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CASE STUDY

Deployment of renewable energy technologies in Bangladesh: Long-term policy implications in power sector

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A B S T R A C T

This paper presents an assessment of future energy-supply strategies for the Bangladesh power sector. It identifies the prospects for the further economic development of the country while ensuring energy security and mitigating environmental impacts. The MARKAL standard version is used to model Bangladesh's power sector including already existing as well as innovative energy conversion technologies. Different policy scenarios for the evaluation of the power sector from 2010 to 2035 are explored. The analysis shows that Bangladesh will not be able to meet the future energy demand without importing energy. However, alternative policies like CO_2 emission reduction by establishing a target, or accelerated deployment of renewable energy technologies reduce the burden of imported fuel, improve energy security and reduce environmental impacts. The model predicts that alternative policies will not result in significantly higher cumulative discounted total energy system cost. The system cost increases up to 7.7% over the base scenario. The alternative policy scenarios reduce imported fuel by up to 100%. Renewable energy technologies, especially solar photovoltaic play an important role in achieving reasonable energy security.

1. Introduction

Electricity is a pre-requisite for the technological development and economic growth of a nation. The future economic development of Bangladesh is likely to result in a rapid growth in the demand for energy with accompanying shortages and problems. The country has been facing a severe power crisis for about a decade. Known reserves (e.g., natural gas, coal, and hydropower) of commercial primary energy sources in Bangladesh are limited in comparison to the development needs of the country. Power generation in the country is almost entirely dependent on fossil fuels, mainly natural gas that accounted for 82.81% of the total installed electricity generation capacity (5823 MW) in 2009–2010 [1] with huge capacity of shortage in respect to demand. By that year, only about 44% of total population had been connected to electricity [2], with vast majority being deprived of a power supply. The government of Bangladesh has declared that it aims to provide electricity for all by the year 2020, although at present there is high unsatisfied demand for energy, which is growing by more than 8% annually [2,3].

Coal is expected to be the main fuel for electricity generation. The government of Bangladesh has planned to generate more power from coal in the next years, although coal power has adverse environmental effects and coal reserves are limited. Power sector development plans shows that 19,200 MW coal-based plants will be added by 2030 [2]. The government has also focused on furnace-oil-based peaking power plants. As a result, the share of CO_2 emissions coming from fossil-fuel-based power plants in the national CO_2 inventory is expected to grow, and there is a growing dependency on imported fossil fuels for power generation.

Increasing the use of fossil fuels to meet the growing worldwide electricity demand, especially in developing countries, not only counteracts the need to prevent climate change globally but also has negative environmental effects locally. In Bangladesh, the power sector alone contributes 40% to the total CO_2 emissions [4]. In this case, it is necessary to develop and promote alternative energy sources that ensure energy security without increasing environmental impacts.

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Bangladesh is facing daunting energy challenges: Security concerns over growing fuel imports, limited domestic energy resources for power generation, and projected demands for electricity that will exceed domestic supply capabilities within a few years. In this study, a MARKAL energy-system model for the Bangladesh power sector was developed for least-cost analysis of alternative technological options for the next 25 years for addressing the above challenges. The intention is not to predict the future, but to provide insights into the implications of energy technology options that can be pursued by Bangladesh. Based on the development strategies for the Bangladesh energy policy for power generation, the following policy scenarios were developed [2,5]:

1) Base scenario: It presumes a continuation of current energy and economic dynamics and provides a reference for comparing impacts of policies or future scenarios.
2) CO_2 emission reduction scenario: It evaluates the effects of CO_2 emission reduction in the entire energy-supply system. A 10% CO_2 emission reduction from 2015 onwards compared to the base scenario is considered. The ultimate objective of the Bangladesh energy policy is to ensure environmentally sound sustainable energy development programs and environmentally compatible electric energy [5,6].
3) Renewable energy target production scenario: It assumes specific policy interventions to accelerate deployment of renewable energy technologies over the base scenario. The government target of 5% of total electricity generation using renewable energy technologies by 2015, 10% by 2020 [2,7] and 20% by 2035 is applied.
4) Null coal import scenario: It assumes specific policy intervention in the import of fossil fuel. The intention is to use all available energy resources and reduce the import of coal for electricity generation. The ultimate objective of the Bangladesh energy policy is to maximize use of indigenous energy resources for power generation [5].

2. The MARKAL methodology

The MARKAL model mainly consists of the description of a large set of energy technologies, linked together by energy flows, jointly forming a reference energy system. The reference energy system is the structural backbone of MARKAL for any particular energy system and its great advantage is that it gives a graphic idea of the nature of the system. Another important characteristic of MARKAL is that it is driven by a set of demands for energy services. The feasible solutions are obtained only if all specified end-use demands for energy for all the periods are satisfied. The user exogenously supplies these demands in the model. Once the reference energy system has been specified, the model generates a set of equations that hold the system together.

In addition, the MARKAL model possesses a clearly defined objective function, which is usually chosen to be minimization of the long-term discounted cost of the energy system. The objective function is optimized by running the model, which means that configuration of the reference energy system, is dynamically adjusted by MARKAL in such a way that all MARKAL equations are satisfied and the long-term discounted system cost is minimized. In this process the model computes a partial equilibrium of the energy system at all intermediate stages in all aspects as explained in Ref. [8]. This study updated the MARKAL-Bangladesh database and applied the recent government policies to find the least-cost energy technology options to meet the future electricity demand in a sustainable way.

3. The MARKAL model of Bangladesh

3.1. Reference energy system of Bangladesh power sector

The reference energy system represents the activities and technologies of an energy system, depicting energy demands, energy conversion technologies, fuel mixes, and the resources required to satisfy energy service demands [9,10]. In MARKAL, the reference energy system is the first step toward building a model of the Bangladesh power sector (Fig. 1). Three basic sets of input information are required for each time step over the entire period of the analysis: 1) energy demands, 2) potential supply and cost of primary energy resources, and 3) the cost and performance characteristics of technologies potentially available for use in the energy system.

3.2. Energy demand

In 1994, the total electrical energy demand was 9.63 TW h and had increased to 27.6 TW h in 2009 [2,3]. Based on the projections of Refs. [3] and [14], this energy demand will increase to 102.42 TW h and 100.08 TW h in 2025, respectively. The Long-range Energy Alternatives Planning (LEAP) tool was examined to form demand scenarios according to the trend of gross domestic product (GDP) growth rates (5.5%, 6.8% and 8%) and the nature of the energy sector itself, and taking into consideration broader factors, e.g., population, households, urbanization and other influencing factors for the time span 2005–2035 [12]. It is worth mentioning here that the actual GDP growth rate in Bangladesh is neither low nor high and therefore, in this study, the demand projection is based on a GDP growth rate of 6.8% (Table 1).

3.3. Energy resources

The model requires that the cost of all primary energy sources be defined along with constraints on their availability. Supply cost estimates are being provided as well as upper bounds on resource availability for fossil fuels (Table 2). The technical potential of grid-connected solar PV, wind, hydro and biomass based power plants is about 50,174 MW, 4614 MW, 550 MW and 566 MW, respectively. For renewable energy resources exploitable resource was defined, as were maximum rates of technology introduction (Table 2).

3.4. Conversion technologies[1]

The characteristics of all technologies must be provided to the model. Conversion technologies convert primary energy into final energy carriers. The model requires users to create detailed profiles for two sets of energy conversion technologies: one for converting primary into final energy carriers, and one for converting final energy carriers into energy services. A reasonably representative set of conversion technologies is developed, which includes a total of 21 distinct conversion technology types (coal steam conventional, advanced coal flue gas desulphurization (FGD) 300 MW, existing fuel oil steam, fuel oil gas turbine, existing gas simple cycle (SC) and steam turbine (ST), new gas SC 100 MW and 150 MW, new gas ST 300 MW, existing gas combined cycle (CC), new gas CC 300 MW, hydro, biomass based plants, wind and solar PV) (Fig. 1). For each of the technology types, values are specified for energy input per unit energy output (efficiency), capital cost, fixed and variable operation and maintenance costs, NO_2 and SO_2 emissions per unit of energy output, and the first year in which the technology was introduced. All costs are in 2009–2010 Bangladesh Taka (1 USD = 70.5 Taka) [15]. The characteristics are performance and cost level inputs to the model for 2010–2035. For most of the technologies, the performance

[1] Cost data, technology selection and technology specification data mainly based on Bangladesh Power Sector Master Plan 2005 and 2010, Bangladesh Power Development Board, and Ministry of Power, Energy and Mineral Resources.