Energy Perspective of Climate Change: The Case of Bangladesh

B.K. Bala, M.S. Alam and Nipa Debnath

ABSTRACT

Previous efforts on modeling energy, the environment, and climate change perspectives are critically examined, and the structure of energy and an environment system model is described. Focus is on sustainable development using Bangladesh as an illustrative example. The model projects energy supply and demand and its contribution to global warming. Simulated results show that the demand for electric energy is increasing, and there is a shortage of electric power. Electricity generation capacity can increase by either transition to nuclear or renewable energy resources or both. However, generation capacity needs to be increased for sustainable development, with gradual transition to renewable energy resources. Mini-grids are advocated for supply of energy, information and communication for rural development and economic growth in isolated areas such as islands. Bangladesh is responsible for a small fraction of the total anthropogenic contribution of CO_2 but could be seriously affected by climatic change. Energy security aspects are also addressed. Regional economic cooperation and sustainable peaceful resolution of long-standing disputes may help the regional entities to enhance their individual and collective energy security.

Keywords: Energy systems, computer modeling, energy scenario, environmental effects, electric power, renewable energy, energy security, Bangladesh.

INTRODUCTION

Energy is needed to meet the subsistence requirement as well as to meet the demand for economic growth and development [1-3]. Global economic growth for the period 2002-2030 is estimated at 3.2% per year with China, India and Asian countries expected to lead. Population worldwide is put at more than 8 billion in 2030, from 6.2 billion in 2002. To meet these requirements, the International Energy Agency (IEA) predicts energy demand to rise by 59% between now and 2030.

Energy has been recognized as one of the most important strategic commodities. A strategic commodity is difficult to define with precision. Zaleski [4] indicates two main attributes of a strategic commodity: It is essential for the economy of a country, and the supply is uncertain or may present a risk. Energy satisfies both these conditions. Andrews [5] argues that energy is a strategic resource that has justified as well as influenced the outcome of wars, has fueled as well as strangled economic progress, and has polluted as well as cleaned up the environment.

Per capita consumption of energy is a measure of physical quality of life [3]. Per capita consumption of electrical energy is also a measure of physical quality of life. Per capita consumption of electrical energy is low in Bangladesh (170 kWh per capita per annum) and it is far below the minimum requirement of per capita consumption of electrical energy for quality of life. Access to electricity in Bangladesh is one of the lowest in the world, covering only about 49% of the total population. The generation of power is also low, at about 200 kWh per capita per annum.

Bangladesh has the largest share of energy from biomass—about 67.25%— comprised mainly of agricultural residues, animal wastes and fuel wood. The trend of commercial energy consumption over the last ten years in Bangladesh suggests that 73% of total commercial energy consumption was provided by natural gas, with remainder almost entirely supplied by imported oil plus limited amounts of hydropower and coal. However, there are significant variations within the region of the Indian sub-continent. For instance, Bangladesh's energy mix is dominated by natural gas (70% in 2011), while in India coal dominates (79% in 2011). Bhutan and Nepal have high shares of hydroelectric power in their energy consumption.

Energy production and use can be major sources of serious environmental impacts. The impacts, in turn, can threaten the overall social and economic development and objectives that energy use is expected to promote. At regional and global levels, fossil fuel consumption leads to acid rain, and most likely to global warming; both phenomena could disrupt normal systems and economic productivity. At the local level, continued reliance on traditional biomass fuels in many developing countries like Bangladesh can place added stress on wood lands and farm lands, resulting in decreased relative humidity and environmental degradation.

The largest challenges facing Bangladesh are related to national energy security, poverty alleviation by 2015, ensuring electricity for all by 2020 and attaining the status of a middle-income country by 2021. Bangladesh government addresses the issues connected with the supply of quality electricity and commercial energy at an affordable price. To meet these challenges, in 2021 per capita electricity consumption needs to increase at least up to 500 kWh [6]. In the medium- to long-term future (2010-2020) energy demand is expected to grow exponentially. The total energy demand is expected to grow at a compound annual growth rate of 7.29%, with natural gas expected to register a growth rate of 6.39% followed by oil and coal. Demand for natural gas is consistently rising in Bangladesh. Among all the commercial energy sources, electricity is expected to register the fastest annual growth—about 9% [7]. At present, 70% of commercial energy demand is met by natural gas and about 80% of primary fuel used for power production is natural gas [8].

South Asia is also home to several of the most polluted cities: Calcutta, Dhaka, Mumbai, Delhi and Karachi. However, the total emission in the region accounts for a small fraction (3%) and this region is responsible for a small contribution to global warming and climate change. The contribution of Bangladesh to global warming and climate change is also a very small fraction [1-2, 9-11].

The Third Assessment Report of the United Nations' Intergovernmental Panel on Climate Change also confirmed that the Earth's climate is changing as a result of human activities, particularly from fossil fuel energy use, and that further change is inevitable. Natural ecosystems are already adapting to the change, some are under threat, and it is evident that human health and habitats will be affected worldwide. Such climate change could also affect the present supplies of renewable energy sources and the performance and reliability of conversion technologies [12].

EU (European Commission) has strongly supported the generation of green electricity in past decades, but the energy obtained from fossil fuels still prevails throughout the region. Bengochea and Faet [13] reported that there exists a relationship between green energy, the price of fossil fuels, and CO_2 emissions, implying that an increase in CO_2 leads to an increase in renewable energy supply.

Many of the existing definitions of energy security begin, and usually end, with a focus on maintaining energy supplies—and particularly supplies of oil [14]. This supply-based focus has as its cornerstones reducing vulnerability to foreign threats or pressure, preventing a supply crisis from occurring, and minimizing the economic and military impact of a supply crisis once it has occurred.

Energy security and climate change have been the forefronts of energy policy. The International Energy Agency [15] reported that unless countries change their energy use policies, oil imports, natural gas and coal use and greenhouse gas emissions threaten to undermine energy security and accelerate climate change. In addition, those who examine specific energy conservation or alternative energy technologies frequently observe a complementarity between the abatement of greenhouse gases and an increase in energy security [16-17]. Although such complementarity can exist for individual technologies, policymakers are confronted with a tradeoff between these two policy objectives. Tradeoffs arise when policymakers choose the mix of individual technologies with which to reduce greenhouse gas emissions and enhance energy security. Various technologies have different costs and contribute differently to the achievement of either or both objectives. As a result, cost differences could lead to an optimal policy that includes a suite of technologies with each contributing more to a single policy objective rather than to individual technologies that contribute to both objectives.

Energy production and use cause CO_2 emissions, and the demand for energy is increasing rapidly, causing more CO_2 emissions. The question arises: What policy needs to be pursued to reduce CO_2 emissions and ensure energy security for sustainable development? With Bangladesh as a case study, this article presents a policy for energy production which ensures energy security and reduces CO_2 emissions.

BANGLADESH ENERGY SYSTEMS

The Bangladesh energy system is comprised of a supply, demand, and emission sectors. The supply sector is categorized as commercial energy and biomass fuels. Commercial energy comes from natural gas, oil and electricity; biomass fuels are agricultural wastes, animal wastes, and fuel wood. In the demand sector, energy consumers make decisions to utilize gas, oil and electricity based on both fuel price and availability, whereas biomass fuel consumption is mainly based on availability. In the demand sector, the major energy consuming entities are residential, industrial and transportation. The supply sectors (commercial and biomass) are the fuel supplies and imports. Imports are equal to the shortfalls in domestic supply.

The present maximum electricity generation capacity is 5000-5300 MW (September, 1011) and the demand is 5700-5800 MW (September, 2011) resulting in a shortage of about 850 MW. The actual demand of power, however, is about 6,000 MW. Because of the short supply of electricity, load shedding is a common phenomenon in Bangladesh. The energy sector needs immediate attention in both generation and management. Energy production and consumption cause emission of greenhouse gases.

Public pressure resulting from frequent load shedding prompted the government of Bangladesh to estimate the probable demand and expected supply of electric power for the period 2009-2015 to ensure reliable supply of electricity to consumers in Bangladesh. The planned supply of electric power is surplus for the period 2009-2015.

COMPUTER MODELING

Energy planning is required for sustainable development and effective environmental management due to the limitations of fossil fuel resources, the high capital costs of renewable energy development, and various concerns about energy supply and demand. This requirement has motivated a number of studies on the development of energy systems models and their applications in the planning of energy activities at different levels. Also there has been an upsurge of interest among the researchers and planners in the modeling of energy systems since the oil embargo of the mid-1970s. Today, many energy system models are available which have been developed for the planning of large energy systems at national or regional levels. These models can be classified into two main categories—simulation and optimization. The simulation models simulate the dynamics of energy systems, i.e., scenarios for management strategies, while optimization models evaluate competition between various sources.

Huq [18] initiated energy modeling in Bangladesh. The model proposed by Huq was further developed for integrated rural energy systems in Bangladesh using the system dynamics approach [19-20]. Alam et al [21] developed a system dynamic model for integrated rural energy systems. The potentiality of this model was illustrated in the micro level by using the data of a village in Bangladesh. The system dynamics model for integrated energy systems was also applied in agriculture for macro-level policy analysis [22-23]. The model prediction has great relevance to the historical behavior and it is a very useful tool for policy analysis and planning.

Nail [24] reported an integrated model of U.S. energy supply and demand, which is used to prepare projections for energy policy analysis in the U.S. Department of Energy's Office of Policy, Planning and Analysis. This model represents one of the real success stories of system dynamics modeling. This model was implemented at the Department of Energy in 1978 as an in-house analytical tool and has been used regularly for national energy policy analysis since that time. Nail et al [25] employed the model to explore a wide range of policy options intended to address the effects of energy use on global warming.

Bala [1-2, 10] presented projections of energy supply and demand and assessed the contributions to global warming for both rural and urban Bangladesh. Bala [9] also reported a computer model of energy and environment for Bangladesh, to project energy supply and demand, and to assess its contribution to global warming

Recently, several optimization models have been developed for energy systems planning [26-28] and several system dynamics models have been reported for energy systems planning [29-31]. Jager et al [31] reported a system dynamics model for the German electricity market to address the impacts of economic and environmental related constraints on the German electricity spot market. This model is based on a similar model for the Nordic electricity market [32], which was transferred, adapted and calibrated for German conditions. More recently Oikonomou et al [33] reported an Energy and Climate Policy Interaction support tool that can assist policymakers in ascertaining optimal blending of policy instruments addressing specific targets. The advantage of this approach is that it demonstrates to some extent the qualitative effects of interacting policy instruments, depending on current policy goals and user preferences.

Mondal et al [34] forecast sector-wide electricity demand of Bangladesh up to 2035 considering the base year 2005, and compared the results with official projections. Mondal et al [35] also examined the impacts of CO_2 emission reduction on future technology selection and energy use in the Bangladesh power sector up to 2035 considering the base year 2005, and also examined the implications of CO_2 emission reduction targets on the country's energy security. Alam et al. [36] investigated the possible existence of dynamic causality between energy consumption, electricity consumption, carbon emissions and economic growth, and reported that there exists bidirectional causality between economic growth and electricity consumption, and also that there is a feedback causality relationship between energy and CO_2 emissions in the long run.

The purpose of this article is to present the structure of the LEAP (Long-range Energy Alternatives Planning) based system dynamics model of energy and environment and the simulated results of electrical energy demand and energy perspective of climate change using Bangladesh as a case of illustrative example.

STRUCTURE OF ENERGY AND ENVIRONMENT SYSTEM MODEL

Earlier works of Bala [1-2, 9] on computer modeling of energy and environment formed the basis of this study. To mathematically express the energy activities within an energy system, the LEAP based system dynamics model is developed to support energy systems planning, policy analysis, and environmental management. The developed model consists of five main components that reflect energy flow and emissions to the environment.

Figure 1 shows the basic interactions between energy production and supply including the effects of energy use on global warming. The first component is the set of energy supply options that provides energy sources including mined resources and renewable energy to the system. Three types of mined resources (oil, coal, and natural gas) are included in the model. The second component is the energy demand sector, which is characterized by demography, economy, technology advancement, and environmental conditions. It includes economic activities that consume energy as an end use. This sector is categorized into five sub-sectors: agricultural, transportation, industrial, residential, and commercial. The third component is the set of supply-side technologies.

Three groups of such technologies are considered in this model, i.e., coal, oil, and natural gas mining and/or recovery technologies including various enhanced oil recovery technologies (EOR); electricity conversion technologies that convert fossil, renewable, and nuclear energy into electricity; and processing technologies that transform energy sources into fuels such as gasoline and diesels. The fourth component is the set of demand-side technologies that drive energy consumption by end users. The fifth component is the emission factor. The emission sector computes the energy related emission of carbon dioxide, methane and nitrous oxide. Every part of energy consumption and use produces emissions. The environmental loadings are computed by multiplying the environmental loading factor for the fuel from EDB (Environmental Data Base) by the amount of fuel consumed or used.

RESULTS AND DISCUSSIONS

Bangladesh Electric Energy Scenarios

Taking 1990 as the base year, a sector-wise projection of electric energy in Bangladesh is shown in Figure 2. Energy demand for the residential sector increases at a faster rate in comparison to energy demand

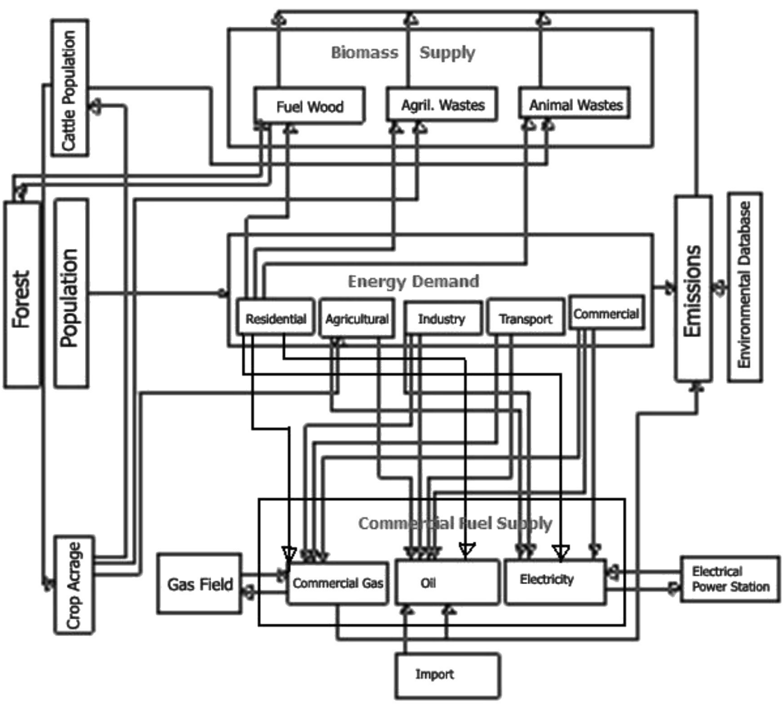

Figure 1. The interactions between energy production and consumption.

for large industry, until 2010. This is mainly due to higher population growth and relatively poor industrial development as predicted by the trend from the base year. Taking 2005 as the base year, the projection of energy demand by sector shows that energy demand for industry increases rapidly because of the rapid development of garment and agro-based industries (Figure 3). However, there is a shortage of electric power in Bangladesh. Since system loss is high (17.32-25.98%), reducing system loss and using end use efficiency improvement devices can save a considerable amount of electric energy [37].

Environmental Effects

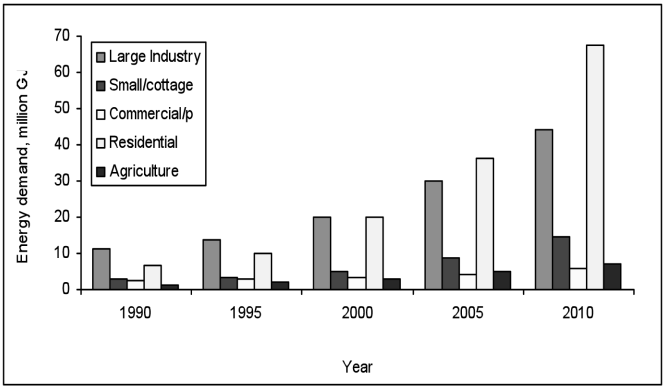

Figure 2. Electric energy demand, by sector, in Bangladesh with 1990 as base year.

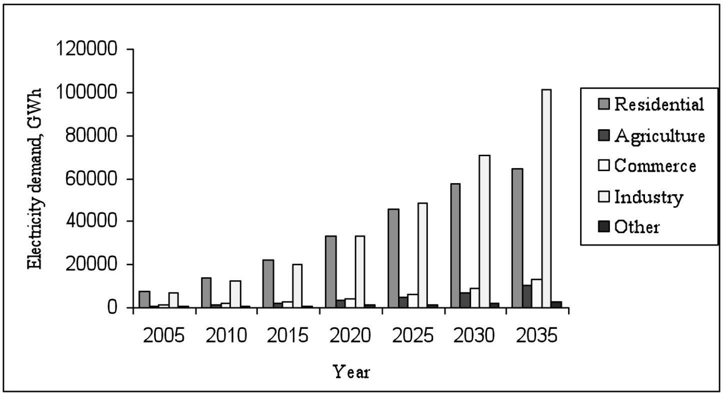

Figure 3. Electric energy demand, by sector, in Bangladesh with 2005 as base year.

Taking 1990 as the base year, emissions of carbon dioxide for energy consumption in Bangladesh are shown in Figure 4. The emissions of these gases are increasing. Environmental emissions of non-biogenic CO_2 increased from 12.19 million tonnes in 1990 to 36.06 million tonnes in 2010, while biogenic CO_2 increased from 49.11 million tonnes in 1990 to 60.36 million tonnes in 2010. To get an idea of how the expected power supply proposed in 2010 affects the CO_2 emissions, we simulated the CO_2 emissions with 2010 as the base year. CO_2 emission for the expected power supply of 5936 MW in 2010 to 1588 MW in 2015 increase from 19.76 million tonnes in 2010 to 58.70 million tonnes in 2015.

Perspective on Electrical Energy Demand and CO_2 Emission Reduction

Our strategy should be to use less polluting energy sources [36], and this can achieved through gradual transition to renewable energy sources [9]. Renewable energy for power generation would rise by 20%, 29% and 35% for 10%, 20% and 30% reduction in CO_2 respectively [35]. However, China is the largest contributor to global warming, and the contribution of Bangladesh to global warming is small. Bangladesh is responsible for a small fraction of the total anthropogenic contribution of CO_2—only 5% as much as China—but could be seriously affected by climatic change. However, emissions can be controlled through application of a suitable carbon tax, and high tax levels would result in substantial penetration of renewable energy technologies, for example so-

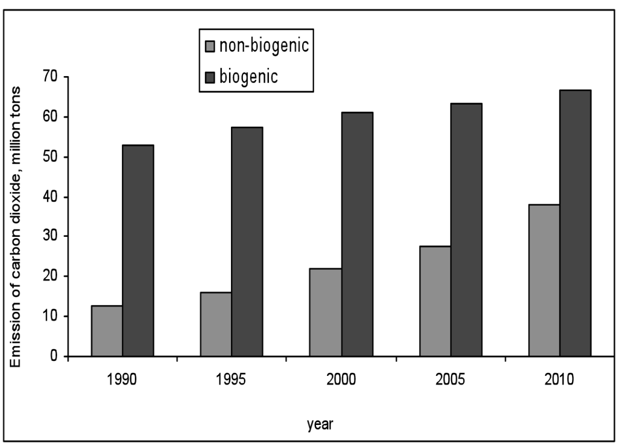

Figure 4. Emissions of carbon dioxide for energy consumption in Bangladesh

lar energy technologies in Bangladesh. The simulated results show that the introduction of the CO_2 emission reduction targets and carbon tax directly affect the shift of technologies from high carbon content fossil-based to low carbon content fossil-based and clean solar PV compared to the base scenario. Thus solar PV plays an important role in achieving reasonable energy security.

GRADUAL TRANSITION TO RENEWABLE ENERGY

Energy (electrical as well) is considered as an important factor for economic growth in Bangladesh and higher energy consumption means higher pollution (Alam et al., 2012). Policymakers should search for less polluting fuels. Renewable and nuclear energy can be the most important candidates for such energy sources. Electricity generation can be increased by transition to either nuclear energy, renewable energy, or both. The disposal of nuclear waste is still a serious problem. For renewable energies, the situation is more advantageous since it would depend on technology imports in the first phase of large-scale renewable energy use. However, the build-up of domestic production infrastructure (including capacity building and R&D) could be managed relatively easily compared to nuclear power infrastructure. Hence, renewable energies prove to be a much more effective response to the energy challenges that Bangladesh faces. As a result, to meet the electrical energy requirements of tomorrow in a sustainable manner, today's central system should be gradually moved into distributed utility which is essentially a hybrid system to minimize emissions and maximize reliability. Figure 5 shows such a distributed utility.

The use of nuclear power and renewable portfolio standards (RPS) to promote the use of solar and wind energy for generating electricity would reduce greenhouse gas emissions from coal- and natural gas-fired power plants, and could reduce the electricity sector's dependence on vulnerable natural gas use/imports to some extent. The overall effects of enhanced energy security in electric power generation are likely to be substantially less than those of transport fuels until electric and plug-in hybrid vehicles penetrate the transportation sector. Other similar options include compact fluorescent light bulbs replacing traditional incandescents.

International experience shows that EU countries have increased

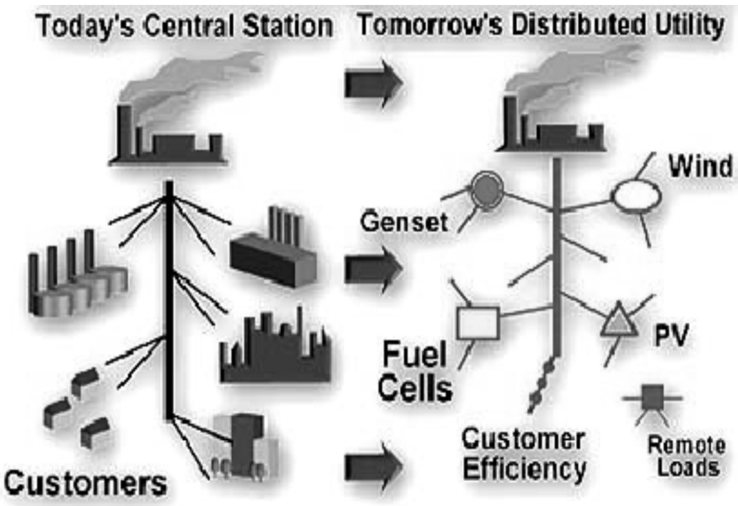

Figure 5. Distributed utility.

their "green electricity" share in energy systems. Despite its higher costs in relation to conventional technologies, green electricity has become competitive in those countries. To address the objective of augmenting the share of RE, EU countries used different incentive mechanisms. There are a lot of mechanisms: green certificates, R&D subsides for renewable resources, internalization of external costs and environmental taxes. Whatever the instrument of policy is, the role of governments is fundamental. Furthermore, the role of energy policy in national development policies is particularly relevant in those countries. Finally, related to the Bangladesh case, it could be said that this country is presently facing an important scarcity of electricity. This situation highlights the role of energy policies to promote the expansion of RE resources. However, these policies are in a very early stage.

The power grid cannot reach everywhere. Yet there are alternatives, and these are mini grids for supply of energy, information and communication using renewable energies for rural development and economic growth [38]. Bangladesh has an abundance of solar radiation. Daily solar radiation in Bangladesh varies from 3 to 6 kWh/m^2 with a maximum during March-April and a minimum in December-January and the total solar energy available in the whole country is estimated to be 691.47 × 10^3 PJ (Peta Joule). Solar PV is proven a viable option for electricity in remote areas of Bangladesh. Solar homes are popular and there is great potential for photovoltaic mini grids to provide power generation for rural development and economic growth. There is also a potential of grid-connected solar PV systems in Bangladesh, and it was estimated to be about 50174 MW [39]. Wind energy is another long-term possibility largely in the 724 km long coastal belts of Bangladesh. Annual average wind speed at 30 m height along the coastal belt is above 5 m/s. Wind speed in northeastern parts is above 4.5 m/s while inland wind speed is around 3.5 m/s for most parts of Bangladesh. Small-scale wind turbines could be installed and tested in locations such as St. Martins Island, Cox's Bazar, Patenga, Bhola, Barguna, Dinajpur, Thakurgaon and Panchagar [40]. Considering the wind speed distribution of Bangladesh, it appears that a wind machine in combination with a conventional diesel backup system will be economically viable for electricity generation in the off-shore islands but not in inland locations [41]. Hence a solar/wind hybrid mini grid is a promising prospect for electric power generation in the isolated islands of Bangladesh where extension of a national electric grid is not economic. The design of those can be optimized using genetic algorithm [42].

ENERGY SECURITY

Bangladesh, because of its unique location may serve as a trade corridor as well as an energy corridor in SAARC (South Asian Association for Regional Cooperation) and most of the regional and global economic actors may take advantage of the opportunities. However, both Bangladesh and the potential regional beneficiaries need to sincerely work for creating an environment conducive to capturing emerging economic opportunities. Sustainable mutual trust, economic cooperation and healthy market-based competition among Bangladesh, India, Bhutan and Nepal are necessary for individual and collective gains. Regional economic cooperation and sustainable peaceful resolution of long-standing disputes may help the regional entities to enhance their individual and collective energy security.

A nation-state is energy secure to the degree that fuel and energy services are available to ensure: (a) survival of the nation, (b) protection of national welfare, and (c) minimization of risks associated with supply and use of fuel and energy services. The five dimensions of energy security include energy supply, economic, technological, environmental, social and cultural, and military/security dimensions. Energy policies must address the domestic and international (regional and global) implications of each of these dimensions.

CONCLUSIONS

The basic conclusions drawn from this study are:

- The demand for electrical energy is also increasing with time and there is a shortage of electric power.
- To meet energy needs of its different areas, Bangladesh needs rational utilization of local resources of gas and coal.
- Electricity generation capacity must be increased with gradual transition towards renewables.
- The performance of electric power generation and utilization can be improved through reduction of system loss and introduction of end-use efficiency improvement devices.
- Bangladesh contributes a very small amount of CO_2 on a per capita basis but could be seriously affected by climate change.

ENERGY POLICY

Basic energy policy is concentrated as follows:

- To provide energy for sustainable growth
- To meet energy needs of the different parts of Bangladesh
- To ensure optimum use of renewable energy resources
- To ensure environmentally sound sustainable programs
- To ensure public and private participation policy

A broad group of energy policies promotes RE today. The simplest schemes consist of both direct subsides to energy production, and indirect incentive mechanisms. The choice of specific instruments relies on energy resources endowments as well as social and economic requirements and the institutional design of the sector. When designing a policy, it is equally important to consider both supply and demand characteristics, and the relevance of each barrier to entry. In the Bangladesh case, for example, financial issues are one of the most important barriers. In this case, it would require a political decision to devote more funds to RE projects through promotion on the credit market.

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