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Development of Optimal Power Generation Mix for Bangladesh in Different Socio-Economic and Emission Reduction Policy Scenarios

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ABSTRACT

Access to affordable and clean energy is one of the basic requirements for sustainable growth. Bangladesh, as one of the developing nations, currently faces rapid growth in the electricity sector. However, limited potential of indigenous natural resources might jeopardize energy security in long-term. Adoption of modern clean energy sources like nuclear power, renewable energy generation technologies have their own economic and technical limitations.

In this study, we analyzed all available and potential energy sources for electricity generation considering techno-economic limitations and applied linear programming to obtain the best electricity generation mix that would ensure low cost and limited emission simultaneously. The whole country is geographically divided in to nine regions to obtain a high spatial resolution of current installed capacities and future potential for expansion. Moreover, hourly demand for all different nodes is projected so that high temporal resolution can be achieved. This dynamic optimal power generation mix model provides optimized generation and capacity mix from 2025 to 2050 at five years intervals with hourly dispatch schedule. Different economic growth scenarios for electricity demand projection and policy scenarios including carbon-emission limits and adaptation of new technologies have been considered for sensitivity analysis. This analysis provides a clear pathway for low-cost optimum electricity sector expansion by incorporation of modern technologies like nuclear power and renewables with storage capacity.

Keywords: optimal power generation mix, electricity, nuclear power, renewable energy, carbon emission, Bangladesh

NONMENCLATURE

Abbreviations	
BAU	Business As Usual
CCS	Carbon Capture and Storage
GDP	Gross Domestic Product
NDC	Nationally Determined Contributions
PSMP	Power System Master Plan

1. INTRODUCTION

Bangladesh is a relatively small country with a huge population (165 million, 8th in the world) in south Asia with potential to become world's 23rd largest economy by 2050 in terms of projected gross domestic product (GDP) rankings at purchasing power parity (PPP) [1]. Bangladesh is also short-listed along with Vietnam and India as one of the three world's fastest growing economies over the period between 2016 and 2050. The country has experienced a rapid, but stable economic growth over the last decade. It is mostly driven by small-medium level industries and commercial service sectors due to an increase in activities because of mega infrastructure projects, youthful and working age population. The economic growth in turn has created ever-growing energy demand, especially in the electricity sector. People with access to electricity almost doubled from 47% in 2009 to 97% in 2020 [2] while per-capita electricity consumption also doubled. Traditionally, the country has always depended on indigenous natural gas as a major component of the energy mix. Indigenous coal resources have hardly been tapped due to high population density near coalmines and techno-economic limitations. As natural gas reserve tends to deplete more due to over consumption, identification and utilization of

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new resources have become a necessity to ensure sufficient electricity to the industries and households to support economic growth and improve quality of life at the same time.

Until now the contribution of developing countries, such as Bangladesh in greenhouse gas (GHG) emissions and global warming has not been significant. However, if the world fails to take timely and necessary actions to reduce CO_2 and other GHG emissions significantly, Bangladesh would be one of the countries facing the worst effects of climate change due to its geographical position. Projections infer that the costs to Bangladesh due to climate change could amount to an annual loss of 2% of GDP by 2050 and 9.4% of GDP by 2100 [3]. As a part of the historic and ambitious international climate agreement at the U.N. framework convention on climate change (UNFCCC) conference of the parties (COP21) in Paris in December 2015, to reduce future emissions, Bangladesh set out the intended nationally determined contributions (INDC) goal from its perspective. According to the INDC of Bangladesh, the country would contribute to reducing GHG emissions by 5% unconditionally and 15% subject to international support (in the form of finance, investment, technology development-transfer, and capacity building) from business as usual (BAU) levels by 2030 in the power, transport, and industry sectors, based on existing resources as a mitigation contribution [4]. We comprehend this study to provide insights regarding the optimal generation expansion for the rapidly developing electricity sector with necessary consideration to carbon emission limits as committed to the international community.

2. METHODOLOGY

To develop the model for optimal electricity generation expansion, we used linear programming to obtain the least cost generation mix for the hourly projected electricity demand considering different techno-economic and resource constraints. The electricity demand forecast was performed using MAED [5] with hourly load data derived from industry, household, commercial service, and transportation sectors based on low, business as usual (BAU) and high economic growth cases considering median variant population projection made by the UN department of economic and social affairs division [6]. Constraints regarding indigenous natural resources of different cost grades, potential for import of fossil fuel and renewable energy growth potential with relevant prices were considered as per available data from national and international sources.

2.1 Electricity Demand Projection

The electricity demand forecast for the years 2025 to 2050 at an interval of 5 years is performed using MAED-2 model taking the actual load data of 2015-2020 as the base year. Three different economic growth projections named as low, BAU and high are considered that correspond to specific electricity demand growth of 8% linearly reaching 4%, 5% and 6% in 2050 respectively. The demand growth projections along with different load coefficients including seasonal, daily, hourly coefficients are generated calibrating the available data for base years and considering possible changes in future analysis years. The annual electricity demand obtained for three different growth scenarios is presented in Fig. 1.

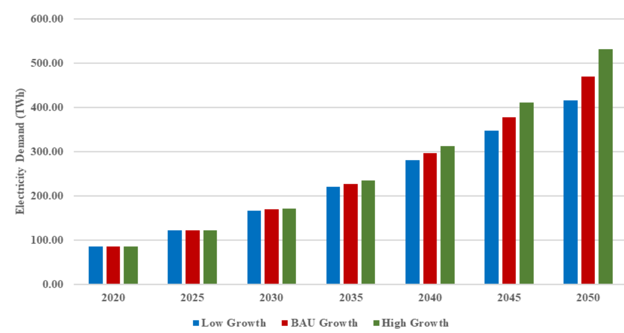

Fig. 1. Annual electricity demand projection for different growth scenarios

2.2 Objective of optimization

The objective of the linear program model corresponds to the net present value of the overall power system cost (in billion USD) over the entire analysis period (2025 to 2050) at discounted value. It is formulated by Eq. (1), taken into considerations of the annual fixed cost (AFC_y) and annual variable cost (AVC_y) for different power generation and storage technologies. The external costs including transmission, distribution and cost for external infrastructure development are not considered here.

$$\min : TC = \sum_{y=0}^{Y}\sum_{s=0}^{S}\left(\frac{s}{(1+\Gamma)^{S\times y+s}} + \frac{(S-s)}{(1+\Gamma)^{S(y+1)+s}}\right)\times\frac{AFC_y + AVC_y}{S} \quad (1)$$

The annual fixed costs for a given year is estimated as the difference between installed power capacity and the remaining capacity from the base year in GW multiplied by capital recovery factor and unit construction cost in USD/kW. It includes annualized value of the initial investment (construction cost), the operation and maintenance cost, the fixed asset tax, and the scrap value of the asset at the end of the lifetime of each power plants and storage technologies.

2.3 Constraints for optimization

Different technical constraints for available electricity generation technologies including power demand and supply balances, capacity constraints and maintenance schedule, carbon emission limitations, operational constraints, capacity reserve constraints for power supply reliability, minimum output level constraints, load following capability of power plants and charge and discharge balance of energy storage technology etc. The details of the constraint formulation have been discussed in previous publication [7].

2.4 Scenario development

As the focus of this analysis is to observe and validate different energy mix and carbon emission scenarios with respect to cleaner energy sources like nuclear and renewables, we consider three different emission scenarios namely business as usual (BAU), INDC case and 50% reduction case. The BAU scenario considers the carbon emission scenario as depicted in the INDC of Bangladesh, where no emission controlling measures have been considered. This case refers to 91Mt CO_2 emission from the power sector in 2030. For this analysis, we extrapolate the BAU case up to the year 2050 at the value of 200Mt CO_2. The Intended Nationally Determined Contributions or INDC case refers to the country's commitment to reduce the emission from power sector by 18% at 75Mt CO_2 by 2030 and then extrapolating the trend up to the final analysis year of 2050. It is quite understandable that the INDC case might be useful for the year up to 2030. However, as demand grows significantly during the middle part of this century, further emission reduction policies would be required after 2030. The 50% reduction scenario confirms 50% reduction of CO_2 emission by the year 2050 with respect to the emission perceived in the BAU case. The historical data for CO_2 emission and projections for the three scenarios are presented in Fig. 2.

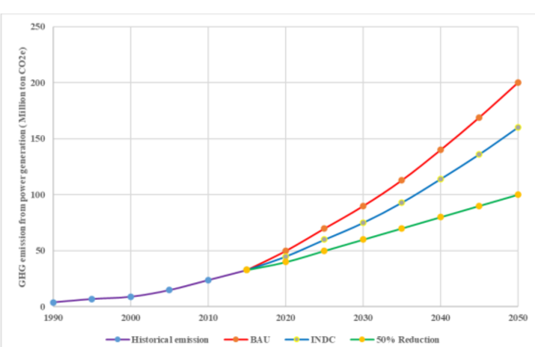

Fig. 2. Historical and projected CO_2 emissions in different scenarios

3. RESULTS

The linear programming model for optimum power generation and expansion used in this analysis takes into consideration technical limitations of the power system and different generation technologies. Moreover, it provides the least cost generation mix for all the analysis years satisfying hourly demand and yearly CO_2 emission limits. The current government policy for future electricity generation has been considered for three different growth scenarios with and without carbon emission restrictions incorporating local indigenous resources, potential for fuel, electricity imports and incorporation of new technologies like nuclear power, variable renewables, and battery storage. We present the results of electricity generation mix and installed capacity for different growth scenarios without and with carbon emission limits in Fig. 3 and Fig. 4 respectively.

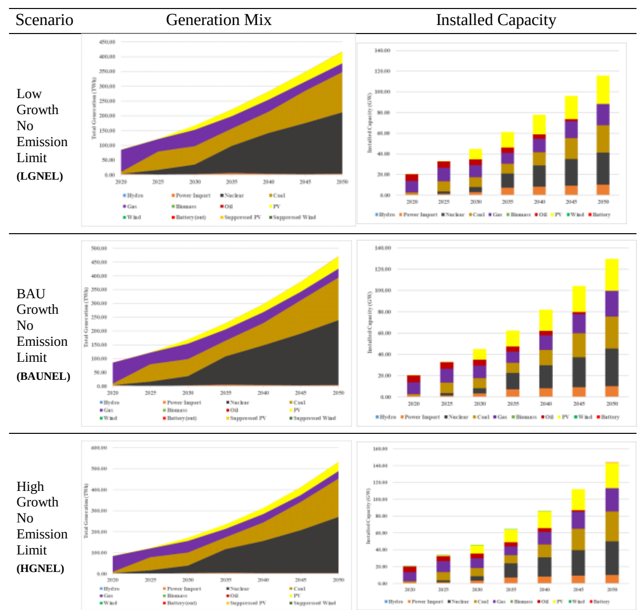

Fig. 3. Optimum generation-mix and installed capacity without CO_2 emission limit

No emission limit (NEL) cases reflect the current generation plan of shifting the dependence on coal from natural gas as the primary resource, which is the least cost generation source based on local fuel production as indigenous natural gas would be depleted by 2030. However, nuclear power comes into the mix quite strongly after 2030 as local coal production also becomes expensive as low-cost grades get depleted. On the other hand, for the emission limited cases (WEL), nuclear power shows rather higher contribution due to carbon neutral characteristics in contrary to that of coal. In both cases, solar PV potential is highly utilized even though low-capacity factor keeps the contribution of PV in the mix relatively low. Moreover, in the WEL cases, we see battery storage elements appear in the mix after 2040 to utilize the excess power in daytime for later utilization in the peak period.

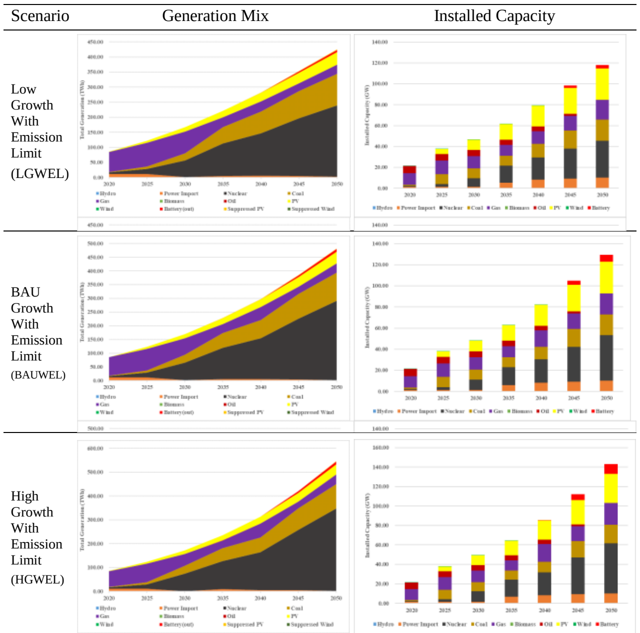

Fig. 4. Optimum generation-mix and installed capacity with CO_2 emission limit

4. CONCLUSION

This paper evaluates the optimal electricity generation mix of Bangladesh for different growth and carbon emission restriction scenarios using a dynamic hourly resolution optimal power generation mix model. The proposed model accommodates full potential of solar, wind and hydropower to reduce the carbon emission level in future generation mix. In addition, traditional fossil fuel-based resources were also considered with the scope of imported fuel as some resources deplete and others remain unusable for different regions. As nuclear power is also becoming popular in some of the developing regions of the world, gradual development of this sector is inevitable due to its very low carbon intensity. The optimized generation mix provide important information regarding policy level implications of different carbon emission strategies.

It is estimated that the demand of electricity would grow about five times over the 25 years analysis period (2025-2050) even in the BAU case. Under the circumstances, diversified energy sources reduce over dependence on single source, which requires huge investment and long-term commitment at the same time. As the country has committed to INDC and set the maximum limit for the power sector, the strategy to achieve the goal needs to be well defined. In this analysis, we show that the INDC target is not too difficult to achieve by simple adjustments in the mix. Nevertheless, the INDC target is up to 2030 only. It might become difficult to change the trend for long-term planning up to the year 2050 when the demand and consumption reaches a significant higher level, so does the emissions. However, considering deep decarbonisation at 50% reduction scenario for medium to long-term planning, large scale nuclear and renewable energy options like solar PV are the best fit. Contribution of nuclear power cannot be ignored as it takes the base load, which the intermittent renewable technologies cannot serve. The cost of decarbonisation (2% increase in system cost for 33% cumulative emission reduction) may not be too high if advance policy is adopted and executed accordingly.

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