AMBIENT AIR SHED QUALITY MANAGEMENT WITH NEW COAL POWER PLANT INSTALLATION

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Environmental Engineering and Management

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ABSTRACT

Average growth rate of electricity demand over last 15 years in Sri Lanka is about 6.5 % per annum. Energy demand in the country was mainly met by hydropower up to the year 1999, and with time thermal generation has become prominent.According to generation expansion planning study – Base case (2013 – 2032), coal is expected to dominate the thermal power sector consumption (75.7 % share) for the next decades in Sri Lanka. During the planning stage of a coal power plant, proper offset provisions should be implemented in order to minimize air shed degradation by achieving relevant emission standards stipulated in regulations. Different factors that influence on ambient air quality degradation should be investigated before the power plant comes fully on stream. Since coal is not considered as a cleaner fuel, health risk is always linked with its hazardous emissions.

This assessment was carried out in order to investigate the impacts from three criteria pollutants, (SO_2, NO_x and PM) emitted from proposed 1200MW coal power plant in Sampoor. Three different scenarios were considered for the development of proposed power plant and four case studies to investigate different conditions under each scenario. Air Dispersion Modeling (AERMOD) was used to predict the ground level concentration within 20 km radius of the emission source. The results from the modeling assessment were used to identify the exposure assessment and then acute health risk impact was identified through dose response measures.

The study shows that high efficient coal power plant can be satisfactorily employed in a place where degraded air quality is already prevailed and also when considering ground level ambient air quality concentrations, it is more favorable to install the coal power plants with less number of units having higher capacity. The results show that non carcinogenic human health impact was not identified from the population cluster locations in the vicinity to the power plant. Based on the assessment most preferred option for development of the proposed power plant with required mitigation measures was identified.

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List of Abbreviations

AAQ	Ambient Air Quality
ADM	Air Dispersion Modeling
CEA	Central Environmental Authority
CEB	Ceylon Electricity Board
ESP	Electro static Precipitator
FBC	Fluidized Bed Combustion
FF	Fabric Filter
FGD	Flue Gas Desulphuration
GDP	Gross Domestic Product
GLC	Ground Level Concentration
HAPs	Hazardous Air Pollutants
HQ	Hazard Quotient
NH_3	Ammonia
NO_x	Nitrogen Oxides
NOAEL	No Observed Adverse effect Level
PC	Pulverized Coal
PM	Particulate Matter
PP	Powr Plant
REL	Reference Exposure Level
SC	Super Critical
SCR	Selective Catalytic Reduction
SNCR	Selective Non catalytic Reduction
SO_2	Sulphur Dioxide
TPCL	Trincomalee Power Company Limited
US EPA	United States Environmental Protection Agency

CHAPTER 01: INTRODUCTION

1.1 Background

An adequate and regular power supply is a crucial factor which supports economic growth. An energy secure nation is a sign of stability and an important indicator for development forecasting. Figure 1.1 below shows the growth rates of electricity demand and GDP from 1993 to 2012. Diverse, secure, affordable and environmentally acceptable supplies of energy are essential to sustainable development of society. Sustainable development - meeting the needs of the present generation without undermining the capacity of future generations to meet their needs - demands a balance between social, economic and environmental considerations. The current challenge is to respond effectively to produce energy with minimum environmental impact while continuing to meet the rapidly increasing energy demands of developing economy.

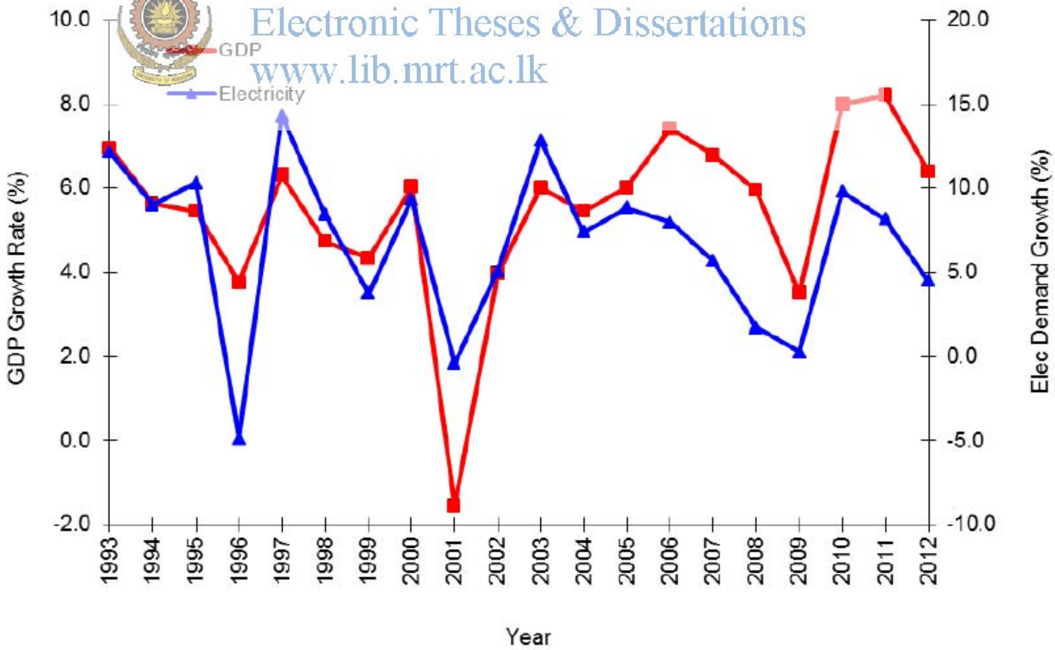


Figure 1.1 Growth rates of GDP and electricity demand (CEB, 2013)

Energy demand in Sri Lanka was mainly met by hydropower up to the year 1999 (CEB, 2013), which meant that the electricity supply was then depended drastically on rainfall. However with time thermal generation has become prominent and today the thermal generation share is much higher than that of hydro. The Figure 1.2 depicts the share of hydro and thermal generation to the overall generation.

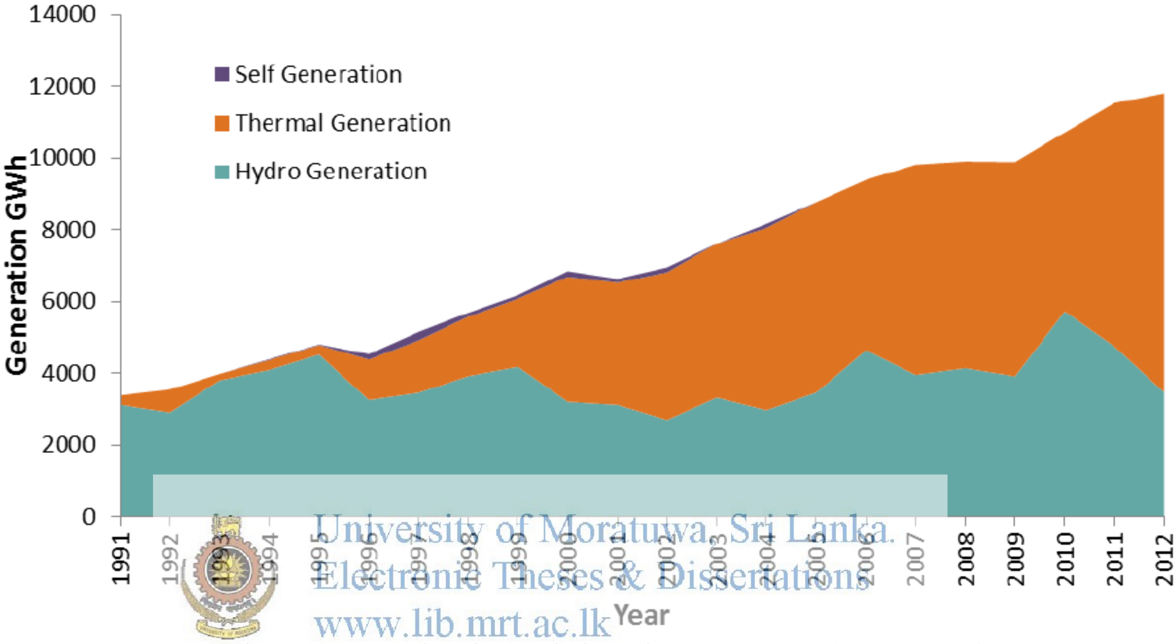


Figure 1.2. Hydro thermal share in recent pass (CEB, 2013)

Average growth rate of electricity demand over last 15 years in Sri Lanka is about 6.5 % per annum (CEB, 2013). Thus, Ceylon Electricity Board of Sri Lanka has studied the feasibility of adding economically optimum new generation plants for the existing system. According to generation expansion planning study – Base case (2013 – 2032), coal is expected to dominate the thermal power sector consumption (75.7 % share) for the next decades in Sri Lanka. Table 1.1 shows the generation planning study proposed by the CEB in 2012. After the implementation of TPCL coal power plant in 2018, 1200 MW coal PP has been proposed by the CEB. The major reason for the dominance of coal power is the cost effectiveness of fuel than other alternative fuels. Hence, coal-fired thermal power plants are expected to play an important role in the supply of future electricity demand of Sri Lanka.

Table 1.1 Generation Expansion Planning Study – Base Case 2013 - 2032

YEAR	RENEWABLE ADDITIONS	THERMAL ADDITIONS	THERMAL RETIREMENTS	LOLP %
2013	-	-	-	1.155
2014	-	*4x5 MW Northern Power** *3x8 MW Chunnakum Extension** *1x300 MW Puttalam Coal (Stage II)*	-	0.819
2015	-	*1x300 MW Puttalam Coal (Stage II)* **1x75 MW Gas Turbine** **1x105 MW Gas Turbine**	6x16.6 MW HeladanaviPuttalam 14x7.11 MW ACE Power Embilipitiya 4x15 MW Colombo Power	1.103
2016	*35 MW Broadlands* *120 MW Uma Oya*	-	-	0.854
2017	-	**1x105 MW Gas Turbine**	-	1.320
2018	**27 MW Moragolla Plant**	**3x250 MW Trincomalee Coal Power plant**	4x5 MW ACE Power Matara 4x5 MW ACE Power Horana 4x5.63 MW Lakdanavi 4x5 MW Northern Power 8x6.13 MW Asia Power	0.133
2019	-	**1x250 MW Trincomalee Coal Power plant**	5x17 MW Kelanitissa Gas Turbines 4x18 MW Sapugaskanda diesel	0.183
2020	-	**1x300 MW Coal plant**	-	0.106
2021	-	**1x300 MW Coal plant**	-	0.067
2022	-	**1x300 MW Coal plant**	-	0.048
2023	-	**1x300 MW Coal plant**	163 MW AES Kelanitissa Combined Cycle Plant 115 MW Gas Turbine 4x9 MW Sapugaskanda Diesel Ext.	0.134
2024	-	**1x300 MW Coal plant**	-	0.102
2025	-	**1x300 MW Coal plant**	4x9 MW Sapugaskanda Diesel Ext.	0.099
2026	-		-	0.346
2027	-	**1x300 MW Coal plant**	-	0.310
2028	-	-	-	0.804
2029	**49 MW Gin Ganga**	**1x300 MW Coal plant**	-	0.633
2030	-	**1x300 MW Coal plant**	-	0.654
2031	-	**1x300 MW Coal plant**	-	0.697
2032	-	**1x75 MW Gas Turbine**	-	1.469
Total PV Cost up to year 2032, US$ **13,740.02 million** [LKR 1,564,983.12 million]				

Coal fired power plants are major source of emissions for several criteria air pollutants. These emissions include both fuel based pollutants - Sulphur dioxide, Particulate matter (where hazardous air pollutants such as arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, radium, selenium and other metals are integral components of fine particulate matter), Hydrogen Chloride, Hydrogen Fluoride and Mercury – that are direct result of contaminants in the coal that is combusted; as well as 'combustion based pollutants' – Nitrogen oxides, dioxins and formaldehyde which are formed during burning of the coal. (EH & E, 2011). Depending on the source of coal the pollutant profiles could change.

Various air pollutants released from coal fired power plants influence environmental quality and health on local, regional and global scales. When emitted into the atmosphere SO_2 and NO_x react with water and other compounds and these pollutants can remain in the air for days or even years. Prevailing winds can transport them hundreds of miles, often across state and national borders.

Health risk of human in the vicinity of coal power plant is a crucial problem. Coal combustion emit particles directly into the air, but their major contribution to particulate matter air pollution is emissions of SO_2 and NO_x which are converted into Sulphate and Nitrate particles in the atmosphere. NO_x react with volatile organic compounds in the presence of sunlight and form Ozone in ground level, and cause respiratory illness and other health problems. Health effects associated with coal combustion include respiratory effects, Decreased lung function and symptomatic effects, cardiovascular effects, premature death, reproductive effects, Neurological effects and Mutagenic of cells.(EH & E, 2011). Exposure via inhalation is the major health risk pathway.

Due to the increasing pressure on environmental and public health impacts from coal power plants worldwide, many options have been developed to mitigate the impacts due to power plant emissions. Since coal is not considered as a clean fuel, health risk associated with the emissions is always linked.

The extent to which an air pollutant or a facility influence on social and environmental quality depends on a number of factors. The geographical location of the facility, meteorological conditions and physical and technological attributes (firing configuration, operating practices, pollution control abatement methods, stack configuration) of the facility and fuel composition are important factors of influence. These characteristics mainly determine whether impacts of a power plant related air emissions are generally local, or can extend to regional or global scale.

Sri Lanka standards for emissions from stationary sources, which is still on Draft stage and coordinated by Central Environmental Authority (CEA) of Sri Lanka stipulated standards for targeted emissions (SO_x, NO_x and PM), to be complied by thermal power plants (PP) according to the type of fuel consumed and the generation capacity. At the same time power plant has to comply the ambient air quality standards gazetted under the National Environmental (Ambient Air Quality) Regulations, 1994.

During the planning stage of a coal power plant, proper offset provisions should be implemented in order to minimize air shed degradation by achieving relevant emission standards stipulated in regulations. Suitable offset measures could include reductions in ambient air quality impacts through (a). Considering efficiency relevant options by using different technologies for the same capacity (b).By varying the capacity distribution (c).Placing proper abatement methods (d).By varying the point source configuration (Stack height) and (e).Using cleaner fuels. The performance of these different mechanisms on managing ambient air quality in the air shed has to be investigated through deploying a validated air dispersion model.

The effect of air pollution control mechanism should always be linked with associated benefits to the environment and the human health conditions. Risk assessment of exposing to criteria pollutants emitted through the stack should combine with the exposure assessment from the air dispersion model.

1.2 Research Need

Ceylon Electricity Board of Sri Lanka has selected coal as the way forward in achieving the increasing local energy demand. The CEB says that this coal dominant long term generation expansion is the least cost option for the country. Thus, CEB has identified possible sites along the Sri Lankan coastal belt for the development of coal power plants. After committing to the TPCL coal PP at Sampoor, another 1200MW coal power plant has been proposed by the CEB for implementation in the same area. Installation of such power plant has to be done without compromising the existing air shed quality. The relevant authorities have to make sure on ambient air quality degradation due to new implementation in an area where an already degraded air shed prevail or the tolerable level of degradation of an unpolluted area.

During the Environmental Impact Assessment of installing coal power plant, prediction on ambient air quality impacts is always carried out by use of an air dispersion modeling. However, it will not support the decision makers to identify the most suitable way of carrying out the project and associated health implications. Different factors that influence ambient air quality degradation should be investigated before the power plant comes fully on stream. Lack of such a study may be difficult for respective personnel to make better decisions on protecting the existing local environmental conditions and thus the human health conditions. It is felt that an EIA study period is not the best time for a study of the nature indicated above. Outputs from an earlier study will help regulatory body in better decision making by suitably framing the conditions. Both investors as well as potential developers too could benefit via a focused research study.

1.3 Research Question

This research thus focuses on the establishment of a 1200 MW coal fired power station at Sampoor on the Eastern coast of Sri Lanka.

The research is to identify the variation of ambient air shed quality with respect to technological parameters in combination with the geographical location and find the most suitable option to minimize the impact on ambient air quality for coal based power generation. The study will consider in a limited way the associated health risk due to short term exposure to the criteria pollutants considering the inhalation pathway based on acute effects.

Figure 1.3 Schematic diagram of a coal power plant

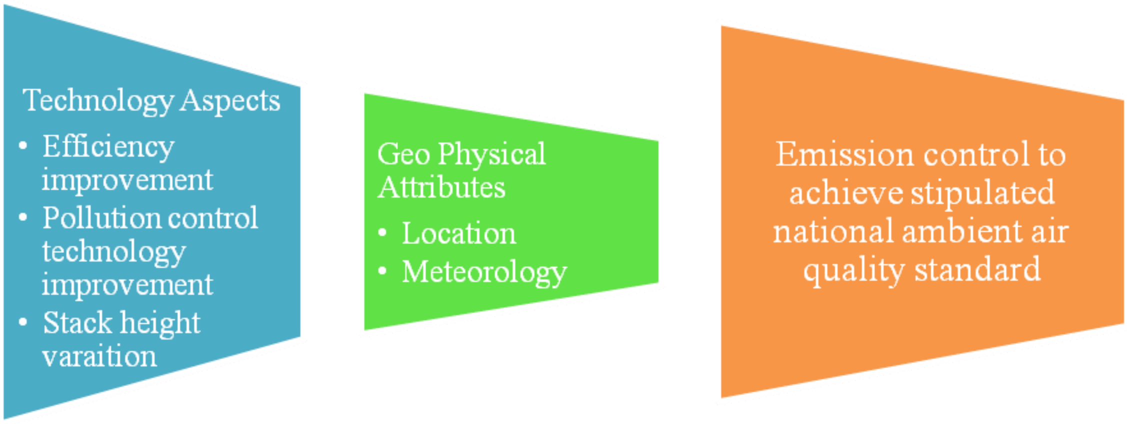


Figure 1.4 Path of identification the most appropriate way of operating coal power plant

1.4 Objectives of the study

The study aims to investigate the variation of ambient air quality level and the acute human health risk from an inhalation pathway in Sampoor where CEB has identified for installing the next coal power plant of 1200 MWe capacity with the specific objectives given below.

- Ground level ambient air quality variation by varying the capacity distribution
- Ground level ambient air quality variation by considering efficiency relevant options by using two different coal power generation technologies for the same capacity
- Sea based desulphurization method to control SO_2 pollution
- Sulphur level in coal – feedstock variation assessment
- Impact of varying stack height
- Acute inhalation health risk associated

1.5 Thesis Outline

This thesis consists of six chapters. The first chapter describes the background, research problem, justification, research question, objectives of the study, limitations of the study and outline of the report.

The second is designated as literature review. It provides relevant literature from internationally published information and research work etc.

Chapter three provides the results and analysis descriptively with the explanations for the results and improved suggestions.

Chapter four summarises the conclusions made based on the results and analysis, reference and appendices.

CHAPTER 02: LITERATURE REVIEW

2.1 Coal Combustion

Emissions from all types of fuel combustion are highly dependent on the efficiency of combustion and type of fuel. Coal is classified by type based on its stage of formation. This classification consists of five categories: Peat, Lignite, Sub-Bituminous, Bituminous and Anthracite. Younger coals such as Lignite and sub Bituminous coals are easier to burn because they contain a larger amount of volatile compounds that evolve as gases when the coal is heated. In contrast, older coals are more difficult to burn as they are made almost entirely of solid carbon.

Table 2.1 Indicative analyses of typical coal(Integrated Pollution Prevention and Control, 2006)

Property	Units (waf = water and ash free)	Lignite	Coal		
			Bituminous	Low volatile bituminous and semi anthracite	Anthracite
Moisture	(% as received)	30 – 70	2 – 20	2 – 20	2 – 20
Ash	(% as received)	5 – 40	1 – 30	1 – 30	1 – 30
Volatile Matter	(daf %)	40 – 66	> 22	8 – 22	< 8
Fixed Carbon	(daf %)	35 – 60	55 – 85	85 – 92	> 92
Total Carbon	(daf %)	60 – 80	80 – 95	90 – 95	92 – 95
Hydrogen	(daf %)	4.5 – 6.5	4.5 – 6.5	3.5 – 4.5	3 – 8
Oxygen	(daf %)	12 – 30	1.5 – 14	1.2 – 6	1.2 – 5
Sulphur	(daf %)	0.5 – 4.7	0.3 – 4.5	0.5 – 1	0.5 – 0.8
High heating value	(MJ/kg daf)	23 – 35	32 – 38.5	35 – 38	35 – 38
Low heating value	(MJ/kg raw)	6.3 – 30 – 1	26 – 32	25 – 32.3	30 – 31.4
daf = dry and ash free basis					

Table 2.2: Coal Varities and their characteristics (Sunshine)

	Anthracite Coal	Bituminous Coal	Sub Bituminous Coal	Lignite Coal
General Properties	• Hardest and most brittle coal type • When burned produces a very hot blue flame • It is considered the cleanest burning of all coal types and produces more heat and less smoke than other coals	• Bituminous coal is the most common coal. • Bituminous and sub-bituminous coal together represent more than 90 percent of all the coal consumed • When burned, bituminous coal produces a high, white flame. • Bituminous coal includes two subtypes: thermal and metallurgical. • Bituminous coal can be categorized further by the level of volatile matter it contains: high-volatile A, B, and C, medium-volatile, and low-volatile.	• Appearance varies from bright black to dull dark brown. • Its consistency ranges from hard and strong to soft and crumbly, because it is an intermediate stage of coal between bituminous and brown coal (lignite) • Sub-bituminous coal is not stable when exposed to air. It tends to disintegrate.	• the lowest quality and most crumbly coal • The balance is used to generate electricity.
Primary Usage	• space heating by residences and businesses	• Thermal coal is sometimes called steaming coal because it is used to fire power plants that produce steam for electricity and industrial uses. • Metallurgical coal is sometimes referred to as coking coal, because it is used in the process of creating coke necessary for iron and steel-making.	• widely used for generating steam power and industrial purposes	• 13.5 percent of lignite coal is gasified into synthetic natural gas and 7.5 percent goes into production of ammonia-based fertilizers. • Because of its high weight relative to its heat content, lignite is typically used in pulverized coal or cyclone-fired electric production power plants close to the mine. • Through a process called coal gasification, lignite can be broken down chemically to create synthetic natural gas that delivers more power and is easier to operate in commercial scale electric generations.
Characteristics	• Contains great deal of fixed carbon (80 – 95 %) ▪ Very low Sulphur and Nitrogen (Less than 1% each) ▪ Volatile matter is low at approximately 5%, with 10 – 20% ash possible ▪ Moisture content is roughly 5 – 15%	• Contains moisture up to about 17 percent • Its fixed carbon content can range up to about 85 percent, with ash content up to 12 percent by weight • About 0.5 to 2 percent of the weight of bituminous coal is nitrogen • Bituminous coal has slagging and agglomerating characteristics.	• Sub-Bituminous coal is non-coking and has less sulfur but more moisture (approximately 10 to 45 percent) and • Volatile matter (up to 45 percent) than bituminous coals. • Carbon content is 35-45 percent and • Ash ranges up to 10 percent • Sulfur content is generally under 2 percent by weight. • Approximately 0.5 to 2 percent of sub-bituminous coal's weight is nitrogen.	• Lignite contains the lowest level of fixed carbon (25 to 35 percent) and • highest level of moisture (typically 20 to 40 percent by weight, but can go as high as 60 to 70 percent) of all the coals. • Ash varies up to 50 percent by weight. Lignite has low levels of sulfur (less than 1 percent) and ash (approximately 4 percent), but high levels of volatile matter (32 percent and higher by weight)

	Anthracite Coal	Bituminous Coal	Sub Bituminous Coal	Lignite Coal
Heating Value	• Burns at the highest temperature of any coal (Roughly 900°C or higher). Typically Producesupto 13,000 to 15,000 BTU/pound.	• Provides approximately 10,500 to 15,000 Btu per pound as mined.	• Approximately 8,500 to 13,000 Btu per pound, as mined.	• Lignite has a heating value of approximately 4,000 to 8,300 Btu per pound.
Emissions and Pollution Controls	• Particulate matter, or fine soot, from burning anthracite can be reduced with proper furnace configurations and appropriate boiler load, under fire air practices, and fly ash reinjection. • Fabric filters, electrostatic precipitators (ESP), and scrubbers can be used to reduce particulate matter pollution from anthracite-fired boilers. • Anthracite that is pulverized before burning creates more particulate matter.	• Hazardous emissions from bituminous coal combustion include particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), trace metals such as lead (Pb) and mercury (Hg), vapor-phase hydrocarbons (such as methane, alkanes, alkenes, benzenes, etc.) and polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (known popularly as dioxins and furans). • When burned, bituminous coal can also release hazardous gases such as hydrogen chloride (HCl), hydrogen fluoride (HF), and polycyclic aromatic hydrocarbons (PAHs). • Incomplete combustion leads to higher levels of PAHs, which are carcinogenic. • Burning bituminous coal at higher temperatures reduces its carbon monoxide emissions. • Therefore, large combustion units and well-maintained ones generally have lower pollution output.	• Combustion of sub-bituminous coal can lead to hazardous emissions that include particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), and mercury (Hg). • Sub-bituminous coals produces ash that is more alkaline than other coal ash. • This characteristic can help reduce acid rain caused by coal-fired power plant emissions. • Adding sub-bituminous coal to bituminous coal introduces alkaline byproducts that are able to bind sulfur compounds released by bituminous coal and therefore reduce acid mist formation. • When sub-bituminous coal is burned at higher temperatures, its carbon monoxide emissions are reduced. As a result, small combustion units and poorly maintained ones are likely to increase pollution output. • High ash content can be a drawback	• Produces high levels of air pollution emissions.
Availability	• Scarce. A tiny percent of all remaining coal resources are anthracite. Pennsylvania anthracite was mined heavily during the late 1800s and early 1900s.	• Abundant. More than half of all available coal resources are bituminous.	• Moderate. • Approximately 30% of available coal resources in the U.S. are Sub-Bituminous. The U.S. far surpasses other countries in its quantity of sub-bituminous coal resources, with estimated reserves of approximately 300,000 million tonnes. Other countries with notable resources include Brazil, Indonesia, and the Ukraine.	• According to the World Coal Association, the top ten countries that produce brown coal are (ranked from most to least): Germany, Indonesia, Russia, Turkey, Australia, U.S.A., Greece, Poland, Czech Republic, and Servia. • In 2010, Indonesia leaped into second place with the highest growth in coal production of any country

	Anthracite Coal	Bituminous Coal	Sub Bituminous Coal	Lignite Coal
Other	• It is slow-burning and difficult to ignite because of its high density, so few pulverized coal-fired plants burn it. • Anthracite is considered "non-clinkering" and free burning, because when it is ignited it does not "coke" or expand and fuse together. • It is most often burned in underfeed stoker boilers or single-retort side-dump stoker boilers with stationary grates. • Dry-bottom furnaces are used because of anthracite's high ash fusion temperature. • Lower boiler loads tend to keep heat lower, which in turn reduces nitrogen oxide emissions.	• Bituminous coal lights on fire easily and can produce excessive smoke and soot (particulate matter) • If improperly burned. It contains high sulfur content. • Bituminous coal commonly contains the mineral pyrite, which can serve as a host for impurities such as arsenic and mercury. • Burning of bituminous coal releases trace mineral impurities into the air as pollution. • During combustion, about 95 percent of the sulfur content of bituminous coal gets oxidized and released as gaseous sulfur oxides.	• Adding sub-bituminous coal to bituminous coal introduces alkaline byproducts that are able to bind sulfur compounds released by bituminous coal and therefore reduce acid mist formation. • When sub-bituminous coal is burned at higher temperatures, its carbon monoxide emissions are reduced. As a result, small combustion units and poorly maintained ones are likely to increase pollution output. • High ash content can be a drawback	• Because of its high moisture content, lignite may be dried to reduce moisture content and increase calorific fuel value. • The drying process requires energy, but can be used to reduce volatile matter and sulfur as well.

2.2 CoalCombustion Technologies

Table 2.3 Different Coal combustion technologies

	Pulverized Coal fired boiler		Atmospheric Circulating Fluidized Bed Combustion	Pressurized Fluidized Bed Combustion	
General Characteristics	• Oldest and most commonly used technology • Can be used for boiler sizes upto and above 1000 MWe • Once designed for a specific coal, PC units are somewhat more sensitive to changes in fuel quality		• Two major categories : – Circulating FBC – Bubbling FBC • Almost all of the recent plant additions have been CFBC units. • CFBC units can tolerate a wide variety of coals and particle sizes and, because of their low operating temperatures and staged combustion, produce low levels of NO_x relative to PC boilers. • The technology is commercially viable for boiler sizes upto 100 MWth. (Designs are going for 600 MW – 800 MW)	• The main advantages of the PFBC technology are the low emissions and the high efficiency • Can be designed for wide range of fuels	• coal is gasified with either oxygen or air, and the resulting raw gas (called syngas, an abbreviation for synthetic gas) is cooled, cleaned, and fired in a gas turbine. • The hot exhaust from the gas turbine passes to a heat recovery steam generator (HRSG) where it produces steam that drives a steam turbine. • Power is producedfrom both the gas and steam turbine.
	Subcritical Pulverized coal fired boiler	Supercritical Pulverized coal fired boiler			
Operating Conditions	Live steam temperature and pressure are below critical values 374.15°C and 221.2 bar (540°C and 140 bar)	Live steam temperature and pressure are above critical values 374.15°C and 221.2 bar (540°C and 240 bar)	• Steam temperature and Pressure is about 540°C and 140 bars. • The temperature of a fluidised bed is typically 800 – 900 ºC.	Temperature of 850 °C to 900°C and a pressure of approximately 1.6 MPa	firing temperature- 1 100°C or -1260°C
Emissions and Pollution Control Technologies	• Emissions of SO_2 and NO_x become unacceptably high • Emission control methods have to be implemented before discharging into the atmosphere	The emissions of SO_x, NO_x, CO_2, and particulate matter (in termsof mg/kWh of electricity generated) will be lower. For a supercritical plant in proportion to itslower coal usage per kWh (i.e., improved heat rate).	• The increase in cyclone efficiency enhances the solid circulation rate to a large extent thus ensuring a constantly high heat transfer in the furnace. • Thus, the most favourable conditions for low NO_X and low SO_X emissions can be reached for a wide fuel range and load range. • Sulphur can be captured directly in thefurnace by limestone injection	• The efficiency is high and the environmental performance is good with low emissions of SO_x and NO_x. • Sulphur can be captured directly in the combuster by limestone or dolomite injection	• By removing the emission-forming constituents (sulfur and nitrogen species and particulates) prior to combustion in the gas turbine, IGCC plants meet extremely stringent air emissionstandards. • Sulfur emissions can be almost completely eliminated
Efficiency	Rather low efficiency – 33 to 37%	Efficiency around 40%	Efficiency ranges from 36 – 38%	Able to achieve thermal efficiencies of up to 45 %.	Plant net efficiency is typically 43-46% on an LHVbasis.

Economical Considerations	Fairly simple to operate and maintain relative to other combustion technologies	SC and USC plants have higher capital costs than conventional subcritical units because of theStricterspecifications of the steel needed to withstand the higher pressure and temperature. However, this is offset to an extent by savings in fuel costs due to the higher efficiency of the process. (Keith BURNARD and Julie JIANG, 2014)	Operation of ACFBC boiler is more complex than that of a PC boiler plant. The cost for a boiler only amounts to approximately 30% of the investment.	High investment cost	High capital cost relative to state-of-the-art PC plants

(Bhattacharya, 2011),(ESMAP - Energy Sector Management Assistance Program, 2001), (European Commission, 2006), (Karin Oskarsson, 1997), (Wikipedia, 2015)

2.3 Emissions from Coal Power Plants

Coal based electricity generation is a major contributor to atmospheric pollution which is associated with many criteria air contaminants and hazardous air pollutants. The emission from the power plant is depended on the type and size of the facility, the technology and pollution control strategies adapted and quality of fuel consumed. Emissions to air can have impacts on regional, local as well as global climate and thus the human health.

During the formation of coal, impurities from surrounding soil and sediments which contain Sulphur and heavy metals such as Mercury, Arsenic, Nickle and Lead are incorporated into it. During the combustion these metals get emanated with particulate matter.The composition of coal depends on condition over a long period during coal is formed.Depend on the quality of coal types, emission of metals incorporated into particulate matter is varying. Coal fired power plants emit 84 of the 187 HAPs identified by EPA as posing a threat to human health and the environment. The following table presents the contaminants in different coal types.(EH & E, 2011)

Table 2.4 Characteristics of Major Coal Types used to generate Electricity

Characteristic	Anthracite	Bituminous	Sub-Bituminous	Lignite
Principal Characteristics				
Percentage of U.S. Production	Less than 0.1%	46.9%	46.3%	6.9%
Heating Value (BTU/lb)	15	11 - 15	8 - 13	4 – 8
Sulphur (%)	Less than 1%	3 – 10 %	Less than 1%	Less than 1%
Hazardous Air Pollutants in Coal				
Arsenic	Not Reported	0.5	0.1	0.3
Beryllium	Not Reported	0.11	0.03	0.2
Cadmium	Not Reported	0.03	0.01	0.06
Chlorine	Not Reported	35	2.7	24
Chromium	Not Reported	1.1	0.4	2.2
Lead	Not Reported	0.6	0.2	1.0
Manganese	Not Reported	1.8	1.3	20
Mercury	Not Reported	0.007	0.006	0.03
Nickel	Not Reported	0.9	0.4	1.2

Emissions of criteria pollutants through stack are primarily important due to high emission quantity, transportation in ambient air and associated health impacts.

Emission of Sulphur oxides result mainly from the presence of organic and inorganic Sulphur in the fuel. During combustion, the majority of Sulphur oxides are produced in the form of Sulphur Dioxide.

The principal oxides of Nitrogen emitted during combustion of fossil fuels are Nitric Oxide (NO), Nitrogen Dioxide (NO_2), and Nitrous Oxide (N_2O). The first two of these form the mixture known as NO_x, which accounts for more than 90% of the Nitrogen Oxides. And the formation of NO_x is governed by three essential mechanisms:

- Thermal NO_x –Result from the reaction between the oxygen and Nitrogen from air
- Fuel NO_x – Formed from the Nitrogen contained in the fuel
- Prompt NOx – Conversion of molecular Nitrogen in the flame front in the presence of intermediate hydrocarbon compounds.

2.4 Control of Emissions from Pulverized coal combustion

Emissions control must be started with reducing fuel combustion through efficiency improvementand thus achieving the emission reduction. The second step of minimizing the emissions is improvement of fuel quality by considering the following measures;

- By using a mixture of coal with different characteristics
- Use of high quality coal (more cleaner coal) having high heating value, low water content, low ash content, low Sulphur, Chlorides and Fluorides.
- By applying coal washing/ cleaning
- Coal gasification

2.4.1 Dust Abatement

In pulverized coal boilers a small percentage of ash (< 20%) is collected as bottom ash while the majority is released as fly ash along with the flue gas. ESP and Fabric filters are widely used for controlling the dust. Amongst, ESP is the most commonly used mechanism in worldwide. ESP with a high voltage intermittent energizing system are able to react to different fuel qualities, including those with a lower Sulphur content. The choice between applying an ESP or fabric filtration generally depends on the fuel type, plant size, boiler type and the configuration.

The ESP is able to achieve low emissions. The designedcollection efficiency of the particulate can be higher than 99.9 %. Table 2.4.1 presents the different techniques to achieve low Particulate matter emission. ((European Commission, 2006)

2.4.2 Techniques to reduce SO_x Emission

Emission of Sulphur oxide arises from the presence of Sulphur in the fuel. The techniques for the reduction of SO_2 emissions are;

- Use of Low Sulphur fuel
- Use of techniques to retain Sulphur in Ash - Addition of sorbent materials in boilers such as lime or limestone
- Flue gas Desulphurisation techniques (FGD) – Dry FGD or Wet FGD

  Dry FGD: Entails sorbent injection into the flue gas and can achieve SO_2 reduction rates of 70% - 95%.

  Wet FGD: Use an aqueous suspension of limestone to absorb SO_2 and has the advantage of reducing emissions of HCl, HF, Dust and heavy metals.

  Sea Water Scrubbing: Use natural presence of carbonates and bicarbonates in the sea water to absorb SO_2. Localised effects can exist due to release of Sulphate, Chloride and heavy metals to the sea and effect of elevated temperature of water discharge. SO_2 removal efficiency upto 98% is possible.

(European Commission, 2006)

2.4.2.1 Sea Water Scrubbing

Sea water scrubbing is well worth as it could achieve high level of SO_2 removal at lower costs than conventional or simplified FGD. The process requires additional alkali if it is used for other than low Sulphur fuels, because Liquid/ Gas ratio would become too high to be cost effective without the added alkali.

Table 2.5Techniques for the prevention and control of dust and particle-bound heavy metal emissions(European Commission, 2006)

Technique	Environmental Benefit	Applicability		Operational Experience	Cross – media effects	Economics	Remarks
		New Plants	Retrofitable				
ESP	Reduction of particulate emissions. The removal of heavy metals and Hg is a positive but minor side effect	Possible	Possible	High	None	Costs from EUR 13 – 60per kWare reported. (without including ash handling & transportation cost)	Economically better for larger sizeplants. Particle–bound mercury is attached tosolids, and can be readily captured inan ESP. In the case of sub-bituminous coals andlignites, the removal of Hg is low dueto the high alkalinity of the fly ash andlow level of HCl in the flue-gases
Fabric Filter	Reduction of PM emissions (PM 2.5 and PM 10), removal of heavy metals and Hg is a positive but minor side effects	Possible	Possible	High	The efficiency of the power plant will be reduced by 0.1 percentage points	Operating and maintenance costs are higher than by an ESP	Mainly used downstream of dry and semi dry techniques to reduce SO2 emissions Particle bound Hg can be readily captured. In the case of sub bituminous and lignite, removal of Hg is low due to the same reason as above
Cyclones	Reduction of particulate emissions	Possible	Possible	High	Very limited reduction of fine particles	Low investment costs	Mechanical cyclones can only be taken as pre deduster with other techniques such as ESP or FF
Addition of activated carbon in FGD	Reduction of Hg emissions	Possible	Possible	Limited		Addition of activated carbon in FGD has lowinvestment and operationcosts	Addition of activated carbon in FGD still has the uncertainty of raising the Hg content of the Gypsum

The pH of the discharged sea water must be adjusted to the level of the original sea water by removing excess carbonates which are removed from the process. In addition, water has to be aerated before discharging to the sea in order to convert Sulphites into Sulphates.

Advantages :

- No waste product is produced because the sea water is returned to the ocean with the reaction products in low concentration and in a soluble form.
- Generally no alkali is needed for SO2 removal.
- The system is very simple

Disadvantages :

- The process is applicable only at coastal installations (For receiving and diluting the discharge)
- It requires high Liquid/Gas ratio if high Sulphur coals are treated. This can be overcome with alkali addition, but then equipment to handle the alkali is necessary.
- There may be opposition to the project due to concern over environmental impacts from contaminants, especially Mercury and other trace metals, transferred from any ash captured by the spray in the absorber to the sea water. This is one of the biggest issues related to this process.
- There may be problems with plume rise, because of the low gas temperatures at the stack exit. This can require reheat that adds considerable cost.

(ESMAP - Energy Sector Management Assistance Program, 2001)

2.4.3. Techniques to reduce NO_x emission

Nitrogen oxides (NO_x) formed during the combustion of fossil fuels are mainly NO, NO_2 andN_2O.NO_x emission reduction should be focused on both thermal and fuel NO_x either in the lower furnace during the combustion process or after NO_x has already left the furnace, in the post combustion region.

Table 2.6 General performance of sea water scrubbing for reducing Sulphur Oxide emissions(European Commission, 2006)

Technique	General SO2 reduction rate	Other performance parameters		Remarks
		Parameter	**Value**	
Sea Water Scrubbing	85 – 98%	Operating Temperature	If flue gas inlet temp. is 145°C, Sea water outlet temp is 30 - 40°C	Flue gas first needs to be dedusted Applicable only for low Sulphur coal and PP at coastal line
		Sorbent	Seawater/ air	
		Residence time of seawater in aerator	15 min. (depends on type of process)	Applicability is high as the process is simple and does not require slurry handling
		Max. flue gas flow per absorber	No limitation in gas flow	Operating cost are low compared with a wet FGD system
		Reliability	98 – 99%	Seawater conditions, tidalflows, the marine (aquatic) environment close to the scrubberwater outlet, etc. needs to be carefully examined in order toavoid negative environmental and ecological effects. Effectsmay arise from the reduction of the pH level in the generalvicinity of the power plant as well as from the input ofremaining metals (heavy metals sometimes called traceelements) and fly ash. This is especially applicable to plantssituated in an estuary
		Residue / by-product	None	
		Energy consumption as % of electric capacity	0.8 – 1.6%	
		HCl removal rate	95 – 99%	
		HF removal rate	95 – 99% in the absorber	
		Water Consumption	15,000 m^3/hr (depending on Bicarbonate concentration in the sea water)	
		Wastewater	None (But Sulphate ions dissolved in seawater)	
		Pressure Drop	10 – 20 (10^2 Pa)	

Table 2.7 General performance of primary measures for reducing NO_x emissions (European Commission, 2006)

Primary Measure		General NO_x reduction rate	Applicability Limitation	Remarks
Low Excess Air		10 – 44%	Incomplete burnout	NO_x reduction strongly depends on the emission level of theuncontrolled plant It might be necessary to seal the furnace, the mills and theairpreheater in order to allow application of low excess air firing.
Air staging in the furnace	Biased Burner Firing (BBF)	10 – 70%	Incomplete burnout (and thus high CO and unburned carbon levels)	problems may arise maintaining the fuel input, because the sameamount of thermal energy has to be supplied to the furnace with feweroperating burners.
	Over Fire Air (OFA)			• Retrofitting overfire air on an existing boiler involves water-walltube modifications to create the ports for the secondary air • NOX reduction of 10 to 40 % is possible for wall-fired furnacesusing OFA.
Flue gas recirculation		20 – 50%	Flame instability	• Retrofitting an existing boiler with flue-gas recirculation presentssome adaptation difficulties, mostly due to efficiency losses of both theboiler and the burners, except when recirculating very small amounts offlue-gas • This NO_x abatement measure can be used for retrofitting whencombined with air staging • Recirculation of flue-gas results in additional energy consumptiondue to the recirculation fan.
Fuel staging (reburning)		50 – 60% (70 – 80% of the NOx formed in the primary combustion zone can be reduced		• Reburning offers some advantages, such as compatibility withother primary NO_x emission reduction measures, simpleinstallation of the technique, use of a standard fuel as thereducing agent, and very small amounts of additional energy.The additional energy consumption by reburning coal over coalcan be higher as a reburning fuel • Combustion downstream of the primary zone also producesnitrogen oxides • When using natural gas as the reburning fuel, particulate matter,SO_2 and CO_2 are also reduced in direct proportion to the amountof coal replaced.

Table 2.7General performance of primary measures for reducing NO_x emissionsContd……….

Primary measure		**General NO_x reductionrate***	**Applicability limitations**	**Remarks**
Low NO_x burner (LNB)	Air Staged LNB	25 – 35%	• Flameinstability • incompleteburn-out	• Low NO_x burners can be used in combination with other primary measures such as overfire air and reburning of flue-gasrecirculation • low NO_x burners with overfire air can achieve reduction rates of 35 – 70 % • A drawback of first generation low NO_x burners is the spacerequirement of the flame separation: the diameter of low NO_x flames is about 30 to 50 % larger than for conventional flames.
	Flue gas recirculation LNB	Upto 20%	• Flameinstability	
	Fuel staged LNB	50 – 60%	• Flameinstability • incompletebum-out	

Table 2.8 General performance of secondary measures for reducing NOxemissions(European Commission, 2006)

Technique	General NO_x reduction rate	Other performance parameters		Remarks
		Parameter	**Value**	
Selective Catalytic Reduction	80 – 95%	Operating Temperature	350 – 450 ºC (high-dust) 170 – 300 ºC (tail-end)	• The ammonia slip increases with increasing NH_3/NO_x ratio, which may cause problems, e.g. with a too high ammonia content in the fly ash. This is a problem which can be solved by using a larger catalyst volume and/or by improving the mixing of NH_3 and NO_x in the flue gas
		Reducing Agent	Ammonia, Urea	
		NH_3/NO_x ratio	0.8 – 1.0	
		NH_3-slip	< 5 mg/ Nm^3	• Incomplete reaction of NH_3 with NO_x may result in the formation of ammonium sulphates, which are deposited on downstream facilities such as the catalyst and air preheater, increased amounts of NH3 in flue-gas desulphurisation waste waters, the air heater cleaning water, and increased NH3 concentration in the fly ash. This incomplete reaction only occurs in the very unlikely case of catastrophic failures of the whole SCR system
		Availability	> 98%	
		SO_2 / SO_3 conversion rate with catalyst	1.0 – 1.5% (tail end)	
		Energy consumption as % of electric capacity	0.5% for all applications	
		Pressure drop at the catalyst	4 – 10 (10^2 Pa)	• The life of the catalyst has been 6 – 10 years for coal combustion, 8 – 12 years for oil combustion and more than 10 years for gas combustion • Catalyst lifetime of 40000 to 80000 operating hours can be reached by periodical washing.

Table 2.8 General performance of secondary measures for reducing NO_x emissionscontd…..(European Commission, 2006)

Technique	General SO2 reduction rate	Other performance parameters		Remarks
		Parameter	Value	
Selective Non Catalytic Reduction (SNCR)	30 – 50%	Operating Temperature	850 – 1050 ºC	• Though some manufacturers report a NO_x reduction level of over 80 %, the common view is that SNCR processes are, in general, capable of 30 – 50 % reduction as an average covering different operational conditions. Further NO_x reductions can be obtained on specific boilers where the conditions are good, as well as lower values where the conditions are bad, sometimes on existing plants. • SNCR cannot be used on gas turbines because of the residence time and temperature window required • Incomplete reaction of NH_3 with NO_x may result in the formation of ammonium sulphates, which are deposited on downstream facilities such as the air preheater, increased amounts of NH_3 in flue-gas desulphurisation waste waters, the air heater cleaning water, and increased NH_3 concentration in the fly ash
		Reducing Agent	Ammonia, Urea	
		NH_3/NO_x ratio	1.5 – 2.5	
		NH_3-slip	< 10 mg/ Nm^3	
		Availability	> 97%	
		Energy consumption as % of electric capacity	0.1 – 0.3%	
		Residence time within temperature range	0.2 – 0.5 sec	

Both Primary and Secondary measures are being used in coal fired boilers in Asia. Low NO_x burners and/ or two stage combustion is typically the lowest cost approach to reduce NOx, but may not be enough to meet required emissions. Post combustion abatement methods such as SCR / SNCR approaches take high capital investment which make higher price for unit production.

2.5 Health Impact Assessment

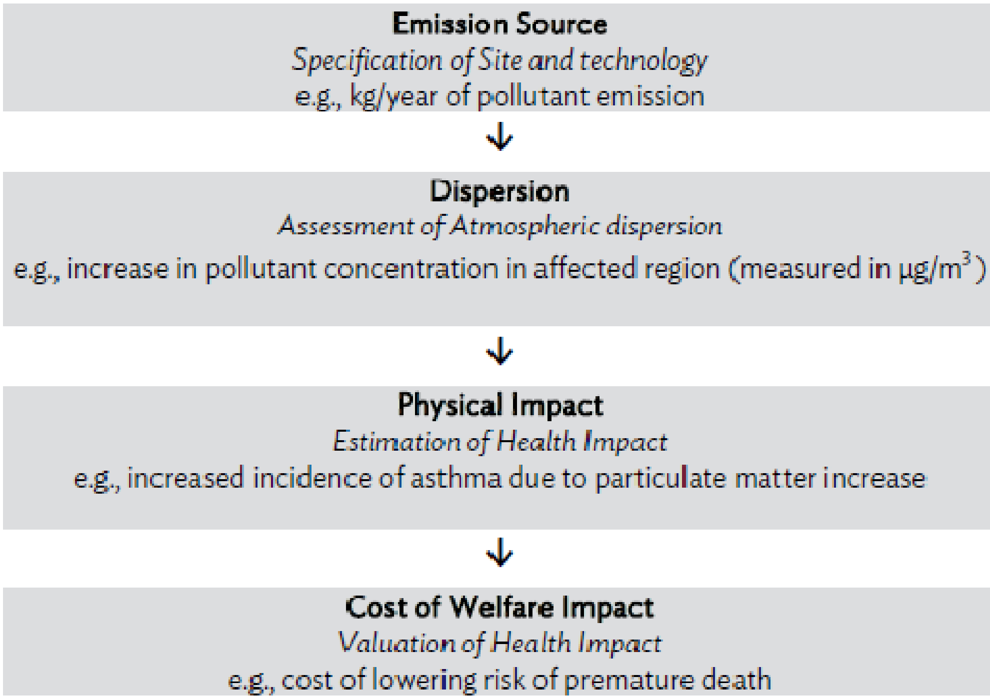
Coal fired power plants are always contributors for various environmental as well as health impacts. Epidemiological studies indicated strong relationships between ambient concentrations of air pollutants and adverse health effects with mortality and morbidity. In most countries around the world, governments regulate ambient air quality, through ambient air quality standards, set to protect human healthand air quality management plans are put in place to manage this. Continuous accumulation of these pollutants aggravated especially cardiac and respiratory diseases, increasing the risk of pre mature death among children and adults. Estimation and assessment on health impacts were carried out in several countries by using several methods and associated health costs have been calculated.

2.5.1 Impact Pathway Approach

Asian Development Bank (ADB) has provided a practical guide for valuation of health impacts of air pollution from power plants in Asia. Impact Pathway approach has been used to quantify health impact of power generation.(Herath Gunatilake, 2014) The IPA has four main steps to be followed.

i. Site specification and emission estimation
ii. Quantification of ambient pollutant concentrations through dispersion modeling
iii. Quantification of health impacts resulting from changes in ambient concentrations
iv. Valuation of health impacts in monetary terms.

This methodology can be used to estimate health cost of air pollution from existing plants as well as plants under consideration for future implementation.



Source: Adapted from European Commission (2005).

Figure 2.1 Impact Pathway Approach

Incremental increase in health impacts can be estimated after predicting the emission concentrations of pollutants (through ADM). Dose response functions (DRFs) quantify the relationship between air pollution and health impacts. Estimates done by Health Effects Institute (HEI) for DRFs were reasonably transferred to Asian countries and impacts assessment could be carried out based on that information.

2.5.2. Hazard Quotient approach

US EPA has provided guideline on estimating the nature and probability of adverse health effects in humans who may be exposed to air pollutants. It generally includes following 4 basic steps.(Human Health Risk Assessment, 2012)

- Step 1 – Hazard Identification : Examines whether a stressor has the potential to cause harm to humans and/or ecological systems, and if so under what circumstances
- Step 2 – Dose Response Assessment : Examines the numerical relationship between exposure and effects

- Step 3 – Exposure assessment : Examines what is known about the frequency, timing and levels of contact with a stressor.
- Step 4 – Risk Characterization : Examines how well the data support conclusions about the nature and extent of the risk from exposure to environmental stressors.

The same methodology is followed by the Office of Environmental Health Hazard Assessment (OEHHA) California Environmental Protection Agency. Under the 'Air Toxics hot spots program guidance manual for preparation of health risk assessment' indicates the same procedure in the risk assessment process. (Air Community and Environmental Research Branch, 2015 February)

The Hazard Identification process is concern on pollutants emitted by the facility and the types of adverse health effects associated with exposure to the pollutants, including whether a pollutant is a potential human carcinogen or is associated with other types of health effects.

The purpose of the exposure assessment to estimate / predict the ground level pollutant concentration by using an ADM and identify the extent to which the population is exposed to. US EPA approved AERMOD air dispersion model is a steady state Gaussian air dispersion model that incorporates air dispersion based on planetary boundry layer turbulence structure and scaling concepts including treatment of both surface and elevated sources and both simple and complex terrain.

Dose response assessment is the process of characterizing the relationship between exposure to an agent and incidence of an adverse health effect in exposed populations. For non carcinogenic effects, dose response data developed from human studies are used to develop acute, 8-hour and chronic RELs which is defined as the concentration at which no adverse non-cancer health effects are anticipated even in sensitive population.

Risk characterization is the final step of the health risk assessment. Information derived from the exposure assessment is combined with information from the dose response assessment to characterize risks to the human health from emissions. Non carcinogenic effects are evaluated by comparing an exposure level (dose) with the toxicity value, expressed as a Hazard Quotient (HQ). In order to calculate the acute HQ, the maximum 01 hour ground level concentration (in μg/m^3) of a pollutant at a receptor is divided by the acute 01 – hour REL (in μg/m^3) for the pollutant:

$$\text{Acute Hazard Quotient} = \frac{\text{01-Hour maximum Concentration } (\mu g/m3)}{\text{Acute REL } (\mu g/m3)}$$

Hazard Quotient of 1.0 or less indicates that adverse health effects are not expected to result from exposure to emissions of that pollutant. HQ increase above one, the probability of human health effects increases by an undefined amount.

(Mutahharah M. Mokhtara, 2014)has carried out a human health risk assessment of emissions from a coal fired power plant in Malaysia using AERMOD modeling. This assessment was carried out to evaluate both long term and short term non carcinogenic impacts from SO_2 and Hg as well as carcinogenic impacts from As and Cr. Air Dispersion modeling (AERMOD) was used to predict the ground level concentration within 10km radius of the emission source and short term and long term impacts were identified.

CHAPTER 03: Materials and Methods

The study is mainly based on development of 1200MW capacity coal fired power plant in 2018. Since CEB has already identified to install the next coal power plant at Sampoor, this study has considered a location near to the permitted 500MW capacity coal power plant of TPCL (Tricomalee Power Company Limited).

Ambient air quality concentrations were predicted by carrying out an air dispersion model study for three targeted air quality parameters; Sulphur Dioxide (SO_2), Nitrogen oxides (NO_x) and particulate matter as total suspended particulates (PM as TSP) under following scenarios. (Figure 3.1 shows the proposed location for coal PP development)

Scenario A: Installation of 1200 MW capacity pulverized coal power plant having 4 units of 300 MW capacity

Scenario B: Installation of 1200 MW capacity pulverized coal power plant having 2 units of 600 MW capacity

Scenario C: Installation of 1200 MW super critical pulverized coal power plant having 2 units of 600 MW capacity

Summary of the methodology followed in the study is presented in figure 3.2 and 3.3.

Figure 3.1 The proposed location for the development of next coal power plant

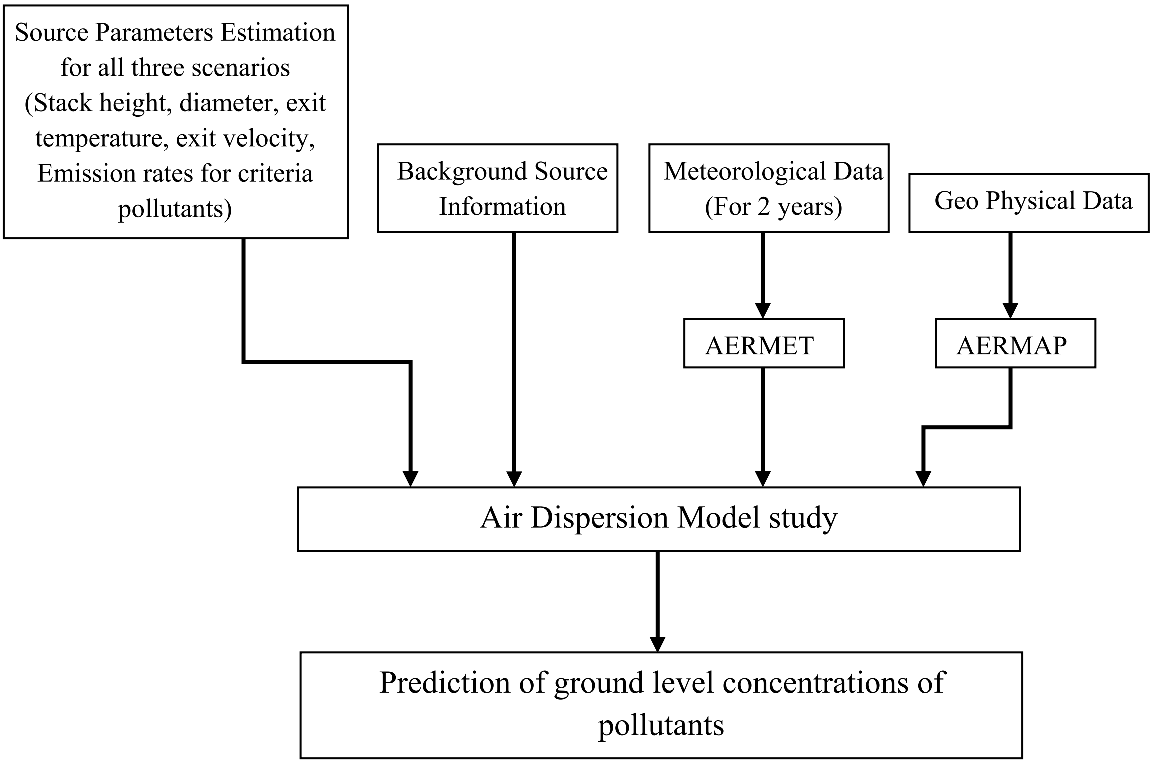


Figure 3.2 Methodology Followed to predict the ambient pollutant concentrations

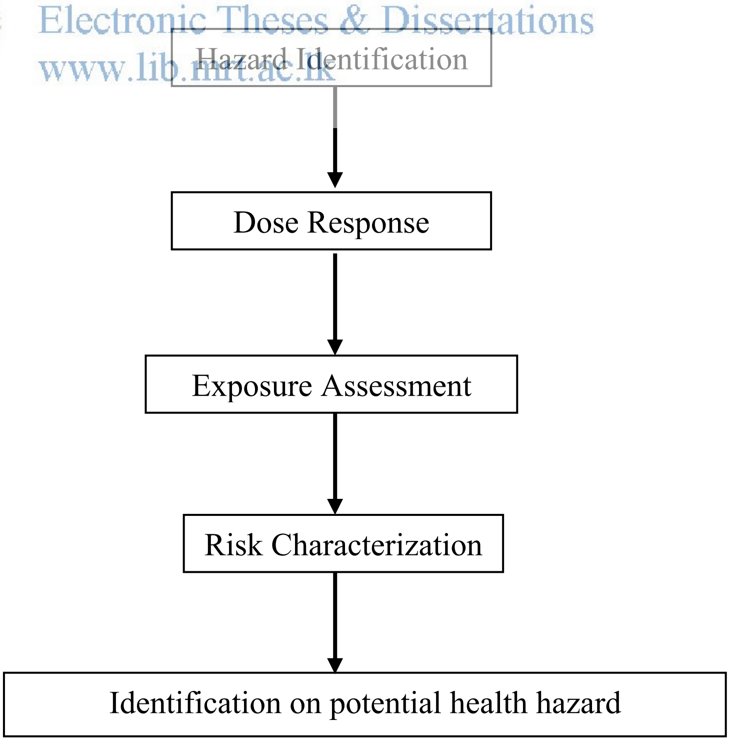


Figure 3.3. Methodology Followed to Health Risk Identification

3.1 Case study Development

The following case studies have been developed for each scenario as depicted in Table 3.1 and 3.2.

Table 3.1 Air Dispersion Modeling study for the proposed PP at Sampoor

Scenario	Case Study	Description
A	01	Considering SO_2, NO_x and PM emission concentrations for Design Coal with FGD
	02	Considering SO_2 emission concentrations for Design Coal without FGD
	03	Maximum allowable stack gas emission concentration of SO_2 that can be emitted until comply with respective ambient air quality standard. (Trial and Error procedure)
	04	Emission concentrations with varying stack height for Pollutant exceeding the respective AAQ standard.
B	05	Considering SO_2, NO_x and PM emission concentrations for Design Coal with FGD
	06	Considering SO_2 emission concentrations for Design Coal without FGD
	07	Maximum allowable stack gas emission concentration of SO_2 that can be emitted until comply with respective ambient air quality standard. (Trial and Error procedure)
	08	Emission concentrations with varying stack height for Pollutant exceeding the respective AAQ standard.
C	09	Considering SO_2, NO_x and PM emission concentrations for Design Coal with FGD
	10	Considering SO_2 emission concentrations for Design Coal without FGD
	11	Maximum allowable stack gas emission concentration of SO_2 that can be emitted until comply with respective ambient air quality standard. (Trial and Error procedure)
	12	Emission concentrations with varying stack height for Pollutant exceeding the respective AAQ standard.

3.2 Emission Load Estimation

Emission loads were calculated based on the factors developed by the CEB for coal power plants. Emission factors for the Lak Vijaya and TPCL PP were developed based on the measured pollutant emission rates through the stack and emission rates estimated during the EIA process respectively. As per the information received from CEB, Coal steam generation through New Coal candidate and Super Critical condition have lower ambient air quality impacts than that of the permitted plants. Higher pollutant reduction is due to the involvement of high efficient pollutant control technologies with the combination of higher quality fuels.

Table 3.2. Emission factors of the coal power plants

Plant Type	NCV of coal		Sulphur Content	Emission Factor			
	kcal/kg	kJ/kg	%	Particulate (mg/MJ)	CO_2 (g/MJ)	SO_x (g/MJ)	NO_x (g/MJ)
Coal Steam – New Coal candidate	5900	24702	0.8	7.00	94.6	0.035	0.140
Coal Steam – Super Critical	6300	26377	0.8	7.00	94.6	0.035	0.035
Coal Steam - TPCL	5500	23027	0.65	35.00	98.3	0.056	0.260
Coal Steam – Lak Vijaya Power station	6300	26377	0.7	15.00	94.6	0.056	0.260

(Source : CEB Generation expansion Plan to be published in 2015)

Table 3.3 Characteristics of existing and candidate coal power plants (For one unit)

Characteristic	New Coal candidate	Super critical coal plant	TPCL	Lak Vijaya plant
Number of units	04	02	02	03
Installed capacity (MW)	300	600	250	300
New capacity (MW)	270	564	227	275
Minimum operating level	105	360	150	200
Calorific Value (kcal/kg)	5900	6300	5500	6300
Heat rate at minimum operating level (kcal/kWh)	2810	2248	2895	2597
Heat rate at full load operating level (kcal/kWh)	2241	2082	2600	2378
Full load Efficiency (%)	38.4	41	33	36

(Source : CEB Generation expansion Plan to be published in 2015)

- Emission loads for scenario A and B were calculated assuming the similar air pollution control measures (thus the same efficiencies) and similar characteristics of coal as with the Lak Vijaya coal power plant. SO_x, NO_x and PM emissions were calculated based on the emission factors derived for the Lak Vijaya PP.
- All the emission factors have considered the impact of pollutant control measures.

Table 3.4 Emission Load estimation

	unit	300 MW	600 MW	600 MW Super critical
Number of units		04	02	02
Net Calorific Value	kJ/kg	26377	26377	26377
Heat Rate	kJ/kWh	9956.21	9956.21	8716.92
Coal required to produce 1kW.h	kg/kWh	0.377458	0.377458	0.330474
Coal Consumption	T/hr	113.2374	226.4748	198.2844
Total energy generation	MJ/sec	829.684	1659.378	1452.828
SO_x Emission Factor	g/MJ	0.056	0.056	0.035
SO_x Emission Rate	g/sec	**46.462**	**92.925**	**50.849**
NO_x Emission Factor	g/MJ	0.260	0.260	0.035
NO_x Emission Rate	g/sec	**215.719**	**431.438**	**50.849**
Particulate Emission Factor	g/MJ	15	15	7
Particulate Emission Rate	g/sec	**12.445**	**24.891**	**10.170**

- Low NO_x burners are used by the Lak Vijaya Power Plant for the reduction of NO_x formation (As per the information had from the PP). NO_x reduction which can be achieved from this method is about 25%.
- SO_x emission without having Flue Gas Desulphuration had been calculated based on the sulphur content of the coal.

Table 3.5 Emission Load estimation without having pollution control abatements

	unit	300 MW	600 MW	600 MW Super critical
SO_x Emission Rate (with sea water FGD)	g/sec	46.462	92.925	50.849
SO_x Emission Rate (without sea water FGD)	g/sec	440.370	880.741	881.270
Efficiency of FGD	%	89.45	89.45	94.23

3.3 Source Emission Characteristics

Source emission parameters were decided based on following details.

- Point source characteristics for scenario A was obtained by considering the similar values as in the existing Lak Vijaya coal power plant.
- Some of the point source characteristics for scenario C was obtained through past EIA studies done for similar type of power plant (Engconsult Ltd., 2013)
- Characteristics for the scenario B is developed based on the typical conditions experienced in thermal power plants

Table 3.6 Source Emission Characteristics

	unit	300 MW	600 MW	600 MW Super critical
Stack Height	m	150	150	150
Stack inside Diameter at the exit	m	4.5	7	7
Stack gas exit Temperature	°C	92.6	80	80
Stack gas exit velocity	m/sec	18.97	20	20

3.4 Background Sources

Assessment of air pollution dispersion was carried out by considering the background sources. For the site to be developed in Sampoor, TPCL (Trincomalee Power Company Ltd.) power plant has been permitted for the installation.

Table 3.7 Source Emission characteristics of TPCL Power Plant

	unit	300 MW
Stack Height	m	135
Stack inside Diameter at the exit	m	4.5
Stack gas exit Temperature	°C	85
Stack gas exit velocity	m/sec	22.23
PM emission Rate	g/sec	35.355
SO_2 emission Rate (with FGD)	g/sec	145.049
NO_x emission Rate	g/sec	169.314
SO_2 emission Rate (without FGD)	g/sec	422.207

3.5 Air Dispersion Model

Industrial Source Complex AMS/ EPA regulatory model ('ISC-AERMOD View') software 'version 8.8.9' developed by Lakes Environmental, USA which is equivalent to United States Environmental Protection Agency, USA (USEPA) 'ISC2' was utilized for this air dispersion modeling study. It is a refined dispersion model for simple and complex terrain for receptors within 50km of a modeled source. Model description is given in Annexure I.

3.6 Model Input Data

a) Study area for this air dispersion modeling study was taken as the area covered by 20 km radius from the stack location of the TPCL power plant.

b) Launch satellite image from 'Google Earth' website was taken to cover the study area

c) Meteorological Data: Two years (From 1st of September 2012 to 31st August 2014) metrological data used in this study were generated by Mesoscale Metrological model (MM5) and purchased from Lakes Environmental in Samson and TD-6201 format files.

The data were then pre-processed using AERMET View (Version 8.8.9). AERMET organize the meteorological data into format which is suitable for the AERMOD dispersion model.

The required meteorology data for AERMOD are surface data (hourly values) that describe conditions closer to ground level and upper air data (daily values) that describe conditions higher in the atmosphere. Surface data consist of wind direction (degrees from true north), wind speed (m/sec), Dry bulb (ambient air) temperature (°C), Dew point temperature (°C), Total and opaque cloud cover (tenth), cloud ceiling height (m), Station pressure (millibar), hourly precipitation amount (hundredths of inches), and relative humidity (%). Upper air data are required to determine convective mixing height (m). Mixing height is defined as the height to which the lower atmosphere will undergo mechanical or turbulent mixing, producing a nearly homogeneous air mass.

d) The topographical effects of the site were addressed by employing the elevated terrain option in the software where by contours lines with resolution of ~ 90m are obtained from the Shuttle Radar Topography Mission (SRTM3) database maintained by the U.S. National Geospatial Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA). The terrain data were pre-processed with AERMAP prior to modeling in AERMOD.

e) A comprehensive Cartesian receptor grid extending to 20 km from the centre of the emission source of TPCL was used in the AERMOD modeling to assess the maximum ground level pollutant concentrations.
Three discrete receptors were placed in nearby areas (Sampoor, Mutur and Tricomalee) in order to compare the ambient air quality degradation.

Figure 3.4 Locations of discrete receptors

Table 3.8 GPS locations of discrete receptors

Location	GPS Position
Mutur	(529519.00 mE, 934833.00 mN)
Sampoor	(532073.00 mE, 935206.00 mN)
Trincomalee	(522376.00 mE, 949075.00 mN)

f) Source Data: Source data considered in each case study are presented in following table 3.9.

Table 3.9 Source Data

Parameter	TPCL	Scenario A	Scenario B	Scenario C
Stack Height (m)	135	150	150	150
Stack Diameter (m)	4.5	4.5	7.0	7.0
Stack gas exit temperature (°C)	85	92.6	80	80
Gas exit velocity (m/sec)	22.23	18.97	20	20
Flow Rate (m^3/sec)	1414.21	1206.82	3078.76	3078.76
Flow Rate (Nm^3/sec)	1078.43	967.58	2381.02	2381.02
PM emission rate (g/sec)	35.355	12.445	24.891	10.170
SO_2 emission rate with FGD (g/sec)	145.049	46.462	92.925	50.849
SO_2 emission rate without FGD (g/sec)	422.207	440.370	880.741	881.270
NO_x emission rate (g/sec)	169.314	215.719	431.438	50.849

3.7 Health Impacts Assessment

Human health risk assessment was carried out for non-carcinogenic pollutants (SO_2, NO_2) emitted from the stack of the studied coal fired power plants that could affect human health conditions. The methodology was referred to which is described in USEPA website on human health risk assessment. (Risk Assessment, 2012) This methodology includes 4 basic steps as described below.

Step 1 - Hazard Identification:

According to the classification of the International Agency for Research on Cancer (IARC), none of the above-mentioned pollutants (NO_2, SO_2) released during the power plant operation is classified as carcinogenic, thus risk assessment for non-carcinogenic substances was discussed. (Risk Assessment, 2012)

Step 2 – Dose Response:

This is the process of characterizing the relationship between exposure to an agent and incidence of an adverse health effect in exposed populations. Dose-response assessment describes the quantitative relationship between the amounts of exposure to a substance (the dose) and the incidence or occurrence of an adverse health impact (the response). For non-carcinogens, dose-response information is presented in the form of Reference Exposure Levels (RELs). RELs are concentrations or doses at or below which adverse effects are not likely to occur following specified exposure conditions. (Risk Assessment, 2012)

Step 3: Exposure Assessment :

Here it was estimated the extent of public exposure to each substance for which potential non cancer effects. Ground level emission quantification and transportation was evaluated by carrying out an Air Dispersion Model study as described above. The pollutants concentration obtained from the model study was then used as an input data to assess the health risk impact to population due to emission from proposed power plant.

Step 4: Risk Characterization :

For noncancerous health impacts due to inhalation, risk characterization is performed by quantifying the hazard using the hazard Quotient approach which is defined as follows.

$$HQ = \frac{\text{Potential Concentration } (\mu g/m^3)}{\text{Reference Concentration } (\mu g/m^3)} \longrightarrow \text{Equation 01}$$

HQ of less than one (HQ < 1) indicates that pollutant concentration is below the reference concentration (RfC) value, whereby, the potential risk is within acceptable level with no action required to reduce the pollutant's level. Therefore, HQ < 1 is considered safe. Nevertheless, it should be noted that HQ > 1 does not necessarily suggest a likelihood of adverse effects. It is more suitable to be used as an indication that a potential risk exists for adverse health effects. (Risk Assessment, 2012)

CHAPTER 4: RESULTS and DISCUSSION

4.1 Metrological Conditions

AERMET is the meteorological preprocessor which organizes and processes meteorological data and estimates the necessary boundary layer parameters for dispersion calculations in AERMOD Air Dispersion Model.AERMET processes meteorological data in 3 stages.

Stage 01 : Extracts hourly surface data and upper air soundings from data files and processes the data through quality assessment checks on variables of interest.

Stage 02 :Combines the different sources of data into one file composed of blocks of 24 hour data. The 24 hour blocks begin with hour 1 and end with hour 24. If any input data to this stage of processing are physically missing for the hour, then the appropriate missing value indicator represents the meteorological variables for that hour.

Stage 03 : Boundary layer parameters are estimated for use by dispersion models. This creates two files that are used by AERMOD (i.e. Surface and Profile files).

The Surface file contains boundary layer parameters including Friction velocity, Monin-Obukhov length, convective velocity scale, temperature scale, convectively generated boundary layer (CBL) height, stable boundary layer (SBL) height, and surface heat flux. The profile file contains multi level data of wind speed, wind direction and temperature. (Office of Air Quality Planning and Standards, 2004)

The meteorological pre processed data was used to determine its corresponding wind rose plot. The percentage frequencies of occurrence of various wind speed classes in different directions were computed from recorded data on 24 hourly bases and presented in the form of wind rose plot. The wind rose shows the most predominant wind direction blows from which the wind blows, and this wind rose diagram shows the pre dominant winds are mainly flowing from South West, with occasional wind from the North East. This means that the emissions plume will be dispersed mainly in these directions.

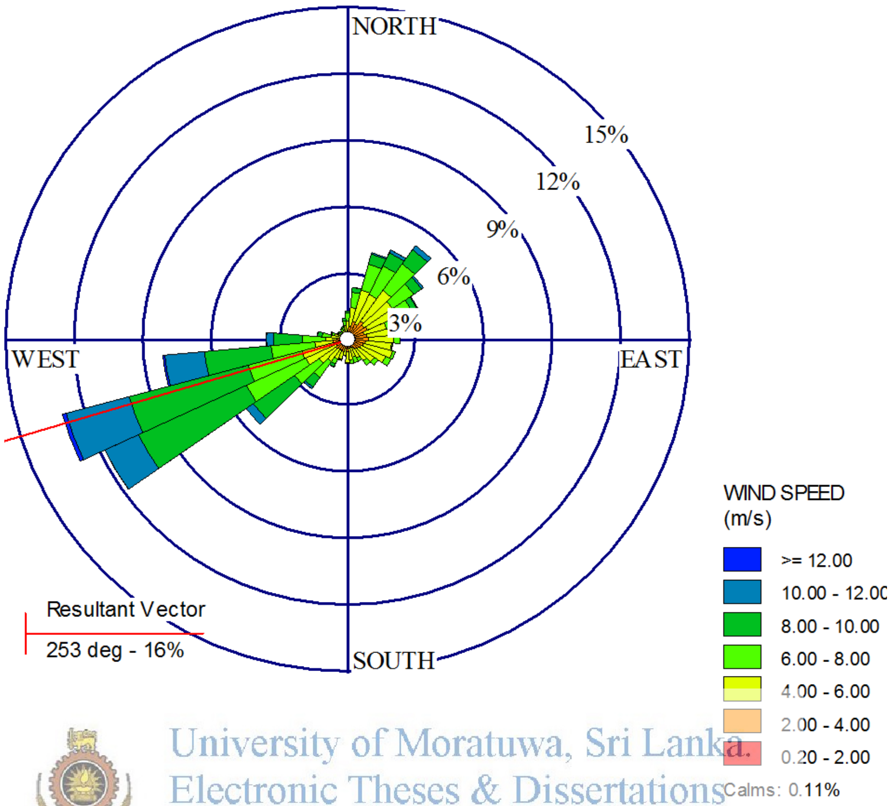


Figure 4.1: Wind Rose Plot for the Sampoor

The wind speed and direction for South West and North East monsoon seasonsare recorded during study period (2012/08/31 – 2014/09/01) at proposed site location. Further analysis of wind data shows that calm conditions are observed for 0.9% of the total 17,520 (hourly wind data for 2 years of period) hours and 29.1% of wind data is in the range of 4.00 – 6.00 m/sec. Thus the average wind speed in the site is around 6.14 m/sec.

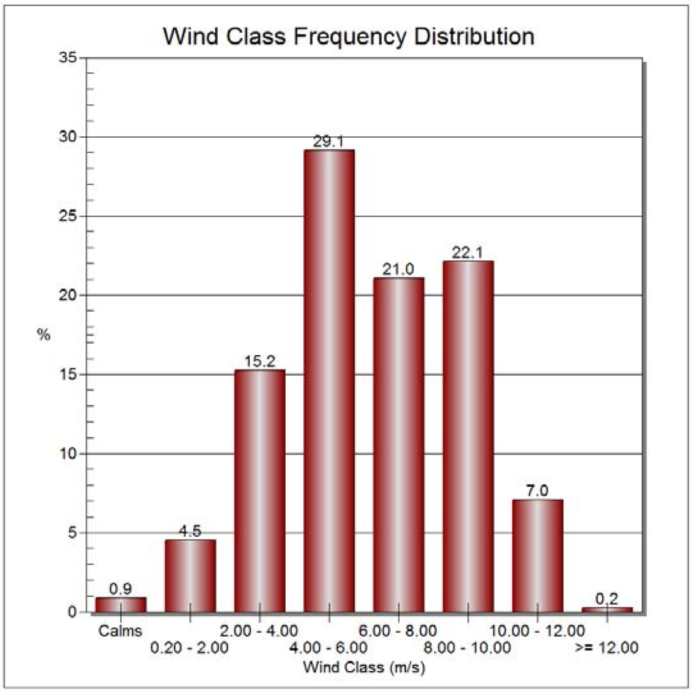


Figure 4.2: Wind Class Frequency Distribution

Model outputs clearly show that high concentration receptors could be mainly found from the North East direction to the stack location of TPCL. Thus, it can be found that the most vulnerable area due to the impacts associated with coal PP is the North East direction (i.e sea side) with smaller impacts to the South West direction. Argument on 'coal power will destroy all the tea plantations and other vegetation by reducing the country as a desert' where environmentalists have frightened the nation without having any critical analysis of direction to which the plume is dispersed, can be exempted. Instead damage could be existed for the habitats in Sea next to Tricomalee due to plume dispersion as well as the thermal dispersion.

4.2 Predicted Maximum GLC

The maximum GLC of the modeled pollutants for 01 hour, 8 hours and 24 hours averaging periods is given in table 4.1 in order to compare the results with respective ambient air quality standards (Annexure II).Model output maps of each case are given in Annexure III.

According to the model outputs, it is clearly indicate that pollutants are mainly concentrated near the source by reflecting the influence of wind pattern from South West and North East directions.

Table 4.1. Emission Concentrations due to operation of coal power plant with FGD

Parameter	Background Condition (TPCL)	Scenario A	Scenario B	Scenario C	Ambient Air Quality Standard[1]
		Case Study 01	Case Study 05	Case Study 09	
01 Hour Averaging Period($\mu g/m^3$)					
SO_2	117.545	182.269	158.810	133.068	200
NO_x	137.208	**807.894***	**465.030***	150.124	250
08 Hour Averaging Period($\mu g/m^3$)					
SO_2	43.300	54.134	52.368	47.843	120
NO_x	50.543	**211.436***	129.329	54.960	150
24 Hour Averaging Period($\mu g/m^3$)					
SO_2	21.356	25.082	21.728	21.384	80
NO_x	24.929	82.734	64.448	24.957	100
PM	3.970	5.551	4.652	3.975	100

*Not comply with the respective AAQ standard

[1] The National Environmental (Ambient Air Quality) Regulations, 1994, published in Gazette Extraordinary, No. 850/4 of December, 1994 is annexed in Annexure II.

4.3 Assessment on SO_2 Emission Prediction

Predicted maximum ground level Sulphur Dioxide concentration values in all scenarios were not exceeded the corresponding AAQ standard.Atmospheric dispersion was carried out for short term as well as long term averaging periods, where 01 hour averaging period shows the less dilution and dispersion in convective boundary layer hence the higher ground level concentrations and with time, plume penetration is high and steady condition with higher dispersion could be prevailed during 24 hour averaging period.

According to the results, ground level SO_2 concentration was controlled due to the following measures. The primary measure taken to control SO_2 emission was the use low Sulphur coal itself. And Flue gas desulphuration with higher removal efficiency (> 89 %) was the secondary measure that was employed to capture SO_2 emission from flue gas. Due to lower heat rate of coal used for the super critical units (Scenario C), total coal consumption has been reduced than that of the sub critical units with the same capacity (Scenario B). Thus, irrespective to the capacity distribution or the technology associated with the power generation,predicted ground level Sulphur Dioxide concentrations were complied with the respective AAQ standard.

FGD process plays an important role in controlling ground level Sulphur Dioxide concentration. Since the power plant is located near to the coastal line, sea water desulphuration process could be used effectively to achieve higher emission removal efficiency (85 – 98 %). Due to the presence of Bicarbonates and Carbonates in the sea water, the SO_2 of the flue gas is absorbed. SO_2 will then be converted to Sulphate (SO_4^{2-}), water will be nearly saturated with oxygen and the pH 6 level will be adjusted normally before the sea water is discharged back to the sea. Applicability of this technology is limited to fuel with low Sulphur content. (European Commission, 2006)

According to the results, Stack height of 150m was then adequate considering the Sulphur Dioxide emission dispersion.Future industrial developments in Sampoor can allow polluting the ambient air shed with regard to SO_2 concentration is less than 9% which is due to theimpact arose from implementation of scenario A. Thus implementation of Scenario B and C are much favorable when addressing the future developments of the site.

Emission concentrations without operating FGD unit would not meet the respective AAQ standards as depicted in Table 4.2.FGD process cools the flue gases down below the exhaust gas temperature of the boiler. After flowing through the boiler, the air preheater and the ESP, flue gas is conducted to the scrubber. The clean gas had to dissipate into the air via a stack at a temperature higher than 80°C (European Commission, 2006) in order to raise the plume of the flue gas after it had left the stack to ensure its spread and wide distribution. Without operating FGD, the temperature of exit gas from the stack would be much higher which is more favorable in pollutant dispersion. This study has conducted by considering the worst case scenario whereas the flue gas exits the stack with minimum temperature required for dispersion the pollutants in the atmosphere.

Table 4.2. SO_2 Concentrations due to operation of coal power plant without FGD

Parameter	Background Condition (TPCL)	Scenario A	Scenario B	Scenario C	Ambient Air Quality Standard[1]
		Case Study 02	Case Study 06	Case Study 10	
01 Hour Averaging Period ($\mu g/m^3$)					
SO_2	117.545	**1647.624***	**943.290***	**942.727***	200
08 Hour Averaging Period ($\mu g/m^3$)					
SO_2	43.300	**431.355***	**263.984***	**263.826***	120
24 Hour Averaging Period ($\mu g/m^3$)					
SO_2	21.356	**168.818***	**128.815***	**128.739***	80

*Not comply with the respective AAQ standard

Ground LevelSO_2concentrations could be achieved below the respective AAQ standard only by operating the PP with FGD. Thus, proper maintenance of FGD has to be highly considered to avoid any failure, which would otherwise lead for overall plant shutdown.

The range of Sulphur percentage of coal that can be accepted for the PP was determined by a trial and error procedure. Maximum allowable Sulphur percentage that can be accepted for the power plant operation is varying with the technology and capacity distribution of power generation. Thus, lower quality fuels can also be accepted for the higher efficientpower plants.

Table 4.3 Maximum allowable Sulphur content of the fueltolerable to comply with respective AAQ standard

	Installation of 300MW PP (4 no.s) Case Study 03	Installation of 600MW PP (2 no.s) Case Study 07	Installation of 600MW SC PP (2 no.s) Case Study 11
Maximum SO_2 emission rate (g/s)	53	160	160
Maximum ambient SO_2 concentration – 01 HrAvg ($\mu g/m^3$)	199.324	199.850	199.850
Maximum allowable Sulphur content of the fuel (%)	0.8	1.2	2.52

According to the results, Super Criticalpower plant can use coal with higher Sulphur content. However, in Sri Lankait has been proposed that Coal – Sulphur specifications for both power sector and industrial sector should be restricted to 1.2%, in order to control the unauthorized entry of low quality coal into the country (Officials' committee appointed for Enhancing the quality of fossil fuels for managing air quality in Sri Lanka). In addition, higher Sulphur content of coal makes the sea water flue gas desulphuration process inefficient. Thus, adhering to the above norms, Supercritical power generation can lead less impact to the environment by leaving ambient air shed for further developments.

4.4 Assessment on NO_x emission prediction

Predicted ground level maximum 01 hour average NO_x concentrations are not complied with the respective ambient air quality standards except in the case of Scenario C. NO_x emission factors used for calculating the emission loadshadalsoconsidered the impacts of abatement methods (staged burners used for NO_x reduction). However due to lower efficiency of combustion technology and the pollution control methods, rate of NO_x emitting along with flue gases were significantly high, whereas over 790 receptor locations (from 6400 receptors) in the modeling domain exceeds the respective AAQ standard.

Air staged low NO_x burners typically have the NO_x reduction capability of 25 – 35% reduction, while fuel staged type burners can achieve more than 50% reduction (European Commission, 2006). Existing LakVijaya Power Plant uses both air and fuel staged technology for NO_x control (As per the information from plant engineer).However the theoretical efficiency could not be achieved in practical situation. Since the emission loads for Scenario A and B were calculated based on the emission factors derived from the LakVijaya power plant, it is evident that NO_x emission could not be controlled during higher capacity power generation by using low NO_x burner systemalone.Insuper critical condition, higher boiler pressure elevates the boiler temperature and the average temperature of heat addition. Thus, the steam cycle efficiency increased and thermal NO_x formation gets reduced. It will support the reduction of pollutants generation even with higher capacity of power generation.

The results show that maximum NO_x emission concentrations were detected in North East and South West direction to the stack locations of the power plants within 5 km boundry.

4.5 Impact of stack height on ground level pollutant concentration

The impact of stack height for the ground level NO_x concentration was investigated and the following table 4.4 shows the predicted ground level concentration.

The results show that, stack height is much important in flue gas dispersion to ensure a low impact on air quality. In case of Scenario A (installation of 4 x300MW coal PP units), although the stack height increase was led to reduce the ambient NO_x concentration, it was not adequate enough to reach to therespective AAQ standard.

Table 4.4 Impact of Stack height variation for ground level NO_x concentration

Scenario	Maximum Ground Level NO_x concentration for different stack heights ($\mu g/m^3$)				
	150 m	200 m	250 m	275 m	300 m
01 Hour Average					
Scenario A – Case Study 04	**807.894***	**705.684***	**572.734***	**496.054***	**436.456***
Scenario B – Case Study 08	**465.030***	**378.540***	**290.125***	**264.727***	249.809
08 Hour Average					
Scenario A – Case Study 04	**211.436***	**160.389***	126.976	112.014	102.483
Scenario B – Case Study 08	129.329	100.194	96.221	95.026	93.816

*Not comply with the respective AAQ standard

For Scenario B, stack height of 300m would only be supportive in achieving the ambient NO_x concentration marginally. Although that stack height of 300m is possible, it would not be economically feasible for a country like Sri Lanka.Number of grid points exceeding the maximum permissible level for all studied stack heights are mentioned in following table.

Table 4.5 Number of grid points exceeding the Maximum Permissible Level – Scenario B

Stack Height (m)	Concentration Range ($\mu g/m^3$)	Number of exceeding points
200	250 – 300	137
	300 – 350	49
	350 - 400	10
250	250 – 300	59
275	250 – 300	13

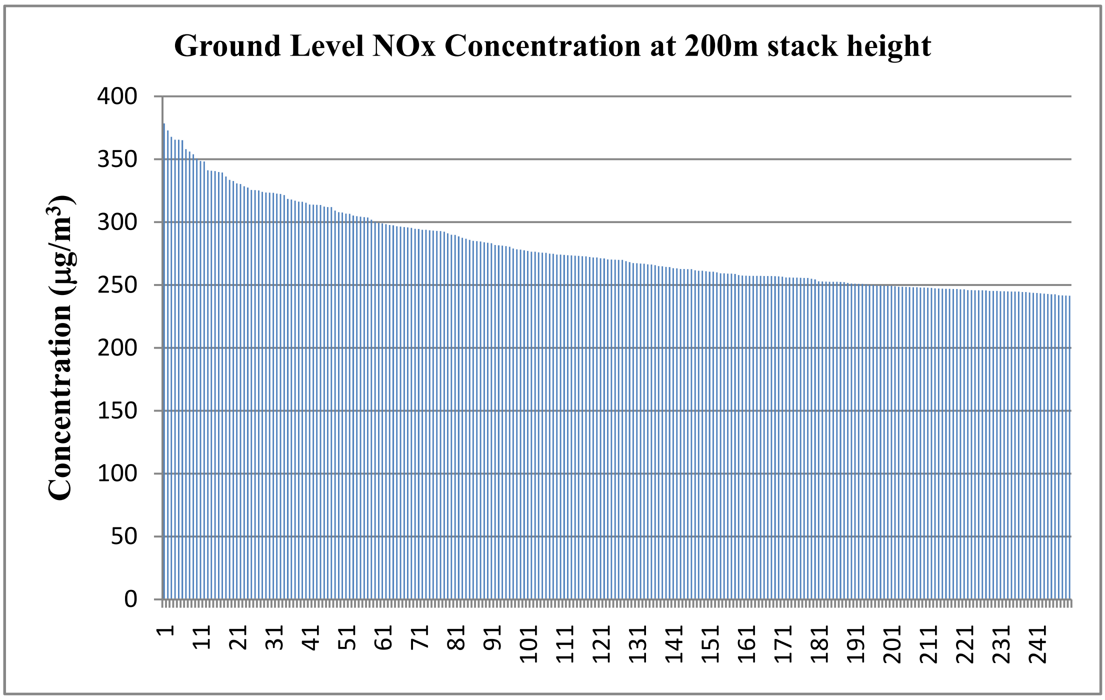


Figure 4.1 Ground Level NOx concentration variation at 200m Stack Height

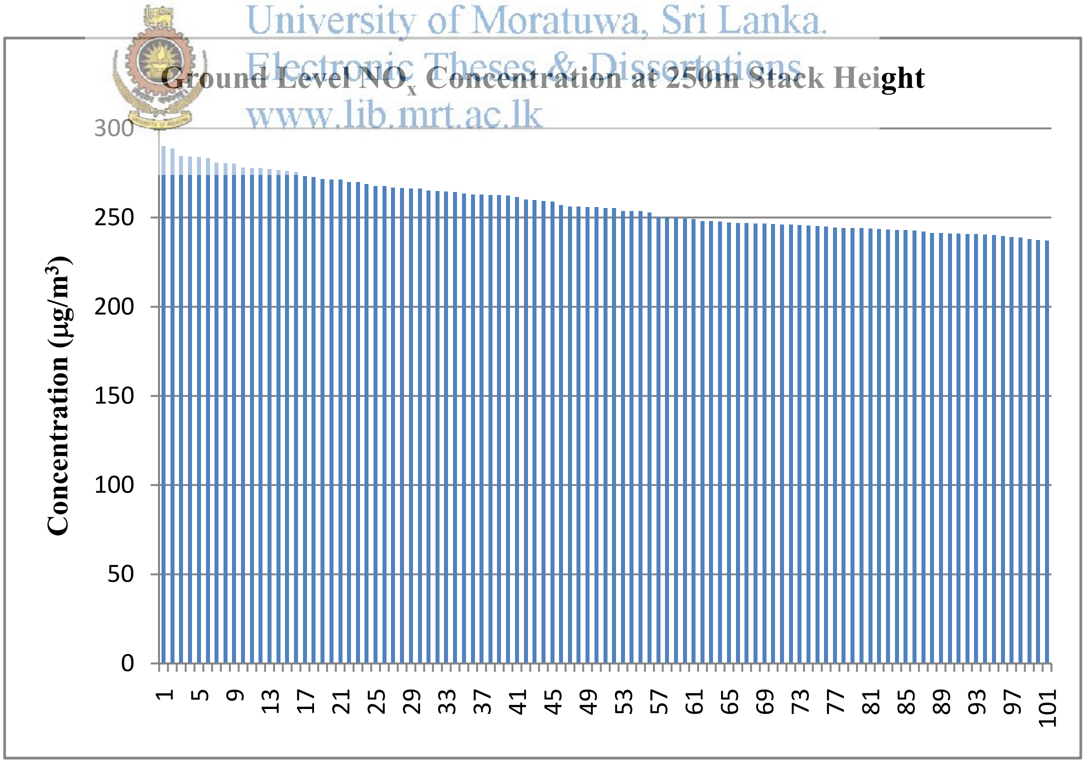


Figure 4.2 Ground Level NOx Concentration Variation at 250m Stack Height

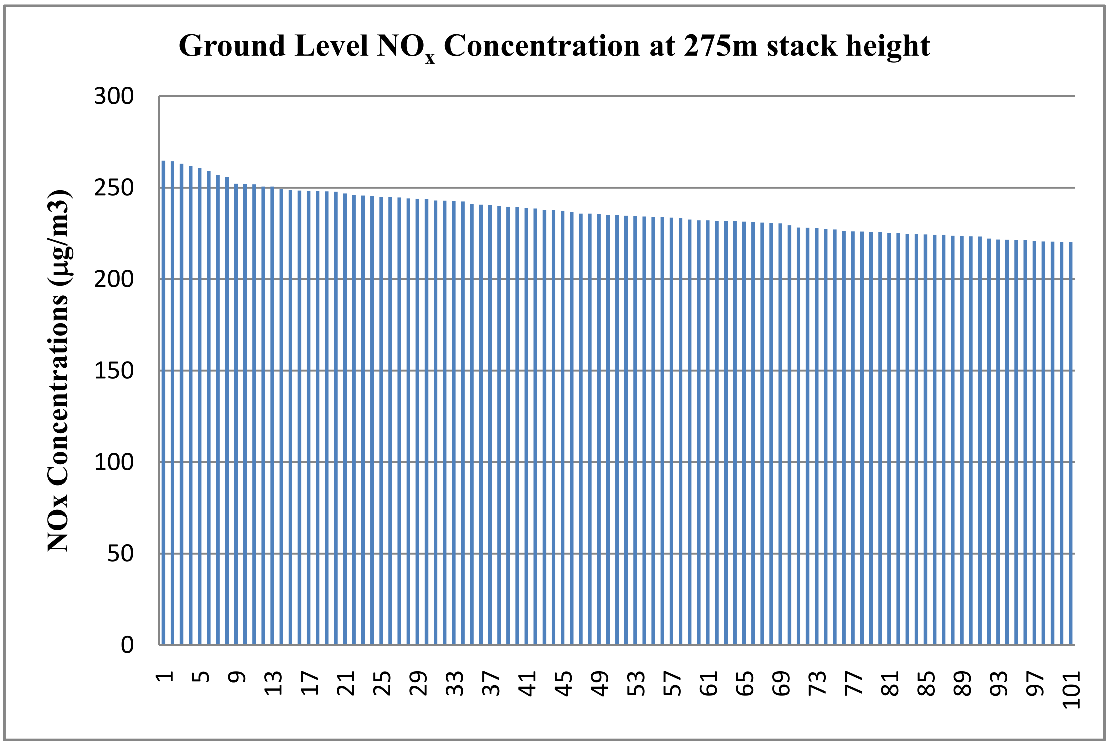


Figure 4.3 Ground Level NOx Concentration Variation at 275m Stack Height

The following figure shows the pollutant concentration variation with increasing height of stack.

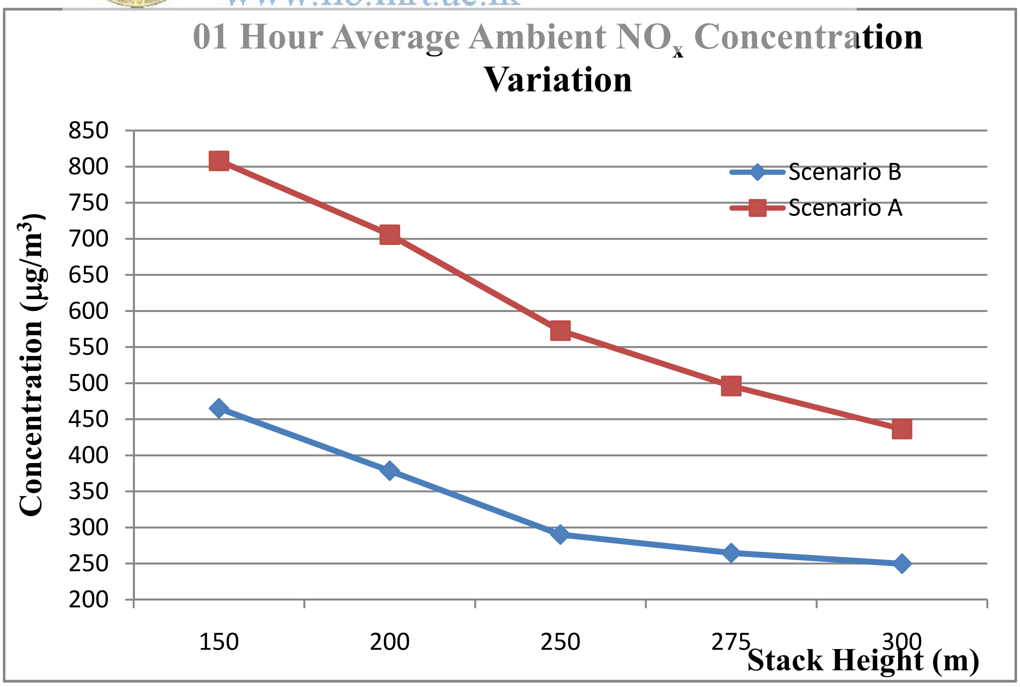


Figure 4.4- 01 Hour Average Maximum Predicted Ambient NO_x concentration variation with stack height

The results from the air dispersion model had shown that the unnecessary increase of stack height would not support to control ambient NO_xconcentration derived from scenario A and B. In addition, higher NO_x emission concentration could not be reduced by adapting most common combustion control technologies such as low NO_xburner systems. In such case reheating the flue gas can improve the dispersion through increase of discharge gas buoyancy under higher temperature or else by having a higher stack gas exit velocity. But, there are limits to the level of NO_x control that can be achieved with combustion controls and other means described above. Therefore, post combustion controls are important to achieve very low emissions of NO_x. Combustion NO_x controls and post combustion NO_x controls can often be used in combination to achieve the required level.

Selective Catalytic Reduction is a post combustion NO_x control system that is placed in between economizer and air pre heater which is capable of achieving greater than 90% removal efficiency. Ammonia is used as a reagent that reacts with NO_x on the surface of a catalyst and the preferred temperature is in the range of 170 - 510°C (European Commission, 2006).One of the major drawbacks associated with SCR technology is that incomplete reaction of NH_3 with NO_x may result in the formation of Ammonium Sulphates which tends to increase the amount of NH_3 in flue gas desulphuration wastewater and increase the concentration of NH_3 in fly ash. In addition, this technology is not yet developed in Sri Lanka due to high capital investment associated with it. According to the literature review the following table 4.4 indicates the costs associated with different technologies used for NO_xreduction. The expensive catalyst material and separate reactor needed for SCR result in a capital cost in the range of 200 – 350 $/ kW. In addition to the operating cost associated with the reagent, SCR requires relatively small quantities of replacement catalyst material. Though that the cost of catalyst has fallen over recent years, still it can amount 70% of the reagent cost, making the operation of an SCR unit generally more costly. (Lockwood, October 2013)

Considering Super Critical PC Power plants are emerging technology in Asian region where it could be provided reliable, cost effective power on a continued basis. For a comparably sized plant, engineering, procument and construction cost for a supercritical unit is 2 – 5 % higher than that of a sub critical unit. Operation and maintenance cost are about the same for both designs. (Nalbandian, May 2008)However overall economics are more favorable with respect to the SC PP, because of the increase in cycle efficiency. In a typical Pulverized Coal PP, fuel accounts for 60 – 80 % of the total operating cost. Hence increase in efficiency would result an annual coal saving of 17%, which is about 16.65 million US $ per year. (Pulverised Coal Combustion with higher efficiency, 2008) This saving can offset the slightly higher capital cost involvement with SC technology.

Table 4.6 Estimates of NOx control costs for different size boiler retrofits in China ((ESMAP), May 2001)

Control	300 MW		600 MW		800 MW	
	1000 US$	$ / kW	1000 US$	$ / kW	1000 US$	$ / kW
BCM (wall*)	876	2.9	1,720	2.9	2,349	2.9
OFA*	802	2.7	1,113	1.9	1,115	1.4
LNB*	4,049	13.5	7,662	12.8	10,325	12.9
LNCFS I†	2,243	7.5	4,246	7.1	4,891	6.1
LNCFS II†	4,810	16.0	6,624	11.0	7,787	9.7
LNCFS III†	6,263	20.9	9,109	15.2	10,230	12.8
GR	1,909	6.4	2,930	4.9	NA††	NA
FLGR	789	2.6	NA	NA	NA	NA
SNCR	2,704	9.0	3,833	6.4	NA	NA
SCRʃ	**15,314**	**51.0**	**28,723**	**47.9**	**37,520**	**46.9**

*Wall fired units – 300MW boiler has 20 burners; 600 MW boiler has 40 burners (20 each on opposed walls in five columns); 800 MW boiler has 48 burners (24 each on opposed walls in six columns)

† T-fired units – 300MW boiler has a single furnace with 5 levels (20 fuel injectors); 600 MW boiler has twin furnace with 5 levels (40 fuel injectors); 800MW boiler has twin furnace with 6 levels (48 fuel injectors)

ʃ SCR costs are based on 75% NO_x reduction on a unit with furnace exit NO_x levels – 650 mg/Nm^3 and using aqueous ammonia reagent.

†† NA – Not demonstrated at this size

BCM – Burner Component Modification
OFA – Overfire Air
LNB – Low NO_x burner (For wall fired boilers)
LNCFS – Low NO_x concentric firing System (For tangential fired boilers – LNCFS I, II and III provide progressively greater NO_x reduction)
SNCR& SCR – Selective Non Catalytic Reduction & Selective Catalytic Reduction
GR – Conventional Gas Reburn
FLGR – Fuel Lean Gas Reburn

According to the above analysis, it is evident that Super Critical Pulverized Coal combustion technology is more desirable in relation to the economical as well as environmental perspective.

4.6 SO_2 concentration on Population cluster locations

Ambient air SO_2 concentration variation in populated locations was investigated by placing descrete receptors at Sampoor town, Mutur Town and Trincomalee town. According to the model outputs pollutants are concentrated to South West and North East Directions to the stack locations. Thus the impact was investigated by placing discrete receptors in heavily populated locations.Maximum predicted concentrations were tabulated in Table 4.5 as below.Ambient pollutant concentrations before implementing any plant (Mantec Consultants (Pvt) Ltd., 2015) was used for comparison the present and future conditions.

Table 4.7 Maximum Predicted ambient SO_2 concentration variation (01 hour average) at different locations

Location	Before implementation of any PP	Installation of TPCL PP 250MW (2 no.s)	Installation of 300MW PP (2no.s) **Scenario A**	Installation of 600MW PP (2no.s) **Scenario B**	Installation of 600MW Super Critical PP (2no.s) **Scenario C**
01 Hour Average Concentrations (µg/m^3)					
Mutur	7 – 13	37.149	44.590	40.383	38.919
Sampoor	6 – 12	27.763	58.146	46.754	33.263
Trincomalee	6 – 12	19.547	30.384	27.266	22.662

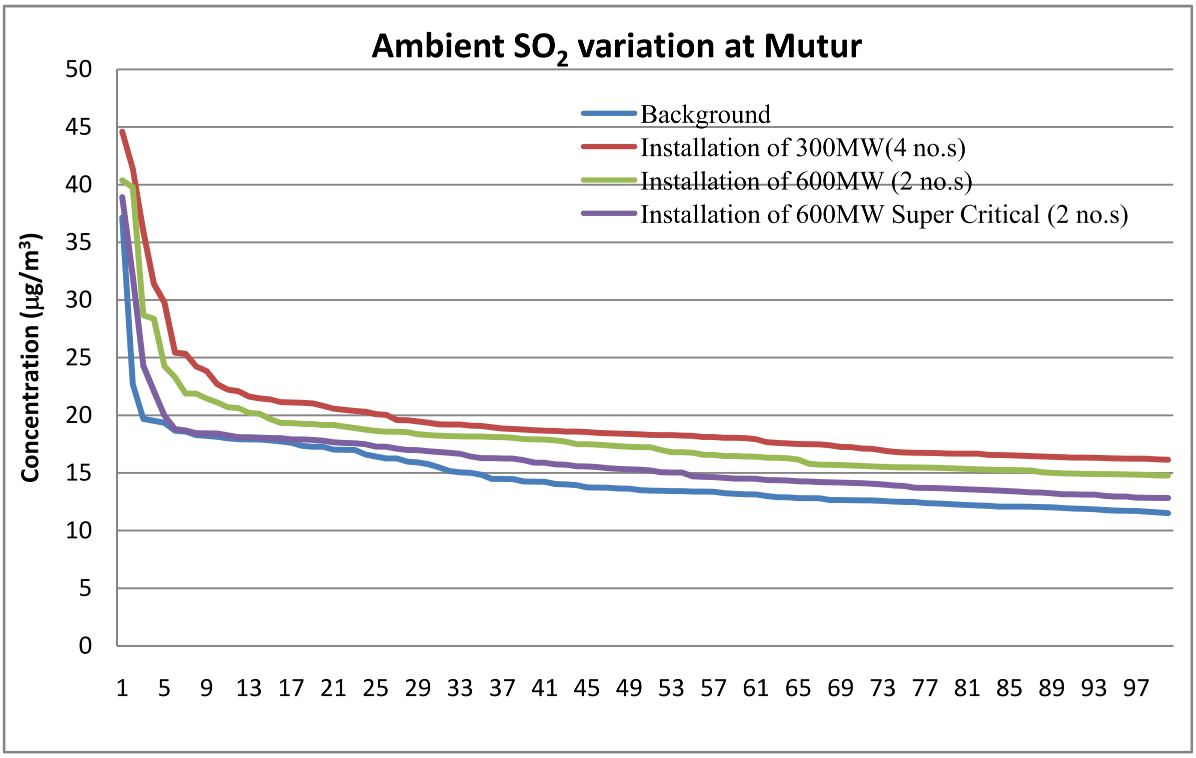


Figure 4.5 -01 Hour Average Ambient Sulphur Dioxide Concentration Variations at Mutur

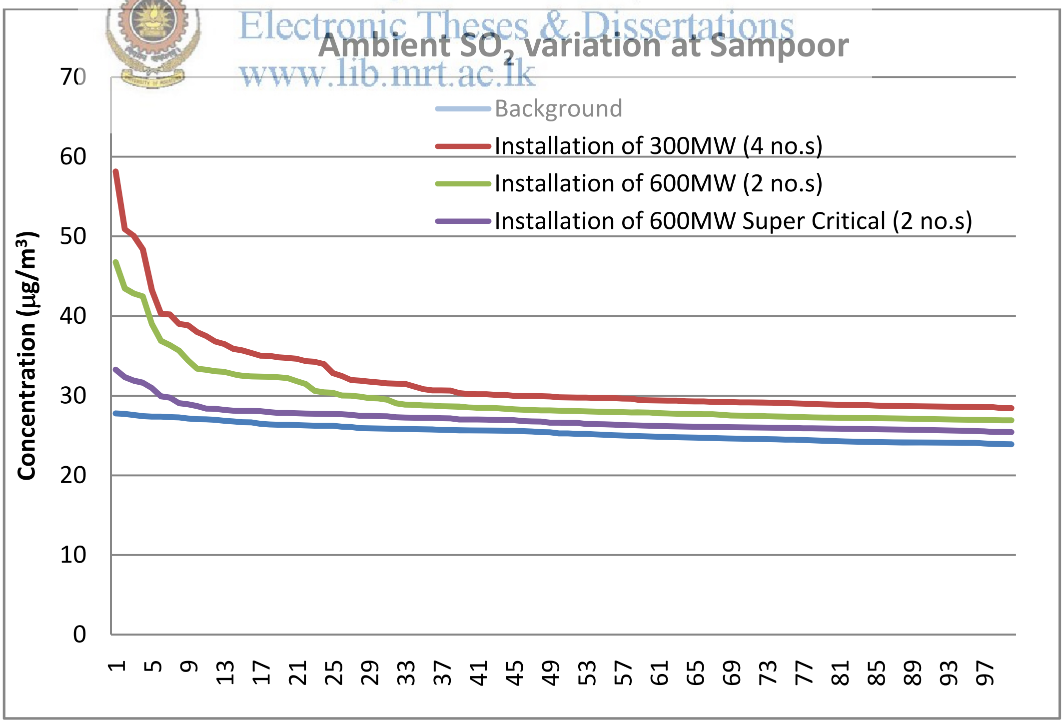


Figure 4.6 - 01 Hour Average Ambient Sulphur Dioxide Concentration Variations at Sampoor

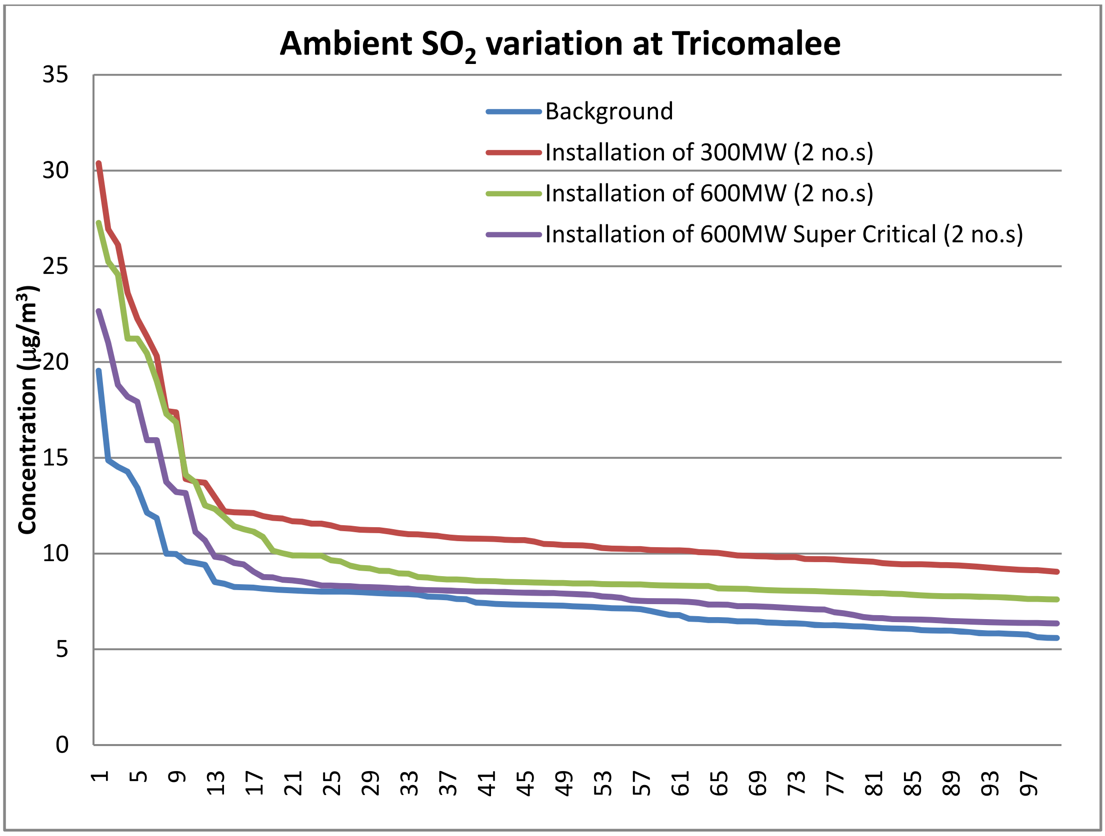


Figure 4.7 - 01 Hour Average Ambient Sulphur Dioxide Concentration Variations at Trincomalee

According to the measured SO_2 concentration in ambient air before implementation of any power plant and predicted values after installing power plants does not vary in a wide range. In any case higher concentrations were detected from the nearest location to the power plants. Among the three discrete receptors, receptor location in Sampoor experienced the highest concentration in all cases due to its proximity to the emission source.

4.7 NO_x concentration on Population cluster locations

Table 4.8 Maximum Predicted ambient NO_x concentration variation (01 hour average) at different locations

Location	Before implementation of any PP	Installation of TPCL PP 250MW (2 no.s)	Installation of 300MW PP (2no.s) **Scenario A**	Installation of 600MW PP (2no.s) **Scenario B**	Installation of 600MW SC PP (2no.s) **Scenario C**
01 Hour Average Concentrations ($\mu g/m^3$)					
Mutur	12 – 24	43.363	153.028	119.315	45.133
Sampoor	14 – 23	32.407	211.037	158.14	36.1
Trincomalee	12 – 22	22.817	94.362	79.881	25.932

NO_x emission is the major impact to the ambient air quality which would lead to higher concentrations. The highest pollution concentrations were experienced in nearest receptor location to the considered point sources.

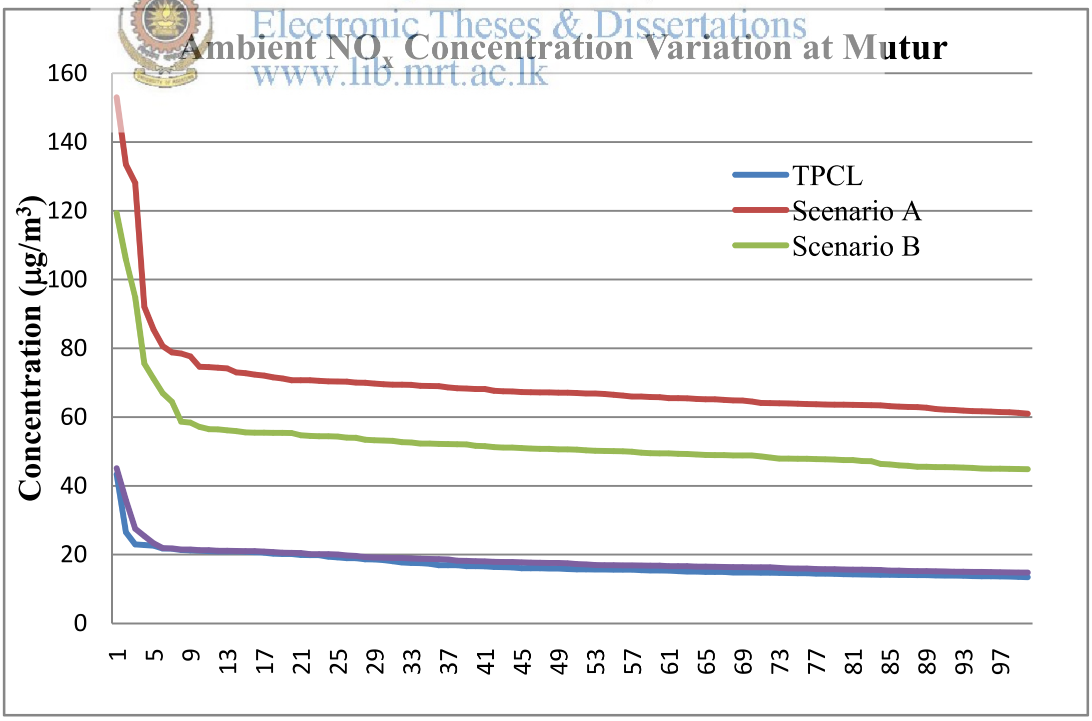


Figure 4.8 - 01 Hour Average Ambient Nitrogen Dioxide Concentration Variations at Mutur

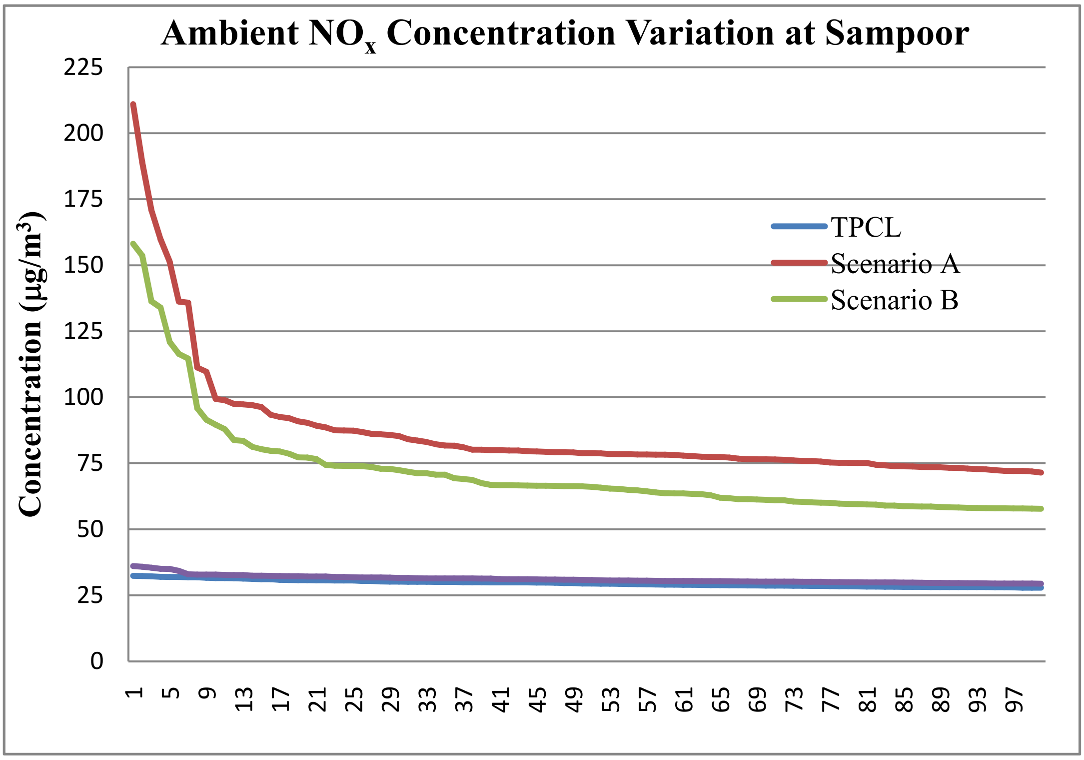


Figure 4.9 – 01 Hour Average Ambient Nitrogen Dioxide Concentration Variation at Sampoor

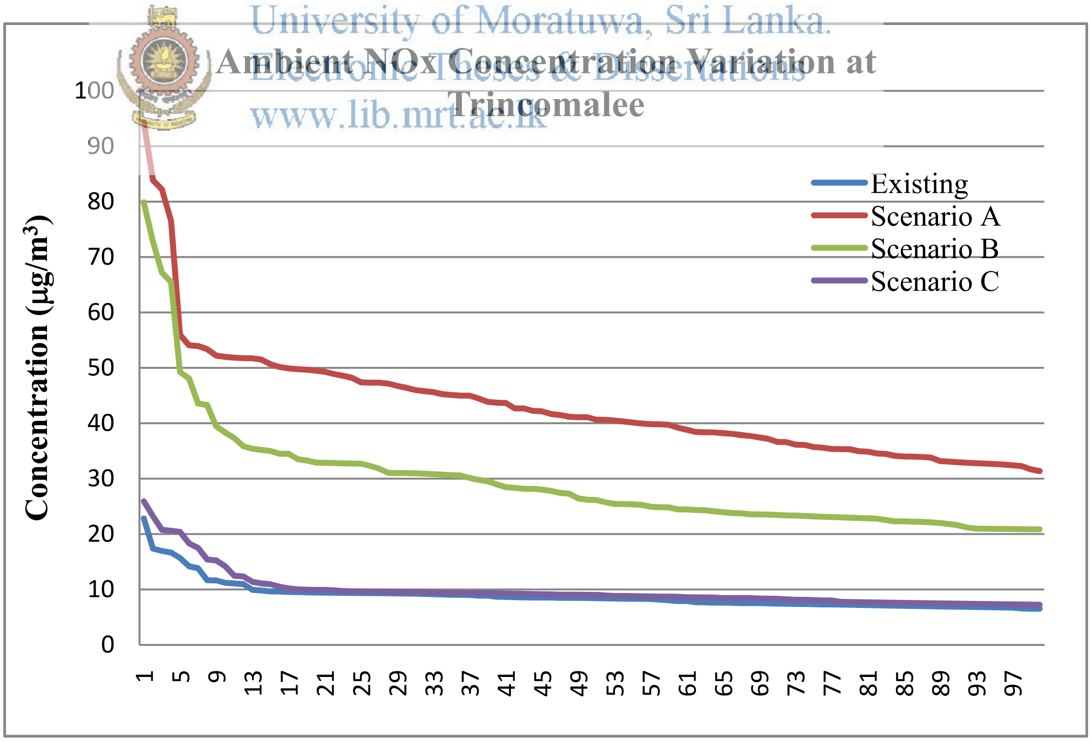


Figure 4.10 - 01 Hour Average Ambient Nitrogen Dioxide Concentration Variation at Trincomalee

Ambient air quality impacts from both SO_2 and NO_xemissionwerenot significantly high in case of implementation of 1200 MW Super critical PP (With background source). It seems that impact from the higher efficient (Greater than 41%) coal fired power plants is minimal than that of the same capacity and less efficient power plants.

4.8 Non Carcinogenic Health Risk Assessment

4.8.1 Hazard Identification

Under the hazard identification, adverse effects related to the substances of concern are discussed.

Table 4.9 The health effects of short term and long term exposure to specific pollutants

Pollutant	Effects related to short term exposure	Effects related to long term exposure
Sulphur Dioxide SO_2	• Increased visits to emergency departments and hospital admissions for respiratory illness, particularly in risk populations including children,elderly, and asthmatics • Breathing with a wistling sound • Chest tightness • Shortness of breath	• Include respiratory illness, alterations in the lungs • Moderate concentrations may cause inflammation of the respiratory tract: wheezing and lung damage • Defences and aggravation of existing cardiovascular dieseases
Nitrogen Dioxide NO_2	• Effects on pulmonary function, particularly in asthmatics • Increase in airway allergic inflammatory reactions • Increase in hospital admissions • Increase in mortality	• Reduction in lung function • Increased probability of respiratory symptoms

(Bake, Vanadzins, Seile, & Martinsone, 2011)

NO_2 is considered a relatively insoluble, reactive gas, such as phosgene and ozone. Short exposures to 100-500 ppm (190-900 mg/m^3) NO_2 may lead to sudden death. ((OEHHA), 2015)

Sulfur dioxide is a colorless gas with a pungent odor. It is a liquid when under pressure. Sulfurdioxide dissolves in water very easily. Once released into the environment, sulfur dioxide moves to the air. In the air, sulfur dioxide canbe converted to sulfuric acid, sulfur trioxide, and sulfates. Sulfur dioxide dissolves in water.Once dissolved in water, sulfur dioxide can form sulfurous acid.(Registry, December 1998)

Hazard associated with these substances are as a result of their intake into the body, mainly by inhalation through the respiratory tract. And the hazards of substances can be present as acute as well as chronic with local impacts which are generally either reversible or irreversible.

4.8.2 Determination of the dose (concentration) - response (effect) relation

Dose – Response information for non cancer health effects is used to determine Reference Exposure Levels. Inhalation RELs are air concentrations at or below which adverse non cancer health effects are not expected.As this study is mainly focused on criteria pollutants, non cancer risk assessment is carried out for acute RELs where chronic RELs are not defined in OEHHA (Office of Environmental Health Hazard Assessment) toxicological database or any other. Acceptable level for exposing to the substances of concern is derived using No Observed Adverse Effect Level (NOAEL) and by considering the appropriate uncertainty factors.

Table 4.10 Acute Inhalation Reference Exposure Levels ((OEHHA), 2015)

	Sulphur Dioxide, SO_2	Nitrogen Dioxide, NO_2
NOAEL (No Observed Adverse Effect Level)	0.25 ppm for 60 minutes	0.25 ppm for 60 minutes
Cumulative uncertainity factor	1	1
Reference Exposure Level	0.25 ppm (250 ppb; 0.66 mg/m^3, 660 $\mu g/m^3$)	0.25 ppm (250 ppb; 0.47 mg/m^3, 470 $\mu g/m^3$)

4.8.3 Exposure Assessment

Ambient pollutant concentrations predicted through the Air Dispersion Model which are presented in Table 4.1, 4.5 and 4.6 for maximum ground level concentrations and pollutant concentrations in population cluster locations had been used for the exposure assessment.

4.8.4 Risk Characterization

Hazard Quotient of SO_2 and NO_2 are computed to determine the short term (1-hr) non carcinogenic health risk.

For most chemicals with non-cancer effects, the non-cancer hazard quotient assumes that threshold level of exposure below which it is unlikely for even sensitive populations to experience adverse effects. If the exposure level (E) exceeds this threshold, there may be concern for potential non cancer effects. As a rule, the greater the value of HQ above unity, the greater the level of concern.

Table 4.11 Hazard Quotient computed for maximum predicted pollutant concentrations during short term exposure

Parameter	Background Condition (TPCL)	Scenario A	Scenario B	Scenario C	Reference Level of exposure
01 Hour Averaging Period (µg/m^3)					
SO_2	0.178	0.276	0.241	0.202	660
NO_x	0.292	**1.719**	0.989	0.319	470

Table 4.12: Hazard Quotient computed for SO_2 short term exposure

Location	TPCL PP 250MW (2 no.s)	300MW PP (2no.s) **Scenario A**	600MW PP (2no.s) **Scenario B**	600MW Super Critical PP (2no.s) **Scenario C**	Reference Level of exposure for SO_2 ($\mu g/m^3$)
Mutur	0.057	0.067	0.061	0.059	
Sampoor	0.042	0.088	0.071	0.050	660
Trincomalee	0.030	0.046	0.041	0.034	

Table 4.13: Hazard Quotient computed for NO_2 short term exposure

Location	TPCL PP 250MW (2 no.s)	300MW PP (2no.s) **Scenario A**	600MW PP (2no.s) **Scenario B**	600MW Super Critical PP (2no.s) **Scenario C**	Reference Level of exposure for NO_2 ($\mu g/m^3$)
Mutur	0.092	0.326	0.254	0.096	
Sampoor	0.069	0.449	0.336	0.077	470
Trincomalee	0.049	0.201	0.170	0.055	

Based on HQs obtained for SO_2 and NO_2 (as higher percentage of$NO_x$is in the form of NO_2), no potential for adverse health effects could be expected except in case of 01 hour average maximum NO_x concentration under Scenario A. Thus, implementation of Scenario A will be most vulnerable for adverse health effects during short term dispersion of NO_x.

Since the same receptor location is exposed to the both pollutants that targets the same organ system, then the HQs for the individual substances are summed to obtain a Hazard Index (HI) for that target organ.

According to the results, short term health impacts could not be identified at population cluster locations which are nearby to the location of power plants to be developed.

Table 4.14: Hazard Index computed for NO_2 and SO_2 short term exposure

Location	TPCL PP 250MW (2 no.s)	300MW PP (2no.s) **Scenario A**	600MW PP (2no.s) **Scenario B**	600MW Super Critical PP (2no.s) **Scenario C**
Mutur	0.149	0.393	0.315	0.155
Sampoor	0.111	0.537	0.407	0.127
Trincomalee	0.079	0.247	0.211	0.089

CHAPTER 05: CONCLUSION AND RECOMMENDATION

The three scenarios studied form the basis for these conclusions. Technology options, geo-physical parameters were incorporated into the modeling process. Clear conclusions can be derived as per the input data for the three scenarios. The conclusions presented correspond to the objectives for this research study stated in Chapter 1.

5.1 Conclusions related to study objectives

- Scenario A and B presents the subcritical pulverized coal combustion technology operating with different capacity distribution. According to the study, scenario B (600MW × 2 units) shows lesser environmental impact than that of Scenario A (300MW × 4 units). Thus, when considering ground level ambient air quality concentrations, it is more favorable to install the coal power plants with less number of units having higher capacity. Since Sampoor is committed to install 500MW capacity coal power plant, implementation of either A or B scenario in the same area cannot be accepted as it could not be able to achieve the required ambient air quality standards.

Table 5.1. Ground Level concentration variation of Scenario A and B
(For Different capacity Distribution)

	SO_2 (µg/m^3)			NO_2 (µg/m^3)		
	01 Hr	08 Hr	24 Hr	01 Hr	08 Hr	24 Hr
Scenario A (300MW × 4 units)	182.269	54.134	25.082	**807.894***	**211.436***	82.734
Scenario B (600MW × 2 units)	158.810	52.368	21.728	**465.030***	129.329	64.448

*Not comply with the respective AAQ standard

- The study reveals that high efficiency coal power plant can be satisfactorily employed in a place where degraded air quality is already prevailed. High efficient supercritical coal power generation technology is more preferable in relation to environmental as well as economical perspective. Rather than sub critical units, implementation of super critical units (with same capacity) enable to remain the ambient air shed for further development activities.

Table 5.2. Ground Level concentration variation of Scenario B and C (Different technologies for the same capacity)

	SO_2 (μg/m^3)			NO_2 (μg/m^3)		
	01 Hr	08 Hr	24 Hr	01 Hr	08 Hr	24 Hr
Scenario B Sub Critical (600MW × 2 units)	158.810	52.368	21.728	**465.030***	129.329	64.448
Scenario C Super Critical (600MW × 2 units)	133.068	47.843	21.384	150.124	54.960	24.957

- The AERMOD modeled isopleths show that the either short term or long term SO_2 concentrations were not exceeded the corresponding ambient SO_2 concentrations for 01 hr (200 μg/m^3), 08 hr(120 μg/m^3)or 24 hr (80 μg/m^3) average in Ambient Air Quality Standards. Hence, Sea water desulphuration mechanism which has removal efficiency greater than 89% can be satisfactorily employed to control SO_2 emissions generated through either scenario A (300MW × 4), B (600MW × 2) or C (Super Critical 600MW × 2). AEROMOD system has applicability for a 50 km radius for both simple and complex terrain.

- Super critical power plant (presented in scenario C) can use coal with high Sulphur content (about 2.5% Sulphur level). However for less efficient subcritical units cannot go beyond 0.8% Sulphur levels in coal. Thus, fuel with higher Sulphur content is acceptable for power plants having higher efficiency.

- Increasing the stack height can be used to reduce higher ground level pollutant concentration. However, increase of stack height alone would not be support in reducing the ground level pollutant concentrations upto the relevant ambient air quality standard. Thus, combination of higher stack height and relevant pollution control measures would be able to achieve the required environmental condition.

- Hazard Quotient derived from the acute risk assessment of substances in concern were well below unity which indicates that main population cluster locations around the area of concern will not be affected due to inhalation of SO_2 and NO_x which disperse during short term averaging periods from the coal power facilities.

- As Sampoor is one of the emerging areas of industrial developments, ambient NOx concentration should not compromised only due to installation of power plants. NOx emission from subcritical pulverized coal fired power plants which generate high thermal output (presented in Scenario A and B) cannot be reduced to achieve the desired level by using combustion controls alone. Hence it is required to take post combustion controls such as Selective Catalytic Reduction measures which provide more than 75% removal efficiency with the combination of combustion controls. According to the comparison of two technologies in the analysis in chapter 04 to reduce NOx emission, Installation of Coal Power plants with Super Critical technology is more beneficial with regard to the environmental as well as economical aspects.

- Meteorological condition of the Sampoor shows that wind is pre dominantly blown from the South West direction, where plume emitted from the stack is mainly dispersed to the North East direction with some occasional plume penetration in South West direction. Thus, highest ground level concentrations could be seen in these directions. And it could be concluded that stack plume will not be dispersed into the center of the island which will cause adverse impacts on human health and the plantations of the country inside.

5.2 Recommendations

- According to the Long Term Generation Expansion Plan of CEB, suggestion made on installing next coal power plant at Sampoor is effective in relation to avoiding the air quality impacts towards the country inside.

- High efficient supercritical technology is the most preferable option to develop of 1200MW capacity coal power plant at a site which is already committed to installation of another coal power plant (like Sampoor).

- During the industrial development of the site having more than one coal power plant, industry compatibility has to be assessed before it comes into the stream. Before implementing any industry having air pollution problem near the site, it should be checked whether the location is suitable for the purpose.

5.3 Future Research Work

Coal fired power plant has been known to emit pollutants such as heavy metals and other hazardous air pollutants such as Hydrogen Fluoride, Hydrogen Chloride, Dioxins and Furans along with the flue gas. Some of these emissions are contributing to global warming as well as causing adverse effects on human health. Coal combustion is already a controversial issue debated around the world, prompting various studies on its adverse effects. In Sri Lanka, source emission regulation is not yet published and safe exposure levels for hazardous air pollutants which can be generated from coal combustion facilities have not yet regulated. Therefore necessity is existed to evaluate the health risks from the hazardous air pollutants for the population living in the vicinity of a coal Power plant. This is crucial due to the increase in coal consumption for power generation.

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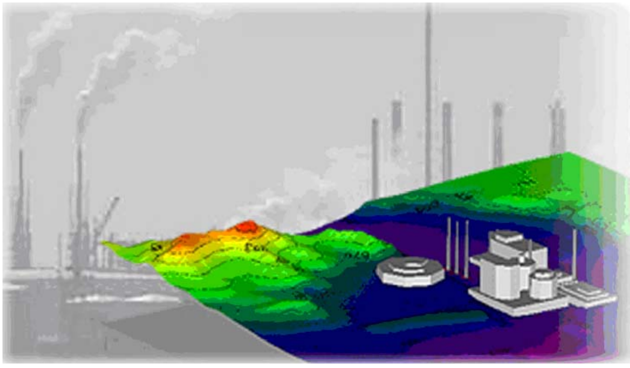
Appendix – I

Model Description

Model Description

'AERMOD View' is a complete and powerful air dispersion modeling package which seamlessly incorporates the following popular U.S. EPA air dispersion models into one integrated interface.

1. AERMOD
2. ISCST3
3. ISC-PRIME



These US EPA air dispersion models are used extensively to assess pollution concentration and deposition from a wide variety of sources.

- The AMS/ EPA Regulatory Model (AERMOD) is the next generation air dispersion model based on planetary boundary layer theory.
- The Industrial Source Complex – Short Term regulatory air dispersion model (ISCST3) is a Gaussian plume model and is widely used to assess pollution concentration and/or deposition flux on receptors from a wide variety of sources.
- The industrial Source Complex – Plume Rise Model Enhancements (ISC-PRIME) dispersion model is similar to the ISCST3 model, but contains enhanced building downwash analysis.

AERMOD utilizes a similar input and output structure to ISCST3 and shares many of the same features, as well as offering additional features. AERMOD fully incorporates the PRIME building downwash algorithms, advanced depositional parameters, local terrain effects, and advanced meteorological turbulence calculations.

Table 1. Technical Specifications – AERMOD

Parameter	**Description**
Model Name	AERMOD
Developed By	AERMIC - (American Meteorological Society (AMS) and United States Environmental Protection Agency (US EPA)
Model Type	Steady-state Gaussian plume air dispersion model
Range	Up to 50km from the source
Atmospheric Stability Model	Planetary boundary layer theory, turbulence scaling concepts
Wind Field	Homogeneous
Release Types	Buoyant or neutrally buoyant plumes
Emission Types	Constant or time-varying, planned or fugitive
Atmospheric Chemistry	NO_X to NO_2 and SO_2 decay
Source Types	Point, area, volume, open pit, line*, flare*
Meteorology	Hourly surface and upper air data (processed by AERMET)
Terrain	Flat or elevated (terrain processed by AERMAP)
Receptors	Several types of grids (Cartesian, polar) and discrete receptors
Other Options	Building downwash (modelled by BPIP-PRIME)
Regulatory Status	Preferred US EPA regulatory model for near-field applications

* Pseudo source types

[Source: www.weblakes.com]

Table 2. Technical Specifications – ISCST3

Parameter	Description
Model Name	ISCST3 - Industrial Source Complex Short Term model (US EPA)
Developed By	United States Environmental Protection Agency (US EPA)
Model Type	Steady-state Gaussian plume air dispersion model
Time Step	1 hour
Range	Up to 50km from the source
Terrain	Flat and elevated
Building Downwash	Modelled by BPIP
Source Types	Point, area, volume, open pit, line*, flare*
Input Meteorology	Hourly surface data and mixing height data (through PCRAMMET)
Atmospheric Stability Model	Pasquill-Gifford Stability Classes
Wind Field	Homogeneous
Release Types	Buoyant or neutrally buoyant plumes
Emission Types	Constant or time-varying, planned or fugitive
Atmospheric Chemistry	NO_X to NO_2 and SO_2 decay
Regulatory Status	Former US EPA regulatory model for near-field applications

* Pseudo source types

[Source: www.weblakes.com]

Table 3. Technical Specifications – ISC-PRIME

Parameter	Description
Model Name	ISC-PRIME model
Developed By	United States Environmental Protection Agency (US EPA)
Model Type	Steady-state Gaussian plume air dispersion model
Time Step	1 hour
Range	Up to 50km from the source
Terrain	Flat and elevated
Building Downwash	Modeled by BPIP-PRIME
Source Types	Point, area, volume, open pit, line*, flare*
Input Meteorology	Hourly surface data and mixing height data (through RAMMET)
Atmospheric Stability Model	Pasquill-Gifford Stability Classes
Wind Field	Homogeneous
Release Types	Buoyant or neutrally buoyant plumes
Emission Types	Constant or time-varying, planned or fugitive
Atmospheric Chemistry	NO_X à NO_2 and SO_2 decay
Regulatory Status	Former US EPA regulatory model for near-field applications

* Pseudo source types

[Source: www.weblakes.com]

Appendix – II

National Ambient Air Quality Standard

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The Gazette of the Democratic Socialist Republic of Sri Lanka
EXTRAORDINARY

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No. 1562/22 - FRIDAY, AUGUST 15, 2008

(Published by Authority)

PART I : SECTION (I) — GENERAL

Government Notifications

L.D.B. 4/81.

THE NATIONAL ENVIRONMENTAL ACT, No. 47 OF 1980

REGULATIONS made by Minister of Environment and Natural Resources under Section 32 of the National Environmental Act, No. 47 of 1980.

PATALI CHAMPIKA RANAWAKA,
Minister of Environment and Natural Resources.

Colombo,
13th August, 2008.

Regulations

The National Environmental (Ambient Air Quality) Regulations, 1994, published in *Gazette Extraordinary,* No. 850/4 of December, 1994 are hereby amended by the subsitution for the Schedule to that regulation of the following :-

"SCHEDULE

Pollutant	*Averaging Time**	*Maximum Permissible Level*		*+ Method of measurement*
		μgm^{-3}	*ppm*	
1. Particulate Matter - Aerodynamic diameter is less than 10 μm in size (PM_{10})	Annual	50	—	Hi-volume sampling and Gravimtric or Beta Attenuation
	24 hrs.	100	—	
2. Particulate Matter - Aerodynamic diameter is less than 2.5 μm in size ($PM_{2.5}$)	Annual	25	—	Hi-volume sampling and Gravimtric or Beta Attenuation
	24 hrs.	50	—	

SCHEDULE *(Contd.,)*

Pollutant	*Averaging Time**	*Maximum Permissible Level*		*+ Method of measurement*
		μgm^{-3}	*ppm*	
3. Nitrogen Dioxide (NO_2)	24 hrs.	100	0.05	Colorimetric using saltzman Method or equivalent Gas phase chemiluminescence
	8 hrs.	150	0.08	
	1hr.	250	0.13	
4. Sulphur Dixoxide (SO_2)	24 hrs.	80	0.03	Pararosaniliene Method or equivalent Pulse Flourescent
	8 hrs.	120	0.05	
	1hrs.	200	0.08	
5. Ozone (O_3)	1 hr.	200	0.10	Chemiluminescence Method or equivalent Ultraviolet photometric
6. Carbon Monoxide (CO)	8 hrs.	10,000	9.00	Non-Dispersive Infrared Spectroscopy"
	1 hr.	30,000	26.00	
	Any time	58,000	50.00	

* Minimum number of observatons required to determine the average over the specified period —

03 hour average	-	03 consecutive hourly average
08 hour average	-	08 hourly average
24 hour average	-	18 hourly average
Yearly average	-	09 monthly average with at least 02 monthly average each quarter.

\+ By using Chemicals or Automatic Analysers.

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Appendix – III

Model Outputs