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Long-Term Sustainable Energy Supply and Mitigation of Greenhouse Gas Emission in Bangladesh

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Abstract – *A comparative study of long-term energy demand and potential greenhouse gas emissions projections from energy sector of Bangladesh was carried out covering the period 2000-2020. The study was conducted employing the IAEA's energy modeling tool, ENPEP- BALANCE, which has been employed by many developing countries. This paper presents long-term energy demand forecast, future energy security, and potential options to minimize carbon gas emission from the energy sector of the country. The primary energy demand distributed by energy carriers and electricity demand have been forecasted based on two macro-economic growth scenarios constructed for Bangladesh National Energy Policy (BNEP). Starting from 187 million boe (barrel oil equivalent) primary energy consumed in 2000, the analysis projected an energy demand growth to about 545 million boe and 453 million boe by 2020 for the high and low growth scenarios, respectively. Gross electricity generation of 16.57 TWh (terawatt hour) in 2000 will grow up to 90 TWh and 69 TWh for high and low scenario, respectively. The conservation of indigenous energy resources and other imported potential energy supply options including nuclear energy were analyzed to build a long-term secured energy supply system for Bangladesh.*

Keywords – BALANCE model, Bangladesh, energy demand, greenhouse gas.

1. INTRODUCTION

Bangladesh is an agro-based developing country with a population of 140 million. It is one of the lowest energy consumer countries in the world. In 2000, the per capita commercial energy consumption and electricity generation were 90 kilogram oil equivalent (kgoe) per year and 120 kWh per year, respectively.

Energy demand projections for the different end-users in Bangladesh are usually performed fuel-wise by utilities from their own restricted perspectives. Several studies of energy demand forecasting have been conducted without considering all energy supply sectors in an integrated program. Bangladesh Power Development Board (BPDB) employed WASP-III model in 1995 for electricity system planning for 1995-2015 period [1]-[2]. A study on CDM (Clean Development Mechanism) project opportunities in Bangladesh was conducted, estimating GHG emission level from energy sector up to year 2012 for business as usual case employing LEAP (Long-range Energy Alternative Planning system), an accounting- and simulation-type model [4].

Bangladesh is signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. It ratified the UNFCCC in February 1994 and ratified the Kyoto Protocol in 22 October 2001. Bangladesh National Environment Policy and National Energy Policy both promote energy efficiency, cleaner production, and renewable energy for greenhouse gas reduction [2]-[3].

The widely used IAEA tool 'Energy and Power Evaluation Program (ENPEP)-BALANCE' model has been employed for this study. Energy demand growth rate, fuel price, annual electrical load demand curve, and category of consumers (residential, agriculture, industrial, service and others) have been considered in an integrated energy network for prediction of energy demand.

The main objectives of this study are to analyze the energy sector of Bangladesh with a long-term forecasting for the national energy demand up to 2020 project greenhouse gas (GHG) emission; and develop prospective options for GHG mitigation. Assessment of potential energy supply sources and potential strategies for strengthening national energy security are also a part of this study.

2. MODELING APPROACH

Energy-economic models are widely employed for long-term energy and carbon gas emission projections. There are a number of energy economic models, which can be applied for energy and GHG emissions projection. These models differ from each other by their sophistication and data intensiveness.

The ENPEP (Energy and Power Evaluation Program) developed at Argonne National Laboratory is a simulation-type model used to model a country's entire energy system. It incorporates the dynamics of market processes related to energy by an explicit representation of market equilibrium; that is, the balancing of supply and demand [5].

Description of Balance Model

ENPEP consists of an executive module and ten other technical modules. The main module is BALANCE module, which was employed for this study. BALANCE

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uses a nonlinear and market-based equilibrium approach to determine energy supply and demand balance for the entire energy system up to 30 years [6],[3] (Figure 1). The model uses an energy network that is designed to trace the flow of energy from primary resources to final energy demand.

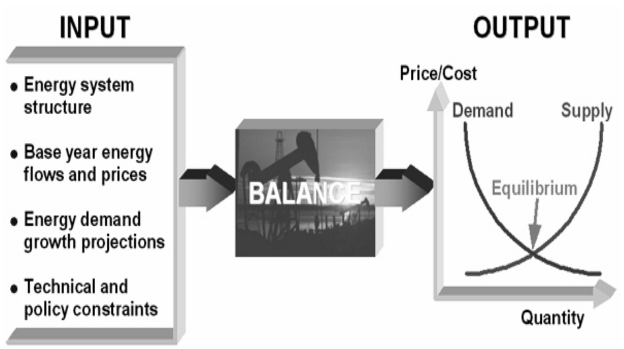


Fig. 1. Structure of BALANCE model

Demand for fuels is sensitive to the prices of alternative fuels, and the supply prices are sensitive to the quantity of demand. The model employs a market share algorithm to estimate the penetration of supply alternatives. The energy quantity for all individual input energy carriers to the decision nodes is determined by Equation 1.

$$Q_i = NQ \times S_i \tag{1}$$

Where,
Q_i = Quantity on input link i,
NQ = Net output quantity of a decision node, and
S_i = Share of input quantity allocated to an input link i.

The market shares for all individual input energy carriers to the decision nodes are determined by Equation 2.

$$\left[S_i = \frac{\left(\dfrac{1}{P_i \times Pm_i} \right)^{\gamma}}{\sum_i^n \left(\dfrac{1}{P_i \times Pm_i} \right)^{\gamma}} \right] \tag{2}$$

Where, S_i = market share on input link i,
P_i = price on input link i,
γ = price sensitivity co-efficient for decision node
n = number of input links to the decision node,
Pm = Premium multiplier on input link i.

In addition to the parameters given in Equation 1, the model employs another parameter called a lagged parameter which was included in the decision node to represent the delay in changing market share or consumer response. This delay may occur due to lack of funding for implementation of new technologies, delaying in adoption of technologies or other constraints. The influence of lagged parameter to determine market share can be seen in Equation 3 [6].

$$S_{i,T} = S_{i,T-1} + (S_{i,t} - S_{i,T-1})\ell \tag{3}$$

Where,
$S_{i,T}$ = market share on input link i at current year with lag considerations included,
$S_{i,T-1}$ = previous year's market share on input link i,
$S_{i,t}$ = intermediate value of market share on input link i without lag considerations as determined by the market share equation,
ℓ = lagged parameter.

In the developing countries, a delay in response often occurs between a change in relative prices and a change in the shares of the supply sources. The lagged parameter values ranging from '0' to '1' are used, which determine what portion of market share will change with changing price. A value of '1' indicates there is no lag in changing market share, and shares respond immediately to current prices. A value of '0' indicates no response to price changes [6]. The values of lag parameters for this study were selected by historical trend as well as expert judgment.

BALANCE simultaneously finds the intersection of supply and demand curves for all energy supply forms and all energy uses that are included in the energy network. Equilibrium is reached when the model finds a set of prices and quantities that satisfy all relevant Equations [7]. Concurrently with the energy calculations, the model computes the environmental residuals associated with a given energy system configuration. Greenhouse gas emissions can be reported in a format that is compatible with the Intergovernmental Panel on Climate Change (IPCC).

Input Parameters

The basic input parameters of BALANCE include data on the energy system structure, base year energy production, energy consumption levels and prices, projected energy demand growth, and technical and policy constraints. Year 2000 was considered as base year for this study.

Required data for the study were collected from the Statistical Year Book of Bangladesh published by the [8] and [9], and Economic Review Report 2003 published by [10]. Projected energy growth rates for national energy policy were used for this modeling. Data for electric sector were collected from [1] and [11].

Although, limited data on long-term energy pricing policy of Bangladesh were available to project energy prices for this study; the impact of fuel price variations in this study is very small because of considering low price sensitivity and lag parameter values. Consumers in developing countries have limited ability to switch quickly to alternative fuels. The values for price sensitivity and lagging of fuel switching considered for this study are 1 and 6%, respectively. Annual price growths of 3% to 6% were assumed for energy calculations.

Energy demand projection for Bangladesh was performed based on two independent energy growth scenarios – a high growth scenario (i.e., a presumably achievable target for economic growth) and a low growth scenario (considering business-as-usual practices to continue), up to year 2020. The energy growth rates for high and low scenarios were calculated based on the economic growth rate projected in National Energy Policy (BNEP) of Bangladesh 1996. The BNEP-1996 document considered two sets of assumptions for economic growth rates to estimate future demand for commercial energy and electricity. The low growth scenario over the period up to 2020 assumes an annual GDP growth rising from 5.25% in 1995-2010 to 6.65% during the following decade.

The high growth scenario (i.e., a presumably achievable target for economic growth) assumes an annual increase from 6% to 8% until 2020 [2]. In the NEP, the energy growth rates were estimated from GDP growth rates by multiplying with a factor called energy coefficient. The energy coefficient is the ratio of energy consumption growth rate to the GDP growth rate in a period. The average energy coefficients were assumed to be 1.37 for the period of 2000 to 2010, and 1.08 for the rest of the study period [3]. It is worth to mention here that the actual GDP growth rate in Bangladesh lies in between low and high growth values, which were estimated in NEP of Bangladesh. In recent years, the actual GDP at constant price of 1995 were 5.9%, 6.3%, and 6.7% in the financial year of 1999-2000, 2003-04, and 2005-06, respectively [12]. And the GOB is trying to reach at the high level of GDP indicated in the National Energy Policy of 1995.

The IPCC emission factors are used to compute the airborne pollutants CO_2, CO, CH_4, SO_2, NO_2, and NOx emissions. The model calculated emissions as a product of activity (e.g. fuel consumption of process) and emission factor.

3. RESULT AND DISCUSSIONS

The projected commercial energy demands are grouped into the following two major categories:

Final energy demand – energy consumption in all economy sectors excluding energy supply sectors - residential, industrial, transport, agriculture, and commercial and service. The energy consumption patterns have undergone substantial changes over the time. The evaluated energy carriers, for this study, are biomass, kerosene, electricity, LPG, natural gas, and coal. In the residential sector, the evaluated energy carriers are biomass, kerosene, electricity, LPG, and natural gas for cooking; the kerosene and electricity for lighting. The aggregate final energy demand by residential sector in 2000 was about 90522 kboe (kilo boe) of which only 15% (13512 kboe) was met by commercial fuel, and the remaining 85% (77010 kboe) came from biomass. The study indicates that the commercial energy consumption in the residential sector will increase to 5 folds for high economic growth and 4 folds for low economic growth by 2020 (Table 1).

Table 1. Final commercial energy demand, million barrel oil equivalent (mboe) [2].

End-use Sectors	Base Year-2000 (Actual)	High Scenario		Low Scenario	
		2010	2020	2010	2020
*Industry	16.02 (34.23%)	42.26 (37.4%)	101.5(39.66%)	36.12 (36.99%)	76.55 (38.9%)
Transport	10.86 (23.21%)	25.13 (22.2%)	57.31(22.39%)	21.74 (22.27%)	43.49 (22.1%)
Commercial and Service	1.73 (3.7%)	3.99 (3.53%)	9.10 (3.56%)	3.45 (3.53%)	6.91 (3.51%)
Agriculture	4.68 (10%)	9.27 (8.2%)	19.06(7.45%)	8.25 (8.45%)	15.16 (7.7%)
Households	13.51 (28.87%)	32.33(28.6%)	68.98 (26.95%)	28.08 (28.76%)	54.68 (27.79%)
Total	46.8	112.9	256	97.64	196.7

* Energy demand for fertilizer industries not included

Table 2. Final energy demand forecast by carriers, million barrel oil equivalent (mboe)

Energy carriers	Base Year- 2000 (Actual)	High Scenario		Low Scenario	
		2010	2020	2010	2020
Natural Gas	14.23 (9.86%)	41.49 (18.82%)	96.91(25.75%)	35.28 (17.21%)	73.76 (23.28%)
Petroleum	22.03 (15.27%)	46.16 (20.93%)	101.65 (27.01%)	40.5 (19.76%)	79.08 (24.96%)
Coal	2.35 (1.63%)	5.44 (2.47%)	12.41 (3.3%)	4.70 (2.3%)	9.41(2.97%)
Electricity	8.20 (5.69%)	19.91 (9.03%)	45.07 (11.97%)	17.03 (8.31%)	34.19 (10.79%)
Biomass	97.48 (67.55%)	107.5 (48.75%)	120.37 (31.98%)	107.5 (52.43%)	120.3 (37.99%)
Total	144.29	220.50	376.41	205.01	316.74

* Energy demand for fertilizer industries not included in final energy computation

The share of commercial fuel in total energy supply (commercial and traditional) for households will gradually increase to 42%; on the other hand, the contribution of biomass will gradually decrease to 58% by 2020. The quantity of biomass production is assumed to be the same for both growth scenarios. The consumption of commercial energy in residential sector will increase significantly due to bringing the entire country under electricity network and unavailability of sufficient biomass for cooking. The projected change of final energy demand structure by energy carriers has been shown in Table 2.

Due to the rapid progress of rural electrification, the utilization of kerosene for lighting purpose will be diminishing. However, the utilization of petroleum as cooking fuel in residential sector will increase because of consumer's fuel switching from traditional fuel to petroleum. The utilization of LPG in households cooking will increase at a higher rate than for kerosene due to consumers' preference for LPG over kerosene. Many consumers could use multiple fuels for the same end-use (e.g., biomass and LPG for cooking). In 2000, the consumption of LPG was about 205 kboe, and the demand will increase to 9000 kboe by 2020 for high growth scenario.

In industrial sector, commercial energy carriers are natural gas, electricity, petroleum, and coal. Commercial energy demand in industrial sector is expected to increase by about 6 and 4.75 times by 2020 for the high and low scenarios, respectively from the level of year 2000. In 2000, the commercial energy consumption in industrial sectors, excluding fertilizer production, was about 34% of total final commercial energy consumption, which is predicted to increase to 40% by 2020 (Table 1).

The final energy demand for agriculture sector will increase significantly over the study period. In 2000, oil and electricity consumption by agriculture sector was 4276 kboe and 652 GWh, respectively. The analysis shows that the petroleum consumption by this sector will increase 3 folds and 2.75 folds by 2020 for high and low growth scenarios, respectively. Electricity consumption will increase about 12 folds for high growth and 8 folds for low growth scenario by 2020. The dramatic increase of electricity demand in agriculture sector will be due to switching from diesel engine to electric motor for irrigation pumps as a result of ongoing rural electrification program and installation of additional new pumps across the country to achieve self-sufficiency in food production.

In transport sector, the final energy demand is predicted to increase by 5.25 and 4 folds by 2020 for high and low growth scenarios, respectively. The projected petroleum demand in transport sector for high and low scenarios are shown in Table 1. In year 2000, the commercial energy demand for commercial and service sectors was 1727 kboe, and the demand in this sector will increase at the same rate as in the transport sector.

Primary energy demand (PED) – projection was performed summing up the projected final energy consumptions by end-users with the self-consumption in the energy sector and transmission and distribution (T and D) losses. Combined energy demands for both economic scenarios are presented in Figure 2 along with its historical demand over the period 1980- 2000. The projected PED, broken down by energy carriers, is presented in Table 3.

Table 3. Annual primary energy demand forecast by carriers, million barrel oil equivalent [2]-[3].

Energy carriers	Base Yr. 2000	High Scenario		Low Scenario	
		2010	2020	2010	2020
N. Gas	62.23	137.2	232.97	119.8	189.9
Petroleum	24.75	48.88	104.41	43.23	81.8
Coal	2.35	10.38	86.56	9.651	61.1
Hydro	0.525	0.525	0.525	0.525	0.525
Biomass	97.48	107.5	120.37	107.5	120.3
Total	187.33	304.4	544.83	280.7	453.6

'Limited Gas' for power generation planning has been considered to aggregate primary energy demand projection

The fuel-mix for electricity generation was predicted for the study period. In 2000, 88.47% of generated electricity came by natural gas, 6% by hydro, and the remaining 5.53% by oil [8]. The final energy demand (consumptions at end-user's level) projections indicate that the electricity demand will increase by 3.5 times by 2015, and 5.5 times by 2020.

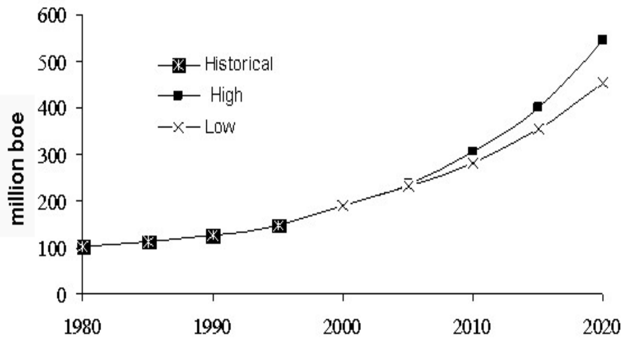


Fig. 2. Historical and projected primary energy demand

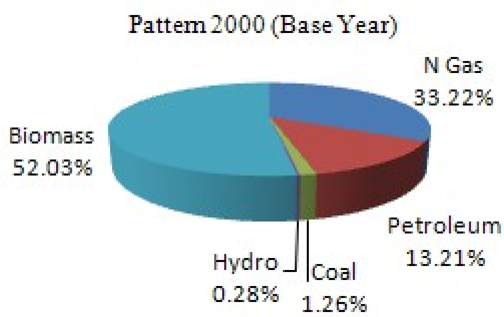
To estimate fuel demand for electricity generation, two individual fuel-mix strategies ('Limited Gas' and 'No New Gas') were assumed for electricity generation. The aggregate projected PED was estimated based on only 'Limited Gas' generation expansion planning strategy.

From the analysis of the PED forecast, it is seen that the increase of natural gas consumption is high under both scenarios due to high demand growth rate in power, industrial, and residential sectors.

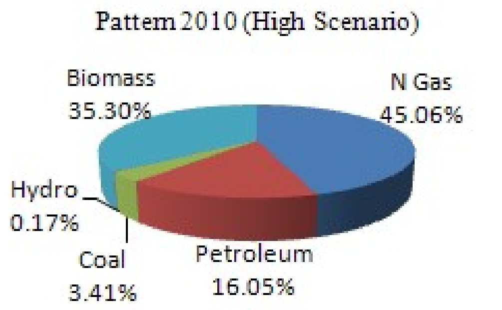
The cumulative consumption of natural gas during 2000 to 2020 period will be 15.43 trillion cubic feet and 14 trillion cubic feet for 'Limited Gas' and 'No New Gas' plans, respectively. To estimate the cumulative gas consumption an average 4% growth of natural gas demand for ammonia fertilizer industries was assumed. The gas demand for fertilizer industries grew at an average 4.22% per year during 1995 to 2000 [19].

The coal demand will also increase significantly for proposed new coal based power plants. Requirements for imported crude and petroleum products will increase several fold. On the other hand, the share of biomass in total energy supply will gradually decrease. For all scenarios, hydropower supply is not expected to increase from 2000 to 2020.

The projected changes of primary energy structure for high growth and low growth scenario are shown in Figure 3 (a to g). The analysis shows that the share of biomass in total energy supply will decrease gradually for both growth scenarios; however it will remain as dominating energy supply source over the period.



(a)



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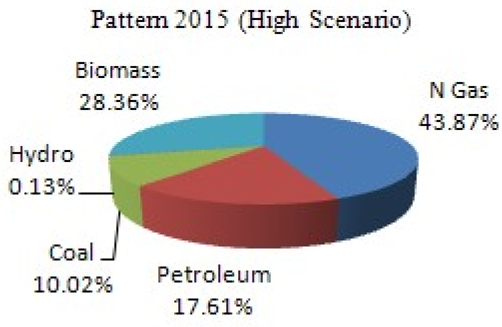

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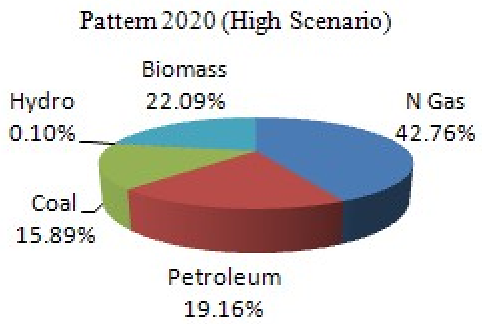

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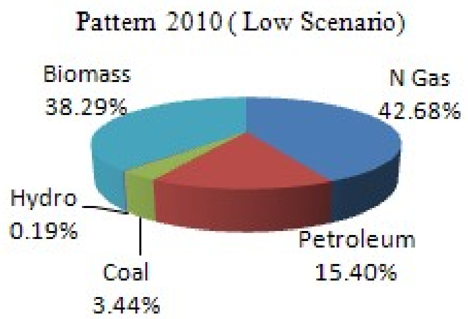

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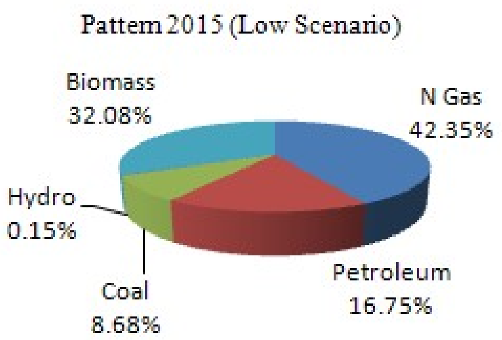

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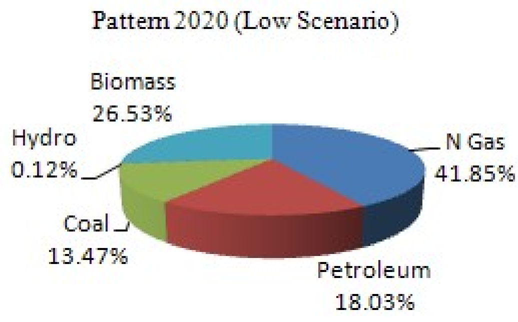

(g)

Fig. 3. Projected changes of primary energy demand structure for high and low growth scenario

Projected Electricity Demand and Fuel Requirement in the Power Sector

The projected peak load demand was estimated based on a system load factor of 60% and an overall station consumption of 6% of gross generation. To estimate the fuel demand for thermal power plants in Bangladesh for 2000-2020, two distinct generation expansion-planning strategies 'Limited Gas' (this plan is based on the no gas fired *base-load* power plant after 2010) and "No New Gas" (this plan is based on only gas-fired combustion turbines for *peaking load* power plant after 2010) were considered. The existing hydro plant with 833 GWh annual plant capacity is expected to work as a peaking plant. Projected gross electricity generation and system peak load over the study period are shown in Table 4.

Table 4. Projection of Gross Electricity Generation

Year	Low Forecast		High Forecast	
	Energy TWh.	Peak Load MW	Energy TWh.	Peak Load MW
2000*	16.57	3153	16.57	3153
2005	24.25	4613	25.39	4831
2010	34.41	6546	40.21	7651
2015	48.98	9319	60.19	11452
2020	69.04	13135	90.86	17287

*the values of the year 2000 are actual demand

Limited Gas Based Expansion Plan

The present gas reserve appears insufficient to meet the demand in industrial and power sector for 2000-2020. Presently, natural gas exploration program in Bangladesh is ongoing, and it is believed that significant additional gas reserve exists in Bangladesh that is waiting to be discovered. Anticipating significant new gas reserve due to successful exploration and development of new gas fields, the 'Limited Gas' generation expansion planning estimates required fuel on the basis that no new gas fired base-load plant will be constructed after 2010. Only coal-fired power plant will be constructed to carry the system's base-load. New gas-fired combined cycle power plant (CCPP) and combustion turbine (CT) plant will be constructed to carry intermediate load and peak load of the national grid of Bangladesh, respectively. The estimated electricity generation mix is shown in Figure 4.

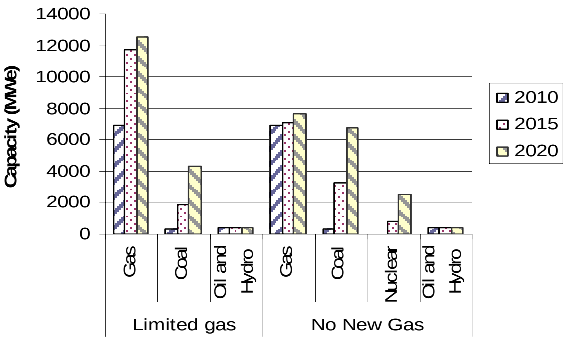

Fig. 4. Structure of electricity generation by source

No-new Gas Based Expansion Plan

According to the Power System Master Plan of Bangladesh (BPSMP)-1995, the most economic alternative fuels are coal and heavy furnace oil (HFO) for base load power generation, and high-speed diesel (HSD) for combustion turbine (CT) peaking plants [1]. But, significant changes in plant construction costs and fuel prices occurred during the last decade. Petroleum prices have increased a great deal; on the other hand, the price of nuclear fuel has dropped considerably. So, the PSMP should be revised on the basis of new forecasting fuel prices and plant construction costs.

According to this planning strategy, nuclear plants and coal-fired plants for base load and intermediate load, and the gas fired CT for peaking load are part of this 'No New Gas' plan. Nuclear power plants with total 3000 MW capacity are proposed to construct until 2020. The expected electricity generation-mix for the two proposed expansion plans are shown in Figure 4.

The BPSMP-1995 estimated nuclear electricity is expensive over other alternative options in Bangladesh due to high capital cost of nuclear power plant (US $2500/kW) [1]. Even so, the capital cost of nuclear power plant (NPP) has decreased a great deal over the last ten years. For instance, the overnight capital cost of 600 MW capacity AP600 nuclear plants is $1300 to $1500/kW [2], [13].

4. NATIONAL ENERGY SECURITY

Bangladesh depends heavily upon traditional biomass fuels, while utilization of commercial energy is rapidly increasing. The share of natural gas in commercial fuel mix is increasing fast because of its domestic abundance, lower price, and superiority to other alternative fuels. Natural gas consumption will increase four folds by 2020, and the cumulative consumption of natural gas will be about 15.5 TCF (Trillion Cubic Feet) during 2000 to 2020 period for high energy growth [2]-[3]. The sector-wise natural gas demand for the study period has been shown in Table 5. Undeniably true that the present gas reserve will be exhausted before finishing lifetimes of presently operating gas based power plants. If the reserve does not increase, certainly Bangladesh will need to import gas for operation of gas-based power plants and for other needs. Moreover, natural gas will be a more attractive fuel in coming decades because it is environmentally friendly and easy to deliver than coal and oil. It has other industrial uses, and its industrial applications will increase in future. It should be preserved as much as possible.

Table 5. Sector-wise natural gas demand forecast, billion cubic feet (bcft) [9]

Economy sectors	Base Year	'Limited Gas' plan	'No New Gas' plan
	2000	2020	2020
Residential	28.95	178.68	178.68
Electricity	148.86	456.39	176.61
Fertilizer	84.9	185.89	185.89
Industrial	42.95	316.94	316.94
Commercial and Service	3.82	20.19	20.19
Loss	21.76	81.84	*61.99*
Total	331.24	1239.93	940.31
Cumulative consumption		15437.2	14003.5

In 2000, the share of petroleum products provided 15% of commercial energy, and is expected to double by 2020 [2]-[3]. Most of the demand for oil over the next two decades will be in the transport sector. Imported oil is vulnerable to supply and price disruptions, and to political instability in oil producing countries. Statistics says that the price of petroleum fuel is most unstable compared to the prices of other fuels. Thus the country should adopt policy on its long-term reliable energy supply system to assure uninterrupted energy supply in affordable prices for sustainable development of itself.

Potential Strategies for Long-term Energy Security

The long-term strategies in [2], [3] can be considered to improve energy security for Bangladesh.

Oil Substitution by Coal and Gas

Coal can reduce oil consumption in the transport sector by initializing electric train. The frequencies of train service can be increased for transportation of passengers and freights. As a result, the consumption of diesel by the road traffics would be reduced. Coal-based power plants can reduce natural gas demand in power sector.

Substituting natural gas for oil in the transport sector is a good option for Bangladesh. Conversion of petrol engines into CNG (Compressed Natural Gas) engines with establishing CNG stations is being carried out in the capital city of Bangladesh to a limited extent. The utilization of CNG can be extended for other cities immensely, and LPG (liquefied petroleum gas) can be distributed in all towns and cities across the country to reduce oil import.

Nuclear Power

Nuclear power reduces the need for import of fossil fuels without increasing GHG emissions. The basic attraction of nuclear power plant (NPP) is very low price of uranium compared with coal, oil, and gas fired plants, and the price of nuclear fuel does not fluctuate abruptly like fossil fuels. The overall fuel cost for NPP is only 0.35c/kWh [14]. While the fuel cost for gas-fired steam power plants in Bangladesh is 1.32 c/kWh [11], which is four times of nuclear fuel. The cost of nuclear power generation has been dropping over the last decade because of declining nuclear fuel costs (including enrichment), operating and maintenance costs [14]. The ultimate electricity generation cost for NPP normally includes spent fuel management, plant decommissioning, and final waste disposal costs. The decommissioning cost of NPP is estimated at 9% - 15% of the initial capital cost [14].

Renewable Energy

The rural people in Bangladesh extensively depend on biomass. The efficiency of presently used biomass stoves is very low (about 15%), which can be improved to 25% - 30% [15]. From the analysis of the statistical data and different studies, the supply of biomass will increase in future; however, it will not be able to cope with the future demand. As a result, the commercial energy will be utilized to meet the future additional demand in parallel to the traditional fuels in rural and sub-urban areas. The commercial energy demand for domestic cooking can be reduced significantly by improving efficiencies of the traditional biomass stoves. Increasing energy density per unit volume of biomass by industrial processing can increase its popularity among sub-urban consumers.

5. AIRBORNE EMISSION PROJECTIONS

The pollutants emissions are directly proportional to the energy consumption. In this study, the pollutants emission projection is accomplished for CO_2, CO, CH_4, NO_2, and NOx as well as SO_2 (Table 6). The levels of CO_2 emission from different sectors for high growth scenario are shown in Figure 5.

Table 6. Pollutants emissions for high growth scenarios (in 10^6 tonnes)

GHG	Year 2000 (Base)	2005	2010	2015	2020
CH_4	0.17	0.20	0.24	0.28	0.33
CO	2.5	2.61	2.91	3.27	3.76
CO_2	86.95	100.9	126.53	166.13	226.22
NO_X	0.172	0.222	0.323	0.473	0.704
Particulates		0.004	0.006	0.039	0.090

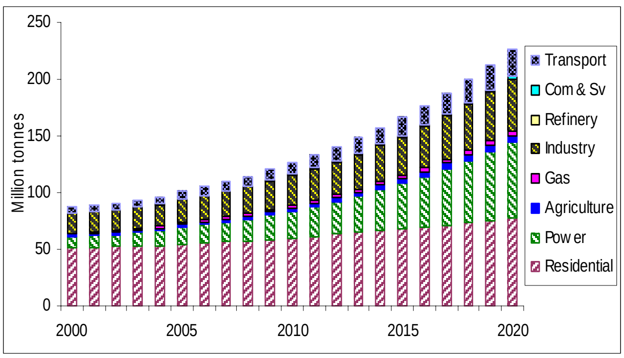

Fig. 5. Sector-wise CO_2 emission in Bangladesh

The residential sector releases largest volume of CO_2 followed by the power generation, industrial, and transport sectors in Bangladesh. Carbon dioxide emissions from agriculture, commercial and services, and natural gas supply sectors are very small. Presently, the power generation fuel-mix of Bangladesh is dominated by natural gas; the first coal-fired power plant in Bangladesh is being commissioned in 2005. In future, the emissions from power generation sector will increase rapidly due to addition of new coal fired power plants in future generation-mix.

GHG mitigation options are required in the residential, electricity, and transport sectors to limit emissions in Bangladesh. Six mitigation scenarios were developed in this study to find out the most attractive options by comparing with baseline emission scenario. The projected GHG emission for high energy growth scenario was considered as baseline scenario. The baseline scenario represents current and future emissions, in which there is no policy or plan designed to reduce GHG discharges.

Potential Mitigation Options

Mitigation scenarios reflect only the technical potentiality for GHG emission reduction considering institutional, cultural, and legal factors [5]. The potential GHG mitigation options for different end-use and energy supply sectors in Bangladesh are utilization of compact fluorescent lights and efficient biomass stoves in the residential sector; reduction of transmission and distribution (T and D) losses, installation of advanced fossil fuel power technologies and nuclear power plants in the power sector; and utilization of CNG vehicles in the transport sector. The pollutant emissions projection is accomplished for CO_2, CO, CH_4, NO_2, and NOx as well as SO_2 (Table 6). The achievable CO_2 emissions reduction by potential mitigation options are shown in Figure 6.

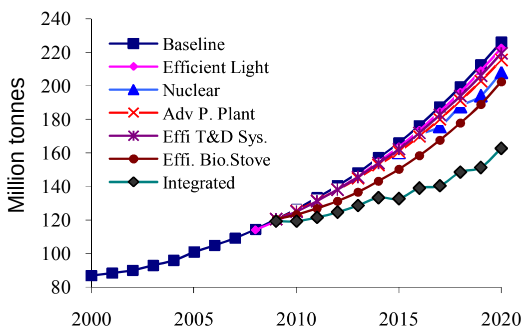

Fig. 6. CO_2 emissions projection for the baseline and mitigation scenarios(10^6 tonnes)

Utilization of Efficient Biomass Stoves

Biomass is the major fuel source in rural areas of Bangladesh. In year 2000, biomass supplied about 560 million GJ energy or 55 % of total energy supply. The efficiency of traditional biomass stoves is very low (about 15%). Utilization of more efficient biomass stoves can reduce GHG emissions.

Bangladesh Council for Small Industries Research has already developed a new biomass stove with efficiency of 25% [15]. All of the traditional stoves were assumed to be replaced gradually by the advanced ones by 2015. A comparison between baseline emission scenario and achievable reduction of CO_2 emission due to utilization of efficient biomass stoves is shown in Figure 6. The improved stoves will reduce fuel consumption by 10% with a proportionate reduction in CO_2 emissions.

Utilization of High-Efficient Electric Lighting

Widely used incandescent lamps are very inefficient. However the incandescent lamps are very popular across the country because of simplicity and low cost. Compact fluorescent lights (CFL) are 3 to 5 times more efficient than incandescent lamps. Presently there are about 5.4 million rural consumers across the country, of which 4.5 millions are residential consumers [16]. The number of rural consumers is increasing due to extensive rural electrification programs across the country. Most rural electrified households and other institutions use incandescent lamps, which can be replaced with compact fluorescent lights.

In this study, all existing 60-watt and 100-watt incandescent bulbs are assumed to be replaced by 20 W and 40W CFLs by 2010. The potential level of CO_2 emission reduction by this measure is shown in Figure 6. The replacement of incandescent lamps can reduce system's peak load by 500 MW and 1000 MW by 2010 and 2020, respectively.

Reduction of Electricity Transmission and Distribution Loss

Transmission and distribution (T and D) loss in Bangladesh is high. In 2001, the T and D loss of power system in Bangladesh was about 30%, due to technical and non-technical losses (e.g. pilfering, etc.) [9]. In 2000, the technical T and D loss was about 16% in Bangladesh, as compared to 7.2% in the USA and 7.4% in the UK [17]. The energy loss for transmission and distribution of electricity in Bangladesh due to unwanted heating effects in conductors and substation equipments is much higher than that in the developed countries.

In this study, a 9% T and D loss is assumed to be achieved by 2010. In practice, it will take 5 to 7 years to be implemented gradually. The T and D loss reduction from 16% to 9% in Bangladesh power system will reduce 1200 MW of system's peak load by 2020. As a result, CO_2 emission rate will decrease proportionally. About 43 million tonnes of cumulative CO_2 emission can be avoided during 2010 to 2020 from this sector (Figure 6).

Implementation of Nuclear Power Plants

Nuclear electricity satisfies environmental protection goals identified in the Rio Principles. A small quantity of nuclear fuel produces large amount of electricity without releasing greenhouse gases. Although the nuclear power industries release some radioactive emissions, but they are under strictly control. The dose commitment from natural background radiation is 325 times higher than that of the world's entire nuclear power industry [18].

In this study, three nuclear power units with 1000 MW capacity each are assumed to be constructed during 2015-2020 period. The resulting carbon emission reductions achieved by nuclear power plants (NPP) over conventional types are shown in Figure 6. Carbon dioxide emissions will drop by 6 million tonnes and 18 million tonnes from baseline scenario by 2015 and 2020, respectively. About 72 million tonnes of cumulative CO_2 emission can be avoided to release in the environment by the three NPPs. The electricity generation from a 1000 MW capacity NPP can avoid annually 7 million tonnes of CO_2, 80 thousand tonnes of SO_2, 23 thousand tonnes of NOx, and 16 thousand tonnes of particulates emissions compare to a coal fired power plants.

Implementation of Advanced Technology Fossil Fuel Power Plants

The advanced technology plants are more efficient but more expensive than conventional plants. Advanced combustion turbine (ACT)-2010 and gas-based advanced combined cycle (ACC)-2010 technology power units were considered in a mitigation scenario. The ACT-2010 plants are about 10% more efficient than conventional combustion turbine (CT)-2010 plants, while ACC-2010 and pulverized coal-2010 plants are about 5% more efficient than conventional plants [20].

The carbon dioxide emission reductions achieved by advanced power plants over conventional plants are presented in Figure 6. Annually about 10 million tonnes of CO_2 emission can be reduced by 2020. About 55 million tonnes of cumulative CO_2 emission can be avoided during 2010 to 2020 by utilizing advanced technology fossil fuel plants.

Substitution of oil Fueled Vehicles by CNG Vehicles

GHG emissions from diesel/petrol combustion are much higher than from natural gas. For this study, CNG fuel was considered to develop a mitigation scenario, where 30% of total road transport vehicles in Bangladesh are assumed to be driven by CNG by 2015. The fuel switching is expected to be gradually phased in during the period. About 10 million tonnes of cumulative CO_2 emission can be avoided during the period from transport sector by using CNG fuel Figure 6.

6. CONCLUSIONS

Future long-term energy demand and prospective GHG emission from energy end-use and supply sectors in Bangladesh have been projected based on two economic growth scenarios. Energy economic model was employed to forecast the energy requirement for 2000 to 2020. The demand for natural gas and electricity will grow faster than for other energy carriers. The indigenous gas reserves of Bangladesh will be depleted before ending the life-time of some of the presently operating gas based plants; even if no further gas-fired plant is constructed after 2010. 'Limited Gas' and 'No New Gas' power generation expansion plans are discussed for future fuel-mix in electricity generation. Coal and nuclear power have been proposed as base load power plants if new gas reserve cannot be discovered.

Potential GHG mitigation options have been analyzed. Significant reduction of GHG emission can be obtained by implementation of electrical transmission and distribution efficiency improvement, nuclear power plants, advanced fossil fuel power generation technologies, and more efficient biomass stoves. Finally, the study results identify the basis on which energy planning can be carried out and emphasize the need for evolving effective strategies to strengthen long-term national energy security.

The major limitations of the study are as follows:

- The price growth rates of commercial fuels were assumed by analyzing some statistical data and reports. The impact of fuel price changes in long-term energy demand projection is small because the consumers in developing countries are less sensitive to energy price changing.

- Price of traditional fuel was not available, and assumed value was used.
- GHG emissions from fertilizer industries and coal mines were not computed in this study because of unavailability of required data.

Cost-effectiveness analysis for GHG mitigation options was not performed in this study. It can be performed in future studies for assessment of mitigation options.

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