BANGLADESH

TECHNOLOGY NEEDS ASSESSMENT AND TECHNOLOGY ACTION PLANS FOR CLIMATE CHANGE MITIGATION

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FOREWORD

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) identifies Bangladesh as one of the worst victims of climate change, although it is one of the lowest per-capita emitters historically and currently.

In addressing climate change, Bangladesh prepared national policies and strategies to make its major development sector climate-resilient and also to mitigate green house gas mitigation from the potential sectors. For example the 'Bangladesh Climate Change Strategy and Action Plan-BCCSAP-2009' identified a number of mitigation measures for short- and medium-term implementation.

Though it is not obligatory for Bangladesh to reduce emission of green house gas and undertake low carbon development path but the country is committed to a low carbon development path, provided the process does not put additional burden on its already overstressed economy and financial capacity and is a win-win option for it with assured adequate international support. Already, dialogues are on internally in Bangladesh with stakeholders for evolving a "green development" concept that promotes a "green economy" and provides "green jobs" in the future. But it has to be in the context of Bangladesh's priorities for accelerating economic growth, poverty reduction, social emancipation and sustainable development.

Undertaking of low carbon development measures especially ensuring energy efficiency and promoting renewable energy also have positive impact on the national economy as it will reduce import cost of primary energy. While technology is important from emission reduction but technology, alone, is insufficient. The enabling environment is needed, including having the right policies in place that create the right incentives.

I found the sectors and projects that have prioritized in TNA Bangladesh mitigation report are quite similar to the sectors and projects emphasized in the BCCSAP. I strongly believe that the implementation of mitigation projects prioritized at the TNA Mitigation report will contribute to the global effort of green house gas mitigation.

I thank TNA National Team, my colleagues in the Ministry, experts of the relevant sectors for their invaluable contribution in the development of this report. I sincerely acknowledge the contribution of the project personnel and experts of UNEP, GEF, UNEP RISO Center and AIT for their relentless effort in the implementation of TNA project and come-up with some specific and prioritized measures for climate change mitigation in Bangladesh.

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PREFACE

There are two broad areas of policy action, globally as well as nationally, to face climate change; one is mitigation which calls for actions to lower and ultimately stop the emission of green house gases into the atmosphere and the other one is adaptation which relates to minimization of the adverse impacts of climate change and associated vulnerabilities.

Within this overall climate change context, both mitigation and mitigation involve use of technology and its management (development, transfer, adaptation, adoption and diffusion) along with other related aspects such as financing. In the global context technology development and transfer has increasingly gained a centre stage in the agenda of negotiations. While in the country context, technology needs assessments (TNA) become as an important management tool for a country in formulating development strategies as well as to identify Nationally Appropriate Mitigation Actions (NAMAs).

Bangladesh, being one of the most vulnerable countries to climate change and though its contribution to the generation of green house gas is miniscule, wishes to play its part in reducing emission now and the future.

Bangladesh Climate Change Strategy and Action Plan 2009 emphasizes 'Mitigation and low carbon development' and identified a series of activities to reduce Bangladesh's carbon emission, now and in the future, including inter alia: a) development of a strategic energy plan and investment portfolio to ensure national energy security and lower greenhouse gas emissions and b) Seek the transfer of state-of-the-art technologies from developed countries to ensure that Bangladesh follows a low-carbon growth path.

In line with the Climate Change Strategy and Action Plan, Bangladesh, with the assistance of UNEP, undertook Technology Needs Assessment (TNA) project to identify the needs for new equipment, techniques, practical knowledge and skills, which are necessary to mitigate GHG emissions and to undertake low carbon development path.

Briefly, this project aims to produce Technology Needs Assessment (TNA) and Technology Action Plans (TAP) for climate change mitigation in Bangladesh. This report provides a list of prioritized the sectors that have potentials for the mitigation of GHG emission. This report also identified a number of mitigation technologies for the sectors having GHG mitigation potentials.

The TNA process in Bangladesh has followed participatory analysis and consultation with the sector-specific relevant experts and stakeholders. I thank all of my colleagues, experts and stakeholders who were involved in TNA and contributed in this report.

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ACKNOWLEDGMENTS

Technology Needs Assessments Report, Part I is an outcome of efforts of a number of people, who shared their experiences and views on the impact of impacts of climate change in important development sectors, discussed number of technological options of GHG mitigation potentials of country's energy and non-energy sectors.

Special acknowledgement is to due to the members of National TNA Team namely Dr Rezaul Karim, Environmentalist and Team Leader of National TNA Team, Dr M Asaduzzaman, Research Director, Bangladesh Institute of Development Studies, Dr Ainun Nishat, Vice Chancellor, BRAC University, Dr Ijaz Hussain, Professor, Bangladesh University of Engineering and Technology, Dr Iqbal Hussain, Assistant Professor, Bangladesh University of Engineering and Technology, Dr AKM Saiful Islam, Associate Professor, Bangladesh University of Engineering and Technology and Mr Md Shamsuddoha of Center for Participatory Research and Development (CPRD).

Acknowledgement is also due to experts and stakeholders of different government and non-government organizations who have participated in the national and local level consultations and provided substantive input throughout the TNA process.

Special thanks to Dr P Abdul Salam , Assistant Professor, Energy Field of Study, School of Environment, Resources and Development, Asian Institute of technology and Dr Mokbul Morshed Ahmed, Associate Professor, Regional and Rural Development Planning, School of Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand and Mr Sudhir Sharma, Senior Climate Change Expert, UNEP RISO Centre for their comments, suggestions and technical inputs while implementing the TNA project in Bangladesh.

Sincere acknowledgement is due to the project personnel of UNEP, GEF, UNEP RISO Center and AIT for their technical support and constructive feedback in all aspect of TNA implementation.

Sincere acknowledgement is also due to Mr Meshba ul Alam, Former Secretary, Ministry of Environment and Forests, Mr Shafiqur Rahman Patwari, Secretary, Ministry of Environment and Forests and to Mr Aparup Chowdhury, Additional Secretary, Ministry of Environment and Forests for their guidance and encouragement in the implementation of TNA project in Bangladesh.

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ABBREVIATIONS AND ACRONYMS

AIT	Asian Institute of Technology
ABWR	Advanced Boiling Water Reactor
ALGAS	Asia Least Cost Greenhouse Gas Abatement
APC	Advanced Pulverised Coal
BCSIR	Bangladesh Council of Scientific and Industrial Research
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BUET	Bangladesh University of Engineering and Technology
BWR	Boiling Water Reactor
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
CC	Closed fuel Cycle
CCC	Climate Change Cell
CEGIS	Center for Environmental and Geographic Information Services
CFL	Compact Florescent Lamp
CNG	Compressed Natural Gas
CCS	Carbon Capture and Storage
CSP	Concentrating Solar Power
EPA	Environmental Protection Agency
ERL	Eastern Refinery Limited
FCK	Fixed Chimney Kiln
FY	Financial Year
GDP	Gross Domestic Product
GENIII	Generation III Reactor
GEF	Global Environment Facility
GHG	Green House Gas
GoB	Government of Bangladesh
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
HFO	Heavy Fuel Oil
HOBC	High Octane Blending Content
HHK	Hybrid Hoffmann Kiln
IFRD	Institute of Fuel Research and Development
IGCC	Integrated Gasification Combined Cycle
INC	Initial National Communication
IPPs	Independent Power Plants
IPCC	Intergovernmental Panel on Climate Change
LDC	Least developed country
LEDs	Light Emitting Diodes
LF	Linear Fluorescent lamp
LPG	Liquid Petroleum Gas
MCDA	Multi Criteria Decision Analysis
MDGs	Millennium Development Goals
MoEF	Ministry of Environment and Forests

MSW	Municipal Solid Wastes
MW	Mega Watt
NOx	Nitrogen Oxides
N_2O	Nitrous Oxide
NAMAs	Nationally appropriate mitigation actions
NGCC	Natural Gas Combined Cycle
NMVOCs	Non-Methane Volatile Organic Compounds
OT	Once through fuel cycle
PFC	Perfluorocarbons
PHWR	Pressurized Heavy-Water Reactor
PIU	Project Implementation Unit
PRDI	Participatory Research and Development Initiative
PV	Photo Voltic
PWR	Pressurized Water Reactors
RE	Renewable Energy
RPGCL	Rupantarito Prakritik Gas Co. Ltd
R&D	Research and Development
SO_2	Sulphur-di-oxide
SEC	Specific Energy Consumption
SGFL	Sylhet Gas Fields Ltd
SFYP	Sixth Five Year Plan
SHS	Solar Home System
SNC	Second National Communication
TNA	Technology Needs Assessments
UFG	Unaccounted for Gas
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
URC	UNEP RISO Centre
VSBK	Vertical Shaft Brick Kiln
VVER	V*odo-Vodyanoi Energetichesky* Reactor

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Part I

Technology Needs Assessments for Climate Change Mitigation in Bangladesh

Executive summary

The First Part of the Technology Needs Assessments Report aims to identify and short-list prioritized sectors, sub-sectors that have maximum potential for mitigation in the light of country's long-term development policies. This report also identified and prioritized sector-specific mitigation technologies that have synergies with the long term country's development priorities i.e. making the country's prioritized sectors resilient to climate change vulnerabilities now and in the future and undertaking clean development path.

This report has been prepared through a consultative process with the involvement of stakeholders from government and non-government organizations of the relevant sectors and sub-sectors prioritized for TNA. In the TNA consultation process, stakeholders from a wider sector and also from the grass-root level have been involved to identify new knowledge, especially local knowledge, and insights on specific technology challenges and opportunities. Aside with stakeholder consultation, a number of policy documents, for example the country's Sixth Five-Year Development Plan (2011-2015 prepared in 2011) and Bangladesh Climate Change Strategy and Action Plan (BCCSAP) prepared in 2009, Second National Communication prepared in 2011 and Vision 2021 etc. have analyzed in identifying and prioritizing the sectors potential for mitigation benefits and adaptation necessities.

Thus, in view of country's efforts to undertake and follow low carbon development path as stated in the BCCSAP, and to realise the targets set for vision 2021 and the Sixth Plan, the sectors/sub-sectors of Energy Sector, especially power generation, has been prioritized for mitigation to meet the rising energy demand.

> Power Generation technology options includes; i) Natural gas combined cycle, ii) Solar home PV, iii) Advanced combustion turbine, iv) Advanced natural gas combined cycle, v) Integrated Gasification Combined Cycle (IGCC) Single unit, vi) Integrated Gasification Combined Cycle (IGCC) Double unit, vii) Advanced Pulverized Coal (APC) Single Unit, and viii) Advanced Pulverized Coal (APC), Double Unit
>
> On the other hand, the technology options for power use include; i) Compact fluorescent lamp (CLF) and ii) Linear fluorescent lamp (LF)

The criteria for selecting mitigation measures priorities have been established by exploring what extent investments in technologies for mitigation would contribute to emission reduction in the context of country's aspiration of achieving sustainable development goal. Thus, the basic criteria for technology prioritization for mitigation measures are: development benefits, implementation potentials and contribution to climate change response goals.

Development benefits define climate change mitigation technologies which offer the greatest value to the country in meeting its current national development priorities. Implementation potential defines scale of implementation and diffusion of the technology which can be realistically achieved if key barriers are overcame. Contribution to climate change response goals defines technologies which will make the biggest contributions to the country's efforts for facilitating to undertake clean development path that will contribute to the global mitigation effort.

CHAPTER 1: Introduction

1.1 Background of Technology Needs Assessment (TNA) report

Bangladesh is widely recognized to be one of the most vulnerable countries in the world to the impacts of climate change. The country is already experiencing the adverse impacts-hotter summers, irregular monsoon, untimely rainfall, heavy rainfall over short period causing water-logging and landslides, little rainfall in the dry season, increased river flow and inundation during monsoon, coastal erosion and river bank erosion. Apart from the changes in weather pattern, Bangladesh is facing with increased frequency, intensity and recurrence of floods, crop damage due to flash floods and monsoon rain, crop failure due to drought etc. Salinity intrusion along the coast leading to scarcity of potable water and redundancy of prevailing crop practices (CCC, 2008).

The Government of Bangladesh not only recognizes the vulnerability of the country, its people and overall development, to the adverse effects of global warming and climate change but also included the issue in the country's overall development and policy planning. The GoB has prepared the Vision 2021 which is based on the principle of sustainable development.

Besides, Vision 2021 and the Sixth Five Year Development Plan of the government of Bangladesh are based on the principle of sustainable development i.e. management of climate change for uninterrupted and sustainable development. Very briefly, it is to eradicate poverty, increase employment opportunity, ensure food security, provide access to energy and power, and achieve economic and social well-being of all citizen of the country. Bangladesh will achieve this goal through a strategy of pro-poor, climate resilient and low carbon development based on the four buildings blocks of the Bali Action Plan-adaptation to climate change, mitigation, technology transfer and adequate and timely flow of funds for investments within an inviolate framework of food, energy, water, livelihoods and health security.

The Government of Bangladesh also undertook a more comprehensive planning process, with its own financial and intellectual resources and prepared Bangladesh Climate Change Strategy and Action Plan (BCCSAP) in 2008. The Climate Change Strategy and Action Plan (BCCSAP) of Bangladesh is a part of the overall development strategy of the country (MoEF, 2009). The BCCSAP outlines the core policy, strategy, and action thrusts as a mechanism to respond to and address the risks related to climate change. The climate change constraints and opportunities are being integrated into the overall plan and programmes involving all sectors and processes of economic and social development. The BCCSAP outlines 44 programmes under six thematic areas, one of which is mitigation and undertaking low carbon development path. The Government of Bangladesh is committed to undertake low carbon path without compromising the need for accelerated economic growth and poverty reduction.

To identify, evaluate (feasibility of) and prioritize technological means for required mitigation actions, Ministry of Environment and Forests (MoEF) of the Government of Bangladesh, with the assistance from UNEP, has been implementing Technology Needs Assessment project started in January 2011.

It is important that the eventual technology choices are clearly in line with the long-term country's development priorities and are intended to make country's prioritized sectors resilient to climate change vulnerabilities now and in the future. In this context, the TNA team, following a consultative process, identified the country's development priorities based on identified country's development priorities as part of national development strategies, such as the Sixth Five-Year National Plan, Poverty Reduction Strategies, Bangladesh Climate Change Strategy and Action Plan, Sector Policies, and National Communications.

Therefore, the priorities for achieving sustainable development are outlined as: ensuring broad-based growth and food security, providing energy security for development and welfare and building a sound infrastructure.

Based on these official publications, the TNA National Team generated a list of development priorities which they considered most applicable to the country's sustainable development, with a view to both the short and longer term, for the purpose of guiding technology needs assessment.

1.2 Objectives of TNA report

The key objective is finalizing a short-list of prioritized (sub) sectors in the light of the country's long-term development policies and according to the maximum potential for mitigation of the prioritized sectors.

The specific objectives are;

i) Identify country's development priorities through reviewing of long-term development policies and respective strategies

ii) Identify possible implications of climate change on the country's development priorities

iii) A short-list of sectors according to their development benefits and GHG reduction potentials and whether sectors have a balanced sustainable development contribution and deliver the maximum benefits.

CHAPTER 2: Institutional arrangement for the TNA and the stakeholders' involvement

2.1 Process followed in TNA

Technology needs assessment is aimed at prioritizing technologies for mitigation and adaptation in the light of countries' development objectives and to explore how this could be fed into strategic development plans at the country level. TNAs are likely to form a key element and information on how technologies may contribute to long-term development goals, their costs, and appropriateness for reduction of GHG emission from the potential sectors.

In this context, it is important to identify country's development priorities which could be used as criteria for selecting strategic sectors for GHG mitigation. The National Team for coordinating technology needs assessments has undertaken the following activities in four states to identify sectors/ sub-sectors for technology needs assessment for climate change adaptation and mitigation actions.

STAGE I: Knowing country's development priorities through a broader reflection on national economy and long-term development policies

STAGE II: Implications of Climate Change on Country's Development Priorities

STAGE III: Clustering Development Priorities

STAGE IV: Initial Identification of priority Sectors potential for GHG mitigation

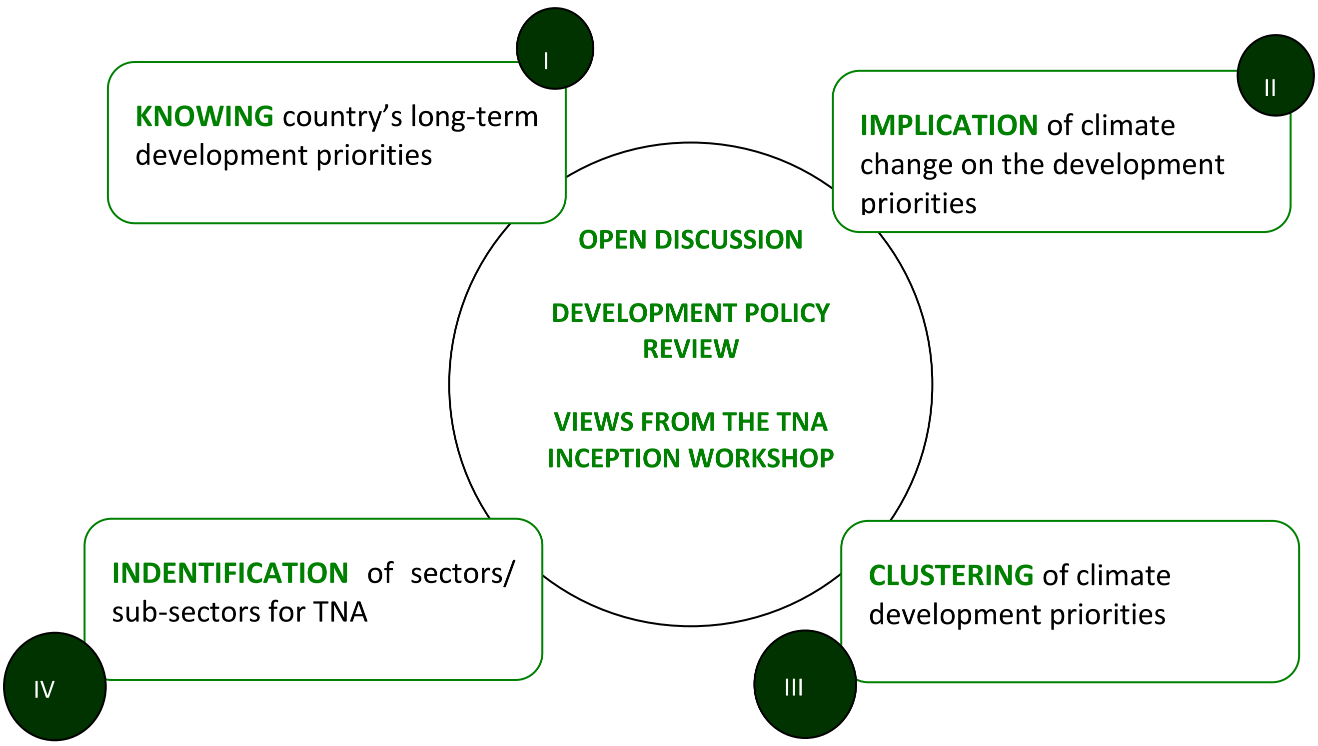


Figure 1: Stages of TNA Sector Prioritization

2.2 Institutional structure for implementation of TNA

With the overall policy guidance of the National Project Coordinator and the National Steering Committee for TNA, PRDI, a research based development organization, has been leading implementation of the TNA through facilitating a coordinated effort of several renowned climate experts in the country who have substantial experiences in the climate change mitigation and adaptation actions; have sector-specific specialization in country's sustainable development planning. The expert team comprises of 5 members who are familiar with national development objectives and sector policies, overall insights in climate change science, and potential climate change impacts for the country, and adaptation needs. Aside with the five-member expert team, there is also flexibility to accommodate additional experts, whenever needed. *Details of National TNA Team provided in Annex 2.*

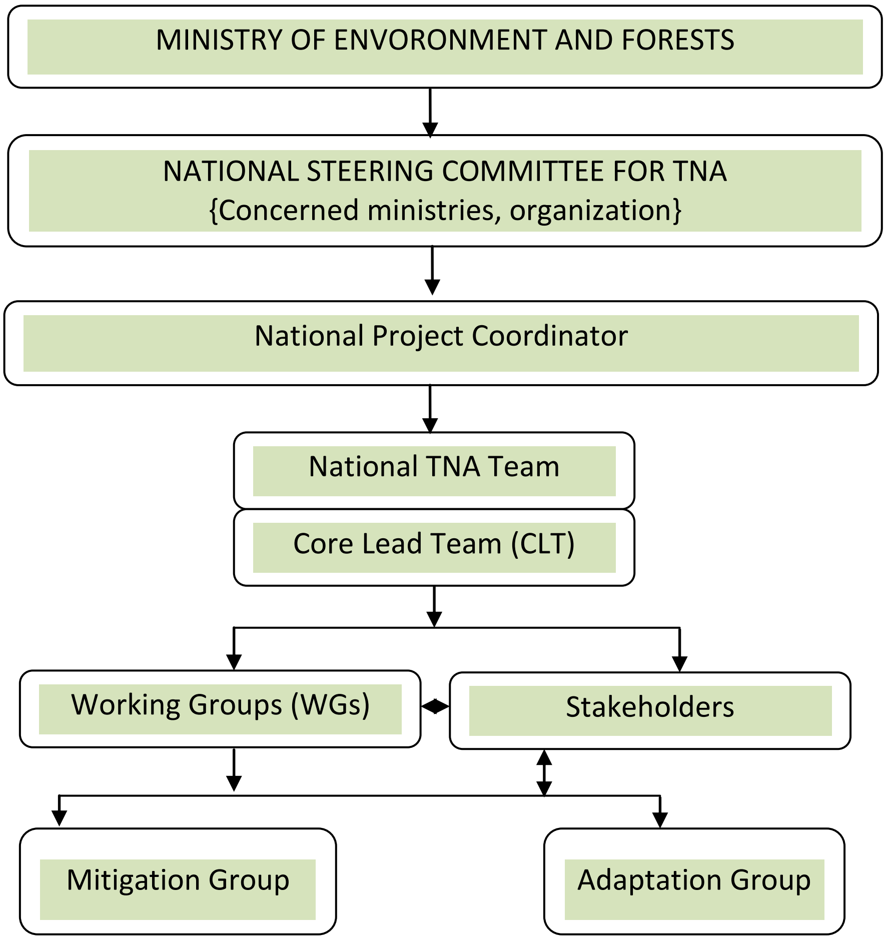


Figure 2: The institutional structure for TNA

The TNA team includes a Team Leader who for many years has been participating in the negotiation on technology transfer of the UNFCCC and also contributing to country's policy process on technology innovation and transfer for change mitigation and adaptation actions. The Team Leader has provided vision and leadership for the overall effort, facilitating communication with the National TNA Team members.

A Project Implementation Unit (PIU) has been established at PRDI to provide support as needed for project execution, especially in organizing workshops, focus group organization, and discussion moderation. The PIU has ensured implementation of stakeholder consultations, both in national and local level, has coordinated tasks among the TNA Team members and also has provided the required logistics to the TNA Team members.

The PIU has hired required professionals (e.g. Task Coordinator, Technology Assistants and requited other staff) to assist TNA National team in undertaking all activities to realize the project objectives that has included collection, analyses, and synthesis of all available data and information in support of the TNA exercise.

2.3 Stakeholder engagement process followed in TNA – Overall assessment

Stakeholder consultation is the main feature of TNA Figure 3. Consultation in various forms, layer and scale has taken place at various steps. Stakeholders ranged from sectoral experts and professionals from different educational and research institutions government ministries, department and agencies and NGOs.

Stakeholders from relevant sectors have identified and grouped into a core group and sub-groups to deal with specific issues in depth, with links to the core group. These groups represent a network of organizations/institutions/individuals working in the field of technology development and transfer in the country. It has been ensured that stakeholders from wider sectors and also from the grass-root level are engaged in TNA process to contribute to the transfer of new knowledge, especially local knowledge, and insights on specific technology challenges and opportunities.

From a practical point of view, since a large number of people are legitimately classified as stakeholders in some of these categories, only representative members (core team) are involved in the assessment process. They are - Core Lead Team (CLT) and the Working Groups (WGs). The CLT was responsible for overall supervision and guidance, comprised of reputed experts. This team was basically a multi-sectoral expert team. Sectoral experts again leaded respective sectoral/thematic teams (or WGs) responsible for TNA for particular sector. The CLT of stakeholders comprises of 10-15 people from each identified sector potential for climate change adaptation and mitigation measures. The CLT then formed working groups by inviting key personnel/ experts from the relevant sector.

The CLT deals with the most substantive issues of the TNA process such as; management, resource assessment, technology costing and preparation of reports and other materials while the working group participates in consultation and engagement activities, such as workshops, and stakeholders' consultation. Outputs from the CLT consultations are communicated to all stakeholders through workshops and brief meetings. In all aspects, the National TNA Team facilitates the active participation of all relevant stakeholders in the prioritization of technologies.

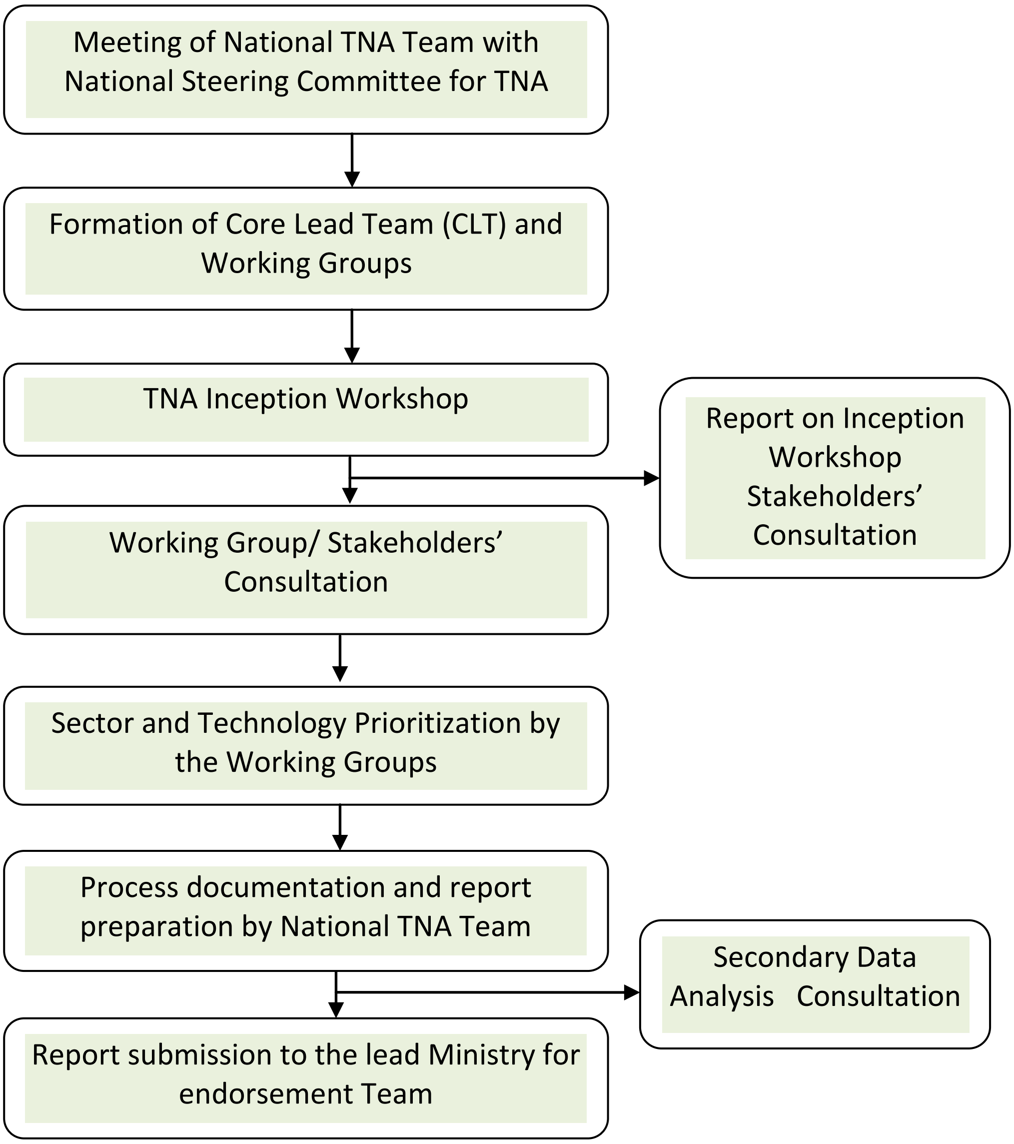


Figure 3: Main feature and snapshot of the whole process followed in TNA

The each working group has reviewed literature, consulted among and beyond and presented preliminary findings to a wider audience during the national consultation workshops. *A list of stakeholders participated in different workshops and meetings are provided in Annex 3.*

CHAPTER 3: The GHG mitigation potentials

3.1 GHG emission status and trends of the different sectors

The GHG assessment for the Second National Communication (SNC) estimated emissions of CO2, CH4 and N2O from the country's energy and non-energy sector. In this portion of the report the emissions of Greenhouse Gases (GHG) from both the energy and non-energy sectors.

The energy sector includes seven sub-sectors, namely - Energy Industries, Manufacturing & Construction, Transport, Residential, Agriculture, Non-Specific Sector (the unaccounted for gas (UFG) and other fuels which were consumed but no specific activities could be identified were placed in this sector) and Commercial Sector. On the other hand, major sub-sectors of non-energy sector are industry, agriculture sector and waste management.

3.1.1 GHG emission from the energy sectors

Table 1 below shows the year-wise summary of CO_2 emission by the different sub sectors under the Energy sector. Among the different fuel consuming sectors, Energy Industries is the highest contributor to GHG emissions, followed by Manufacturing & Construction. Figure 4 shows relative contribution of energy sub-sectors for the year 2005.

Table 1: Sub-sectoral Summary of Energy Sector CO_2 Emission (Thousand Tones)

Energy Sub-Sectors	2001	2002	2003	2004	2005
1. Energy Industries	10,693	11,105	11,223	12,056	12,780
2. Mfg & Construction	8,755	8,728	10,087	10,652	11,276
3. Transport	4,551	4,566	4,585	4,955	5,500
4. Residential	3,811	4,075	4,737	4,974	4,675
5. Agriculture	1,625	1,626	1,597	1,764	1,993
6. Non-Spec Sector	549	1,148	631	1,097	1,426
7. Commercial	226	236	255	266	270
Total Emission from Combustion Activities	30,210	31,484	33,115	35,764	37,920
Fugitive CO_2 Emission	23	24	26	28	30
Grand Total	30,233	31,508	33,141	35,792	37,950

Source: Second National Communication, 2012, MOEF

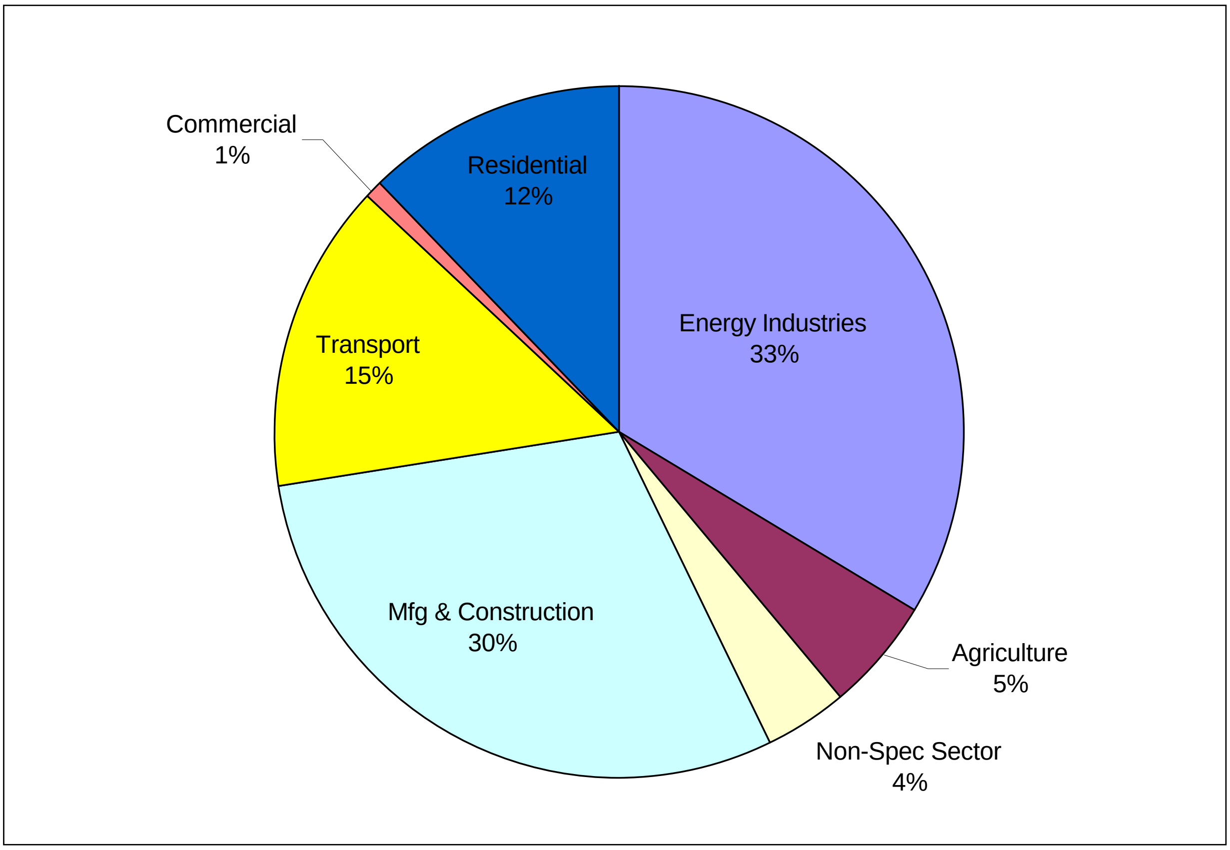


Figure 4: Relative contributions to CO_2 emission by different sub-sectors (2005)

Source: Second National Communication, 2012, MOEF

a) **Energy Industries:** Electricity generation is the only significant CO_2 emission source in the "Energy Industries" category (Table 2). Emission from the petroleum refinery, where furnace oil is used for refining, is significantly less as there is only one refinery in the country of modest capacity. The "Other Energy Industries" include the energy consumption by the gas-fields. Data for internal gas consumption for gas processing has been found for six out of the fifteen gas-fields. The reported amount was 0.1-0.15% of gas production. In the absence of any other data, CO_2 emission for all the other gas-fields has been estimated by assuming that 0.1% of gas production is internally consumed.

Table 2: CO_2 Emission from Energy Industries

Energy Industries	2001	2002	2003	2004	2005
Electricity Generation	10,629	11,042	11,152	11,988	12,713
Petroleum Refining	44	41	47	43	41
Other Energy Industries	21	22	23	25	27
Total	10,693	11,105	11,223	12,056	12,780

b) **Manufacturing & Construction:** CO_2 emission from the manufacturing and construction sector disaggregated to some key industry categories (Figure 5). In Bangladesh, fertilizer, included under the "Chemicals" group, is treated as a separate sector because historically it was the second largest gas consuming sector – second only to the power sector. It was so big that the combined consumption of all industries in the country was smaller than that of the fertilizer sector.

Emission from "Manufacturing and Construction" sector for the year 2005 is presented in a pie diagram (Figure 6). Percentage of emission from the 8 categories of industry shown in pie diagram shows that Brick, Textile & Leather, and Chemicals (Fertilizer) industries together contribute 83% of the total emission of this sub-sector. Steel & Iron, Food, Beverage & Tobacco and Non-metallic Minerals each have only a 2% share of the total CO_2 emissions.

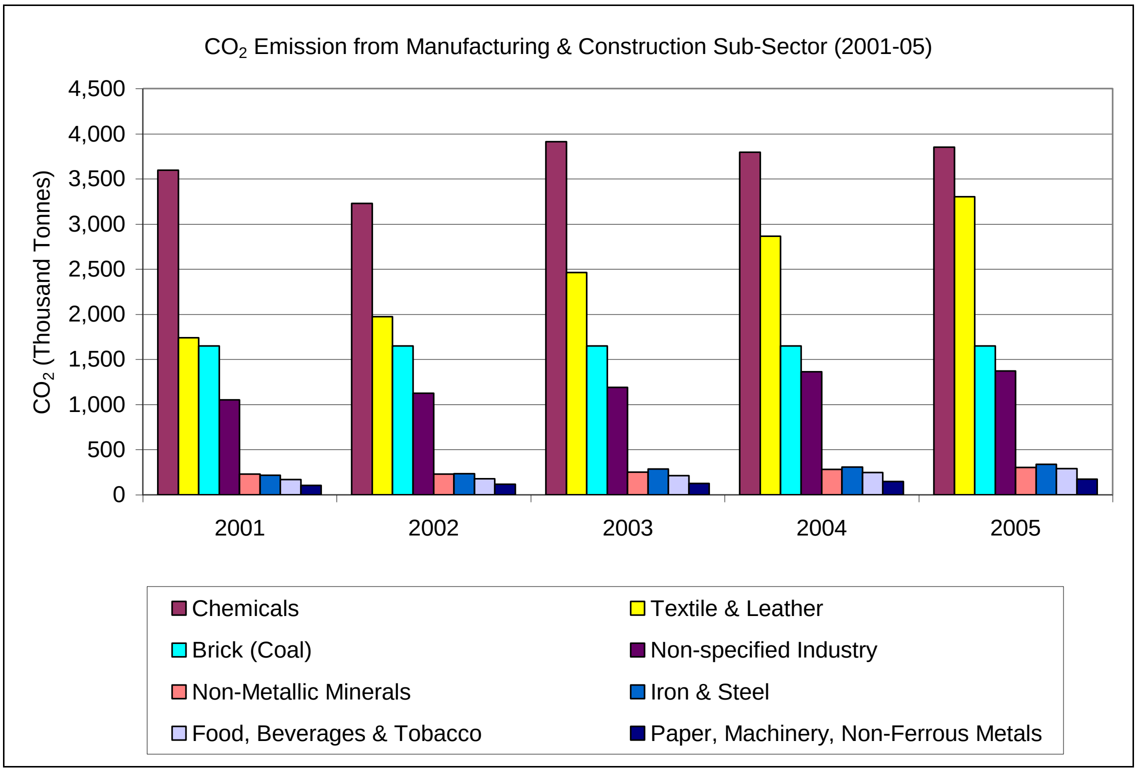


Figure 5: Emission from industries under the "Manufacturing & Construction" subsector

Source: Second National Communication, 2012, MOEF

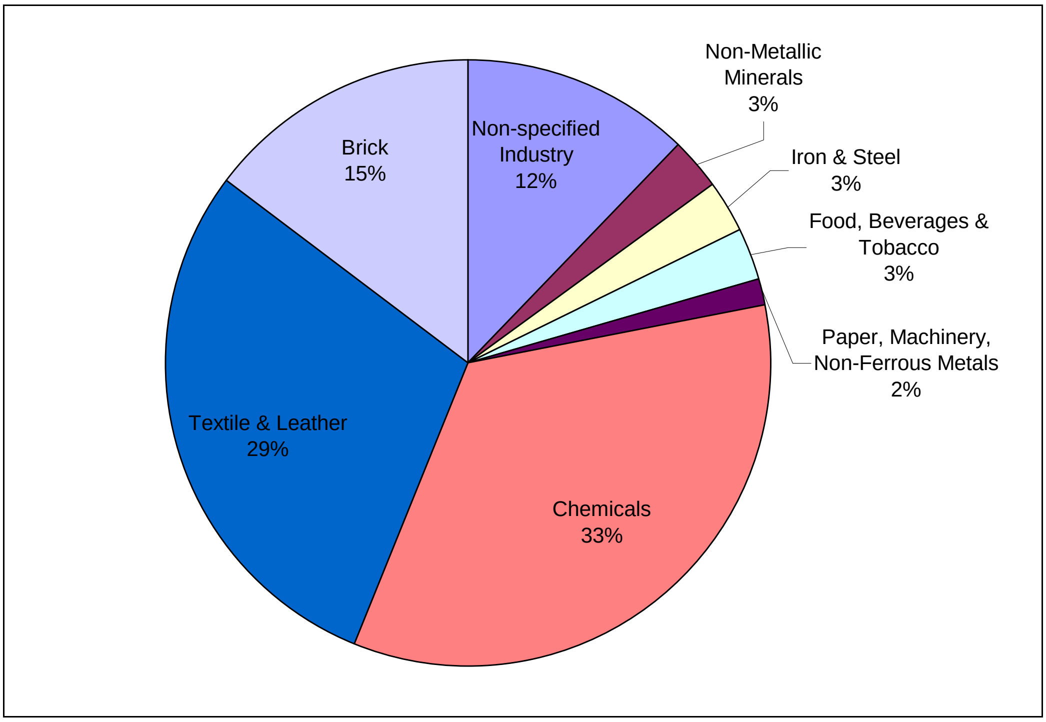


Figure 6: Emission from the "Manufacturing & Construction" subsector (2005)
Source: Second National Communication, 2012, MOEF

c) **Transport:** Figure 7 gives a breakdown of emissions from the transportation sector, while Figure 8 shows the relative contributions of the different transportation modes. It is observed that approximately two-thirds of emissions come from "Trucks & Buses."

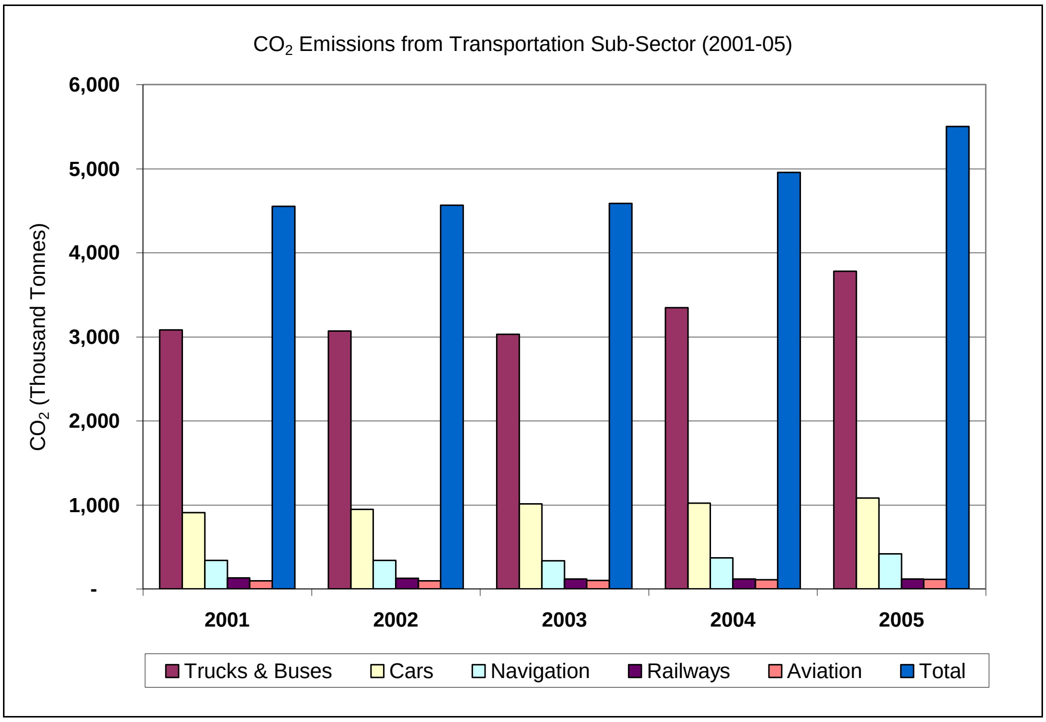


Figure 7: CO_2 Emission by different types Transportation
Source: Second National Communication, 2012, MOEF

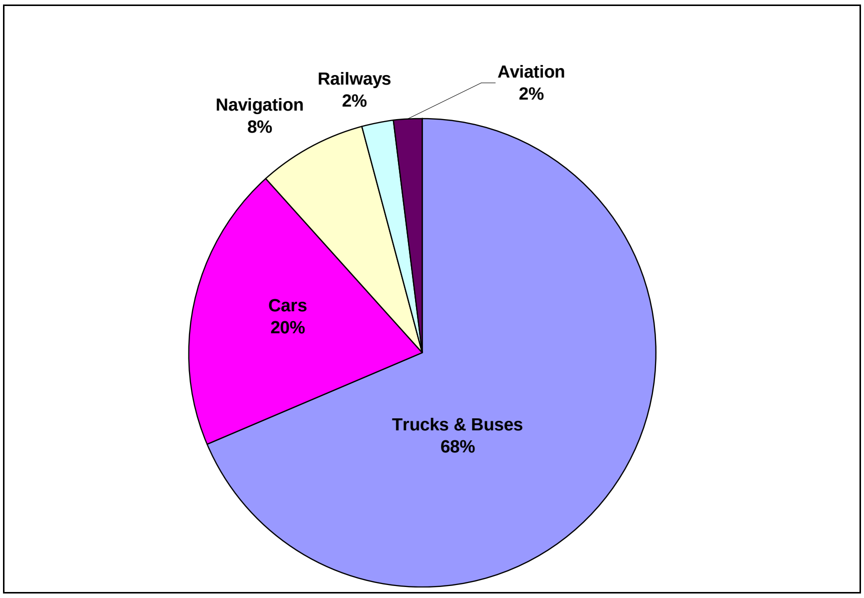


Figure 8: CO_2 Emission by different Transportation Modes (2005)
Source: Second National Communication, 2012, MOEF

d) **Residential & Commercial:** The Commercial sector consumes only natural gas, while the residential sector consumes LPG, natural gas and kerosene. Natural gas and LPG is used mainly for cooking, kerosene is mainly used by rural households for lighting.

Table 3: CO_2 Emission from Residential and Commercial Sectors

Sector	Fuel	2001	2002	2003	2004	2005
Commercial/ Institutional	Natural Gas	226	236	255	266	270
Residential	LPG	61	60	66	68	64
	Natural Gas	1,772	2,044	2,497	2,748	2,920
	Kerosene	1,978	1,971	2,174	2,158	1,691
Residential Total		3,811	4,075	4,737	4,974	4,675

Source: MOEF Second National Communication, 2012

e) **Agriculture:** The main fuel consuming activity is water-pumping using diesel pumps for irrigation. It is assumed that 80% of the diesel consumed in the agriculture sector has been used for irrigation, and the rest in operating other farm equipment such as power tillers, tractors and rice/wheat threshers. The results are shown in Figure 9.

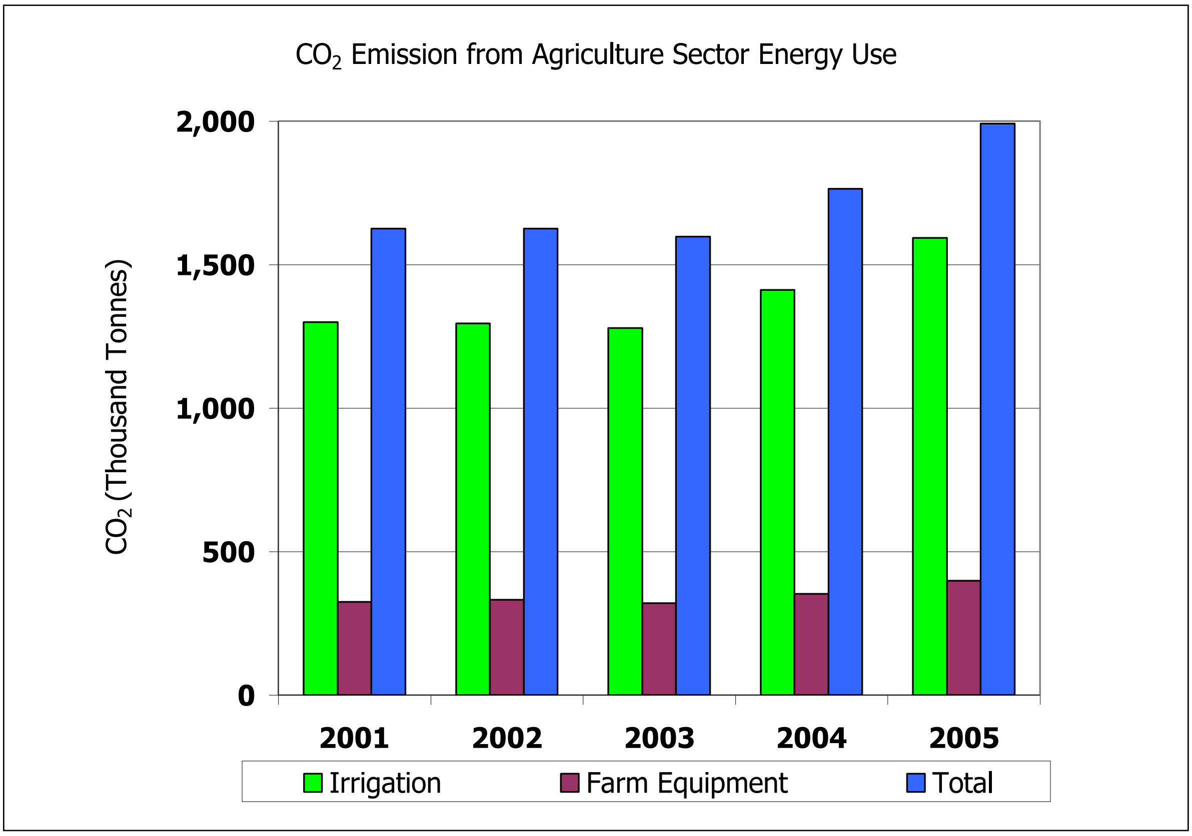


Figure 9: CO_2 Emission from Agriculture Sector energy Use
Source: Second National Communication, 2012, MOEF

f) **Non-Specified Sector:** The unaccounted for gas (UFG) and other fuels which has been consumed, but no specific activities could be identified,is placed in this sector. In reality this is not a sector, but for accounting purpose this is convenient because otherwise the inventory would be incomplete. Table 4 and Figure 4 show the calculated emissions from the Non-Specified sector. It is worth emphasizing that a substantial quantity of gas, assumed to be oxidized, is involved here. The contribution of this sector is more than the commercial sector, and in the year 2005 the emission from this sector is comparable to that of the Agriculture sector, as is evident from Figure 4.

3.1.2 GHG emission from the non-energy sectors

a) Emission from Industry Sector

Major GHG emitting industries in Bangladesh

- Mineral industry: Clinker production (for cement production), lime production, soda ash production and use, asphalt roofing production & use and glass industry
- Chemical industry: Ammonia and urea fertilizer
- Metal production: Steel and ferroalloy production
- Food products: Soft drinks, alcoholic beverages, sugar and bread

Table 8 and Figure 10 show CO_2 emissions from industries in the years 1990 (ALGAS), 1994 (INC), 2001 and 2005 and the SNC

Table 4: CO2 emission from industries in 1990, 1994, 2001 and 2005

Year	CO_2 emission (Gg)
1990	1491
1994	1281.46
2001	2915.87
2005	2912.72

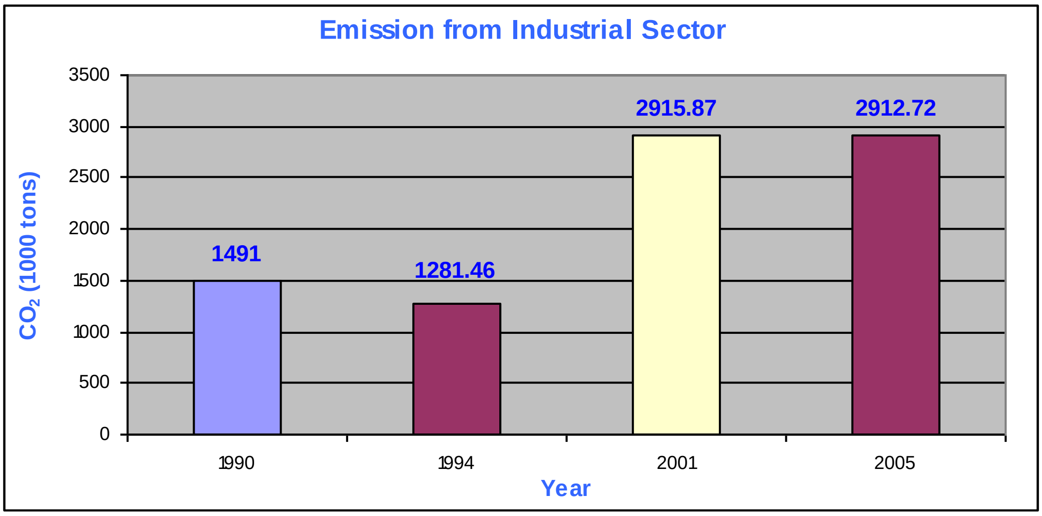


Figure 10: Emission from industrial sectors in 1990, 1994, 2001 and 2005
Source: Second National Communication, 2012, MOEF

It is seen that CO_2 emissions in the years 2001 and 2005 have increased by a factor of about 2 when compared with the value for 1994. All the industries were in operation in 1994 also. The higher value may be attributed to increased rate of production or uncertainties on the previous calculation. In 2001 and 2005, type and number of industries have remained the same and as such emission status have not changed much.

b) Emission from Agriculture Sector

Methane (CH4) emission from cultivated rice fields: In Bangladesh, paddy is cultivated three times a year in most of the areas. Considering growing season of paddy, it is familiar as Aus (May to August), Aman (July – December) and Boro (December – May). Estimations of CH_4 for the years 2000-01, 2001-02, 2002-03, 2003-04, and 2004-05 are given below.

Table 5: Year wise methane emission form harvested areas of rice fields

Year		Harvested area (million ha)		Total methane emission (Gg)		Methane emission per million ha (Gg/mha)
1989-90	....	8.03	....	767.00	....	95.52
1994	....	10.07	....	662.23	....	65.76
2000-01	....	10.80	....	658.62	....	60.98
2001-02	....	10.66	....	660.98	....	61.95
2002-03	....	10.78	....	667.80	....	61.83
2003-04	....	10.82	....	671.09	....	62.14
2004-05	....	10.37	....	653.18	....	62,99

Source: Second National Communication, 2012, MOEF

In 1994, from a total harvested area of 10,073 million ha, 662.23 Gg of methane has been produced, whereas in the years 2001, 2002, 2003, 2004 and 2005, with yearly harvested areas varying from 10.66 to 10.79 million hectares, methane produced varied from 401.76 to 414.02 Gg.

Methane (CH4) emission from enteric fermentation of livestock: In Bangladesh, cattle, buffalos, sheep, goats, poultry and ducks are the main domestic animals and birds. Methane (CH_4) emission from enteric fermentation for the years 1990 (ALGAS), 1994 (INC) and 2001-2005 are given in the following table and shown graphically in Figure 11.

Table 6: Methane (CH_4) emission from enteric fermentation

Year	Emission (Gg)
1990	519.00
1994	417.00
2001	467.78
2002	474.07
2003	480.18
2004	486.60
2005	493.16

Source: Second National Communication, 2012, MOEF

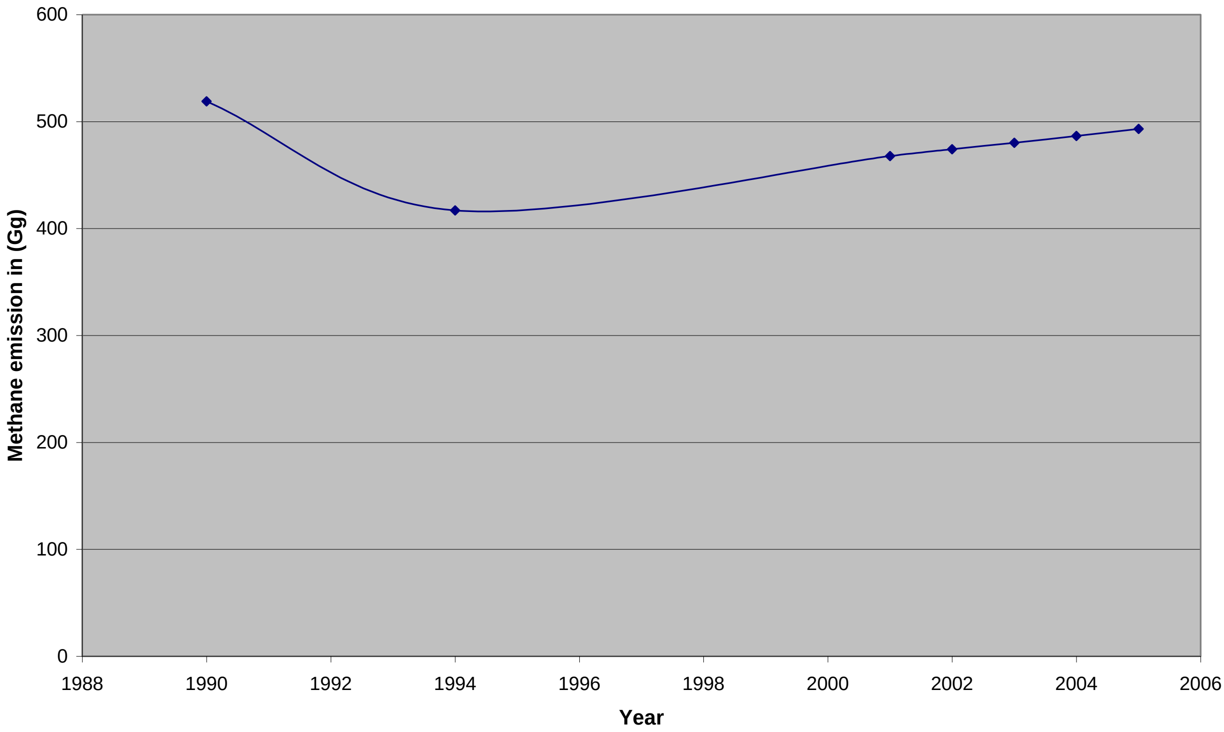


Figure 11: Methane emission from enteric fermentation (1990-2005)

Source: Second National Communication, 2012, MOEF

Emission from Manure Management: Extensive research work on biogas has been done in the Institute of Fuel Research and Development (IFRD) of BCSIR on biogas. According to BCSIR, under Bangladesh conditions, biogas produced from cow dung is 0.037 m3 per kg. According to GIZ, maximum biogas producing capacity of a poultry bird is 0.07 m3 per kg. Since cattle dung is dumped by farmers in pits of depth 4-6 ft, according to IPCC Guidelines, methane correction factor is taken as 0.4 for cattle dung and 0.45 for poultry litter.

Bangladesh's emission factor has been estimated at 0.0088 m3 methane per kg of cattle dung. The value for poultry was 0.0189 m3 per kg litter. Methane emission for cattle dung for the years 2001, 2002, 2003, 2004 and 2005 are 469.94, 472.90, 475.70, 478.67 and 481.68 Gg respectively.

N_2O emission over the period 2000 – 05 has varied from 28.88 to 33.83 Gg.

Emission from Field Burning of Agricultural Residue: Field burning of agricultural residues is a common practice in almost all the countries. This burning gives considerable amount of carbon dioxide with comparatively small amounts of methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and nitrogen oxides (NOx). It is assumed that carbon dioxide (CO_2) released into the atmosphere is reabsorbed during the next growing season, although a significant portion of crop residue is removed and taken home for burning as a source of energy. This kind of burning is included in the Energy Sector to avoid double counting.

Based on the GWP values, CO_2 equivalent emissions for the above 4 Non-CO_2 gases are in the years 2000, 2001, 2002, 2003, 2004 and 2005 are 479.79, 453.42, 473.59, 484.62, 418.06 and 451.14 Gg respectively.

c) Emission from Waste Sector

Emission from Municipal Solid Wastes (MSW): In Bangladesh context, as all the landfill sites are unmanaged and open dump, these sites can be the optimal candidates for land-fill gas emissions. Each day huge amount of MSW is dumped in the dumping sites, which produce significant amount of CH_4 for emission into the atmosphere. A significant fraction of the generated wastes remain scattered and because of aerobic conditions, the scattered wastes produce little or no methane. As per IPCC guidelines total annual methane (CH_4) generation from wastes in six City Corporations (Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet) is about 15.513 Gg. And as per Bangladesh specific methodology total emission of six City Corporations have been 6.46 Gg in 2005

Maximum average emission of CH_4 per Kg MSW under condition of Bangladesh is 0.0276 m^3 under anaerobic conditions. In the open dumping site measured in Dhaka, average CH_4 production is 0.0179 m^3 per Kg of MSW. Based on this emission factor, total emission from MSW of six City Corporation is 6.46 Gg in 2005

Methane emission from Waste Water: Total CO_2 equivalent emission from domestic waste water and from industrial waste water of pulp & paper, dairy product and sugar industries stand at 13, 640 Gg in 2001. Contribution from industrial sub-sector is rather insignificant in comparison with domestic sub-sector. It may be noted that according the EPA (United States Environmental Protection Agency), estimated total emission from waste water in Bangladesh in the year 2000 was 14,000 Gg

3.2 An overview on the country's development priority in the context of national economy and long-term policies on sustainable development

Over the past 40 years since independence, Bangladesh has increased its real per capita income by more than 130 percent, cut poverty by more than half, and is well set to achieve most of the millennium development goals. Some of the underlying specific achievements include, reducing total fertility rate from 7.0 to 2.7; increasing life expectancy from 46.2 years to 66.6 ; increasing the rate of economic growth from an average rate of 4% in the 1970s to 6% in the 2000s; increasing the savings and investment rates from below 10 percent each in the 1970s to 24 percent (investment rate) and 28 percent (savings rate) in the financial year 2010 (FY10); achieving gender parity in primary and secondary education; and more than tripling of the production of rice (from 10 million metric tons in FY73 to 32 million metric tons in FY10) thereby achieving near self-sufficiency in normal production years.

Even with this past progress, Bangladesh remains a low income country with substantial poverty, inequality and deprivation. An estimated 60 million people are living below the poverty line with a significant proportion living in female-headed households, in remote

The broad development goals underlying the Perspective Plan mentioned earlier in line with the Sixth Five-Year-Plan include:

- Building a secular tolerant liberal progressive democratic state
- Promoting good governance and curbing corruption
- Promoting sustainable human development
- Reducing the growth of population
- Instituting a prudent macroeconomic policy mix
- Promoting a favorable industrialization and trade policy regime
- Addressing globalization and regional cooperation challenges
- Ensuring adequate supply of electricity and fuel
- Achieving food security
- Making available adequate infrastructure

areas, and consisting of socially excluded and other vulnerable people. These people, and among them especially women and children, are also disproportionately affected by natural disasters and the adverse effects of climate change.

Recognizing the need to overcome the long -term development challenges, the Government adopted the Vision 2021 and the associated Perspective Plan 2010-2021 that have set solid development targets for Bangladesh till the end of 2021. Vision 2021 lays down a development scenario where citizens will have higher per capita income leading to higher standard of living, better education and social justice with more equitable socio-economic environment and the sustainability of development will be ensured through better protection from climate change and natural disasters.

Against the backdrop of poverty reduction, employment and growth rate targets set in Vision 2021; the Sixth Five- Year-Plan (2011-2015) has endeavored to initiate the transition to the higher growth path. This growth path, while ambitious, is achievable through a strategy that transforms Bangladesh from a rural agro-based economy towards an urban manufacturing-based economy. The driving force for the strategy will be the deepening of a labor-intensive, export-oriented manufacturing sector, and a much more diversified, commercially motivated agricultural sector.

In the pursuit of the above broad development goals the following aspects will factor in prominently in the context of climate-resilient development planning:

a) **Acceleration of economic growth and employment:** Economic growth and its composition will have an effect on job creation. Acceleration of the economic growth rate will require a substantial increase in the rate of investment from the present 24 percent of GDP level. Much of the higher investment will need to be deployed to reduce and eventually eliminate the infrastructure constraint (primarily power and transport) and to strengthen human development.

b) **Sustaining Bangladesh's Agrarian Economy:** A strong agriculture is fundamental to poverty reduction and for food security. With land increasingly becoming a constraint for a growing population and urbanization pressure, enhancing the productivity of land is a must. The emphasis on productivity improvements will be consistent with the need to ensure food security. R&D in agriculture and infusion of new technologies at community level would be essential to achieve the goal of food security.

c) **Gradual Transformation of Agro-based Economy to Manufacturing and Service Sector:** Transforming Bangladesh's agrarian economy into a modern manufacturing and service-based economy is a long-term challenge. Yet, this is needed to be achieved at a faster pace of growth and good job creation. The focus on manufacturing does not mean neglect of agriculture. It is simply recognition of two important points. Firstly, the rapid expansion of agriculture is limited by the availability of land, which is a fixed factor, and by demand (food tends to have low income elasticity). And secondly, the increase in average labor productivity will require a strategy to withdraw labor from activities e.g. agriculture to higher productivity activities e.g. manufacturing and modern services.

c) **Power Sector Reforms:** The annual loss to production and income from power outages could well exceed 0.5% of GDP per year. The availability of domestic primary fuel supply is getting so scarce that it is forcing severe measures like shutting down fertilizer factories, rationing gas supplies for household and transport uses, and keeping idle installed power units.

Every 1% of GDP growth is estimated to lead to a growth of 1.4% in electricity demand in a typical developing country. For a 5-6% typical annual economic growth rate, this would imply a need for close to 7-8% growth in electricity supply. Rural electrification ratio expanded rapidly since the early 1990s, growing from 10 percent in 1994 to 37% in 2008. Yet, this is still amongst the lowest in developing world.

Due to the severity of the power crisis, the Government has been forced to enter into contractual agreements for high-cost, temporary solutions, such as rental power and small IPPs, on an emergency basis, much of it diesel or liquid-fuel based. This has imposed tremendous fiscal pressure, as budgetary transfers are routinely made to the power sector in order to enable it to stay current on payments to power suppliers. The Government is aware that precious resources are being diverted to cover operating losses of the utility that arise from purchasing short-term high cost power which is not sustainable for the financial health of the sector in the long run. Therefore, the longer term strategy embedded in the SFYP power sector plan is to use budgetary allocations to promote low-cost, sustainable expansion of power generation, transmission, and distribution capacity.

d) **Managing the land constraint:** Being one of the most densely populated countries of the world, Bangladesh has to properly manage scarce land resource. Efforts to reduce the growth of population will help, but better management of land is of utmost importance for sustaining rapid growth in Bangladesh. Sound land management also has a direct effect on people's welfare and poverty reduction. Landless farmers are amongst the poorest of the poor. The rapidly expanding slum population and rising land prices in urban areas are indications of increasing difficulties Bangladesh faces in providing people with proper shelter.

Bangladesh has been losing its precious land resources because of conversion of agricultural land to multiple uses (e.g. housing, unbanization) river erosion and sea-level rise. In the severe climate scenario, 1 meter sea level rise will permanently destroy extensive and highly productive low-laying coastal areas that are home to millions of people who will have to be relocated permanently.

e) **The urbanization challenge:** Bangladesh has been experiencing rapid increase in its urban population ever since its independence in 1971. Urban population as a percentage of total population increased from around 8 % to nearly 23 % during 1974-2001 periods. By the year 2015, nearly one-third or 33% of the population of Bangladesh will be living in urban areas. Along with other extreme weather events like flooding and tropical cyclone, sea-level rise is an impending threat to the coastal areas in Bangladesh that would force physical dislocation of more than 35 million people who may find their ways to the urban areas for shelter and income opportunities.

The phenomenal rate of urbanization is posing a major development challenge. The cities and towns of Bangladesh, numbering more than 525, suffer from acute problems of deteriorating infrastructure in the form of poor housing, inadequate and unsafe drinking water, poor drainage and sewerage facilities, logjam of urban transport, and pollution. This situation is going to get worse under climate change scenario as is already manifested by drainage congestion, urban flooding and the heat stress.

The role of urbanization in transforming traditional societies can hardly be over-emphasized. The emerging socio-economic situations in developing countries like Bangladesh have made this amply clear. In Bangladesh, cities and town are playing a crucial role in the country's socio-economic development despite the adverse socio-economic and environmental consequences resulting from rapid growth of these urban centers. At present, urban dwellers constitute about 30 percent of the total populations of Bangladesh, but their contribution to GDP is more than 60 percent indicating that the productivity of labor in urban areas is much higher than in rural areas.

3.3 Framing sectoral strategies for GHG reduction in the context of country's development priorities

In Bangladesh, the Planning Commission is the central planning body responsible for macro and micro economic plans and policies i.e. National Five-Year-Plan and Annual Development Plans. When this comes to a sectoral policy and plan, the ministries are responsible for the policy formulation, planning, evaluation and execution.

In this perspective, Ministry of Environment and Forests of the Government of Bangladesh is mandated according to prevalent rules of business of the Government is to look after and take action regarding climate change. Therefore, in line with the country's development priorities, the government prepared Bangladesh Climate Change Strategy and Action Plan (BCCSAP) in 2009 that outlined six thematic areas to address climate change vulnerabilities in different sectors. BCCSAP is a 10-year programme (2009-2018) to build the capacity and resilience of the country which will contribute to the achievement of country's long-term development goal as well to undertake low carbon development path.

Table 7: Sectoral strategies and action plan of undertaking low carbon development path

Long-term development priorities (Sixth Five-year Development Plan 2011-2015)	Sectoral strategies and action plan e.g. BCCSAP-2009
Power Sector Reform	Theme 5: Mitigation and low carbon development Proposed relevant actions: i) Develop a strategic energy plan and investment portfolio to ensure national energy security and lower greenhouse gas emission. ii) Seek the transfer of state-of the art technologies from developed countries to ensure that we follow a low-carbon growth path (e.g. clean coal and other technologies) iii) Review energy and technology policies and incentives and revise these, where necessary, to promote efficient production, consumption, distribution and use of energy.

3.4 Clustering development priorities in the context of GHG mitigation potentials

The development priorities that have been identified are interlinked for the ultimate objective to accelerate the economic growth aiming at increasing employment, and income keeping social justice, safeguarding food security, and maintaining environmental integrity. In attaining these objectives, the development priorities focus on addressing an array of challenges that fall in realm of traditional economic sectors in Bangladesh such as Finance, Planning, Commerce, Agriculture, Water, Environment and Forests, Energy, Transport, Industry, Land, Disaster, Local government, and Health. There are sub-sectors, or inter-sectoral overlaps that can be brought into prominence in the light of the reduction in GHG mitigation for consideration such as efficiency in energy production and distribution systems, generation of renewable energies etc. and also the economic goals of the vision 2021 and the Sixth Five-Year-Plan including the MDGs.

The clustering of the priority development areas in economic, social and environmental considerations cannot be done in exclusivity ignoring sectoral overlapping. However the following table gives a clustering of some of the major sectoral functions based on where the major thrust of the activities lie. The clustering has been done through an exercise and consultation with the working group members. At the onset development priorities are identified and listed down from the country's development policies and strategies e.g. vision 2021, sixth five-year plan 2011-2015, BCCSAP, Poverty Reduction Strategies etc. All these development strategies and policies are following the objective of sustainable development within the scope of low carbon development path.

Thus 24 development priorities are listed down, which again are prioritized through an exercise of putting score, ranges from 1 to 5, to the each priority by a wide range of stakeholders. The development priority that scored the highest is market as priority 1. Following the prioritization of the development priorities then they are group into three categories on the basis of their economic, social and environmental considerations. Understanding on the development priority through the scoring method is critical to indicate priority area for action to achieve sustainable development in the concern sector under the overall develop plan of the country. Such prioritization would be basis for taking action for the most priority areas as well as designing and planning action in the specific sector. For instance mitigation action in energy security must address poverty reduction to ensure sustainable development.

Table 8: Clustering of development priorities

		Development Priority
Economic	Poverty Eradication	Priority 1
	HRD for productivity improvement	Priority 11
	Increase employment opportunity	Priority 5
	Accelerate growth for rural non-farm sector	Priority 4
	Land management	Priority 16
	Protection of coastal areas	Priority 9; will complement in implementing priority 2
	Manage river system and water bodies to prevent land loss	Priority 10
	Urban management	Priority 16
	Infrastructure development	Priority 13, will complement in implementing priority 2
	Ensure food security	Priority 2
	Ensure energy security	Priority 3
	Disaster management	Priority 7
Social	Social safety net	Priority 6
	Invest in human resource development	Priority 17
	MDGs related to social aspects	Related to priority 6
	Achieve economic and social well-being of all citizen of the country	Priority 14
	Ensure livelihood security of the marginalized sector of population	Priority 15
Environmental	Integrate the environmental/Climate Change issues in all policy and plans and living condition of slums	Priority 8
	Conserve biodiversity and control air/industrial pollution, improve solid waste management	Priority 11

	Improve water quality	Priority 12
	Provide Safe Water, Sanitation and maintain healthy Environment for all	Related to Priority 6
	Ensure environment friendly transport in Bangladesh	Related to priority 3 and 16
	Ensure conservation measures for economic and efficient use of energy	Related to Priority 3
	Protect wetland/mangroves, saline water intrusion	Related to Priority 9

CHAPTER 4: TNA for mitigation

4.1. Sector prioritization for climate change mitigation

4.1.1 Prioritized Sectors/ Sub-sector for mitigation

Under sustainable development framework, the Government of Bangladesh has emphasized on green growth, efficiency improvement of the energy sector etc. that will lead to reduced GHG emission. This has been already included in the BCCSAP and also to the country's long-term development vision and planning.

To complement the country's development priority e.g. attaining sustainable development through green growth and attaining energy security the following sectors/ sub-sectors require technological support that will contribute to the reduction of GHG emission. These are power generation and use, industry and agriculture.

Table 9: Sectors with high GHG potentials

Sectors	GHG emissions in year 2005 (Gigatons CO_2-eq)
Power Generation and use	Energy sector includes sub-sectors e.g. Energy Industries, Manufacture & Construction, Transport, Residential, Agriculture, Non Specific Sectors and Commercial Sectors. Total emission from these energy sub-sectors in 2005 was 37950 (thousand tones)
Industry	The Industrial Processes category accounts for emissions generated in the production and use of minerals, the production of metals, the chemical industry, some processes such as paper production, foods and drinks, and finally, in the production and consumption of halocarbons and Sulphur hexafluoride. CO_2, CH_4, NO_2, HFC, PFC, and SF_6 are the GHGs emitted from industrial processes. In addition, other secondary gases such as carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_X), and non-methane volatile organic compounds (NMVOCs) are taken into account. In general terms, the main gas emitted in this category is CO_2. Although Bangladesh is not an industrialized country, Bangladesh has made great efforts in preparing an inventory of greenhouse gas emissions

	along with efforts to reduce its own emissions of greenhouse gases. Major GHG emitting industries in Bangladesh a) Mineral industry: Clinker production(for cement production), Lime production, soda ash production and use, asphalt roofing production & use and glass industry b) Chemical industry: Ammonia and urea fertilizer c) Metal production: Steel and ferroalloy production d) Food products : Soft drinks, alcoholic beverages, sugar and bread Emission from Cement and Fertilizer industry in 2004-2005 was respectively 82.72 Gt and 2080 Gt, in total Gt 2912.72
Agriculture	**Emission from agriculture sector includes ;** **a) Methane (CH4) emission from cultivated rice fields:** In Bangladesh, paddy is cultivated three times a year in most of the areas. Considering growing season of paddy, it is familiar as *Aus* (May to August), *Aman* (July – December) and *Boro* (December – May). Estimations of CH_4 for the years 2000-01, 2001-02, 2002-03, 2003-04, and 2004-05 shows that in 1994, from a total harvested area of 10,073 million ha, 662.23 Gg of methane was produced, whereas in the years 2001, 2002, 2003, 2004 and 2005, with yearly harvested areas varying from 10.66 to 10.79 million hectares, methane produced varied from 401.76 to 414.02 Gg. **b) Methane (CH4) emission from enteric fermentation of livestock:** In Bangladesh, cattle, buffalos, sheep, goats, poultry and ducks are the main domestic animals and birds. Methane (CH_4) emission from enteric fermentation for 2005 was 493.16 Gg. **c) Emission from Manure Management:** Extensive research work on biogas has been done in the Institute of Fuel Research and Development (IFRD) of BCSIR on biogas. According to BCSIR, under Bangladesh conditions, biogas produced from cow dung is 0.037 m3 per kg. According to GIZ, maximum biogas producing capacity of a poultry bird is 0.07 m3 per kg. Since cattle dung is dumped by farmers in pits of depth 4-6 ft, according to IPCC Guidelines, methane correction factor is taken as 0.4 for cattle dung and 0.45 for poultry litter. Bangladesh emission factor was estimated at 0.0088 m3 methane per kg of cattle dung. The value for poultry was 0.0189 m^3 per kg litter. Methane emission for cattle dung for the years 2001, 2002, 2003, 2004 and 2005 are 469.94, 472.90, 475.70, 478.67 and 481.68 Gg respectively. N_2O emission over the period 2000 – 05 varied from 28.88 to 33.83 Gg.

Following identification of sectors with GHG reduction potential, sub-sectors of each sector are listed down. The sub-sectors under each sector are scored categorically on the basis of their economic, social and environment priorities and putting numeric value ranges from 1 to 5. On the other hand, GHG reduction potential of each sub-sector also scored putting numeric value ranges from 1 to 5.

Table 10: Sector rating for mitigation

Sectors	Subsectors	Improvement by low carbon technologies beyond baseline/ existing situation			GHG reduction potential	Total Score
		Relevance with the development priorities				
Power Generation and use	**Non Renewable**	Maximize economic development priorities	Maximize environmental development priorities	Maximize social development Priorities		
	Fuel non-specific technology	3	3	3	4	13
	Gas-based technology	4	5	4	5	18
	Coal-based technology	5	3	4	5	17
	Nuclear power generation technology	4	3	3	4	14
	Renewable					
	Power generation as hydroelectricity	4	4	3	3	14
	Solar power generation	3	4	4	5	16
	Wind-based power generation	3	3	3	4	13
	Domestic Lighting (power use)	3	3	4	5	15
Industry	Mineral industry	4	3	3	4	14
	Chemical industry	3	3	3	3	12
	Metal production	3	3	2	3	11
	Food products	3	3	2	2	10

Agriculture	Emission from cultivated rice fields	3	3	2	3	11
	Emission from enteric fermentation of livestock	3	3	3	3	12
	Emission from Manure Management	3	3	4	3	13
	Emission from burning of agricultural residue	2	3	3	3	11

Note: Score 0 represents no benefit; 1 faintly desirable; 2 fairly desirable, 3 moderately desirable; 4 very desirable and 5 extremely desirable.

In view of country's goal to undertake low emission development path, and to realise the targets set for vision 2021 and the Sixth Five-Year-Plan (2011-2015), the following sector may be considered for this project in the development, diffusion and adaptation of climate change technologies:

- Mitigation technologies for Power Generation and use

On the basis of scores given to different subsectors, the criteria contribution graph is prepared that gives and overview on the contribution of each subsector on the criteria.

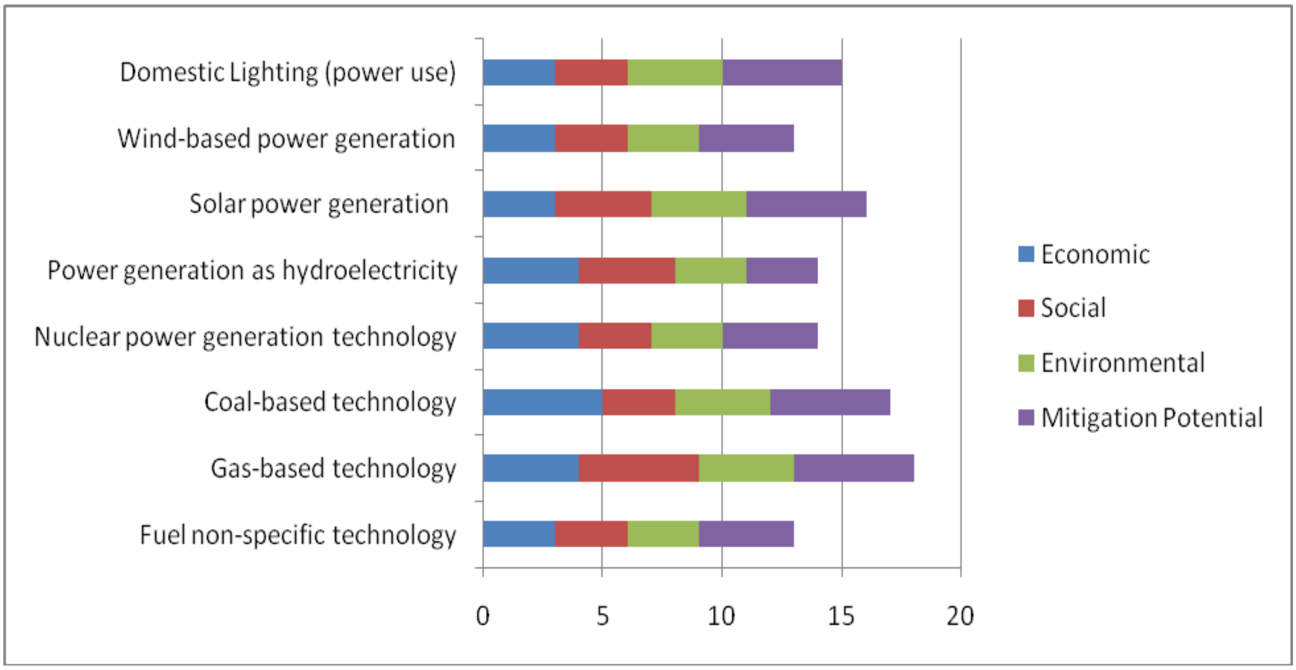


Figure 12: Criteria contribution graph of the subsectors of Power Generation and use

On the basis of the criteria contribution graphs (Figure 12) Table 11 shows the cumulative score of development priorities of the sub-sectors of power generation and use. Sector prioritization process through scoring method can be used as tool for indicating priority mitigation potential sub-sector of power generation and use. It has helped to identify specific areas within the sector and hence the following areas are identified as highly potential areas for future mitigation action such as, i) Gas-based technology, ii) Coal-based technology, iii) Solar power generation and iv) Domestic Lighting (power use).

Table 11: Cumulative score clustered under development priorities and mitigation potential of power generation and use subsectors

Power Generation and use		
Subsectors	Development priorities	Mitigation potentials
Gas-based generation	13	5
Coal-based generation	12	5
Renewable-based power generation-Solar	11	5
Domestic Lighting (power use)	10	5
Fuel non-specific technology	9	4
Nuclear power generation technology	10	4
Power generation as hydroelectricity	11	3
Wind-based power generation	9	4

As per Table 11, sub-sectors that got higher cumulative score of development priorities and mitigation potentials have classified as desirable sub-sectors and presented in Table 12. Sub-sectors with cumulative score of development priorities above 10 and mitigation potentials 5 are considered extremely desirable power generation subsectors. There is a clear linkage between development priority and mitigation potential among technology choice.

Table 12: Desirability of technological intervention of power generation subsectors

Power Generation		
Subsectors	Development priorities	Mitigation potentials
Gas-based technology	Extremely desirable	Extremely desirable
Coal-based technology	Extremely desirable	Extremely desirable
Solar power generation	Extremely desirable	Extremely desirable
Domestic Lighting (power use)	Extremely desirable	Extremely desirable
Fuel non-specific technology	Faintly desirable	Faintly desirable
Nuclear power generation technology	Faintly desirable	Faintly desirable
Power generation as hydroelectricity	Extremely desirable	Faintly desirable
Wind-based power generation	Faintly desirable	Faintly desirable

CHAPTER 5: Mitigation technology prioritization for energy generation and use

5.1. An overview of GHGs Emission- National Situation

The contributions of the different sectors along with the total emissions for the year 2005 are 37,950 Gg. It is seen that Bangladesh in 2005 emitted only 68000 Gg of carbon di-oxide of which combustion for energy related activities accounted for nearly 38000 Gg (56%). Another 28000 Gg (or, 39%) was contributed by LUCF. For non-CO_2 emission, agriculture is the main source. Of the total emission of nearly 2500 Gg of methane, 1800 Gg or nearly two-thirds has been contributed by agriculture. Agriculture, particularly poultry litter management accounted for the bulk of the nitrous oxide emission.

5.1.1 GHGs Emission: Power generation

The generation of electricity accounted for just over 11900 Gg t of CO_2 equivalent emission in 2005. It has been projected under the baseline scenario to increase to just over 59000 Gg of CO_2 equivalent by 2030 or to nearly 5 times that in 2005 (Fig. 13). Not just that, electricity generation shall account for an increasing share of the release of CO_2 equivalent. In 2005, it was about 28 percent. By 2030, it may rise to more than 40%. Population increase as well rising income along with the policy of reaching electricity to every household will lead to such growth. Given such a situation, it is natural to look for technology, systems and policies for lowering the emission from activities related to power generation. To do that we need to first look at the technology at present and what may be the options for the future. Figure 13 shows amount of power generation and GHGs emission from different sectors to achieve development.

(Th mt of CO_2 equivalent)

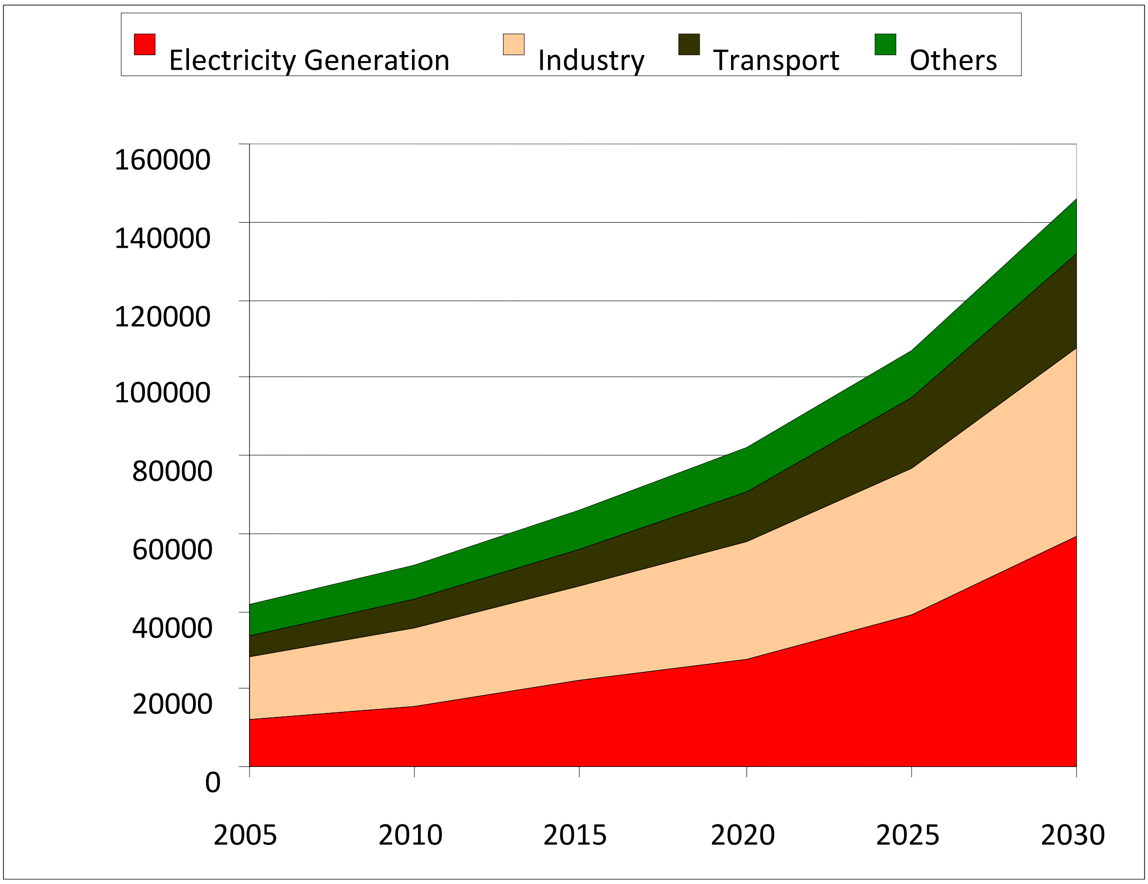
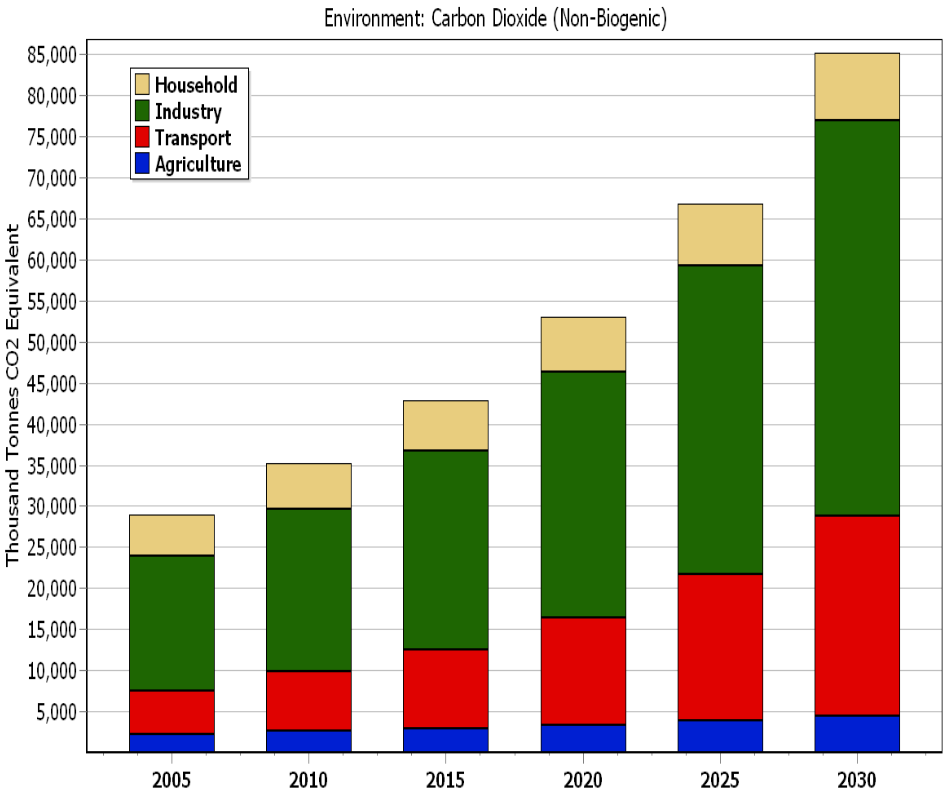


Figure 13: Emission of GHGs in Bangladesh; Source: MoEF, Second National Communication, 2012

5.1.2 GHGs Emission from Various Sectors

In addition to CO2 emission from power generation, Figure 14 shows CO2 emission from households, transports, industries and agriculture as highly demand sectors for development. It is rather critical to address CO2 emission from these sectors to achieve sustainable development goal by following the low carbon development path as articulated in the BCCSAP. Efficient technologies in these sectors are only option to do so.

Figure 14: Projected CO_2 emissions from various demand sectors 2005-2030



Source: MOEF, Second National Communication, 20122

5.1.3 Sources of primary energy for generation of power

Figures 15 and 16 depict the shares of primary fuel in power generation in the country in 2008 and 2012 (September). While the two indicate the same broad pattern with gas as the main fuel, there is also a worrying pattern emerging.

In 2008, natural gas was the primary fuel in just about 82% of installed capacity while oil (diesel and furnace oil) accounted for only 9% or so of the share in installed capacity. By July, 2012, the share of gas has fallen to just above 67% while the share of oil has gone up to almost 28%. This is worrying from the view point of mitigation because of the greater carbon content of oil compared to gas and also that the anecdotal evidence suggest the installation of rather old technology of power generation with oil (see later). Thus, the carbon intensity of power generation may have actually increased over the last 4 years.

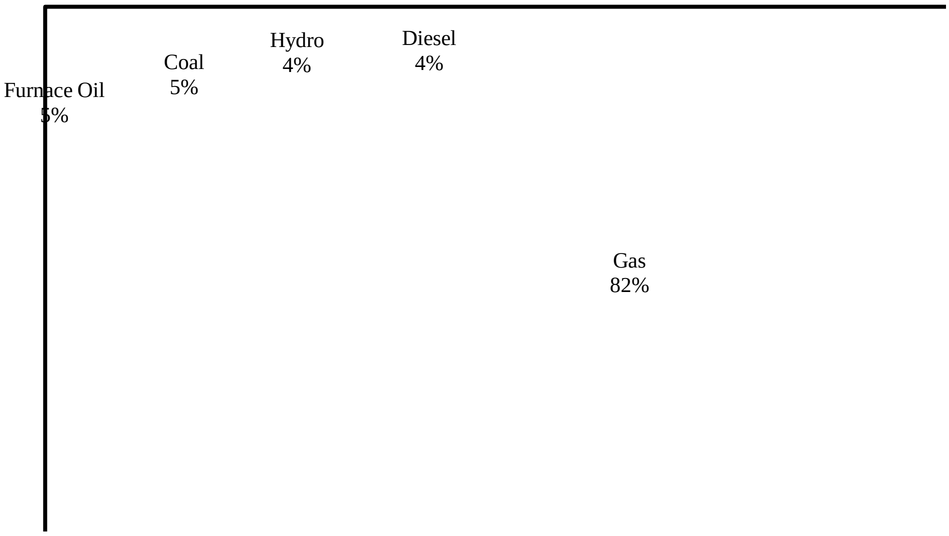


Figure 15: Shares of Primary Fuel in installed Power Generation Capacity (2008); *Source:* Asaduzzaman and Ahmed (2011) ,in Mujeri and Alam (ed.), (2011)

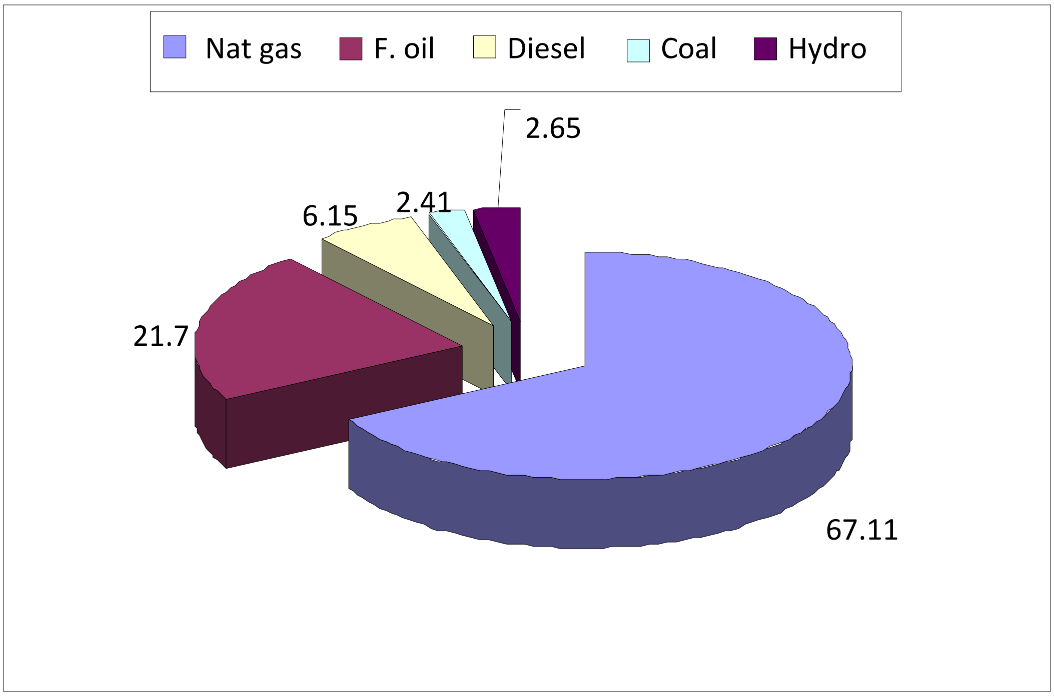


Figure 16: Shares (percent) of Primary Fuel in Installed Power Generation Capacity (2012)

5.1.4 Lighting- national situation

Kerosene is the main source of lighting in rural areas. Even households having access to rural electricity grid, have to often use kerosene due to poor quality of supply of power. In urban areas, the situation is better. Still, on the whole with at most around 40% of households with access to electricity, electrical lighting has penetrated only that much at most. Factoring in quality of supply will of course lower that figure still.

There may thus be a dual purpose for relevant policy here. One part of the policy must be to reach electricity to all households as quickly as possible, which is the main mandate for power generation. Related to this is the production of electricity as efficiently as possible but with an eye on costs to keep it as affordable to people as possible. The latter is analyzed separately in this report. The other is to raise the efficiency of electrical lighting system as lighting is a major reason for use of electricity.

5.1.5 Types of electrical lighting

There appears to be not much by way of recent information on use of electric lighting, their numbers and places of use and sometime the information are also against anecdotal evidence. A survey in 10 urban centres in 2009 found that an average urban household consumes 136 kWh of electricity per month of which only an average of 22.2 kWh is for lighting (Table 13).[1] This comes to just 20% of total electrical load. The survey also does not report any CFL. Incandescent bulbs are still the norm, particularly in less urbanized areas (Table 13) and although the penetration of CFL has begun a few years back it still remains an incomplete agenda. Halogen lamps and LEDs are hardly observed.[2] Yet, other limited information indicate that incandescent, fluorescent and CFLs, all are used. The relevant information is reproduced in Table 14.

Table 13: Total Household Consumption of Electricity and for Lighting in Urbanized Areas (2009)

District	Average HH consumption per month (Kwh)	Average consumption for Lighting per month	Lighting as percent of total consumption
Dhaka	127	27.6	21.7
Chittagong	115	25.92	22.5
Rajshahi	141	38.28	27.1
Sylhet	177	22.11	12.5
Bogra	103	30.09	29.2
Barishal	90	30.54	33.9
Khulna	99	28.56	28.8
Comilla	157	25.56	16.3
Mymensingh	176	27.09	15.4
Rangpur	154	22.2	14.4
Weighted Average	136	27.24	20

[1] Clean Energy Alternatives Inc., *Report on Survey on the Electrical Lighting Load and Consumption in the Urban Household Sector of Bangladesh,* (unpublished), Dhaka, 2009.
[2] Lighting is used in many appliances. Here we are examining only the space lighting in residential houses and other commercial, industrial and organization buildings.

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Table 14: Types of Lighting Devices in Urban Bangladesh (Number)

SL	Types of lamps (Weighted Average)	Division headquarters (All Six)	Zilla headquarters (4 cities)	Municipalities (2 municipality)	Villages (HDRC Study 2002)
01	Incandescent Lamps	2.23	2.66	3.14	3.7
02	Florescent Tube Lights	2.45	2.83	1.93	0.41
03	Total	4.68	5.49	5.07	4.11

The information contained in the source from where Table 15 has been extracted clearly indicate that the families which have been looked into were all upper middle-class families and are thus not representative of either the general urban or the rural households. Yet, what we observe is that where there is no AC usage, the proportion of electricity used for lighting is 56% and in most other cases, it is around 40%. Thus, on an average Bangladeshi household with access to electricity, the proportion of electrical energy consumed for lighting is not likely to fall below 60-65%. It may be even more for really poor households.

Table 15: Energy Used for Lighting and Devices in Dhaka Residences

Indicators	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
AC tonnage	1.5	1.5	1	3.5	3.5	0	3
Incandescent	16	6	6	16	30	8	9
Fluorescent	12	12	11	11	12	10	9
CFL	2	16	16	7	3	-	7
Spot light	11	5	0	6	4	0	2
Lighting energy(%)	46	30	40	41	42	56	29
Lighting energy (kwh)	811	422	300	518	574	252	383
Total energy (kwh)	1762	1401	900	1263	1356	450	1316

Source: Ahsan, Tahmina, *Passive Design Features for Energy-Efficient Residential Buildings in Tropical Climates: the context of Dhaka*, Bangladesh, KTH, Department of Urban Planning and Environment Division of Environmental Strategies Research – fms, Stockholm 2009

The information also tells us how far the penetration of energy saving CFL lamps have taken place. Except in two households, the number of CFL is small while the number of fluorescent lamps is 10-12. But also note the almost inverse relationship between the use of incandescent lamps and CFLs. This is also reflected in the estimated total usage by incandescent and CFL lamps.

5.1.6 Current status of mitigation technologies in the selected sectors

Even though Bangladesh's contribution to the generation of GHGs is miniscule, the country wishes to play its part in reducing emissions now and in the future. The mitigation activity must be consistent with the need for country's energy security as the demand for energy will increase with the increasing pace of economic and infrastructure development. Government of Bangladesh, therefore, encourages increased energy efficiency in the development and utilization of conventional energy. Emphasis is also given to the development of renewable energy, particularly for solar home systems and biogas plants as measures for energy access in isolated areas, and to promote renewable energy use. In partnership with civil society, a major nationwide program of social forestry has also been implemented and coastal 'greenbelts' has been planted as a key adaptation-mitigation strategy.

Bangladesh adopted Renewable Energy (RE) policy was adopted in 2008. The objectives of the policy are to harness the potential of RE, dissemination of RE technologies, facilitate both public and private investment in this sector, and increase energy supplies to substitute indigenous non-renewable energy. To achieve the objective government has set targets for developing renewable energy resources to 5% of total power demand by 2015 and 10% by 2020."

Bangladesh has become a showcase for Solar Home System (SHS) with more than 750,000 units installed in less than 10 years. The biogas program is also gaining momentum with more than 50,000 units installed. Several other measures to promote renewable energy are being considered. A government order has been issued to ensure that a portion of electricity in all Government buildings is solar PV. To get new electricity connection, buildings must generate using solar PV 1-3% of their demand depending on space availability. The example of activities in the renewable energy and energy efficiency activities are the following:

More than 700,000 Solar Home Systems (SHS) have been installed in rural Bangladesh and more are being added. This remarkable success is possible due to innovative approach in the promotion of this system in the off grid isolated communities. At present total solar power generation would be about 15-20 MW. Efforts are underway to generate solar energy in MW scale, to introduce solar pumps for irrigation, and to install wind power generation plant in the coastal areas.

The Government is also requiring the new high rise buildings to meet 1/3 percent of their demand through solar energy depending on space availability and eventually they will have to meet their common area lighting through solar energy.

Through a project Efficient Lighting Initiatives in Bangladesh 10.5 million CFL bulbs were distributed to replace the existing inefficient bulbs that have the potential to reduce the peak load by 300 MW.

There are a lot of potential for efficiency improvement in the electricity generation sector as these are mostly based on low efficiency Rankine Cycle steam turbines. Similar potential also exists in the efficiency improvement in the boilers in industrial sector, and in technological overhauling of the transport sector.

Pilot scale project has been undertaken to introduce efficiency in Brick Kiln industry by introducing Hybrid Hoffman Kiln and kiln from India called Vertical Shaft Brick Kiln.

5.2 An overview of potential mitigation technology options in 'power generation and use' subsectors (Long list of technologies)

The technology for power generation varies by the type of primary fuel in use. For Bangladesh, the three main fossil fuels in use are natural gas, coal, furnace oil and diesel oil. Then there are the renewable sources such as the sunlight, the wind and moving water. Add to this the nuclear which may come in at least two variations, uranium based and thorium-based. Several criteria may be used for understanding the desirability of one option over the other. Some of these are generic and some are due to specific national circumstances.

Bangladesh is an energy-starved country and more so for electricity as nearly 60% of households are without any access to electricity. At the same time without the availability of adequate levels of energy, particularly electricity, the prospects for fast development of the national economy is not much bright.[3] Bangladesh therefore cannot compromise on availability of energy for the foreseeable future for the general socio-economic development of the country and raising the standard of living of its people. Indeed, when defining right to sustainable development that essentially signify its inalienable rights to security of food, energy, water and livelihood (including health). And this has been enshrined in many relevant documents of the country including the present Sixth Five–Year-Plan. What these mean is that while we advocate technology for power generation, Bangladesh cannot sacrifice on the level of generation to be achieved under any recommended technology. Energy efficiency is acceptable for raising the available services from the same amount of gross primary energy, but not any reduction in its total supply.

The recommended technology has to be cost-effective as well as reducing pollution including greenhouse gases. At the same time, it must be such that the new generation is forthcoming as soon as possible given the high level of energy shortage the country has. Thus, cost, ease of installation and a long life cycle particularly in case of generation form less dirty fuels become important. In case of cost-effectiveness, it is not simply the cost of installation that matter but also those for operation and maintenance and its ease also become important. Country capacity to manage such plants thus becomes a major point in evaluating the technology.

Different types of technologies of power generation and use are listed in the Table 16 from which efficient and suitable technologies have been prioritized for introducing in the country as part of mitigation effort as well as ensure energy security.

[3] For a recent analysis of the relationship between energy and development (GDP) in the Bangladesh context, please see Asaduzzaman and Ahmed (2012).

Table 16: Long List of Technology in Power Generation and Use

Power Generation and Use	Type	Technology		Nominal Capacity (kW)
Power Generation	Gas-based	Conventional combustion turbine		85,000
		Advanced combustion turbine		210,000
		Natural gas combined cycle		540,000
		Advanced natural gas combined cycle		400,000
		Advanced NGCC with CCS		340,000
	Coal-based	Single Unit APC		650,000
		Double Unit APC		1,300,000
		Single Unit APC with CCS		650,000
		Double Unit APC with CCS		1,300,000
		Single unit IGCC		600,000
		Double unit IGCC		1,200,000
		Single unit IGCC with CCS		520,000
	Solar-based	Solar thermal		100,000
		Concentrating solar power (CSP)		50,000
		Small photovoltaic		7,000
		Large photovoltaic		150,000
	Wind-based	Onshore Wind (Enercon 600kW)		30,000
		Onshore Wind (Nordex 1000kW)		30,000
		Onshore Wind (2000 kW)		30,000
		Onshore Wind (1500)		100,000
		Offshore Wind (5000)		400,000
	Hydroelectricity-based			**Power Output (kW)**
		Hydro turbine		Large hydro (>100000)
		Hydrokinetic turbines		Small hydro (100-2000)
	Nuclear-based		**Reactor type/ fuel cycle option**	**Net capacity in cost estimates (MWe)**
		Pressurized Water Reactors (PWR)	PWR/OT	2 682.4
			PWR/OT	1 906
			PWR/CC	1 590
			PWR/OT	1 590
			PWR/OT	1 500
			PWR/CC	1 600
			VVER/OT	1 000
			VVER/OT	894
			PHWR/OT	1 406
			PHWR/OT	665
		Boiling Water	BWR/OT	1600

		Reactor (BWR)		
		Generation III Reactor (GENIII)	GENIII/OT	1000
			ABWR/CC	1330
Power Use	Basic lighting	Incandescent		
		Florescent		
		Compact Florescent Lights (CFL)		
		LED Lights		
		Mercury Vapor		
		Metal Halide		
		High Pressure Sodium (HPS)		

5.2.1 Fuel non-specific technology

Before we get to the construction and discussion of the long list of technology, it may be reiterated that these are initially distinguished by the primary fuel or source of energy and then by the design of the technique of production of electricity. Therefore, one perhaps first introduces the issue of technology when it is not fuel specific. In fact, this is basically the steam turbine technology, a backbone technology perhaps under any circumstances. Steam turbines can be run with steam under high pressure with heat produced from any primary fuel, coal, gas, oil, biomass, solar or nuclear. The design of boiler for burning the primary fuel is what basically distinguishes the various steam turbine plants as the power generation part using the turbine is basically the same. Steam turbines are therefore not discussed anymore as a separate category; rather we discuss it wherever applicable under the specific primary fuel-based technology.

5.2.2 Gas-based technology

As natural gas is the main primary fuel for power generation in the country, and there are other uses for natural gas particularly as feedstock for production of nitrogenous fertilizer the availability of which is critical for agriculture and ensuring food security, higher efficiency in gas based power generation is extremely important. Annex 1: Table 1 provides some background information of available gas-based technology.

The typical plants under conventional systems, e.g. conventional combustion turbine and advanced combustion turbine, are usually smaller in size and the investment costs for the normal conventional ones are similar to the combined cycle plants although the variable O&M costs are lower and may be even lower in developing countries. Yet, given the rather high heat rate and thus the resulting technical efficiency, one may consider ‘advanced combustion turbine’ as one option. On the other hand, the combined cycle with carbon capture and storage (Advanced NGCC with CCS) has very high investment costs as well as higher O&M costs. The real question here is if the very substantially lower emission of carbon can compensate for the higher investment costs.

The main alternatives of interest here are; a) Natural gas combined cycle, b) Advanced natural gas combined cycle as well as c) Advanced combustion turbine. The environmental attributes indicate that except for the carbon capture and storage with advanced combined cycle, the carbon emission does not fall at all on a per unit of heat rate basis. This issue will be taken up later for short listing of technology and their prioritization.

5.2.3 Coal-based technology

Bangladesh has some coal and intends to raise the proportion of coal-based generation in future along with coal imported from other countries. As coal is a comparatively new fuel for power generation, it is advisable to begin with as much improved technology as possible rather than with the old conventional coal-based steam turbines. The available improved technologies are shown in Annex 1: Table 2.

The technologies embodying CCS are far more costly than those without both for the pulverized and integrated gasification technologies. The IGCC is a new type of technology which is at demonstration stage. The advanced pulverization technology which employs supercritical or ultra-super critical conditions to generate power has higher efficiencies than the conventional coal-based steam turbines and thus lowers operational costs although the investment costs are higher. Then again consider the double unit plants. These have much higher absolute investment costs but relatively lower investment costs per unit of installed capacity. But the double units also generate double the electricity. These considerations leave us with further consideration of technologies under 1, 2, 5 and 6 if coal has to be used for power generation.

5.2.4 Nuclear power generation technology

Annex 1: Table 3 provides the attributes of the available nuclear power generation technology. It shows that there are various types of combinations of reactor types and fuel cycle options. Without going into the details of the options, it may be decided whether nuclear should be an option. Several issues are important.

Given that nuclear installations are very costly as the table indicates although operations costs are small, and that there are issues of safety as well as future safe storage of spent yet radioactive fuel, public concerns and resistance will be high despite the good safety records of nuclear power plants. There are also the needs for as pointed out in the NEA/IEA/OECD (2010) clearly there are vast needs of proper regulatory systems as well as required human still in the forms of scientists, engineers and technical hands of the proper order and capability. Furthermore, there will be oversights by the international agencies which create management complications furthermore. While the table below shows for the sake of completeness a list of the available technologies, none therefore are included in the short list later on.

Note here that there are continuous R&D going on for far safer, price competitive and simpler technology and such research are likely to bear fruit not any time soon as the new inventions need to be demonstrated for their commercial viability. Also, as there are attempts going on for using thorium as an alternative fuel to uranium and plutonium, and thorium is available in Bangladesh perhaps it would be in the best interest not to look forward to nuclear power generation yet. Possible around 2020-25 when new and mature, safer and cost-effective nuclear technologies will be available, that would be the time for deciding on this option. Around that time also other new type of technology based on nuclear fusion (as opposed to the present fission-based reactors) are expected to be built providing a far richer option than at present.

5.2.5 Power generation as hydroelectricity

Electricity can be produced from the energy of falling water (hydroelectricity) or the in the current of rivers or tides (hydrokinetic electricity). The present ideas regarding such technologies are shown in Annex 1: Table 4.

The prospects of large hydro based on dams are not bright in the country as there are very few suitable sites, if at all, for such dams in the country. Mini hydro more on the lower range of the small hydro may be possible but immediate prospects are limited as identification and pilot schemes for testing the ground level possibilities are not yet within the planning horizon of the Government. Given that banks of most large rivers are thickly populated and are thus use the rivers for various purposes, only isolated small streams in the comparatively hilly parts in the north-east and south-east part of the country, being less encumbered, may have certain possibilities for such projects. But on the whole while off-grid communities in these areas may be served, these are unlikely to be of much significance nationally and also note that these are comparatively costlier to build compared to than larger hydroelectricity installations. In this exercise therefore, hydroelectricity is not considered for the new or improved technology for power generation for the medium term future of 5-7 years.

5.2.6 Solar power generation

Using solar radiation to produce electricity is possible with the help of three basic types of technology, solar thermal, concentrating solar power and solar photovoltaic. Their generic attributes are shown in Annex 1: Table 5. Among these, only the solar photovoltaic are mature technologies. The others are either just coming into the market or are still in R&D stage. Hence, it may be discounted by and large these technologies for the time being and concentrate more on the solar PV systems. Note that the large scale solar PV systems can generate electricity at a level comparable to the other systems being developed.

Bangladesh is a land scarce country with very high population density and there is hardly any level land left that is not used for some economic or other purposes. As solar panels the basic element of a solar PV system needs a lot of land (Annex 1: Table 5), it is understandable that such large scale systems may not be suitable for Bangladesh. At most one can think of rather small scale applications on a off-grid situation. Among these only the 1st generation technologies (Annex 1: Table 5) is in mature and commercialized scale. Second generation technologies still have glitches while the 3rd generation ones are in experimental stage. That leaves the rather small 1st generation ones in purview. There is not much of a difference between the two available first generation technologies in terms of efficiency of commercialized applications, cost and surface area need for solar panels. These are therefore the best at the moment and are ready for immediate application.

Indeed, that is already in practice in Bangladesh through the use of solar panels for irrigation and the quite small sizes solar panels for solar homes. The latter has become one of the major success stories from Bangladesh. Some of the Bangladesh-specific information shall be provided later on. While the solar home is already in large scale application, and may possibly be expanded much further in its present state of technology, one particular problems relates to the batteries the replacement and disposal of which is a vexatious issue, more particularly because it is the batteries which make the costs of installation of solar home comparatively high to many poor households. Already one hears about a new technology developed by the Chinese scientists who have no need for batteries and thus making the costs of installation much less and also solving a major management and environmental issue related to battery disposal. Unfortunately, the evidence so far is anecdotal. What all these sums down to is that for the time being we consider only the solar home PV as an issue of up-scaling of a proven technology. If batteryless systems are available down the line, so much the better.

Table 17: An Overview of Performance of Major PV Technologies

Technology	Units	1st Generation		2nd Generation			3rd Generation		
		Single crystalline silicon (sc-Si)	Poly-crystallin silicon (pc-Si)	Amorphous silicon (a-Si)	Copper Indium Gallium Diselenide (CIS/ CIGS)	Cadmium Telluride solar cells (CdTe)	III-V compound Multijunction, Concentrated PV (CPV)	Dye-sensitized (DSSC)	Organic or Polymer (OPV)
Best research solar cell efficiency at AM1.5*	%	24.7		10.4 Single junction 13.2 Tandem	20.3	16.5	43.5	11.1	11.1
Confirmed solar cell efficiency at AM1.5	%	20-24	14-18	6-8	10-12	8-10	36-41	8.8	8.3
Commercial PV Module efficiency at AM1.5	%	15-19	13-15	5-8	7-11	8-11	25-30	1-5	1
Confirmed maximum PV Module efficiency	%	23	16	7.1/10.0	12.1	11.2	25		
Current PV module Cost	USD/ W	<1.4	<1.4	~0.8	~0.9	~0.9			
Maximum PV module output power	W		320	300	120	120	120		
PV module size	M^2	2.0	1.4-2.5	1.4	0.6-1.0	0.72			

Area needed per kW	M^2	7	8	15	10	11			

Source: International Renewable Energy Agency, *Renewable Energy Technologies: Cost Analysis Series,* IRENA Working Paper Series, Solar Photovoltaics, ,Volume 1: Power Sector, Issue 4/5, June 2012.
Note: Under standard testing conditions, temperature 25^o C; light intensity $1000W/m^2$, air mass 1.5.

5.2.7 Wind-based power generation

Power generation using wind energy has become much of an almost mature technology. Some of the technologies and their possibilities are shown in Annex 1: Table 6. Quite obviously, the technology has progressed fast since 1980s when only a fraction of the present possibilities could be foreseen. There are certain possibilities in Bangladesh to develop the system. However, the technical feasibilities for large scale application are still to be carried out. It is known that there are activities for mapping the wind situation all over the country. Once this is done, only then the implementation of wind-based power generation would be possible in a large scale, at least in the coastal region where wind speeds are higher than elsewhere in the country. Therefore the wind-based power generation is not considered any further.

5.2.8. Available Efficient Technologies for Domestic Lighting (Power use)

Earlier, we have discussed the available technology for lighting for domestic purposes. The improved technology in such cases is actually the same technology but with improvements over time. In that sense the linear fluorescent (the normal tube light) and the compact fluorescent lights (CFL) are the main contenders for replacement of the incandescent lights. Yet, we provide a picture showing the differences among the basic technology. This is shown in Table 18.

There are many reasons why incandescent bulbs still hold a sway. One reason is their cheapness. A fluorescent bulb costs more and CFL costs even much more. But it is the difference in operating hours that make them cheaper in the long run. But the length of operation also depends on the quality of electricity supply which is not satisfactory in Bangladesh. Still because the operating costs are much lower, CFLs may gain popularity over time. Thus, we will be basically discussing the advantages of CFL including its cost over the incandescent ones the CFL being the short-listed technology for lighting at least for the next one decade or so. In doing that we shall also examine the problems that other countries are facing in replacing incandescent bulbs.

Table 18: Characteristics of Selected Basic Lighting Technology

Type	Lumen per watt	Life X 1000 Hours	Relative efficiency based on HPS	Start-up-time (minute)	Lumen maintenance	Colour Rendition	Operating Cost
Incandescent	15-25	0.75-12	19%	Immediate	Fair to Excellent	Excellent	High
Florescent	55-85	7.5-24	65%	Immediate	Fair to Excellent	Good to Excellent	Average
Compact Florescent Lights (CFL)	45-60	10	45%	Immediate	Good	Good	Low
LED Lights	70-120	50-100	92%	Immediate	Very Good	Good	Low
Mercury Vapor	50-60	16-24	46%	2-7	Very Good	Poor to Excellent	Average
Metal Halide	80-100	1.5-15	77%	2-5	Good	Very Good	Below Average
High Pressure Sodium (HPS)	75-130	20-24	100%	3-4			

5.3 Short listed mitigation technologies in power generation and use

All the technology tables by primary fuel or energy in the preceding section together constitute the long list. It is not reproduced here to save space. The short-listed or edited technologies for gas and coal-based technologies as well as the solar home PV are shown below in Table 19. This short-listing, it may be reiterated, has been made from the long lists based on mainly the country contexts as well as some other attributes such as the costs of the investments and O&M. Now that we put them together, we have much better understanding of the *inter se* desirability of the technologies.

Table 19: List of short-listed technologies for power generation and use

Power	**Category**	**Technology**
Power generation	Gas-based	Advanced combustion turbine
		Natural gas combined cycle
		Advanced natural gas combined cycle
	Coal-based	Advanced Pulverised Coal (APC) Single Unit
		Advanced Pulverised Coal (APC) Double Unit
		Integrated Gasification Combined Cycle (IGCC) Single unit
		Integrated Gasification Combined Cycle (IGCC) Double unit
	Solar	Solar Home PV
Power use	Domestic Lighting	Linear fluorescent lamp (LF)
		Compact fluorescent lamp (CFL)

All the short-listed technologies are further categorized on the basis of its availability in time and applicability in scale. The criteria of categorization are short-term, medium-term and long-term and, small scale and large scale.

- The short term is meant that it has proven to be reliable, commercial technology in a similar market mechanism
- The technologies in the medium term would be pre-commercial in that given market context (5 years to full market availability)
- A long-term technology would still be in an R & D phase or a prototype
- Small scale technologies are applied at the household and/ or community level, which could be scaled up into a program, and
- All technologies applied on a scale larger than household or community level are considered large scale technologies.

A list of edited technologies with their scale and availability is presented in Table 20.

Table 20: List of edited technologies for power generation and use with scale and availability

Power supply	**Category**	**Technology**	**Scale**	**Availability**
Power generation	Gas-based	Advanced combustion turbine	Large	Short term
		Natural gas combined cycle	Large	Already in use; up-scaling needed
		Advanced natural gas combined cycle	Large	Short to medium term
	Coal-based	Single Unit APC	Large	Short to medium term
		Double Unit APC	Large	Short to medium term
		Single unit IGCC	Large	Medium term
		Double unit IGCC	Large	Medium term
	Solar	Solar Home PV	Small	Already in use
Power use	Domestic Lighting	Linear fluorescent lamp (LF)	Large	Already in use
		Compact fluorescent lamp (CFL)	Large scale	Already in use

5.4 Assessing technologies with Multi-Criteria Decision Analysis (MCDA)

The edited lists as above are further subjected to a multi-criteria analysis. Such an analysis in the present context involves providing scores to various attributes under broad categories of costs, environment, economic and social dimensions. The scores based on both stakeholder ideas as well as expert opinion are shown in Tables 19 and 20. Under each broad category of criteria there are several sub-categories.

5.4.1 Criteria and process of technology prioritization

In this exercise priority sectors/areas have been identified by exploring to what extent investments in technologies for mitigation would contribute to emission reduction in the context of country's aspiration of achieving sustainable development goal. Therefore, the main objectives on which a measure or technology are judged include the following:

- Minimize any GHG emissions from the potential sectors
- Maximize effort to low carbon development
- Maximize development priority benefits in terms of environmental, social and economic benefits and also maximize the co-benefits of emission reduction e.g. reduction of health hazards caused by pollution etc.

For climate change mitigation technology prioritization, the following criteria have been considered in the discussion and decision-making of technology prioritization

Criteria category 1: Contribution to development goals in the light of climate change impact scenarios for the country. Some of these are obvious and some have to be based on indicators. Such indicators are note, wherever applicable.

Environmental improvement, which includes:

- Reduced or avoided local air pollution for improving air quality by reducing Short-Lived Climate Pollutants such as SOx, NOx, Suspended Particulate matters, non-methane volatile organic compounds, dust, fly ash and odor.
- Reduced water pollution to improve water quality for safe drinking water and sanitation, save water bodies such as rivers, canals, streams, wetlands, tanks and lakes to ensure ecological process for productivity
- Reduced waste to improve overall environmental quality of air, water and soil as well as ecosystems for ensuring clean environment
- Reduced resource use particularly in terms of the reduction in use of the primary fuel for generation of power and to improve sustainable management of natural resources

Social improvement, which includes:

- Health improvement by using clean technology
- Improved quality of life (which may come about through lowering of drudgery, better lighting, space cooling etc.)
- Education (through improved scope for night time of children)
- Equality (through say women's empowerment as they have better scopes for study, income earning opportunity and consequent social mobility etc,)

Economic improvement, which includes:

- Poverty alleviation (such as reduction in the proportion of poor due to better income and consumption prospects)
- Job creation and quality (more jobs availability due to establishment of new enterprises or expansion of old ones due to availability of electricity)
- Skills improvement (as with better prospects for jobs, people may train for skills improvement)

- Enterprise stimulation (growth or expansion of firms)
- Balance of payments effects (due to, say, increased costs of imported technology)

Criteria category 2: GHG reduction potential in a sector of the technology. This criterion considers the baseline emissions of the baseline technology, GHG emissions of the substituting technology, and on the technical potential to replace successfully high GHG emitting technologies with the clean technologies.

Criteria category 3: Costs of technology

- Capital costs for introducing efficient and clean technology
- Operational and maintenance (O&M) costs of newly introduced technology

5.4.2 Assessment of technologies:

5.4.2.1 Scoring and weighing of power generation technology options

Scoring of power generation technology options: Scoring to the short- listed mitigation technologies of power generation subsectors has been done following consultations with the stakeholders of relevant sector. On the basis of the technology information and criteria stated in 'Technology Fact Sheets' of each technology the stakeholders scored each of the technologies for each criteria. The score is given on a scale of 0-100. The 'Technology Fact Sheets' are presented respectively as Annex 1.

The scores based on both stakeholder ideas as well as expert opinion are shown in Tables 27 and 28.

Table 21: Scoring of technologies for power generation – Costs and Environmental considerations

Sl no	Technology	Investment cost ($/kw)	Fixed O&M ($/kw/year)	Variable O&M ($/MWh)	CO_2 (lb/MMBtu)	SO2 (lb/MMBtu)	NOx (lb/MMBtu)	Resource use efficiency
Gas-based power generation								
1	Advanced combustion turbine	90	90	70	70	80	70	90
2	Natural gas combined cycle	85	80	90	70	80	90	75
3	Advanced natural gas combined cycle	80	80	90	70	80	90	70
Coal-based power generation								
4	Single Unit APC	75	75	85	50	70	50	80
5	Double Unit APC	70	70	75	50	70	50	80
6	Single unit IGCC	55	60	85	50	70	90	85
7	Double unit	50	55	75	50	70	90	85

	IGCC							
Solar home PV								
8	Solar home PV*	95	-	-	100	100	100	100

Table 22: Scoring of technologies for power generation – Economic and social considerations

Sl no		Economic				Social			
	Technology	Productivity increased	Job creation /new enterprises	Poverty reduced	Balance of payment	Improved quality of life	Better education	Security	Women's empowerment
Gas-based power generation									
1	Advanced combustion turbine	75	80	70	70	70	70	70	70
2	Natural gas combined cycle	75	80	70	65	70	70	70	70
3	Advanced natural gas combined cycle	75	80	70	60	70	70	70	70
Coal-based power generation									
4	Single Unit APC	75	80	70	55	70	70	70	70
5	Double Unit APC	75	80	70	45	70	70	70	70
6	Single unit IGCC	75	80	70	50	70	70	70	70
7	Double unit IGCC	75	90	90	45	70	70	70	70
Solar home PV									
8	Solar home PV	60	65	70	80	80	90	90	70

Weighting of power generation technology options: Following scoring and identification of the most preferred and least preferred technology options through stakeholders' consultation, weights of each criterion are determined in several steps. First, we estimate the swing weights for each attribute of the technology. These are then converted into relative weights and subsequently normalized (as detailed below) which are finally used for weighting the scores given to the technology attributes earlier and summed up as the final score.

The swing weights are estimated as, for a given attribute, the relative spread of the attribute score across technologies compared to the highest score. Thus, for example, the highest and lowest scores for investment costs (in Table www) are respectively 95 (for solar PV) and 50 (for double unit IGCC). The swing weight for capital costs thus becomes (95-50)/95 or 0.47. All other swing weights are estimated similarly. These are shown in Table 29.

Table 23: Swing Weights by Attribute of Technology (incl Solar PV)

Costs			Environment			
Investment cost	Fixed O&M	Variable O&M	CO2 emission	SO2 emission	Nox emission	Resource use efficiency
0.47368421	0.388889	0.222222	0.5	0.3	0.5	0.3

Economic				Social			
Productivity increased	Job creation / new enterprises	Poverty reduced	Balance of payment	Improved quality of life	Better education	Security	Women's empowerment
0.2	0.1875	0	0.4375	0.125	0.22222222	0.222222	0.222222

The swing weights are used to estimate relative weights of the attributes of a technology. The attribute having the highest swing weight is given a value of 100. Other values are set proportionately. While the relative weights seem cardinal, in reality, the inter se relationship is rather ordinal. Thus, a relative weight of 16 is not 80% of a relative weight of 20, but that 16 is lower than 20, not how much lower. It is the ordinal ranking which matters here. Once these relative weights are given, these are normalized by expressing each weight as proportion of the total of the weights for a given technology. Table 29 shows the intermediate or relative weights based on the swing weights described earlier and their normalized equivalents.

Table 24: Comparative swing weights, weights and normalized weights

Indicators	Investment cost	Fixed O&M	Variable O&M	CO2 emission	SO2 emission	Nox emission	Resource use efficiency	
SW excl PV	0.44	0.39	0.22	0.28	0.125	0.44	0.22	
Weight	100	90	75	80	60	100	75	
Normalised	0.125	0.1125	0.09375	0.1	0.075	0.125	0.09375	
SW incl PV	0.47	0.39	0.22	0.5	0.3	0.5	0.3	
Weight	90	80	60	100	70	100	70	
Normalised	0.09	0.08	0.06	0.10	0.07	0.10	0.07	
	Productivity increased	Job creation / new enterprises	Poverty reduced	Balance of payment	Improved quality of life	Better education	Security	Women's empowerment
SW excl PV	0.2	0.1875	0	0.35714286	0	0	0	0
Weight	70	65		85				
Normalized	0.0875	0.08125	0	0.10625	0	0	0	0
SW incl PV	0.2	0.1875	0	0.4375	0.125	0.22	0.22	0.22
Weight	55	50		85	40	60	60	60
Normalized	0.06	0.05	0	0.089	0.04	0.06	0.06	0.06

The normalized weights are then used to sum up the scores for a technology given earlier based on multi-criteria analysis. That is for each technology, the multi-criteria scores are averaged using the normalized weights. The result is the final weighted average scores based on which one may rank the short listed technologies. The highest final score is ranked 1 and the next one ranked 2 till all the technologies are similarly ranked. These are shown in Table 31. The first column indicates the scores when the solar PV is not considered together. The second column is constructed by taking solar PV into consideration.

The first point of note is that whichever generation technology set is used, the broad rankings remain the same. While it is difficult to interpret the weighted values, if these have any cardinal meaning, gas based technologies are in general better on the whole than coal-based ones. When solar PVs are considered, these occupy a place along with the gas-based ones. Given this, note that the coal-based technologies are not far behind in their values compared to the gas-based ones and thus, in terms of prioritization the two types of technologies are on the whole more or less at par with each other.

Within the gas-based technologies, the normal combined cycle has a slight edge over the advanced gas turbine or advanced combined cycle , both of which appear to be very similar in ranking. On the other hand, while coal-based technologies are similar, IGCC which is a new entrant in the market has certain edge over others such as single or double unit pulverised coal using supercritical heat systems.

Table 25: Final Scores of power generation technology options

Gas-based power generation		
Advanced combustion turbine	76.19	74.87
Natural gas combined cycle	78.91	76.63
Advanced natural gas combined cycle	76.06	74.62
Coal-based power generation		
Advanced Pulverised Coal (APC) Single Unit	68.69	67.91
Advanced Pulverised Coal (APC) Double Unit	66.31	66.07
Integrated Gasification Combined Cycle (IGCC) Single unit	69.03	68.60
Integrated Gasification Combined Cycle (IGCC) Single unit Double unit	69.03	67.45
Solar home PV		
Solar home PV		75.61

***Note*: The second column takes into account all the technologies including PV; the first column excludes it.**

5.4.2.2 Scoring and weighing of power use technology options

Scoring to the short- listed mitigation technologies of power use subsectors has been done following consultation of the stakeholders of relevant sector. On the basis of the technology information and criteria stated in 'Technology Fact Sheets' of each technology, the stakeholders scored each of the technologies for each criteria. The score is given on a scale of 0-100. The 'Technology Fact Sheets' are presented in Annex II.

The swing weights are estimated as, for a given attribute, the relative spread of the attribute across technologies. The normalized scores have then been applied on the multi-criteria scores to arrive at a weighted average score for each of the technologies. Table 32 shows multi-criteria analysis, swing scores and prioritization of domestic lighting technology options

Table 26: Multi-criteria Analysis, Swing Scores and Prioritization of Domestic Lighting Technology

Sl no	Technology	Cost			Environment			
		Investment cost	Fixed O&M	Variable O&M	CO_2	SO2	NOx	Resource use efficiency
1	LF	70	50	60	60	0	0	60
2	CFL	50	70	80	80	0	0	80
Swing score		0.29	0.29	0.25	0.25	0	0	0.25
Weight		100	100	90	90	0	0	90
Normalised weights		0.15	0.15	0.13	0.14	0	0	0.14
	Technology	Economic				Social		
		Productivity increased	Job creation/new enterprises	Poverty reduced	Balance of payment	Improved quality of life	Better education	Security
1	LF	60	0	0	70	70	70	80
2	CFL	70	0	0	50	80	70	80
Swing score		0.14	0	0	0.29	0.125	0	0
Weight		50	0	0	100	40	0	0
Normalised weights		0.08	0	0	0.15	0.06	0	0

5.5 Final decision and results of technology prioritization

After calculation of normalized weights, the overall weighted score has been calculated by multiplying each of the criteria specific weighted score with the normalized weights and then adding all the criteria scores of each technology option.

On the basis of overall weighted score the technology options are prioritized and ranked from high priority to low priority order. For example, among the power generation technology options 'Natural gas combined cycle' got the highest weighted average score of 76.63 and is given the rank 1 and with the highest priority. 'Double Unit APC' got the lowest weighted average score of 66.07 and thus considered as the lowest priority technology.

On the other hand the weighted average score for the technologies CFLs and LF are 68.6 and 62.1 respectively. These scores put CFL ahead of LF in terms of consumers' preference but the scores being rather close also indicate that the superiority of CFL is not established beyond doubt probably because of the much higher initial investment and dependence on imports despite the rather long life compared to LFs. Thus, for some people, the appeal of LFs may not be less than that of the CFL. Thus, we can have both in the set of efficient technologies, with LF being an intermediate step with the ultimate transition to CFL.

Table 27 and 28 below shows the prioritized technology options respectively of power generation and power use.

Table 27: Power generation technologies as per priority order

Technology	Weighted score		Priority order
	Without PV	With PV	
Natural gas combined cycle	78.91	76.63	1
Solar home PV	75.61		2
Advanced combustion turbine	76.19	74.87	3
Advanced natural gas combined cycle	76.06	74.62	4
Integrated Gasification Combined Cycle (IGCC) Single unit	69.03	68.60	5
Integrated Gasification Combined Cycle (IGCC) Double unit	69.03	67.45	6
Advanced Pulverized Coal (APC), Single Unit	68.69	67.91	7
Advanced Pulverized Coal (APC), Double Unit	66.31	66.07	8

Table 28: Power use technologies as per priority order

Technology	Weighted score	Priority order
Compact fluorescent lamp (CLF)	68.6	1
Linear fluorescent lamp (LF)	62.1	2

Note that the above gives the priority order of all the short-listed technology. If all of them are chosen by the policy maker, he/she should use the priority order. But suppose only 3 are to be chosen; only the first three should be in the final priority list. What the final priority list cannot be stated *a priori* because which constraint becomes binding to the policy maker is not known beforehand, although some speculation may be made.

At the present state of knowledge, Bangladesh may run out of gas in a decade's time. Gas is used among others for fertiliser production. As food security may be a binding constraint, the policy maker may wish to turn away from gas and switch to coal technologies instead and divert the gas so far destined for power plants will be diverted to fertiliser plants. At this stage we can thus provide only a priority ranking, not which one is to be prioritized.

CHAPTER 6: Summary / Conclusions

Considering the country's long-term development priorities and strive for poverty reduction and economic growth, this report prioritized the country's 'power generation and use' for its GHG mitigation potentials. A wide range of technologies are discussed, identified and prioritized through a series of consultations, both in national and local levels. The technology options for power generation include;

a) Natural gas combined cycle
b) Solar home PV
c) Advanced combustion turbine
d) Advanced natural gas combined cycle
e) Integrated Gasification Combined Cycle (IGCC) Single unit
f) Integrated Gasification Combined Cycle (IGCC) Double unit
g) Advanced Pulverized Coal (APC), Single Unit
h) Advanced Pulverized Coal (APC), Double Unit

On the other hand, the technology options for power use include;

a) Compact fluorescent lamp (CFL)
b) Linear fluorescent lamp (LF)

Stakeholder consultations facilitated a process for prioritization of technology in power generation and use during technology need assessment. These consultations process recognized the importance of introducing efficient mitigation technologies for ensuring energy security. Bangladesh, as member of the LDCs has no obligation to take mitigation effort under the UNFCCC process without any support from international mechanism, has developed BCCSAP by giving emphasis on low carbon development. As part of implementation of the BCCSAP, national funding entities such as, the Bangladesh Climate Change Trust Fund and the Bangladesh Climate Change Resilience Fund have been established to access both national and international financial support. Considering the existing national and international support mechanisms and very high demand for energy requirement for ensuring sustainable development, stakeholders' consultations recommended for above mentioned potential power generation and use technologies in the country.

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ANNEX I: Long lists of technology by attributes

Table 29: Technical and Cost Attributes of Gas-based Power Generation Technology

SL	Technology	Nominal capacity (kw)	Heat rate (btu/kwh)	Investment cost ($/kw)	Fixed O&M ($/kw/year)	Variable O&M ($/MWh)
1	Conventional combustion turbine	85,000	10,850	974	6.98	14.70
2	Advanced combustion turbine	210,000	9,750	665	6.70	9.87
3	Natural gas combined cycle	540,000	7,050	978	14.39	3.43
4	Advanced natural gas combined cycle	400,000	6,430	1,003	14.62	3.11
5	Advanced NGCC with CCS	340,000	7,525	2,060	30.25	6.45

Source: U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010,
Note: NGCC – natural gas combined cycle; CCS – carbon capture and storage

Table 30: Coal-based Improved Technology

Name of Technology	Nominal Capacity (kW)	Nominal Heat Rate (Btu/kWh)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	SO2 (lb/ MMBtu)	NOX (lb/M MBtu)	CO2 (lb/MMB tu
Single Unit APC	650,000	8,800	3,167	35.97	4.25	0.1	0.06	206
Double Unit APC	1,300,000	8,800	2,844	29.67	4.25	0.1	0.06	206
Single Unit APC with CCS	650,000	12,000	5,099	76.62	9.05	0.02	0.06	20.6
Double Unit APC with CCS	1,300,000	12,000	4,579	63.21	9.05	0.02	0.06	20.6
Single unit IGCC	600,000	8.700	3,565	59.23	6.87	0.025	0.0075	206
Double unit IGCC	1,200,000	8,700	3,221	48.90	6.87	0.025	0.0075	206
Single unit IGCC with CCS	520,000	10,700	5,348	69.30	8.04	0.015	0.0075	20.6

Source: U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010, *Note:* APC –advanced pulverised coal; IGCC – integrated gasification combined cycle; CCS – carbon capture and storage

Table 31: Nuclear Power Generation Technology

Technology	Reactor type/ fuel cycle option	Net capacity in cost estimates (MWe)	Overnight construction costs	
			MUSD	USD/kWe
PWR	PWR/OT	2 682.4	2 880	1 074
	PWR/OT	1 906	2 303	1 208
	PWR/CC	1 590	2 474	1 556
	PWR/OT	1 590	2 819	1 773
	PWR/OT	1 500	2 843	1 895
	PWR/CC	1 600	3 432	2 145
	VVER/OT	1 000	1 089	1 089
	VVER/OT	894	1 561	1 747
	PHWR/OT	1 406	1 931	1 373
	PHWR/OT	665	1 200	1 805
BWR	BWR/OT	1 600	3 012	1 882
GENIII	GENIII/OT	1 000	1 894	1 894
	ABWR/CC	1 330	3 338	2 510

Source: NEA/IEA/OECD, Projected Costs of Generating Electricity, 2005 Update.

Note: PWR= pressurized water reactors (PWR), CC= closed fuel cycle, OT= Once through fuel cycle; PHWR= pressurized heavy-water reactor; BWR= boiling water reactor; VVER= *vodo-vodyanoi energetichesky* reactor; ABWR =Advanced Boiling Water Reactor; GENIII= Generation III **reactor**

Table 32: Attributes of Hydroelectricity Generation

SI No.	Type of technology	Power output (kW)	Life cycle (years)	Installed costs (US$/kW)	O & M costs (% of installed costs)	Levelised cost of electricity (2010 US$/kWh)	Capacity factor (%)
1	Hydro turbine	Large hydro (>100000)	40-80	1050 – 7650	2-2.5	0.02-0.19	25-90
		Small hydro (100-2000)	40-80	1300-8000	1- 4	0.02-0.27	20-95
2	Hydrokinetic turbines	40		7850	4	0.68	
		60		4717	2.4	0.68	
		17000		7253	3.6	0.11	
		5200		9230	2.9	0.28	

Source: International Renewable Energy Agency, *Renewable Energy Technologies: Cost Analysis Series, Working paper Series, Hydropower, Volume 1: Power Sector*, Issue 3/5, June 2012; and Johnson, Jerome B. and Dominique J. Pride, *River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska*, Prepared for the Alaska Energy Authority, Alaska Center for Energy and Power, November 1, 2010

Note: Output of hydrokinetic electricity depends on the strength of flow in the rivers resulting in large range in output.

Table 33: Solar Power Generation Technology

Technology	Nominal Capacity (kW)	Nominal heat rate (Btu/kWh)	Life cycle (years)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
Solar thermal	100,000	N/A		4692	64.00
CSP	50 000	N/A	20 – 30	5912	
Small photovoltaic	7,000	N/A		6,050	26.04
Large photovoltaic	150,000	N/A		4,755	16.70

Source: U. S. Energy Information Administration Office of Energy Analysis, Updated Capital Cost Estimates for Electricity Generation Plants, November 2010, for CSP, OECD/IEA, *Technology Roadmap, Concentrating Solar Power*, 2010
Note: CSP – Concentrating solar power

Table 34: Power generated by wind

Technology	Nominal Capacity (kW)	Types of Turbine	Nominal Heat Rate (Btu/kWh**)**	Life cycle	Capital Cost ($/kW	O&M cost($/kW-yr)	Annual Energy production (MWh)
Onshore Wind	30,000	Enercon 600kW	N/A	25	1643	17.92	100000
Onshore Wind	30,000	Nordex 1000kW	N/A	25	1605	17.92	110000
Onshore Wind	30,000	2000 kW	N/A	25	1587	24.95	90000

Onshore Wind	100,000	1500	N/A		2,438	28.07	
Offshore Wind	400,000	5000	N/A		5,975	53.33	

Source: *Prospects of wind farm development in Algeria*, Desalination 239 (2009) 130–138; U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010.

ANNEX II: Technology Fact Sheets (TFS)

Technology Fact Sheet – Advanced Gas Combustion Turbine

Sector	**Power generation**
Technology name	Advanced Gas Combustion Turbine
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	The Advanced CT Facility produces electricity using a single natural gas-fueled, state of the art F-class CT and associated electric generator. The CT is equipped with an inlet evaporative cooler to reduce the temperature of the turbine inlet air to increase summer output. The Advanced CT Facility has the same general electrical and control systems as the Conventional CT Facility, except that the electric generator is rated at approximately 234 MVA and the corresponding General Set up Transformer is larger in the Advanced CT Facility. Note that there have been over time other variants, such as G and H-class CT which are somewhat improved versions of the F-class CT. We have chosen F-class, because, it is a completely proven technology. **Based on U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants, November 2010*.**
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Many of the new power plants in the pipe line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for this technology. It should be noted, however, that of the 3 gas-based power generation technology, this one is ranked 3rd. More emphasis is likely to be given, under gas based generation, to combined cycle and advanced combined cycle technology. The nominal capacity, heat rate and the emission factor that have been assumed are 210 MW, 9750 Btu/kwh and 117 lb of CO_2 emission per MMBtu

Reduction in GHG emission	While the actual lowering of CO_2 emission depends on the run time and production, note that the heat rate is somewhat lower for ACT compared to the conventional gas turbine. We assume a 320 days running time a year for 24 hours which give the CO_2 emission for one year's run time for ACT at 928 thousand mt and for equivalent CT power 834 thousand mt, i.e., 93 thousand mt or 10% less than for ACT compared to equivalent power generation with CT. This is for one year's run time. If an ACT and equivalent CTs are established today (say, 2010) by 2030, this will mean about 1.9 mn mt of less carbon di-oxide emission.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the ACTs will produce almost 2.5 times the nominal generation of combustion turbines and probably at much lower gas consumption. This will allow more gas and electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. Job creation will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to be imported from abroad and more sophisticated technology may be costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may have not be large.
Country environment development priorities	The emission factors of SO_2 and NOx will be the same as for the conventional gas turbines. But for equivalent output of electricity, again the emission will be broadly 1/3rd of the conventional gas turbine. Thus there will be less emission and the air pollution will be comparatively less. There is likely to be a small fall in resource (gas) use efficiency as the heat rate is somewhat lower, 9750 Btu/kwh for ACT compared to 10850 Btu per kwh for CT i.e., for the latter it is 10% less.
Other considerations and priorities	-
Costs	

Capital costs	The costs of a ACT is 665/kw and a CT 974/kw. Given that the capacity of a ACT is 210 MW and that of a CT is 85 MW, the price tag of a CT with equal capacity as ACT is 2.47 times the cost/kw of each CT. That is for a CT it is 2.47*US$ 974//kw which comes to US$ 204 mn compared to an ACT of same capacity at just about US$140 mn. There is thus a huge cost advantage of ACT over CT.
Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for CT: US$ 6.98 and for ACT: 6.70 per year per kw. The differences are small on a kw basis, but when the comparison on an equivalent capacity basis is made, the costs for fixed O&M for CT becomes US$ 1.46 mn and for ACT US$ 1.40 mn. The differences are rather small and may be ignored for comparative purposes. The case for variable O&M is however quite different. For CT it is 14.70/Mwh and for ACT it is 9.87/MWh. If we assume that the two are run exactly the same number of hours in a year, CT variable O&M costs become US$24 mn and for ACT US$16 mn at the most. Again a somewhat clear cost advantage for ACT over CT for the same level of output.
Cost of GHG reduction	As the capital costs are far lower for ACT and the fixed O&M costs are similar while variable O&M costs are somewhat less for ACT for a year's run time, this means that the 10% lower emission is achieved at negative costs.

Technology Fact Sheet – Natural Gas Combined Cycle

Sector	**Power generation**
Technology name	Natural Gas Combined Cycle
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	In NGCC plants, natural gas is used as fuel in a gas turbine. Electricity is produced from the generator coupled to the gas turbine, and the hot exhaust gas from the turbine is used to generate steam in a waste heat recovery unit. The steam is then used to produce more electricity. The output from both the gas turbine and the steam turbine electrical generators is combined to produce electricity very efficiently. NOx control in gas turbines is proven technology and can be accomplished with relatively inexpensive "low NOx burners." In addition, NOx can be reduced still further with such "add-on" control technology as Selective Catalytic Reduction. Emissions of particulate matter generated with this method are also quite low, although some secondary particulate matter is produced through atmospheric chemistry reactions involving NOx. **Based on: 2006 Update Including a Discussion of Carbon Capture and Storage in an Ontario Context, *A Comparison of Combustion Technologies for Electricity Generation, December 2006.***
Implementation assumption, how the technology will be	Many of the new power plants in the pipe line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of

implemented and diffused across the sub-sector	gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for this technology. More emphasis is likely to be given, under gas based generation, to combined cycle and advanced combined cycle technology. The nominal capacity, heat rate and the emission factor that have been assumed are 540 MW, 7,050 Btu/kwh and 117 lb of CO_2 emission per MMBtu
Reduction in GHG emission	While the actual lowering of CO_2 emission depends on the run time of the plant and production, note that the heat rate is somewhat lower compared to the conventional gas turbine and thus, the emission of CO_2 is expected to be lower per kwh. The lowering of CO_2 emission depends on the nominal heat rate as the rate of emission is 117 lb per MMbtu for both NGCC and conventional turbine. The CO2 emission per year is 1.55 mn mt for an NGCC and 2.39 for an equivalent capacity CT plant, i.e., 0.84 mn mt or 35% less than for equivalent CT power output.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the NGCC s will produce almost 6.35 times the nominal generation of combustion turbines and probably at much lower gas consumption because of the use of the heat from the first round of power output in the combined cycle. This will allow more electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to import from abroad and more sophisticated technology is costlier. However, for each case of new power generation technology, the

	marginal effect of import of newer technology equipments may have not be large.
Country environment development priorities	The emission factor of SO_2 will be the same as for the conventional gas turbines. But for equivalent output of electricity, again the emission will be broadly 1/6th of the conventional gas turbine. Thus there will be less emission and the air pollution will be comparatively less. There is likely to be a small fall in resource (gas) use efficiency as the heat rate is somewhat lower, 7050 Btu/kwh for NGCC or 35% less compared to 10850 Btu per kwh for CT.
Other considerations and priorities	-
Costs	
Capital costs	The costs of a NGCC unit is 978/kw and of a CT 974/kw. Given that the capacity of a NGCC is 540 MW and that of a CT is 85 MW, for equivalent capacity, the price tag of a CT establishment with equal capacity as NGCC is 6.35 times the cost/kw of a single CT unit. That is for a CT it is 6.35*US$ 974//kw which comes to US$ 525 mn compared to an NGCC of same capacity at just about US$528 mn.
Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for CT US$ 6.98 and for NGCC 14.39 per year per kw. The differences are around double on a kw basis, but for comparison on an equivalent capacity basis, the costs for CT gets to US$ 3.77 mn and for NGCC US$ 7.77 mn. The case for variable O&M is however quite different. For CT it is 14.70/Mwh and for NGCC it is 3.43/MWh. If we assume that the two are run exactly the same number of hours in a year (320 days for 24 hours), CT variable O&M costs become US$ 60.9 mn and for NGCC US$14 mn at the most, a very clear cost advantage for NGCC over CT for the same level of output.
Cost of GHG reduction	If CT is replaced with NGCC, for equivalent output of CT as for NGCC, the reduction in CO2 emission as pointed out earlier is 0.84 mn mt per year. The yearly operational costs are estimated to be US$ 64.67 mn for CT equivalent to an NGCC while for the latter it is US$ 21.77 mn. Noting that if we assume similar life cycle for the two types of plants, the cost of depreciation of capital is more or less the same. The lower emission is thus achieved at a negative (operational and total) cost.

Technology Fact Sheet – Advanced Generation Natural Gas Combined Cycle

Sector	**Power generation**
Technology name	Advanced Generation Natural Gas Combined Cycle
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	The Conventional NGCC technology utilizes two natural gas-fueled F-class CTs and associated electric generators, two supplemental-fired heat recovery steam generators (“HRSG”), and one condensing ST and associated electric generator operating in combined-cycle mode. The AG-NGCC design is the same as the Conventional NGCC, except an H-class CT is utilized in lieu of F-class, and there is only one CT/HRSG supporting the ST included. Since the H-class CT design employees steam cooling of both stationary and rotational hot parts, the HRSG systems and the ST are both considered “advanced” designs, as compared to the Conventional NGCC. **Based on: U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants, November 2010*.**
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Many of the new power plants in the pipe line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for this technology. It should be noted that of the 3 gas-based power generation technology, this one is ranked second. The nominal capacity, heat rate and the emission factor that have been assumed are 400 MW, 6430 Btu/kwh and 117 lb of CO_2 emission per MMBtu
Reduction in GHG emission	While the actual lowering of CO_2 emission depends on the run time of the plant and production, note that the heat rate is somewhat lower compared to the conventional gas turbine and thus, the emission of CO_2 is expected to be lower per kwh. The lowering of CO_2 emission depends on the nominal heat rate as the rate of emission is 117 lb per MMbtu for both NGCC and conventional turbine. Gross CO_2 emission for a 400MW AG-NGCC is 1.05 mn mt. For CT with equivalent capacity, gross CO_2 emission is 1.77 mn mt. Thus, the emission from an AG-NGCC is lower by 0.72 mn mt or 40% less from CT of equivalent capacity in a year.
Impact Statements – How this option impacts the country development priorities	
Country social	Each of the AG-NGCC will produce almost 4.7 times the nominal

development priorities	generation of combustion turbines and at much lower gas consumption because of the utilisation of the residual heat from the first round generation. This will allow more gas and electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to import from abroad and more sophisticated technology may be costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may have not be large.
Country environment development priorities	The emission factors of SO_2 and NOx will be the same as for the conventional gas turbines. But for equivalent output of electricity, again the emission will be broadly 1/5th of that from conventional gas turbine. Thus there will be less emission and the air pollution will be comparatively less. There is likely to be apparently a small fall in resource (gas) use efficiency as the heat rate is somewhat lower, 6,430 Btu/kwh for AG-NGCC compared to 10850 Btu per kwh for CT i.e., AG-NGCC heat rate is nearly 40% lower. However, note that for the surplus heat no additional fuel is necessary. Thus, on the whole the over-all resource use efficiency may be no less than that for CT.
Other considerations and priorities	-
Costs	
Capital costs	The investment cost of an **AG-NGCC plant** is US$ 1,003/kw and for a CT it is US$ 974/kw. Given that the capacity of a **AG-NGCC** is 400 MW and that of a CT is 85 MW, for equivalent capacity, the price tag of a CT with equal capacity as **AG-NGCC** is 4.7 times the cost/kw of CT. That is for a CT it is 4.7*US$ 974//kw which comes to US$ 389 mn compared to an **AG-NGCC** of same capacity at just about US$401 mn. There is thus a small investment cost advantage of CT over **AG-NGCC.**

Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for CT is US$ 6.98 and for AG-NGCC it is US$ 14.62 per year per kw i.e., almost double that for CT. When the comparison is made on an equivalent capacity basis, the costs for CT gets to US$ 2.79 mn and for AG-NGCC it becomes US$ 5.85 mn which is more than double the cost for equivalent capacity with CT. The case for variable O&M is however quite different. For CT it is 14.70/Mwh and for **AG**-**NGCC** it is 3.11/MWh. If we assume that the two are run exactly the same number of hours in a year (320 days for 24 hours /day), CT variable O&M costs become US$ 45.10 mn and for **AG**-**NGCC** US$ 9.55 mn at the most. There is thus a very clear cost advantage in terms of variable O&M for **AG**-**NGCC** over CT for the same level of output.
Cost of GHG reduction	If CT is replaced with AG-NGCC, for equivalent output of CT as for AG-NGCC, the reduction in CO2 emission as pointed out earlier is 0.72 mn mt per year. The yearly operational costs are estimated to be US$ 47.89 mn for CT equivalent to an AG-NGCC while for the latter it is US$ 15.40 mn. Noting that if we assume similar life cycle for the two types of plants, the cost of depreciation of capital for AG.NGCC may be is more or less the same as for equivalent CT or slightly more. The lower emission is thus achieved at a negative (operational and total) or almost equivalent cost.

Technology Fact Sheet – Advanced Pulverized Coal (Single Unit)

Sector	**Power generation**
Technology name	Advanced Pulverized Coal (Single Unit)
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	Pulverized coal power generation starts by crushing coal into a fine powder that is fed into a boiler where it is burned to create heat. The heat produces steam that is used to spin one or more turbines to generate electricity. Subcritical plants make up the bulk of the U.S. pulverized coal system, with efficiencies for new plants usually around 37 percent. Pulverised sub-critical plants can be taken to be the benchmark for evaluating super critical, ultra super critical and IGCC plants. Advanced Pulverized Coal Facility is provided for a nominally 650 MW coal-fired supercritical steam-electric generating unit which employs a supercritical Rankine power cycle in which coal is burned to produce steam in a boiler, which is used to run a ST to produce electric power. The steam is then condensed to water and pumped back to the boiler to be converted to steam once again to complete the cycle. **Based on:** 1. Ngo, Christian and Joseph Natowitz, *Our Energy Future: Resources, Alternatives and the Environment*. 2. U. S. Energy Information Administration Office of Energy Analysis,

	Updated Capital Cost Estimates for Electricity Generation Plants, November 2010.
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Many of the new power plants in the pipe line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of coal used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for this technology. It should be noted, that of the 4 coal-based power generation technology, this one is ranked 2nd although there are little differences in the final scores of prioritised coal-based technologies. More emphasis is likely to be given, under coal based generation to dual unit advanced pulverized coal technology because the investment costs are somewhat lower while the power output becomes double of that for single unit plants (see later). The nominal capacity, heat rate and the emission factor that have been assumed for a single unit plant are 650 MW, 8,800 Btu/kwh and 206 lb of CO_2 emission per MMBtu
Reduction in GHG emission	The benchmark as argued should perhaps be the Pulverised sub-critical plant. Unfortunately it is difficult to get comparable figures for sub-critical plants. Hence we use the CT as the reference point. In fact, perhaps that is what it should be as the most prevalent mitigation friendly power generation technology in Bangladesh is the conventional combustion turbine. Hence the comparison may be with CT. Given this, the CO_2 emission actually increases, not reduced, if the APC single unit supercritical technology is used compared to the equivalent power generation with CT. The respective emissions are 2.87 mn mt for CT and 4.10 mn mt for APC single unit with supercritical technology. Thus, the increase in CO2 emission is almost 43%.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the single unit APCs will produce nominally 650 MW. This is larger than even the NGCC typical plant size of 540 MW. Thus the additional output will allow more electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.

Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to be imported from abroad and more sophisticated technology may be costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may not be large.
Country environment development priorities	The emission factors of SO_2 and NOx will be the same as for the pulverized coal technology. But for equivalent output of electricity, again the emission will be broadly decreased in dual unit APC. Thus there will be less emission and the air pollution will be comparatively less.
Other considerations and priorities	-
Costs	
Capital costs	The investment cost of a single unit APC is US$ 3,167/kw. Given that the capacity of a single unit APC is 650 MW the price tag of a single unit APC is US$ 3,167*650000 or 2.06 bn. For CT of equivalent capacity it is only US$ 633.34 mn. Going for a coal-based supercritical technology as one unit establishment, is thus going to be extremely costly compared to gas-based generation.
Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for single unit APC US$ 35.97 per year per kw. Thus for a single unit estimated APC fixed cost is US$ 23.38 mn. For a CT of comparable capacity, the fixed cost becomes US$ 4.54 mn. Variable O&M for single unit APC it is 4.25/Mwh and the total comes to US$ 21.21 mn per year. For CT of equivalent power generation, the total variable O& M costs come to US$73.41 mn. Thus CT variable O& M costs are much higher compared to APC single unit.
Cost of GHG reduction	The emission actually increases, not reduced, from equivalent CT-based generation. Hence the cost of reduction is redundant

Technology Fact Sheet – Advanced Pulverized Coal (Double Unit)

Sector	**Power generation**
Technology name	Advanced Pulverized Coal (Double Unit)
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	Pulverized coal power generation starts by crushing coal into a fine powder that is fed into a boiler where it is burned to create heat. The heat produces steam that is used to spin one or more turbines to generate electricity. Subcritical plants make up the bulk of the U.S. pulverized coal system, with efficiencies for new plants usually around 37 percent. Pulverised sub-critical plants can be taken to be the benchmark for evaluating super critical, ultra super critical and IGCC plants. Advanced Pulverized Coal Facility is provided for a nominally 650 MW coal-fired supercritical steam-electric generating unit which employs a supercritical Rankine power cycle in which coal is burned to produce steam in a boiler, which is used to run a ST to produce electric power. The steam is then condensed to water and pumped back to the boiler to be converted to steam once again to complete the cycle. The APC double unit has the same features as for APC single unit above with the provision that the rated nominal capacity is 1300 MW. But as we shall see, not everything gets doubled including costs. Based on: **1. Ngo, Christian and Joseph Natowitz*, Our Energy Future: Resources, Alternatives and the Environment*. 2. U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants,* November 2010.**
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Many of the new power plants in the pipe-line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also, new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. While new gas-based plants may be set up, clean coal technology is an attractive alternative from two points in view. Firstly, the country has some, though not very abundant, coal reserves. This need to be utilized well and highly efficient technologies such as IGCC may be utilized for the purpose. Secondly, while there may be improved situation related to gas reserves, dependence on coal is likely to increase in future in which case efficient but also cleaner technologies (because coal is the dirtiest fuel from CO_2 emission point of view) needs to be employed to make the most of the scarce resource. And in that case global

	support leveraged by UNFCCC (in the form of Green Climate funding) is likely to be available if the case is made well. It should be noted, that of the 4 coal-based power generation technology, this one is ranked 4th although there are little differences in the final scores among the prioritized technologies. More emphasis is likely to be given, under coal based generation to dual unit advanced pulverized coal technology because the investment costs are somewhat lower while the power output becomes double of that for single unit plants. In fact, one Bangladeshi coal-based plant is having a similar capacity of nearly 1300 MW. The nominal capacity, heat rate and the emission factor that have been assumed for a Double unit plant are 1300 MW, 8,800 Btu/kwh and 206 lb of CO_2 emission per MMBtu.
Reduction in GHG emission	The benchmark as argued should perhaps be the Pulverised sub-critical plant. Unfortunately it is difficult to get comparable figures for sub-critical plants. Hence we use the CT as the reference point. In fact, perhaps that is what it should be as the most prevalent mitigation friendly power generation technology in Bangladesh is the conventional combustion turbine. Hence the comparison may be with CT. Given this, the CO_2 emission actually increases, not reduced, if the APC Double unit supercritical technology is used compared to the equivalent power generation with CT. The respective emissions are 5.75 mn mt for CT and 8.21 mn mt for APC Double unit with supercritical technology. Thus, the increase in CO2 emission is almost 43%, the same as for APC Single unit compared to CT.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the double unit APCs will produce nominally 1300 MW. This is more than double the capacity of even the NGCC typical plant size of 540 MW. Thus the additional output will allow more electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. Poverty will be reduced as more and more jobs are created and people are gainfully employed.

	BoP may be negatively impacted; however, as the machineries need to import from abroad and more sophisticated technology may be costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may not be large.
Country environment development priorities	The emission factors of SO_2 and NOx for APC double unit are higher compared to CT; 0.1 and 0.06 lbs/MMBtu for APC as opposed to 0.001 and 0.03 lbs/MMBtu for CT respectively. This means that air pollution may increase due to use of APC double.
Other considerations and priorities	-
Costs	
Capital costs	The investment cost of a double unit APC is US$ 2,844/kw. Given that the capacity of a double unit APC is 1300 MW the price tag of a double unit APC is US$ 2.844*130000 or 3.70 bn. For CT of equivalent capacity it is only US$ 1.26 bn. Going for a coal-based supercritical technology as one unit establishment, is thus going to almost 3 times costly investment compared to benchmark gas-based generation.
Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for double unit APC US$ 29.67 per year per kw. Thus for a double unit APC fixed cost is US$ 35.06 mn. For a CT of comparable capacity, the fixed cost becomes US$ 9.07 mn. Variable O&M for double unit APC it is 4.25/Mwh and the total comes to US$ 42.4 mn per year. For CT of equivalent power generation, the total variable O& M costs come to US$146.72 mn. Thus CT variable O& M costs are almost three times as much compared to APC double unit.
Cost of GHG reduction	The emission actually increases, not reduced, from equivalent CT-based generation. Hence the cost of reduction is redundant

Technology Fact Sheet - Single Unit Integrated Gasification Combined Cycle

Sector	**Power generation**
Technology name	Single Unit Integrated Gasification Combined Cycle
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	Single Unit IGCC power plant is a new power generation system, consisting of a gasifier which gasifies coal to CO and H2 and separates ash from coal, a gas clean-up facility which separates dust and sulfur from the resulting gas, and a gas turbine combined cycle power plant using coal gas from the gas clean-up facility. IGCC has a potential of higher than 50% net thermal efficiency with increased gas turbine combustion temperature, as this has already been realized with natural gas fired combined cycle power plants. It will also result in a 20% reduction of CO_2 while generating the same amount of

	electricity using coal. Although many research and development projects aimed at CO_2 reduction and fixation have been carried out worldwide, it appears difficult to achieve an economical and industrial scale. Thus, it is clear that increased net thermal efficiency is the most practical way for reduction of CO_2, making IGCC an attractive and important technology for the next century. Another feature of IGCC is its superior environmental performance which is attained by means of the conversion process from ''dirty'' coal to ''clean'' purified gas and disposal of non-leaching glassy slag in place of fly ash. Based on: **The development of advanced energy technologies in Japan IGCC:** ***A key technology for the 21st century, Energy Conversion and Management*** **43 (2002) 1221–1233**
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Many of the new power plants in the pipe line are based on oil and are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. While new gas-based plants may be set up, clean coal technology is an attractive alternative from two points in view. First, the country has some, though not very abundant, coal reserves. These needs to be utilized well and highly efficient technologies such as IGCC may be utilized for the purpose. Secondly, while there may be improved situation related to gas reserves, dependence on coal is likely to increase in future in which case efficient but also cleaner technologies (because coal is the dirtiest fuel from CO_2 emission point of view) needs to be employed to make the most of the scarce resource. And in that case, global support leveraged by UNFCCC (in the form of Green Climate funding) is likely to be available if the case is made well. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for IGCC Single as well as double unit technology. It should be noted, that of the 4 coal-based power generation technology, the single unit IGCC has been ranked 1st. The nominal capacity, heat rate and the emission factor that have been assumed are 600 MW, 8,700 Btu/kwh and 206 lb of CO_2 emission per MMBtu.
Reduction in GHG emission	While the actual CO_2 emission depends on the run time and production, note that the heat rate is somewhat lower compared to the conventional gas turbine but due to the higher carbon content of the primary fuel, the Single unit IGGCC compares poorly with gas-based CT. For Single unit IGCC the CO_2 emission from the nominal capacity plant is 3.75 mn mt and for a CT with comparable capacity the emission is 2.65 mn mt in a year of operation.

Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the single unit IGCCs will produce almost the same of the nominal output of single unit APCs. This will allow more electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service centres. Job creation will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. Poverty will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to import from abroad and more sophisticated technology like IGCC is far costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may not be large.
Country environment development priorities	The emission factors of a single IGCC unit are far less than the single unit APC. For SO_2 and NOx these are 0.025 and 0.0075 lbs per MMBtu respectively for the single IGCC. For the single APC these are 0.1 and 0.6 ibs/MMBtu. For equivalent power generation, therefore the lower emissions are expected to result in much less air pollution than single APC units. IGCC is basically coal turned into cleaner gas before using the gas turbine to produce electricity. In that sense it conserves the gas. On the other hand while it has lower heat rate, the net thermal efficiency can go up to 50% or more. In that sense, with less coal, one can have more electricity.
Other considerations and priorities	-
Costs	
Capital costs	The costs of a single unit IGCC is 3,565/kw and a single unit APC 3,167/kw. Given that the capacity of a single unit IGCC is 600 MW and that of a single unit APC is 650 MW, for equivalent capacity, the price tag of a single unit APC with equal capacity as single unit IGCC is somewhat similar. For a single unit APC it is US$ 1900 mn compared to an IGCC of same capacity at just about US$ 2139 mn. There is, thus, about a 10% cost advantage for investment in a of single unit APC over single unit IGCC.

Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for single unit APC US$ 35.97and for single unit IGCC 59.23 per year per kw. The differences are large on a kw basis, but when the comparison on an equivalent capacity basis, the costs for single unit APC gets to US$ 23.38 mn and for single unit IGCC US$ 38.50 mn. The absolute difference is also somewhat large. The case for variable O&M is, however, quite different. For single unit APC it is 4.25/Mwh and for single unit IGCC it is 6.87/MWh. If we assume that the two are run exactly the same number of hours in a year, single unit APC variable O&M costs become US$21.2mn and for single unit IGCC US$31.65 mn or so. Again, a clear cost advantage for single unit APC over single unit IGCC for the same level of output.
Cost of GHG reduction	Compared to the gas-based CT which may be used as the benchmark, because of the similarity of the generation part of the technology, the estimated CO2 emission is higher for single unit IGCC. And thus, the issue of cost of reduction does not arise.

Technology Fact Sheet - Double Unit Integrated Gasification Combined Cycle

Sector	**Power generation**
Technology name	Double Unit Integrated Gasification Combined Cycle
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation
Background/short description of technology	The Double Unit Single Unit IGCC power plant is basically a dual unit of the single unit IGCC plant. As discussed earlier, IGCC is a new power generation system, consisting of a gassifier which gassifies coal to CO and H2 and separates ash from coal, a gas clean-up facility which separates dust and sulfur from the resulting gas, and a gas turbine combined cycle power plant using coal gas from the gas clean-up facility. IGCC has a potential of higher than 50% net thermal efficiency with increased gas turbine combustion temperature, as this has already been realized with natural gas fired combined cycle power plants. It will also result in a 20% reduction of CO_2 while generating the same amount of electricity using coal. Although many research and development projects aimed at CO_2 reduction and fixation have been carried out worldwide, it appears difficult to achieve an economical and industrial scale. Thus, it is clear that increased net thermal efficiency is the most practical way for reduction of CO_2, making IGCC an attractive and important technology for the next century. Another feature of IGCC is its superior environmental performance which is attained by means of the conversion process from ‘‘dirty’’ coal to ‘‘clean’’ purified gas and disposal of non-leaching glassy slag in place of fly ash. **Based on:** U. S. Energy Information Administration Office of Energy Analysis *Updated Capital Cost Estimates for Electricity Generation Plants, November 2010*.
Implementation	Many of the new power plants in the pipe line are based on oil and

assumption, how the technology will be implemented and diffused across the sub-sector	are small as emergency measures for tackling the present shortages of electricity. One major problem had been the estimated shortage of gas. However, the present plants are very old and the same quantity of gas used in these plants can produce much more electricity using better technology. Also new discoveries and assessments of gas reserves indicate that the future supply of gas may not dwindle as fast as may have been thought so far. While new gas-based plants may be set up, clean coal technology is an attractive alternative from two points in view. First, the country has some, though not very abundant, coal reserves. This need to be utilized well and highly efficient technologies such as IGCC may be utilized for the purpose. Secondly, while there may be improved situation related to gas reserves, dependence on coal is likely to increase in future in which case efficient but also cleaner technologies (because coal is the dirtiest fuel from CO_2 emission point of view) needs to be employed to make the most of the scarce resource. And in that case global support leveraged by UNFCCC (in the form of Green climate funding) is likely to be available if the case is made well. The revision of the existing Power Sector Master Plan is therefore necessary to take account of these new realities. The revision may thus include provisions for IGCC Single as well as double unit technology. It should be noted, that of the 4 coal-based power generation technology, the double unit IGCC has been ranked 3rd. The nominal capacity, heat rate and the emission factor that have been assumed are 1200 MW, 8,700 Btu/kwh and 206 lb of CO_2 emission per MMBtu.
Reduction in GHG emission	While the actual CO_2 emission depends on the run time and production, note that the heat rate is somewhat lower compared to the conventional gas turbine but due to the higher carbon content of the primary fuel, the Double unit IGGCC compares poorly with gas-based CT. For Double unit IGCC the CO_2 emission from the nominal capacity plant is 7.49 mn mt while that from a comparable capacity CT plant is 5.31 mn mt for a year of operation.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the double unit IGCCs may produce 1200 MW of electricity. This will allow more electricity to the citizens to consume allowing a better quality of life. With increased supply of electricity, and consequent access to it, the lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with increased access to electricity the may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, better supply may spur the establishment of new factories and facilities and various service

	centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to import from abroad and more sophisticated technology like IGCC is far costlier. However, for each case of new power generation technology, the marginal effect of import of newer technology equipments may not be large.
Country environment development priorities	The emission factors of a double IGCC unit are far less than the double or single unit APC. For SO_2 and NOx these are 0.025 and 0.0075 lbs per MMBtu respectively for the single IGCC. For the double unit APC these are 0.1 and 0.6 lbs/MMBtu which are the same as for single unit APC. For equivalent power generation, therefore the lower emissions are expected to result in much less air pollution than double APC units. IGCC is basically coal turned into cleaner gas before using the gas turbine to produce electricity. In that sense it conserves the gas. On the other hand while it has lower heat rate, the net thermal efficiency can go up to 50% or more. In that sense, with less coal, one can have more electricity. And thus, it economises on the use of coal.
Other considerations and priorities	-
Costs	
Capital costs	The costs of a dual unit IGCC is 3,221/kw and a single unit APC 3,167/kw. Given that the capacity of a dual unit IGCC is 1,200 MW and that of a single unit APC is 650 MW, for equivalent capacity, the price tag of a single unit APC with equal capacity as single unit IGCC are quite similar. That is for a single unit APC it is 1.85*US$ 3,167//kw which comes to US$ 3808.3mn compared to an dual unit IGCC of same capacity at just about US$3865.2mn.
Operation and maintenance costs Fixed O&M Variable O&M	Fixed O&M costs are for single unit APC US$ 35.97and for double unit IGCC US$ 48.90 per year per kw. Compared to the double unit APC, the differences are even larger as the fixed cost of double unit APC is US$ 29.67/kw/year While the differences are large on a kw basis, when the comparison is made on an equivalent capacity basis, the fixed costs for a single unit APC gets to US$ 43.2 mn and for dual unit IGCC US$ 58.7 mn which means a relative narrowing of difference despite the large disparity in size between the two. The case for variable O&M is however quite different. For single unit APC it is 4.25/Mwh and for dual unit IGCC it is 6.87/MWh. If we assume that the two are run exactly the same number of hours in a year (320 days ona 24 hour basis), single unit APC variable O&M costs becomes US$ 39.25 mn and for dual unit IGCC US$ 63.31 mn. This

	shows again a very clear cost advantage for single unit APC over dual unit IGCC for the same level of output.
Cost of GHG reduction	Compared to the gas-based CT which may be used as the benchmark for GHG reduction comparison because of the similarity of the generation part of the technology, the estimated CO2 emission is higher for double unit IGCC. And thus, the issue of cost of reduction does not arise.

Technology Fact Sheet – Solar PV

Sector	**Power generation**
Technology name	Solar PV
Subsector GHG emission (mn mt CO2 equivalent	11.9 mn mt of CO_2 equivalent from power generation in 2005
Background/short description of technology	The following describes a nominally 7 MW-AC Photovoltaic ("PV") Facility. In contrast to solar thermal electricity generation, in case of solar photovoltaic, solar energy is directly converted into electrical energy. The PV Facility uses numerous arrays of ground-mounted, fixed-tilt PV modules which directly convert incident solar radiation into DC electricity, which can then be inverted to AC. the basic structure of a photovoltaic cell consisting of p-conducting base material and an n-conducting layer on the topside. The entire cell rear side is covered with a metallic contact while the irradiated side is equipped with a finger-type contact system to minimise shading losses. Also full cover, transparent conductive layers are used. To reduce reflection losses the cell surface may additionally be provided with an anti-reflecting coating. A silicon solar cell with such construction usually has a blue colour. By the incorporation of inverse pyramids into the surface reflection losses are further reduced. The inclination of the pyramid surfaces is such that photons are reflected onto another pyramid surface, and thus considerably enhance the possibility of photon penetration into the crystal. **Based on:** U. S. Energy Information Administration Office of Energy Analysis, *Updated Capital Cost Estimates for Electricity Generation Plants, November 2010*; Kaltschmitt, Martin, Wolfgang Streicher and Andreas Wiese, Renewable *Energy; Technology, Economics and Environment.*
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Till recently, solar power generation has been limited to installation of rather small solar PV systems at homes and small establishments in rural and off-grid areas. However, the Government is aware that despite limitations, there may be scope for power generation based on solar energy. Given that space is a constraint in this country; such facilities need to be small such as the proposed plant here so that solar panels do not take much space. The plants are small and therefore may be put up by the private sector with either a contract to sell the electricity to PDB's grid; or, if put up enterprises, they may sell any surplus electricity to the grid. The negative aspect of the solar

	PV is the high per unit cost. In fact, it is costliest in terms of capital requirement on a per MW basis. The nominal capacity has been assumed to be 7MW
Reduction in GHG emission	Solar energy does not emit any GHG. In that sense, whatever power generation based on fossil fuel a solar unit replaces, the emission due to the fossil-fuel based power generation unit is totally reduced. If the size of operation is considered, the replaced unit is likely to be one run with reciprocating engine which in Bangladesh is usually operated with diesel or furnace oil.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	Each of the small solar unit will produce more or less 7 MW. Being small, these may be suitable in off-grid areas for small communities as well as for commercial enterprises. This may allow a quality supply and ensure access of the people in poorer and remote region. With new supply of electricity, and consequent access to it, it may be used for all kinds of economic and domestic uses including lighting. Lighting for studies will improve leading to better education prospects as well as security. The process of women's empowerment will be better served as with new access to electricity they may enjoy facilities to which their access was limited previously.
Country economic development priorities	*Productivity* may increase as with new or better supply of electricity new technology may be introduced or the run time of factories may lengthen. On the other hand, new or better supply may spur the establishment of new factories and facilities and various service centres. *Job creation* will be facilitated because of productivity increase or the establishment of new enterprises. Both direct and indirect job creation may happen. *Poverty* will be reduced as more and more jobs are created and people are gainfully employed. *BoP* may be negatively impacted; however, as the machineries need to be imported from abroad and more sophisticated technology may be costlier. In fact, the proposed technology is the costliest on per MW capacity basis.
Country environment development priorities	The Solar PV is an environmentally benign technology as there is no emission of GHGs or SO_2 or NOx.
Other considerations and priorities	-
Costs	
Capital costs	The costs of a small solar PV is US$ 6050 /kw compared to the costliest gas-based technology of US$2060/kw and costliest coal-based technology of US$ 5348 both including carbon capture and storage and state of the art technology. The total costs are, however, not large as the capacity is small.

Operation and maintenance costs Fixed O&M	Fixed O&M costs are not comparatively high, at US$ 26.04/kw-year.
Cost of GHG reduction	The total cost of a solar PV is the cost of GHG reduction from plants that it replaces which is not unique by country. But as the capital costs are rather high, for equivalent power production the costs of zero emission under solar PV are rather high.

Technology Fact Sheet – Linear Fluorescent Lamps

Sector	Lighting (domestic)
Technology name	Linear fluorescent lamp
Subsector GHG emission (mn mt CO2 equivalent	CO_2 emission from power generation in 2005 was 11.9 mn mt. The ultimate supply of electricity is less than its output. How much the domestic sector is responsible for use of the supplied electricity seems to be not known with any precision. It is known however that the access by households to electricity supply is still limited, probably to 40% or so. And of the total supply, lighting probably accounts for somewhere within the range of 50-70 percent. The percent of households connected to the grid is around 40% or so and the highest percentage of household consumption for lighting in the capital city has been found to be 56. In villages, it must be much higher. On the whole, we may thus think of the over-all residential activities in 2005 to give rise to CO_2 emission of 4.7 mn mt. As lighting may account for more or less 50% of total electricity use in households, this means that nearly 2.4 mn mt of CO_2 emission was due to electrical lighting purposes.
Background/short description of technology	In Fluorescent lamps, mercury vapor is excited inside a tube by alternating current, and light is emitted by the gas. The light strikes the inner coating of the tube which is some type of fluorescent material, producing a soft glow. Traditionally fluorescent bulbs have long cylinders ranging from a few watts to 40 watts. New “parallel lengths” or PL lamps are now available that are much more compact. The PL lamps fold back the long cylinder to make a compact “H” shape, double “H” or quard PL lamps are also available. PL type lamps are available 5,7,9,13,18 or 24 and 36 watts. To operate from DC power, a ballast is needed to produce high frequency AC current.
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	Fluorescent lamps are rather well-known. The problem is in price compared to incandescent lamps. Particularly, a LFL needs a ballast as well as a starter and also a holder. The nominal lumen capacity, relative efficiency and life lengths are 55-85 per watt, 65% and up to 24000 hours depending on particular designs. The lowest life is 7500 hours.

Reduction in GHG emission	LFLs are much more efficient than incandescent lamps. Lumens per kw for incandescent lamps are about 15-25 while for LFLs it has a range from 55-85. The LFLs are at least 3 times as efficient as incandescent bulbs. Thus, for the same lighting service, roughly two-thirds of the electricity is saved leading to a proportionate reduction in carbon di-oxide.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	With better lighting quality, study habits may change for the better leading to better education prospects as well as security.
Country economic development priorities	*Productivity* may increase as with better quality of light, workers' incentive to work may improve. Also security in the work place may become better. Better lighting in commercial establishments may attract better more customers in the evening than previously spurring higher sales and incomes. Poverty may be reduced because people may have more time to engage in income-earning activities due to better lighting. Impact on BoP is not likely to be impacted much either negatively or positively. Much of the demand for LFLs can be met from domestic production while a certain percentage is always likely to be imported which will have a low negative impact on BoP.
Country environment development priorities	Little direct impact on air pollution may result from the use of LFLs. But the disposal of unusable tubes may create a problem due to the presence of mercury in them which may be leaked to the air or may be leached into the ground water. There will be a fall in use of electricity for lighting for the same number of hours implying positive outcome on resource use.
Other considerations and priorities	-
Costs	
Capital costs	The costs of an incandescent bulb may vary from US$ 1-3 while for an LFL it ranges from US$ 2.5-6.
Operation and maintenance costs O&M	An LFL needs special ballast, a starter and holders while an incandescent bulb needs none. But an LFL lasts far longer 10-20 thousand hours compared to 750 hours-1200 or so for an incandescent lamp. Thus the latter needs to be replaced far often than an LFL. The O&M costs for the incandescent is high (roughly 20 times the purchase cost of an average 60 W bulb. For LFL is much less because it is infrequent but costlier each time.
Cost of GHG reduction	While many factors may impinge upon the actual emission reduction and the costs, it appears that the cost may not be high on a life cycle analysis basis.

Technology Fact Sheet – Compact Fluorescent Lamps

Sector	**Lighting**
Technology name	Compact fluorescent lamp
Subsector GHG emission (mn mt CO2 equivalent	CO_2 emission from power generation in 2005 was 11.9 mn mt. The ultimate supply of electricity is less than its output. How much the domestic sector is responsible for use of the supplied electricity seems to be not known with any precision. It is known however that the access by households to electricity supply is still limited, probably to 40% or so. And of the total supply, lighting probably accounts for somewhere within the range of 50-70 percent. The percent of households connected to the grid is around 40% or so and the highest percentage of household consumption for lighting in the capital city has been found to be 56. In villages it must be much higher. On the whole, we may thus think of the over-all residential activities in 2005 to give rise to CO_2 emission of 4.7 mn mt. As lighting may account for more or less 50% of total electricity use in households, this means that nearly 2.4 mn mt of CO_2 emission was due to electrical lighting purposes.
Background/short description of technology	In Fluorescent lamps, mercury vapor is excited inside a tube by alternating current, and ultraviolet light is emitted by the gas. The light strikes the inner coating of the tube which is some type of fluorescent material, producing visible light. Compact fluorescent is a new technology with a history of about 40 years and new developments for bettering its performance is continuing. It uses the same basic features as for the LFLs but introducing design and other changes. It has already generated legislations in many countries to phase out incandescent bulbs with CFLs or other similarly energy-saving lighting technology. A CFL of 23 W produce the same light as an incandescent bulb of 100 W i.e., a CFL uses 75% less power than an incandescent lamp to produce the same lumen.
Implementation assumption, how the technology will be implemented and diffused across the sub-sector	CFLs are less well-known than LFLs the latter being in the market far longer and also because it is much cheaper. Compact fluorescent lamps are far costlier compared to incandescent lamps and this is a major barrier to its widespread use. Already, the Government has introduced as a promotional case swapping an incandescent for a CFL and reportedly has replaced a million incandescent lamps that way. Obviously clear-cut and transparent procedures would be needed. One issue may be the tariff imposed on its import and the other is to lower tariffs on raw materials for producing CFLs in the country. A third process may be strictly enforcing quality control so that CFLs deliver the number of hours of service these are intended to provide. A fourth issue would be the measures for safe disposal of the unusable CFLs particularly the mercury it contains (about 5 mg/lamp)

	The nominal lumen capacity, relative efficiency compared to high pressure sodium (HPS) light and life lengths are 45-60 per watt, 65% and 10,000 hours.
Reduction in GHG emission	CFLs are much more efficient than incandescent lamps. Lumens per kw for incandescent lamps are about 15-25 while for LFLs it has a range from 45-60. The CFLs are at least 4 times as efficient as incandescent bulbs. Thus, for the same lighting service, roughly 3/4th of the electricity is saved leading to a proportionate reduction in carbon di-oxide. On a life cycle analysis basis, use of a typical CFL results in an emission of 184 kg of CO2. The comparable emission from an incandescent lamp is 734 kg. Thais CFL use leads to 75% reduction in emission. Note that all these are actually indirect emission in the production, transportation and use of the CFL. **Based on:** Ramroth, Laurie, *Comparison of Life-Cycle Analyses of Compact Fluorescent and Incandescent Lamps Based on Rated Life of Compact Fluorescent Lamp*, Rocky Mountain Institute, February 2008.
Impact Statements – How this option impacts the country development priorities	
Country social development priorities	With better lighting quality, study habits may change for the better leading to better education prospects as well as security.
Country economic development priorities	*Productivity* may increase as with better quality of light, workers' incentive to work may improve. Also security in the work place may become better. Better lighting in commercial establishments may attract better more customers in the evening than previously spurring higher sales and incomes. Poverty may be reduced because people may have more time to engage in income-earning activities due to better lighting. Impact on BoP is not likely to be impacted much either negatively or positively. Part of the demand for CFLs can be met from domestic production while a certain percentage is always likely to be imported which will have a low negative impact on BoP.
Country environment development priorities	Direct impact on air pollution may result from the disposal of CFLs due to use of mercury in the lamp. There will be a 75% fall in use of electricity for lighting for the same number of hours implying positive outcome on resource use.
Other considerations and priorities	-
Costs	
Capital costs	The costs of an incandescent bulb may vary from US$ 1-3 while for an CFL it is at least US$ 10.
Operation and maintenance costs O&M	A CFL needs ballast. These days it comes integrated with the lamp and thus fixed costs are little or none. It does not generally need to be replaced for 10,000 hours although the actual life may get reduced if the on-off cycle is rather short (15 minutes to half hour). A CFL lasts far longer 10 thousand hours compared to an average of 1000 hours. Thus the latter needs to be replaced about 10 times while the CFL is replaced only once. But because CFL investment cost is far higher, the over-all O&M costs may not be much different.

Cost of GHG reduction	While many factors may impinge upon the actual emission reduction and the costs, it appears that the cost may not be high on a life cycle analysis basis. In fact it may be near zero if the investment costs and O&M costs for equivalent hours (10,000) for CFL and incandescent lamps are considered.

ANNEX III: The brief profile of TNA team members

Name	Key Qualification	Project Relevant Experience
Dr. S.M. Munjurul Hannan Khan (National Coordinator)	PH.D. in Natural Resource and Environment Management: Long (more than 15 years) experience in strategy and policy development and implementation related to climate change, biodiversity conservation, natural resource and environment management	Extensive experience in international climate change negotiation process of the UNFCCC process, specifically on adaptation and finance. Actively engaged with national development planning process to achieve sustainable and green development vision. Participated in all negotiation meetings of the UNFCCC and provided technical support to the process as negotiator of the LDCs.
Dr Rezaul Karim (Team Leader)	Ph.D. in engineering; Long (15 years or more) experience in international development support process particularly in relation to environment and sustainable development	Familiar with the international climate change negotiation process especially on technology issues Participated in the inception workshop of the UNEP/GEF Technology Needs Assessment Project in Paris, France in February 2010 Participated in the regional capacity building workshop of the UNEP/GEF Technology Needs Assessment Project in Bangkok, in September 2010 As part of government delegation participated in the climate change negotiation in CoP 13, CoP 14, CoP 15 and CoP 16
Dr M Asaduzzaman	Ph.D. in Economics; Long (at least 15 years) experience of analysis of development problems of growth, and planning in various core national development sectors	Experience with qualitative assessments (e.g., stakeholder consultations, Multi Criteria Decision Analysis) as well as quantitative assessments of technology costs and performance characteristics; Familiarity with the international climate change negotiation process especially on long term vision and adaptation Contributed in the development of Bangladesh Climate Change Strategy and

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		Action Plan (BCCSAP)
Dr Ainun Nishat	Ph.D in Civil Engineering Long years experience in coastal infrastructure development planning.	Familiar with current technologies in operation in the country's sectors and the regulatory and policy context for technology transfer; Experience on the technology issues on the climate change adaptation and mitigation
Dr AKM Saiful Islam	Ph.D in Civil Engineering Extensive experiences in water resources modeling and climate change modeling	Water resources and flood management. Extensive experience in modeling the impacts of climate change
Md Shamsuddoha	M.Sc in Marine Science Hands on experience on climate change adaptation and disaster risk reduction (DRR) measures in the coastal areas.	Experience with participatory processes Familiar with the international climate change negotiation process especially on finance and adaptation As part of government delegation participated in the climate change negotiation in CoP 15 and CoP 16.

Annex IV: List of Stakeholders of different sectors consulted in the process of TNA

List of Stakeholders of Climate change adaptation in agriculture sector

NAME	ORGANIZATION
Mr Khandoker Atiar Rahman	Joint Secretary (Proc), Food Division, Ministry of Food & Disaster Management Government of the People's Republic of Bangladesh Bangladesh Secretariat, Dhaka, Bangladesh
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Dr. Md. Mafizur Rahman	Ministry of Environment and Forests Government of the People's Republic of Bangladesh Bangladesh Secretariat, Dhaka, Bangladesh
Dr. Mazharul Aziz	Dept. Agriculture Extension

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	Ministry of Agriculture Khamarbari, Farmgate, Dhaka-1215.
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List of stakeholders of Energy Sector

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List of stakeholders: Water Sector

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