Exploration and Corrective Measures of Greenhouse Gas Emission from Fossil Fuel Power Stations for Bangladesh

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Abstract: Greenhouse gas emission is increasing alarmingly due to bulk electricity generation from fossil fuel such as coal, gas and oil with its limited stock. While researchers are struggling to minimize the emission using suitable mitigation techniques including renewable energy sources, the Government of Bangladesh is implementing several Coal based power plants. This paper presents mathematical model of parameters related to Greenhouse gas emission and demonstrates its emission rates resulting from various fuels used in Bangladeshi power plants. The Greenhouse gas emission from the existing fossil fuel power plants using HOMER (Hybrid Optimization of Multiple Energy Resources) software is analyzed in this research. The result shows that power plants of coal, diesel and natural gas emit 0.90 kg, 0.76 kg and 0.566 kg of CO₂ per kWh, respectively. Furthermore, several Greenhouse gas mitigating procedures are proposed for fossil fuel-based power generating stations.

Keywords: Fossil fuel; Greenhouse gas emission; CO₂ emission; HOMER

1. Introduction

The fastest-growing population and industrialization lead to huge electricity demand in the entire world with a significant challenge in reducing Greenhouse gas (GHG) emission. Researchers around the world are concerned about reducing emission corresponding to electricity generation. Limited resources of fossil fuel like coal, natural gas and diesel are being used in the majority of power generating stations in the world. The use of fossil fuel resources in power generation is increasing global warming potential, intensifying sea level and destroying the climate forms. Despite these drawbacks, the total capacity of fossil fuel-based power plants around the world is increasing and reached up to 3500 GW by 2016 leading to threaten to the environment [Amin et. al. 2019].

Among other fossil fuels, coal is prominent for production of several harmful greenhouse gases including CO₂, SO₂, NO_x, and other particulate matters. Research exhibited that combustion of coal is greatly responsible for a large amount of GHG emission which further escalates global warming potential [Smith et. al. 2019]. Major portions of the coal power plants are operated with older technologies with low quality coals which also increase CO₂ emission [Eyre et. al. 2018]. Different technologies are recognized to lessen CO₂ emission in a coal-fired power plant. Use of carbon capture & storage technologies in conventional power station reduces up to 84% GHG emission compared to sub-critical coal based power plant, whereas integrated gasification coal combustion helps to reduce up to 160 g/kWh [Baky et. al. 2017]. Another study performed in the perspectives of Bangladesh reveals that the major barriers to coal based

power generation include coal locations, legal policy, technological improvement, health, safety, and environmental issues [Zaman et. al. 2018].

Another notable fossil fuel is natural gas used for power generation. Rapid fuel switching from coal to natural gas lay down the GHG emission by 6% in Great Britain as showed in a study [Wilson et. al. 2018]. On the other hand, electricity generation based on conventional Liquefied Natural Gas (LNG) burned in an open cycle gas turbine plant emits 38% less GHG over its life cycle compared to black coal burned in a sub-critical plant in Australia [Weldu et. al. 2017]. GHG emission from natural gas based power plant is two times lesser than imported coal-fired power plant in India [Cristian Dinca et. al. 2008]. However, natural gas resources are declining worldwide with their involvement in various applications, such as cooking, transportation sector and so on. Thus, the researchers are looking for the substitution of natural gas for integrating in bulk amount of power generation [Gilbert et. al. 2018].

Petroleum oil such as diesel, heavy fuel oil, liquefied petroleum and gasoline based power generation is facing difficulties with high cost and corresponding GHG emission to the atmosphere. An analysis shows using time varying carbon intensity exhibits coal (sub-bituminous), natural gas and diesel based generation yields 0.87 kg, 0.42 kg and 0.63 kg of CO₂ per kWh, respectively, in the perspective of New Zealand [Khan et.al. 2018]. A comparative Life Cycle Assessment (LCA) of GHG emission executed in Macau city, China reports that electricity generation from natural gas, heavy oil & municipal solid waste incineration harvests 0.42 kg, 0.7 kg and 0.95 kg of CO₂ per kWh, respectively [Song et. al.2017]. Another study presented that organic waste composting techniques promotes environmental sustainability by limiting GHG emission and provides fertilizer for the agricultural sector [Kamyab et. al. 2015].

Developed countries are focused heavily on lowering carbon program in the power sector by lessening the use of fossil fuel. In the case of developing countries, the use of fossil fuel in power generation is increasing where no carbon mitigation technologies are employed. Therefore, the chance of GHG emission in those power plants is more and causing great harm to the environmental sustainability [Xiang Yu et. al. 2018]. Like other developing countries, Bangladesh is also experiencing huge GHG emission problem from fossil fuel power stations. Although conventional fossil fuel used in power plants requires low cost, plant efficiency is getting decreased due to ageing effects. As a consequence more GHG emission is occurring by the existing fossil fuel power plants in Bangladesh. To achieve sustainable development in the power sector, the government has a plan towards net-zero carbon emission policy 2041 [Hoque et. al. 2019]. However, there is no clear strategy against reducing GHG emissions from fossil fuels.

On the other hand, globally fossil fuel based power plant is getting decreased owing to the inadequacy of fossil fuel resources with environmental pollution [Kaberger et. al. 2018]. Hence, environmentalists are discouraging to establish such type of fossil fuel power plants in the worldwide [Zhou et. al. 2019]. However, in Bangladesh, this type of power plant construction is rising. Additionally, a sudden increase in electric vehicles in Bangladesh involves huge electricity consumption which further increases the GHG emission indirectly

[Karmaker et. al. 2018]. In this context, it is essential to determine the GHG emission from such power plant in Bangladesh to overcome this problem by taking proper mitigating strategies.

As it is known, Bangladesh is ranked the 10th largest densely populated country in the world and is rapidly flourishing in socio-economic and technological advancement [Rahman et. al. 2019]. For making such development to a sustainable one, electricity plays a vital role. With the rapid proliferation of electricity demand, the power plant infrastructure with its capacity is also expanding. Total installed capacity of electricity generation is increased to 15,519 MW by 30th December, 2018 where energy generation can be divided as natural gas (64.52%), coal (1.81%), diesel (6.36%), furnace oil (20.87%), hydro (1.66%) (1.66%) and renewable energy (0.02%) [Amin et. al. 2019]. However, using existing energy generation capacity, it is quite impossible to meet the emerging demand of electricity and the GHG emission from corresponding power generation is very perilous [Sharif et. al. 2018].

Conversely, the huge potentiality of renewable resources, such as solar, biomass and wind, based electricity generation reduces GHG emission significantly in Bangladesh which is demonstrated in various studies [Das et. al. 2018; Rashid et.al. 2017]. In another research, it is presented that waste to energy (WTE) technology can be a potential solution for subsiding GHG emissions in Bangladesh to build a sustainable environment [Islam et. al. 2017]. An analysis revealed that it increases the system stability with declining CO₂ emission up to 497,78,600 tons by 2022 when Egyptian power network integrated with 20% renewable energy [Nassar et. al. 2018]. Besides, the use of available renewable resources can meet the electricity demand as well as maintain the global warming potential within a safe limit [Owusu et. al. 2016]. Although it is described in the contemporary researches that renewable energy utilization decreases GHG emission noticeably, it is not practiced in the power generating sector of Bangladesh effectively due to lack of policies, awareness and improved technologies regarding mitigation of GHG emission.

While there are a number of research articles present in the literature, for example several carbon emission reasons from NewZealand electricity grid [Walmsley et. al. 2018], assessing carbon footprint from Iranian power network [Dalir et. al. 2018], and research to reduce CO₂ in Brazil, Europe, and Japan [Audoly et. al. 2018], to the best of authors' knowledge, no research articles on the analysis of GHG emission from fossil fuel power plant and the mitigating strategies in details are published, especially from Bangladeshi context. Therefore, this paper explores and proposes effective mitigating strategies of GHG emission based on fossil fuel power system. The main contributions of the study are:-

- To analyze the GHG emission with respect to different fuels, technology and rating of the generating stations
- To develop a mathematical model to measure the GHG emission from different power plants
- To demonstrate the GHG emission from fossil fuel power generating stations using HOMER software and

- To propose several GHG mitigating procedures for conventional power systems in Bangladesh.

The construct of the paper is as follows. Section 2.0 illustrates the methods where analytical framework is demonstrated. In addition to this, mathematical modeling of the GHG emission from power station involving several parameters is presented. Section 3.0 presents the results and discussion whereas section 4.0 shows the implications for mitigating GHG emission. Finally, section 5.0 concludes with the findings and future research directions.

2. Methods

The methods section comprises two subsections including analytical framework and mathematical model. Analytical framework mainly describes the whole process where the exploration of GHG emission is conducted in this research. Moreover, the mathematical modeling section analyzes the expression for GHG emission.

2.1. Analytical framework

In order to explore the GHG emission from the existing fossil fuel power stations in Bangladesh, the primary data related to energy consumption, demand along with the fuel used is collected from the online sites of the power sector. Also, the data corresponding to fuel consumption and GHG emission is obtained from the field visit of the different power stations in Bangladesh. For achieving data, authors have visited Ghorashal Power Station Company Limited, Ashuganj Power Station Company Limited, Rural Power Company Limited, Northwest Power Generation company Limited and also the Coal Power Generation Company Limited which is under construction now. Besides, the contemporary researches allied with the power plant emission provide the secondary data. The analytical framework for the exploration of the GHG emission is shown in Fig.1.

Fig.1: Analytical framework for the research

In this research, the data (i.e. energy generation, load demand, fuel consumption, technology used, and so on) acquired from different power stations are used in HOMER software. HOMER stands for Hybrid Optimization of Multiple Energy Resources which is a software developed by the National Renewable Energy Laboratory in the United States. It is used for designing and evaluating the technical, financial and environmental parameters of fossil fuel and renewable based generation. In this paper, the environmental impacts of the fossil fuel power station are evaluated using HOMER software. Mathematical analysis of the GHG emission is illustrated using the data which are collected from HOMER analysis & existing power plant in Bangladesh. Finally, several policies for minimizing GHG emission from fossil fuel power plant are proposed in this paper.

2.2. Mathematical Model

Electricity generation plant often plays a vital role in producing GHG emission. The amount of GHG emission is thus needed to be calculated precisely. In a GHG analysis model, activity rate and emission factor are the two major components. These two factors are influenced by energy consumption, type of fuel and the technology used in the plant. Emission factor, a constant, represents the amount of pollutant emancipate to the atmosphere. It is generally expressed as amount of pollutant divided by a unit weight. The general equation for emissions estimation is given in equation (1):

$$E = \lambda * Ef * \left(\frac{1 - Er}{100}\right) \quad (1)$$

where E is the total emissions; λ is the activity rate; E_f is the emission factor and Er is the overall emission reduction efficiency [Hondo et. al. 2005]. CO_2 is the paramount part of GHG emission. The CO_2 emission can be calculated using the formula given below;

$$E_F = \frac{\sum_i FC * NCV * EF_{CO_2}}{E_G} \quad (2)$$

where FC is the fuel consumption for all units of power generation, NCV is net calorific value and EF_{CO_2} is CO_2 emission factor and E_G is the generation of energy supplied to the grid [Board C.E. 2009]. The total energy generation supplied to grid can be calculated as equation (3):

$$E_G = \frac{\sum_i FC * NCV * \eta_e}{3.6} \quad (3)$$

where η_e is the energy conversion efficiency. If the E_{cap} is the net capacity of the plant, PLF is the plant load factor, then in case of off-grid power plant the E_G can be expressed as follows [Board C.E. 2009]:

$$E_G = E_{cap} * PLF * 8760 \quad (4)$$

GHG emission depends upon different factors i.e. activity rate, energy use, technology used and so on [Tan et. al. 2017]. Thus it can be expressed as the function of these parameters in equation (5):

$$E = f(x_1, x_2, x_3, \dots, x_n) \quad (5)$$

where $X_1, X_2, X_3, \dots, X_n$ are the factors influencing GHG emission from power station and E is the total GHG emission. Due to uncertainty of the GHG emission from power plant, there always a difference is found between original value of the emission and the estimated value of GHG emission.

$$E_{ori} = E_{est} + \varepsilon \quad (6)$$

where E_{ori} , E_{est} and ε are the original value, estimated or inventory value and unknown error of the GHG emission, respectively. Using Gaussian probability distribution, the probability of the error can be identified [Saikawa et. al. 2017].

$$P(\varepsilon) = \frac{1}{2\pi\sigma} \times \exp\left\{-\frac{(\mu - \varepsilon)^2}{2\sigma^2}\right\} \quad (7)$$

where $P(\varepsilon)$ is the probability of error value ε ; μ is mean error, also called a systematic error and

σ is the standard deviation of errors, a measure of the uncertainty of the result.

3. Results

3.1. GHG emission from power plant in Bangladesh

Power plant in Bangladesh utilizes fossil fuel, such as natural gas, coal and oil, in a large-scale where renewable energy, i.e. hydro, solar, wind and biogas/biomass, are used in a small-scale. Fig. 2 displays the fuel based power plant capacity in Bangladesh. It illustrates natural gas, diesel and furnace oil are contributing maximum in power generation, whereas renewable energy resources are bottommost. Recently, coal based several projects are under construction which are Coal Power Generation Company Limited (1200 MW), Bangladesh- India Friendship Power Plant Company Limited (1320 MW) and Bangladesh- China Power Plant in Patuakhali (1320 MW) in Bangladesh. As the coal and natural gas based power generating stations are increasing rapidly, it is a crucial issue to analyze corresponding GHG emission for environmental sustainability.

Fig. 2: Installed capacity of power plant in Bangladesh by fuel type [SREDA 2019]

Fig. 3: Projection of power generation scenario per financial year

A prediction of CO₂ emission is estimated considering the statistics of electricity generation taken from Bangladesh Power Development Board (BPDB) from 2006-2007 to 2024-2025 financial year. It is observed in Fig. 3 that extrapolation technique forecasts the energy generation at 2024-25 that will be 1,32,520 GWh. Rapid industrialization and improved life style of the people of Bangladesh leads to increasing the power demand that is facilitated by the use of electricity in charging the electric vehicles. Owing to such situation, GHG emission from the power generation is also increasing. A study discussed that, CO₂ produced per kWh energy generation in Bangladesh is about 0.64 kg [Das et. al. 2017]. Using extrapolation, the value of CO₂ emission due to energy generation will be 83,000 M ton in the financial year of 2024-25, which is depicted in Fig. 4.

Fig. 4: Statistics of CO₂ generation per financial year

As the extrapolation techniques results GWh and CO₂ emission throughout the country in the year of 2024-25, it has some errors. The generation and corresponding GHG emission is actually quite different from the actual one due to the changes in fuel, the generation technological process, up gradation of the technology to be an optimized & effective one. The quality of the fuel and their burning mechanism are being changed, thus extrapolation results may bring incorrect results. In other cases, the rapid industrialization raises the electricity demand which will be a threat to the GHG emission rendering environmental pollution. Therefore, to make the power system less dependable to fossil fuel for lower the rate of GHG emission, the results demonstrate possible outcome.

3.2. GHG emission from HOMER analysis

GHG emission is increasing with huge electricity demand in Bangladesh. In this case, it is an urgent issue for mitigating GHG emission coming from power generation. In this paper, first data, such as fuel type, technology used and generation capacity, are collected from the different power plants of Bangladesh. It is observed from the results using HOMER software simulation, almost all the power plant depends on the coal, natural gas and furnace oil/diesel with the significant amount of GHG emission.

Table [1]: GHG emission results (HOMER Analysis)

Type of Fuel	Emission Parameter	Amount of Emission (kg/ kWh)
Diesel	CO ₂	0.760
	CO	0.005
	Unburned Hydrocarbons	0.00021
	Particulate Matters	0.0000293
	SO ₂	0.0018
	NO _x	0.00455
Coal	CO ₂	0.90
	SO ₂	0.00707

	NO _x	0.00428
Natural Gas	CO ₂	0.566
	CO	0.00186
	Particulate Matters	0.0000525
	NO _x	0.0039

In Table [1], GHG emission from different fuels is shown. It can be seen that coal based power plant is the highest GHG emitter, and the diesel and natural gas have also a significant amount of GHG emission.

Fig. 5: Comparison of CO₂ emission from various resources with average CO₂ emission

Relative comparison between the average CO₂ emission from fossil fuel based power station and the HOMER result are given in Fig. 5. It is seen from Fig. 5 that the calculated value of CO₂ per kWh is less than the average value of CO₂ per kWh. It means that the actual emission differs from the usually used CO₂ emission data.

Proliferation of the coal based power plant in Bangladesh is responsible for high amount of GHG emission to the environment. Use of coal having lower heating value increases the GHG emissions. The calorific value fluctuates for bituminous coal from 27,912 kJ/kg to 34,890 kJ/kg and for sub-bituminous coal from 19,300 kJ/kg to 26,749 kJ/kg. In the case of Barapukuria and Khalishpur coal mine, the calorific value varied from 32,960 kJ/kg to 29,099 kJ/kg and from 34,225 kJ/kg to 29,773 kJ/kg, respectively. On the other hand, in the case of imported coal, the gross calorific value varied from 20,818 kJ/kg to 25,540 kJ/kg [Kibria et. al. 2018]. The gross calorific value of Bangladeshi coal was higher than that of imported coal. It was also shown from the caloric value that-Bangladeshi coals are bituminous and imported coals are sub-bituminous [Bhuiyan et. al. 2014]. Thus, the use of bituminous coal lowers the chance of producing GHG emissions. As stated by Bangladesh Power Development Board (BPDB), at present diesel based generation becomes 2,889 MW. Thus, the large amount of power generation using diesel/furnace oil penetrates

higher GHG emission where about 0.76 kg of CO₂ produced per kWh. Therefore, the use of diesel/oil in power generation needs higher heating value. Among diesel and coal fueled power plant, natural gas demonstrates the lowest GHG emission.

Table [2]: Error calculation

Fuel Type	Average CO ₂ (g/kWh)	% Relative Error
Diesel	640	18.75
Coal		40.625
Natural gas		-11.5625

Table [2] indicates the relative error regarding CO₂ emission per kWh. The difference between CO₂ per kWh found from HOMER and the average value is called as error. As the average CO₂ emission per kWh energy generation is 640 g, the relative error in the case of different fuels can be easily deduced. In Bangladesh, natural gas, coal and diesel are the main fuel and their contributions in power generation are not equal. Thus, the resultant relative error from different fuels is unequal.

4. Discussion

4.1. Strategies for GHG emission mitigation

The GHG emission from the fossil fuel power stations influences significantly global warming level. Therefore the mitigation of such emission from conventional fossil fuel power station is very essential now-a-days. Several factors are identified in this paper which are directly involved in GHG emission from fossil fuel power station in Bangladesh, i.e., carbon & sulfur content of the fuel, amount of energy generation, technology used, energy efficiency and improper waste disposal techniques and so on. The low carbon development programs cover low GHG emission, reduce vulnerabilities of climate change, use of renewable energy and less effect on socio-economic aspects and make the energy sector sustainable [Lee et. al. 2018]. With the increasing electricity demand, GHG emission rate is increasing with the same proportion of rising electricity demand in Bangladesh. As it is obvious, government of Bangladesh has taken a large number of initiatives for establishing fossil fuel based power station to meet the huge demand of electricity. Thus, it is crucial to find out the best system for reducing GHG emission. The study suggested several mitigating procedure in this section corresponding to fossil fuel power stations in Bangladesh.

4.1.1. Integration of renewable energy sources

Renewable energy resources give the reasonable amount of GHG emission reduction than fossil-based power station. By integrating renewable energy resources, it would be a meaningful option for reducing GHG emission. Huge potentiality of renewable resources like solar, biogas/biomass can be employed to generate power in Bangladesh. Studies show that renewable resources used in electricity generation help to curtail the GHG emission [Amponsah et. al. 2014; Rahman et. al. 2018]. Another comparative analysis performed claims that renewable resources like nuclear, wind and hydro-electric power have less environmental pollution than coal fired power plant [Siddiqui et. al. 2017]. Fig. 6 illustrates renewable resources, such as solar, wind, nuclear, hydro, geo-thermal and biomass, have the least amount

of CO₂ emission than other non-renewable sources. Biogas/biomass has the highest amount of CO₂ emission than other renewable resources. Although utilization of biogas resources makes the environment clean, fresh and free from bad smell. It also gives fertilizer which is beneficial for the agriculture and fish feed.

Fig. 6: CO₂ emission from various resources [IPCC 2014]

Fig. 7 exhibits technological advancement that may reduce GHG emission remarkably [Ravindra et. al. 2019]. However, the incorporation of renewable resources for electricity generation becomes the most affordable and reliable process for sustainable development.

Fig. 7: GHG Emission reduction for different cases

4.1.2. Tree plantation around the power plant

Trees capture carbon particulates and release oxygen (O₂) to the atmosphere by means of photosynthesis. The captured carbon is then converted into branches, roots and leaves using solar energy. Thus tree plantation is imperative option around the power plants where CO₂ produces for every kWh generation. There are many trees in Bangladesh, which absorb CO₂ appreciably. It is also shown in a research that pollutants like CO₂ exhausted by a plant are useful and beneficial for the trees to grow up faster [Aba et. al. 2017]. Planting trees would be a cost-effective and eco-friendly way to bring down the pollutions due to GHG emission from the power generating station. The value of CO₂ captured by a tree in pounds can be represented by the equation (8), (9) given below [Amin et. al. 2019]. Therefore, tree plantation would be a constructive way to resolve particulates from coal burning process in power plant.

$$W = \frac{0.25 * D^2 * H * 120\% * 72.5\% * 50\% * 3.6663}{Tree_Age(year)}; \text{ (when } D < 11 \text{ inches) (8)}$$

$$W = \frac{0.15 * D^2 * H * 120\% * 72.5\% * 50\% * 3.6663}{Tree_Age(year)}; \text{ (when } D \geq 11 \text{ inches)(9)}$$

where W = Weight of the CO₂ captured by a tree per year in pounds, D = Diameter in inches and H = Tree height in feet.

4.1.3. Use of modern technologies

As a large number of power stations are operated since long term in Bangladesh, the technologies need to be changed to increase energy efficiency and to decrease GHG emission. Aged equipment causes more emission than the new one. Improper combustion of fuel is the leading factor for producing GHG emission. Air-fuel ratio must be maintained to obtain extensive combustion of fuel which increases the energy efficiency. When burning a fuel in a combustion chamber, there some heat energy out as exhaust and if the burning are not properly happened then the particulate becomes pollutant. In the case of coal based power plant, monitoring performance of optimized pulverize coal can be a fruitful strategy for augmenting energy efficiency. Additionally, lower rank coals (Brown coal) is dewatered to recover the calorific value and then pulverized for proper combustion. Thus, the energy conversion efficiency of coal will be enhanced [Huisinigh et. al. 2015]. Using modern technology, the proper combustion of the fuel can be ensured and resulting energy recovering efficiency will be improved.

Another point is that open cycle power plant should be converted into combined cycle power plant to utilize the exhaust heat which may affect the environmental sustainability. A study interconnected to the diminution of GHG emission from power plants indicates that using modern technologies to control the CO₂ emission plays a prominent role [Petrescu et. al. 2017; Bui, Mai, et. al. 2018]. Table [4] validates the efficiency data for coal, diesel and natural gas with various technologies.

Table [4]: Efficiency for fossil fuel power plant [Li, Aijun, et. al. 2018]

Fuel type	Generation Technologies	Efficiency
Coal	Subcritical	37% - 39%
	Supercritical	45%
	Ultra-supercritical	50%
	IGCC (Integrated gasification Combined Cycle)	50%
Oil	Steam turbine	37.5% - 39%
	Open cycle	30% - 39.5%
	Combined cycle	46%
Natural gas	Steam turbine	37.5%
	Open cycle	30% - 39.5%
	Combined cycle	46% - 60%

Fig. 9 shows that ultra-supercritical and IGCC technology give the higher efficiency in case of coal based power plant. In the case of combined cycle power plant, the efficiency increased up to 60% with the use of natural gas. Energy efficiency improvement plan comprises the following tools and techniques- such as, plant assessment, master plan and implementation of each phase properly. The lack of technical skill, initiatives for improving energy efficiency and ignorance of the legal policy can be major barrier for a power plant analyzed in a study[Kangas et. al. 2018].

Fig. 9: Efficiency variation for different technologies [Li, Aijun, et al]

Zhang et. al. described several methods to improve the energy efficiency of fossil fuel power plants which will be cost-effective and eco-friendly [Zhang et. al. 2015]. Recent progression of technologies (i.e. high efficiency generators & transformers, variable frequency drives, power quality checking instrumentation and switchgear equipment etc.) for monitoring, controlling

and optimizing the whole process can be an effective way to ameliorate the energy efficiency of the power plants.

4.1.4. Use of carbon capture & storage (CCS) technology

Fossil fuel power plants originate substantial amount of CO₂ emissions throughout the atmosphere which is demonstrating as the ruling cause of climate change. Among other CO₂ mitigation techniques, CCS is supposed to be a potent technology to curtail the CO₂ emissions from fuel combustion. CCS technology is used for capturing and storing carbon where exists three technological ways for capturing CO₂ from power plants: post-combustion, pre-combustion and oxy-fuel combustion [Petrescu et. al. 2019]. In this process, the coal is chemically washed, gasified and finally burned to produce steam. To remove the SO₂, the subsequent flue gas treats the steam and re-burned to make CO₂ in the flue gas parsimoniously recoverable & storable. Although CCS technology absorbs carbon contamination from the fossil fuel power plant but it reduces the overall plant efficiency. On the other hand, recent research demonstrates that, approximately 60% of the energy penalty comes from the carbon capture process itself, 30% originates from carbon compression and remaining 10% comes from electricity requirement for necessary pumps and fans [Bui, Mai, et al. 2018]. In addition, CCS technology utilizes 10% - 40% of the energy produced by a power plant [Groesbeck et. al. 2018]. To cut down the cost of carbon capturing process, different research explained the utilization of biomass or waste derived bio char for carbon capturing technology [Kolster, Clea et. al. 2017].

Bio char is produced by pyrolysis of organic wastes in the absence of oxygen. This is a cheapest mode of carbon capturing process along with proper waste management which resolves the issue of landfill burden and CO₂ emissions. In a research, it is found that bio char made of waste wood saw dust improves the air quality and increases the carbon capture and sequestration capability by reducing 8.33 times [Liu et. al. 2019]. These researches reveal that, solid biofuel reduces the cost of carbon capturing with technical, financial and environmental benefits. In addition, bio char reduces nitrate level by increasing doses made from solid bio fuels [Kua HW et. al. 2019; Maroušek J et. al. 2017]. Fig. 8 shows that the use of CCS technology spread out clean gas with reduced amount of CO₂ and other pollutants.

Fig. 8: CCS technology used in power plant

Table [3]: Emissions to atmosphere with CCS in kg/MWh [Booras et. al. 2013]

GHG Parameters	Natural gas Combined Cycle	Pulverized coal	Integrated gasification combined cycle (IGCC)
CO ₂	0.43 (-89%)	1.07 (-87%)	0.97 (-88%)
NO _x	0.11 (+22%)	0.77 (+31%)	0.1 (+11%)
SO _x	-	0.001 (-99.7%)	0.33 (+17.9%)

Table [3] shows the GHG emission to atmosphere with CCS and percentage shown in brackets indicates increased or decreased amount GHG parameters with the plant without CCS. Levelized cost of CO₂ avoided represents overall cost of using CCS among the plants with and without CCS. Mathematically it can be said as-

$$Cost_of_CO_2_avoided = \frac{LCOE_{CCS} - LCOE_{REF}}{(tCO_2 / MWh)_{REF} - tCO_2 / MWh)_{CCS}} \quad (10)$$

where $LCOE_{CCS}$, $LCOE_{REF}$ represents levelized cost of energy with CCS and without CCS respectively [Cebrecan et. al. 2014].

4.1.5. Selection of fuels

Fuel selection is important for reducing GHG emission from the fossil fuel power plants. There is a wide variation in CO₂ emission per kWh of electricity generation observed due to energy conversion efficiency, fuel selection, and plant age. However, a steady decaying in average GHG emission per MWh is perceived with the changes to low carbon fuels (i.e. natural gas) to carbon-intensive fuel (i.e. coal) [Gingerich et. al. 2018]. The difference of GHG emission from different coal can also be seen in table [5] given by European Environment Agency (EEA) in 2008 [Volker quaschning 2015].

Table [5]: Different fuels with GHG emission parameter

Pollutant	Hard coal	Brown coal	Fuel oil	Other oil	Gas
CO₂ (kg/kJ)	94,600	101,000	77,400	74,100	56,100
SO₂ (kg/kJ)	765	1,361	1,350	228	0.68
NO_x (kg/kJ)	292	183	195	129	93.3
CO (kg/kJ)	89.1	89.1	15.7	15.7	14.5
Non methane organic compounds (kg/kJ)	4.92	7.78	3.70	3.24	1.58
Particulate matter (kg/kJ)	1,203	3,254	16	1.91	0.1
Flue gas volume total (m³/GJ)	360	444	279	276	272

Almost all the power plants in Bangladesh are based on coal. Therefore, selection of fuel like clean coal would be a new concept for reducing environmental pollution and mitigating the climate change. It provides a way to enhance both efficiency & environmental acceptance in coal based power plant. Usually, clean coal technology deals with the atmospheric problems

forming from burning coal. The gaseous emission is initiated by the thermal disintegration of the coal which has adverse effect on the environment & human health. To overcome these negative impacts from coal based power generation, clean coal technologies are discovering its popularity to diminish GHG emissions to the atmosphere [C2ES 2018]. Techniques that are involved with the decline of GHG emission from coal power plants include chemically washing minerals and impurities from the coal, integrated gasification combined cycle (IGCC), use of advance technology for treating flue gases. These techniques help to eliminate pollutants to a standard level and at higher efficiency.

4.1.6. Optimization process

Conventional power plant uses up to 7% to 15% of its own electrical power to operate its electrical systems [EPRI 2011]. This power is generated by the plant, although it is not reaching the grid. Optimization process usually deals with the performance of combustion and steam processes. EBOP (Electrical Balance of Plant) is an important terms that describes how the all electrical loads are getting power. By making electrical components more efficient, the losses can be minimized for increasing efficiency [Ashiquzzaman et. al. 2019]. Mainly, different motors that drive pumps, fans, light and auxiliary systems are in a power plant. Older motors are less efficient than today's standard. The pump or fan runs at constant power despite of load requirements. The air flow or water flow is controlled with bypasses that results insignificant energy waste. It can be solved by using variable speed drives with high efficiency.

4.1.7. Waste disposal techniques

Waste (i.e. solid particles, exhaust heat) releases from the power plant affects the environment seriously. These wastes are generally mixed with the water, land or atmosphere. Wastes can be recycled or disposed properly using appropriate technologies. In Bangladesh, older power plant operates at open cycle form and produces more wastes or pollutants. Proper management of the wastes plays a noteworthy role for reducing GHG emission. Waste to energy (WTE) projects can improve the environmental health by less land filling the wastes generated from power plants [NETL 2018; Cucchiella et. al. 2017].

4.1.8. Ageing effects

Electrical asset (i.e. generators, transformers, cables, switchgear, accessories and so on) influences greatly to different environmental and operational stress factors throughout their entire service life. Thus ageing and degradation in electrical insulating materials leads to the early and unexpected failure of the assets. A research performed in a thermal power plant demonstrates that, the root cause analysis and predictive maintenance by smart monitoring techniques can help to solve the ageing problem of a power plant equipment [Nagarjun, Y., et. al. 2015]. Efficiency of the equipment (i. e Boiler, generator etc.) used in power plant can be decreased due to ageing effect. Another point is that, power plant of Bangladesh always runs on peak demand. So, maintenance of the equipment does not happen periodically. Only maintenance is done whenever equipment shuts down unexpectedly. Thus the equipment efficiency decreases. This can be minimized by regular maintenance of the equipment used in power station.

4.2. Implications of findings

Rising of GHG emission from fossil fuel power plants around the world becomes a burning issue now-a-days. This paper firstly determines the GHG emission from the fossil fuel power plants in Bangladesh and thereafter a comparative analysis is presented among various fossil fuel based power generating stations. Therefore this study offers huge implications for analysis of the GHG emission. The GHG emission corresponding to conventional power plants can be reduced remarkably by using the proposed mitigation strategies which is discussed in this work.

It is predicted by using extrapolation techniques that Bangladesh will be the prominent CO₂ emitter from fossil fuel power stations in the financial year 2024-2025. The amount of CO₂ for 1,32,520 GWh electricity generation is found 83,000 Metric ton which will be dangerous for such densely populated country. While developed countries are trying to limits fossil fuel consumption with increasing renewable energy generation, the power sector of Bangladesh is expanding the generation capacity by coal based power plant [Ashiquzzaman et. al. 2019; Zaman et. al. 2018]. Therefore, the industry professionals and environmentalists are looking towards the amount of GHG emission from the power sector.

The average CO₂ emission per kWh is assumed as 640 g [Das et. al. 2017]. However, the present work demonstrates it varies with type of fuels, the technology used and also on the ageing effects. Although, CO₂ covers the major portion of GHG emission, there are also other gases affecting environmental pollution significantly. Hence, this work identifies the amount of CO, SO₂, NO_x, unburned hydrocarbon and other particulate matters produced from fossil fuel power plants as shown in Table [1]. Addition to this, the relative error for different fossil fuel based GHG emission is explained in Table [2]. This error rate indicates that the real value differs from theoretical value due to having its chemical composition and technology used by the power plants.

Existing coal based power plants in Bangladesh are operating on the oldest technology which is also a reason for increasing GHG emission. Different technological approaches are discussed in this paper to highlight the issues of energy efficiency with lowering GHG emission. Renewable resources showed better performance regarding GHG emission downing capacity [Rahman et. al. 2018; Ravindra et. al. 2019]. Thus, the authors encourage to promote renewable based power generation which notably reduces GHG emission and energy cost. Addition to these, proper waste management can be performed using biomass based power & heat generation by keeping environment neat and clean [Song et. al. 2018].

Tree plantation around the power plants could be an imperative way to cut the GHG emission as it absorbs CO₂ considerably. However, the absorption rate depends on the size and height of the trees. Therefore, it is suggested to planting trees around the plants which are growing faster. Another important techniques discussed in this paper is CCS technology which is very much expensive and consumes energy from the power station itself. Consequently, authors' of this paper recommend for using bio char instead of CCS technology. Bio char is made of waste wood which improves the air quality and reduces environmental pollution by capturing carbon [Liu et. al. 2019].

Besides these, older power plants having apparatus with ageing effect leads to GHG emission. It is also encouraged by the authors to take steps regarding periodic and regular maintenance of the power plants apparatus.

As the study suggested several GHG mitigating procedures to overcome the environmental pollution during electricity generation by burning fossil fuels, it will surely help to build sustainable infrastructure in Bangladesh as well as in the world.

5. Conclusions

Higher GHG emission caused by conventional power station has a detrimental impact on the environment and human health leading to hinder in sustainable development. This research forecasts that Bangladesh will be placed one of the most CO₂ emitting countries in the financial year of 2024-25 with 83,000 Metric tons of CO₂ for 1,32,520 GWh electricity generation. Increasing electricity demand in Bangladesh leads to establish more conventional fossil fuel power stations which is a key reason for proliferating GHG emission. This work demonstrates that coal, diesel, and natural gas-based power station emits 0.90 kg, 0.76 kg, and 0.566 kg of CO₂ per kWh, respectively. Besides, other GHG gases such as CO, SO₂, NO_x, unburned hydrocarbons, and other particulate matters are determined for per kWh electricity generation in Bangladesh. This measurement will give a clear understanding of the CO₂ emission rate from three major fossil fuels used in Bangladesh for power generation. It is observed that the amount of GHG emission varies according to fuel composition, combustion techniques and the technology used in power generation.

Several mitigation procedures are presented to conclude that GHG emission can be significantly reduced by considering renewable resources, tree plantation, increasing energy efficiency, carbon capture & storage technology, use of clean coal, use of bio char made of solid waste, optimization process and consideration of aging effect. Although CCS technology is very effective for carbon capture, the technology consumes energy and increases cost that provokes to choose an alternative way of CO₂ emission reduction. Moreover, the authors suggest available renewable resources would be a potential solution that offers a significant reduction of GHG emissions effectively.

Although this research represents the case of Bangladesh, analysis for fossil fuel power stations and corresponding GHG emissions around the world can be a reliable option for future research directions. It is also recommended that the technological advancement in renewable energy integration into the grid and optimization process lead to low GHG emission rate during electricity generation. Mitigation strategies presented in the paper can be easily executed by the power sector with the financial & technological support from the Government of Bangladesh, global partners, and developed countries.

Conflict of Interest

Author declares there is no conflict of interest regarding publication of the paper.

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