A Modeled Carbon Emission Analysis Of Rampal Power Plant In Bangladesh And A Review Of Carbon Reduction Technologies

Gour Chand Mazumder, Md. Habibur Rahman, Saiful Huque, Nasif Shams

Abstract: today's most important concern of Bangladesh is power generation. Government has planned a 1320 MW coal-fired power station at Rampal near Sundarbans. Environmentalists have indicated that this plant will face environmental issues. So we tried finding the capability of Sundarbans to face carbon emissions. We figured out approximate carbon emission of that power plant using an arbitrary operational model. We found 3.16MKg of carbon emission daily. We used mangrove's carbon sequestration rate to calculate the carbon tolerance level of Sundarbans and found approximately 4.2 MKg of carbon per day. The amount of emission we found here is marginal with the ability of Sundarbans as it is already contributing to sequester carbon from other sources. We studied and showed technology wise carbon reductions. It is possible to reduce 90% to 95% carbon emission by using these technologies. We recommend these advanced technologies to ensure sundarbans' environmental safety.

Index Terms: Rampal power plant, Sundarbans, Carbon-emission, Green- house-gas, Sequestration, reduction, Carbon-Capture.

1 Introduction

Coal plants are one of the top sources of carbon dioxide (CO_2) emissions and the primary cause of global warming. Coal burning is one of the main causes of creating smog, acid rain, and toxic air pollution. Despite of these facts the Bangladesh Government planned for a 1320 megawatt coal-fired power station at Rampal Upazila of Bagerhat District in Khulna [18]. This work is proposed as a joint partnership between India's state-owned National Thermal Power Corporation and Bangladesh Power Development Board. The joint venture company is known as Bangladesh India Friendship Power Company (BIFPC) [18].The proposed project, on an area of over 1834 acres of land, is situated 14 kilometers north from the edge of the world's largest mangrove forest 'Sundarbans' which is a UNESCO world heritage site [22].Coal fired Rampal power plant planning is considered to be one of the most controversial decisions as this project has environmental issues. The crucial discussion about environmental security of Sundarbans is not satisfied yet. Regarding this we tried to find out the natural capability of Sundarbans to face environmental changes which will be implied by this plant. We tried to figure out the approximate carbon emission by that power plant and calculated the tolerance level of Sundarbans by itself. Beside this we discussed about technologies which may actually secure Sundarbans from being destroyed.

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2 Methodology

We used very simple method of calculation [3] to find out the carbon emission. We assumed an operational model for that power plant. We selected the best quality coal to use as the primary fuel. On the basis of these two parameters we calculated CO_2 emission. From this data we calculated further to know the amount of carbon. We used mangroves carbon sequestration rate per area of land mass [13] and the area of Sundarbans to find out Sundarbans natural capability of sequestration. We reviewed and described technologies in brief here. These can reduce carbon and GHG emissions. We also showed how much can be reduce by these particular technologies.

Table 1: Modelled Generation Profile

Time	T	L	G=L×C	O=G×T× 000
6:00AM to 10:00AM	4	20%	264	1056000
10:00AM to 02:00PM	4	80%	1056	4224000
02:00PM to 03:00PM	1	30%	396	396000
03:00PM to 6.00PM	3	80%	1056	3168000
6:00PM to 10:00 PM	4	40%	528	2112000
10:00PM to 12:00AM	2	20%	264	528000
12:00AM to 6:00AM	6	10%	132	792000
Total	24			**12276000**

2.1 Plant's Operational Model

Generally no power plant runs at their full generation capacity. Carbon emission depends on the amount of load the generation system is serving [3]. To simplify our calculation we took an arbitrary generation profile for a typical day (Table 1). This includes interval of time period, hours of operation (t) and percentage of load over full generation capacity (L). Generation in MW (G) and output in KWh (O) is then calculated. This is so simple that anyone can change the parameters and can calculate on different operational conditions. Here, Plants full capacity (C) is 1320MW. Figure 1 shows the generation graphs which picturizes required generation with time intervals.

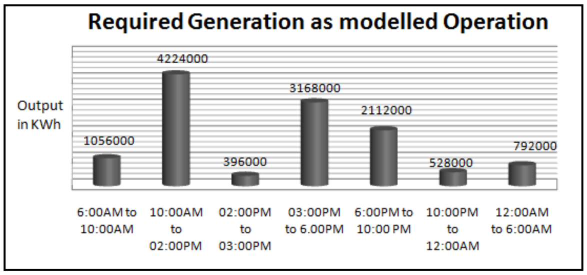

Figure 1: *Generation profile segmented by time period*

2.2 Coal Selection

Emissions also depend on coal quality[5]. There are several types of coal available in the international markets. These are popularly used in coal fired power plants [7].Categories of coal and their properties are given below (Table 2). One of the important properties of coal is emission factor. Carbon di oxide emission factor is defined as the amount of carbon di oxide produced by burning a specific fuel to generate one BTU. Carbon emission also depends on the quality of generator or alternator. Heat rate of a generator is an indicator of the quality of that generator. The heat rate is the amount of heat which is consumed by an electrical generator or power plant for producing one kilowatt-hour (kWh) of electricity [1]Low heat rate indicates a good quality of a generation system. We selected the type of coal which emits the least amount of CO_2. We can calculate the amount of carbon dioxide (CO_2) produced per kilo-watt-hour (kWh) for a specific fuel and a specific type of generators by multiplying the CO_2 emissions factor (in pounds of CO_2 per million Btu) of coal by the heat rate of a generator (in Btu per kWh), and dividing the result by 1,000,000.The amount will be in CO_2/kW-h [8]. We denoted CO_2 emissions factor as CF, Heat Rate as HR and Emission of CO_2 per kWh as Eco(Table 2).Considering heat rate and carbon emission ratio bituminous can be an environmentally efficient choice as the primary fuel. We carried out our rest of the calculation assuming bituminous coal as primary fuel.

Table 2: *Properties of coal*

Fuel	C_F	(H_R)	$E_{co}=(C_F \times H_R)/1000000$ In Lbs
Bituminous	205.3	10,107	2.08
Sub-bituminous	212.7	10,107	2.16
Lignite	215.4	10,107	2.18

2.3. Emission Calculation

We calculated carbon emission in two steps. At first we calculated CO_2 emission by multiplying O (Table 1) and Eco (Table 2) together. From this amount of carbon di oxide we calculated the amount of carbon embedded in it.

2.3.1. CO_2 Emission

Multiplying O and E_{CO} gives the amount of carbon-di-oxide in pound (Table3, column 4). We converted it to million Kg multiplying it further with 0.453592 and dividing the whole by 1000000 (Table 3, column 5). Where, 1 pound is equal to 0.453592 Kg.

Table 3: *CO_2 emission from modelled Operation*

Time	O	E_{CO}	O × E_{CO}	$\{(O \times E_{CO}) \times 0.453592\} \div 1000000$
6:00AM to 10:00AM	1056000	2.08	2196480	1.0
10:00AM to 02:00PM	4224000	2.08	8785920	4.0
02:00PM to 03:00PM	396000	2.08	823680	0.4
03:00PM to 6.00PM	3168000	2.08	6589440	3.0
6:00PM to 10:00 PM	2112000	2.08	4392960	2.0
10:00PM to 12:00AM	528000	2.08	1098240	0.5
12:00AM to 6:00AM	792000	2.08	1647360	0.7
Total	**12276000**		**25534080**	**11.6**

Figure 2 illustrates carbon emission by that plant according to the modelled generation profile per day with respect to the time interval. The operation considers fixed assumed load for a profiled time period.

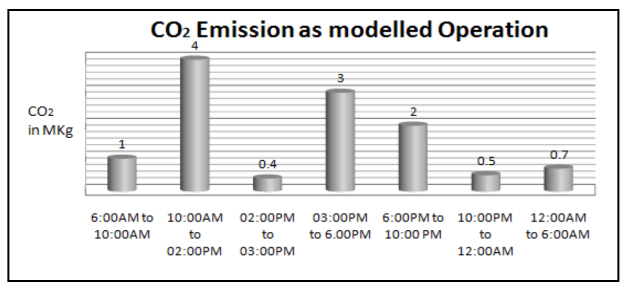

Figure 2: *Plant Emission by time interval*

2.3.2. Carbon Emission

Now we need to know the amount of carbon (The Mole & Molar Mass, www.chemteam.info, Molecular weight of Carbon, www.convertunits.com) in 11.6 MKg of CO_2.

44 gm of CO_2 = 1 mole

1000 gm of CO_2 = $\frac{1000}{44}$ = 22.7 moles of C.

1 Mole of C= 12 gm of C

22.7 moles of C =22.7×12 = 272.4 gm of C

1kg of CO_2 contains 272.4 gm of C = 0.2724 Kg of C

11.6 Kg of CO_2 contains =11.6V×0.2724 = 3.15948 kg of C

[Molar mass of CO_2 = 44 gm/mole, gram molar mass of C = 12. [21] So 11.6 Million Kg of CO_2 contains 3.16 Million Kg of Carbon. As of our approximate generation profile we found that RAMPAL power plant will produce near about 3.16 million Kg Carbon for every 24 hours of operation. Now we need to find the amount of carbon Sundarbans can sequestrate.

2.4. Carbon Sequestration

Sometimes sequestration is understood as absorption. Actually there are some differences between absorption and sequestration. Sequestration is not only absorbing the carbon but sending it to the soil through ecological systems (Janzen H.H, 2004).Carbon sequestration involves long-term storage of carbon dioxide or other forms of carbon aiming to reduce greenhouse effect[6]and avoid dangerous climate change. Figure 1 shows carbon cycle where up arrows indicate release of carbon and down arrows for take up. Length of arrow signifies the proportional amount of carbon released or taken in.

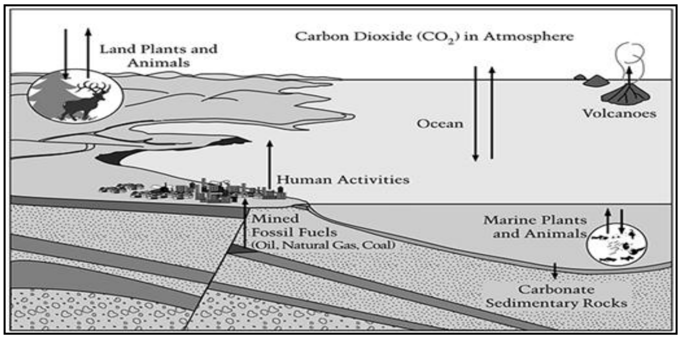

Figure3: *Carbon Cycle*

Source: www.learningpod.com

2.4.1. Approximate Sequestration Capability of Sundarbans

Mangrove forest and land area sequestrates more carbon other than any type of forest kind [20]. Mangrove traps fine sediment, organic matter and coarse sediment driven by waves of tide and storm. These materials make special mangrove sediment together. Beside this sedimentation rate is higher in mangroves. Litter forms very quickly, which provides more carbon sequestration ability inside sediments [16]. Below ground carbon attaching ability is indicated by these properties. Some parameters as like as area in km2, NPP, organic carbon expel were approximated by researchers to measure Global Carbon Mangrove Budget. The global storage of carbon (C) in mangrove biomass is approximately 4.03 Pg C. Wood production average rate is 12.08 Mg ha–1yr–1, which is nearly of 0.16 Pg C/yr stored in mangrove biomass at a global scale [23].Mangroves sequester approximately 25.5 million tons of carbon each year. In other unit Mangroves can sequester nearly 1.5 metric tons/hectare/yr of carbon or 3.7 lbs/acre/day of carbon (1336 lbs/acre/yr.[13] The amount of carbon Sundarbans would be able to sequestrate per day can be calculated easily if we know the land mass area of Sundarbans. The total area of Sundarbans is 10,000 km2. About 60% of the land mass lies in Bangladesh and the rest are in India. The land area, including exposed sandbars, occupies 414,259 ha (70%) with water bodies covering 187,413 ha (30%) [19]We have calculate and showed the result (Table 4). Here 'A' is the area of Sundarbans in acre and Sq is carbon sequestration rate in Kg.

Table 4: *Approximate carbon Sequestration by Sundarbans Per day*

AT	Area in Acre (A)	SQR	S_q	S_q× A	(S_q×A)/1000000
10,000	2471050	3.7	1.7	4200785	4.2

So far we can conclude roughly (Table 4) that if we supply 4.2 million Kg of carbon daily, Sundarbans can sequester this easily.

2.5. Review of Carbon and GHG Reduction Technologies

Establishing a state of art technology involves higher cost. We must setup equipment which will filter the exhaust/flue gas to the tolerable level before being fed to the chimney [12]. Figure 4 shows some pollutant control equipment used for the treatment of exhaust gas from a coal fired power plant. How much improvement can be achieved through these methods is given below (Table 5). Importantly these are very costly equipment to be established as well as for maintenance [24].

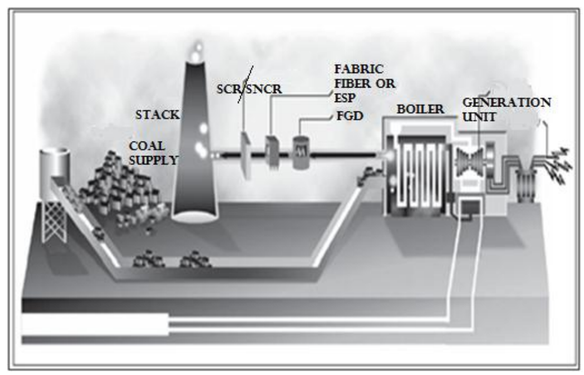

Figure 4: *Plant using Pollution control Unit*

Source: GAO analysis of information from Electric Power Research Institute and Tennessee Valley Authority

2.5.1 Efficiency Improvement for Low Emission

If it is unavoidable that we have to establish a coal fired power plant in RAMPAL then we should build a very efficient one. An efficient power plant needs lesser amount of coal, emits low carbon, and has low variable costs. Energy Audits, efficiency improvement analysis and implementation at power plants are significant and economic for carbon dioxide (CO_2) and GHG emission reductions. Actually the efficiency of a power plant is meant to be monitored and examined periodically. Faults and glitches are to be rectified on a regular basis [24]. These activities are very important to improve further and maintaining the same efficiency level. An increase of 1% efficiency can result 2.7% reduction of CO_2 emission in an as usual type of pulverized coal–fired plant [12]. As this plant has severe environmental issue we have to make sure that we are running efficiently. Sometimes the term efficiency is described as heat rate. Improvements in heat rate reflect the improvement of efficiency [24]. Table 5 lists the improvement options of heat rate. It also shows how far we can reduce carbon emission by improving different sections and parts of a coal fired power plant.

TABLE 5: *SUMMARY OF GHG CONTROL EQUIPMENT AND USEFULNESS*

Targeted Pollutants	Control Equipments	Working Principal	Percentage of Removal
Particulate Matter	ESP(Electrostatic Precipitators)	Electrical induction is used to charge the particles. Charged particles are then collected attracting toward different electrode.	99.0 to 99.5%
Particulate Matter	Fabric Filter(Commonly referred to as a ('Baghouse')	A filter made of fabric is used. Flue gas is guided to flow through this.	99.9%
SO_2	FGD(Flue Gas Desulphurization) unit (Commonly referred to as a 'Scrubber')	In Wet FGDs a liquid sorbent like $CaCO_3$ is sprayed or injected into the flue gas. This absorbs SO_2 and forms a damp solid which can be disposed and dried afterward.	80-99%
		In Dry FGDs a dry sorbent is placed, such as lime into the flue gas. This forms a solid by-product which can be separated easily	70-95%
NO_X	Combustion control technologies such as low-NOX burners	Control unit for coal combustion are tuned to minimize lesser NO_X emission	40-45%
NO_x	Post combustion controls, Such as SCR(Selective Catalytic Reduction) and SNCR (Selective Non Catalytic Reduction)units	In SCRs ammonia is administered into flue gas. Nitrogen and water is then formed. A catalyst is used to accelerate the reaction.	70-95%
		SCNRS use ammonia as well, but without the presence of any catalyst	30-75%

From figure 5 we can see and make a summery on the advantages and contributions of the technologies discussed above. Black bars indicate the least amount of removal efficiency and white bars indicates the maximum.

2.5.2 COAL GRADE

The extent of heat rate improvement largely depends on the coal type. Heat recovered from flue gas is used to dry coal. Coal drying equipment which uses or enables recovered heat to dry coal is popular and desirable [15]. Many other improvement options (Table 6) are being practiced also. Improving efficiency of boiler combustion, turbine cycle and by reducing power usage of auxiliaries is most common. Other than these options heat rate improvements also depend on many site-specific factors. Minimizing losses from those facts result improved efficiency [9]. About 50% coal of the world coal reserve is low quality coal. In these coal moisture content is pretty much high. As a result these are low ranked and less costly. Usage of this type of coal is increasing in coal fire power plant industries [15]. Burning this low grade coal consumes more energy. During the time of burning the coal to heat boiler more than 7% of heat input is used to separate the water molecule from coal by evaporating and superheating the moisture. This is because of the latent heat of evaporation for water is high [10]. The water content exhausts with flue gas. This is why moist coals have low heating value.

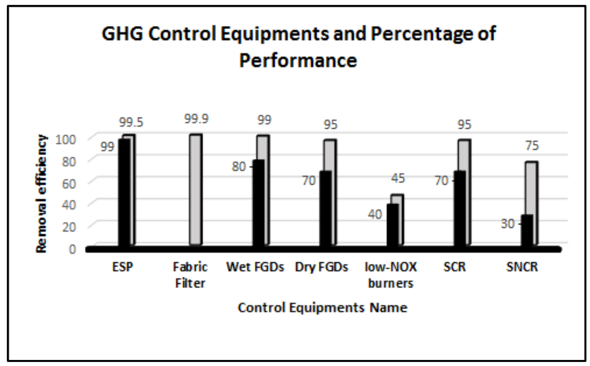

Figure 5: *Performance of technology wise reductions*

Beside these, use of moist coal results higher fuel consumption. Flue gas flow rate becomes high because of vapour. Auxiliary power use, overall heat rate, mill, coal pipe, and burner maintenance becomes higher in comparison to bituminous coal. So we should not use any low rank coal for this power plant. On the other hand, thermal drying of coal increases boiler as well as plant efficiency. Plant operation, economics and above all it reduces CO_2 emissions [10].

TABLE 6: *TECHNOLOGY WISE OPTIONS FOR EFFICIENCY IMPROVEMENT*

Improvement Option	Heat Rate Improvement (%)	Comment
Reducing moisture from coal	0.6 to 5.9	Largely Depends on coal type and heat is consumed
Recycling of Heat	1.2 to 3.6	Heat is recovered from exhaust or flue gas
Upgrading steam turbine Loop	2 to 4.5	Well established
Heat rejection system upgradation	0.5 to 3	Load Specific
Upgrading boiler auxiliaries	0.2 to 1	In situ dependent
Replacing and using advanced sensors and controls	Up to 1.5	Ageing dependent
Controlling and balancing of coal flow	Up to 1	In situ dependent
Optimization of combustion	1 to 2	In situ dependent
Optimization of air blowing	1 to 2	In situ dependent

Despite of many advantages of thermal drying of coal there are some issues about this technology. This involves complex mechanical process or primary energy or steam to dry the coal [10] which increases fuel processing cost. Increased cost is not an attractive option for any industry. So we have to use high grade coal to minimize the heat loss as well as the fuel processing cost.

2.5.3 ADVANCED COAL-FIRED POWER PLANT

Fluidized Bed Combustion: FBC or Fluidized Bed Combustion is very useful method for burning coal. Many combustible materials including general waste, biomass and coal can be burnt by FBC. FBC systems reduces SOx and NOx approximately 90% and hence reduces GHG emission which is good for environment [2] The reactor used by FBC is actually a bed where coals are burnt. Gas is fed to that bed which facilitates a turbulence in fuel[4]. FBC has improvised combustion, good heat transfer and waste products can be recovered. FBC can be operated at lower temperature than other conventional pulverized coal combustion system (PCC). At earlier days poor quality coal wastes were not utilized but flexibility of FBC systems enables this feature to use abandoned coal waste[4].

Pulverized coal combustion systems: Coal fired power plant uses many technologies of different efficiency levels to produce or generate electricity. Pulverizing the coal before burning is also a way of such kind. There, coal is first grinded into powder and then combusted. It is estimated that about 97% of coal-fired power plants use pulverizing technique [2]. The overall average net efficiency is about 35%. This type of plant can have generation capacity up to 1000MW.This technology is available and popular around the world.

Supercritical &Ultra supercritical Technology: Supercritical and Ultra supercritical plants need high temperature and pressure to operate. They have higher efficiencies than general coal fired power plants. Supercritical and Ultra supercritical plants also emit less CO_2, NOx and SOx in significant amount [14]. Supercritical steam cycle technology has been developed to commercial level and now days it is proffered in many countries for establishing new coal fired power plant. Extensive research and development work is going on to increase efficiency level of Ultra supercritical power plants. It is expected to pull up to 50% [2]. Denmark, Germany and Japan have already established some Ultra super critical power plant for higher efficiencies, low fuel costs and are emitting less GHG.

Integrated Gasification Combined Cycle (IGCC): Gasification technology can add further efficiency improvements to a normal pulverized coal-fired power plant. A gasifier is used to make syngas from coal or other type of carbon based materials. Syngas is then used to run a gas turbine [11]. In gasifier oxygen and steam are mixed with coal at a certain temperature and pressure for a certain time period. The result of reaction is syngas. Syngas is consisted by H2 and carbon monoxide (CO). Sulphur like impurities is then filtered. Normally gas turbines waste significant amount of heat. This waste heat is recovered in IGCC. Recovered heat is used to produce steam to drive a steam turbine. Thus IGCC produces more electricity. In addition CO_2 can be formed by a shift reaction combining hydrogen and CO. Afterward CO_2 can be captured and stored. Despite of these advantages some challenges are also there in IGCC deploying and commercializing. This system is more expensive [11] than super critical and ultra super critical technologies.

2.6 CARBON CAPTURE AND STORAGE SYSTEM

Carbon Capture and Storage (CCS) is a very efficient technology. It can capture up to 90% of the carbon dioxide (CO_2) emissions produced from any process. This prevents the carbon dioxide from entering into the environment [25]. The use of CCS with renewable biomass is one of the few carbon abatement technologies. This may evolve in 'carbon-negative' mode which means to take carbon dioxide out of the atmosphere. The CCS chain has three distinguished steps; capturing, transporting and storing securely. Generally the storage is done in depleted oil or gas fields and deep saline aquifer, see figure 6 and figure 7 [26]. Carbon capturing technologies allow the separation of carbon dioxide from gases produced in electricity generation and other industrial processes. There are three methods for doing this. Pre-combustion capture, post-combustion capture and oxy-fuel combustion are used to capture carbon. Carbon dioxide is then transported by pipeline or by ship to store securely for a long time, showed in figure 6. Now days Millionsof tons of carbon dioxide are being transported for commercial purposes by road tanker, ship and pipelines.

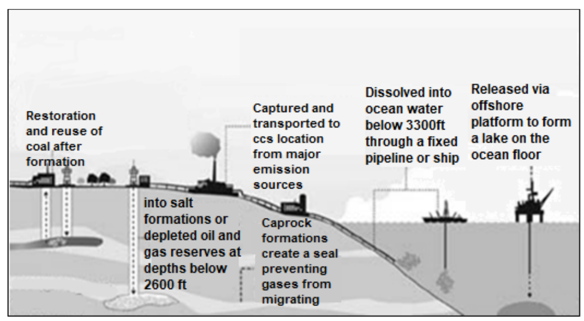

Figure 6: *Carbon Capture*

Source: *Intergovernmental Panel on climate change AP The carbon dioxide is then stored in carefully selected geological rock formations that are typically located several kilometres below the earth's surface, see figure 7 [25]. At every point in the CCS chain, from production to storage, the process technologies are free from health risk also.*

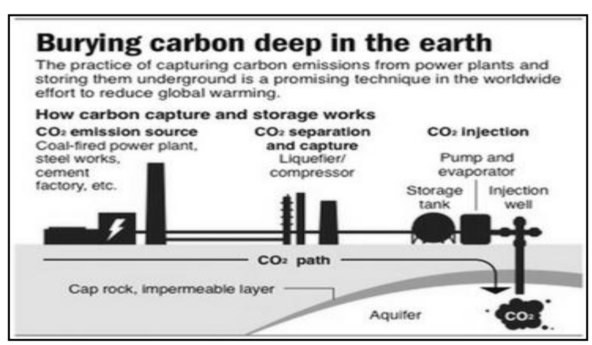

Figure 7: *Burying Carbon*

***Source:** Intergovernmental Panel on climate change AP The commercial deployment of CCS will involve the widespread adoption of these CCS techniques, combined with robust monitoring techniques and Government regulation [17] From above discussions of plant technologies we can summarize technology wise advantages in below table (Table 7).*

***TABLE 7:** TECHNOLOGY WISE ADVANTAGES*

Name	Advantages
Fluidized Bed Combustion:	Reducing SOx and NOx emissions by 90%.
Pulverized coal combustion systems:	An efficiency level of 45% can be reached
Supercritical &Ultra supercritical Technology:	Efficiencies, potentially up to around 50%.
Integrated Gasification Combined Cycle (IGCC):	Syngas is used and residue gases can be used in other process
Carbon Capture and Storage System	can capture up to 90% of the carbon dioxide (CO_2) and no health issue

3 RESULTS
So far we have discussed and calculated we have found a handful data. First of all we were to find the approximate carbon-di-oxide and carbon emission by an arbitrary operational portfolio. From this we have got some of 11.6 million Kg of CO_2 which will be emitted per day where 3.16 million Kg of Carbon is equivalent to this amount of carbon-di-oxide. After that we have found approximate carbon sequestration ability of Sundarbans which is 4.2 million Kg per day. This is very marginal for acceptance. To ensure environmental safety we need to consider and rely on mitigation technologies. We have mentioned and discussed some advanced technologies. From these we have got carbon and GHG reduction possibility ranges from 70% to 99% by different type of technologies. Some advanced power plant technologies can earn about 40% to 50% overall efficiency to reduce carbon as well as GHG emission. Carbon capture system can clean and capture about 90% carbon di oxide from exhaust or flue gas. CCS is expensive but can be chosen for the sake of Sundarbans. More over the area of the plant has geographical advantages to have CCS.

4 CONCLUSION
In fact Sundarbans supports and holds wide range of variety of life and nature. We cannot leave any Environment issues untreated to alter its ecosystem. It is true that we need power and power plants will accelerate our economy. If we have to establish a coal based power generation unit over there then we must contemplate on it to make sure that it is safe. Also we have to have a clear knowledge of how much safe we are. In this write-up we tried to find the approximate amount of carbon emission for a day on the basis of an arbitrary generation profile. We discussed about advanced technologies which are being used in many countries for environment protection. We have talked about pollution control and advanced coal firing technologies also. If we want to minimize carbon emission to zero level we may choose CCS technology. As the Sundarbans is near the Bay of Bengal we will get an advantage on carbon carriage. CCS can remove 90% of the carbon dioxide (CO_2) emissions produced. And if we use some pollutant control technology along with CCS we may be able to expect a clean Sundarbans as it is today. We need to know that coal transportation also pollutes environment. There are also many advanced carrying systems to protect environment. Establishing a clean power plant involves cost, however it is not invaluable as the Sundarbans. First we have to find out how much we need to spend for clean generation. Then we need to calculate whether these costs are recoverable through payback period or not. If we are able to ensure a safe coal fired power plant to its tolerance level, only then may we think of it. Otherwise it will be too dangerous for us as well as for the world's largest mangrove forest.

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