV wafers/cells can be an interesting application to produce 'green solar cells'. Some solar cell manufacturers have shown interest in this concept. Installation of such a plant in this region can bring down the cost of solar PV cells and systems substantially, making them cost-effective.*

1 Solar systems, which include solar thermal systems such as water heating systems and solar photovoltaic systems.
2 Solar passive systems for building heating.

Various solar technologies are being developed worldwide, and various products are available in the market. Few systems such as solar home lighting systems and solar water heating systems are useful for distributed applications in the residential sector. These are discussed in detail in the next chapter.

Solar photovoltaic for power generation

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 generation costs unless the cost of grid extension as well as low capacity utilization of this infrastructure are also taken into account. However, solar photovoltaic is an excellent option for distributed generation, since solar resource is freely available; systems are modular, stationary, and easy to install; there are no moving parts, and O&M is cheaper. Hence, the technology can be considered on demonstration basis by installing plants of, say, 100-kW capacity. Currently, under the Integrated Energy Management Master Plan (IEMMP) project, the DoE has planned to install first gird-connected solar photovoltaic plant of 2.3 kW_p capacity as demonstration project.

HYDROGEN AS ALTERNATIVE ENERGY CARRIER CUM STORAGE

Hydrogen is emerging as a clean energy carrier in recent times. Though hydrogen technologies are still in development and testing phase, considering the thrust and importance given to the research and development for developing hydrogen technologies, it is expected that hydrogen can become a major energy carrier and energy storage option in coming years. If generated from renewable energy resources such as sun, wind, and water, hydrogen generation is pollution free. Hydrogen is also being considered as a viable fuel for the transport sector, which so far is heavily dependent on petroleum fuels such as diesel, petrol, liquefied petroleum gas (LPG), and natural gas.

Hydrogen can be used directly as a fuel in modified internal combustion engines or turbines, either in mixed fuel mode or as a single fuel. Another technology being developed is hydrogen fuel cell technology. Fuel cells are electrochemical devices that produce electricity from externally supplied fuel (hydrogen) and oxidant (oxygen). Wind and hydropower technologies are currently being evaluated in the US, European countries, Japan, and other countries as electricity sources that could enable the production of large quantities of low-cost renewable hydrogen for use in distributed generation and transportation. This will facilitate the use of hydrogen storage for off-peak storage of hydropower. In the context of Bhutan, where hydropower is abundantly available but suffers from seasonal variations, hydrogen can be considered as a storage medium to store hydroelectricity, which is environment-friendly. Although wind power is not being utilized for the commercial production of electricity, in near future, wind energy resources can also be exploited for decentralized electricity and hydrogen production. By 2020, smaller-scale stand-alone and/or grid-connected systems serving local transportation fleets and distributed power generation schemes can be envisaged. Indian research organizations have developed hydrogen-powered motorcycles and generator sets for small-scale distributed power generation using hydrogen. The Ministry of New and Renewable Energy, Government of India, has recently announced an ambitious project that envisages introducing 10 million two- and three-wheelers running on hydrogen in India. The Government of India and the RGoB can take up a joint project to explore hydrogen production using hydropower and/or wind energy. This would be a major step in enhancing energy security for Bhutan.

Recently, Young and others have published a paper, which considers the use of hydrogen as storage media for hydropower plants in Bhutan. The paper discusses the feasibility of generating hydrogen using excess electricity available from Sengor Hydropower Plant. The paper estimates the total cost of system (including 100-kW hydropower plant at a cost of $190 000) to be $1424 775. Besides Sengor project, the paper also discusses various options for unelectrified Thanza Hamlet.

Sengor Power Plant is now operational, and it has a potential to generate 876 000 kWh per annum. The plant has connected load of capacity 20 kW. Currently, only about 100 000 kWh is likely to be used in a year (Box 3). It would be interesting to consider hydrogen technology options in near future. The Renewable Energy Division of the DoE can look at this option as futuristic technology development, and a donor-assisted project can be initiated to study the hydrogen production and storage option for future, in conjunction with hydropower plants.

It is recommended that a project, which would evaluate a realistic path for hydrogen production and storage from these two renewable energy resources – water and hydrogen – be taken up as a first step. This project could also examine how to integrate this technology in nation's energy infrastructure, if found feasible.

Geothermal energy

Geothermal energy is the heat energy available in the core of the earth. The exploitation of geothermal energy to meet heat requirements and/or produce electricity is common in certain countries like Iceland, USA, and the Philippines.

BOX 3

100-KW SENGOR MICRO HYDROPOWER DEMONSTRATION PROJECT

Location

- Sengor, Saling Gewong, Mongar Dzongkhag

Funding

- United Nations Development Programme (UNDP), Global Environment Facility (GEF), and Royal Government of Bhutan (RGoB)

Implementing agency

- Department of Energy, Ministry of Trade and Industry (presently Ministry of Economic Affairs)

Goals

- Adequate and reliable supply of electricity for the next 20 years for the Sengor Community.
- Reduction of greenhouse gas (GHG) emissions by using hydropower energy instead of burning fossil fuels, which emits GHGs.

Objective

- To enhance livelihoods
- To alleviate poverty
- To stimulate socio-economic development
- To encourage community-based rural enterprises

Project features

- Sengor is located in the Thrumshingla National Park area and the extension from the available nearest grid is not environment-friendly. Therefore, there is a need for a stand-alone 100-kW micro hydro system.
- Duration of the project: August 2005–June 2008.
- The total cost for Sengor Micro Hydropower Demonstration Project is $1 065 000.00.
- Community-based micro hydropower project in which the community will take the full responsibility for operation, maintenance, electricity pricing, and bill collection, along with ensuring the sustainability of the micro hydro plant in the long run. This will enhance their livelihoods and create a sense of ownership.
- The project will benefit about 57 households, which include the community, social institutions, and national workforce. Moreover, the project is also expected to benefit daily highway commuters.

Details on the geothermal energy technologies are given in Annexure 4.6.

Geothermal potential and its exploitation in Bhutan

Several hot springs (*tsachhus*) are known to exist in Bhutan. These occur in two regions—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. In 1996, a reconnaissance study of thermal springs and medicinal water springs (*menchhus*) in Gasa and Punakha Dzongkahg was carried out by the Geology and Mines Division, Ministry of Trade and Industries (Gyenden 1996).

The study included analysing soil and water sample, studying geology around the area, and collecting information on medicinal properties of the thermal springs, besides registering medicinal plants en route.

The study report mentions that the temperature of the spring water ranges between 40 °C and 50 °C. Highest temperature of 50 °C was recorded at Chubu Tsachhu, which is located in North East Tsachuphu village and is approachable by motorable road up to Samdinkha from Wangdi Phodrang.

In short term, it is possible to use hot water springs for space heating in the houses in the vicinity and also in guest houses for tourists, as a demonstration project. Drying facilities for agricultural products and medicinal herb can also be established in the areas around the hot springs. These facilities would offer income and employment generation opportunities for local youths. Moreover, these projects by themselves would become a tourist attraction. The Renewable Energy Division can conduct a detailed feasibility study in the Tenth Plan.

In medium and long term, detailed exploration and plotting of thermal profiles of the underground sources, along with the study of geological structures, are required to establish the potential and feasibility for the large-scale use of geothermal energy in the region for applications like electricity generation. These studies could be undertaken by the Department of Geology and Mines, along with the Renewable Energy Division of the DoE.

Further, geological study and exploration of thermal potential for direct use of geothermal energy can be taken up in future.

WASTE-TO-ENERGY

Waste generation is increasingly being associated with human settlement and rapid urbanization, with the problem of proper management of solid waste so generated also showing an upward trend. Thimphu and Phuentsholing alone generate about 37 tonnes and 25 tonnes of solid waste, respectively, daily, containing a lot of organic matter (Bhutan Energy Data Directory 2005). It has been estimated that in Bhutan, about 81 119 tonnes of solid waste is generated annually. If this waste can be used for the generation of energy (either for electricity generation or for supplying thermal energy), besides augmenting the energy supply per se, it would take care of waste management as well. Bhutan has, therefore, potential to sustain over 3 MW of power generation capacity.

To start with, a biomethanation system of capacity 1 tonne/day may be set up in Thimphu as a demonstration plant, treating its organic waste, including that generated from hotels and vegetable market.

FOSSIL FUELS

In the absence of petroleum reserves in the country, Bhutan meets its requirement of the petroleum fuels – diesel, petrol, kerosene, and LPG – through imports from India.

Typically, about 10% of the conventional petroleum-based diesel is envisaged to be replaced with bio-diesel. Considering the scale of use of diesel in the country, Bhutan can directly import bio-diesel blended diesel from India, once the Indian oil companies start supplying the blended diesel in sufficient quantities.

Natural gas based combined cycle power plant

As evident from the analysis of the peak demand in Bhutan and the firm power produced from the hydropower plant, there will be a gap of about 250 MW in power supply during lean season till 2015 when Punasangtchu and Mangdechu power plants will get commissioned. To plug the gap between the peak demand and power supply during the lean season of hydropower generation, a natural gas based combined cycle power plant of an approximate capacity of 300 MW in Assam/ West Bengal is recommended. This plant may supply power to India during the summer, and during winter, Bhutan government can utilize all the power generated from it. Salient features of the plant are as follows.

Plant capacity	300 MW
Plant efficiency	50%–52%
Plant load factor (PLF)	85%–90%
Capital cost	Rs 10 500 million
Natural gas fuel required for power generation	447 million m^3 per year
Cost of fuel	\$4.2-4.5 per million BTU (that is, Rs 8–8.5/m^3)
Cost of generation	Rs 4.5-5.5/kWh

This project, which can be installed on the Indian side as a joint venture will offer the following advantages.

- Lean power shortage is eliminated.
- Bhutan's energy security issue is addressed due to the diversity in fuel for power generation. Since currently, the majority of electricity is generated by two hydropower plants, which

incidentally, are on same river and are run-of-the-river type with limited storage.

- Industries can pay higher charges during winter for assured power supply.
- Gas power plant can respond faster to change in demand.
- Natural gas being a relatively cleaner fuel, the pollution impact is negligible.
- The gestation period is small (about two years); hence, it is a quicker and ideal solution

Only barrier for this project could be the availability of natural gas.

Coal

Coal is primarily used in industries. The overall contribution of coal in the energy supply mix is only about 8%. Efficient technologies for coal utilization can be promoted. Locally produced coal is mainly used for reduction processes in the industries. Coal-based power plants are not envisaged for following reasons.

- Locally available coal is of poor quality and is available in limited quantity.
- Large hydropower potential is available.
- A coal plant may be useful for improving firm power, but it is not essential if medium hydropower plants are installed in next four to five years.

CONCLUSION

The above analysis clearly shows that being cheapest and pollution free, hydropower will remain the main source of power in Bhutan for a long time to come. However, for faster development of hydropower plants, involvement of the private sector as equity partner or IPP or captive power producer is essential. It is essential to develop small- and medium-sized hydropower plants on fast track mode so as to avoid power shortages, especially in winter, with appropriate incentives and financial packages for IPPs.

Other renewables can play an important but limited role in electricity generation. However, the establishment of demonstration plants using biomass, small wind, solar photovoltaic, and municipal solid waste should be considered to develop diverse resources, distributed generation, and energy security.

Energy-intensive industries could be encouraged to set up captive power plants to achieve twin goal of employment generation and industrial development without hampering the export of electricity or supply of electricity to the citizens of the country.

The DoE could take up a study to prepare detailed feasibility report for setting up a solar photovoltaic silicon cell and wafer manufacturing industry in near future. Hydrogen and geothermal energy can be explored as futuristic options.

The potential of biomass for thermal applications in small-scale industries and for processing agro products can also be explored.

Cheap and renewable hydroelectricity can be effectively used in the transport sector, which is an environment-friendly option.

Demand side efficiency enhancement or energy demand management

Energy demand management or demand side efficiency enhancement strategies fundamentally aim at optimizing the use of energy delivered through end-use efficiency enhancement, demand side management practices, and reduction in waste and unnecessary use, thus substantially increasing the 'net' energy available to end-users.

Taking clue from the projected energy consumption and predicted fuel mix for each sector, an attempt has been made to carry out an analysis, by sector, and prioritize various strategies for demand side efficiency enhancement, along with the promotion of eco-friendly fuels and renewable energy resources so as to evolve a long-term strategy.

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. According to Census 2005 of Bhutan, about 46 064 households use kerosene for lighting, while about 4502 households use fuelwood, candle or other resources for lighting. Hence, there is a need to put in place strategies for cutting down fuelwood as well as kerosene consumption in this sector. Reduction in the consumption of fuelwood and kerosene as well as in the total residential energy consumption can be achieved by adopting one of the following strategies.

1 Improving the overall efficiency
2 Using modern or renewable energy sources
3 Developing energy-efficient housings/buildings

Improvement in the overall efficiency

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

Strategy 1: Promotion of improved cook stove

Goal

The main aim of this strategy is to reduce fuelwood consumption for cooking and space heating in rural households.

Approach

Reduction in fuelwood consumption can be effected through awareness campaign and promoting fuel-efficient cook stoves and *bukharis*. Eleven Dzongkhags – Dagana, Wangdue, Mongar, Tsirang, Haa, Trashiyangyse, Trashigang, Pemagatshel, and Sandrup Jongkhar – that have highest per capita fuelwood consumption and house more than 48% of the rural population can be targeted in the Tenth Plan.

Giving subsidized electric cook stoves can also be considered a strategy in these Dzongkhags. Most of these Dzongkhags are located in central and eastern regions, which are mostly underdeveloped.

However, given the fact that about 69 000 households (37%) still use fuelwood for cooking and space heating, it is important to have an ambitious programme on the distribution of efficient cook stoves in Bhutan. The United Nations Development Programme (UNDP) office in Bhutan had earlier supported improved cook stove programme, but such activities were not supported on a long-term basis. It is important to carry out this programme on a sustainable basis and for a longer period.

Recommendations

It is recommended that a target of about 20 000 improved cook stove installations in households can be set under the programme. A nationwide awareness campaign can also be undertaken.

The Department of Energy (DoE) can implement the programme with the help of NGOs such as Tarayana Foundation and Royal Society for Protection of Nature (RSPN).

Monitoring of fuelwood consumption in selected villages before and after implementation can indicate the impact of the programme.

Strategy 2: Use of improved cook stoves for fodder cooking

The Integrated Energy Management Master Plan (IEMMP) survey has estimated that about 26% of the energy consumed in the residential sector is used for fodder cooking in rural areas. Most of the fodder cooking is being done using conventional three-stone cook stoves.

Since fuelwood is available free of cost, alternative fuels such as LPG or electricity were not used for fodder cooking activities.

Goal

Reduce fuelwood consumption for fodder cooking by improving efficiency.

Approach

Improved cook stoves can be supplied free of cost through Dzongkhag offices, for fodder cooking. Specially designed turbo cook stoves developed by organizations such as The Energy and Resources Institute (TERI) can be tried on a demonstration basis.

Recommendations

A programme for supplying about 500–1000 cook stoves on demonstration basis can be initiated in the Tenth Plan. These cook stoves can be distributed through subsidy programmes by renewable and natural resource centres. The Agriculture Machinery Centre (AMC) can be the focal agency for manufacturing and distribution of these stoves.

Strategy 3: Promotion of CFLs, LED lamps, and other energy-efficient lighting fixtures in electrified areas

Compact fluorescent lamps (CFLs) are efficient and effective in saving electricity used for lighting. Bhutanese households commonly use 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.

Goal

The main goal is to reduce the energy consumption in the electrified areas by introducing energy-efficient lighting systems.

Approach

One approach is the promotion of CFLs and energy-efficient lighting through awareness campaign. For areas having off-grid hydropower plants, supply of CFLs through subsidy/cost sharing scheme can also be considered. Similar experimental scheme implemented by the DoE and the Bhutan Power Corporation (BPC) in Ura Micro Hydro Power Project area in 2005 has shown good success.

Recommendations

In Thimphu/Phuentsholing and other urban areas, introduction of the CFL under promotional scheme for replacing bulb can be undertaken by the BPC. Certain number of CFLs, say four per households, can be provided to each consumer, and the cost of the same can be recovered through electricity bills.

Promotion of 36-watt tube light instead of 40-watt tube lights is also being considered under the South Asia Regional Initiative for Energy programmes. Similarly, schemes for promotion of energy-efficient lighting can also be taken up.

Use of modern fuel and renewable energy sources

Strategy 4: Promotion of efficient LPG stoves

LPG is a modern cooking fuel, causing less pollution. It is an efficient burning fuel and is easy and convenient to use.

Use of LPG as cooking fuel is common in urban areas. However, in rural areas, LPG is still not a preferred fuel due to the following reasons.

- High cost mainly due to high transportation costs
- Limited availability
- Difficulty in transporting it to the households.

Goal

Replacing fuelwood with LPG and efficient use of LPG by introducing efficient LPG cook stoves.

Approach

Small LPG cylinders that are easy to transport can be introduced. Figure 1 depicts a woman carrying LPG cylinder. Simultaneously, energy-efficient LPG cook stoves can also be introduced.

Recommendations

It is expected that LPG consumption is likely to increase by three to four times by 2020. Introduction of standards and labelling system for LPG cook stove can help in introducing efficient LPG cook stoves in Bhutan. As mentioned in Chapter 3, efficiency improvement of 5% over and above the efficiency of currently available LPG cook stoves is possible.

FIGURE 1 A WOMAN CARRYING LPG CYLINDER

Strategy 5: Use of briquettes and pellets for space heating

Briquettes made from saw dusts are now available in Thimphu region, which are mainly supplied through briquetting plant set up by the Natural Resources Development Corporation (NRDC). Similar briquetting plants can be installed at other places so that briquettes are available in most parts of the country. Further, small pellets made from sawdust and forest waste can be used for space heating. Pellet manufacturing is a major industry in Europe, and sophisticated pellet stoves are also available.

Goal

The strategy is to reduce fuelwood consumption for space heating.

Approach

Pellets and briquettes can be produced from saw dust and forest wastes. Pine needles and other forest waste can be effectively used for manufacturing pellets.

Recommendations

Small-scale saw dust should be introduced along with forest waste briquetting and pelletizing in various towns of the country. Simultaneously, new energy-efficient pellet stoves and boilers should also be introduced in towns.

Strategy 6: Promotion of solar lanterns and home lighting systems in unelectrified areas

Proper lighting is the basic requirement in a modern society. It is not only important from health point of view but is also essential for socio-economic development, as it gives an opportunity to people to extend their working hours and also enables students to study for longer period. People can carry on with their day-to-day activities even after sunset.

According to the Census 2005, there are about 46 064 households that use kerosene as a primary source of lighting and about 4502 households that use fuelwood, candle or other resources for lighting. Figure 2 shows the percentage use of fuels for lighting purpose in households in Bhutan.

Goal

To reduce the use of imported kerosene as well as to reduce indoor pollution and provide improved lighting to rural unelectrified households.

Approach

Though all households will eventually be covered under rural electrification programme, an immediate and intermediate solution can be providing solar lighting systems and solar lanterns.

Recommendations

Solar lanterns are designed to provide quality light for about two to six hours. Solar home lighting systems are typically designed with two to four CFL tube lights and an additional point for small radio or TV.

Both these products are commercially available in the international and local markets. They are available in various models and sizes. The DoE has been working with some organizations like Barefoot Engineer College, Tilonia, India, for training rural youth in installation and operation and maintenance (O&M) of these systems. About 300 rural women were trained recently under an Asian Development Bank (ADB)-funded programme.

Promotion of solar lantern and/or solar home lighting systems as an interim solution for lighting can be done in two ways.

1. *Direct sale* Direct sale of solar lanterns and home lighting systems to individual households under subsidy scheme can be promoted through the Dzongkhag offices or the Bank of Bhutan or Bhutan Development Finance Corporation (BDFC) or Renewable Natural Resource (RNR) centres.
2. *Solar women entrepreneur scheme* Solar entrepreneurs, especially women, can be groomed, who can set up charging stations for charging solar lanterns during daytime and rent them to users during night-time. However, the scattered nature of village households and

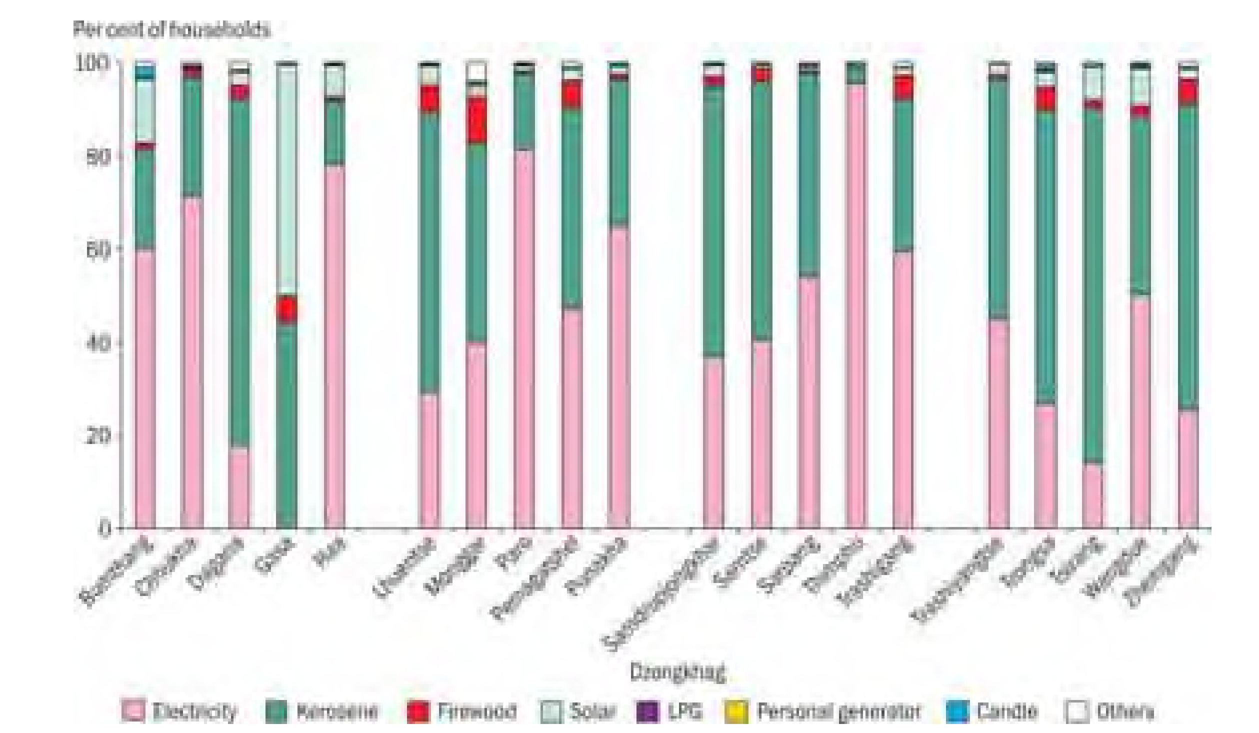


FIGURE 2 SOURCES OF LIGHTING IN HOUSEHOLDS (CENSUS 2005)

mountainous terrain may affect the efficacy of such schemes. The Renewable Energy Division of the DoE is already in the process of training rural women on solar home lighting systems as 'barefoot engineer' from Barefoot College, Tilonia, and Rajasthan, India. These women can be further trained to run small business of renting solar lantern.

Simultaneously, the use of kerosene wick lamps should be discouraged through awareness campaign.

Solar home lighting systems are already being promoted in Bhutan under different funding programmes. Most of these are promoted in rural areas that fall under protected forest areas. Recently, proposed draft Renewable Energy Policy by the DoE envisaged supply of solar home lighting systems to 3018 households for off-grid electrification. The same scheme can be extended to the households in rural areas, where electricity is not likely to reach for another four to five years.

Strategy 7: 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.

Goal

The main goal under this strategy is to introduce solar water heating systems to save electricity and fuelwood.

Approach

In Bhutan, initial studies carried out by the DoE through Austrian consultants have shown that these systems may not be cost-effective. TERI team carried out an analysis of solar water heating system with the help of RETScreen software by using cost details provided by the local solar system supplier. The analysis showed that subsidy and soft loans are required for making solar system attractive, and the cost of transportation and installation is high due to geographical reasons and small market size.

Recommendations

The DoE has already carried out initial studies on solar water heating systems for institutional consumers. The studies have established the fact that these systems are workable, but the costs are very high. Moreover, electricity and fuelwood – two most commonly used fuels for water heating – are very cheap. Therefore, following suggestions are made for promoting solar water heating systems.

- Initially, solar water heating systems can be promoted in urban areas through awareness campaign. Special soft loans can be made available to interested users through the BDFC.
- The DoE may also offer a rebate on monthly electricity bills for those users who have installed solar water heating systems.
- Similarly, a rebate may be given on annual municipal/property taxes to commercial and institutional buildings with solar water heating systems.

Specially designed smaller and lighter systems using plastics can be installed on demonstration basis.

Strategy 8: Use of hydrogen as a cooking fuel

In future, the potential of hydrogen production using hydropower to store surplus hydro energy can be explored. A pilot study and a pilot plant for hydrogen production and storage have been suggested elsewhere in this report. Use of hydrogen for cooking can be explored at a later stage. Issues such as costs and safety need to be addressed before this technology can be recommended for large-scale use. Figure 3 shows a hydrogen cook stove developed by Banaras Hindu University, Varanasi.

The Ministry of New and Renewable Energy (MNRE), Government of India, has been funding various research programmes on hydrogen technology development. Some of the technologies, such as hydrogen-based motorcycles, can be tested in Bhutan in future.

FIGURE 3 HYDROGEN COOK STOVE DEVELOPED BY BANARAS HINDU UNIVERSITY, VARANASI

Development of energy efficient housings/ buildings

Energy consumption for lighting and space heating 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. A brief note on energy conservation techniques in the buildings is presented in Annexure 5.1. Following strategy is suggested for the introduction of energy-efficient housing in Bhutan.

Strategy 9: To introduce energy-efficient housing in Bhutan

Goal

The goal of this strategy is to introduce energy-efficient buildings in Bhutan.

Approach

The energy-efficient building designs can be introduced initially for new housing complexes being developed by government agencies

Recommendations

External expert agencies can be initially involved in developing designs. This can be simultaneously followed by organizing capacity building training courses for architects and builders. The DoE can develop such courses jointly with the Government of India and government agencies like Bureau of Energy Efficiency (BEE).

A detailed note on energy conservation in the buildings in Bhutan is given in the subsequent section.

Energy conservation in buildings in Bhutan

Design concept of eco-housing and eco-friendly building ensures the following.

- Overall site planning and design of building architecture have coherence and integration with the surroundings.
- All buildings are oriented and designed for energy efficiency and use natural climatic conditions to reduce energy consumption by adopting passive solar design concepts.
- Conservation and efficient use of natural resources such as rainwater available at site are ensured.
- Renewable energy is used, such as using solar energy for water heating and space heating, using biogas for cooking, and using other renewable energies, wherever applicable.
- Eco-friendly, low-embedded energy materials, and energy saving building materials are used.
- Energy-efficient technologies and appliances are used to reduce energy consumption in the building. For example, using heat pumps for space heating and cooling, using insulation in walls and roofs for reducing heat loss, and using energy-efficient lighting fixtures.

Bhutan has developed its own traditional housing and building design guidelines, which are being followed strictly.

Traditionally, locally made mud bricks and traditional housing construction techniques using bamboo and mud are still used in rural areas. However, in urban areas, the practice of using cement and concrete for construction, and using galvanized iron (GI) sheets for roofing material is prevalent.

In the context of Bhutan, following are the recommendations to develop and adopt eco-friendly and energy-efficient housing codes and concepts.

- National-level awareness programmes and capacity-building programmes for common citizens and architects need to be developed.

- Collaborative programmes with other agencies, especially with the government agencies like the BEE, can be undertaken to develop database for weather data, best practices, design norms for Bhutanese weather conditions, alternative materials, and so on.
- Materials like bamboo and mud walls need to be analysed and documented.
- The use of bamboo and its products for buildings, such as mats for walls and bamboo-based roofing materials, can be explored. Currently used GI sheet roofing material can be replaced with bamboo mats.
- Workshops for architects and construction agencies to sensitize them on energy conservation and energy efficiency in buildings should be conducted.
- Agencies like Standards and Quality Control Authority (SQCA), National Housing Development Corporation, Construction Association of Bhutan, National Environment Commission, Ministry of Works and Human Settlement, and Urban Development Department can work together towards developing energy-efficient buildings.
- Some specific recommendations that can be considered are as follows.
  - Longer façades should face the north–south direction.
  - Spacing between buildings should take into account winter sunpath and should get maximum radiation on south glazing for direct solar space heating.
  - Spaces that are occupied during the day time in residential units should face south side.
  - Night-time spaces should be located on the north side, with thermal insulation on the north wall.
  - Insulation is also recommended for the walls on the east and west sides.
  - There should be double-shuttered double-glazing windows.
  - Heaters with timers should be used for different heating set points for day and night operations.
  - Glazing should be on the south wall, with internal low 'e' glass.
  - Infiltration should be controlled by having concrete cornices for windows.

General recommendations

Since capital cost of energy-efficient/renewable energy devices is a major barrier in adopting them, a common loan scheme for energy-efficient/renewable energy devices can be taken into consideration. This loan scheme can provide loans on convenient terms to individuals for the purchase of energy-efficient/renewable energy devices certified by the DoE. Till the time such labelling facilities are developed in the country, energy/star-labelled energy-efficient devices as well as those renewable energy systems that conform to international standards may be endorsed by the DoE for use in Bhutan.

Small isolated houses can explore small wind machines and small solar photovoltaic (PV) power plants for providing electricity to the households. Wind/solar hybrid pumps can be used in farmhouses.

COMMERCIAL AND INSTITUTIONAL SECTOR

The commercial and institutional sector comprises four major types of consumers as far as energy is concerned

1 Bulk users like armed forces, monastic bodies, schools, hospitals
2 Tourism activities
3 Commercial offices
4 Small shops

Bulk users use energy for cooking, water heating, lighting, and space heating, while shops and commercial offices use energy mostly for lighting, space heating, and running other appliances like computers and printers. Most commonly used fuel in these sectors are fuelwood for cooking and water heating, mainly by bulk users, monastic bodies, schools and hospitals, and so on, and electricity for lighting and heating, mainly by the hotel industries and commercial offices. Following paragraphs describe the strategies that can be used for the reduction in the demand for fuelwood and kerosene and can be helpful in saving electricity.

- Promotion of use of energy-efficient appliances
- Use of modern fuel and renewable energy sources
- Development of energy-efficient buildings

Promoting the use of energy-efficient appliances

Strategy 10: Use of energy-efficient cook stoves and other devices for cooking

Army units, monastic bodies situated in remote areas, and schools with hostels use fuelwood-based cook stoves for cooking.

Wood-fired water-jacketed cook stoves, commonly known as Althaps, which are produced locally, are found to be used in many places. These were developed under the UNDP-funded projects.

Goal

Goal of this approach is to promote the use of energy-efficient cook stoves for these institutions.

Approach

Reduction in fuelwood consumption can be encouraged through awareness campaign and promoting fuel-efficient cook stoves and *bukharis*.

Recommendations

The World Wide Fund for Nature (WWF) was recently engaged in promoting electric rice and curry cookers for institutional users. These cookers have shown good potential for saving fuelwood. However, these electric cookers by themselves are not ISI marked, and efficient electric cook stoves need to be promoted.

In urban areas where LPG and electricity are available, the use of efficient LPG cook stoves, and electric rice cookers and curry cookers is recommended.

Turbo cook stoves, or wood gas cook stoves, can be introduced in the institutional segment. Canada International Agency (<http://www.acdi-cida.gc.ca/CIDAWEB/acdicida.nsf/ En/STE-320162243-T98>) also distributed efficient cook stoves in schools in Bhutan. Such projects can be taken up more aggressively through coordinated efforts for effective distribution, efficient after-sales service, and post-project monitoring.

Strategy 11: Promotion of CFL and other energy-efficient lighting fixtures in commercial buildings

CFLs are efficient and effective in saving electricity that is used for lighting. Commonly used appliances are electric bulbs for lighting. Replacement of these bulbs with CFLs can save as much as 80% of electricity used for lighting. Box 1 gives the comparison of an 11-W CFL and a 60-W incandescent lamp.

Goal

The main aim is to reduce energy consumption in the commercial and institutional sector by introducing energy-efficient lighting systems.

BOX 1

A COMPARISON OF A 60-W INCANDESCENT LAMP WITH AN 11-W COMPACT FLUORESCENT LAMP (CFL)

Lamp characteristics	*CFL* (11 W)	*GLS (Incandescent lamp)*
Lamp wattage (W)	11	60
Lamp life (burning hours)	10 000	1000
Colour temperature (CCT °K)	2700	2700
Lumen output (Lumens)	900	720
Lumen efficacy (Lumens/watt)	81.8	12
Colour rendering index (CRI)	82	100
Energy saving	60%	—
Simple payback periods (months)	2 to 3	—

Approach

One approach is promoting CFLs and energy-efficient lighting through awareness campaign. Providing CFLs through subsidy/cost-sharing scheme can also be considered.

Recommendations

In Thimphu/Phuentsholing and other urban areas, introduction of the CFL under promotional scheme for replacing bulb can be undertaken under an appropriate programme launched by the DoE through a designated department.

Energy audit may be made compulsory for big hotels, commercial complexes, and institutions. This will motivate the users to switch to the use of energy-efficient CFL lights and other electrical fixtures.

Strategy 12: Introducing energy efficiency in the hotel industry

The hotel industry is an integral part of the tourism industry. Energy efficiency measures focused on hotel industry would go a long way towards eco-tourism and energy savings.

Hotels in Bhutan vary from simple lodges to five-star hotels built by international groups. Typically, hotels in Bhutan have about 20–30 rooms. The tourism department has planned to develop and upgrade facilities of the existing hotels to three- or four-star grade.

Use of energy-efficient LPG cook stoves and lighting fixtures will reduce the total energy demand of the hotels.

Recommendations

- Energy auditing can be made mandatory for hotels having a minimum of 20 rooms. The DoE can provide the auditing support.
- These hotels can be asked to submit the details of energy consumption to the DoE on an annual basis. Over a period of time, norms for energy consumptions can be developed for the hotel industry.
- Hotels can be encouraged to adopt energy efficiency through star rating systems.

Use of modern fuel and renewable energy sources

Strategy 13: Promotion of dish-type solar cookers

Dish-type solar cooker may be promoted in the monastic bodies, schools/colleges hostels, hotels, and so on, where large-scale cooking is required. This will help in reducing the fuelwood consumption for cooking.

Strategy 14: Promotion of solar water heaters

Solar water heaters are the most useful devices for saving fuelwood as well as electricity, which are being used for heating water in most of the hotels and institutions. These institutions can be provided with special incentives to install solar water heating systems to meet their hot water requirement. Although there are hindrances to installing solar water heaters, such as low cost of electricity and lack of required infrastructure, know-how, and service network, the DoE can promote the use of solar water heaters by undertaking awareness campaigns, highlighting their environmental benefits, providing incentives to the user, and making them compulsory for large hotels.

Strategy 15: Promotion of solar PV and small wind-based power plants

Solar PV based power plants and small wind-based power plants may be promoted in institutions, especially monasteries and schools. This will reduce the dependency on hydropower, especially in winter when the power from hydro system become less. This solar PV and small wind-based plants will also help in electrifying the rural area where grid electricity has not reached.

Development of energy-efficient buildings

Energy consumption in buildings can effectively be reduced by suitably designing the buildings. The DoE may promote the development of eco-friendly buildings, which are designed to reduce heat loss and use daylight for internal lighting.

Strategy 16: Introduction of energy efficient commercial buildings

Goal

The main aim of this strategy is to introduce energy-efficient commercial buildings in Bhutan

Approach

New office buildings of Royal Government of Bhutan can be made energy efficient on the lines of the new building of the DoE. This design can be extended to other institutions also.

Recommendations

An energy-efficient building code for Bhutan may be developed, and it should be incumbent on hotels and big institutions buildings, including the commercial office buildings, to follow this code as per the building category. To generate awareness on these energy-efficient buildings, the DoE may organize some training courses for the owners of the buildings, builders, and the government department.

INDUSTRIAL SECTOR

The industrial sector mainly consumes electricity, fuelwood, furnace oil, and coal. The country's growth is based on the industrial growth, which is taking place at a rapid pace. Because of this growth, energy consumption in the country, as discussed in Chapter 3, is enormous. To reduce energy consumption in the industrial sector, specific strategies for different categories of industries are required. As Bhutan has good potential for electricity generation and is dependent on the import of fuels like furnace oil and coal, it is necessary to reduce the consumption of fuelwood, coal, and oil by the industries. The strategy for fuel consumption reduction in the industries is as follows.

Strategy 17: Promote the use of energy-efficient equipment and technologies in small- and medium-scale industries

Goal

The main aim of this strategy is to improve energy efficiency and reduce energy consumption as well as pollution in the small- and medium-scale industries

Impact/energy saving potential

The Long-range Energy Alternatives Planning (LEAP) analysis has shown that implementing these measures will save approximately 10% of electricity in future.

Implementation strategy

The DoE has established an energy laboratory under the IEMMP project. The laboratory facilities and the infrastructure available with the Department of Industries on Training and Capacity Building can be used to develop training and energy audit programmes for small-scale industries

The programmes can be developed for specific types of industries such as textile, paper, food processing, and so on.

Barriers

Small-scale industries may find investments in energy efficiency equipment an expensive proposition. Lack of awareness is one of the reasons for not using efficient devices.

Demand side management in new industries should be followed diligently for reducing the total demand for energy.

Energy demand reduction strategies, by industry

Ferro alloys

From earlier analysis, it is observed that the ferro alloy industry is one of the most energy-intensive industries in Bhutan and a significant consumer of electricity. This industry 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. The largest ferro alloy plant in Bhutan is the Bhutan Ferro Alloys Ltd (BFAL). However, a number of such units are expected to come up by 2008. It is recommended that energy-efficient technologies be used extensively. Some technological and application-based recommendations are as follows.

- Use of pre-heated (up to 950 °C) charge in a specially designed reactor (such as rotary kiln/vertical shaft furnace) can bring down the specific power consumption to less than 3000 kWh.

These reactors can also be converted to reduction reactors for supplying pre-reduced manganese ore to electric smelting unit.

- Use of hot pre-reduced ore from the above reduction reactors (rotary kiln/vertical shaft furnace) integrated to smelting unit can bring about a drastic reduction in specific power consumption (around 2000 kWh).
- Although it is possible to run the electric furnace with an MnO content of the slag as low as 15%–16%, it would mean high slag basicity, high power consumption, and high fume losses.
- 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 Rs 500 per tonne of ferro-manganese.
- The use of partially burnt coal (jhama) 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.
- Annual energy auditing can be made compulsory, as it helps to identify the under/overutilization of machineries, leading to increased consumption of energy, particularly electricity.
- Use of energy-efficient technologies in new plants with soft loan/tax credit to cover part of additional expanses can be made mandatory.

Units violating the rated norms can be fined based on the degree of violations. Regular training programmes can also be made mandatory for plant officials, which will help them use energy efficiently and also provide them with latest information on state-of-the-art technological developments.

Cement industry

The cement industry is poised to play a big role in meeting Bhutan's major infrastructural need in the coming years. As mentioned earlier, the cement industry is an energy-intensive industry in which electricity and coal form major inputs to production. 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

Use of energy-efficient equipment gives very encouraging results even at the cost of some capital investment. The energy-efficient equipment that can be used by the cement industry are highlighted below.

- Slip power recovery system
- Variable voltage and frequency drive
- Grid rotor resistance
- Soft starter for motors
- High efficiency fans
- High efficiency separators
- Vertical roller mill
- Pre-grinder/roller press
- Low pressure pre-heater cyclones
- Multi-channel burner
- Bucket elevator in place of pneumatic conveying

- Fuzzy logic/expert kiln control system
- Improved ball mill internals
- High efficiency grate cooler

Active participation of employees in energy conservation efforts has been very fruitful in India (National Council for Cement and Building Materials). The suggestion box schemes, quality circles, brainstorming sessions, and cash rewards for good suggestions are some of the schemes the plants can adopt for ensuring active participation of employees. Setting up of an energy conservation cell for monitoring and controlling energy performance of the plant is gaining importance in the Indian plants. Cement units can also train manpower, as has been done in the Indian cement manufacturing companies. Industry audits should be made mandatory, and as mentioned earlier, there should be provisions for imposing fines for violations against non-compliance.

Iron and steel

A number of licensed industries are expected to come up in Bhutan. Iron and steel plants will constitute a significant number, with some specializing in iron re-rolling, while others in the iron and steel making. The globalization of the steel industry has ushered in a new era of cost-competitiveness. The steel industry is the single largest energy consumer, accounting for about 4% of the world's energy consumption. The energy used is a major cost factor for the steel industry. In developed countries, cost of energy is between 15% and 20% of the overall cost of production. In India, it is between 30% and 33%, and for Bhutan, it is close to 40%. In the steel industry, the greatest saving in energy is achieved through improvement in technologies used for manufacturing iron and steel. In the current route, through direct reduced iron (DRI) to electric arc furnace (EAF), first cold DRI/hot briquetted iron (HBI) is produced at ambient temperature, and this is then fed to EAF to produce steel. This involves loss of substantial energy due to multiple heating and cooling. So, there is a potential for saving energy by utilizing the energy technology and process of steel making. Various scrap pre-heating technologies are now available and have been designed to convey hot DRI from DRI reactor to EAF. These systems include mechanical conveyors, transport vessels (rail or truck), and pneumatic conveying systems. There are two primary benefits of hot charging of DRI to an EAF: (1) lower energy consumption for melting and (2) increased productivity due to shorter tap-to-tap time. The energy savings occur because less energy is required to bring DRI to melting temperature. As a thumb rule, power consumption can be reduced by about 20 kWh/tonne of liquid steel for each 100% increase in the composite charge temperature. Also, in addition, there is saving in electrode consumption to the tune of 0.004 kg/kWh due to its linear relationship with power consumption. At 80% hot DRI charging, the savings in electrode work out to be Rs 50 per metric tonne (PMT) at current electrode prices. Some specific measures that can be adopted are as follows.

- Effectively utilizing free space post combustion
- Scrapping pre-heating system
- Using hot runner and riser
- Insulating pit for hot empty ladles
- Converting spout tapping to submerged tapping
- Using hot metal in EAF
- Blowing lime fires into EAF
- Using supersonic oxygen blowing
- Sliding gate system in EAF tap hole
- Placing ladlehood in ladle furnace station
- Continuous DRI/HBI charging
- Post combustion system
- Insulating pit for hot empty ladle
- Modifying ladle cover and reduction in cover height
- Using submerged tap hole
- Using hot metal
- Modifying ladle cover for online wire feeding
- Changing mix optimization
- Ladle in circulation
- Using ladle pre-heating system
- Using evacuating system
- Using post-combustion technology
- Using foamy slag practice
- Using lime as flux
- Measuring finished bath temperature
- Using crucible and riser

As reported by MECON India Ltd, by implementing some of the ECOs (energy conservation opportunities), some selected steel plants based on electric arc furnace and induction furnaces have reported significant reduction in energy consumption.

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

Ferro-silicon plants in India have reported more efficient performance than that reported by the Ferro-silicon Company in Bhutan. The advanced technologies can be introduced in new companies.

Awareness programme, along with support for energy audit, can be adopted as a strategy for the industrial sector. Similarly, industry-specific energy efficiency measures can be suggested for most small- and medium-scale industries after energy audit.

Industries like wood and steel milling industries can be specifically targeted by conducting energy audit. Replacement of motors and use of energy-efficient lighting are two major energy measures for these small units.

TRANSPORT SECTOR

The transport sector in Bhutan comprises road and air transport. Bhutan's transport sector contributed 16% to the overall gross domestic product (GDP) at the end of the Eighth Five-year Plan (1997–2001). The development strategy for the transport sector in Bhutan aims at achieving a number of milestones, as articulated in a comprehensive vision statement of Bhutan's future (*Bhutan 2020: A Vision of Peace, Prosperity and Happiness*). These milestones include (1) 75% of rural population living within half-day's walk from nearest road, (2) national trunk roads upgraded to take 30-tonne lorries, and (3) completing second transnational highway.

The vision of Bhutan's National Transport Policy is to ensure 'access to quality transport services by all, taking into consideration the requirements of a landlocked country'.

Strategies for surface transport, which are put forth in the policy, include the following.

- Improving rural access and inter-connection among Dzongkhags
- Exploring alternate modes of transport
- Enhancing safety and traffic management system
- Improving frontline services
- Promoting the use of public transport
- Promoting regional cooperation in transport

'Good Governance Plus' recommends eco-friendly mass transport system in the major urban areas.

Petrol and diesel are the two fuels that are used in the transport sector in Bhutan. The country imports both these fuels, and over a period of time, there is an increasing trend in their consumption levels. Diesel imports were 51 460 kilolitres in 2005, of which a substantial proportion (about 49 197 kilolitres) was used in the transport sector alone. The imports for petrol stood at 13 795 kilolitres in 2005, which was mainly used for transportation. At present, alternative fuels such as natural gas, electricity, and LPG are not used in Bhutan.

Bhutan has no vehicle manufacturing facilities, and all vehicles are imported. Majority of vehicles are imported from India, Japan, and Korea. Import of vehicle is increasing as the economy is progressing. The number of different categories of motor vehicles imported in Bhutan in 2005 is given in Table 1.

Table 1

IMPORTS OF DIFFERENT CATEGORIES OF MOTOR VEHICLES (IN NUMBER)

Vehicle category	*2000*	*2001*	*2002*	*2003*	*2004*
Passenger cars	1807	2270	1533	1457	1363
Two-wheelers	629	673	303	299	785
Buses	20	3	11	0	0
Trucks	108	331	234	188	180
Others	44	62	182	542	80

Source *MoF (2005)*

Currently, vehicles are concentrated in Thimphu, Paro, and Phuentsholing area, where more than 80% vehicles are registered.

In future, petrol and diesel will remain the dominant fuels.

Current and anticipated issues in the transport sector of Bhutan

The options to improve energy efficiency and reduce consumption of petroleum fuels in the transport sector can be classified into following major categories.

- Introducing efficient mass transport and/or improving mass transport efficiencies.
- Improving energy efficiency of petrol and diesel vehicles by making the latest European vehicle efficiency norm compliance mandatory for the imported vehicles.
- Introducing alternative fuel vehicles.
- Designing transport system, including traffic flow analysis, for reducing traffic congestion.
- Introducing alternative transport methods such as river navigation and rope ways.

Improving energy efficiency of petrol and diesel vehicles

Situational analysis

Bhutan imports vehicles from nearby countries. Majority of vehicles come from India, followed by Korea and Japan. Due to regulations in customs and major imports being through the state-owned State Trading Corporation of Bhutan and balance through the agents of major vehicle manufacturers like Maruti Motors in India and Hundai from Korea, Bhutan has so far not experienced dumping of old vehicles from nearby countries due to the prohibition imposed by the Royal Government of Bhutan (RGoB). This has prevented the use of old and inefficient vehicles in the country. However, in the future, import of even more efficient motor vehicles should be encouraged.

Engine exhaust emissions are also closely linked to the fuel efficiency of the vehicles. Thus, use of efficient vehicles is of paramount importance to keep the local air pollution levels low. Various fuel efficiency norms are developed and adopted in India and other European countries. As a policy measure to promote the use of fuel-efficient vehicles, the government could put in place mandatory strict vehicle emission control norms. These norms also encourage the use of fuels of certain specifications, which also contain low percentages of pollutants.

In case of Bhutan, the import of latest vehicles, for example 4WD Hi Lux or Scorpio, which need special high-octane petrol has also been accompanied by import of this fuel in the past few years. This is evident from the import figures of the past few years.

A separate Transport Sector Master Plan is being developed, which is essentially looking into the aspects of (1) emission reduction strategies, (2) traffic density and traffic flow analysis, and (3) suggestions on mass transport and alternative transport means like rope ways and river navigation for mountainous areas. The Transport Sector Master Plan study team has already identified some strategies for the above aspects. However, it is advisable to study them from energy efficiency point of view so that energy-efficient technologies are selected.

For a place like Bhutan, which has very few industries and no thermal power plants, the transport sector contributes substantially to air pollution. As all major settlements are situated in valleys, local air pollution levels are bound to increase due to the extensive use of fossil fuels in the transport sector. The Transport Sector Master Plan is looking into the pollution levels and emission standards issues; hence, these are not considered exclusively in this study.

Introduction of vehicles running on alternative fuel

Vehicles running on alternative fuels are becoming reality in many countries. Alternative fuels offer choice of fuels that contain less or practically zero pollutant. Examples of such fuels are CNG (compressed natural gas) and biofuels, which can be produced in an environment-friendly way by using carbon-neutral bioenergy. Vehicles running on electricity are also becoming popular. Futuristic options include hybrid vehicles that run on hydrogen and electricity. A range of fuel options are being evaluated for the transport sector worldwide (TERI 2005) and are discussed in the subsequent sections.

Compressed natural gas

Use of CNG as a clean and cheaper fuel for transport has proved to be successful in many cases, including public transport system of the Indian capital city of New Delhi. It is a safe, clean burning, and environment-friendly fuel. It has been established that exhaust emissions like hydrocarbons and carbon monoxide are significantly reduced when CNG is used as compared to other fuels. Toxic emissions of lead and sulphur are completely eliminated. Existing petrol vehicles can use CNG by fitting a conversion kit. The CNG-converted vehicles have the flexibility of operating either on petrol or on CNG. Recently, major vehicle manufacturers in India have introduced CNG vehicles in the Indian market. However, in Bhutan, lack of infrastructure and limited availability of CNG are major barriers in the use of CNG in the transport sector. However, under South Asian Association for Regional Cooperation (SAARC) initiative, Bhutan can look into the possibility of getting CNG for the transport sector and industries, at least in the border areas of Bhutan. Techno-financial feasibility studies are required for this purpose, which can be taken up in the Tenth Plan period. Investments in the development of infrastructure for CNG transport and handling would be a critical issue, considering the number of vehicles in the countries and their distribution.

Liquefied petroleum gas

LPG is deemed to be superior to petrol and diesel in terms of vehicular emissions. To abate pollution caused by vehicles, a number of countries have been using LPG as auto fuel.

Typically, the 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.

Recommendations

Currently, Bhutan imports LPG from India, and under the bilateral arrangement, the LPG is provided at subsidized rate. Thus, because the use of LPG as a cleaner fuel to reduce air pollution is an option, its import under subsidy quota for transport applications could be discussed in bilateral meetings with India. This may have impact on trade balance. A study to compare the pros and cons of using LPG for other applications in general and for the transport sector in particular is required, as other issues like infrastructure for distribution, and market segments and their share in LPG demand are also important and need to be studied in detail. A joint study between Bhutan and India can be taken up in the Tenth Plan.

Biofuels

Biofuels are the fuels derived from biomass, that is, recently living organisms or their metabolic by-products. Ethanol, methanol, and bio-diesel are important biofuels that can be used for vehicular applications.

Ethanol and methanol

Mixing of ethanol and methanol in petrol and diesel, up to 10%, is possible for use in conventional petrol and diesel engines without any modification. Ethanol and methanol are generally produced as by-products in sugar and other industries. Bhutan currently has no industries producing ethanol or methanol.

Bio-diesel

Bio-diesel is produced by processing vegetable oil. This process, called as esterification, converts vegetable oil to a diesel-like fuel having properties similar to diesel. The interest in bio-diesel is increasing worldwide since 2000. The US and the European countries are using soybean, rapeseed, and other edible oils for producing bio-diesel. In India, bio-diesel production using locally available species of non-edible oil-bearing plant seeds such as jatropha and pongamia is preferred. In Bhutan, locally available oil-bearing plants can be studied, and indigenous development of bio-diesel can be taken up as a joint research project with the Indian institutes under the aegis of the Department of Science and Technology (DST). This would be a medium-term (five to seven years) strategy, which can be initiated in the Tenth Plan.

Electric vehicles

With vast potential available for hydropower generation, use of electricity for mass transport and use of electric/hybrid vehicles for personal transport are viable options for Bhutan in medium term.

Hybrid (petrol–electric) and electric vehicles are now being developed by many major automobile manufacturers worldwide. Currently, vehicles are imported from India, Japan, Korea, and China. Automobile companies in these countries, especially in India and Japan, have already flooded the market with electric vehicles. Major automobile manufacturers like M/s Mahindra and Mahindra and M/s Bajaj Auto Ltd from India are already testing electric three-wheelers (six-seater vehicles) in Indian markets. These vehicles can be introduced in Bhutan on demonstration basis for public transport in cities like Thimphu and Phuentsholing. A note on the experience of implementing electric vehicles as public transport is given in Box 2. Market for electric cars like REVA can also be explored, especially in flat terrain areas in southern Bhutan.

Electric minibuses are being introduced by many Indian automobile manufacturers like Mahindra and Mahindra and others.

Minibuses and three-wheelers running on electricity can be promoted in small urban areas and in major town areas like Thimphu. The DoE and the Ministry of Information and Communications (MoIC) can undertake a joint project, which can also be submitted as a Clean Development Mechanism (CDM) project.

Recommendations on improving energy efficiency of petrol and diesel vehicles

Technological innovations are increasingly gaining importance in the transport sector. The average fuel economy of new small cars sold in India is about 13.6 km per litre, while that of a small four-stroke motorcycle is 54 km per litre, and that of buses is around 3 km per litre. These figures do not reflect the state-of-the-art technology but point to the fact that due to lower power requirement and small size, coupled with advanced technology, considerable improvements are possible in vehicles. The fuel economy based on typical vehicles likely to be operated in India through 2020 is given in Table 2. These could be considered for Bhutan as well, as most of the vehicles are imported from India.

Table 2

FUEL ECONOMY BASED ON TYPICAL VEHICLES LIKELY TO BE OPERATED IN INDIA

Vehicle type	*Fuel economy in 2000* (km/litre)	*Fuel economy in 2020* (km/litre)
Gasoline motor scooter (two-stroke)	38.4	42.4
Gasoline motor scooter (four-stroke)	53.8	39.9
Gasoline car	13.6	14.5
Diesel car	20.0	21.3
Diesel bus	3.27	3.36

Note Fuel consumption estimates are based on the study by Bose and Nesamani (2000)

Diesel vehicles have better fuel economy than the gasoline ones, as diesel engines are more efficient and diesel fuel contains more energy per litre. However, emissions from diesel vehicles are a serious problem.

The sulphur in diesel has considerable potential to pollute the air and adversely affect human health, causing respiratory disorders due to the

BOX 2

NEPAL'S EXPERIENCE WITH ELECTRIC VEHICLE

To tackle the problem of air pollution in Kathmandu valley, Nepal started using electric vehicles in 1997. These were known as Safa tempos. About 600 of these tempos were introduced. Subsequently, a major project was initiated by 'Kathmandu Electric Vehicle Alliance (KEVA)' to improve the operational efficiency of these tempos.

KEVA is a joint programme undertaken by an NGO (non-governmental organization), government, and private sector to improve the air quality of the Kathmandu valley. Details of the project are available at <http://www.cleanairnet.org/caiasia/1412/articles-60355_project.pdf>.

emission of high level of respirable particulate matter. Hence, low sulphur diesel, that is, diesel containing 0.5% sulphur by weight as against the normal proportion of 1% by weight, or ultra low sulphur diesel, that is, diesel containing 0.25% sulphur, is used in many countries. The Ministry of Economic Affairs can consider making ultra low sulphur diesel mandatory in phased manner in Bhutan.

AGRICULTURE SECTOR

Energy needs of the agriculture sector vary at different stages, as shown in Figure 4.

Currently, energy consumption in farming is very low, mainly due to the mountainous nature of the terrain, small farm size, and low investment in farming.

However, modern energy based interventions to improve farm productivity and labour efficiency, thereby reducing the requirement of human labour and, most importantly, proper storage, handling, and processing of harvested produce to reduce wastage are few things that can be considered jointly by the DoE and Ministry of Agriculture (MoA).

Various studies conducted and data generated show that the diesel-powered multi-utility power tillers are the most useful and, hence, sought-after farm equipment in Bhutan. These are currently subsidized under Japanese funds. The RGoB can consider providing further support for this programme to improve the availability of such power tillers. Some applications for the agriculture sector, which can help reduce the overall energy demand or import of energy, are discussed subsequently.

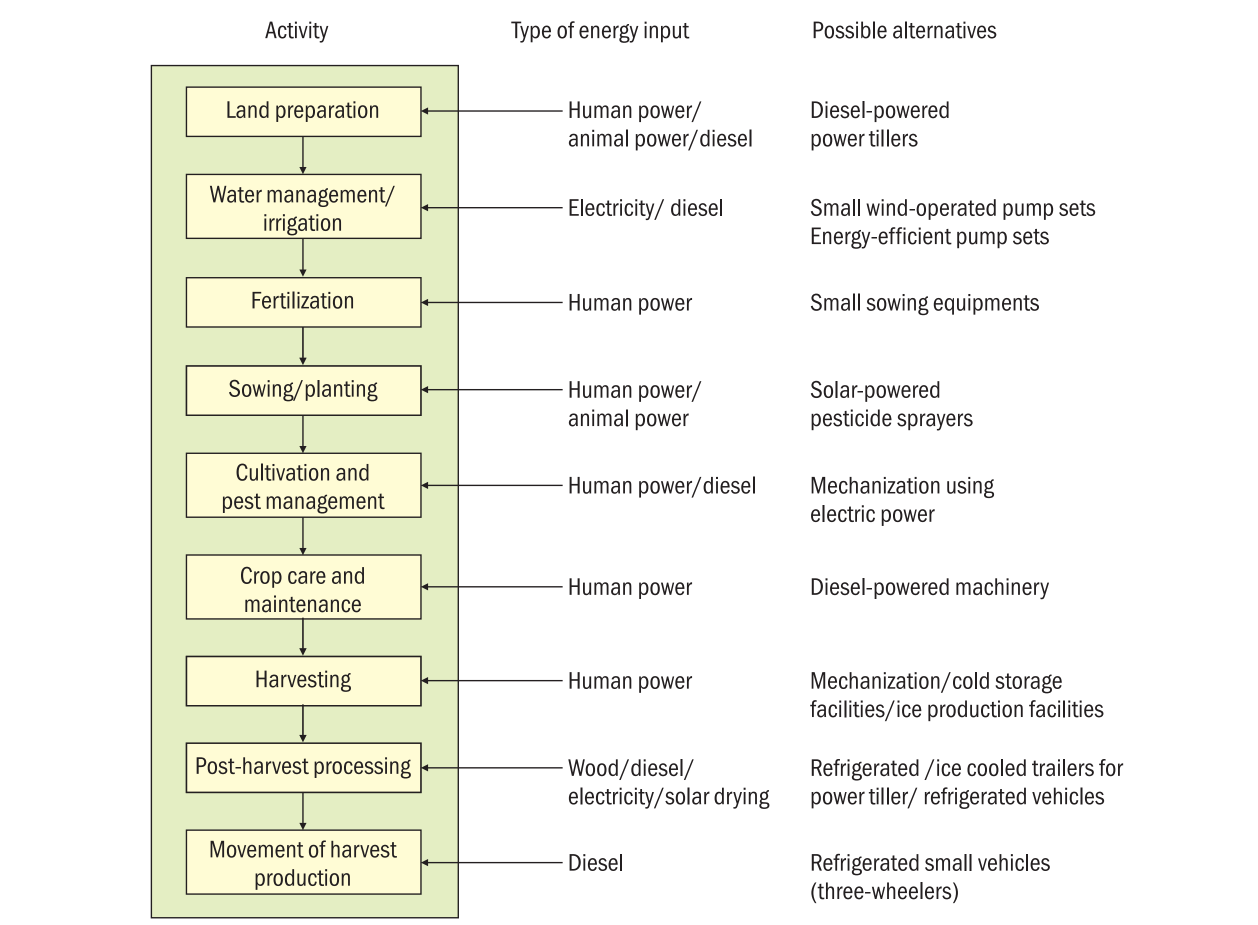


FIGURE 4 ENERGY INPUTS IN THE AGRICULTURE SECTOR IN BHUTAN

Biogas-based water pumping, space heating, and food processing

The agriculture sector generates biomass residue as a farm product waste, along with other wastes like animal dung. Biogas plants may be developed at these farm sites, and the gas produced can be used for pumping water, space heating, and food processing applications. The DoE can take initiatives in the implementation of these plants by creating awareness and providing subsidy schemes.

Diesel-powered power tillers

Diesel-powered power tillers are currently provided by the MoA through Japanese government's aided scheme on subsidy. These power tillers are multi-purpose and are quite popular among farmers as is evident from the fact that there is a waiting list for procuring these tillers. These tillers are driven by diesel and their faster penetration would lead to improved farm productivity.

Small wind-operated pump sets

Bhutan's agriculture sector represented by dry land farming, which depends on rainwater. Because the terrain is mountainous, It is difficult to dig canals and pump water. In windy areas, small mechanical wind pumps or small wind electric generator powered pump sets can be installed. These would be site-specific applications. The DoE can initiate a demonstration programme on these lines.

Energy-efficient pump sets

Although water pump sets are not used extensively in the agriculture sector in Bhutan when compared with other countries, energy-efficient pump sets can be promoted through labelling scheme, which is proposed for all electrical appliances.

Solar-powered pesticide sprayers and solar fencing

Solar-powered pesticide sprayers are handy equipment, which run on solar-powered packs. These would be useful for farmers as they are light weight and easy to operate.

It is recommended that the MoA and DoE introduce them under jointly funded subsidy/ demonstration programme. Also, solar-powered fencing may be implemented in the farms.

Mechanization/cold storage facilities/ice production facilities

Refrigerated/ice cooled trailers for power tiller/ refrigerated vehicles

Loss of agriculture produce in transit between farms and marketplace is common in Bhutan due to difficult terrain and lack of farm roads in most parts of the country. This loss can be reduced by developing small movable refrigeration/ice storage systems, which can store farm produce in cold storage till they are delivered. Special research and development project can be taken up jointly by research organizations in India, such as TERI, in collaboration with the DoE and MoA. This would prove to be a very useful strategy in long term.

Promotion of gasifier for cardamom drying

Cardamom is one of the most important agriculture products in Bhutan, which requires drying. To use the locally available biomass resources for the drying purpose, biomass gasifiers can be used for drying. Initially, the DoE may install a gasifier under a demonstration project and then promote the installation of these gasifiers by undertaking awareness campaign and providing subsidy to farmers.

Overall implementation strategy for the demand side management

The precise time schedule for the implementation of the strategies suggested above are given in Table 3, and the results of the impact assessment of the proposed strategies are given in Table 4.

ESTIMATED BUDGET FOR THE IMPLEMENTATION OF DIFFERENT STRATEGIES RECOMMENDED FOR DEMAND SIDE MANAGEMENT OF ENERGY

A budget has been estimated for different strategies, by sector, as suggested for the implementation of the plan related to the demand side management of energy and is given in Table 5. This budget head does not include the capital cost and manpower cost involved from the implementing agencies.

Table 3

PROPOSED IMPLEMENTATION SCHEDULE FOR DEMAND SIDE MANAGEMENT (DSM) MEASURES

		2008		2010					2015					2020
Residential	Promotion of improved cook stoves													
	Promotion of efficient fodder cooking devices													
	Use of energy-efficient liquefied petroleum gas (LPG) stove													
	Promotion of energy-efficient appliances and compact fluorescent lamp (CFL)													
	Promotion of briquettes and pellets													
	Promotion of solar lanterns or home lighting systems													
	Promotion of solar water heating systems													
	Use of hydrogen cook stoves													
	Promotion of energy-efficient building technologies/ materials													
	Promotion of small wind systems for farm houses													
Commercial and institutional sector	Use of energy-efficient cook stoves and other devices for cooking													
	Promotion of CFL and other energy-efficient lighting fixtures in commercial buildings													
	Promotion of use of dish-type solar cookers													
	Promotion of solar water heaters													
	Promotion of solar photovoltaic systems for schools/ monasteries													
	Promotion of energy-efficient buildings/codes													
Industrial Sector	Energy efficient systems and mandatory measures for energy efficiency in industries													
	Introduction of norms for energy consumption in industries													
Transport sector	Deployment of electric vehicles													
	Alternate (LPG/liquefied natural gas) fuel vehicles													
	Efficient public transport system for cities and inter-cities													
	City traffic planning													
Agriculture sector	Biogas based water pumping , space heating, food processing													
	Solar fencing for agriculture farms													
	Promotion of solar and wind pumping systems													
	Development and deployment of hybrid dryers													
	Promotion of gasifiers for cardamom drying													

Table 4

IMPACT ASSESSMENT OF PROPOSED STRATEGIES

Main categories	*Social equity*	*Energy security*	*Reduction in local pollution*	*Forest conservation*	*Trade balance*	*Energy conservation*	*Millennium Development Goals served*
Promotion of compact fluorescent lamp		Yes					
Promotion of improved cook stoves			Yes	Yes			
Promotion of briquettes and pellets		Yes		Yes	Yes	Yes	
Promotion of energy-efficient appliances		Yes			Yes	Yes	
Promotion of energy-efficient building technologies/materials		Yes	Yes	Yes		Yes	
Promotion of efficient fodder cooking devices		Yes	Yes	Yes		Yes	
Promotion of solar water heating systems		Yes	Yes	Yes			
Promotion of solar lanterns and home lighting systems	Yes	Yes	Yes	Yes			
Hydrogen cook stoves		Yes				Yes	

Table 5

BUDGET ESTIMATES FOR IMPLEMENTATION OF DIFFERENT STRATEGIES FOR DEMAND SIDE MANAGEMENT (IN MILLION NU)

Sector	*Proposed strategy/measure*	*Targets*	*Role of the Department of Energy*	*2012*	*2015*	*2020*	*Total*
Residential	Promotion of improved cook stoves	50% (40 000) of the total households that are using wood/kerosene for cooking will be provided with improved cook stove by 2012, 75% will be provided by 2015, and 100% by 2020	Providing subsidy and then distribution of improved cook stove, especially in rural areas	120	120	50	290
	Promotion of efficient fodder cooking devices	About 500–1000 cook stoves on demonstration basis in the Tenth Plan	Providing subsidy and then distribution of improved cook stove for fodder cooking	50	50	50	150
	Use of energy-efficient liquefied petroleum gas (LPG) stove	50% replacement of old LPG cook stoves with efficient cook stoves by 2015, and 100% by 2020	Organize awareness campaign and providing subsidy for efficient LPG stove and make available these stoves to people	10	10	10	30
	Promotion of energy efficient appliances and compact fluorescent lamp (CFL)	50% of the households start using CFLs by 2015 and 100% by 2020	Implement the scheme of distribution of the CFLs to the all households	5	5	5	15
	Promotion of briquettes and pellets	One or two briquette making industry may be developed by 2015	Develop a plan for the implementation of the briquetting/pelleting industry	5	5	5	15
	Promotion of solar lanterns or home lighting systems	Providing solar lanterns/solar PV systems to the households that use fuelwood or kerosene as a source for lighting; 50% to be provided by 2012 and 100% by 2015	Develop strategy for distribution of the solar lanterns/small solar PV systems to rural households	250	100	50	400
	Promotion of solar water heating (SWH) systems	25% of the total households would start using SWH system by 2015 (that is, 1.8 million litres per day capacity water heating system) and 50% by 2020 (3 850 000 litres per day)	Make plan for implementation of the solar water heating systems by the households in Bhutan	162	150	150	461.9352
	Use of hydrogen cook stoves	5%–10% of the households start using Hydrogen cook stoves by 2020	Organize awareness campaign			10	10
	Promotion of energy-efficient building technologies/ materials	2500 new households constructed by 2015 will be energy-efficient; and this figure will be about 5000 by 2020	Organize awareness campaign for the public as well as the architects and developers, Financial support for incorporation of measures	317.5	350	350	1017.5
	Promotion of small wind systems for farm houses	5%–10% households will start using small wind-solar hybrid systems for the lighting in their houses by 2015	Implement few small windmills on demonstration basis and provide subsidy to the people for using these windmills	200	300	100	600

Table 5 contd...

Table 5

CONTD...

Sector	Proposed strategy/measure	*Targets*	*Role of the Department of Energy*	*2012*	*2015*	*2020*	*Total*
Commercial and institutional sector	Use of energy-efficient cook stoves and other devices for cooking	50% of the commercial users will start using improved cook stoves by 2015	Subsidy schemes, awareness creation, promotional campaign	200	200	200	600
	Promotion of CFL and other energy-efficient lighting fixtures in commercial buildings	Replacement of normal bulbs by CFL in all commercial buildings	Subsidy schemes, awareness creation, promotional campaign	200	200	200	600
	Promotion of the use of dish-type solar cookers	50 installations by 2012	Subsidy schemes, awareness creation, promotional campaign	2.5	5	5	12.5
	Promotion of SWH		Subsidy scheme, Promotional activities	15	20	25	60
	Promotion of solar PV/ wind hybrid systems for schools/monasteries	1000 installations by 2012	Feasibility study, subsidy scheme, Implementation	50	50	50	150
	Promotion of energy-efficient buildings/ codes	10–15 buildings by 2012	Awareness campaign and development of codes for energy efficiency in buildings	200	500	1000	1700
Industrial Sector	Energy-efficient systems and mandatory measures for energy efficiency in industries	Five major industries by 2012	Support to carry out audits, Funding for implementation, Awareness campaign and development of the measures for energy efficiency	10	20	30	60
	Introduction of norms for energy consumption in industries	Norms to be developed by 2012	Development of norms and formation of policies/ regulation	10	10	10	30
Transport sector	Deployment of electric vehicles	100 vehicles by 2012	Development of scheme for promotion, subsidy support	50	50	100	200
	Alternative (LPG/liquefied natural gas) fuel vehicles	Feasibility study by 2010, Infrastructure development by 2015	Funding for feasibility study	10	500		510
	Efficient/electric public transport system for cities and inter-cities	Feasibility study by 2010, Infrastructure development by 2015	Study for implementation model, project development, implementation for Thimphu-Paro road	100	-	-	100
	City traffic planning	Transport plan to be developed through RSTA	Awareness campaign and development of plan	50			50
Agriculture sector	Biogas based water pumping , space heating, food processing	100 plants by 2012	Feasibility study and technology assessment	10	10	10	30
	Solar fencing for agriculture farms	100 farms by 2012	Subsidy support, supply of solar fencing	2	10	10	22
	Promotion of solar and wind pumping systems	100 numbers by 2012	Feasibility study, technology assessment, subsidy programme	20	20	20	60
	Development and deployment of hybrid dryers	500 numbers by 2012	Feasibility study, technology assessment, subsidy programme	50	50	50	150
	Promotion of gasifiers for cardamom drying	100 numbers by 2012	Feasibility study, technology assessment, subsidy programme	1.5	2	3	6.5
			TOTAL	2060	2717	2493	7330.44

CHAPTER 6

Overarching issues: energy, development, and environment

There are many issues that are closely related with the way the development of the energy sector is taking place in Bhutan. While some of these cross linkages are quite obvious, a few are not that apparent. The following sections attempt to put these critical issues in the right perspective.

ENERGY SECURITY

The concept of energy security has witnessed a paradigm change. Historically, energy security focused primarily on concerns on oil disruption in the oil-producing world. This concern has not been addressed till now. In fact, many other related concerns have emerged now. Concerns over energy security are not limited to oil alone; reliability of electricity supply systems has become an important issue, given the chronic power shortages in developing countries and incidents of blackouts in the developed world. Sophisticated integration of energy systems also means that a break at any point in the supply chain can reverberate through the entire system. Moreover, it must be recognized that energy security is not a stand-alone entity. It assumes a larger dimension among countries. At the same time, a new range of vulnerabilities has become more evident—energy systems are at unprecedented risk from political turmoil, terrorism, and the impacts of climate change.

Bhutan is already confronting some of these issues. The country has no known reserves of fossil fuels and has no option but to import oil to satisfy its growing needs.

While hydropower is available in plenty to meet the country's needs, there are concerns about the shortage of electricity in the lean season, especially to meet the needs of a growing industry. Bhutan's energy system is also particularly vulnerable to the impacts of climate change, given that water flows are likely to be affected due to global warming in future (ICIMOD 2005). Apart from this, other climate change adaptation issues may emerge over the period. The issue of adaptation to climate change is discussed later in this chapter.

For a developing country like Bhutan that has a mountainous terrain, energy security also needs to be looked at from a micro perspective—are the remotest regions and the poorest assured of secure and affordable energy? The basic nature of energy would imply that the energy for essential household needs should be given preference when energy is available in limited quantity. Although policy directives are clear on this front, this also necessitates that decentralized or non-conventional source of energy be tapped not just to minimize import dependence but also to provide energy where conventional supply networks cannot reach.

Following points reflect some of the country-specific energy security concerns in Bhutan.

- Plugging electricity demand–supply gap during lean period.
- High dependence on hydropower, with hydropower accounting for more than 99% of the electricity generated. Furthermore, country's two major power plants, namely, Chukha and Tala hydropower plants, are responsible for the majority of electricity generation.
- Vulnerability of power generation to water supply due to the impact of climate change.
- Dependence of the country on oil import from India.

- Little choice of other energy resources, as the electricity sector is highly subsidized and hydropower is cheap.

While maintaining the security of supply at the macro and micro levels by investing in infrastructure and diversification of the energy portfolio, another important aspect of energy security is reducing energy consumption by improving energy efficiency. This has increasingly become a feasible alternative today due to the advancement of technology and the possibility of international technology transfers. In most cases, the best near-term option for increasing energy security is through energy efficiency. These options are covered extensively in the earlier chapters.

ENERGY FOR POVERTY REDUCTION AND BALANCED REGIONAL GROWTH

It is now well established that income (or the lack of it) is only one aspect of poverty. In a wider sense, poverty is deprivation, which may be traced to five inter-related clusters of disadvantages: physical weakness (lack of strength, under-nutrition, ill health, disability, high ratio of dependents to active adults); isolation (physical remoteness, ignorance, and lack of access to information or knowledge); income poverty (lack of income and wealth); vulnerability (increased exposure to contingencies, and danger of becoming more deprived); and powerlessness (inability to cope, adapt, and choose) (Chambers 1989).

Energy can play a fundamental role in minimizing each of these disadvantages, as shown in Figure 1.

While issues related to electricity export and optimizing the use of electricity for the promotion of domestic industry have been dealt with before, this section discusses the importance of energy systems and options to be planned so as to promote regionally balanced development.

A quick look at the economic and social indicators for Bhutan shows the presence of regional disparities – in terms of per capita income and availability of basic services – both across the different geographical regions of the country as well as between rural and urban areas. Almost 70% of the Bhutan's population, comprising 634 982 people (Census of Bhutan 2005), resides in rural areas. Not surprisingly, poverty in Bhutan is largely a rural phenomenon as the data of the *Bhutan Living Standards Survey 2003* noted that about 40% of the rural population was poor, while less than 5% of the urban population was poor.[1] Likewise, the poverty gap and poverty severity indices showed that poverty was deeply entrenched and more severe in rural areas as compared to urban areas.[2]

The regional disparity is also evident in the spread of the electricity network in the country, as discussed in Chapter 4. These disparities are reflected in the tendency of most immigrants to move towards the western part of the country. Migration to towns in the western region is almost double of that in the eastern region.

This divide would need to be tackled using a two-pronged approach—on the one hand, there is a need to plan more townships, particularly in the eastern part of the country, on the other, the 'push factor' from rural areas needs to be arrested through concerted efforts at rural development. The importance of rural development in poverty reduction is evident from the fact that it has been identified, together with the promotion of balanced regional development, private sector development, and infrastructure development as the main objectives in the Tenth Five-year Plan guidelines. The next section describes the challenges facing rural economic development in Bhutan and expounds how energy services can address them.

Challenges in rural development

About 66% of the Bhutanese workforce is engaged in agriculture and forestry (Statistical Yearbook of Bhutan 2005).[3] Farming in Bhutan is a challenge

[1] The poor include households with real consumption less than the poverty line.

[2] The Poverty Gap Index measures the intensity of poverty for the population—it reflects the difference between the poverty line and actual expenditure. The Poverty Severity Index is calculated as the weighted sum of poverty gaps (as a proportion of the poverty line), with weight proportionate to poverty gaps.

[3] The main cereals growing in Bhutan are rice, maize, wheat, barley, buckwheat, and millet. Cash crops include oranges, potatoes, apples, plums, walnuts, and vegetables. Cereal cultivation is, however, dominated by maize and rice.

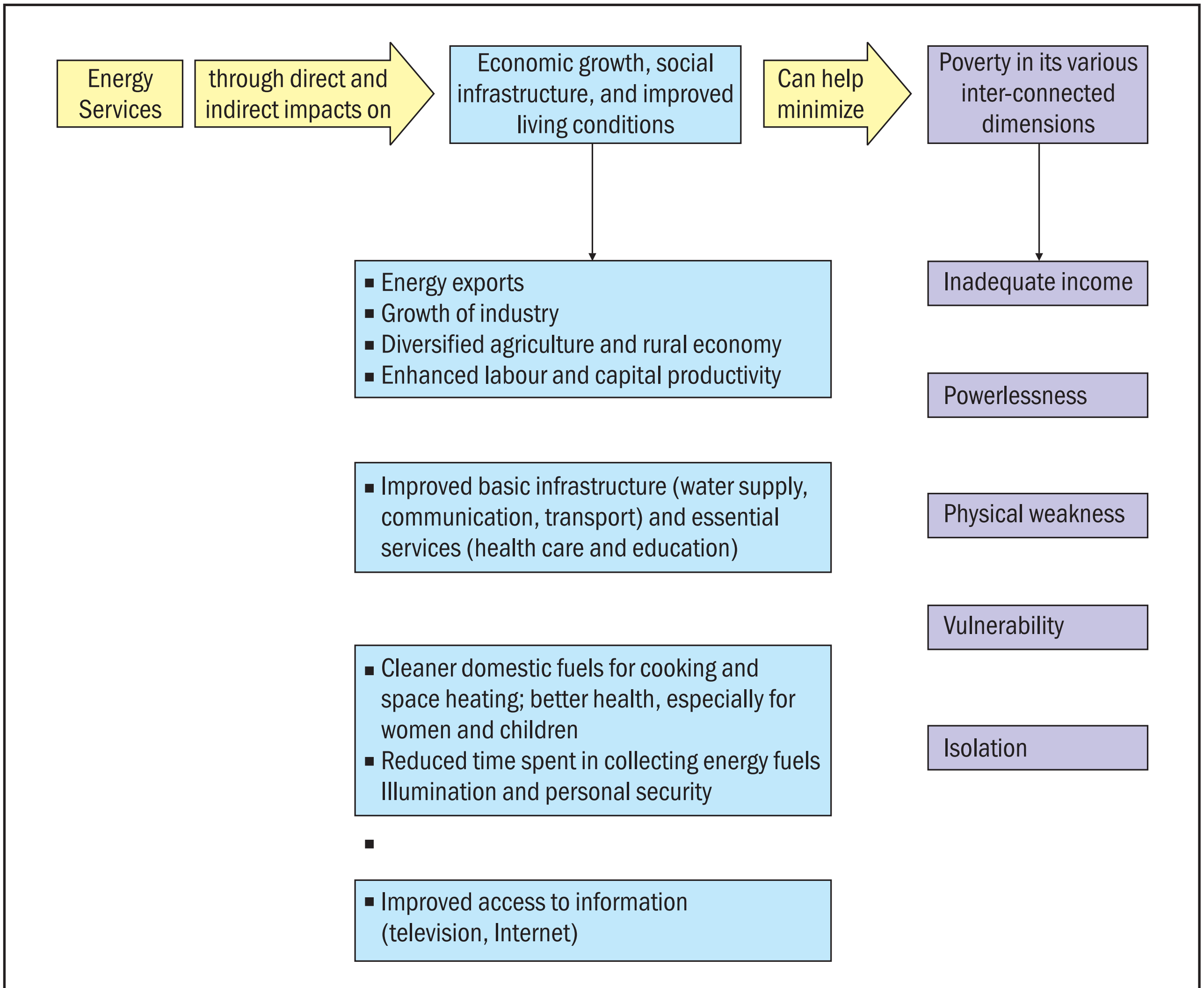


FIGURE 1 ENERGY SERVICES CONTRIBUTE TO BREAKING THE DEPRIVATION TRAP

because of low soil fertility, poor infrastructure, small landholding size, occurrence of natural disasters like floods, and the mountainous terrain, all of which make the activity labour-intensive. The majority of the farming households own less than 3 acres of land (RNR Statistics 2000), which can only provide subsistence living, as is evident from the fact that less than 5% of the domestic rice production in the country in 2002 (38 000 tonnes) was marketed. Some 54 000 tonnes of rice was imported to meet domestic demand. Studies suggest that in many villages, up to 50% of the households are often food insecure, while seasonally, this figure may go up to 75%. Box 1 presents constraints encountered in food grain production.

Livestock rearing is an integral part of the farming system in the country. Close to 95% of the rural households own an average of five to nine cattle, which primarily serve as a source of draught power and manure for their fields and dairy products for household uses. However, the potential of livestock in contributing to farm income is constrained by the lack of adequate feed and fodder and poor health services.

Inadequate return from agriculture is fuelling migration from rural to urban areas. The resulting decline in the availability of labour further affects the productivity of the sector, which has historically been labour-intensive. The influx of migrants is restricted to a few urban centres. Some estimates suggest that at 10% rate of growth of population,

BOX 1

CONSTRAINTS IN FOOD GRAIN PRODUCTION

According to a survey carried out by the Ministry of Agriculture, Royal Government of Bhutan, the main constraints faced by the farming households in food grain production include destruction by wild animals (54% of the respondents saw this as a major concern), lack of irrigation (28%), labour shortage (20%), and small size of landholding (13%). Destruction by pests and diseases (13%) and limited access to markets (10%) also affect food grain production

Source *RNR Statistics (2000)*

Thimphu is growing at a rate, which is more than three times the national rate, with Phuentsholing only slightly behind. At this rate, close to half of Bhutan's population will be living in urban areas within the next 20–25 years (Vision 2020). The rate of urbanization is a concern for several reasons.

- Given the topography of the country, the land required to accommodate the growing urban population is limited. The general absence of flat land for population could result in the settlement at steeper valley slopes, which should be best left for vegetation cover. Apart from enhancing deforestation, this could also add to the risks of erosion, disruption of watercourses, and the possibility of flooding and landslides during monsoons.
- Towns are poorly equipped to deal with a rapid influx of migrants, as urban infrastructure and services, including land legislation and land markets, are not well developed.
- Employment opportunities in urban areas will not be enough for a growing urban population, which could result in social and political instability in the country (see Box 2).

There is a need to restrict migration by creating viable opportunities in rural areas, which would allow the poor to participate in the market economy and improve their livelihoods. Given the intrinsic constraints faced by the agriculture sector in Bhutan, the key to rural development will be agricultural diversification and promotion of small-scale and cottage industries in rural areas, with an emphasis on high-value niche markets. This will also catalyse more dispersed and regionally balanced growth and employment compared to

BOX 2

RURAL–URBAN MIGRATION: DRIVERS AND FALLOUT

The first labour force survey held in 1998 found that 76% of the labour force was employed in the agriculture sector.After that, employment in the Renewable and Natural Resources (RNR) sector decreased to about 66% in 2004. Over 81% of the unemployed in Bhutan live in rural areas. A study on rural–urban migration, carried out by the Ministry of Agriculture, found that 47% of all households comprised migrants. While lack of educational facilities was the reason behind migration of 46% of the people, 19% left their villages due to small landholdings, drudgery of farm work, unproductive agriculture, crop damages by wild animals, and natural calamities.

The demographic transition in the country will mean that the growth in the demand for jobs will far exceed the rate of population growth. *Vision 2020* for Bhutan notes that by 2020, a total of 267 000 jobs will need to be created even under the most favourable demographic scenario. The number of job seekers will be considerably higher if one factors in those who chose to leave the RNR sector and migrate to urban areas and those who are displaced as a result of mechanization or improvements in labour productivity in the agriculture and other sectors.

On the other hand, the gross domestic product (GDP) growth in Bhutan in the last decade or so has been driven by hydropower, construction, service, and power-intensive manufacturing sectors, which have relatively low employment elasticity. The Bhutanese have a preference for public sector jobs; however, given the emphasis on the formation of a compact, professional, and efficient organization, future opportunities in the government will also be limited.

large industry. Currently, over 55% of industries in Bhutan are located in Thimphu, Chukha, and Paro Dzongkhags (Statistical Yearbook 2005). The importance of industry and services in rural areas is evident from the fact that in rural areas, a greater proportion of the non-poor work in these sectors compared to the poor (Table 1).

Table 1

SECTOR OF EMPLOYMENT, BY POVERTY STATUS

Sector of employment	*Urban (%)*		*Rural (%)*	
	Poor	*Non-poor*	*Poor*	*Non-poor*
Agriculture	7.49	5.76	95.52	88.89
Industry	15.96	10.47	0.54	1.81
Services	76.55	83.77	3.94	9.30

Source *National Statistical Bureau (2004)*

Though small- and cottage-scale firms comprise about 40% of the industrial units in Bhutan (Figure 2), the sector is dominated by micro-enterprises (largely comprising small family-run business such as restaurants, tea stalls, and rice mills) that have limited scope for expansion.

The Royal Government of Bhutan (RGoB) is following a 'triple gem approach' for agricultural development and diversification by increasing productivity, accessibility, and marketing in order to achieve national food security, raise cash incomes and employment opportunities in rural areas, generate export revenue, and achieve an improvement in the nutritional status of the rural population while conserving and managing natural resources. Several initiatives are being undertaken in rural areas, as listed below.

- Enhancing food grain production through improved crop varieties and complementary inputs.
- Exploiting the regional and seasonal comparative advantages that Bhutan has in the cultivation of both temperate and sub-temperate fruits and vegetables. In 2004, exports of oranges constituted about 3.4% of the total value of top 10 exports from Bhutan (Statistical Yearbook of Bhutan 2005). The government aims at increasing the value of horticultural exports by 200% by 2007 and by 300% by 2012 (Vision 2020).
- Diversifying the rural economic base by encouraging other high-value, low-value, and off-season produce, such as medicinal and aromatic plants, and floriculture.
- Developing small and cottage industries in rural areas with an emphasis on creating productive employment rather than capturing export markets.
- Promoting animal health services, feed and fodder production, and animal breeding services, given that livestock represent an important asset, especially for the marginal farmers. Further, development of backyard livestock farms can also bring down imports of animal products like cheese and meat.

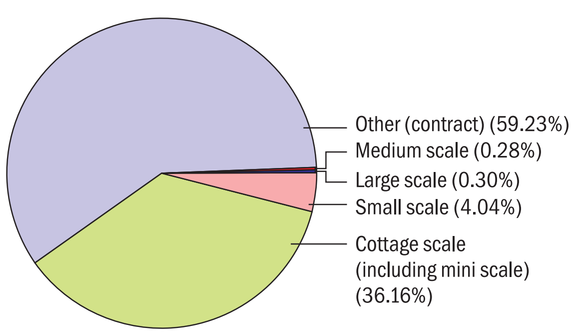


FIGURE 2 DISTRIBUTION OF INDUSTRY, BY SIZE (%)

The realization of these objectives calls for urgent and significant expansion of rural infrastructure, including farm mechanization, irrigation, roads, cold storage facilities, and access of small-scale producers to technology, credit, and markets. Left to market mechanisms, the focus on the growth of urban and large industry will continue for reasons related to economies of scale, profitability, and access to infrastructure, markets, credit, and technology.

Energy will be a key input in the government's efforts towards rural development and reducing the rates of rural–urban migration. The Vision Statement clearly brings out the importance of roads and electricity in bringing the communities out of their isolation, increasing access to markets and services, and facilitating rural industrialization and, hence, creating productive employment in rural areas.

Energy for rural development

Energy is a key ingredient for rural development, whether it is for agricultural growth and diversification, for the promotion of rural industry or for augmenting the provision of basic education and health care services.

Energy constitutes a key direct and indirect input into agriculture. Direct energy needs include energy required for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage, and the transport of agricultural inputs and outputs. Indirect energy needs are in the form of sequestered energy in fertilizers, herbicides, pesticides, and insecticides. Modern energy consumption can also be expected to increase agricultural productivity and food security.[4]

Agriculture in Bhutan continues to be based, to a large extent, on animal and human energy. Commercial energy use in agriculture is limited (Bhutan Energy Data Directory 2005). While the input supply system in Bhutan is subsidized and access is universal, its benefits are constrained by the lack of proper storage facilities, transport, and access roads, the development of all of which is dependent on energy infrastructure in rural areas. For example, horticulture products require a temperature-controlled atmosphere for transportation between the farm and the end market, and storage. Again, irrigation systems in the country, largely dependent on the monsoons, are usually small, being typically less than 100 hectares in extent, and are gravity-fed from streams. The development of engineered irrigation, especially for horticulture, will also need energy inputs as is true for livestock health services. Small-scale rural industry can also benefit from augmented energy infrastructure in rural areas.

ENVIRONMENTAL SUSTAINABILITY

Preservation and sustainable use of the environment are the main principles of the development philosophy in Bhutan. This is not only important in itself but also closely linked to both economic growth of the country (given the economic importance of hydropower and tourism) and poverty reduction (given the dependence of communities on forests for food, medicines, energy, fodder, organic fertilizers, and so on). Environmental sustainability would, therefore, be a key criterion in the policy-making across sectors. From the point of view of the energy sector, important environmental issues include possible diversion of forest land towards constructing energy infrastructure, ecological impacts of large hydro projects, more so in the case of storage projects that are likely to come up in future, and the potential impacts of climate change on the energy sector of Bhutan. Subsequent sections discuss these aspects in detail.

Impacts of energy infrastructure on forest area and ecology

Conservation of forests and biodiversity is a central tenet in Bhutan's development endeavour. The Department of Forests (now known as the Department of Forestry Services) was, interestingly, the first government department to be instituted in 1952, with the objective to harvest timber, the most visible natural resource at the time. The principle of conservation against exploitation began as early as 1969 when the Bhutan Forest Act was enacted. The Act brought all forest resources under state control with the intent to curb exploitation and rationalize usage. Subsequently, a number of legislations have been enacted to protect the forests of the country. Box 3 gives a chronology of conservation legislation and initiatives in Bhutan.

Bhutan currently has about 72% of its total area under forest, including about 25% area declared

[4] Analysis at a broad regional level suggests a correlation between high per capita modern energy consumption and food production. While regional data may conceal many differences between countries, crop types, and urban and rural areas, the correlation is strong in developing countries, where high inputs of modern energy can be assumed to have a positive impact on agricultural output and food production levels. The correlation is less strong in industrialized countries, where food production is near or above required levels, and changes in production level may reflect changes in diet and food rather than any advantages gained from an increased supply of modern energy.

as protected area. The National Forest Policy and the Constitution of Bhutan made it mandatory to keep 60% of the land under forest cover.[5] Forests in the country face extreme pressure in terms of meeting the needs of the population (for timber, fuelwood, fodder, medicinal and aromatic plants, pastures, organic manure, bamboo and cane for handicrafts and household implements, and pulp for traditional paper making) as well as commercial harvest of forest resources, resulting in localized overuse of forests.

Such activities are not prohibited in forest areas but are restricted and subject to a clearance from the government. The Environmental Assessment Act, 2002, establishes procedures for the assessment of the potential effects of strategic plans, policies, programmes, and projects on the environment and for the determination of policies

BOX 3

CHRONOLOGY OF CONSERVATION LEGISLATION AND INITIATIVES IN BHUTAN

The Department of Forests (now known as the Department of Forestry Services) was the very first government department to be instituted in 1952. The objective was to harvest timber, the most visible natural resource at the time. The principle of conservation against exploitation was introduced as early as 1969 when the Bhutan Forest Act was enacted. The Act brought all forest resources under state control, with the intent to curb exploitation and rationalize usage. As the forerunner of all modern legislation, it also reflected the importance attached by the government to the conservation of forests. This was further consolidated in 1974 with the formulation of the National Forest Policy, the nationalization of logging operations in 1979, and the establishment of a network of protected areas in 1983.

A ban on the exports of wood logs was imposed in 1973, which affected the cutting of forests in Bhutan for commercial exploitation.

The Bhutan Trust Fund (BTF) for Environmental Conservation was created in 1991 under the Royal Charter as an independent mechanism to sustain financing for environmental conservation, primarily in protected areas. The national protected areas system was revised again in 1993 to make it more representative of the various major ecosystems in the country. In 1995, the Forest and Nature Conservation Act, or FNCA, was ratified, repealing the Bhutan Forest Act, 1969. The aim of the FNCA was to address evolving conservation needs, including community participation and protected area management. In the same year, Bhutan ratified two major international conventions related to environmental conservation—the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC). In keeping with the requirements of the CBD, the country produced its first Biodiversity Action Plan in 1998 and, subsequently, updated it in 2002 to reflect progress and new conservation needs. A network of biological corridors linked the national protected areas system in 1999, enlarging the system from 26% to 35% of the country's total geographical area. In November 1999, the biological corridors were bequeathed as a 'Gift to the Earth' from the people of Bhutan.

The Environmental Assessment Act was passed by the National Assembly in 2000 and the Regulation for Environmental Clearance of Projects and the Regulation on Strategic Environmental Assessment came into effect in 2002. The Environmental Assessment Act, 2000, entered into force on 14 July 2000. The Regulation for Environmental Clearance of Projects and the Regulation on Strategic Environmental Assessment came into effect on 4 April 2002. Many conservation milestones were charted as Bhutan passed the National Biodiversity Act, 2003, and acceded to the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora and the UN Convention on Combating Desertification (UNCCD) in 2003.

Source *Department of Forestry Services, Ministry of Agriculture. 2004; National Environment Commission website <http://www.nec.gov.bt/>*

[5] At present, two definitions exist for the calculation of forest cover in Bhutan. The legal definition in the Forest and Nature Conservation Act defines forest as 'any land and waterbody, whether or not under vegetative cover, in which no person has acquired a permanent or transferable right of use and occupancy, whether such land is located inside or outside the forest boundary pillars, and includes land registered in a person's name as grazing land or woodlot for collection of leaf litter'. While the international definition of forests includes only forest proper and scrub forest, the legal definition includes woodlot for collection of leaf litter, pastureland, and waterbodies. It is noted that the Ministry of Agriculture uses both these definitions in different contexts—for prevention of encroachments and management of forest area, the legal definition is used, whereas for resource assessment, the international definition is adopted.

and measures to reduce potential adverse effects and promote environmental benefits. To support the implementation of the Act, the Regulation for the Environmental Clearance of Projects and Regulation of Strategic Environmental Assessment was adopted in 2002. The National Environment Commission (NEC) has issued guidelines for a number of sectors, including hydropower, and transmission lines to assist project proponents through the process of acquiring an environmental clearance for their project.

The main requirements under the Environmental Assessment Act in the context of hydropower projects are summarized in Box 4. While these cover the major impacts that are likely to arise, it is suggested that in view of the possible increase in the diversion of forest areas for the creation of large generation capacity (especially if storage projects are also built in the future) and transmission infrastructure, a policy of compensatory afforestation be introduced once the project meets all the requirements of the Environmental Assessment Act.

In India, for instance, compensatory afforestation is one of the most important conditions stipulated by the central government at the behest of the Supreme Court. This financial mechanism mandates providing a comprehensive scheme, including the details of non-forest/degraded forest area identified for compensatory afforestation, maps of areas to be taken up for compensatory afforestation, phased forestry operations, by year, details of species to be planted and a suitability certificate from afforestation/management point of view, along with the cost structure of various operations while seeking approval for proposals of dereservation or diversion of forest land for non-forest uses. There are two basic ways in which compensatory afforestation has been envisaged in India.

1 Afforestation to be carried out over an area equivalent to the diverted forest land. This land should be close to reserved forest or protected forest so as to enable the forest department to effectively manage the newly planted area.
2 Compensatory afforestation may be done on the degraded forest land the extent of which is twice that of the forest area that is being diverted/dereserved. The identified non-forest land is claimed by the state forest department and declared as protected forests so that the plantation raised can be maintained permanently.

It is further suggested that forests that are managed and valued primarily for their ecological values (as against timber and non-timber forest products) be classified as conservation forests, with more severe restriction on diversion compared to other forests.

BOX 4

DETAILS SOUGHT FOR ENVIRONMENTAL CLEARANCE OF HYDROPOWER PROJECTS

- Project details (for example, type, size, location, costs, technical parameters)
- Roads and transmission lines to be constructed
- Alternatives, including energy and site alternatives
- Project physical environment details, for example, topography, hydrology, possibility of being affected by glacier lake outburst flood (GLOF), erosion rates, and sediment yield
- Biological environment, for example, impact on land use, vegetation, protected areas, wildlife, fish species, and wetlands
- Social environment, for example, land tenure of areas, families affected, loss of houses and infrastructure, cultural and heritage sites, water use conflicts (presence of water users in dewatered areas), aesthetics
- Mitigation measures and costs
- Monitoring programme

Source *Application for Environmental Clearance Guideline for Hydropower, National Environment Commission, RGoB, 2004*

Forest conservation and forest regeneration

In Bhutan, forests are developed using the principle of natural forests. The forest area that is cleared is left untouched for the regeneration of forest naturally. This policy is followed to retain the composition and nature of natural forest. Plantation of outside species is not encouraged. However, in rural areas that are close to settlements, community social forestry is now being encouraged. June 2 is celebrated as 'Social Forestry Day' every year, which encourages afforestation.

Transmission network needs large area of land to establish the network, and efforts are needed to keep it safe from forest fires. Mainly the land around the tower is cleared, and once electrical lines are installed, green cover is regenerated in most of the area. Pruning and cutting are done to maintain the clarity and visibility between the trees and transmission lines.

Forests are also important to maintain the watershed areas and reduce the erosion of land, which ultimately affects the silting of hydropower plants and river basins.

Potential impacts of changing climatic conditions on the energy sector

Despite Bhutan being a low contributor to the global emissions, climate change is likely to have adverse impacts on the country, spanning all sectors of the economy and impacting livelihoods and well-being at large. Several studies project the impacts of climate change to be severe in fragile ecosystems such as mountainous regions. As a least developed country situated in a mountain ecosystem and owing to its limited coping capacity, Bhutan is doubly vulnerable to possible climate change impacts. Situated in one of the most seismically active zones of the world, Bhutan faces continual threat of earthquakes. Flash floods and landslides are annual occurrences, which cause significant losses to lives and damage to property.[6] IPCC (2007) reiterates that settlements in mountain regions are at enhanced risk to glacial lake outburst floods, or GLOFs, caused by melting glaciers. A note on climate extreme events is given in Box 5.

The most likely climatic events in Bhutan are increased GLOF events and flooding. Also, increased precipitation in areas without proper drainage systems can cause soil instabilities and, consequently, landslides and flash floods. The first National Communication (NATCOM) of Bhutan identifies six key areas vulnerable to climate change. These include forests and biodiversity, agriculture, water resources, GLOFs, health, and landslides.

The agriculture and hydropower sectors are the most vulnerable owing to their innate dependency on the monsoon and temperature patterns. As more than 70% of the Bhutanese population depends on subsistence farming, crop failure and stress on livestock rearing will affect the most vulnerable communities in the rural areas. Uncertainty associated with the timing of monsoons adds to the vulnerability of the farming community. The main cash crops grown by farmers (rice, potatoes, chillies, apples, and oranges) are extremely sensitive to water and temperature variations (NEC 2006). The presence of mountainous topography and scattered settlements implies high costs for social services and development of infrastructure, which add to the climate vulnerability of the country.

Impacts on the hydropower industry due to changes in the water regime and increased natural

BOX 5

NOTABLE CLIMATE EXTREME EVENTS IN BHUTAN

- The October 1994 flash flood on the Pho Chhu river, following a glacial lake outburst in the Lunana area, seriously damaged the lower valleys of Punakha.
- A rare dry spell with no snowfall occurred in the winter of 1998, and even rarer mid-summer snowfall occurred in some places in the north in July 1999.
- Flash floods in early August 2000 caused by torrential rains had large-scale impacts on life and property.

[6] <http://www.undp.org.bt/env/factsheets/Disaster%20Mar06.pdf>

disasters can hamper production, leading to the reduction of exports, which will ultimately impact economic growth (Alam and Tshering 2004). Changes in the climate system have both direct and indirect implications on the hydrological regime. An increase in rainfall intensity may increase run-off and rates of soil erosion on cleared land and may also accelerate sedimentation in the existing water supply network or reservoirs.

Increase in temperature will result in the retreat of glaciers, increasing the volume of lakes, ultimately leading to GLOFs. Possible impacts of GLOFs in Bhutan include disruption of river flows and changes in sediment yield, thereby impacting hydropower generation and water supply; destructing settlements, infrastructure, and agricultural land; and leading to the loss of biodiversity, apart from other impacts on human lives downstream.

Adaptation and mitigation options

The National Adaptation Programme of Action identifies least-cost options (economic, social, and environmental) based on the use of local resources for adaptation to climate change. There are also several 'no-regrets' strategies. These are usually targeted on the most severe effects and the greatest vulnerabilities to climate change. Investments in such options essentially present 'win-win' solutions, since they have ancillary benefits, apart from avoiding direct climate-related costs. Some adaptation measures suggested for the country to address various hazards are listed in Table 2.

These measures will require the development of information and research systems to better monitor and understand the impacts of climate change as well as assess significant capacity building of relevant institutions in the country and climate-sensitive sectors, and inform the vulnerable population on climate change and adaptation options. Several of these issues have been

Table 2

ADAPTATION OPTIONS ACCORDING TO HAZARD TYPE

Climate hazard	*Adaptation option*
Glacial lake outburst flood (GLOF; due to temperature rise)	Installation of early warning systems
	Artificial lowering of glacier lake levels
	Assessment of glacial lake outburst flooding threats to hydropower projects
Landslide (due to high-intensity rain)	Soil conservation and land management
	Preparation of a national database on landslide-prone areas and intensity of landslides to assess the risk of landslides
	River bank protection and small stream catchment protection
	Slope stabilization of areas prone to major landslides and flash floods
Flash flood (result of GLOF or due to high-intensity rain)	Watershed catchment management integrated with land management/soil conservation
	Weather and climate forecasting
	Promote community-based forest management and afforestation projects in ways to conserve land, water resources, and wood production
	Protect water treatment plants to ensure safe drinking water
Drought (due to temperature rise and/or longer intervals between rains)	Optimize the installed power plant capacities
	Low river flow/water shortage studies/impact on hydropower generation, drinking, and irrigation water supply, and so on
	Weather and climate forecasting
	Research and development on water use efficiency, resistant crop varieties, water harvesting

highlighted in National Adaptation Programme of Action (NAPA) and NATCOM. It is proposed that a high-level taskforce, headed by the NEC, be constituted to study the impacts of climate change on the hydropower sector specifically and propose various mitigation and adaptation measures that need to be taken in a time-bound manner.

GOVERNANCE OF ENERGY

The energy sector needs to be governed for meeting social, environmental, and growth objectives linked to energy while providing conditions that are conducive to private investment, thus empowering local governments and communities to play a proactive role in managing energy systems.

Structure of the energy sector

One important aspect of governance is the ownership and structure of the energy sector and its regulation. For much of the 20th century and in most countries, network utilities were vertically and horizontally integrated state monopolies. The reasons for public control of infrastructure were many—the sector's economic importance, a desire to protect public interest in industries supplying essential services, concerns about private monopolies, and the belief that the large investments required for infrastructure creation could only be augmented from public resources. However, the performance of state-owned monopolies was far from satisfactory, whether in terms of efficient and cost-effective delivery of services or in the attainment of universal service obligations. The 1990s saw a dramatic change in views on how network utilities should be owned, organized, and regulated, with much emphasis on the efficiency benefits of competition and privatization. However, over a period of time, a strong need has emerged to qualify the benefits of the new model and develop clear guidelines on how it should work (World Bank 2004).

One of the key messages that emerged from the experience of the last decade is that network utilities encompass distinct activities with entirely different economic characteristics. Electricity generation and distribution may be potentially competitive segments, but transmission is a natural monopoly (involving large sunk costs). While competition should be encouraged in the former segment, the latter should be regulated and perhaps even be operated by the public sector.

Further, the new model needs to be pursued after carefully assessing its institutional and structural prerequisites in a specific country or industry.

In Bhutan, the Bhutan Power Corporation (BPC) is responsible for the construction and maintenance of the transmission and distribution network in the country. Additionally, the BPC also owns and operates small and micro power plants. Major power plants like Tala, Chukha, Kurichu, and Basochhu are operated by independent power corporations or authorities. The Department of Energy (DoE) has brought these generating companies under one umbrella by creating larger Druk Green Power Corporation Ltd (DGPC).

Some of the issues that would need to be factored in while determining structural reforms in the energy sector are as follows.

- *State of network facilities* Unbundling and introduction of competition require mature well-developed network facilities, minimizing the need for new investments wherein the incentive problems are more likely as compared to potentially competitive segments like distribution. In case of Bhutan, as discussed in Chapter 4, network facilities still require considerable expansion and investment.
- *Institutional capacity* The transition from monopoly to competition or the co-existence of the two forms in different segments of the sector plays a critical role. Regulatory requirements in the latter systems are likely to be far more complex, requiring strong institutional capacity.
- *Profile of consumers* The general economic status of consumers and their ability to pay are important determinants of the success of privatization. Private investment may not be forthcoming in cases where the government wants to provide energy at lifeline tariffs to a large section of consumers, as is the case in Bhutan, unless the private investors are assured of a reasonable rate of return.

For all these reasons, it may be premature to restructure and open up the electricity sector in Bhutan. On the other hand, the DGPC is a holding company responsible for building additional hydropower projects as well as operating and maintaining the built-in projects by 2008, in a manner similar to the National Hydro Power Corporation (NHPC) established in India.[7] Further, transmission and distribution are likely to remain in the public sector in the foreseeable future. However, given the limited availability of public financial and administrative resources, the government should tap private investment, including foreign capital, in the electricity generation sector and more proactively involve local communities in managing off-grid systems and the operation and maintenance of local distribution lines.

Tariff regime

The other related issue in terms of financial and cost constraints is tariff setting for the sale of electricity domestically and for exporting to India. Over the years, Bhutan has regulated the electricity prices domestically, setting them below the economic costs to fulfil the social obligations and promote industrial sector. This act is justified in providing assistance to the underprivileged sections and in promoting regional balanced development, but has led to increased inefficiencies in the consumption patterns of energy. Coupled with this is the lack of demand side management (DSM) measures, which have further resulted in inefficient usage of the available resources.

The prevalent low tariffs have also resulted in subsidizing the inefficiencies in the industrial sector. While the pricing policies have been designed to strengthen the industrial base in Bhutan, provision of subsidized electricity in several ways can harm the economic progress if it is unable to generate adequate forward linkages to compete with the export proceeds of sale of power to India. In the current situation of low electricity tariffs, while power-intensive industries are foreseen to emerge, a careful feasibility analysis needs to be performed before granting any further licenses, keeping in mind their stipulated energy demand and available supply options during the lean seasons.

The setting up of industries needs to be determined within an overall environmentally sustainable framework. Promotion of industries should be such that aspects such as available power, export of power, utilization of export proceeds, employment generation, value addition, trade, and alternative patterns of industrial growth are carefully considered. In the existing subsidized regime for the industrial sector, provision of subsidized power to the energy-intensive sector may be at the cost of revenues forgone from exports. Integrating the opportunity cost in supplying to the industrial sector, it is recommended that niche industries be encouraged in Bhutan, which utilize natural resources, along with other industries that can function with minimal energy. A note on viability of power-intensive industries is given in Box 6.

The existing tariff regime should also be modified so as to recover the complete economic cost of providing electricity. The tariff rationalization towards gradual removal of subsidies to high voltage and medium voltage consumers remains important in this respect. It is seen that while the average tariffs have been revised several times, they still remain highly subsidized. In January 2003, the flat rate system of tariff was replaced by the progressive charge with different rates for the domestic and industrial usage. Accordingly, in the low-voltage category, consumers with less than 80 kWh consumption had to pay Nu 0.60 a unit, while the rate for those consuming 80–120 kWh and above 200 kWh per month was fixed at Nu 0.95 and Nu 1.20 per unit, respectively. The tariff for the medium and high voltage was fixed at Nu 0.95 and Nu 0.90 per unit, respectively, along with the capacity charge of Nu 54 000 per megawatt per month.

Though the steps towards tariff revisions have reduced the level of subsidies, the burden still remains high. The Bhutan Electricity Authority (BEA), an independent regulator, has been entrusted with the responsibility of tariff regulation. The Authority

[7] Compendium of background papers, BIMSTEC workshop on ‘Sharing of experience in developing hydro projects’, 30–31 October 2006, organized by the Ministry of Power, Government of India

BOX 6

VIABILITY OF POWER INTENSIVE INDUSTRIES

Electricity tariffs have largely been affordable to stimulate the industrial sector in Bhutan. The industrial sector consumes 26.4% of the total energy and is the largest consumer of electricity in the country; its consumption is pegged at 420 MU, which is about 64.7% of total electricity consumed by the industrial sector in 2005. The main manufacturing industries in Bhutan are Penden Cement Authority Ltd (PCAL), Bhutan Ferro Alloys Ltd (BFAL), and Bhutan Calcium Carbide Ltd (BCCL). Besides these, Druk Cement Company Ltd (DCCL), Druk Iron and Steel Plant (DISL), and Bhutan Steels Ltd (BSL) have also been set up, which consume almost 95% of the electricity used by the sector.

As seen from the energy demand analysis for the BAU (business-as-usual) scenario, with the upcoming industries that have recently received licenses, the energy demand from the sector is bound to increase in the coming years. This increased demand level would lead to a serious conflict with the total available supply, which has to meet the growing needs of other sectors as well, besides industrial sector. Besides the availability factor, viability of the power industries is also dependent on the cost of available supply. With the prevalent low tariff regime for the industrial sector, industries are viable options. However, with the phasing out of subsidies, as proposed by the Bhutan Electricity Authority (BEA), their existence might come under threat.

would determine the tariff as per the tariff policy, with public announcement and dissemination. The overriding objective of the tariff policy has been gradual phasing out of the subsidies—a 10% increase in power tariff is proposed annually for the next five years till 2012.

Besides tariff revision, another option that could be explored in the context of Bhutan is cost plus tariff. In case the industry wishes to overdraw electricity, the regulator could consider the option of providing it at a cost above the actual tariff rate, subject to the availability and fulfilment of legal requirements. The other alternative could be to charge the second tariff to the level of export proceeds.

TRANSMISSION AND DISTRIBUTION OF ELECTRICITY

The power transmission and distribution network in Bhutan is managed by the BPC and comprises two main grids, the western grid and the eastern grid, each of them covering parts of eight Dzongkhags.

System planning

The network can be divided into a bulk power transmission system for supplying power from Bhutan to India and an area supply or sub-station system for supplying domestic loads (WRMP 2004).

CHAPTER 7

Recommendations

This chapter consolidates various components of the energy management plan in a comprehensive manner. The analysis carried out in the earlier chapters has identified and quantified current and future needs of the energy sector, and accordingly, certain strategies have been recommended with probable impact analysis.

INTEGRATED ENERGY MANAGEMENT PLAN COMPONENTS

The previous chapters discussed specific supply and demand side strategies for Bhutan. This chapter examines some overarching issues that cut across these strategies and, in a sense, link them with the larger development objectives of the country.

The national development targets, as reflected in the Ninth Plan and *Bhutan 2020*, closely match the Millennium Development Goals and reflect a strong national political commitment to socio-economic development. Energy systems need to be planned in such a way that they promote these objectives, with a focus on poverty reduction and balanced regional development, taking into account the special needs of remote and rural communities. This will require an emphasis on small- and medium-sized units and reduced dependence on the (hydropower) construction industry such that the employment generating capacity of industry is enhanced. Also, there is an urgent need to revive agriculture through a focus on value-added products and rural development, since over 60% of the country's labour force is still dependent on agriculture.

At the same time, energy development must plan for environmental externalities because, first, augmenting energy infrastructure will have impacts on forests, biodiversity, and the environment; and second, in designing energy systems, the potential impacts of climate change in Bhutan need to be taken into consideration.

Governance of the energy sector will be crucial in meeting social and environmental obligations while tapping various sources of investments and building capacity across the tiers of the government to manage energy systems. This is especially relevant, since the political system in Bhutan is in a phase of transition. But first, a critical cross-cutting issue of energy security is considered, which almost all countries of the world are facing.

INSTITUTIONAL SET-UP

The analysis of the energy sector of Bhutan reveals that there is no focal ministry/department to undertake the coordination of all the activities related to energy. Moreover, the relevant information on various energy sources/fuels is scattered along various sources because single source of information is not available. As far as renewable energy and energy conservation/efficiency are concerned, there is very limited awareness among the stakeholders, particularly the users. This lack of awareness hampers their ability to make an informed and judicious choice.

The existing institutional infrastructure for the energy sector in Bhutan is shown in Figure 1.

A brief note on different institutions presented in Figure 1 is given in the subsequent section.

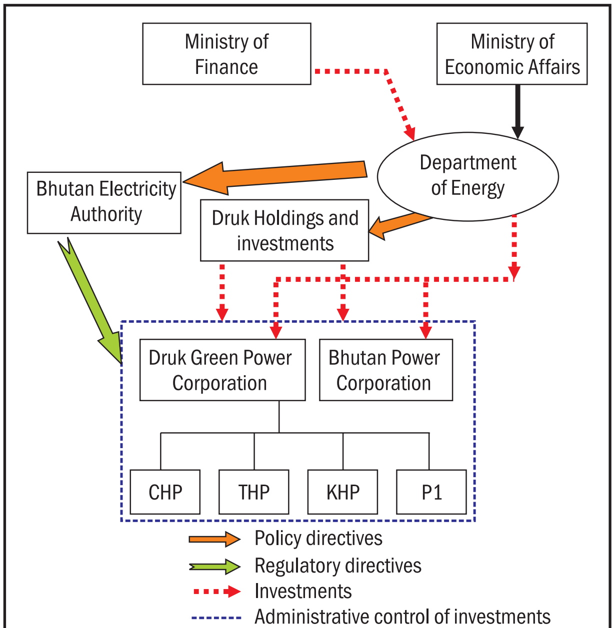


FIGURE 1 EXISTING INSTITUTIONAL INFRASTRUCTURE IN ENERGY SECTOR

Ministry of Economic Affairs

The erstwhile Ministry of Trade and Industry, which was subsequently renamed as the Ministry of Economic Affairs, was established in 1967. Initially, known as the Ministry of Trade, Commerce and Industry, it was established as a full-fledged Ministry in 1968, under the reign of the third Druk Gyalpo His Majesty King Jigme Dorji Wangchuck, and renamed as the Ministry of Trade, Industry and Forests. Presently, besides the inclusion of the power and mining sector, it has been officially designated as the Ministry of Economic Affairs from 17 October 2007. The Ministry of Economic Affairs comprises four technical departments, namely, the departments of trade, industry, energy, and geology and mines besides the four service divisions, namely, the Policy and Planning; Administration and Finance; Human Resource; and Intellectual Property.

Department of Energy

The Department of Energy (DoE) within the Ministry of Trade and Industry has been formed during the restructuring process of the erstwhile Department of Power in July 2002. The DoE is responsible for the formulation of energy and power sector policy, plans, programmes, and guidelines/regulations; conducting feasibility studies related to hydropower development; and preparing detailed project reports (DPRs) for the sustainable development of hydropower projects. The DoE also performs the function of Royal Government of Bhutan (RGoB)/donor/lender fund coordination related to energy/power sector projects. It also has the mandate to issue techno-economic clearances and technical sanctions for all capital works in the energy/power sector.

Bhutan Electricity Authority

The Bhutan Electricity Authority (BEA) is a functional autonomous agency established as per Section 7 of the Electricity Act of Bhutan, 2001, to regulate the electricity supply industry of Bhutan. The Authority consists of four commission members and a chairman, appointed by the minister as per the Electricity Act, 2001, and has a full-time secretariat in Thimphu. Functions of the BEA are as follows.

- To regulate the electricity supply industry.
- To set technical, safety, and performance standards for the electricity supply industry.
- To develop electricity tariff regulations and approve domestic tariffs.
- To develop subsidy regulations.
- To issue licenses and monitor compliance to licenses.
- To settle disputes that may arise between licensees and between licensees and customers.
- To prescribe royalties, fines, and penalties, to be paid by licensees.

Druk Holding and Investment

Pursuant to the Royal Charter dated 11 November 2007, and the Executive Order of the prime minister, the Druk Holding and Investments Ltd (DHI) have been formed for the following purpose.

- Hold shares of government-linked companies (GLCs), the primary mandate of which is commercial.
- Strengthen the corporate sector.
- Make investments by optimal usage of resources or raising funds.

- Lead, complement, and spearhead the growth of a dynamic private sector, individually or through joint ventures.

Druk Green Power Corporation

The Druk Green Power Corporation Ltd (DGPC) was formed on 1 January 2008, with the amalgamation of the erstwhile hydropower corporations.

The DGPC is responsible for the optimal utilization of resources in the management of existing power plants and building capacity to develop hydropower projects either independently, through joint venture or by any other arrangement.

Bhutan Power Corporation

Bhutan Power Corporation Ltd (BPC) was launched as a public utility on 1 July 2002, with the mandate of distributing electricity throughout the country and also providing transmission access for generating stations for domestic supply as well as export. One of BPC's basic mandate was to not only ensure that electricity is available to all the citizens but to also make sure that it is reliable, adequate, and above all, within the means of all consumers.

Given the complexities of different energy sub-sectors in the country, it is desirable to take an integrated and holistic approach to address myriad challenges that the country is facing in the field of energy. It is, therefore, suggested to bring petroleum as well as coal under the purview of the DoE, besides electricity, renewable energy, and energy conservation/efficiency. In order to take on these wider responsibilities, the DoE may be transformed into a full-fledged Ministry of Energy. Indeed, Good Governance Plus document also mentions the formation of the Ministry of Energy and Water Resources Management. This move would accelerate the progress of development as envisaged in the vision documents and master plans.

In the interim, the DoE may be mandated to look after not only the hydropower energy and renewable energy but also policies regarding import of petroleum fuels and coal. Thus, different departments/divisions may be created to look after the specific areas, as mentioned subsequently.

- Hydropower development and planning (including hydrology, meteorology, and flood warning services)
- Hydropower promotion and trade
- Power systems
- Sustainable energy
- Fossil fuels

Considering the facts that (1) any surplus electricity is a potential source of revenue earner through exports and (2) the preservation of its pristine environment is country's topmost priority, it is evident that much more emphasis would have to be laid on (1) new renewable energy resources (such as biomass and solar) and (2) energy conservation and energy efficiency. To attain these goals, the present Renewable Energy Department (RED) may be converted to Sustainable Energy Department (SED).

The SED would, therefore, make the endeavour of mainstreaming renewable energy and energy efficiency within the country. The SED would also help in taking an integrated view of the energy situation, wherein renewable energy and energy conservation play complementary roles. The broad functions of the SED will include the following.

- Facilitation, policy formulation, planning, coordination, and monitoring
- Promotion of R&D in renewable energy and energy efficiency in association with the engineering colleges; demonstrations and resource assessment
- Capacity development at various levels, including at the Dzongkhag levels
- Energy labelling/endorsement
- Financing
- Knowledge management and awareness creation
- Integration with other organizations and developmental programmes

With the SED playing a pivotal role, the following institutional set-up is suggested to promote renewable energy and energy efficiency.

- The SED would formulate guidelines, policy measures, plans, and programmes in consultation with Dzongkhags. The policy framework may be designed taking into account the district needs and recommendations. The bottom-up approach would help in providing solutions appropriate to the Dzongkhags concerned.

- It may be desirable to have ‘decentralized institutional set-up’ at the Dzongkhag level. Rather than creating new agencies, the relevant existing department(s), like the Planning Department, may be designated and empowered to carry out activities related to renewable energy and energy efficiency.
- The SED may undertake setting up of energy efficiency labelling programme in collaboration with the STQA and the Industrial Development Centre.
- The task of creating awareness at various levels, on the potential and relevance of renewable energy and energy efficiency in the emerging energy scenario as well as their different aspects may be undertaken by the SED through the dzongkhags, Industrial Development Centre, Royal Society for Protection of Nature (RSPN), Bhutan Chambers of Commerce and Industries (BCCI), and suitable NGO(s).
- The SED may establish an information centre on renewable energy and energy efficiency, which would function as a single source of information.

Figure 2 shows the suggested institutional set-up graphically. A detailed note on the structure and function of the organization is given in Annexure 7.1

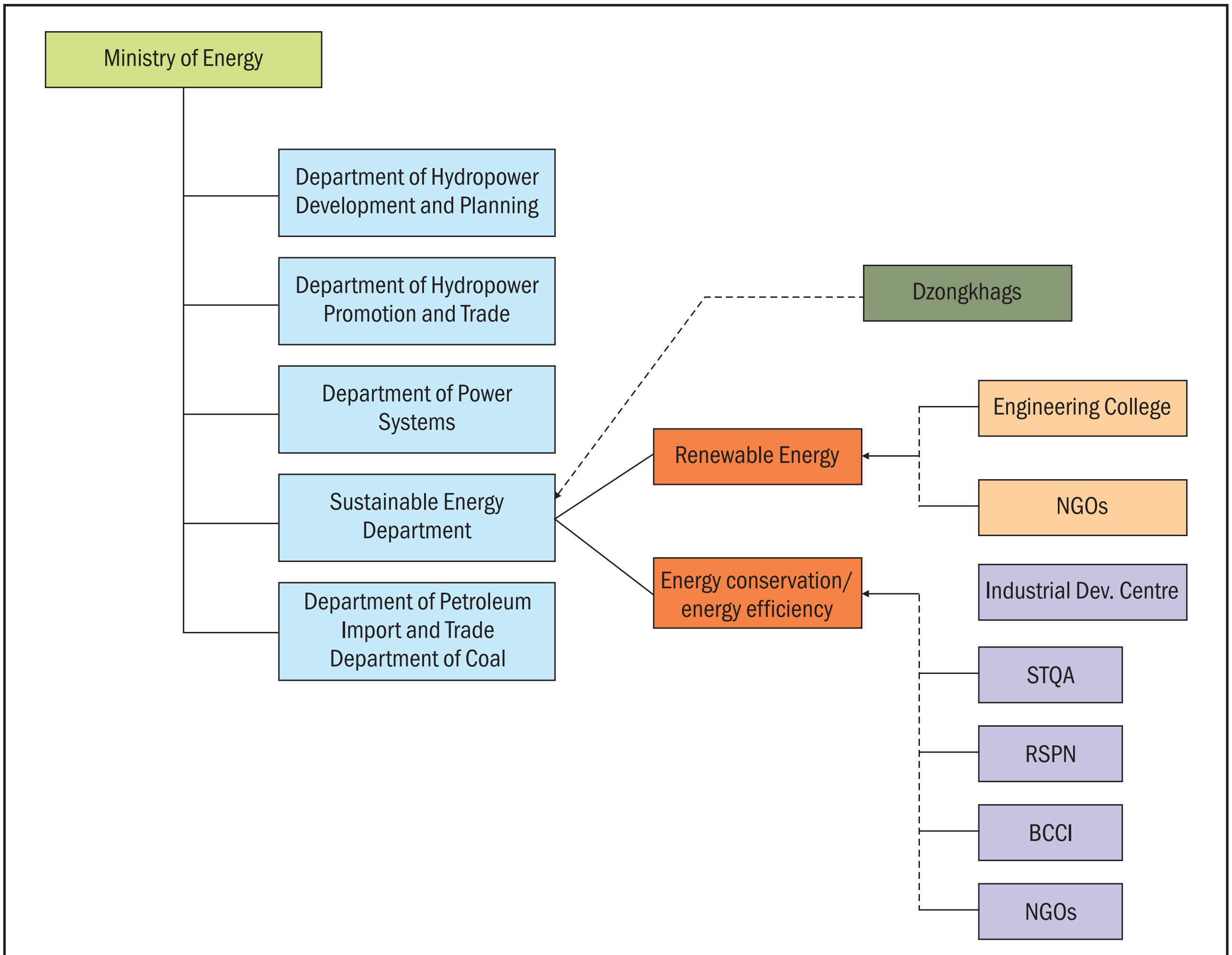


FIGURE 2 SUGGESTED INSTITUTIONAL SET-UP

IMPLEMENTATION OF ELECTRIC VEHICLES

With vast potential available for hydropower generation, use of electricity for mass transport and electric/hybrid vehicles for personal transport are viable options for Bhutan.

Hybrid (petrol–electric) and electric vehicles are now being developed by many major automobile manufacturers worldwide.

Use of electric vehicle by the individuals as well as for the public transport system may reduce the burden of import of petrol and diesel on the Bhutanese economy. It is observed that the replacement of personnel petrol vehicle and some public transport systems such as mini buses in the city like Thimphu with the electric vehicles can not only reduce the petrol consumption of the city but will also help in reducing pollution.

Total petrol consumption in 2005 was 13 775 kilolitres, which is projected to increase to 34 105 kilolitres in 2015 and to 51 673 kilolitres in 2020 under the business-as-usual (BAU) scenario. Petrol is mainly consumed by light transport vehicles such as cars and two-wheelers. In 2000, total number of light vehicles was 7438, which increased to 17 712 in 2006. A projection has been made based on the trend from 2000 to 2006, and it is found that the number of light vehicles will be increased to 48 452 in 2015 and to 73 680 in 2020 under the BAU scenario. To reduce the petrol consumption by vehicles, the government may promote the use of electric vehicles by citizens. An analysis on the potential savings in petrol accrued by using electric vehicles is presented in the subsequent section.

Economy of the use of electric vehicles

An analysis has been carried out for comparing the economy in the use of petrol vehicle and electric vehicle. The result is presented in Figure 3, which shows the cost in Nu/km/person for different occupancies of the vehicle. For the most common case of two occupancy, the use of petrol vehicle costs about Rs. 1.50 per person per kilometre, while the electric vehicle costs about Re 0.11 per person per kilometre (Figure 3).

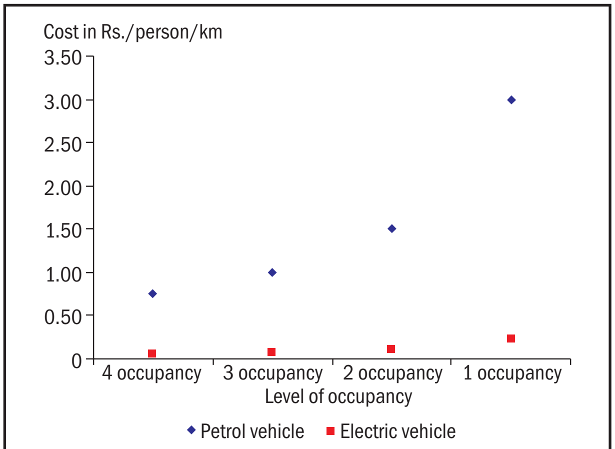


FIGURE 3 COST PER PERSON PER KILOMETER FOR PETROL VEHICLE AND ELECTRIC VEHICLE AT DIFFERENT OCCUPANCIES

Potential for petrol saving by using electric vehicles

Following assumptions have been made to calculate the estimated petrol savings.

- Electricity consumed during one full charging of the electric vehicle is 9 kWh.
- Distance travelled by electric vehicles in one full charging is 80 km. Mileage of petrol vehicle is 12 km per litre.
- Price of electricity is Rs. 2.00 per kWh.
- Number of days the vehicles are used in a year is 365 days.
- Price of petrol is Rs 45.00 per litre.
- Average run per day per vehicle is about 15 km.

It is suggested that initially, about 1000 personal electric vehicles may be introduced by 2012 and then up to 5000 vehicles by 2015 and up to 15 000 vehicles may be introduced by 2020. Based on the assumptions given above, saving in the amount of petrol is calculated. It is estimated that by following this approach, total saving of petrol by the year 2015 will be about 2281 kilolitres, and by 2020, it will be about 6843 kilolitres. The replacement of petrol vehicles with electric vehicles will reduce the petrol demand in future and will increase the total electricity demand in Bhutan. Based on the above assumptions, it is estimated that by 2015, Bhutan may save about Nu 94 million per year, and by 2020, it will save about Nu 280 million per year.

CDM potential of using electric vehicles

There is a good potential for Clean Development Mechanism (CDM) by using electric vehicles. The use of electric vehicle will also help Bhutan in keeping its environment clean and reducing the greenhouse (GHG) emission because of the reduction in petrol consumption and the use of clean electric power, which is generated by hydropower projects. It is estimated that by 2015, Bhutan can help in reducing about 5656 tCO_2 per year, and by 2020, about 16 969 tCO2 will be reduced per year by replacing petrol vehicles with electric vehicles.

Strategy for the implementation of electric vehicles

The implementation of electric vehicles can be initially for the office-goers, who will require commuting between office and home. Various organizations may also provide charging plugs in the parking place of the office building, so that employees may charge their vehicles whenever they want to. This charging facility may be available on paying nominal fees or it may be provided free to the employees to promote the use of electric vehicles in initial phase.

Charging stations may be set up at various parking places and the charging facility can be provided free of cost as a subsidy to the electric vehicle owners.

The government may introduce mini buses running on electricity within Thimphu city and later on from Thimphu to Paro. It is, therefore, suggested to develop a master plan for the introduction of electric/hybrid vehicles in Bhutan.

Projected socio-economic variables

Table 1

GROSS DOMESTIC PRODUCT (NU BILLION @ 2000 PRICES)

Year	*BAU*	*HIG*
2005	28.9	28.9
2006	31	31.8
2007	33.3	35
2008	35.7	38.5
2009	38.3	42.3
2010	41.1	46.6
2011	44.1	51.2
2012	47.4	56.4
2013	50.8	62
2014	54.5	68.2
2015	58.5	75
2016	62.8	82.5
2017	67.4	90.8
2018	72.3	99.8
2019	77.6	109.8
2020	83.2	120.8

BAU – business-as-usual; HIG – high growth

Table 2

POPULATION STATISTICS (IN THOUSAND)

Year	*Rural regular population*	*Urban regular population*	*Transient and institutional population*	*Floating population*	*Total population*
2005	410.9	167.4	56.7	37.4	672.4
2006	402.8	185	55.4	37.3	680.5
2007	392.6	202.9	56.1	37.8	689.4
2008	382.3	221	56.8	38.3	698.4
2009	371.8	239.3	57.5	38.8	707.4
2010	361.1	257.9	58.3	39.3	716.6
2011	350.3	276.7	59.1	39.8	725.9
2012	339.5	295.8	59.8	40.3	735.4
2013	328.4	315.1	60.6	40.8	744.9
2014	317.3	334.6	61.3	41.4	754.6
2015	305.9	354.4	62.2	41.9	764.4
2016	294.4	374.5	63	42.5	774.4
2017	282.7	394.8	63.9	43	784.4
2018	271	415.4	64.6	43.6	794.6
2019	259	436.3	65.6	44.1	805
2020	246.9	457.4	66.4	44.7	815.4

BAU – business-as-usual; HIG – high growth

Table 3

GROSS DOMESTIC PRODUCT PER CAPITA (THOUSAND NU @ 2000 PRICES)

Year	*BAU*	*HIG*
2005	45.5	45.5
2006	45.6	49.5
2007	48.3	53.7
2008	51.2	58.3
2009	54.2	63.3
2010	57.4	68.8
2011	60.8	74.7
2012	64.4	81.1
2013	68.2	88
2014	72.3	95.6
2015	76.5	103.8
2016	81.1	112.7
2017	85.9	122.4
2018	91	132.9
2019	96.3	144.3
2020	102	156.7

BAU – business-as-usual; HIG – high growth

Table 4

TOURIST INFLUX (IN THOUSAND)

Year	*BAU*	*HIG*
2005	13.6	13.6
2006	15.7	16.5
2007	18	19.9
2008	20.7	24.1
2009	23.8	29.2
2010	27.4	35.3
2011	31.5	42.8
2012	36.2	51.7
2013	41.7	62.6
2014	47.9	75.8
2015	55.1	91.7
2016	63.4	110.9
2017	72.9	134.2
2018	83.8	162.4
2019	96.4	196.5
2020	110.9	237.8

BAU – business-as-usual; HIG – high growth

Table 5

NUMBER OF COMMERCIAL ESTABLISHMENTS (SHOPS AND RESTAURANTS)

Year	*BAU*	*HIG*
2005	5 967	5 967
2006	6 385	6 564
2007	6 832	7 220
2008	7 310	7 942
2009	7 822	8 736
2010	8 369	9 610
2011	8 955	10 571
2012	9 582	11 628
2013	10 252	12 791
2014	10 970	14 070
2015	11 738	15 477
2016	12 560	17 025
2017	13 439	18 727
2018	14 380	20 600
2019	15 386	22 660
2020	16 463	24 926

BAU – business-as-usual; HIG – high growth

ANNEXURE 3.2

List of upcoming industries

Table 1

LIST OF UPCOMING INDUSTRIES IN BHUTAN

Industries	*Activity*	*Location*	*Power demand*	*Power allocated*
AWP Brewery Projects	Manufacturing beer	Gelephu	7.2 MWh	0.9
Bhutan Dairy and Agro Products Ltd	Ultra high temperature (UHT) milk and fruit juice	P/ling		0.44
Bhutan Brewery Pvt. Ltd	Production of beer	Pasakha	700 kVA	0.64
Bhutan Carbide and Chemicals Ltd	Low carbon silico manganese	Pasakha	11 MW	11
Bhutan Carbide and Chemicals Ltd	Manufacturing magnesium metal	Pasakha	12 MW	12
Bhutan Concrete Bricks	Manufacturing solid bricks and hollow blocks	Pasakha		0.05
Bhutan Ferro Industries	Manufacturing ferro silicon	Pasakha	27 MW	8.1
Bhutan Health Food Products Pvt. Ltd	Manufacturing specialty fats	Pasakha	1000 kW	1
Bhutan Metals Pvt. Ltd	Manufacturing copper wire	Pasakha		0.18
Bhutan Packaging Industry		P/ling		0.25
Bhutan Polymers Company Ltd	Production of woven fabrics	Samtse		0.5
Bhutan Rolling Mills Pvt. Ltd	Steel re-rolling	Bhalujhora	1.4 MVA	3.4
Bhutan Wood Panel	Manufacturing wooden products	P/ling		0.27
Choden Engg Workshop	Automobile workshop	P/ling		0.26
Drangchu Beverage	Production of soft drinks	P/ling		0.4
Druk Ferro Alloys Ltd	Manufacturing ferro silicon	Pasakha	21.5 MVA	18
Druk Iron and Steel (Phase II)	Manufacturing steel ingots	Rabtengang	2.3 MW	2.3
Druk Wang Alloys Ltd	Manufacturing ferro silicon	Pasakha	21.5 MVA	17.5
Gyeltshen Steel Industries	Manufacturing steel ingots	Pasakha	9.3 MW	3.4
Jatu Wood Industries	Manufacturing wooden furniture	P/ling		0.09
Jigme Industries Pvt. Ltd	Dolomite processing	Samtse		0.45
Jigme Polytex Pvt. Ltd	Polyester yarn texturing	Samtse		0.75
Kenpa Pvt. Ltd	Manufacturing vanaspati	Pasakha	7.2 MWh	0.6
Kimpex Pvt. Ltd	Stone crushing	P/ling		0.13
Kimpex Pvt. Ltd	Manufacturing of laundry and toilet soaps	Pasakha	420 000 units	0.13
KK Iron & Steel Pvt. Ltd	Induction furnace	Pasakha	W#$8	3.3*(15
Kuenchap Rod and Wire Industries Pvt. Ltd	Manufacturing copper rod and wire	Pasakha		0.1
Lhojong Emulsion Industry	Bitumen emulsion	P/ling		0.05
Mega Pvt. Ltd	Manufacturing vanaspati, margarine, and edible oils	Pasakha		1.05
Bhutan Ferro Alloys Ltd	Manufacturing ferro silicon	Pasakha	18 MVA	12.33

Table 1 contd...

LIST OF UPCOMING INDUSTRIES

Table 1				
CONTD...				
Industries	*Activity*	*Location*	*Power demand*	*Power allocated*
Omzin Manufacturing Company	Manufacturing polyster yarn and silk fabrics	Bhalujhora		0.43
Quality Gases	Production of liquefied nitrogen/oxygen	Pasakha	1000 KW	1
Rabten Wire Industry	Manufacturing wire products	Pasakha		0.26
RSA Poly Products Pvt. Ltd	Manufacturing poly films and fabricks	Pasakha	1200 KVA	1
RSA Polymers	Manufacturing multi-layer filaments/yarn	P/ling		0.65
RSA Pvt. Ltd	Marble slabs	Pasakha		0.75
S D Eastern Bhutan Ferro Silicon	Manufacturing ferro silicon	S/Jongkhar	19 MVA	17
Samphel Norbu Products Pvt. Ltd	Production of livestock feeds	Pasakha		0.02
Singye Vanaspati Manufacturing Company	Production of vanaspati oil and fats	Pasakha		0.05
Tashi Metal and Alloys Pvt. Ltd	Manufacturing calcium silicide cordwire	Pasakha	13.2 MVA	12
Ugen Ferro Alloys Pvt. Ltd	Manufacturing ferro silicon	Pasakha	20 MVA	18
Yarab Pvt. Ltd	Manufacturing copper wire	P/ling		0.1
Yarkey Minerals	Manufacturing marble slabs, chips, and tiles	Pasakha		0.43
Yarkay Poly Products	Manufacturing textured polyster yarn	P/ling		0.65
Yarkay Poly Products	Manufacturing textured polyster yarn	P/ling		0.2
Zoya Enterprise	Manufacturing zinc chloride	Pasakha		0.02
Bhutan Aluminum Products Pvt. Ltd	Manufacturing aluminum rod and ACSR conductors	Pasakha	400 KVA	0.36
Chaksampa Steel Pvt. Ltd	MS ingots and structural steel	Pasakha	5.5 MW	3
Dragon Sarvesh Bhutan Pvt. Ltd	Manufacturing fused dolomite	Pasakha	6 MW	6
Dralha and R Piyarelall Steel Co. Pvt. Ltd	Manufacturing MS angles, rods	Pasakha		3
Lhaki Steels and Rolling Pvt. Ltd	Wire rod re-rolling, TMT bars and structural steel	Pasakha	20 MW	12
Non-Ferrous Metals Extrusions Ltd	Manufacturing non-ferrous metals	Pasakha	7000 KW	2
Royal Government of Bhutan	Dungsum cement project (1 MTPA)	Nanglam	18 MW	18
S Gobain Ceramic Materials Bhutan Ltd	Manufacturing silicon carbide	Pasakha	26 MW	13
United Industries Pvt. Ltd	Manufacturing specialty fats	Pasakha	1 KVA	0.9

ANNEXURE 3.3

Projected energy demand in Bhutan, by fuel

Projection of the demand of each fuel under different scenarios has been carried out using LEAP. Results of the projections are given.

Abbreviations used
BAU – business-as-usual; EE – energy-efficient; HIG – high growth; HIGEE – high growth combined with energy efficient

Table 1

PROJECTED ELECTRICITY DEMAND (MILLION UNITS)

Year	BAU	EE	HIG	HIGEE
2005	612	612	612	612
2006	763	763	769	769
2007	862	862	872	872
2008	2215	2017	2232	2042
2009	2465	2185	2490	2217
2010	2494	2206	2528	2247
2011	2524	2229	2570	2280
2012	2557	2253	2616	2317
2013	2592	2279	2665	2355
2014	2629	2307	2720	2398
2015	2832	2482	3555	3167
2016	2880	2518	3629	3226
2017	2937	2560	3717	3295
2018	2999	2605	3813	3372
2019	3067	2655	3920	3457
2020	3067	2655	3921	3458

Table 2

PROJECTED FIREWOOD DEMAND (THOUSAND TONNES)

Year	BAU	EE	HIG	HIGEE
2005	735	735	735	735
2006	749	754	744	749
2007	827	837	810	820
2008	830	637	804	618
2009	834	640	801	616
2010	840	645	801	617
2011	850	653	805	620
2012	862	661	813	627
2013	877	674	825	638
2014	896	688	842	653
2015	918	706	865	672
2016	944	727	895	697
2017	974	751	931	727
2018	1010	780	975	763
2019	1051	813	1028	807
2020	1097	850	1091	859

Table 3

PROJECTED LIQUEFIED PETROLEUM GAS (LPG) DEMAND (THOUSAND TONNES)

Year	BAU	EE	HIG	HIGEE
2005	4.34	4.34	4.34	4.34
2006	4.60	4.60	4.87	4.87
2007	4.96	4.96	5.31	5.31
2008	5.22	5.04	5.84	5.66
2009	5.66	5.31	6.37	6.19
2010	6.02	5.66	6.99	6.73
2011	6.37	6.02	7.61	7.35
2012	6.73	6.46	8.23	7.96
2013	7.17	6.81	8.94	8.67
2014	7.61	7.26	9.73	9.38
2015	8.05	7.61	10.53	10.09
2016	8.50	8.05	11.33	10.97
2017	8.94	8.50	12.30	11.86
2018	9.47	9.03	13.27	12.74
2019	10.00	9.47	14.34	13.81
2020	10.53	10.00	15.49	14.96

Table 5

PROJECTED COAL DEMAND (THOUSAND TONNES)

Year	BAU	EE	HIG	HIGEE
2005	123.7	123.7	123.7	123.7
2006	143.4	143.4	143.4	143.4
2007	143.4	143.4	143.4	143.4
2008	245.7	217.1	245.7	217.1
2009	585.7	457.2	585.7	457.2
2010	585.7	457.2	585.7	457.2
2011	585.7	457.2	585.7	457.2
2012	585.7	457.2	585.7	457.2
2013	585.7	457.2	585.7	457.2
2014	585.7	457.2	585.7	457.2
2015	585.7	457.2	585.7	457.2
2016	585.7	457.2	585.7	457.2
2017	585.7	457.2	585.7	457.2
2018	585.7	457.2	585.7	457.2
2019	585.7	457.2	585.7	457.2
2020	585.7	457.2	585.7	457.2

Table 4

PROJECTED KEROSENE DEMAND (THOUSAND KILOLITRES)

Year	BAU	EE	HIG	HIGEE
2005	12.5	12.5	12.5	12.5
2006	12.2	12.2	11.8	12.5
2007	11.9	11.9	11.0	12.5
2008	11.6	11.6	10.3	12.5
2009	11.4	11.4	9.7	12.5
2010	11.1	11.1	9.1	9.1
2011	10.7	10.7	8.1	8.1
2012	10.4	10.4	7.3	7.3
2013	10.1	10.1	6.5	6.5
2014	9.8	9.8	5.8	5.8
2015	9.5	9.5	5.2	5.2
2016	9.1	9.1	3.9	3.9
2017	8.7	8.7	3.0	3.0
2018	8.3	8.3	2.2	2.2
2019	8.0	8.0	1.7	1.7
2020	7.7	7.7	1.3	1.3

Table 6

PROJECTED DIESEL DEMAND (KILOLITRES)

Year	BAU	EE	HIG	HIGEE
2005	51 440	51 440	51 440	51 440
2006	60 467	60 467	62 417	62 417
2007	66 123	66 123	70 360	70 360
2008	72 193	64 974	79 099	71 189
2009	78 706	70 835	88 710	79 839
2010	85 694	77 124	99 284	89 355
2011	93 192	83 873	110 914	99 823
2012	101 237	91 114	123 707	111 337
2013	109 870	98 883	137 780	124 002
2014	119 133	107 220	153 260	137 934
2015	129 072	116 165	170 288	153 260
2016	139 737	125 763	189 019	170 117
2017	151 180	136 062	209 623	188 661
2018	163 459	147 113	232 288	209 059
2019	176 634	158 971	257 219	231 497
2020	190 771	171 694	284 642	256 178

Table 7

PROJECTED PETROL DEMAND (KILOLITRES)

Year	BAU	EE	HIG	HIGEE
2005	13 775	13 775	13 775	13 775
2006	14 570	14 570	15 125	15 125
2007	16 181	16 181	17 387	17 387
2008	17 909	15 402	19 875	17 093
2009	19 763	16 996	22 612	19 446
2010	21 753	18 708	25 623	22 035
2011	23 888	20 544	28 934	24 884
2012	26 179	22 514	32 577	28 016
2013	28 637	24 628	36 584	31 462
2014	31 275	26 896	40 992	35 253
2015	34 105	29 330	45 841	39 423
2016	37 141	31 942	51 174	44 010
2017	40 400	34 744	57 041	49 055
2018	43 896	37 751	63 494	54 605
2019	47 648	40 977	70 593	60 710
2020	51 673	44 439	78 402	67 426

Table 8

PROJECTED AVIATION TURBINE FUEL (ATF) DEMAND (KILOLITRES)

Year	BAU	EE	HIG	HIGEE
2005	1145	1145	1145	1145
2006	1303	1303	1296	1296
2007	1398	1398	1447	1447
2008	1501	1501	1598	1598
2009	1610	1610	1749	1749
2010	1728	1728	1900	1900
2011	1854	1854	2120	2120
2012	1989	1989	2340	2340
2013	2134	2134	2560	2560
2014	2290	2290	2780	2780
2015	2457	2457	3000	3000
2016	2637	2637	3415	3415
2017	2829	2829	3830	3830
2018	3036	3036	4244	4244
2019	3257	3257	4659	4659
2020	3495	3495	5074	5074

ANNEXURE 4.1

Tariff design

Tariff design, from the point of view of an operator, is aimed at profit maximization, while the government's interest is welfare maximization and making available affordable service to the poor. To maximize profits, the operator seeks prices that equate marginal revenue (defined as the extra revenue the operator receives when it increases output by one unit) and marginal costs. Different types of options exist for designing tariffs, and some of them are discussed in the subsequent sections.

MARGINAL COST PRICING

In case of competitive environment, marginal revenue equals marginal costs. This marginal cost pricing maximizes welfare, with the interest of the operator coinciding with the interests of the government.

Deviation from marginal cost pricing: multipart prices

In case the operator possesses some market power, its profit maximization prices would exceed the marginal cost, resulting in welfare loss unlike the perfectly competitive environment. An example of a deviation from the marginal cost pricing is the multipart tariffs, wherein the operator charges separate prices for different elements of the service unlike in linear tariff, wherein a single price is charged for the service. A common example of multipart tariff is the two-part tariff in the electricity sector, where the customer pays a monthly fee for access and a usage fee for the consumption of electricity.

Optional tariffs

Optional tariffs are closely related to the multipart tariff, where the operator offers the customer a menu of pricing plans, amongst which the customer chooses the option that best meets his requirements.

Peak load pricing

Peak load pricing is a kind of pricing variation, wherein the operator would maximize his profits by charging higher prices during the peak hours and lower prices during the off-peak hours. The peak load pricing, however, requires sophisticated measurement of customer usage, with advanced metering technologies for energy and water sectors. The cost of implementing these technologies, however, must be weighed against the welfare gains for metering before pursuing the usage of peak load pricing.

REGULATION OF THE ENERGY SECTOR

Irrespective of the structure of the sector, there is a need to introduce an arms-length energy regulator, combining the powers of rule making (legislative) and implementation and enforcement (executive) with quasi-judicial powers of review and appeal against their orders (judicial). Independent regulation is required to safeguard consumer interests, especially those of vulnerable groups and geographically distant consumers, promote efficiency and economy in the sector, accelerate decision-making, facilitate investors and others in planning and raising finances for the long-term investments, and supply quality services at economic prices.

The Bhutan Electricity Authority (BEA) has been established under the Electricity Act, 2001, to play the role of a regulator in the development of the energy sector. Some of the important functions of the Authority as per the Act include development of regulations, standards, codes, principles and procedures; process applications; modifying and revoking licences and monitoring the performance of licensees and their compliance; determining/

approving/reviewing tariffs; prescribing and collecting fees, charges or royalties from licensees; imposing fines, sanctions or penalties for any breach of provisions of this Act; establishing a dispute resolution process; and settling disputes and other duties or responsibilities delegated by the minister.

While the BEA can play the role of a regulator in the short term, experience worldwide has underscored the need for rule-making, decision-making or adjudicative functions to be under an independent regulator outside of the government and the legal system. Government departments may be perceived as not being able to provide insulation from external influences. Also, it may not be feasible to develop courts for different kinds of expertise required. In addition, independent regulators can also bring in more stability since they are not concerned with electoral politics but have to keep the interest of the public in mind. Further, entrusting price regulation to a regulatory body also has major advantages for governments—it provides insulation from politically unpopular pricing decisions that need to be taken in the interest of the industry and creates a source of expertise.

In the foreseeable future, the government will remain the largest player in the electricity sector in the country (likely in the form of Druk Green Power Corporation). Here, the regulator should closely monitor the capital and revenue expenditure of the incumbent utility and ensure that costs are not padded so as to get higher tariffs or that the utility is not unduly burdened with the costs of the government's social obligations.

Simultaneously, the regulator would need to identify segments where private capital and competition can be introduced. The regulator would need to ensure the harmonious co-existence of the private sector (in generation) with the natural monopoly segment, transmission, likely to remain in the public sector, with particular attention to non-discriminatory access to incumbent facilities.

One of the key areas that a regulator would need to focus on is tariff determination. The following issues are of importance.

- To set multi-year tariff principles.
- To progressively reflect cost of supply of electricity and also reduce and eliminate cross-subsidy within a specified time frame.
- To ensure that tariff is sensitive to the type of consumer, time of supply, area of supply, and nature/purpose for which supply is required.
- To promote renewable energy through incentives built into tariffs.

Some other important functions of the regulator would be as follows.

- Promoting energy efficiency and enforcing various energy efficiency measures and developing infrastructure/standards/codes for energy efficiency.
- Promoting the growth of renewable and non-conventional sources of energy, including solar, mini-micro hydel, and so on. Regulator can look into the utilization/creation of additional funds to support the development of the renewable energy sector for electricity generation.
- Bridging the gap in people's understanding of the sector, including the demand/supply situation and the accompanying imperatives, implications, and status of reforms through public hearings and proactive information dissemination, which are not merely perfunctory. This understanding is crucial for public buy-in of reforms, minimizing uncertainties in public reactions, and creating an environment that is more conducive for foreign direct investment (FDI).

The success of the regulator in meeting these objectives will require capacity, transparency, accountability, and a strong political and administrative commitment to their effectiveness.

DECENTRALIZED ENERGY GOVERNANCE

Bhutan has a well-designed framework for decentralized planning process at the Dzongkhag and Gewog level. The government has established Dzongkhag Yargay Tshochung (DYT), or district development committees, giving the Dzongkhags administrative responsibilities. At the block level, Gewog Yargay Tshochung (GYT) has been formed for devolving administrative responsibilities to the blocks. Measures are also being taken to improve the resource base and capacity of these bodies. In the energy sector, these local bodies can play a major role in decentralized mini hydro projects and in operation and maintenance of local distribution lines, involving the local community in billing and collection.

In the 1990s, small hydropower plants were managed by the community; however, due to various constraints such as lack of capacity and technical know-how required to operate and maintain these plants at community level, these plants were brought under the control of the Bhutan Power Corporation (BPC). However, recently built 70-kW mini hydroplant at Chendenbji and 100-kW hydroplant at Sengor are being transferred to community for operation and maintenance, with technical backstopping and support being provided by the Department of Energy (DoE)/BPC. The collection of tariff and maintaining accounts of tariff collection are the responsibilities of the community, and a village committee is set up for this purpose. This experiment has been successful so far, and in future, such decentralized governance of small plants should be encouraged.

Bhutan is also planning to develop FDI policy for hydropower development, which will encourage IPP and captive power production. A whole range of issues needs to be addressed for this to materialize. The DoE has suggested change in its current organization structure to include additional responsibilities such as negotiating contracts with private producers, marketing hydropower projects, and so on.

Ideally, regulator should look into these matters as an independent authority and develop suitable guidelines, regulation, and so on and advise the government on policy and rules, regulations, and acts.

INDICATIVE TARIFF FOR MEDIUM SIZE HYDRO PLANT (CAPTIVE POWER GENERATION)							
ASSUMPTIONS							
All costs are in million Rs							
Capital cost	6000		Capitalized cost of project				5748.72
Cost	5100		Debt				4024.10
Grant component	15%		Equity				1724.62
Equity	30%	Debt	70%		Plant load factor	55%	
Return on equity	14%	Interest rate	12%		O&M	2% of capital cost	
		Repayment period (inclusive of moratorium)	15.0 years		Escalation in O&M	2.0%	
		Moratorium	0.0 years		Fuel consumption	1	
		Life	30 years		Fuel cost	0	
		Construction period	2 years		Escalation in fuel cost	0%	
		Discount rate	12.00%		Annual generation	481.8	

LEVELIZED TARIFF ESTIMATION														
Year		1	2	3	4	5	6	7	8	9	10	11	12	
Return on equity (ROE)		241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	
Debt		4024.10	3755.83	3487.56	3219.28	2951.01	2682.74	2414.46	2146.19	1877.92	1609.64	1341.37	1073.09	
Capital repayment		268.27	268.27	268.27	268.27	268.27	268.27	268.27	268.27	268.27	268.27	268.27	268.27	
Depreciation		170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	
Interest payment		482.89	450.70	418.51	386.31	354.12	321.93	289.74	257.54	225.35	193.16	160.96	128.77	
O&M expenses		76.50	78.03	79.59	81.18	82.81	84.46	86.15	87.87	89.63	91.42	93.25	95.12	
Total expenses		970.84	940.18	909.54	878.94	848.37	817.84	787.33	756.86	726.43	696.03	665.66	635.34	
Sales		481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	
Tariff		2.02	1.95	1.89	1.82	1.76	1.70	1.63	1.57	1.51	1.44	1.38	1.32	
Levelized tariff		1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	
Discounted ROE		1944.89												
Discounted interest payments		2196.93												
Discounted O&M		718.75												
Discounted principle Repayment		1333.33												
Discounted expenses		6193.90												
Discounted sales		3880.99												
Levelized tariff (Rs/kWh)		1.60												

Capacity	100 MW		Allowance of funds used during construction			
Capital cost	5100		Interest during construction (IDC)	Year 1	Year 2	Total IDC
Debt	3570		Expenditure	40%	60%	
Equity	1530			2040	3060	
			Loan	1836	1734	3570
				1836	3570	
			Equity	204.00	1326.00	1530.00
			Interest on loan	220.32	428.4	648.72
Levelized generation cost		481.8	1.60			
Royalty sale	5%	24.09	0.3			
Cost of rest of units	95%	457.71	1.66			

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45	241.45
	804.82	536.55	268.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	268.27	268.27	268.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00
	96.58	64.39	32.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	97.02	98.96	100.94	102.96	105.02	107.12	109.26	111.45	113.67	115.95	118.27	120.63	123.05	125.51	128.02	130.58	133.19	135.85
	605.05	574.79	544.58	514.41	516.46	518.56	520.71	522.89	525.12	527.39	529.71	532.08	534.49	536.95	539.46	542.02	544.63	547.30
	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80
	1.26	1.19	1.13	1.07	1.07	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.14
	1.60	1.60	1.60	1.60	1.60	1.60	1.60						1.60					

INDICATIVE TARIFF CALCULATION FOR MEDIUM SIZE HYDRO PLANT FOR INDEPENDENT POWER PRODUCTION (IPP)							
ASSUMPTIONS							
All costs are in million Rs							
Capital cost	6000		Capitalized cost of project				6572.40
Cost	6000		Debt				4600.68
Grant component	0%		Equity				1971.72
Equity	30%	Debt	70%		Plant load factor	55%	
Return on equity	14%	Interest rate	9%		O&M	2% of capital cost	
		Repayment period (inclusive of moratorium)	15.0 years		Escalation in O&M	2.0%	
		Moratorium	0.0 years		Fuel consumption	1	
		Life	30 years		Fuel cost	0	
		Construction Period	2 years		Escalation in fuel cost	0%	
		Discount rate	12.00%		Annual generation	481.8	

LEVELIZED TARIFF ESTIMATION												
Year	1	2	3	4	5	6	7	8	9	10	11	12
Return on equity (ROE)	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04
Debt	4600.68	4293.97	3987.26	3680.54	3373.83	3067.12	2760.41	2453.70	2146.98	1840.27	1533.56	1226.85
Capital repayment	306.71	306.71	306.71	306.71	306.71	306.71	306.71	306.71	306.71	306.71	306.71	306.71
Depreciation	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Interest payment	414.06	386.46	358.85	331.25	303.64	276.04	248.44	220.83	193.23	165.62	138.02	110.42
O&M expenses	90.00	91.80	93.64	95.51	97.42	99.37	101.35	103.38	105.45	107.56	109.71	111.90
Total expenses	980.10	954.30	928.53	902.80	877.10	851.45	825.83	800.26	774.72	749.22	723.77	698.36
Sales	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80
Tariff	2.03	1.98	1.93	1.87	1.82	1.77	1.71	1.66	1.61	1.56	1.50	1.45
Levelized tariff	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68
Discounted ROE	2223.56											
Discounted interest payments	1883.78											
Discounted O&M	845.59											
Discounted principle repayment	1568.63											
Discounted expenses	6521.55											
Discounted sales	3880.99											
Levelized tariff (Rs/kWh)	1.68											

Capacity	100 MW		Allowance of funds used during construction			
Capital cost	6000		Interest during construction (IDC)	Year 1	Year 2	Total IDC
Debt	4200		Expenditure	40%	60%	
Equity	1800			2400	3600	
			Loan	2160	2040	4200
				2160	4200	
			Equity	240.00	1560.00	1800.00
			Interest on loan	194.4	378	572.4
Levelized generation cost		481.8	1.68			
Royalty sale	10%	48.18	0.3			
Cost of rest of units	90%	433.62	1.83			

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04	276.04
	920.14	613.42	306.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	306.71	306.71	306.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
	82.81	55.21	27.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	114.14	116.42	118.75	121.13	123.55	126.02	128.54	131.11	133.74	136.41	139.14	141.92	144.76	147.65	150.61	153.62	156.69	159.83
	672.99	647.67	622.40	597.17	599.59	602.06	604.58	607.15	609.78	612.45	615.18	617.96	620.80	623.70	626.65	629.66	632.73	635.87
	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80	481.80
	1.40	1.34	1.29	1.24	1.24	1.25	1.25	1.26	1.27	1.27	1.28	1.28	1.29	1.29	1.30	1.31	1.31	1.32
	1.68	1.68	1.68	1.68	1.68	1.68	1.68						1.68					

INDICATIVE TARIFF CALCULATIONS FOR CHAMKAR HYDROPOWER PLANT - LARGE HYDRO POWER PLANT WITHOUT GRANT

All costs are in million Rs

ASSUMPTIONS	
Capital cost	37 520
Cost	37 520
Grant component	0%

Capital cost as per Masterplan in $			Estimated cost with 5% escalation in 2007	
546	573.3	601.965	632.06325	25 282.53
1.05				

Capacity	670 MW		Net generation (MU)	3207						
Equity	30%	Debt	70%			Plant load factor	55%			
Return on equity	14%	Interest rate	9%			O&M	1.5% of capital cost			
		Repayment period (inclusive of moratorium)		15.0 years		Escalation in O&M	2.0%			
		Moratorium		0.0 years		Fuel consumption	1			
		Life		30 years		Fuel cost	0		Discount rate	12.00%
		Construction period		6 years		Escalation in fuel cost	0%			

LEVELIZED TARIFF ESTIMATION

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Return on equity (ROE)	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39
Debt	33189.82	30977.16	28764.51	26551.85	24339.20	22126.54	19913.89	17701.24	15488.58	13275.93	11063.27	8850.62	6637.96
Capital repayment	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65	2212.65
Depreciation	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67
Interest payment	2987.08	2787.94	2588.81	2389.67	2190.53	1991.39	1792.25	1593.11	1393.97	1194.83	995.69	796.56	597.42
O&M expenses	562.80	574.06	585.54	597.25	609.19	621.38	633.80	646.48	659.41	672.60	686.05	699.77	713.77
Total expenses	6791.94	6604.06	6416.40	6228.97	6041.78	5854.82	5668.11	5481.65	5295.44	5109.49	4923.80	4738.38	4553.24
Sales	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00
Tariff	2.12	2.06	2.00	1.94	1.88	1.83	1.77	1.71	1.65	1.59	1.54	1.48	1.42
Levelized tariff	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73
Discounted ROE	16041.00												
Discounted interest payments	13589.80												
Discounted O&M	5287.73												
Discounted depreciation	9809.15												
Discounted expenses	44727.69												
Discounted sales	25832.97												
Levelized tariff (Rs/kWh)	1.73												

Total cost of generation				5552.66
Revenue from royalty sale	15%	481.05	0.30	144.32
Revenue from export	85%	2725.95	1.80	4906.71
Total revenue				5051.03
Net revenue				-501.63

Capital cost	37 520		
Debt	26 264		
Equity	11 256		

Allowance of funds used during construction							
Interest during construction (IDC)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total IDC
Expenditure	10%	20%	25%	20%	15%	10%	
	3752	7504	9380	7504	5628	3752	
Loan	3377	6753.6	8442	6753.6	938	0	26 264
	3377	10 130	18 572	25 326	26 264	26 264	
Equity	375.20	750.40	938.00	750.40	4690.00	3752.00	11 256.00
Interest on loan	303.912	911.736	1671.516	2279.34	2363.76	2363.76	9894.024

Capitalized cost of project	47414.02
Debt	33 189.82
Equity	14 224.21

		Unit (GWh)	Tariff
Levelized generation cost		3207	1.73
Royalty sale	15%	481.05	0.3
Cost of rest of units	85%	2725.95	1.98

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39	1991.39
4425.31	2212.65															
2212.65	2212.65															
1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67	1250.67
398.28	199.14	0.00														
728.04	742.60	757.45	772.60	788.06	803.82	819.89	836.29	853.02	870.08	887.48	905.23	923.33	941.80	960.64	979.85	999.45
4368.38	4183.80	3999.51	4014.66	4030.11	4045.87	4061.95	4078.35	4095.07	4112.13	4129.53	4147.28	4165.39	4183.86	4202.69	4221.90	4241.50
3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00	3207.00
1.36	1.30	1.25	1.25	1.26	1.26	1.27	1.27	1.28	1.28	1.29	1.29	1.30	1.30	1.31	1.32	1.32
1.73	1.73	1.73	1.73	1.73	1.73						1.73					

INDICATIVE TARIFF CALCULATIONS FOR DAGACHU HYDROPOWER PLANT WITHOUT GRANT

All costs are in million Rs

ASSUMPTIONS

Capital cost	8208
Cost	8208
Grant component	0%

Capacity	651 MW		Generation	500 GWh						
Equity	25%	Debt	75%			Plant load factor	0.41			
Return on equity	14%	Interest rate	9%			O&M	1.0% of capital cost			
		Repayment period (inclusive of moratorium)		15.0 years		Escalation in O&M	4.0%			
		Life		30 years		Fuel cost	1		Discount rate	12.00%
		Construction period		4 years		Escalation in fuel cost	0%			

LEVELIZED TARIFF ESTIMATION

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Return on equity (ROE)	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98
Debt	7413.75	6919.50	6425.25	5931.00	5436.75	4942.50	4448.25	3954.00	3459.75	2965.50	2471.25	1977.00	1482.75
Capital repayment	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25	494.25
Depreciation	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60
Interest payment	682.07	636.59	591.12	545.65	500.18	454.71	409.24	363.77	318.30	272.83	227.36	181.88	136.41
Loan repayment	955.67	910.19	864.72	819.25	773.78	728.31	682.84	637.37					
O&M expenses	82.08	85.36	88.78	92.33	96.02	99.86	103.86	108.01	112.33	116.83	121.50	126.36	131.41
Total expenses	1383.72	1341.53	1299.48	1257.56	1215.78	1174.15	1132.67	1091.35	1050.20	1009.23	968.43	927.82	887.40
Sales	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Levelized tariff	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
Discounted ROE	2786.89												
Discounted interest payments	3103.07												
Discounted O&M	914.93												
Discounted depreciation	2203.90												
Discounted expenses	9008.79												
Discounted sales	4027.59												
Levelized tariff (Rs/kWh)	2.24												

Total cost of generation				1118.38
Revenue from royalty sale	15%	75.00	0.30	22.50
Revenue from export	85%	425.00	1.80	765.00
Total revenue				787.50
Net revenue				-330.88

Capitalized cost of project	9885.00
Debt	7413.75
Equity	2471.25

Capital cost	8208		Total interest during construction
Debt	6156		1677
Equity	2052		
Levelized generation cost		500	2.24
Royalty sale	15%	75.00	0.3
Cost of rest of units	85%	425.00	2.58

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98	345.98
	988.50	494.25															
	494.25	494.25															
	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60	273.60
	90.94	45.47															
	136.67	142.14	147.82	153.73	159.88	166.28	172.93	179.85	187.04	194.52	202.30	210.40	218.81	227.56	236.67	246.13	255.98
	847.19	807.18	767.40	773.31	779.46	785.85	792.51	799.42	806.62	814.10	821.88	829.97	838.39	847.14	856.24	865.71	875.55
	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
	2.24	2.24	2.24	2.24	2.24	2.24						2.24					

INDICATIVE TARIFF CALCULATIONS FOR CHAMKAR HYDROPOWER PLANT - LARGE HYDRO POWER PLANT WITHOUT GRANT

All costs are in million Rs

ASSUMPTIONS	
Capital cost	37 520
Cost	37 520
Grant component	0%

Capital cost as per Masterplan in $			Estimated cost with 5% escalation in 2007	
546	573.3	601.965	632.06325	25282.53
1.05				

Capacity	670 MW		Net generation (MU)	3207						
Equity	30%	Debt	70%			Plant load factor	55%			
Return on equity	14%	Interest rate	9%			O&M	1.5% of capital cost			
		Repayment period (inclusive of moratorium)		15.0 years		Escalation in O&M	2.0%			
		Moratorium		0.0 years		Fuel consumption	1			
		Life		30 years		Fuel cost	0		Discount rate	12.00%
		Construction period		6 years		Escalation in fuel cost	0%			

LEVELIZED TARIFF ESTIMATION

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Return on equity (ROE)	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10
Debt	102478.50	95646.60	88814.70	81982.80	75150.90	68319.00	61487.10	54655.20	47823.30	40991.40	34159.50	27327.60	20495.70
Capital repayment	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90	6831.90
Depreciation	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94
Interest payment	9223.07	8608.19	7993.32	7378.45	6763.58	6148.71	5533.84	4918.97	4304.10	3689.23	3074.36	2459.48	1844.61
O&M expenses	835.18	851.89	868.92	886.30	904.03	922.11	940.55	959.36	978.55	998.12	1018.08	1038.44	1059.21
Total expenses	13597.29	12999.12	12401.29	11803.80	11206.65	10609.86	10013.43	9417.37	8821.69	8226.39	7631.48	7036.97	6442.87
Sales	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00
Levelized tariff	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Discounted ROE	6082.51												
Discounted interest payments	51232.06												
Discounted fuel cost	0.00												
Discounted O&M	7846.87												
Discounted depreciation	21834.83												
Discounted. expenses	86996.27												
Discounted sales	55725.76												
Levelized tariff (Rs/kWh)	1.56												

Total cost of generation				10800.03
Revenue from royalty sale	10%	691.80	0.30	207.54
Revenue from export	90%	6226.20	1.80	11207.16
Total revenue				11414.70
Net revenue				614.66

				Allowance of funds used during construction								Capitalized cost of project	47414.02
Capital cost	37 520			Interest during construction (IDC)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total IDC	Debt	33 189.82
Debt	26 264			Expenditure	10%	20%	25%	20%	15%	10%		Equity	14 224.21
Equity	11 256				3752	7504	9380	7504	5628	3752			
				Loan	3377	6753.6	8442	6753.6	938	0	26264		
					3377	10130	18572	25326	26264	26264			
				Equity	375.20	750.40	938.00	750.40	4690.00	3752.00	11256.00		
		Units (GWh)	Tariff	Interest on loan	303.912	911.736	1671.516	2279.34	2363.76	2363.76	9894.024		
Levelized generation cost		3207	1.73										
Royalty sale	15%	481.05	0.3										
Cost of rest of units	85%	2725.95	1.98										

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10	755.10
	13663.80	6831.90															
	6831.90	6831.90															
	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94	2783.94
	1229.74	614.87															
	1080.40	1102.00	1124.05	1146.53	1169.46	1192.85	1216.70	1241.04	1265.86	1291.17	1317.00	1343.34	1370.20	1397.61	1425.56	1454.07	1483.15
	5849.18	5255.92	4663.09	4685.57	4708.50	4731.89	4755.75	4780.08	4804.90	4830.22	4856.04	4882.38	4909.25	4936.65	4964.61	4993.12	5022.20
	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00	6918.00
	1.56	1.56	1.56	1.56	1.56	1.56						1.56					

ANNEXURE 4.2

Techno-economic analysis details of a 5-MW biomass-based power plant

A techno-economic analysis of 5-MW biomass-based power plant has been carried out and the detailed financial analysis is given.

INDICATIVE TARIFF CALCULATIONS FOR BIOMASS BASED POWER PLANT

Assumptions

All costs are in million Rs

Cost	Rs 50 million/MW	
Grant	10%	

Equity	30%	Debt	70%				Plant load factor	70%				
Return on equity	14%	Interest rate	9%				O&M	2% of capital cost				
		Repayment period (inclusive of moratorium)			10.0 years		Escalation in O&M	2.0%				
		Moratorium			0.0 years		Fuel consumption	2				
		Life			20 years		Fuel cost	1		Discount rate		12.00%
		Construction Period			2 years		Escalation in fuel cost	2%		Capital recovery factor		

Capacity	5 MW		Allowance of funds used during construction					Capitalized cost of project			246.26
Capital cost	225		Interest During Construction	Year 1	Year 2	Total IDC		Debt			172.38
Debt	157.5			7.09	14.18	21.26		Equity			73.88
Equity	67.5										

Levelized generation cost		30.66	3.38
Royalty sale	0%	0.00	0.3
Cost of rest of units	100%	30.66	3.38

LEVELIZED TARIFF ESTIMATION

Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Return on equity (ROE)		10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34	10.34
Debt		172.38	155.15	137.91	120.67	103.43	86.19	68.95	51.72	34.48	17.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital repayment		17.24	17.24	17.24	17.24	17.24	17.24	17.24	17.24	17.24	17.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depreciation		11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25
Interest payment		15.51	13.96	12.41	10.86	9.31	7.76	6.21	4.65	3.10	1.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loan repayment		26.76	25.21	23.66	22.11	20.56	19.01	17.46	15.90												
Fuel cost		61.32	62.55	63.80	65.07	66.37	67.70	69.06	70.44	71.85	73.28	74.75	76.24	77.77	79.32	80.91	82.53	84.18	85.86	87.58	89.33
O&M expenses		4.50	4.59	4.68	4.78	4.87	4.97	5.07	5.17	5.27	5.38	5.49	5.60	5.71	5.82	5.94	6.06	6.18	6.30	6.43	6.56
Depreciation		10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13					
Cumulative depreciation		10.13	20.25	30.38	40.50	50.63	60.75	70.88	81.00	91.13	101.25										
Total expenses		102.93	102.69	102.48	102.30	102.15	102.02	101.92	101.85	101.81	101.81	101.83	103.43	105.07	106.74	108.44	110.18	111.95	113.76	115.60	117.48
Sales (MU)		30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66	30.66
Tariff		3.36	3.35	3.34	3.34	3.33	3.33	3.32	3.32	3.32	3.32	3.32	3.37	3.43	3.48	3.54	3.59	3.65	3.71	3.77	3.83
Levelized tariff		3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38
Discounted ROE		77.26																			
Discounted interest payments		56.24																			
Discounted fuel cost		518.74																			
Discounted O&M		38.07																			
Discounted principle repayment		84.03																			
Discounted. expenses		774.33																			
Discounted sales		229.01																			
Levelized tariff (Rs/kWh)		3.38																			

Total cost of generation (Million Rs)				103.66
Revenue from royalty sale	0%	0.00	0.30	0.00
Revenue from export (Million Rs)	100%	103.67	1.80	186.60
Total revenue				186.60
Net revenue (Million Rs)				82.93

Biomass densification technologies

Many non-woody biomass residues cannot be used efficiently, as they have low bulk densities. For example, the bulk density of majority of the agro-residues lies in the low range of 50–200 kg/m^3 (Table 1) as compared to 800 kg/m^3 for the coal of the same size. This necessitates huge storage space. This is combined with difficulty in handling and higher transportation cost. All these factors make them uneconomical as a marketable commodity for their widespread utilization over longer distances. Also, low bulk densities and loose nature of available biomass are associated with faster burning of fuels, resulting in higher flue gas losses (lower operating thermal efficiencies) and emissions in the form of fly ash or particulates in the atmosphere. This makes them poor quality biomass fuel. In order to improve the marketability of the available loose biomass and exploit this renewable and sustainable source of energy, pre-processing becomes necessary.

Densification of biomass can be done by using briquetting or pelletizing technology, which compresses loose biomass into densified form called briquettes or pellets. This takes care of the low bulk density of biomass and helps in reducing transportation and storage cost and improves the quality of biomass so that it could be used as a better combustible fuel.

Densified briquette/pellet produced from biomass is a fairly good substitute for coal, lignite, and firewood, and offers several advantages.
Densified briquette is a renewable and sustainable source of energy. It has the following advantages.

Table 1

BULK DENSITY OF SELECTED LOOSE BIOMASS

Biomass material	*Bulk density* (kg/m^3)
Bagasse pith	74
Bamboo dust	205
Coffee dust	215
Coir pith	47
Cotton shell (pulverized)	79
Groundnut shell	165
Jute dust	74
Mustard stalk (pulverized)	208
Rice husk	235

Source *Biomass thermo-chemical characterization, IIT Delhi, 2002*

- It is cheaper than coal.
- It has consistent quality and size.
- It has better thermal efficiencies than loose biomass.
- It has high specific density (800–1200 kg/m^3) compared to loose biomass (50–200 kg/m^3).
- It is easy to handle.
- It requires less storage space.
- It involves low handling and transportation cost.

APPROPRIATE BIOMASS RESIDUE FOR BRIQUETTING

Almost all types of biomass can be densified. However, there are many factors that need to be considered before biomass qualifies as an appropriate feedstock for briquetting. The main characteristics of appropriate biomass residue for briquetting are described in the subsequent sections.

Moisture content

Higher moisture content poses problem in grinding, and higher energy is required for drying operation. Therefore, biomass with lower moisture content, preferably below 10%–15%, is a more attractive feedstock for briquetting.

Ash content and composition

Majority of biomass residues (except rice husk with 20% ash) have low ash content, but they contain higher percentages of alkaline (especially potash) minerals. They also contribute towards lowering sintering temperature, leading to ash deposition, and higher ash content increases the slagging tendency, which becomes more intense in biomass with more than 4% ash.

Flow characteristic

Finer granular material with uniform size flows easily in fuel hoppers and storage bins/silos.

Thus, some of the appropriate biomass material for briquetting includes saw dust, coffee husk, groundnut shell, pulverized mustard stalk, cotton sticks, and so on.

Binding mechanism of densification

Briquetting is one of the several agglomeration techniques used for the densification of biomass residues. On the basis of compaction, briquetting technologies can be classified as follows.

- High pressure compaction
- Medium pressure compaction
- Low pressure compaction

Normally, binders are not required in high- and medium-pressure compaction, but sometimes, preheating of biomass is carried out to enhance the compaction process. In all compaction processes, individual particles are pressed together in a confined volume. In case of biomass, the binding mechanism under pressure can be divided into cohesion and adhesion forces, van der Waal's attractive forces between solid particles, and mechanical interlocking bonds under pressure, making the bonding during compaction strong. Binders, that is, high viscous bonding media, such as tar and other molecular organic liquid or cow dung, are used in low-pressure compaction to enhance adhesion among biomass particles by creating solid–liquid bridges. Lignin in biomass helps in creating such bonds due to its softening at higher temperatures and its adsorption on solid particle layers, which can contact, or penetrate into, each other. The strength of the resulting agglomeration depends on the type of interaction and the material characteristics. Selected important characteristics and their significance are discussed in the following sections.

Effect of particle size

Granular biomass material of size 6-8 mm, with about 10%–20% powdery (< 4 mesh) material, normally gives best results. Though high-pressure (1000–1500 bar) compaction machines such as piston press or screw extruder can produce briquettes from larger particle size biomass, they can lead to the choking of the entrance to ram or die. Condensation of vapour released from larger particles on finer particles can create lumps, affecting free flow. However, only finer material is not always good due to low density and flowability, and the presence of particles of varying size improves the packing dynamics, contributing to higher strength.

Effect of moisture

Moisture content is a very critical factor. Right amount of moisture (7%–10%) develops self-bonding properties in lignocellulosic substances at elevated temperatures and pressures prevailing in piston press and screw extruder briquetting machines. Higher moisture content can result in poor and weak briquettes with cracks due to the escape of steam and also results in erratic operation due to the choking of feed flow because of steam formation. It is also important to maintain the moisture content in input feed material so as to ensure that briquettes produced have moisture content higher than the equilibrium value, otherwise it would regain moisture from the atmosphere, resulting in swelling during briquette storage and transportation stages, and would disintegrate when exposed to humid conditions.

Effect of biomass feed temperature

At higher temperatures, moisture of biomass gets converted into steam under higher prevailing pressures, which hydrolyses the hemicellulose and lignin portion of biomass into lower molecular carbohydrates, lignin products, sugar polymers, and other derivatives. These act like in situ binding material. Better compaction, along with higher biomass feed temperature and pressure, results in briquettes with higher density and strength (Figure 1). This also softens the fibres and their resistance to briquetting, which results in lower power requirements and reduction in wear of the contact parts. However, the temperature should be kept lower than 300 °C, as beyond this temperature, decomposition of biomass starts.

Briquetting can be done with or without a binder material. No binders are generally required in high-pressure briquetting. Prior to its introduction into the briquetting machine, biomass has to be disintegrated into small size and then dried so that the moisture content is in the range of about 12%–15%. Briquetting plants set up so far in India are using saw dust, bamboo dust, groundnut shell, mustard stalk, cotton stalk, coffee husk, bagasse, sugar mill waste mud (commonly called as press mud), jute waste, coir pith, and so on as raw materials. All these biomass briquettes, except press mud, have a calorific value of the order of 3800–4000 kcal/kg, which is considered good.

Commercially, briquetting technologies used for biomass without binder include the briquetting machine based on

- screw press and
- ram-piston press technology.

In both the piston press and screw press technologies, the application of high pressure increases the temperature of biomass, and lignin present in the biomass liquefies and acts as a binder.

Ram-piston press technology

Biomass briquetting using ram-piston technology involves drying, grinding, sieving, and compacting. Moisture is removed from the loose biomass with the help of a dryer, and then it is ground in a hammer mill grinder. The ground material is then separated from the air by using cyclone separator. It is then sieved and stored in the bin above hopper for ensuring continuous flow of biomass material into the press. In piston press technology, biomass is punched into a die by a reciprocating ram to

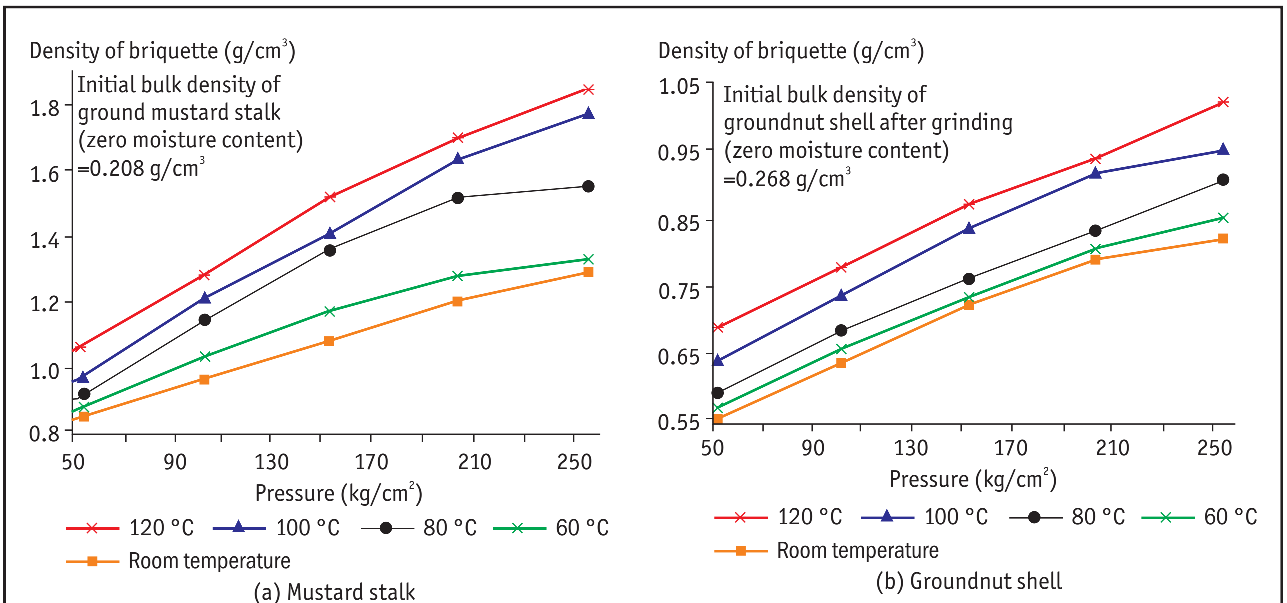


FIGURE 1 VARIATION IN BRIQUETTE DENSITY WITH PRESSURE AT DIFFERENT BIOMASS FEED TEMPERATURE: (A) MUSTARD STALK, (B) GROUNDNUT SHELL

produce briquettes (Figure 2). The ram moves about 250–300 times per minute in the process. In briquetting machine, the wear of contact parts, here, ram and piston, is a major issue and requires frequent maintenance and/or replacement. The average frequencies of replacement for some of the machine components are 300 hours (for ram, scrapper, and wear rings) and 500 hours (taper and split die, and hammers).

In India, commercially available piston press briquetting machines are commonly used in different parts of the country. They are available in different capacities, ranging from 250 kg/hour to 2250 kg/hour. Table 2 gives the share of various input costs in the production of biomass briquettes. It can be seen that at higher production capacities, the raw material contributes more as input cost, and the share of other costs diminishes due to scale of production. Table 3 gives the power requirement for machines with different capacities for briquetting various types of biomass materials. Power requirement is higher for higher capacity machines. Production capacity increases from finer to coarser to stalky biomass due to increasing pre-processing requirement of biomass. Wet biomass requires higher power for additional drying operation in order to bring the moisture content in feed material to uniform desired value for smooth operation as well as for generating better quality briquettes.

Screw press technology

In this process, biomass is dried to get an optimum moisture content value by passing hot air produced

Table 2

CONTRIBUTION OF INPUT COST IN UNIT COST OF BRIQUETTE FOR COARSE GRANULAR WET MATERIALS

	Briquetting machine production capacity (kg/hour)					
Input cost component	250	500	750	1000	1500	2250
Capital	19.2	14.6	12.1	9.7	8.8	7.7
Raw material	41.3	54.5	59.6	57.1	64.3	67.2
Operation	10.1	6.6	4.8	4.4	3.3	3.2
Electricity	25.5	20.3	19.9	24.7	19.9	18.0
Repair and maintenance	3.9	4.0	3.6	4.1	3.7	3.9

Source *Tripathi et al. (1998)*

Table 3

POWER REQUIREMENT FOR BRIQUETTING UNITS

Briquetting production capacity (kg/hour)	*Power requirement* (kW)					
	Fine granular		*Coarse granulated*		*Stalky material*	
	Dry	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*
250	17.5	26.5	36.0	45.0	43.5	52.5
500	25.0	34.0	43.5	52.5	51.0	60.0
750	32.5	41.5	58.5	67.5	73.5	82.5
1000	50.5	65.5	101.0	116.0	116.0	131.0
1500	65.5	80.5	108.5	123.5	123.5	138.5
2250	98.0	113.0	141.0	156.0	156.0	171.0

Source *Tripathi et al. (1998)*

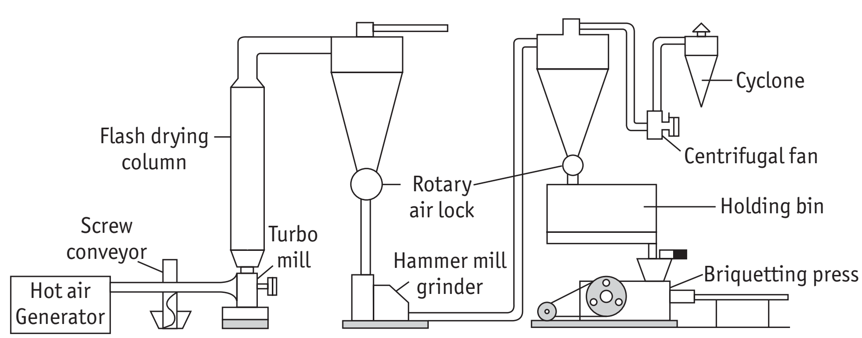


FIGURE 2 RAM PISTON TYPE BRIQUETTING PRESS

by burning part of briquettes in furnace. Using heated oil obtained in heat exchanger, the biomass is further preheated to about 100–120 °C so as to minimize wear of the die and improve the true density of the briquettes formed. This preheated material is then fed to the screw extruder, where revolving screw (at about 600–700 RPM) continuously compacts the material through a tapered die, which is heated externally to reduce friction between the biomass and die surface (Figure 3). The outer surface of the briquettes obtained through this technology is partially carbonized and has a hole in the centre.

The briquettes extruded using screw press are more homogeneous (as output is continuous and not in strokes), with better crushing strength and combustion properties (due to large combustion area per unit weight). Since outer surface of the briquettes is carbonized, it facilitates easy and clean ignition, and this impervious layer provides protection from moisture ingress, thereby increasing the storage life of the briquettes. However, power consumption and wear of screw are higher than those experienced in ram-piston-type reciprocating machines.

Table 4 shows a comparison between a piston press and a screw extruder.

Table 4

COMPARISON OF A PISTON PRESS AND A SCREW EXTRUDER

Parameter	*Piston press*	*Screw extruder*
Optimum moisture content of raw material	10%–15%	8%–9%
Wear of contact parts	Lower	Higher
Output from machine	In strokes	Continuous
Power consumption	50 kWh/tonne	60 kWh/tonne
Density of briquette	1–1.2 g/cm^3	1–1.4 g/cm^3
Maintenance	Higher	Lower
Combustion performance of briquettes	Good	Better
Homogeneity of briquettes	Non-homogenous	Homogenous

Source *FAO Field Document No 46, 1996*

Pelletizing machine

Biomass with very low bulk density is normally densified using flat die pelletizing technique. Pelletizing generally requires conditioning of biomass material either by mixing binder or raising the temperature of the biomass by direct addition of steam. The material is dropped in the pressing chamber of the pellet mill, where it builds a carpet on the die surface. The rollers roll over this layer and compress it through tapered die holes. The pressing force keeps on increasing during rolling in the direction of die holes. With every roll pass,

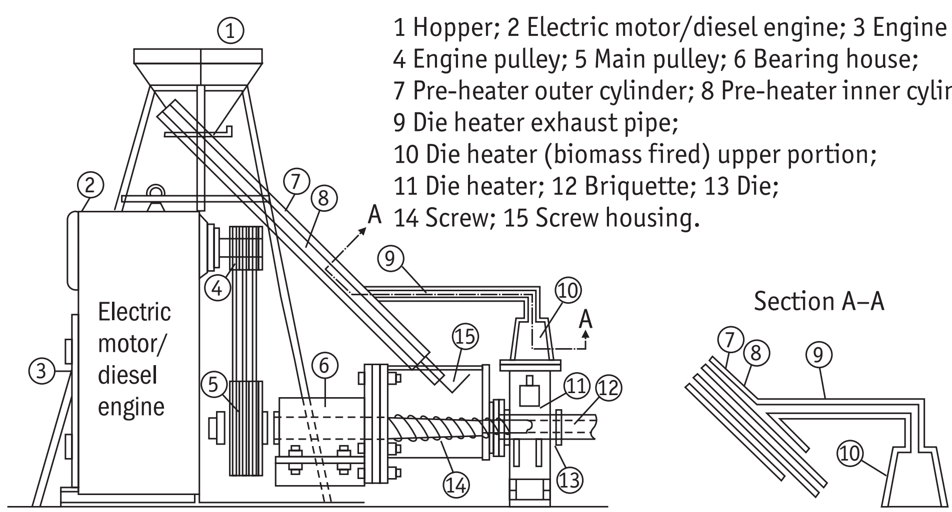


FIGURE 3 SCHEMATIC OF SCREW BRIQUETTING MACHINE WITH BIOMASS STOVE DIE HEATER

a small disc is formed in the die hole, which gets attached to the pressed piece already in the die hole. The plugs are uniformly pushed forward and hot pellets are ejected at a temperature of about 50–90 °C, which are cooled on conveyor belts before their storage (Figure 4). Compared to briquetting machine, pellet mills are simpler, and since they work with rotary motion, the power consumption levels are lower. The processing requirements are also relatively less rigid for pelletizing.

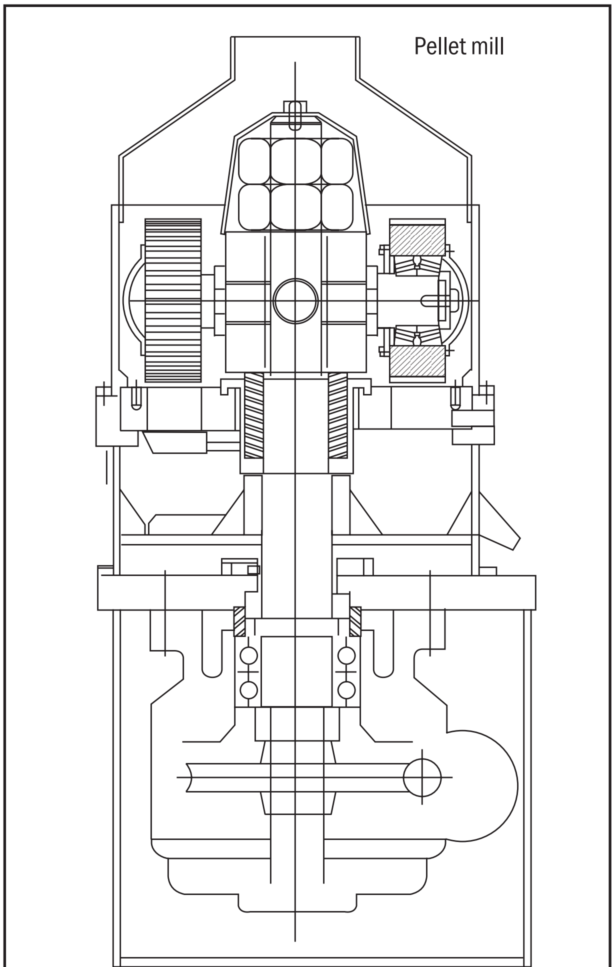


FIGURE 4 SCHEMATIC OF PELLETIZING MACHINE

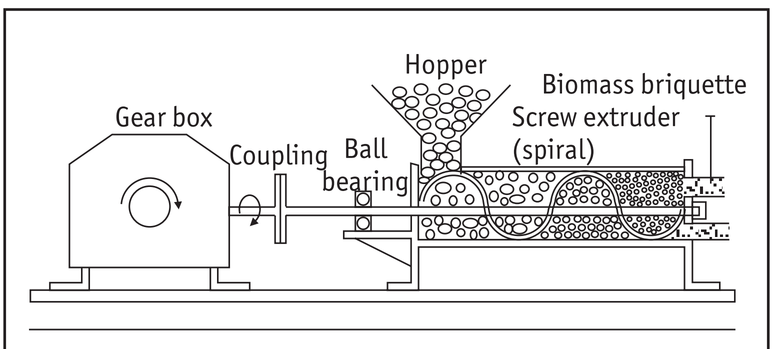


FIGURE 5 LOW-DENSITY SCREW EXTRUDING BRIQUETTING MACHINE

LOW-DENSITY BRIQUETTES USING BINDER

In remote areas, for decentralized operation, a simple low-pressure briquettng technique using binder material like tar or cow dung is generally adopted. The Energy and Resources Institute (TERI), New Delhi, has developed a simple screw extruder (Figure 5) coupled to a small motor, which produces medium-density briquettes (400–600 kg/m^3). The system was operated in village Dhanwas in Haryana for converting locally available agro-residues (mustard stalk) into briquettes (after manual preprocessing like chopping and pulverizing) using cow dung as a binder material. These briquettes were sold in local area as fuel substitute to coal in roadside restaurants (called *dhabas*) and as gasifier fuel to provide electricity to village community and for operating the briquetting machine (Raman et al. 1993).

Recently, TERI has successfully carried out feasibility study for making briquettes from oil refinery waste sludge by mixing it with locally available loose biomass material. This would not only take care of the waste disposal problem of hazardous waste from oil refineries but also produce easy-to-use briquettes, which can substitute coal in the surrounding region (TERI 2001).

In IIT Delhi, a simple briquetting plant operated by hand mould was developed for making beehive charcoal briquette for using it as a clean burning fuel, substituting charcoal. Locally available leafy biomass or pine needles are carbonized using simple pyrolyser, which is prepared using 200 litres of used oil barrel. This is then mixed with suitable binding material like clay and cow dung, and the mixture is prepared using adequate quantity of water. This material is then pressed into hand mould to form large cylindrical briquettes of about 90 mm height and 125 mm diameter, with several (about 19) parallel vertical holes in it (Figure 6). One person can make

FIGURE 6 LOW-DENSITY BEEHIVE BRIQUETTING MOULD

about 30 briquettes (weighing about 0.5 kg after drying) per hour if charcoal–clay mixture is kept ready. These briquettes after drying can be used in *angethi chulha*, which burns slowly for long duration without releasing any smoke. These are becoming popular as livelihood option in rural areas. With about 20% clay content in hardwood charcoal powder, the calorific value is about 18 MJ per kg, or 9 MJ per briquette, and one briquette can burn for about an hour. Normally, single briquette is used in Indian chulha, but multiple vertically stacked briquettes for long duration operation are commonly used in high altitude areas of Tibet.

ANNEXURE 4.4

Bioenergy technologies for thermal applications – potential biomass technology options

INTRODUCTION

Biomass can be utilized for different purposes such as cooking, process heating, electricity generation, steam generation, mechanical or shaft power applications, as well as producing variety of chemicals as by-products. Various biomass conversion processes can be broadly classified into the following categories.

- Thermo-chemical
  - Combustion
    - Fixed bed or grate-fired
    - Suspension burners
    - Fluidized bed systems
  - Pyrolysis
  - Gasification
    - Updraft (countercurrent)
    - Downdraft (co-current)
    - Cross draft
    - Fluidized bed
  - Liquefaction
  - Ammonia production
- Chemical: acid hydrolysis
- Biochemical
  - Anaerobic digestion to produce methane
  - Ethanol fermentation
- Physical: densification into briquettes

Only a few of these technologies are covered under the planned Global Environment Facility (GEF) project, given the scale and type of target industries concerned. Other technologies are yet to be commercialized, for their scale of operation is not suitable for the target intervention clusters.

COMBUSTION

Combustion is the direct process of converting biomass into usable energy, which can be used for various applications. The most difficult aspect of combustion is to start the process, as high (at least 550 °C) temperature is required for the ignition of biomass. However, once ignition takes place, it is difficult to stop the combustion process if sufficient air supply is available till complete combustion converts the biomass into residual ash. Figure 1 shows the fire triangle, emphasizing essential components like fuel, air, and heat, which permit fire/combustion to continue to grow. Fire can be extinguished either by removing fuel or by smothering (removing air) or by cooling (spraying with water).

Biomass combustion is being used for various useful applications such as electricity generation, process heating, and cogeneration (simultaneous, sequential production of electricity and process heat). With rising prices of fossil fuels, biomass is gaining importance, and there is increasing refinement of the biomass combustion process to exploit its energy content. In order to harness the energy content of the biomass to the maximum, it is important to understand the properties of biomass fuels and fundamentals of numerous complex reactions associated with their oxidation to carbon dioxide and water. This can help in

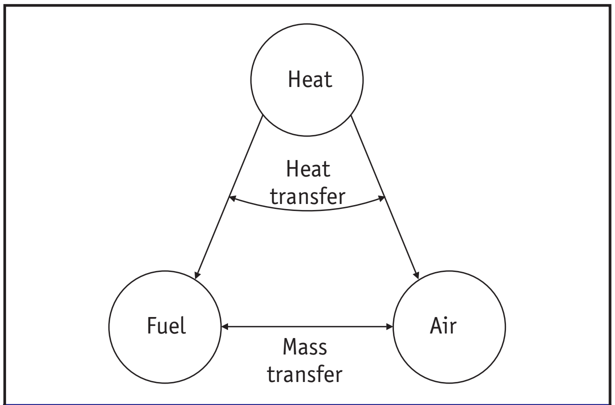


FIGURE 1 FIRE TRIANGLE

manipulating biomass combustion for maximizing thermodynamic efficiency and minimizing adverse environmental impacts. Combustion is a process in which carbon and hydrogen in the fuel react with oxygen to form carbon dioxide and water through a series of free radical reactions, resulting in the liberation of useful heat. General combustion mechanisms have been proposed, defining various stages of chain reactions like initiation, propagation, and termination. Generally, these mechanisms include the following processes.

- Heating and drying
- Pyrolysis and reduction
- Gas phase pre-combustions and combustion reactions
- Char oxidation reactions
- Post-combustion reactions

A general biomass combustion model is shown in Figure 2. This general model gives some insight into combustion reaction that can be generalized as

$$C_xH_y + (x + 0.25y)O_2 \rightarrow xCO_2 + (0.5y)H_2O$$

Direct combustion systems are generally used to produce heat, which can be either used directly or transferred to working fluid, such as steam, for further use in process heating or in steam engine or turbine for power production. The combustion efficiency can be defined as follows.

$$\eta_{comb} = \frac{\text{thermal energy available in the flue gas}}{\text{chemical energy in the supplied fuel}}$$

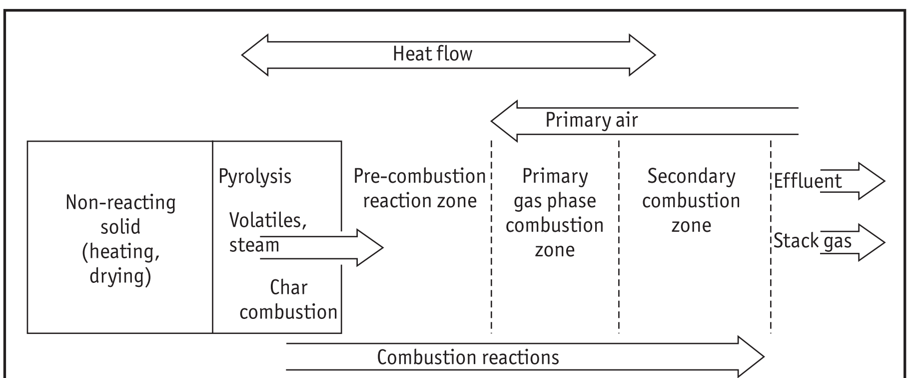


FIGURE 2 REPRESENTATIVE MODEL OF BIOMASS COMBUSTION MECHANISM

The combustion efficiency is mainly determined by completion of combustion process and the heat losses from the furnace or combustion device. Flame temperature also plays an important role in the overall efficiency of combustion device. Excess air has more influence on adiabatic flame temperature than moisture content. Theoretically, highest temperature can be achieved with stoichiometric air supply ($\lambda = 1$), but in reality, excess air is always supplied to ensure complete combustion. The optimal values of lambda depend on furnace design, fuel type, and fuel feeding/firing system used. The value of λ in well-designed furnaces/combustion devices is in the range 1.6–2.5, while in poorly designed furnaces, the value of λ reaches as high as 4–5.

BIOMASS STOVES

Archaeological evidence indicates that mankind has known the use of fire for 400 000 years now. In the early years, fire was used to keep the caves warm. The use of fire for cooking started 100 000 years ago, and in the earlier days, open fire was used (mainly for cooking/roasting meat), with fuel arranged in pyramid shape. The benefits of fire in preserving food, protecting against large animals and rodents, and providing warmth outweighed the drawbacks of improper control on fire and smoky conditions. A major development in open fire was the evolution of vessels of different shapes, followed by the development of shielded three-stone stove for holding the pot firmly over the open fire. Subsequently, shielded fire was changed to a U-shaped mud or mud/stone stove, with front opening for feeding fuel and entry of combustion air. Despite several developmental work on wood stoves, large population in the developing world still employs traditional three-stone or U-shaped shielded fire stove, and in many cases, there is a retrogressive movement from the use of wood to the use of cow dung cakes and agro-residues as fuel (FAO 1993).

Classification of biomass stoves

Stoves that burn biomass such as firewood and agro-residues are called biomass stoves. These are used at both domestic as well as institutional levels for cooking, heating, and space heating purposes.

Stoves burning biomass can be classified in several different ways, based on their attributes, functions, material, fuel types, and so on (FAO 1993). Stoves can be classified as follows.

- Fuel type: woody biomass, powdery biomass, briquettes, cow dung, and so on.
- Function: monofunction or multifunction stoves
- Construction material: metal, clay, ceramic, brick, and so on.
- Portability: portable (metallic, ceramic) or fixed (mud, clay, brick)
- Number of pots: single, two pots, three pots, and so on.

Stove designed for a particular fuel and for a particular application can be used with different fuels and can have various applications but might not perform with same efficiency.

Design criteria

Stove is a consumer-specific device. Efforts on developing improved stoves are mainly aimed at improving energy efficiency (saving fuel) or reducing emissions (improving working conditions, reducing adverse impact on health). While designing a stove, both engineering and non-engineering or social parameters are required to be considered.

Social factors

Interlinkage between various criteria for stove design is shown in Figure 3 (Verhaart 1983). User need and availability of local biomass are the two important social factors that need to be taken into account while designing a stove. User needs include various cooking operations such as boiling, frying, baking, grilling, steaming, pressure cooking, and so on, which are needed to be performed using a stove. Apart from this, it is also important to know cooking time and process heat requirement, which would determine power range for the stove. Availability of the local construction material, desired portability, seasonal availability of local biomass, and so on also need to be considered while designing a stove for the target group under consideration.

Technical factors

A high-performance stove should be efficient and low in emission. A fuel-efficient stove would reduce the drudgery of users in fuel collection, while improvement in emissions would save users from harmful impacts due to smoke exposure. However, as mentioned earlier, the general strategy

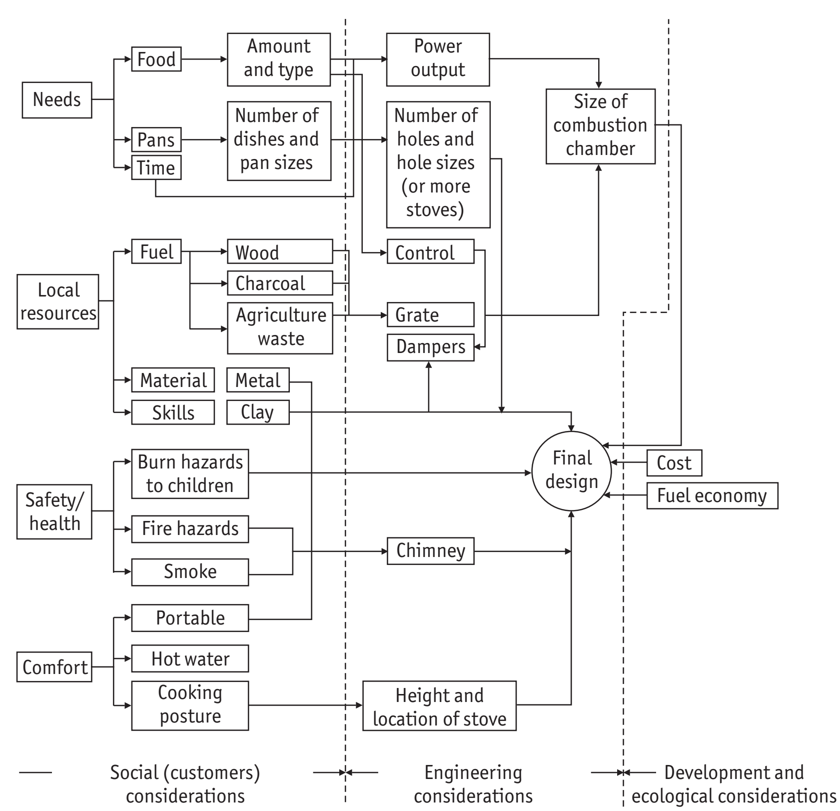


FIGURE 3 DESIGN CONSIDERATIONS FOR A STOVE

adopted in designing improved stove is improving energy efficiency (by enhancing heat transfer) and providing chimney for the removal of smoke. Though this strategy improves the fuel efficiency and also indoor air quality, the overall emission reduction is questionable. Therefore, besides improving the heat transfer efficiency, it is necessary to ensure improvement in combustion efficiency, whereby emission of unburned harmful pollutants can be minimized. Complete combustion can be ensured by adopting the following steps.

- Maintaining higher temperatures in the combustion chamber.
- Providing sufficient air and ensuring proper mixing for complete combustion.
- Ensuring sufficient residence time for the completion of combustion reactions.

Process factors

Composition of biomass in terms of C–H–O content, ash, and moisture-free nature is quite similar (as mentioned earlier), but other parameters such as moisture content and volatile fraction have profound effect on its combustion characteristics. Besides, there are a number of other process factors that need to be considered while designing a stove for maximizing efficiency and minimizing emissions. The effects of these process factors are not easily quantifiable. Table 1 summarizes their qualitative effect.

The overall thermal efficiency (η_o) of a stove is defined as the ratio of the amount of useful heat absorbed for cooking food to the amount of energy content in the fuel used. It is a combination of partial efficiencies such as combustion efficiency η_c (fraction of energy content of a fuel converted into heat through its combustion), heat transfer efficiency η_h (fraction of heat generated, which is transferred to the pot), and pot efficiency η_p (fraction of useful energy actually used for cooking food out of total heat transferred to pot).

Emissions from biomass stoves

$$\eta_o = \frac{\text{Useful heat abosrbed by food}}{\text{Heat conetent of biomass fuel used}} = \eta_c \times \eta_h \times \eta_p$$

Among the numerous pollutants emitted from biomass stoves, the most significant ones are carbon monoxide (CO), total suspended particulates (TSP), polycyclic aromatic hydrocarbons (PAH), and formaldehyde. Several design and operating parameters result in incomplete combustion, thus contributing to these emissions. These parameters include insufficient supply of combustion air, lower temperatures in combustion zone, improper mixing of air and fuel, and so on. Many a times, some design modifications to improve thermal performance or efficiency, such as reducing gap between the pan and the stove mouth as well as between the pan and the grate, may prove detrimental, resulting in increased emissions. Therefore, there is a need to take into consideration the effect of any design modification on stove as a whole. Generally, with increasing power levels, emissions from the stove are observed to increase. Similarly, higher

Table 1

QUALITATIVE EFFECTS OF VARIOUS FACTORS ON STOVE DESIGN

Factor	Action needs to be taken to	
	Maximize efficiency	Minimize emissions
Stove factors		
Combustion chamber volume	Maximize	Minimize
Temperature of combustion chamber	Minimize	Maximize
Excess air levels	Optimize	Optimize
Preheating of primary air	Maximize	Maximize
Thermal mass		
For short cooking time	Minimize	Minimize
For long cooking time	Maximize	Maximize
Operational factors		
Fuel burning rate	Minimize	Maximize
Fuel charge size	Minimize	Minimize
Ratio of charge size to burn rate	Minimize	Minimize
Volume to surface ratio	Maximize	Maximize
Fuel factors		
Moisture content	Optimize @ 10%	Optimize @2 5%
Volatile matter content	Minimize	Minimize
Ash content	Minimize	Minimize

emissions are observed with smaller stoves. Many a times, this is due to the lower residence time of the fuel in the combustion chamber of the stove, resulting in incomplete combustion and, hence, higher emissions.

BIOMASS GASIFICATION

Thermochemical biomass gasification is a process in which solid biomass fuel is converted into gaseous combustible form (called producer gas) by means of partial oxidation. The reaction is carried out at elevated temperatures in a reactor called gasifier. Application of gasifiers assumed significant importance during World War II due to the scarcity of petroleum products. By the end of the World War in 1942, more than million vehicles using gasifiers were in operation throughout the world. However, after the end of the War, they were largely decommissioned, as petroleum products once again became widely available at cheap rates. The energy crisis in the 1970s generated renewed interest in gasification. The technology was perceived as a relatively cheaper option in developing countries having sufficient sustainable biomass for small-scale industrial as well as power generation applications. Gasification of biomass looks simple in principle, and many types of gasifiers have been developed. Production of gaseous fuel from solid fuel offers easy handling, better control on combustion, and possibility of using it in internal combustion engine for shaft power or electricity production, which makes gasification very appealing, especially for small decentralized options. However, biomass fuel used in gasifier varies widely in its physical and chemical properties, and makes the gasifier reactions complicated to design.

Principle of gasification

Biomass gasification is a process of converting solid biomass fuel into gaseous combustible gas (called producer gas) through a sequence of complex thermochemical reactions. In the first stage, partial combustion of biomass to produce gas and char occurs along with the generation of heat. This heat is utilized in drying biomass to evaporate its moisture as well as for pyrolysis reactions to produce volatile matter and provide heat energy necessary for further endothermic reduction reactions to produce producer gas, which mainly consists of a mixture of combustible gases such as CO, hydrogen, traces of methane, and other hydrocarbons. Normally, the air is used as a gasifying agent; however, the use of oxygen can produce rich, higher calorific value gas, but due to cost implications, it is not usually preferred.

Gasification reactions

A complete understanding of the various complex reactions occurring in a gasifier has not been possible so far. However, the following reactions explain the process of gasification fairly well.

$C+O_2 \rightarrow CO_2+393\,800$ kJ/kg mole (combustion)

$C+H_2O \rightarrow CO+H_2 - 131\,400$ kJ/kg mole (water gas)

$C+CO_2 \rightarrow 2CO - 172\,600$ kJ/kg mole (Boudouard reaction)

$CO+H_2O \rightarrow CO_2+H_2+41\,200$ kJ/kg mole (water shift reaction)

$C+2H_2 \rightarrow CH_4+75\,000$ kJ/kg mole (methane reaction)

With the help of the above reaction scheme, and with the knowledge of the equilibrium constants, it is possible to predict the equilibrium composition of the gaseous products. The equilibrium composition of a given solid fuel depends on the air supply per unit weight of the biomass. A dimensionless parameter, known as the equivalence ratio (ER), is applied to characterize the air supply conditions, and is usually defined as follows.

Weight of the actual oxygen supplied/Weight of the theoretical oxygen required

The denominator in the above equation is the oxygen required for the complete combustion of the fuel, and it varies from fuel to fuel. It is generally observed that for effective gasification, the ER should be in the range of 0.2–0.4. Below the ER value of 0.2, pyrolysis dominates the process and above the ER value of 0.4, combustion predominates.

In a real gasifier, however, the composition of the gas does not reach the equilibrium value and is generally dependent on the gasifier design. Factors affecting the gas composition are temperature distribution in the fuel bed, average gas residence time, and the residence time distribution. These are, in turn, dependent on the mode of air entry, dimensions of the gasifier, and the quantum of heat loss to the surroundings. The modelling of the various processes occurring in the gasifier requires not only the knowledge of kinetics but also an understanding of the heat and mass transfer processes occurring in various zones of the gasifier. A brief description of some important factors that affect the quality of producer gas generation in gasifier is given subsequently.

Fuel size

Fuel size affects fuel movement within biomass as well as the rate of reactions and energy intensity per unit volume. Large wood pieces provide smaller surface area per unit volume of reactor, which, in turn, affects the quality of gas, as volatilization or pyrolysis becomes less intense. Very small-sized biomass leads to intense volatilization process, leading to the formation of significant pyrolytic liquid, which is not desirable in gasification, though it might be desired otherwise for obtaining liquid fuel. Larger fuel size also leads to fuel bridging, which hampers the smooth fuel movement within gasifier reactor. Smaller fuel size results in higher pressure drop across the fuel bed in the reactor. Therefore, normally, fuel of the size one-fourth or one-fifth of the smallest dimension of the reactor cross-section is preferred to avoid fuel bridging. If pulverized fuel is used in the fixed bed gasifier, the fuel movement becomes non-uniform and takes place in an uneven manner, and many a times, tunnelled gas pathways are generated in the fuel bed, causing tar carryover without cracking, resulting in high tar content in raw gas.

Fuel moisture content

With higher moisture content, the net calorific value of fuel decreases and so does the calorific value of the producer gas generated, thereby leading to a reduction in gasification efficiency. Also, the tar fraction in the producer gas increases with an increase in the moisture in the biomass. Because of higher moisture content in the gas, more air is required to combust biomass required to generate heat for drying/heating of the biomass as well as for achieving endothermic gasification reactions. As a result, with higher moisture content in the biomass, the carbon dioxide fraction in the gas increases and CO fraction reduces. It also becomes difficult to maintain high fuel bed temperature, as the biomass has very high moisture content. The percentage of hydrogen in the gas increases slightly initially till the biomass has about 20% moisture content, but then again it starts decreasing.

Residence time

Often, the effect of residence time is overlooked while designing a gasifier. In order to generate good quality gas at various rates of fuel burning (or rates of producing gas), there is a need to ensure sufficient time for the completion of gasifier reactions within the reactor zone. This helps in achieving tar cracking under reducing environment in the high temperature zone in the presence of char, resulting in reduced components for tar cracking. Cleaning in this system may work out to be a costly affair, especially for smaller systems.

Ash content and its nature

Materials with high ash content are difficult to handle, as they can lead to the problem of clinker formation in the fuel bed, especially if ash has low fusion point. Also, the presence of several inorganic matters such as mud, sand, and grit is not quite unusual in agro-based biomass. This may not pose any problem in combustion devices/furnaces but can block the entire reactor operation due to ash fusion taking place inside the reactor at higher temperatures, which hampers the fuel movement and gasification process.

Gasifier reactor types

The various types of reactors used for biomass gasification can be classified in different ways, of which density factor (ratio of dense biomass phase to total reactor volume) is a simple and effective way of classification. Thus, gasifiers can be classified as follows.

- Dense phase reactors
- Lean phase reactors

In dense phase reactors, such as fixed bed reactors (updraft, downdraft, cross draft, and so on), biomass or feedstock occupies maximum reactor volume, with typical density factors of about 0.3–0.8. On the contrary, in lean phase reactors, such as fluidized bed reactors, biomass occupies very little reactor volume, that is, of the order of 0.05–0.2. Dense phase reactors can be classified as follows.

Updraft, or countercurrent gasifier

In a countercurrent moving bed reactor, also called as updraft gasifier, the air flows in countercurrent to downward fuel flow and enters into the gasifier from below the grate and flows in the upward direction within the gasifier. The updraft gasifier has defined distinct zones for partial combustion, reduction, and distillation (Figure 4A). The gas produced in the reduction zone leaves the gasifier reactor, along with the pyrolysis products and the steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has relatively higher calorific value. Therefore, it is more suitable for thermal applications such as direct heating in industrial furnaces, as it gives higher operating thermal efficiencies. If the gas is to be used for electricity generation by internal combustion (IC) engines, it has to be cleaned thoroughly.

In most updraft gasifiers, steam is injected or evaporated into the hot partial combustion zone, which has a beneficial effect on the gas quality and also prevents the lower portion of the gasifier from overheating. Generally, the sensible heat of the producer gas or the radiative heat from the gasifier shell is used for generating the necessary amount of steam.

The characteristics of an updraft gasifier are as follows.

- It has clearly defined zones for various reactions.
- Its efficiency is high because hot gases pass through entire fuel bed and leave at lower temperatures. The sensible heat of the hot gas is used for reduction, pyrolysis, and drying processes.
- Products from pyrolysis and drying, containing water vapour, tar, and volatiles, leave the gasifier without passing through high temperature zones and, therefore, do not get cracked. Hence, elaborate gas cleaning is required before using it, making it less suitable for engine operation.
- It is unsuitable for high volatile fuels.

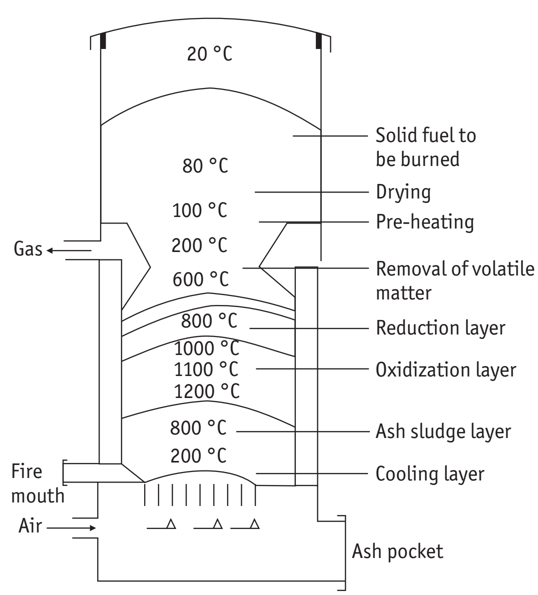


FIGURE 4A UPDRAFT GASIFIER

Downdraft, or co-current gasifier

In a co-current moving bed reactor, or a downdraft gasifier, the air enters at the middle level of the gasifier, above the grate, and the resulting mixture of air and gas flows down cocurrently through the gasifier reactor (Figure 4B). All the decomposition products from the pyrolysis and drying zones are forced to pass through an oxidation zone. This leads to the thermal cracking of the volatiles, resulting in reduced tar content in the producer gas. For this reason, this gas is preferred for engine applications. There is always a constriction at the level of the oxidation zone to force the pyrolysis products through a concentrated high temperature zone to achieve complete decomposition. This concentrated oxidation zone can cause sintering or slagging of ash, resulting in clinker formation and consequent blocking of the constricted area and/or

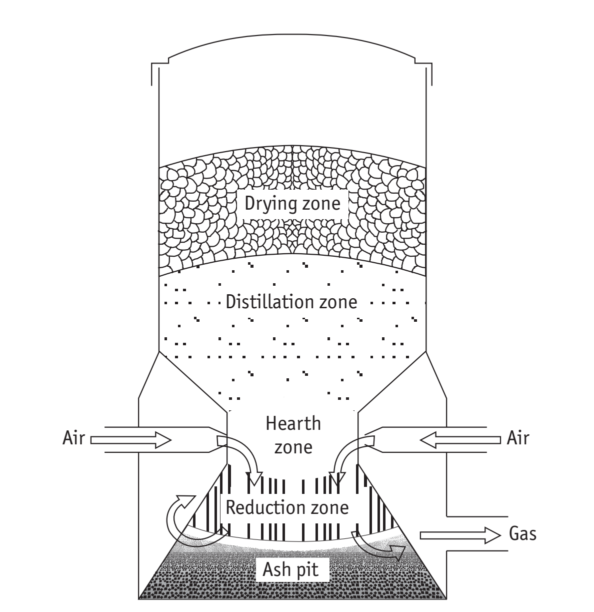


FIGURE 4B DOWNDRAFT GASIFIER

channel formation. Continuous rotating ash grates or other mechanical shaking may be required to avoid this problem. Compared to an updraft gasifier, the disadvantages of a downdraft gasifier are higher gas outlet temperature and lower thermal efficiency. Additional steam or water injection is not common in downdraft gasifiers. They can be operated at very high specific gasification rate – in the range 2900–3900 kg/h m^2 – which corresponds to about 1 Nm^3/h m^2 (highest reported was 5020 kg/h m^2). The initial ignition time required for a downdraft gasifier is lower compared to an updraft gasifier, which is in the range of 15–20 minutes, but it is still perceived longer. A downdraft gasifier has relatively better load following capability (ability to quickly extend the partial combustion zone to produce higher required gas quantity).

The characteristics of a downdraft gasifier are as follows.

- Before leaving, tar-laden gases pass through the high temperature bed of coal in the oxidation zone and, hence, get cracked. Thus, the output gases are relatively clean, requiring less elaborate gas cleaning system.
- The gases leave at a relatively high temperature, about 400–500 °C; hence, the operating thermal efficiency of this gasifier is less than that of an updraft gasifier.
- This gasifier is not suitable for high ash, high moisture, and low ash fusion temperature fuels.

Cross-draft gasifier

In a cross-draft gasifier, the air enters from one side of the gasifier reactor, and gas leaves from the other side (Figure 4C). A cross-draft gasifier has very few applications and can hardly be credited with any advantage besides a good permeability of the bed. The characteristics of this type of gasifier are given below.

- Grate not required.
- Single air tuyere.
- Ash formed due to high temperature falls to the bottom and does not hinder operation.
- The high exit temperatures of the gas and high carbon dioxide emission result in poor quality of the gas and low efficiency.

Tables 2 and 3 give typical operational data and producer gas composition and quality for different gasifier reactors.

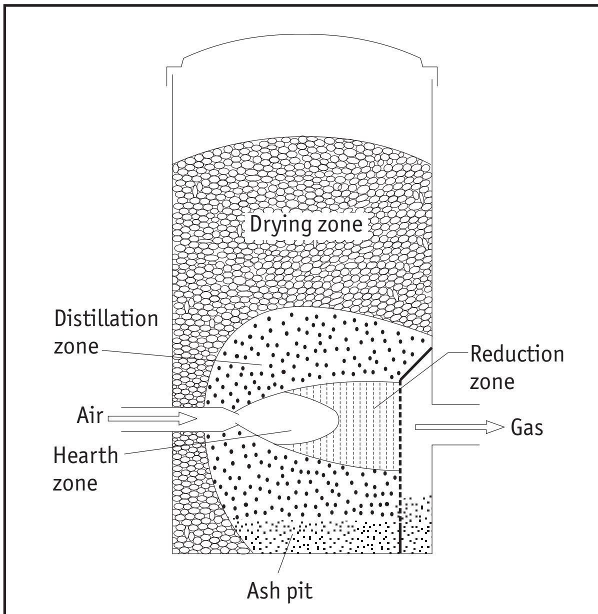


FIGURE 4C CROSS-DRAFT GASIFIER

Producer gas cleaning and conditioning

As mentioned earlier, the quality of gas with respect to impurities such as tar, dust, and water vapour varies with different reactors, and even for

Table 2

TYPICAL OPERATIONAL DATA FOR DIFFERENT TYPES OF GASIFIERS

	Downdraft	*Updraft*	*Fluid bed*	
			Conventional	*Circulating*
Grate energy release, GJ/h.m^2	1.5–4	2.5–5	6–9	40
Off gas temperature, °C	600–800	75–150	650–850	800–900
Oils and tar, kg/kg dry feed	0.001–0.01	0.05–0.15	0.01–0.05	–
Char loss, kg/kg dry feed	0.02	0.01–0.02	0.02–0.05	–

Table 3

PRODUCER GAS CHARACTERISTICS FROM DIFFERENT GASIFIERS

Gasifier reactor type	*Gas composition, dry,* vol %					*HHV* (MJ/m^3)	*Gas quality*	
	H_2	CO	CO_2	CH_4	N_2		*Tars*	*Dust*
Fluid bed air-blown	9	14	20	7	50	5.4	Fair	Poor
Updraft air-blown	11	24	9	3	53	5.5	Poor	Good
Downdraft air-blown	17	21	13	1	48	5.7	Good	Fair
Downdraft oxygen-blown	32	48	15	2	3	10.4	Good	Good
Multisolid fluid bed	15	47	15	23	0	16.1	Fair	Poor
Twin fluidized bed gasification	31	48	0	21	0	17.4	Fair	Poor

HHV – high heating value

a particular reactor type, it varies with the fuel used as well as operating conditions. Depending on the application, the gas needs to be cleaned and conditioned. There is always a possibility of tar and vapour condensing along with dust particles to form a semi-solid mixture, which blocks various filters and gasifier system components down the line. In order to prevent this, the gas is cleaned and conditioned. However, the best strategy would be to obtain a clean gas, which, in turn, would reduce gas cleaning requirement. Normally, dust particulates from the gas are removed in hot conditions (tar and water vapour remaining in gaseous form), and then the gas is cooled to condense tar and water vapour to form liquid condensate, which is then trapped and removed. The extent of treatment required varies, depending on gas applications.

Generally, no elaborate treatment is required for direct thermal applications of gas, as all the tar gets burned if burner is designed properly. Thus, only dust particulates are removed. However, if the gas is to be used directly for drying seeds or agricultural products, tar needs to be removed, as the seed layer acts like a granular bed filter and tar gets deposited in the first layer. Similarly, in some cases, tar needs to be removed in pottery or ceramic industry application in order to prevent any adverse effect on the product quality.

Producer gas utilization

Depending on the gasifying agent, like air and oxygen/steam, gas with low (calorific value of 3–7 MJ/Nm^3) or medium (calorific value of 12–16 MJ/Nm^3) heat value is produced. In most of the gasifiers, air is used as a gasifying agent, and so, gas with low heating value is produced, which needs to be utilized at the site, as compressing and transporting it become expensive due to high (about 50%–55%) nitrogen content in gas.

The primary objective of gasification is to convert solid biomass into a more convenient-to-use gaseous form (two steps up on the energy ladder) called producer gas, which, in turn, can be used in gas burners to use biomass more efficiently (reducing biomass consumption) or replace fossil fuel (gas/oil fired burners). Also, after extensive cleaning, the gas can be used for producing power by using IC engines.

Various gas characteristics (physical and chemical parameters), along with velocity, affect the performance of the gas in a burner. These are listed as below.

- Gas density compared to air density
- Heating value of gas
- Stoichiometric air requirement (for complete combustion)
- Flame speed coefficients of gas constituents

Variation in these parameters can result in flame lift-off (excessive gas velocity, resulting in its losing contact with the burner), internal burning of flame back (lower gas velocity than flame propagation, resulting in internal burning) or unstable flame. Flame back can be dangerous as flame starts moving upstream in a premixed gas–air mixture and can be prevented by flame arrester but can result in the flame getting extinguished. While changing the type of gaseous fuel used in the gas burner, there is a need to give attention to calorific value (heating value), stoichiometric air requirements, and its effect on adiabatic flame temperature as well gas flue gas volumes. Table 4 gives a comparison for the usage of low heating value (LHV), medium heating value (MHV), and natural gas in the burner.

It can be observed that for the generation of 1 MJ of energy, the producer (LHV) gas requirement is 8.5 times higher than the natural gas requirement. As a result, higher flue gases are generated when producer gas is used instead of natural gas, and therefore, modifications in flue gas paths might become necessary for compensating higher head losses. Lower flame temperature attainable with producer gas can have limitations in its use (and so at higher temperatures like metal melting of cement kiln dual firing becomes necessary) and also result in lower heat transfer efficiencies, resulting in derating of burner capacity.

Gasifier stove

The heating of biomass causes chemical decomposition ('pyrolysis'), which releases volatile solids or gases, which need to be subsequently burned in 'secondary combustion' process. This process occurs nearly simultaneously in regular biomass combustion stoves/fires, making the two stages difficult to observe or even control. But if these pyrolysis gases are not burned immediately, they can escape as products of incomplete combustion (PIC). As mentioned earlier, the PIC have more global warming potential (GWP) than carbon dioxide, which is obtained through complete combustion of fuel. The pyrolysis process is easier to understand, observe, and control. This process is informally known as 'gasification'. As mentioned earlier, commercially viable gasification has long been understood and used in the industry sector and even in transportation, but does not find application for small applications such as a household stove.

Since 1985, Dr T B Reed worked for about a decade on the development of a very small gasifier for meeting the domestic stove needs of impoverished people. He worked on developing

Table 4

COMPARISON OF HEATING VALUE, STOICHIOMETRIC COMBUSTION VOLUMES, AND FLAME TEMPERATURE

Fuel	*Stoichiometric combustion volumes* (Nm^3/MJ)				*Heating value* (MJ/Nm^3)	*Adiabatic flame temperature* (°C) *(with 10% excess air)*
	Air	Fuel	Fuel+air	Flue gases		
LHV	0.20	0.231	0.43	0.39	4.30	1480
MHV	0.20	0.104	0.30	0.27	10.0	1870
Natural gas	0.25	0.027	0.28	0.28	38.0	1860

LHV – low heating value; MHV – medium heating value an inverted downdraft (IDD) natural convection gasifier stove. Figure 5 shows the schematic diagram of a gasifier stove. He tested this stove for efficiency measurement, which was quite high, of the order of 30%–35%. Later, he worked on sizing the stove and trying to use it for making charcoal. There was no real success with applications. So, Dr Reed stopped his research work in 1995. However, later in 1998, he began working on a smaller, forced convection model with a fan, and in 2001, a prototype forced air gasifier stove was operated on a kitchen table. Figure 6 shows the schematic diagram and photographs of gasifier turbo-stove.

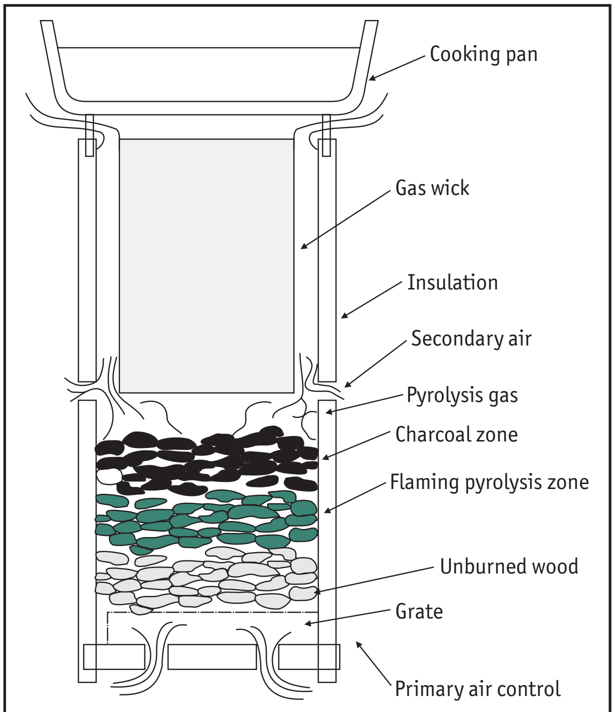


FIGURE 5 NATURAL DRAFT GASIFIER STOVE OPERATING ON INVERSE DOWNDRAFT PRINCIPLE

A series of modifications and improvisation resulted in the gasifier turbo-stove concept. These modifications include different stackable units in a heat column over a gasifier unit with an air pipe, smaller holes for the entrance of secondary air, pre-heated secondary air, a tapered chimney, and independent structural components for the stove body. The gasifier chamber is removable and, therefore, can be emptied to save the resultant charcoal, re-loaded with biomass, re-lighted, and re-inserted into the heat column. Later in 2002, a 'wood gas camp stove' was developed with forced air designs with the intention of constructing a stove for the affluent North American camper market. It had a battery-powered fan and could produce an impressive blue flame for sustained periods.

BIOGAS TECHNOLOGY

Microbial conversion of agricultural, industrial, and domestic waste has been a common practice for the past 50 years. The conversion leads to the utilization of biomass waste as a valuable resource and production of a fuel gas called biogas, which can be used for cooking, lighting, and power generation. Biogas systems have, in recent years, become an attractive option for decentralized rural development, as they produce a cheap fuel and good quality, rich manure. They also provide an effective and convenient way for disposing of

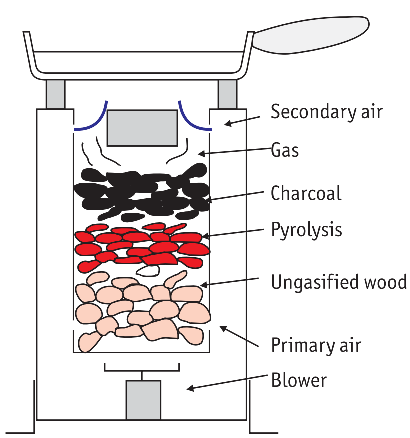


FIGURE 6 GASIFIER TURBO-STOVE

night soil and generate social benefits in terms of reduction of drudgery, time, and effort for fuelwood collection and cooking by women and young girls. They do not generate smoke, thus eliminating the adverse effects of smoke on women and children.

Process

The process of anaerobic digestion is a three-stage process. The stages proceed simultaneously and include the activities of diverse group of microbes with specific metabolic requirements. In the first stage of enzymatic hydrolysis, bacteria like *Clostridium*, *Ruminoccus*, and *Cellumonas* produce extracellular enzymes, such as cellulase, protease, amylase, and lipase, which degrade organic materials like complex carbohydrates, lipids, and proteins present in the organic biomass into more simple compounds such as sugars. During the second stage of acidification, fermentative acid-producing bacteria, such as *Anaerovibrio lipolytica*, *Bacteroides amylophilus*, *Bacteriodes ruminocola*, and so on, convert the simplified compounds into volatile fatty acids, hydrogen, and carbon dioxide. In this process, the facultative anaerobic bacteria utilize oxygen and carbon, thereby creating anaerobic conditions necessary for methanogenesis. In the final stage, obligate anaerobes, which are archaebacteria and mainly include *Methanosarcina barkeri*, *Methanococus mazei*, and *Methanothrix soengenii*, decompose low molecular weight compounds (acetic acid, hydrogen, carbon dioxide) to form biogas, sometimes also referred to as 'gobar' gas. This gas consists of methane and carbon dioxide, along with some traces of other gases, notably hydrogen sulphide. The exact composition will vary according to the substrate used in the methanogenesis process, but as an approximate guide, when cattle dung is a major constituent of fermentation, the composition of the resulting gas will be 55%–66% methane, 40%–45% carbon dioxide, and a negligible amount of hydrogen sulphide and hydrogen.

Factors affecting methanogenesis

The anaerobic microbial conversion of organic substrates to methane is a complex biogenic process involving a number of microbial populations and is controlled by various environmental factors like pH, temperature, ionic strength or salinity, nutrients, and toxic or inhibitory substrates. Among all these, the most crucial parameter is temperature, as methanogenesis is strongly temperature dependent, with reaction rates generally increasing with the increase in temperature. The most optimum temperature range for gas production is 30–35 °C (mesophilic), below which the digestion process slows down, with little gas produced at a temperature of 15 °C and less. Therefore, in areas that witness temperature fluctuation, such as mountainous regions, temperatures have to be maintained by providing heat or increasing insulation to prevent heat losses. The hydrogen ion concentration, or the pH, is another important factor, as most anaerobic conversion processes operate best at near neutral pH. Excess production and accumulation of acidic or basic conversion products such as organic fatty acids or ammonia lead to pH fluctuations outside the optimal range, thereby displacing the bicarbonate buffer system that has more neutral pH, thus inhibiting methanogenesis. Methane formation is also affected by the quantity of daily feeding (loading rate) and the retention period of the feedstock in a biogas plant. The loading rate and retention period are optimized, depending on the nature of the feedstock and climatic conditions. A high loading rate that is more than the rated capacity will form excessive acids, leading to low rate of gas formation and production of undigested slurry. The retention period for most plants ranges between 30 days and 55 days, and is found to reduce if temperatures are raised or more nutrients are added to the digester. The optimum nutrient requirement is generally 20–30 C/N ratio. The presence of trace elements like iron, magnesium, calcium, sodium, barium, tungsten, and nickel activates the enzyme systems of acetogenic and methanogenic bacteria and results in higher gas production, while heavy metals like mercury, lead, chromium, and sulphites, if present, are toxic to the anaerobic process.

Design of biogas plant

Biogas plants are classified on the basis of loading cycle, gas storage system, digester position and size, and feed material. The process can be a continuous, semi-continuous or batch type. In the batch type, the loading of digester is done periodically, and after a fall in the gas production, the digester is unloaded and recharged. This is suitable for crop and forest waste, agro-industrial waste, and other waste that does not mix homogeneously with water. In a semi-continuous digester, feeding is done once in three to four days, and the digester is suitable for cattle dung, crop residues, forest waste, and so on. Continuous digesters are more suitable for regularly and sufficiently available waste that can be mixed homogeneously, such as cattle dung and night soil.

A typical biogas plant consists of a digester in which the slurry (dung mixed with water) is fermented; an inlet tank, which is used to mix the feed and from where it is passed into the digester; a gas holder/dome in which the generated gas is collected; an outlet tank to remove the spent slurry; distribution pipeline(s) to take the gas to the kitchen; and a manure pit in which the spent slurry is stored. Based on the gas storage system, there are two main digester designs: the floating dome and the fixed dome. In the floating dome biogas plant, also known as the KVIC model, the biogas is stored in a drum that can be made of steel, ferro-cement or fibre glass. Based on the quantity of the gas stored in it, the drum moves up and down on a guide frame, which is fixed in digester walls. In the fixed dome type, the digester and gas storage dome are integrated with the space for storing usable gas between the dome and the digester, and the most common design is the Deenbandhu model.

While the Deenbandhu model is appropriate and more suitable for individual family-type requirements, the large-sized floating dome KVIC design biogas plants have been successfully adopted for cattle dung, night soil, kitchen and domestic waste, vegetable market waste, and so on (Figure 7). While the ministry continues to promote individual cattle dung based family-type biogas plants under its National Biogas Programme, an approach for promoting medium-sized biogas plants for small communities (six to eight families) is being adopted.

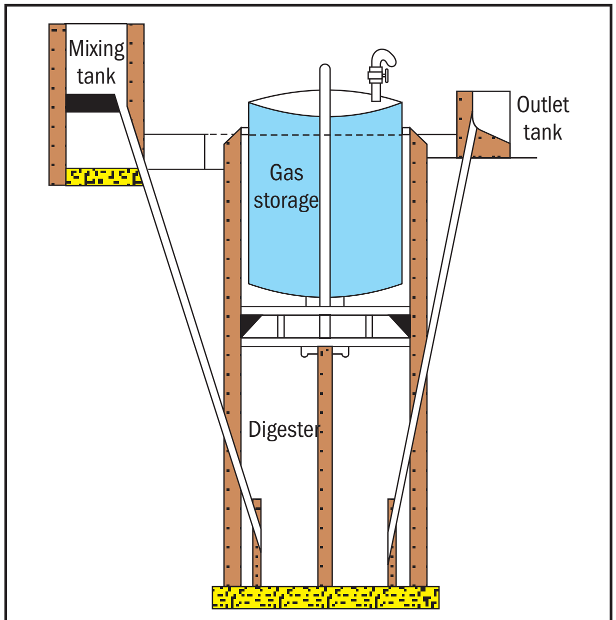


FIGURE 7 KVIC FLOATING DOME BIOGAS PLANT

Salient features of the KVIC model with respect to its features and cost economics are as follows.

- Feedstock: cattle dung, night soil, kitchen waste, leafy biomass, vegetable market waste
- Single chamber digester with floating drum for gas storage
- Retention time of 35–40 days
- Cost economics
  - Cost of plant (1 m^3/day): Rs 4500
  - Feedstock: 25 kg/day
  - Payback period: 1–2 years
  - liquefied petroleum gas (LPG) saved: Rs 3982/annum
  - Kerosene saved: Rs 2105 /annum
  - Wood saved: Rs 1894 /annum
  - Manure production: 4500 kg/annum

Designs for alternative feedstock

In rural areas, it is a common practice to use cattle dung and night soil as feedstocks in biogas plants that meet the cooking energy requirements. However, the availability of cattle dung in rural areas is limited, and the cattle population is also diminishing fast. Hence, there is a need to use alternative feedstocks for meeting the increasing cooking energy needs. Alternative organic feed substrates like agriculture residues, oil cakes, dry and wet leaves, vegetable market waste, and kitchen waste, which are abundantly available in villages, also have the potential, which can be tapped through appropriate technology for energy generation, thus, meeting the increasing cooking energy demand. So, the production of biogas from other biomass like leafy waste, agro-residues, and kitchen waste garbage is an attractive option, which will facilitate extending the benefits of biogas technology to a larger section of the society. It is estimated that the total potential of leafy biomass production in India is of the order of 1130 million tonnes (MT) (dry). If even 10% of this biomass could be mobilized for biomass production, about 67% of the rural families could be provided with biogas for cooking. After years of R&D efforts, different designs have been developed in order to harness the biogas potential of such substrates.

TERI'S ENHANCED ACIDIFICATION AND METHANATION PROCESS

TERI's Enhanced Acidification and Methanation, or TEAM, reactor is a biphasic design, which is operational since the past four years at Gual Pahari, Haryana (Figure 8). Main features of this design reactor are as follows.

- Feedstocks: different agro-residues, vegetable market waste, and kitchen waste
- Six acidification modules
- One methanation reactor
- Retention time of seven days
- Minimal water requirement and operational problems like scum formation
- Cost economics
  - Cost of plant (1 m^3/day): Rs 20 000
  - Feedstock: 50 kg/day organic waste
  - Payback period: 2–5 years
  - LPG saved: Rs 3982/annum
  - Kerosene saved: Rs 2105/annum
  - Wood saved: Rs 1894/annum
  - Manure production: 1500 kg/annum

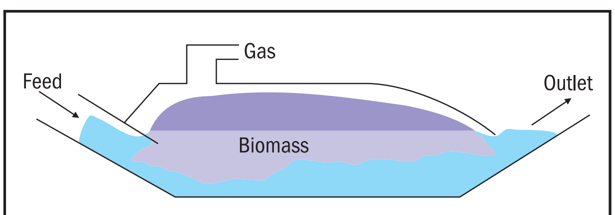


FIGURE 8 A TEAM REACTOR

The acid reactor is daily fed with waste in serial order and submerged in water for microbial action. The water is re-sprinkled thrice a day for 15 minutes over the waste bed. Percolate rich in volatile fatty acid is collected from the bottom of the reactor after six days and is fed to the methane reactor. The effluent discharged from the methane reactor is recycled to the acid reactor for drawing more acid-rich liquor from the waste. A biphasic plant based on the similar principle is operational at Maharashtra Scooters for treating 300 kg/day of canteen waste generated in their campus canteen.

APPLICATION OF SCIENCE AND TECHNOLOGY TO RURAL AREAS PLUG FLOW DIGESTER

The Application of Science and Technology to Rural Areas, or ASTRA, design developed at IISc, Bangalore, is based on the fermentation and floating properties of the biomass feedstock (Figure 9). Main features of this design are as follows.

- Feedstocks: mixed green leaf biomass, grasses, twigs
- Single chamber brick masonry structure for the digester walls and cylindrical brick masonry vault cover
- Retention time of 35 days

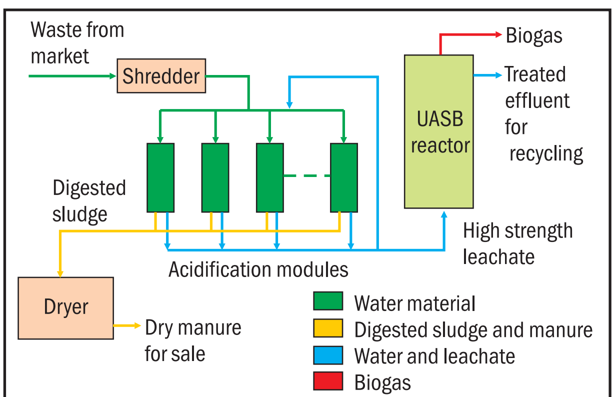


FIGURE 9 TERI'S ENHANCED ACIDIFICATION AND METHANATION PROCESS

- Gas collected in balloons
- Minimal water requirement
- Operational problems like scum formation
- Cost economics
  - Cost of plant (1 m^3/day): Rs 7500
  - Feedstock: 17 kg/day
  - Payback period: two to four years
  - LPG saved: Rs 3982/annum
  - Kerosene saved: Rs 2105 /annum
  - Wood saved: Rs 1894/annum
  - Manure production: 3000 kg/annum

In plug flow digesters, freshly fed biomass feedstock in the slurry form undergoes about three to five days of rapid decomposition while being submerged under the digester liquid. This removes the problematic volatile fatty acid producing constituents. After this phase, methanogens adequately colonize the partially decomposed biomass. The biomass acquires buoyancy at this stage and floats above the fermenter liquid. The rate of acidogenesis and methanogenesis is adequately balanced, which produces biogas. Two plants of capacities 60 × 4 m^3 and 60 × 6 m^3 are operational near Kannati, Chikkamangalur, for treating coffee waste water. These are being run for eight months with leafy biomass and for the balance three months as biomass-supported fixed film biogas plant for treating coffee waste water.

BHABHA ATOMIC RESEARCH CENTRE

The Bhabha Atomic Research Centre developed a biphasic system that uses the potential of thermophiles for enhanced recovery of biogas by using conventional biogas KVIC model. Main features of the plant are as follows.

- Feedstocks: kitchen waste, vegetable waste, and leafy biomass
- A mixer/pulper for crushing the solid waste
- Premix tanks (three in number), pre-digestion tank, air compressor, and solar heater for heating water
- Gas delivery system
- Main digestion tank
- Tank for recycling of water and water pump
- Gas utilization system
- Retention time of 12 days
- Cost economics
  - Cost of plant (1 m^3/day): Rs 3500
  - Feedstock: 25 kg/day organic waste
  - Payback period: 1–2 years
  - LPG saved: Rs 3982/annum
  - Kerosene saved: Rs 2105/annum
  - Wood saved: Rs 1894/annum
  - Manure production: 4500 kg/annum

The conventional biogas KVIC design has been modified in two ways. First, by introducing a 5-HP mixer to process the waste before putting it into a pre-digester tank, and second, by using thermophilic microbes for faster digestion of the waste. The growth of thermophiles in the pre-digester tank is ensured by mixing the waste with hot water and maintaining the temperature in the range of 55–60 °C by using solar heater. From the predigester tank, the slurry enters the main tank, where it undergoes anaerobic digestion. The undigested ligno-cellulosic and hemi-cellulosic material then enters the settling tank. Manure is dug out from the settling tanks about a month later. The gas generated in the plant is used for cooking in the nearby canteen/hostel and also for gas-based lights fitted around the plant.

ANNEXURE 4.5

Small wind systems

While large grid-connected wind farms are now common in many countries, small wind machines are also developing their own niche in the renewable energy sector.

Typically, small wind machines of capacity up to 100 kW are called small wind machines. Small wind energy systems are of the following types.

- Mechanical pumping systems
- Battery charging aero-generators of capacities less than 100 kW
- Grid-connected wind farms using small machines (Figure 1 illustrates small wind mills installed in Thailand)

SMALL WIND MACHINES

Energy is the prime mover of economic growth and human development, which encompass all sectors of the economy. However, the production and use of fossil fuels for power generation, industrial application, and transportation have been associated with adverse local environmental impacts such as deforestation, land degradation, and water and air pollution. In addition, there are concerns about the release of greenhouse (GHG) emission from the energy sector, particularly during power generation using fossil fuels. One strategy to address these environmental issues and diversifying sources of energy supply at the same time is the development and promotion of renewable energy technologies.

During the past two decades, considerable efforts have been made towards large-scale penetration of renewable energy technologies in India. Grid-connected power generation through wind energy in the country has crossed the 9521 MW mark, making India the fourth largest wind power generating country in the world after Germany, Spain, and USA. At the end of 2006, worldwide capacity of wind-powered generators was 73.9 gigawatts, although it currently produces just over 1% of worldwide electricity use.

FIGURE 1 WIND FARM USING SMALL WIND MACHINES

Source Unitron, India

Wind energy

All renewable energy (except tidal and geothermal power), including the energy in fossil fuels, ultimately comes from the sun. The sun radiates 174 423 000 000 000 kWh of energy to the earth per hour. In other words, the earth receives 1.74 × 10^{17} watts of power. About 1%–2% of the energy coming from the sun is converted into wind energy, which is about 50 to 100 times more than the energy converted into biomass by all plants on earth.

Wind is a form of solar energy and is created by the unequal heating of the earth's surface by the sun. During the day, the air above the land heats up more quickly than the air over water. The warm air over land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun compared to the land near the North Pole and South Pole.

The terms 'wind energy' and 'wind power' describe the process by which the wind is used to generate mechanical power, or electricity. Wind turbines convert the kinetic energy in the wind into clean electricity. Wind power uses the kinetic energy of the flowing air to generate mechanical energy in a wind turbine, which can be transformed into pollution-free electricity.

Air moves around the earth because of the existing differences in temperature and atmospheric pressure. Wind turbines harness the movement of the air to produce energy. The wind turns the blades, which turn a rotor shaft. This produces mechanical power, which is used to drive an electric generator. When the wind spins the blades of the wind turbine, a rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator. Most turbines have automatic overspeed-governing systems to keep the rotor from spinning out of control in very high winds. Flow chart given in Figure 2 shows the steps of generation of energy from wind and its distribution.

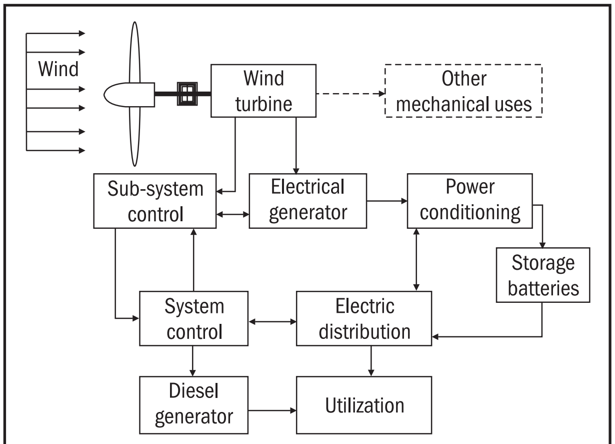


FIGURE 2 GENERATION OF WIND ENERGY AND ITS DISTRIBUTION

Wind turbine types

Modern wind turbines fall into two basic groups: the horizontal axis type such as the traditional farm windmills used for pumping water and the vertical axis type such as the egg-beater-style Darrieus model, named after its French inventor. Most large modern wind turbines are horizontal axis turbines.

Horizontal axis

Most wind machines that are in operation today are the horizontal axis type. Horizontal axis wind machines have blades that resemble airplane propellers. A typical horizontal wind machine stands as tall as a 20-storied building and has three blades that span across 200 feet.

Vertical axis

Vertical axis wind machines have blades that span from the top to the bottom, and the most common type (Darrieus wind turbine) looks like a giant two-blade egg beater. This type of vertical wind machine is typically 100 feet tall and 50 feet wide. These machines are available in the capacity size of 650 watts to 2 MW for onshore application. For offshore application, 5-MW capacity wind turbine is commercially available.

Horizontal and vertical axis wind turbines are presented in Figure 3, and the internal structure of a horizontal axis turbine is given in Figure 4.

Almost all wind turbine generators consist of rotor blades, which rotate around a horizontal hub. The hub is connected to a gearbox and a generator, which are located inside a nacelle. The nacelle houses electrical components and is mounted at the top of a tower.

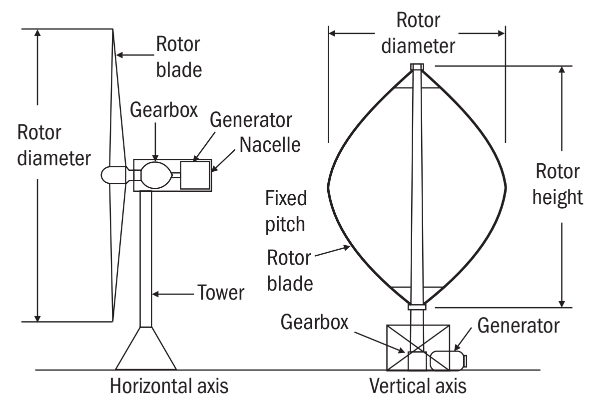


FIGURE 3 HORIZONTAL AND VERTICAL AXIS WIND TURBINES

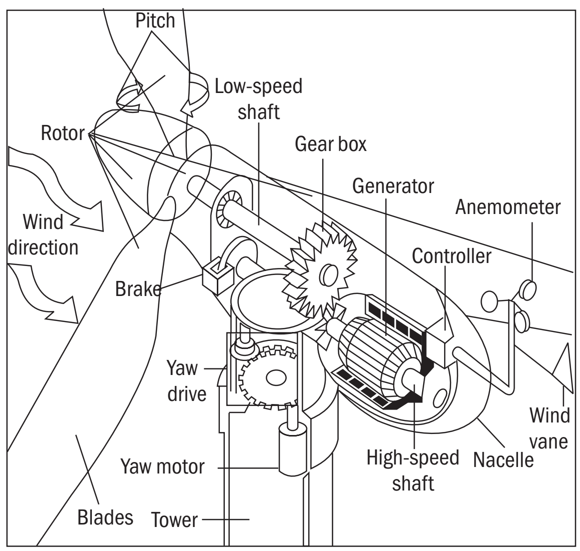


FIGURE 4 INTERNAL STRUCTURE OF HORIZONTAL AXIS WIND TURBINE

Turbine components

Horizontal turbine components include the following.

- A blade or a rotor, which converts the energy in the wind to rotational shaft energy.
- A drive train, usually including a gearbox and a generator.
- A tower that supports the rotor and drive train.
- Other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

The formula for calculating power from a wind turbine is

$$P = ½(k* Cp*ρ*A*V3)$$

where, P = power output, kilowatts
Cp = maximum power coefficient, ranging from 0.25 to 0.45, dimensionless (theoretical maximum = 0.59)
ρ = air density, lb/ft^3
A = rotor swept area, ft^2 or (π D^2)/4 (D is the rotor diameter in feet, π = 3.1416)
V = wind speed, mph
k = 0.000133, a constant to yield power in kilowatt (multiplying the above kilowatt by 1.340 converts it to horsepower [that is, 1 kW = 1.340 horsepower]).

To get a preliminary estimate of the performance of a particular wind turbine, the following formula is used.

$$AEO = 0.01328 *D2* V3$$

where, AEO = annual energy output, kWh/year
D = rotor diameter, feet
V = annual average wind speed, mph

Basic parts of small wind electric system

Small wind energy systems for home lighting generally comprise a rotor, a generator or an alternator mounted on a frame, a tail, a tower, wiring, and the balance of system components, controllers, inverters, and/or batteries (Figure 5). Through the spinning blades, the rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator.

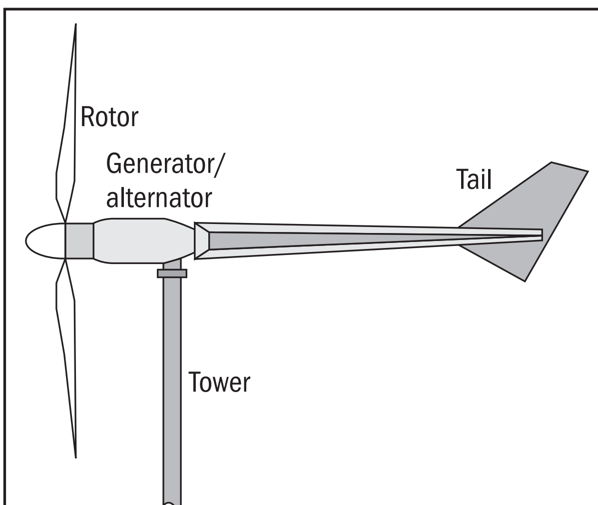


FIGURE 5 BASIC PART OF SMALL WIND TURBINE

Wind turbine

A wind turbine generator converts mechanical energy into electrical energy (Figure 6). Most turbines manufactured today are horizontal axis upwind machines with two or three blades, which are mostly tubular and made of steel. The blades are made of fibre-glass-reinforced polyester or wood-epoxy.

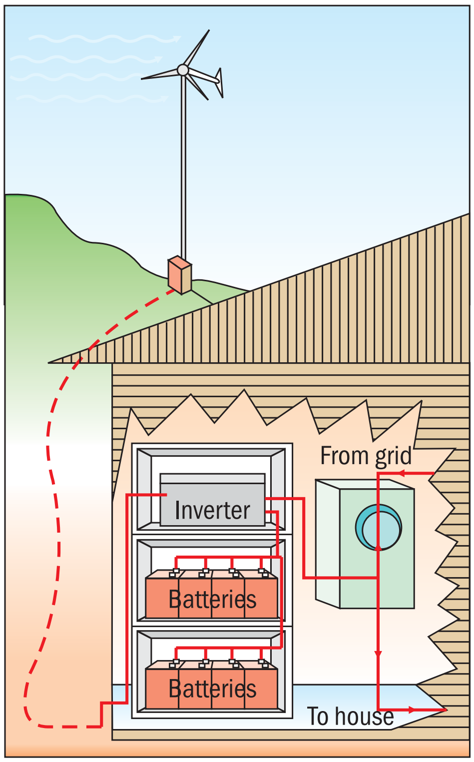


FIGURE 6 SMALL WIND TURBINE FOR HOME LIGHTING

Tower

Wind speed increases with height; therefore, the turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence and obstructions such as hills, buildings, and trees. A general rule of thumb is to install the wind turbine on a tower with the bottom of the rotor blades at least 30 feet (9 metres) above any obstacle that is within 300 feet (90 metres) of the tower.

Balance of system

The parts that are needed in addition to the turbine and the tower, or the other system parts, will depend on the application. The balance of system required will also depend on whether the system is grid-connected, stand-alone or part of a hybrid system. For a residential grid-connected application, the balance of system parts may include a controller, storage batteries, a power-conditioning unit (inverter), and wiring.

Stand-alone systems

Stand-alone systems (systems not connected to the utility grid) require batteries to store excess power generated for use when the wind is calm. They also need a charge controller to keep the batteries from overcharging. Small wind turbines generate DC (direct current) electricity. In very small systems, DC appliances operate directly off the batteries.

Grid-connected systems

In grid-connected systems, the only additional equipment required is a power-conditioning unit (inverter), which makes the turbine output electrically compatible with the utility grid. Figure 7 depicts the arrangement showing wind turbine connected with grid

Following components form a part of small wind turbine systems.

- Control and protection systems
- Towers
  - *Tilt-up towers* usually for systems with capacity under 1000 watts (1 kW)

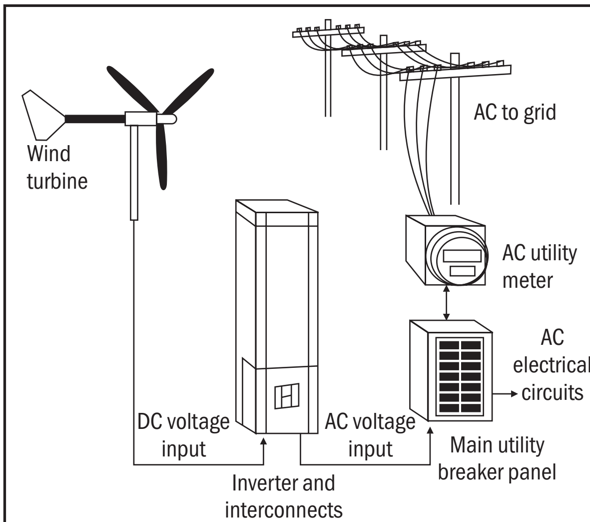


FIGURE 7 WIND TURBINE CONNECTED TO GRID

- *Guyed towers* usually used for systems with capacity between 1 kW and 50 kW
- *Self-supporting towers* usually for turbines with capacity above 50 kW

- Battery
- Inverter
- Rectifier
- Monitoring system

Wind speed to operate a turbine

The greater the annual mean wind speed, the better a turbine works. In general, most small/micro wind turbines start generating electricity when wind speeds are in the range of approximately 3–4 m/s, and most products achieve their maximum, or rated, output at a wind speed of 10–12 m/s, which is crucial when comparing products. In order to measure the annual wind speed, the knowledge of prevailing wind and its direction are required at the site.

In addition to geologic formations, other obstacles such as trees, buildings, and hills should also be considered. The turbine needs to be sited upwind of buildings and trees, and it needs to be 30 feet above anything to reach the height of 300 feet.

Any site will have different average wind speeds at different locations. An assessment of the site should include taking into consideration elevated structures like hills in the vicinity of the turbine. Such sites with elevations are more suitable than gullies or the lee side of hills.

A site where annual mean wind speed is 5 m/s, a turbine with a rating of 1 kW and a diameter of 2.3 m would generate approximately 1200 kWh, or units, of electricity per year. For an average household to meet all its electricity needs from a small wind turbine, a system of 2.5–6 kW would be needed, depending on wind speed.

Wind resource assessment

Wind resources vary with the time of day, season, elevation, and type of terrain. Wind plays an important role in determining success or failure of a small wind turbine project. At the same time, the cost of assessing wind resources for a smaller project can be too high.

Generation of electricity from wind at a given wind speed and wind turbine type varies to a great degree with the wind speed distribution around the mean value. For example, on a site where 50% of the time wind speed V_{av} = 12 m/s and 50% of the time V_{av} = 0 m/s, a wind turbine would generate much more electricity than that which is on a site where 100% of the time wind speed V_{av} = 6 m/s. This is due to the fact that wind energy, in theory, is proportional to the cube of the wind speed.

Wind resource evaluation is a critical element in projecting turbine performance at a given site. The energy available in a wind stream is proportional to the cube of its speed, which means that doubling the wind speed increases the available energy by a factor of eight. Furthermore, the wind resource itself is seldom a steady, consistent flow. It varies with the time of day, season, height above ground, and type of terrain. Proper siting in windy locations, away from large obstructions, enhances a wind turbine's performance.

In general, annual average wind speed of 5 m/s (11 miles per hour, or mph) is required for grid-connected applications. Annual average wind speed of 3–4 m/s (7–9 mph) may be adequate for unconnected electrical and mechanical applications such as battery charging and water pumping. Wind resources exceeding this speed prevail in many parts of the world.

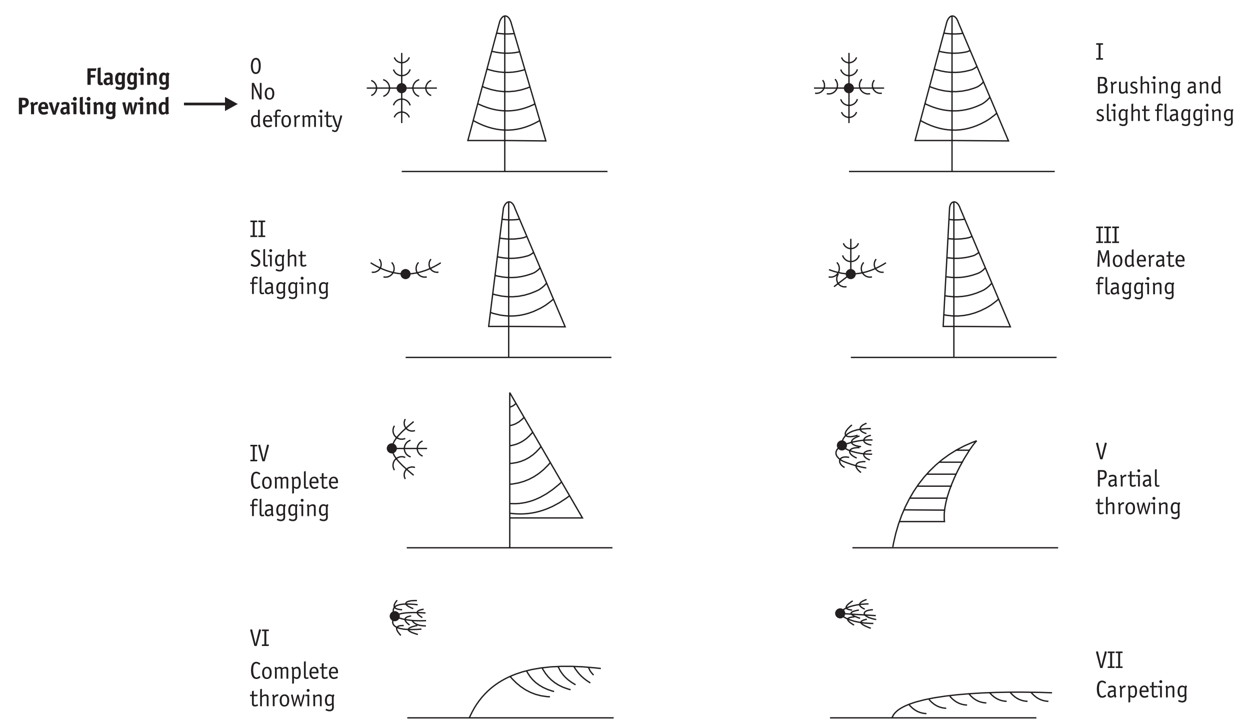
Wind power density is a useful way to evaluate the wind resource available at a potential site. The wind power density, measured in watts per square metre, indicates how much energy is available at the site for conversion by a wind turbine. Wind speed generally increases with height above ground. Table 1 gives the classes of wind power density at 10 m and 50 m elevation.

Another useful indirect measurement of the wind resource includes observing an area's vegetation. Trees, especially conifers or evergreens, can be permanently deformed by strong winds. This deformity, known as 'flagging', has been used to estimate the average wind speed for an area. Figure 8 shows different level of flagging, depending on different wind speed levels.

Table 1

CLASSES OF WIND POWER DENSITY AT 10 M AND 50 M ELEVATION

	10 m (33 feet)		50 m (164 feet)	
Wind power class	*Wind power density* (W/m^2)	*Speed* m/s (mph)	*Wind power density* (W/m^2)	*Speed* m/s (mph)
I	<100	<4.4 (9.8)	<200	<5.6 (12.5)
II	100–150	4.4 (9.8)/5.1 (11.5)	200–300	5.6 (12.5)/6.4 (14.3)
III	150–200	5.1 (11.5)/5.6 (12.5)	300–400	6.4 (14.3)/7.0 (15.7)
IV	200–250	5.6 (12.5)/6.0 (13.4)	400–500	7.0 (15.7)/7.5 (16.8)
V	250–300	6.0 (13.4)/6.4 (14.3)	500–600	7.5 (16.8)/8.0 (17.9)
VI	300–400	6.4 (14.3)/7.0 (15.7)	600–800	8.0 (17.9)/8.8 (19.7)
VII	>400	>7.0 (15.7)	>800	>8.8 (19.7)



Griggs-Putnam Index of Defermity

Index	I	II	III	IV	V	VI	VII
Wind mph	7-9	9-11	11-13	13-16	15-18	18-21	22+
Speed m/s	3-4	4-5	5-6	6-7	7-8	8-9	10

FIGURE 8 LEVELS OF FLAGGING CAUSED BY THE PREVAILING WIND DIRECTION

Windmill pumps

A windmill pump consists of a wind rotor, a pump, and a power transmission mechanism connecting the rotor to the pump. The rotor extracts energy from the wind and converts it into useful mechanical shaft power. A transmission mechanism conveys the energy from the rotor to the pump rod, which in turn transmits power to the pump. The useful life of a well-designed windmill pump is expected to be 15 years or more with proper maintenance and care. The useful life of a windmill pump may get reduced due to corrosion, which predominantly affects the structure and the parts of the pump. Characteristics such as rotor diameter and cut-in and cut-out wind speeds for various types of small wind turbines are given in Table 2.

Table 2

CHARACTERISTICS OF VARIOUS SMALL WIND TURBINES

					Wind speed (m/s)			
Windmill design/type	*Manufacturer*	*Rotor diameter* (m)	*No. of blades*	*Solid area* (m^2)	*Cut-in*	*Rated*	*Output*	*Capital cost* (E)
GM-II (geared)	Rural Engineering School, Bhavanagar	3	18	4.55	2.2	3.3	13.9	1256
SICO (General)	The Scientific Instrument Company Limited, Allahabad	3	18	5.37	2.2	5.0	23.9	1922
AV-45 (direct)	Auroville Centre for Scientific Research (Aureka), Tamil Nadu	4.5	18	7.63	1.8	2.8	10.0	1669
AV-55 (direct)	Auroville Centre for Scientific Research (Aureka), Tamil Nadu	5.7	24	10.70	1.5	3.0	10.0	2220
APOLY-12-PU500 (direct)	Institute of Engineering and rural Technology, Allahabad	5.0	12	6.19	2.5	5.0	10.0	763

Geothermal energy

Geothermal energy is the natural heat of the earth. The earth's interior heat is a result of high temperature dust and gas that can be traced to over 4 billion years ago and is continually regenerated from the decay of radioactive elements that occur in all rocks.

From the surface down through the crust, the normal temperature gradient (the increase of temperature with the increase of depth) in the earth's crust is 17–30 °C per kilometre of depth. Below the crust is the mantle, which is made up of highly viscous, partially molten rocks that have temperature in the range of 650–1250 °C. At the earth's core, which consists of a liquid outer core and a solid inner core, temperatures may reach 4000–7000 °C.

GEOTHERMAL ENERGY UTILIZATION

Currently, geothermal energy is exploited from the underground water stored in permeable rocks. This is also called as hydro-thermal system. In this process, the water is heated by hot rocks. The heat can also be extracted using geothermal heat pumps that extract heat directly from the ground.

In another process, hot rocks are artificially fractured, and water is circulated between two wells – injection and producer wells – which are connected to the underground hot water reservoir in the rocks. These are known as hot dry rock (HDR) systems. Another method, which is under investigation, is the exploitation of the large quantities of heat stored locally at accessible depth in molten rock (magma). This can provide high temperature underground water, which can provide energy for many applications. These applications include district heating, individual residential heating, and spa uses.

Following are the commonly used technology

- High temperature: >220 °C
  - Water or steam power generation; direct use flash steam; combined (flash and binary) cycle; direct fluid use heat exchangers; heat pumps
- Intermediate temperature: 100–220 °C
  - Water power generation direct use; binary cycle; direct fluid use; heat exchangers; heat pumps
- Low temperature: 50–150 °C
  - Water direct use; direct fluid use; heat exchangers; heat production

Heat available between 100 °C and 150 °C can be used to generate electricity with special type of plants. Heat above 150 °C is used for generating electricity.

ANNEXURE 5.1

Energy conservation techniques in the buildings

ECO-HOUSING AND ECO-FRIENDLY BUILDING DESIGN

Eco-house is a house that has minimal environmental impact during its construction and operation period. During its construction, it causes minimum disruption to surroundings. After its construction when it becomes habitable, it consumes very less electricity. It is naturally lit and ventilated. Energy-efficient architecture of eco-house ensures the reduced consumption of electricity for cooling and heating. The plumbing system of eco-house uses less water and puts relatively fewer loads on city's sewage system. This is designed giving due consideration to solid waste management system, reducing the burden on city's solid waste disposal system. Broadly, an eco-house follows six basic principles: site planning, energy-efficient architecture, energy-efficient systems in the building, use of renewable energy, efficient water management, and solid waste management system.

EFFICIENT SITE PLANNING

Overall site planning and design of an eco-building integrates all natural principles. These give due consideration to preservation and conservation of natural features or resources present on the site. These resources may include trees and vegetation, soil, water, and other natural characteristics of the site. The building layout is drawn without disturbing trees and vegetation. Care is taken to ensure that trees are not disturbed by construction activities. The fertile eco-housing site is preserved before starting the construction process and is utilized again for landscaping of the new building. During the construction stage, there is efficient management of waste water and solid waste. Efficient waste management plan ensures that the entire site is protected from hazardous construction waste.

ENVIRONMENT-FRIENDLY AND ENERGY-EFFICIENT BUILDING DESIGN

All buildings in eco-housing are designed for energy efficiency. There is an efficient utilization of natural climatic conditions by using passive solar design concepts. These design concepts include the following.

- *Orientation and shading* Buildings are oriented in such a way that there is efficient use of sunlight and wind. Interiors of the properly orientated buildings are naturally heated in winters and cooled in summers.
- *Building layout* The building layout is designed in such a way that the rooms have naturally comfortable environs during their occupancy period. For example, if the living room in an eco-house is planned to be used extensively during afternoons in summers, then its location will be planned in such a way that it receives sufficient natural and diffused light so that the environment remains cool.
- *Window design* Efficient window design enhances lighting and ventilation in the building. Windows in an eco-house are sized and placed according to solar path. During summers, only diffused light comes from the window, and during winters, warm sunlight filters through these windows and makes interiors

more cosy. The windows of an eco-house are high-performance windows; these are shaded well in order to protect the interiors from the sun in harsh summers and from rains in monsoons. If the buildings are air-conditioned then the window frames of high performance windows reduce heat losses and bring down the loads on air-conditioners.

- *Energy- and resource-efficient technologies in building construction* An eco-house is constructed with efficient building technologies, which use eco-friendly materials, and less water and power during construction.
- *Low-energy building materials* An eco-house is constructed with low energy materials. Manufacture and transport of building materials are very resource and energy intensive. Low energy materials comprise materials that are locally available and require less energy and resources during the construction process. The materials that are made from waste or are the by-products of some other industry are also considered as low energy building materials.

USE OF RENEWABLE ENERGY IN THE BUILDING

All buildings in eco-housing are fully or partly powered by renewable sources of energy. Examples are using solar energy for water heating and space heating, biogas for cooking, and other renewable energies wherever applicable.

USE OF EFFICIENT SYSTEMS IN THE BUILDING

The lighting, cooling, heating, and air-conditioning systems are efficiently designed in the eco-housing. High performance, energy-efficient, and energy-labelled products are commonly used in buildings. These appliances are based on the use of energy-efficient technologies and appliances, and automatic control systems. Use of such equipment reduces energy consumption in the building. For example, heat pumps are used for space heating and cooling, insulation is used in walls and roofs for reducing heat loss, and so on.

EFFICIENT WATER MANAGEMENT IN THE BUILDING

Eco-housing emphasizes on water conservation. There is significant reduction in water loss and consumption, and there is efficient utilization of water for various applications in buildings. Emphasis is laid on two aspects, that is, water conservation and water efficiency. Water conservation means the preservation and efficient management of water. This includes use of fixtures that lead to conservation of water. Water efficiency includes prevention of wastage, overuse, and exploitation of the available resource.

EFFICIENT WASTE MANAGEMENT IN THE BUILDING

Eco-housing emphasizes on solid waste management in the building. Solid waste generated from households generally reaches the city dumping sites. There is no resource recovery in most of the cases. In general, the household waste generated constitutes various materials such as plastics, paper, and glass that can be recycled and reused. In addition, the waste has a high organic content, which can be used to recover useful resources such as energy and manure. Solid waste management in a building would also ensure safe and environment-friendly disposal of waste.

Bhutan has developed its own traditional housing and building design guidelines, which are being followed strictly. Traditionally, locally made mud bricks and conventional housing construction techniques using bamboo and mud are still used in rural areas. However, the use of cement and concrete for construction in urban areas and the use of GI sheets for roofing material are prevalent. In the context of Bhutan, following recommendations to develop and adopt eco-friendly and energy-efficient housing codes and concepts can be considered

- National-level awareness programmes and capacity-building programmes for common citizens and architects need to be developed.
- Agencies like the Standards and Quality Control Authority (SQCA), National Housing Board, Association of Construction Contractors, National environment Commission, Ministry of Works and Human Settlement, Urban Development Department, and so on can work together.

- The SQCA, which is already working with the construction industry, can be strengthened to work as a focal agency for sustainable buildings.
- Capacity building will include vesting national-level authorities with following responsibilities.
  - To govern the construction activities taking place in the country.
  - To guide and monitor the local development authorities for energy-efficient building techniques.
  - To study, analyse, and document the local architecture and locally available materials, and explore and identify energy efficiency techniques in the buildings.
  - To explore energy-efficient techniques and their implications in contemporary era.
  - To develop new building technologies.
  - To develop building codes for energy efficiency.
  - To collaborate with international architects for advisory services.
- Collaborative programmes with other agencies, especially with the Government of India agencies like the Bureau of Energy Efficiency (BEE) to develop database for weather data, best practices, design norms for Bhutanese weather conditions, alternative materials, and so on can be developed.
- Workshops should be designed for architects and construction agencies to sensitize them about energy conservation and energy efficiency in buildings.
- There should be market development for sustainable habitat and encouragement of the industries that process and manufacture environment-friendly building products like solar water heaters, photovoltaic cells, energy-efficient household equipment, low volatile organic compound (VOC) paints, low energy building materials, water-efficient plumbing fixtures, sewage treatment units, recyclable and reusable products, and so on.

ACTION POINTS

- Study on buildings and materials and development of database for modifying building codes to incorporate energy efficiency and sustainability in buildings.
- Pilot projects to demonstrate energy-efficient technologies, design practices, and low energy materials. These projects can be taken up under the ongoing government projects like construction of housing colonies and school buildings. This would lead to the development of guidelines for such type of projects. The Ministry of Environment and Forests, Government of India, has prepared similar guidelines, which can be accessed at <http://envfor.nic.in/divisions/iass/Construction_Manual.pdf>.

ANNEXURE 7.1

Institutions in the energy sector and their functions

THE DEPARTMENT OF ENERGY

The Department of Energy (DoE) is a central government agency responsible for the formulation of policies, plans, programmes, and guidelines related to the energy sector. Formed in 2002, it deals with all forms of energy, including hydropower and alternative forms of energy. It also provides technical advice to the Royal Government of Bhutan on all aspects related to energy, including formulating development strategy, monitoring and evaluating implementation plans, and preparing and maintaining programmes and schedules. It is also responsible for giving techno-economic and budgetary clearances to major projects and programmes related to energy.

The responsibilities of the DoE are increasing over the period. It is assumed that it will play increasingly important role in the overall development of the energy sector. Therefore, there is a need to strengthen and reorganize the DoE. The responsibilities of the DoE are likely to expand and include activities that can be classified/ categorized under various divisions, as discussed subsequently.

The DoE has four divisions—the Planning and Coordination Division (PCD), Hydro-Met Services Division (HMSD), and Renewable Energy Division (RED). Additionally, the Bhutan Electricity Authority (BEA) is also under the DoE.

Planning and Coordination Division

This division is looking after the overall planning and coordination work. Besides planning and coordination of internal activities, it also coordinates donor-funded projects handled by the DoE. Major tasks handled by this division are as follows.

- Complete planning of the energy sector.
- Planning and preparing detailed project reports for new projects.
- Executing new projects.
- Negotiating with the Government of India and other funding agencies.
- Coordinating with donor-funded projects.
- Coordinating and monitoring with Bhutan Power Company, other power generating companies, and other stakeholders.
- Coordinating with other ministries.

Hydro-Met Service Division

The HMSD has three sections: hydrology, flood warning, and meteorology.

The flood warning section monitors flood warning stations established across the country and coordinates with the Government of India on flood warning data collection and information sharing. The hydrology section is responsible for the collection and analysis of hydrology data for hydropower plant design.

The meteorological section is responsible for collection and processing of meteorological data. It has set up 72 weather stations across the country and has a repository of the weather data for last few years. The division also maintains flood warning systems, which are established in coordination with India.

Renewable Energy Division

This division is responsible for promoting renewable energy related activities in the country. The division, so far, has concentrated its activities on the distribution of solar photovoltaic home lighting system, preparation of feasibility reports for small and micro hydro projects (four projects are being studied), development of improved cook stoves and *bukharis* in collaboration with Austrian Development Agency, rehabilitation of solar photovoltaic systems, development of servicing and training network, and so on. The division has also worked on developing the draft renewable energy policy.

RENEWABLE AND ENERGY EFFICIENCY RELATED ACTIVITIES

- Promotion of energy-efficient appliances and monitoring of the same.
- Monitoring of renewable energy resources and preparation of long-term database for solar, wind, biomass, and other energy resources.
- Promotion of renewable energy devices.
- Formulation of subsidy and finance schemes for promoting renewable energy systems.
- Promotion of energy-efficient buildings.
- Development of local capacities in developing and operating renewable energy and energy efficiency technologies.
- Establishment of energy efficiency laboratory and making available training, auditing, and other services to industries, hotels, and institutions for improving their efficiencies.
- Coordination with other agencies and developing and implementing strategies for using other energy resources such as biomass, solar, wind, and waste to energy projects.

RED can be renamed and restructured as Sustainable Energy Division.

METEOROLOGICAL AND HYDROLOGICAL SERVICES

- Analysis of hydrology data and preparation of long-term data archives.
- Maintaining meteorological data in scientific and internationally approved formats.

Planning and coordination

The activities of the meteorological and hydrological services department can be classified into three categories.

1 Routine activities
- Coordination with other ministries, departments, generating companies, and power corporations
- Coordination with donor agencies
- Monitoring of implementation of plans
- Coordination with the Government of India

2 Development of accelerated hydro master plan and private sector participation
- Private sector participation in the power sector would increase the responsibilities of the department manifold. Some important functions of the department would include the following.
  - Developing policies and norms for private sector participation
  - Developing site and preparing project reports
  - Evaluating and approving private sector projects
  - Monitoring of projects and facilitation of project completions
  - Resolving disputes

3 Implementation of large hydropower projects
- Includes implementation of ongoing and planned projects

4 Management and coordination of National Load Despatch Centre

MODELS FOR RENEWABLE ENERGY AND THEIR USEFULNESS AND LIMITATIONS WITH RESPECT TO BHUTAN

Various financial and business models, which are successfully used in market-based country situation for delivering solar photovoltaic systems are as follows.

Direct Cash Sales Model

- The consumer buys the renewable energy system by either paying cash or by arranging the dealer credit.

- The end-user immediately becomes the owner of the system.

Credit Sales Model

- The model involves a specialist finance partner, along with a maintenance contract during the finance term.
- End-user acquires the renewable energy system on credit. Credit sales are divided into three categories.
  1 *Dealer Credit Model* On receiving all the payments for an renewable energy system through credit arrangements, renewable energy dealer/ supplier sells renewable energy system/s to end-user and the end-user immediately becomes the owner of the system.
  2 *End-user Credit Model* After providing third party consumer credits to the end-user, renewable energy dealer/supplier sells the renewable energy system to the end-user. Usually, the end-user becomes the owner of the system immediately, but this can be delayed until all the payments are made. The renewable energy system is used as a collateral against the loan.
  3 *Lease/Hire Purchase Model* The solar photovoltaic supplier/dealer or a financial intermediary leases the photovoltaic system/s to an end-user. At the end of the lease period, ownership may or may not be transferred to the end-user, depending on the agreement. During the lease period, the leaser remains the owner of the system and is responsible for its maintenance and repair.

Fee-for-Service Model

- A large-scale 'utility–type' approach that usually involves providing subsidies to users.
- An energy service company (ESCO) owns the system and provides energy service to end-user, who pays a periodic fee (for example, monthly) to ESCO.
- The end-user is not responsible for the maintenance of the system and never becomes the owner.

Concession Model

- Structurally identical to the Fee-for-Service Model, with the only difference being the concession availed to serve specified region with some degree of monopoly.
- Concessionaire and regulatory-type model approach to rural electrification is being tested in many countries and maybe more suitable for rural off-grid electrification.

Rural Energy Service Concession Model

Bhutan has developed Rural Energy Service Concession Model (RESCOM), which is a combination of Fee-for-Service Model and Concession Model.

With this approach, consumer would not be required to make his own payment, and quality of services is systematically assured. This modified model also enables the development of market for renewable energy technologies by creating a critical mass essential for making commercially sustainable business. Rural energy service provider operator will be selected through bidding for it to have concessional exclusive rights, being technically and financially qualified service provider for a specific region for a specific period of time.

By effective application of RESCOM, Bhutan is planning off-grid electrification of 4000-8000 households by 2013.

Getana Model

The Getana Model has been implemented by the Department of Energy (DoE) with the purpose of demonstrating a scheme for community-based solar photovoltaic energy services. Figure 1 shows the framework and other details of the Getana Model.

HYDROPOWER AND CLIMATE CHANGE

The recently released Intergovernmental Panel on Climate Change (IPCC) assessment reports have established the phenomenon of global warming beyond any doubt. The climate change may bring about a tremendous impact on the high mountainous glacial environment like that in Bhutan. Many of the big glaciers melt and form glacial lakes. The global warming induces faster

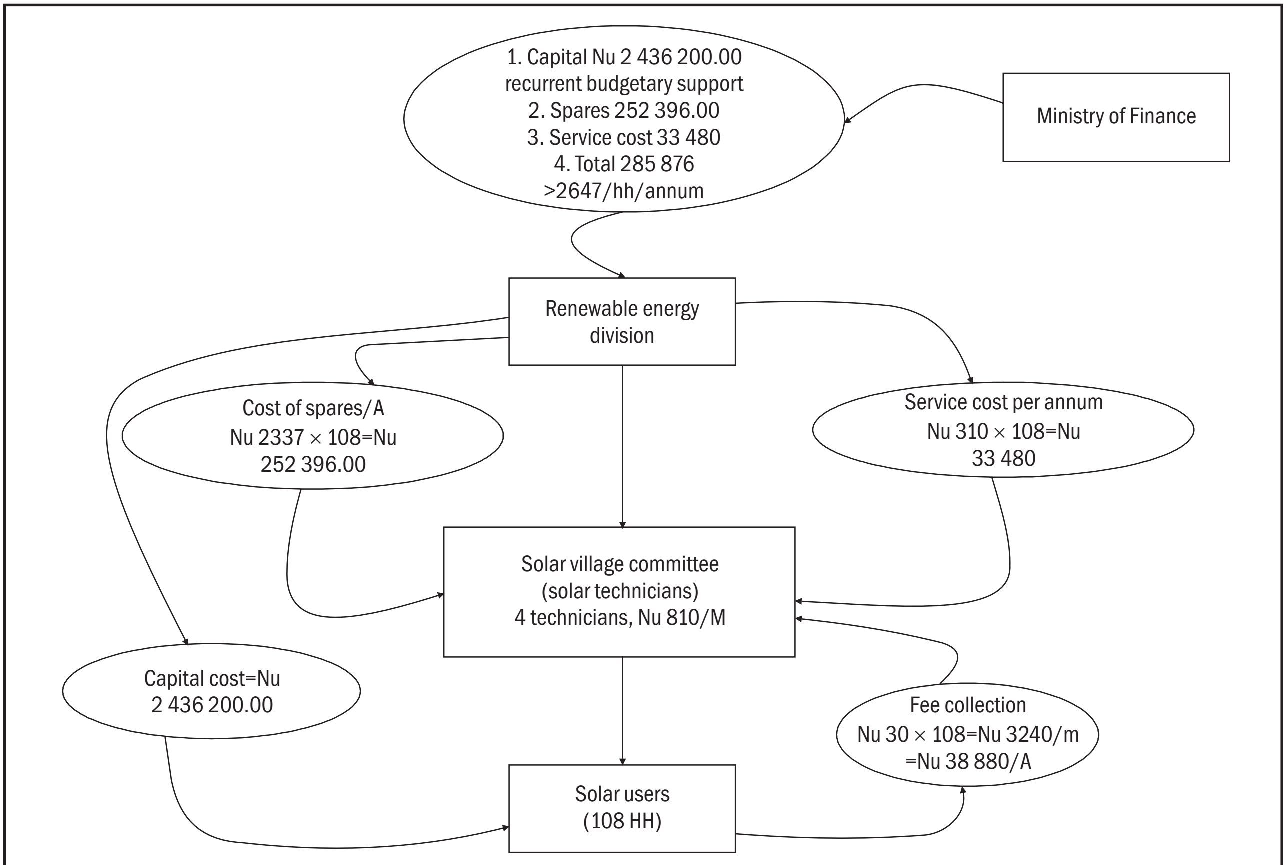


FIGURE 1 GETANA MODEL

rate of ice and snow melting, leading to a rapid level rise in these lakes. The sudden discharge of large volumes of water and debris from the glacial lakes – known as glacial lake outburst flood (GLOF) – could cause flooding downstream. The GLOF can severely damage hydropower plants. This had happened in Nepal in 1985 when the Dig Tsho GLOF destroyed the Namche small hydropower project.

It is recommended, therefore, to set up 'Glacial Lake Outburst Flood Monitoring and Early Warning System' to continuously monitor the likely GLOF hazards and take early preventive actions. Towards this end, Bhutan may work with the United Nations Environment Programme (UNEP); the International Center for Integrated Mountain Development (ICIMOD), Nepal; National Remote Sensing Agency, India; and Asian Institute of Technology, Bangkok. Such a system would also help in assessing the environmental condition of the high mountainous regions.

THE 'DUTCH DISEASE'

As detailed elsewhere in this report, the export of hydropower is the mainstay of the Bhutanese economy. In a classic economic parlance, such a situation might lead to 'Dutch disease'. A natural resource-based export boom can cause major distortions in an economy by discouraging production and investment in the non-booming exportables sector, often referred to as 'Dutch disease'.[1] However, the studies show that there is no evidence of a stagnation of the non-power tradable sector so far.

Nonetheless, it would be prudent to take the necessary preventive measures. Given the fact that Bhutan is blessed with so many natural resources that can be utilized both for value-added

[1] Kojo N C. Bhutan: Power Exports and Dutch Disease. Centre for Bhutan Studies. Monograph #16. 2005

products and for power generation, the focus may be concentrated on such decentralized cottage industries. Therefore, there is a need to shift focus from large, power-intensive industries to small, village-level industries. Such industries can be established around decentralized power plants based on small hydro, biomass, and solar energy. Such an approach would also help in minimizing the migration of the rural populace to cities.

Besides, taking advantage of cheap and abundant electricity, clean environment, and the educated youth, Bhutan may establish itself as a hub for service-oriented exports (for example, software, business, and knowledge process outsourcing). This may fetch much more revenue than the plain exports of electricity. Needless to say, this would also result in the creation of job opportunities for the local youth.

ENERGY AND MDGS

The Millennium Development Goals (MDGs) reflect an international undertaking to significantly improve the condition of the world's poorest by 2015.

MDGs were drawn from the actions and targets present in the Millennium Declaration that was adopted by 189 nations during the UN Millennium Summit held in September 2000.

Eight MDGs and their 18 quantifiable targets, along with their 48 trackable indicators that were adopted by the UN, can also be compared with the targets and goals set by the Royal Government of Bhutan (RGoB). Table 1 gives a glimpse of the goals and targets of the MDGs.

Four main pillars of Gross National Happiness (GNH) have been elaborated to guide public

Table 1

MDG GOALS AND THEIR TARGETS

MDG goal	*Targets*
Eradicate extreme poverty and hunger	Reduce by half the proportion of people living on less than a dollar a day between 1990 and 2015
	Reduce (between 1990 and 2015) by half the proportion of people who suffer from hunger
Achieve universal primary education	Ensure that by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary education
Promote gender equality and empower women	Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015
Reduce child mortality	Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate
Improve maternal health	Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio
Combat HIV/AIDS, malaria and other diseases	Have halted by 2015 and began to reverse the spread of HIV /AIDS
	Have halved by 2015 and begun to reverse the incidence of malaria and other major diseases
Ensure environmental sustainability	Integrate the principles of sustainable development in country policies and programs and reverse the loss of environment resources
	Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation
Develop a Global Partnership for Development	Develop further an open rule-based, predictable, nondiscriminatory trading and financial system.
	Address the social needs of the Last Developed Countries' exports.
	Address the special needs of landlocked developing countries and small island developing states.
	Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term.
	In cooperation with developing countries, develop and implement strategies for decent and productive work for youth.
	In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries.
	In cooperation with the private sector, make available the benefits of new technologies especially information and communication technologies.

policy: equitable socio-economic development, conservation of the natural environment, promotion of cultural heritage, and establishment of good governance.

GNH is based on the belief that the pursuit of happiness is the inherentt desire of every human being, and that of every citizen of the kingdom. The concept suggests a much broader, comprehensive, and balanced approach to development.

The operationalization of GNH, which entailed transposing cultural, social, spiritual, and environmental consciousness into development, has been conducted in Bhutan, essentially through five year plans.

THIMPHU AS SOLAR AND RENEWABLE ENERGY CAPITAL CITY BY 2015

Target is to meet more than 90% energy needs from renewables in all sectors

Thimphu energy balance

Thimphu Dzongkhag has urban energy consumption in the residential and commercial sectors.

Major areas: Residential and commercial

Energy consumption areas

Plan – Phase I

Develop plan for transport sector fuel replacement/reduction

- Reduce intra-city vehicle movement
  - Improve public transport
  - Curb on vehicle movements
    - o Car free Sunday
    - o Create public awareness and opinion about energy efficiency and pollution due to vehicles
    - o One family one vehicle
      - Second/third vehicle can be an electrical vehicle
- Introduce electric mass transport vehicles
  - Mini busses with frequent trips
  - Designated areas for electric bikes/
    - o Point to point electric/hybrid car service
      - Tourism initiative
- High quality vehicles to attract tourists
- Encourage tourists to travel within city on trendy electric vehicles specially designed for Bhutan tourism
- Other alternate fuels
  - Natural gas in border areas
  - Natural gas /hydrogen vehicles in Thimphu
    - o Global Environment Facility (GEF)/Clean Development Mechanism (CDM) project
  - Trolley ropeways from Motithang to main city centres
    - o Feasibility study can be taken up

Small-scale industries

Use of natural gas by 2015

South Asian Association for Regional Cooperation (SAARC) has initiated the process of developing regional grid and gas pipeline network among SAARC countries, which may be persuaded earnestly.

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