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RESEARCH REPORT

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Costs and Benefits Of Flue Gas Desulfurization For Pollution Control At The Mae Moh Power Plant, Thailand

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This study provides a cost-benefit analysis of the flue-gas desulfurization (FGD) systems installed at the Mae Moh power station in northern Thailand. A 'before and after' study focused on the impact this air pollution cleanup technology had on human health in the area surrounding the power plant. Impacts on local agricultural and forest productivity are also assessed. The setup and operational costs of the plant, along with other key costs, are compared with the economic value of all the benefits that the FGD systems will bring over their twenty-five year lifespan.

The study finds that this cleanup technology has not been cost effective at this site – in other words it is an economic burden, rather than a benefit, to society. While the study acknowledges that the pollution clean up has had many positive benefits, it argues that cheaper options could have been considered

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LIST OF ABBREVIATIONS AND CONVERSION RATES

BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
COI	Cost of illness
CPH	College of Public Health (*Thailand*)
CPI	Consumer price index
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental impact assessment
eq./ha/yr	Equivalent per hectare per year
FGD(s)	Flue Gas Desulfurization (systems)
FIO	Forest Industry Organization (*Thailand*)
GBH	Girth at breast height
GPP	Gross Provincial Product
GWh	Gigawatt hour
IRR	Internal rate of return
km.	Kilometer
KWh	Kilowatt-hour
LSD	Least significant difference
m^3	Cubic meter
MAI	Mean annual increment
MW	Megawatt
NGOs	Non-governmental organizations
NPV	Net present value
NTFPs	Non-timber forest products
O&M	Operating and maintenance
OR	Odds ratio
PCD	Pollution Control Department (Thailand)
ppm	Parts per million
PV	Present value
PVB	Present value of benefits
PVC	Present value of costs
SO_2	Sulfur dioxide
WTP	Willingness to pay

$\mu g/m^3$ microgram per cubic meter

Conversion Rates

The exchange rate before July, 1997 was 1 US dollar for approximately 25 baht. As at January, 2006 it was about 40 baht (official exchange rate available at Bank of Thailand website (www.bot.go.th).

1 rai = 0.16 hectare or 1 hectare = 6.25 rai

1 ppm = 2,620 $\mu g/m^3$ (approximate)

COSTS AND BENEFITS OF FLUE GAS DESULFURIZATION FOR POLLUTION CONTROL AT THE MAE MOH POWER PLANT, THAILAND

Varaporn Punyawadee, Ratana Phothisuwan, Numpet Winichaikule, and Kanitta Satienpeerakul

EXECUTIVE SUMMARY

The Mae Moh power plant is the largest lignite-fired thermal power plant in Thailand using lignite with high sulfur content as fuel. The high sulfur dioxide (SO_2) emitted from the plant in 1992 caused severe impacts to human health and ecosystems in the area. To ensure reductions in SO_2 emissions, eight units of wet scrubbing flue gas desulfurization systems (FGDs), which can absorb 92-97 per cent of SO_2 prior to discharge into the atmosphere, were installed at the Mae Moh power plant from 1994 to 2000. FGDs absorb gaseous SO_2 from flue gas and produce gypsum as a by-product which is collected for safe disposal or beneficial uses such as gypsum board. Since the complete installation of all the FGD systems in 2000, the recorded maximum hourly average ambient SO_2 concentrations have significantly declined from more than 3,000 micrograms per cubic meter in 1992 to less than 500 micrograms per cubic meter.

This study presents a detailed analysis of the economics of investments in the FGDs installed at the Mae Moh power plant in the northern region of Thailand to reduce the adverse environmental impacts resulting from sulfur dioxide emissions. The possible direct benefits associated with FGD controls investigated in this study include damage reductions in health morbidity, and agriculture and forest productivities, while gypsum is assessed as the byproduct of the abatement process. In addition to the direct costs of investments, the indirect costs of carbon dioxide emissions attributed to the FGD process are estimated. The incremental benefits and costs with and without the installation of the FGD equipment are analyzed by assuming an FGD lifespan of 25 years.

The quantification of the health end points in physical terms was carried out using dose-response relationships developed in an epidemiological study by the College of Public Health, Chulalongkorn University. Monetization of these effects used the cost of illness approach. The results were then converted to willingness to pay equivalents to reflect the full costs of avoiding morbidity health risks, including pain and discomfort. The Organisation for Economic Co-operation and Development (OECD) dose response function was applied to quantify reductions in agricultural damages and those of non-timber forest products in association with improved ambient sulfur dioxide concentrations attributable to FGD investments. Changes in productivity of teak forest plantations were statistically assessed using the Forest Industrial Organization database. Emissions of carbon dioxide were estimated from the chemical FGD process and valued using the optimal carbon tax.

Our findings of a negative net present value and a benefit-cost ratio of less than one suggest that FGD investments may not have reached economically efficient outcomes. The present value of benefits (calculated in 1994 prices) associated with the installation of FGDs at the Mae Moh power plant over their lifespan of 25 years is

approximately 4,700 million baht, which is about a third of the present value of total costs (13,800 million bath).

The estimates of benefits in FGD installation found that health impacts are a major component, accounting for almost 80 per cent of the total benefits. The increase in forest productivity contributes about 18 per cent, while benefits associated with agriculture and gypsum are less significant. On the composition of the FGD abatement cost, the initial capital costs account for almost 52 per cent while the operation and input costs contribute about 15 and 27 per cent of the total, respectively. As a result of the FGD chemical process, optimal marginal abatement costs of carbon dioxide emissions (which contribute to global warming) represent about 6.6 per cent of the total FGD costs.

A sensitivity analysis suggests that high uncertainties exist in the estimation. If the risk of premature mortality had been taken into account as suggested by most of the health science literature, the FGD investments at the Mae Moh power plant would be financially justified. However, in this study, premature mortality was not taken into account in the base case analysis because there was no strong scientific evidence to support the association between health mortality and exposure to high levels of ambient SO_2 concentrations. Also, we did not have sufficient data for a detailed investigation.

Electricity consumption in Thailand has increased by approximately 70 per cent over the past decade due to economic growth and increase in population. Lignite, which is one of the main indigenous sources of fuel used in electricity production, remains a significant source of energy in Thailand. However, lignite and other fossil fuels combustion in electricity generation cause environmental problems especially air pollution. The lessons that we learn from the case of the Mae Moh power plant indicate that careful strategic planning for appropriate environmental protection measures by government authorities is very important for future electricity development projects, not only in terms of technical capabilities but also in economic and social considerations.

1.0 INTRODUCTION

The Mae Moh power plant, with its 2,625 megawatt (MW) installation capacity, is the largest thermal lignite[1]-fired power plant in Thailand and in Southeast Asia, meeting approximately 18 per cent of the national power demand. There have been substantial environmental and social concerns regarding the operation of the plant especially after the first incidence of air pollution caused by it in 1992 when the expansion of the plant reached the capacity of 2,025 MW – apparently hitting the ecological carrying limit of the surrounding environment. An all-time high reading of the hourly average ground level of ambient sulfur dioxide (SO_2) concentration of 3,418 micrograms per cubic meter ($\mu g/m^3$) was observed as compared with the then hourly average Thai standard of 780 $\mu g/m^3$.

This abnormal increase in SO_2 emission levels caused many people in several villages near the power plant to suffer from respiratory symptoms such as cough, asthmatic attacks, chest tightness and wheezing. Many of them were hospitalized. In addition to the health impacts, damage to crops, trees and livestock was also reported.

[1] Lignite is also called brown coal, the lowest rank of coal in terms of quality.

Damage to rice, field crops and vegetables was obvious; the leaves of many trees withered and dropped overnight.

Negative reactions from the public, the affected people, non-governmental organizations (NGOs) and the media due to the 1992 and subsequent air pollution occurrences caused by the plant, and the high level of sulfur dioxide found in the air in the Mae Moh area accelerated the decision to retrofit FGDs to the eight remaining power generation units (unit 4-11), starting in 1994. This has resulted in substantially improved ambient air quality since the year 2000.

The primary objective of this study is to conduct a detailed retrospective study to assess the economic viability of the investments of FGD technology for the Mae Moh power plant, with the following specific objectives.

1. To identify and quantify in monetary values the relevant benefits associated with the installation of FGD systems i.e., the reduction in environmental damages.

2. To identify and assess economic costs of installing and operating FGD systems, including the potential global damages of carbon dioxide emissions generated by the FGD abatement process.

3. To conduct benefit-cost analyses of investments in FGD systems over their lifespan using standard capital investment measurements, i.e., net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR).

4. To determine the optimal level of pollution abatement in the case of FGD technology by assessing the benefits of pollution control and costs of abatement.

The report is organized into seven main sections. After the introduction in Section 1, Section 2 briefly considers the background of the environmental performance of the Mae Moh lignite-fired power plant both pre- and post- installation of the FGD systems in the power generation units. The relevant physical effects that could be attributed to FGD control technology are identified for setting up an analytical framework. Note that the study does not attempt to assess every possible damage caused by sulfur dioxide emissions from the power plant. In most cases, the data was not available and in some particular cases, we did not have strong evidence, such as loss of life and material damages, to support the hypothesis. Particular attention is focused on the benefits from improved morbidity health outcomes, and increase in productivity of agricultural and forest resources. Carbon dioxide emissions as an indirect cost of the desulfurization process are also considered. Section 3 presents details of research methods employed in this study. This section attempts to lay out the conceptual issues and theoretical framework to support our subsequent investigation of benefits and costs associated with FGD abatement technology. Sections 4 and 5 then examine and assess the benefits and costs attributed to FGD technology in the case of the Mae Moh power plant, respectively. These two elements come together in a benefit-cost analysis, the main subject in Section 6. Traditional measures including NPV and BCR are analyzed. A sensitivity analysis is performed for effects and factors with high uncertainty. Section 7 finally provides a summary and policy implications. All the tables supporting the contents are provided in Appendix A.

2.0 BACKGROUND OF THE STUDY

This section presents a brief description of the study site where the power plant is located. A brief introduction on the development of the plant and relevant information associated with the environmental impacts and the FGD mitigation measures is provided. The section ends with a summary of the physical impacts attributed to FGD technology.

2.1 Brief Description of the Study Site

The Mae Moh power plant is located in the Mae Moh valley in the Mae Moh District, 25 kilometers east of the province of Lampang in the northern region of Thailand (Figures 1 and 2). The province of Lampang is located 600 kilometers north of Bangkok and approximately 120 kilometers to the southeast of Chiang Mai province. Lampang covers an area of about 12,500 square kilometers, with a total forest area of about 71 per cent. The population in Lampang is about 0.79 million. Lampang's per capita Gross Provincial Product (GPP) was about the same as the northern region's average but 51 per cent lower than the national figure in 2003. Mining contributed about 17.4 per cent towards Lampang's GPP while agriculture contributed only 8.2 per cent. However, it should be noted that agriculture, which accounted for less than 10 per cent of the GPP, employed about 52 per cent of the total labor force. Of the total farmland in Lampang, about half was devoted to paddy rice, while 23 and 17 per cent were under fruit trees and field crops, respectively.

The Mae Moh District covers an area of approximately 855 square kilometers, of which about 70 per cent are mountainous. Most of it is situated within the national forest reserves. High hills surround the Mae Moh valley, particularly to the east and west. Passing almost north-south along the east is a huge limestone ridge. The district of Mae Moh has five sub-districts and 34 villages, with a population of approximately 40,000. The Gross District Product comes mainly from mining (23%) and agriculture (12%). Forty-four per cent of households are still engaged in traditional agriculture – the main crops include rice, pineapple, maize, chili, and vegetables. However, the economy relies heavily on the Mae Moh power plant and mine as the main source of income.

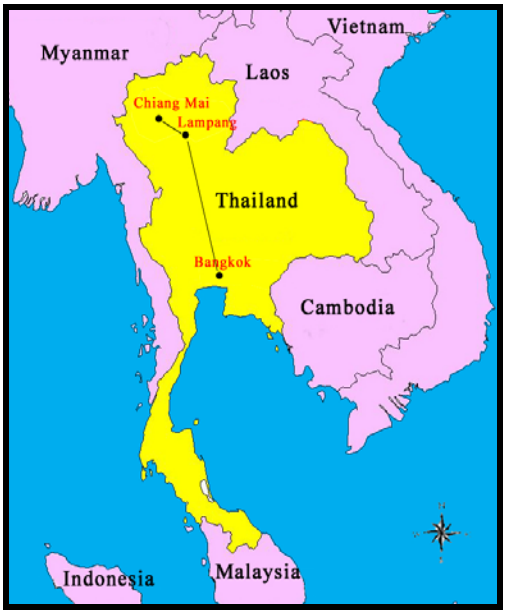

Figure 1. Map of Thailand, showing the location of Lampang

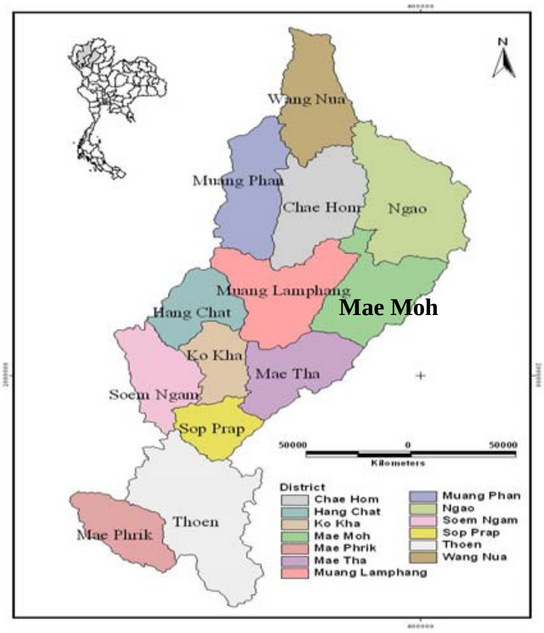

Figure 2. Map of Lampang Province

2.2 The Mae Moh Power Plant and Flue Gas Desulfurization Technology

Owned and operated by the Electricity Generating Authority of Thailand (EGAT), the first generation unit of the Mae Moh power plant was first operated in 1978 and gradually expanded until it reached the capacity of 2,025 MW with 11 operating units in 1992 when the first incident of excessively high ambient SO_2 (ground level one-hour average of 3,418 $\mu g/m^3$) occurred. This resulted in acute health damages to people and ecosystems. There was also an adverse psychological effect on the nation in terms of a negative perception of the lignite-fired power plant and distrust in EGAT.

Shortly after the 1992 incident, the Pollution Control Department (PCD) and EGAT jointly implemented several short-term and long-term measures to tackle the pollution problem. In response to considerable environmental and social concerns regarding the operation of power plants, the installation of the high investment wet scrubbing type FGD systems was urgently introduced as a long-term measure to effectively reduce SO_2 emissions to permissible levels.

The Mae Moh power plant's expansion to units 12 and 13 had to be equipped with FGD systems at the time of construction in 1993. EGAT's plan to set up the new Lampang power plant with an additional installed capacity of 2,400 MW was aborted due to the limited carrying capacity of the environment and the negative impacts on human health and the environment.

Table 1 summarizes the six main stages of the development of power generation facilities at the Mae Moh power plant. These are:

- Installation of units 1 to 3 rated at 75 MW each from 1978-1981
- Installation of units 4 to 7 rated at 150 MW each from 1984-1985

- Installation of units 8 to 11 rated at 300 MW each from 1989-1992
- Installation of units 12 to 13 rated at 300 MW each in 1995. Both units are fitted with FGD systems
- Retrofitting of FGD systems to units 8 to 11 from 1994-1998
- Retrofitting of FGD systems to units 4 to 7 from 1997-2000

Overall, the Mae Moh project comprised 13 lignite-fired generating units with a total power generation capacity of 2,625 MW. Units 1-3 were not equipped with FGD systems and have been permanently shut down since October 2003. With its current production capacity of 2,400 MW, the Mae Moh power plant is still the biggest thermal power plant in Thailand, supplying about 18 per cent of Thailand's power demand. Currently, all the operating units have been fully equipped with wet scrubbing type FGDs, i.e., there are eight FGD plants for the ten power generation units, each with a capacity of 300 MW. Their efficiency rate in removing SO_2 is between 92-97 per cent as compared with the efficiency rate of the dry type at 50-55 per cent.

The main fuel source for the Mae Moh power plant comes from the Mae Moh lignite mine. Approximately 17.5 million tons of lignite, is supplied to the generating units annually when they operate at full capacity. The Mae Moh lignite deposit occurs as a synclinal basin lining within a north-northeast basin 18.3 kilometers long by 8.8 kilometers wide, covering an area of 135 square kilometers. The total lignite reserves at the Mae Moh mine can sustain the power plant at the current production capacity for at least another 40 years i.e., approximately 771 million tons of lignite reserves are remaining. However, lignite from the Mae Moh basin has a high sulfur content ranging from 2.2 to 3.1 per cent with an average of about 2.5 per cent, 17-27 per cent ash, and 2,639 kilocalories per kilogram (kcal/kg.).

Over 500,000 tons of sulfur dioxide was emitted annually when the plant operated at full capacity without emission controls. Since the strict implementation of FGD technology, sulfur dioxide emissions have been controlled at rates far below the ambient standards. The amount of SO_2 emitted from power generation at the Mae Moh plant dropped to below 30,000 tons per year between 2001 and 2004 (Table 2 and Figure 3). Comparisons of the highest monthly maximum 1-hour average and 24-hour average of ambient SO_2 between pre-FGD and post-FGD periods at different EGAT air quality monitoring stations (AQMS) are also shown in Table 3. The monitoring stations surround the power plant at distances varying between 1.5 and 22 kilometers from the plant. These findings show that the current levels of sulfur dioxide in the areas surrounding the Mae Moh power plant are at permissible Thai standards.[2]

[2] The current Thai standards for 1-hour, 24-hour and 1-year ambient SO_2 are 780, 300 and 100 $\mu g/m^3$ respectively, compared with World Health Organization (WHO) standards of 350, 125 and 50 $\mu g/m^3$, respectively.

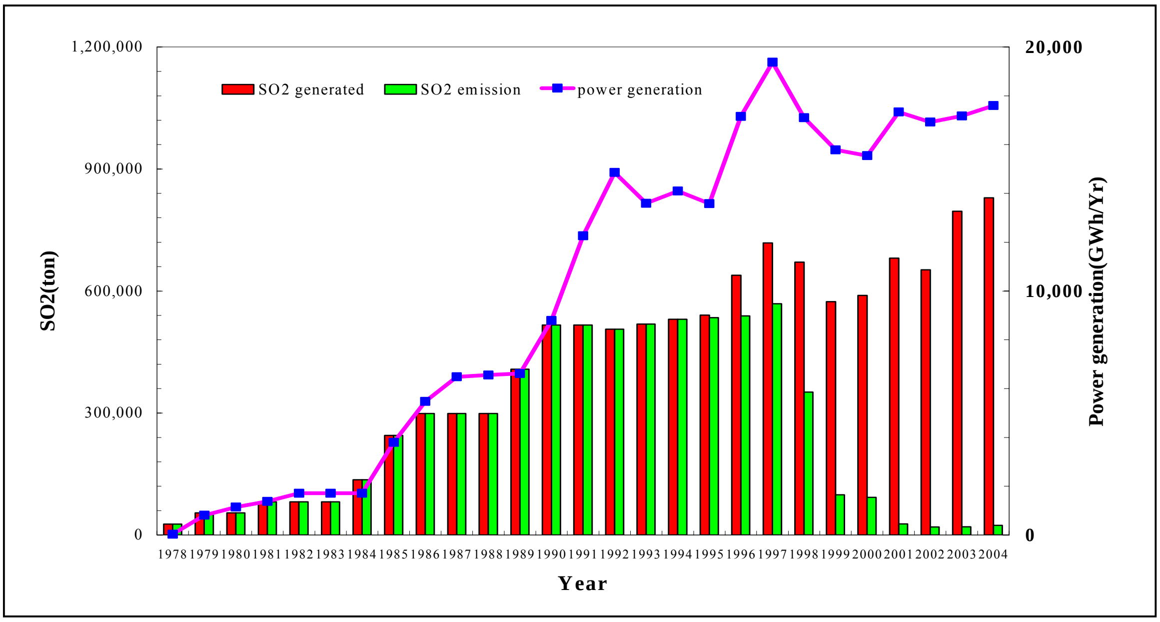

Figure 3. Sulfur dioxide generated and emitted from the Mae Moh power plant

In the desulfurization process, approximately 1.2 million tons of limestone is currently used as the main input in the FGD plants annually. The existing limestone quarry is located to the east of the power plant. As the FGD system uses calcium carbonate ($CaCO_3$) as the absorbent, gypsum or wet calcium sulfate ($CaSO_4.2H_2O$) is the main positive byproduct from this chemical process as shown below.

$$CaCO_3 + SO_2 + \frac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4.2H_2O + CO_2 \uparrow \qquad (1)$$

Unfortunately, the attempt to solve the problem of sulfur dioxide emissions by using the wet scrubbing FGD system may in fact create another long term impact of greenhouse gas. The chemical process replaces SO_2 emissions with CO_2 emissions which will be retained in the atmosphere for hundreds of years. This may pose a threat with regards to global warming. In this study, this is considered as an indirect cost of the FGD abatement technology.

2.3 Benefits and Costs Attributed to the FGD Systems

A synthesis of previous EIA (environmental impact assessment) reports and other related empirical studies plus consultation with academics, and local and provincial administrators and officials suggest that the major damages from SO_2 emissions impact human health, agriculture and forest resources. Therefore, this study focuses on evaluating the reduction of damage to health, crops, and forests associated with the installation of FGD systems. Gypsum, a by-product of the abatement process, is considered as an indirect benefit. On the cost side, the analysis includes capital or investment costs, operating and maintenance (O&M) costs, input costs (e.g., limestone, energy, raw and processed water, etc.), and the indirect cost of carbon dioxide emissions. These estimates are used as the main inputs in the benefit-cost analysis of the investments in the FGD controls.

3.0 RESEARCH METHODS

This section provides the theoretical framework employed in estimating the physical impacts and monetary values associated with the environmental improvements expected from the investments in FGD systems at the Mae Moh power plant. The evaluation of FGD investments is performed using a benefit-cost analysis (BCA) on "with" and "without" FGD scenarios. In order to make use of historical data on the "worst case" damages induced by high ambient sulfur dioxide without any FGD control in 1994, this study evaluates only the six FGD units retrofitted to power generation units 4-11. Note that the generation units 1-3 were not installed with FGDs due to their relatively small size and the short remaining period of operation. These three units were decommissioned in 2003. The last two generation units (12 & 13) were equipped with FGDs at the time of construction and were brought into operation in 1995. The period of study therefore stretches from the year 1994 when the first four FGD systems were retrofitted to units 8-11, to the year 2024 when the last two FGD systems retrofitted to units 4-5 will be decommissioned. This assumes a time horizon of 25 years for each of the FGD plants with no salvage value as suggested by EGAT. As each FGD unit became operational at different times, there is a partial effect of the FGD systems at the beginning (1994-2000) and the end (2023-2024) of the study period.

3.1 Benefit-Cost Analysis

The environmental benefit-cost analysis technique is employed in this study in appraising the FGD investments. Unlike private decisions, this study applies BCA to public environmental management; hence, it is conducted from societal and economic perspectives where relevant externalities are taken into consideration. From an economic perspective, the assessment of FGD investments is conducted on "with" and "without" bases to reflect the true welfare changes attributable to the project in accordance with the theory of welfare economics underlying the BCA technique.

Streams of benefits and costs are all expressed in 1994 constant prices to account for expected changes in the price level over time, the so-called inflation correction. The consumer price index (CPI) is employed to convert the annual nominal value to its real value. Without adjusting for these differences, the benefit-cost analysis would be inaccurate or yield biased results. In addition, the estimated values of benefits and costs are not realized in a single period or do not accrue at the same time; the capital costs are normally incurred immediately, while it takes time for the benefits to be realized. Therefore, we need to adjust for time differences, either present value or future value, in order to account for the opportunity cost of money. In this analysis, we discount all values of benefits and costs to their present values in the year 1993. The real discount rate of six per cent which approximates the real rate of interest on low risk government bonds is selected to reflect the social rate of time preference. In this study, all monetary values are calculated and presented in local currency, Thai baht. All the data of direct costs of FGD abatement technology including capital costs, operating and maintenance costs and costs of inputs employed in the FGD abatement process from 1994 to 2004 employed in this analysis are given by EGAT.

3.2 Areas Affected

Determination of the areas affected by air pollution caused by the Mae Moh power plant is one of the crucial issues in this analysis. The larger the area, the greater will be the values of estimated damages. Even though the increase in the pollution concentrations would be minimal for areas far away from the plant, the population and the ecosystems affected can be large, resulting in quite substantial damages. The reduction in damages associated with the decline in ambient SO_2 concentrations after FGD installation would be the benefits attributable to the FGD investments.

In this analysis, the areas affected are considered separately in terms of the health effects, and the impacts on agriculture and forests. An investigation of meteorological data in line with the existing monitoring data compiled by EGAT and the PCD exhibits the highest concentrations of ambient SO_2 to the north of Mae Moh, with the lowest concentrations to the east during the period 1993 to 2000.

The climate of the Mae Moh District is influenced by the southwest and northeast monsoons. The southwest monsoon prevails between March and September, producing a hot wet season, and the northeast monsoon blows between October and February, producing a dry cool season. During the cool season, the Mae Moh basin (covering the two districts of Lampang Province, i.e., Mae Moh and Mae Tha) is under the influence of high air pressure when temperature inversion normally occurs, causing high ambient SO_2 concentrations to accumulate which in turn induce acute severe health effects among the population. Fortunately, high hills and mountain ranges between the south of the Mae Moh basin and the southern districts of Lampang, i.e., Sob Prap and Toen help diminish the impact of the winds further down south during the northeast monsoon.

There are a few studies on acidic deposition and critical loads of sulfur in northern Thailand. These studies appear to arrive at similar conclusions: that the areas in the northern region surrounding the Mae Moh power plant are subjected to high acidic deposition as the power plant is the largest point source of SO_2 emissions. In 2001, approximately 95 per cent of total SO_2 emissions in the north came from the power plant, while mobile sources contributed less than 5 per cent and less than 0.1 per cent came from area sources, i.e., forest fires (Thepanondh 2004). Milindalekha et al. (2001) employed the steady state mass balance approach to estimate the maximum critical loads of sulfur ($CL_{max}S$) in Thailand. The results indicated that the predominant values of $CL_{max}S$ were distributed in the range of less than 50 to 2,925 eq./ha/yr (equivalent per hectare per year) with a minimum value of 3.5 eq./ha/yr in the north and a maximum value of 2,925 eq./ha/yr in the south. This implies that the southern region is more able to accept a higher level of sulfur deposition without any harmful effects on the ecosystem compared to other regions and that the northern region is very sensitive to sulfur deposition.

Towprayoon et al. (2001) further compared the maximum critical loads of sulfur and the estimated amounts of sulfur deposition in Thailand using the RAINS-ASIA model.[3] Extremely high readings were found in the northern part and eastern coast of Thailand. This implies that acid deposition due to further expansion of industries as well as power plants using fossil fuels can have a negative impact on ecological systems.

EGAT (1994) investigated the acidic deposition in northern Thailand. The study employed the data of SO_2 emissions from the Mae Moh power plant from 1991 to 1992 (the first air pollution episode) and other meteorological data to make predictions on areas with acidic deposition by setting up 15 deposition network stations. The results indicated that six stations were under significant and high influence of atmospheric emissions originating from the Mae Moh power plant, with mean wet sulfate deposition rates between 20-30 kg/ha (classified as significant by EGAT) and more than 30 kg/ha (classified as high by EGAT). These six stations were located in three provinces, i.e., Lampang, Phrae and Phayao (Figure 4).

[3] The "Regional Air Pollution Information and Simulation" (RAINS) model was developed by the International Institute for Applied Systems Analysis (IIASA) as a tool for the integration assessment of alternative strategies to reduce acid deposition in Europe and Asia. The RAINS-ASIA model was specially designed from the collaborative efforts of scientific institutions in Asia and developed countries to address the dynamic and rapidly changing conditions of the Asian energy system (IIASA, 1994).

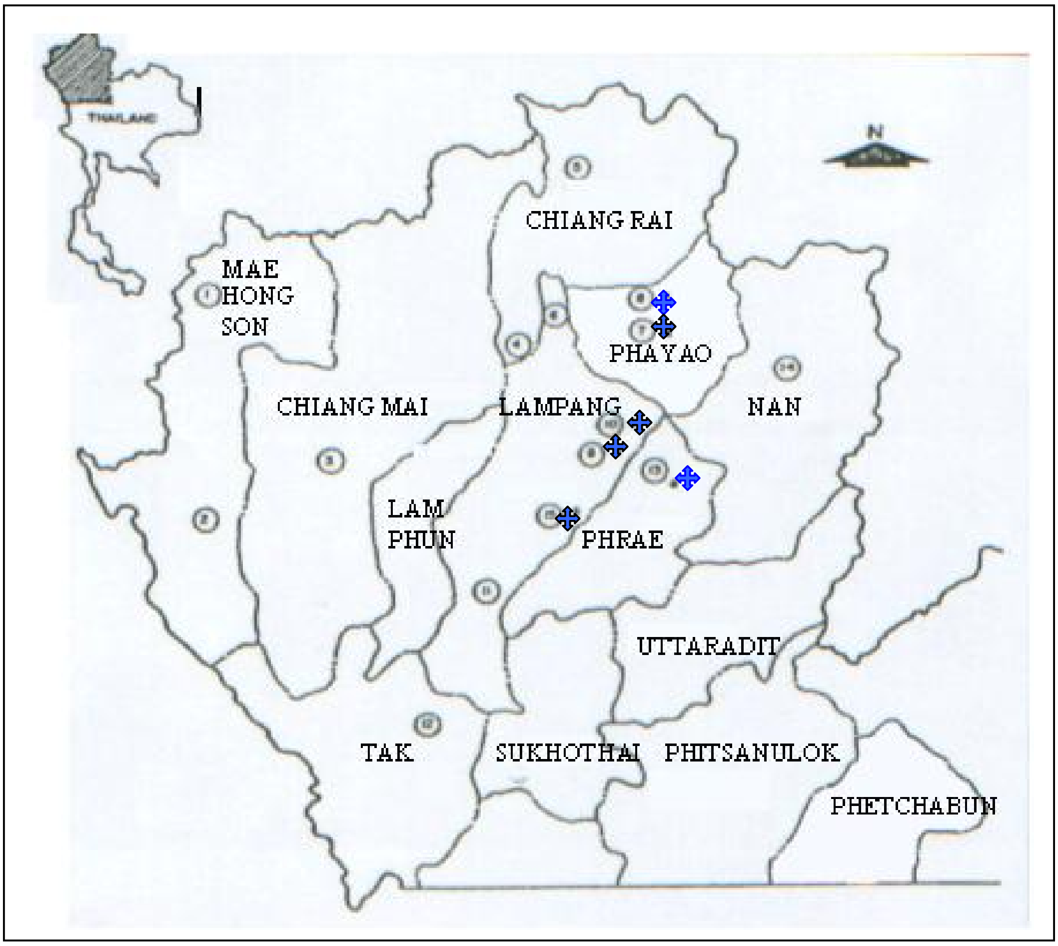

Figure 4. Location of precipitation monitoring stations in northern Thailand

Source: EGAT, 1994

Note: The areas indicated with ✦ represent those with significant and high acidic deposition.

Determination of the geographical zones for each of the environmental impacts is based on this scientific information together with interviews with people from Mae Moh and surrounding districts, i.e., Muang, Hang Chat, Sop Prap, Mae Tha and Thoen in Lampang Province. In the base case model, the assessments of environmental improvements brought about by FGDs are as follows:

- The health effects, as well as the impacts on agriculture, are considered for only local impact in the Mae Moh basin covering the districts of Mae Moh and Mae Tha of Lampang Province.

- For timber and non-timber forest products, the areas affected include the three provinces, i.e., Lampang, Phrae and Phayao which are subjected to significant and high acidic deposition as discussed earlier.

3.3 Impacts and Valuation

This section outlines the research methods employed in estimating health benefits, and reduction in damages to crop and forest resources, resulting from the FGD investments. The estimation is generally based on secondary data from EGAT; Department of Health, Ministry of Public Health; Forest Industrial Organization; Department of Agricultural Promotion and Office of Agricultural Statistics, Ministry of Agriculture and Cooperatives and related local studies conducted by such as College of Public Health (2001 & 2002), Suthduk (2000) and Somboonchai (2002).

3.3.1 Estimation Methods for Health Benefits

Ambient air pollution has been associated with a multitude of health effects, including mortality, respiratory hospitalizations, changes in lung function, and loss of wages. To examine the impacts of the health benefits associated with the FGD investments in the Mae Moh power plant, a literature search on studies on the health effects of sulfur dioxide was performed. We focused particularly on the empirical results of the epidemiological local study on "Health effects of ambient air pollution exposure in Mae Moh District" by the College of Public Health (CPH), Chulalongkorn University (2001 & 2002). The study period was from 1994 to 2000, just after the 1992 air pollution incident.

The CPH Study

The main objective of the CPH study (2001, 2002) was to determine both the short-term and long-term effects of air pollution emitted from the Mae Moh lignite power plant on children and adults living in Mae Moh District. The project composed of four different research areas i.e., (1) base population, (2) lung function growth, (3) baseline lung function and (4) panel or time series. In the CPH study, Muang Pan and Muang districts in Lampang Province were selected as control sites because they had similar geographical and socio-economic characteristics as Mae Moh but without the same air pollution source of sulfur dioxide i.e., a power plant. Even though the CPH study reported the two main categories of health outcomes, i.e., respiratory symptoms and illnesses, and measurements of lung functions (FVC – Force Vital Capacity, FEV_1 – Force Expiratory Volume 1 and PEFR – Peak Expiratory Flow Rate), the analysis followed focused only on respiratory symptoms and illnesses for the purpose of estimating economic loss of health impacts. The results of the CPH base population study (1994-2000) is the main reference used in this analysis.

In the CPH study, the multivariate logistic regression model was employed to identify risk factors associated with the occurrence of acute and chronic respiratory symptoms and illnesses. Illness was interpreted as a quantal response i.e., presence or absence of specified respiratory symptoms. Interviews and health examinations were done by nurses.

Respiratory symptoms and illnesses investigated in the CPH study included cough, chronic cough, phlegm, chronic phlegm, wheezing, asthma and bronchitis. Several control variables hypothesized to be related to the respiratory symptoms of the populations were assessed by performing statistical analysis. Two logistic regression models, one for the adult group aged 15 years and above, and the other for children aged below 15 years were separately estimated with several other control variables.

Air pollution, considering the exposure to sulfur dioxide emitted by the power plant, was hypothesized to have an influence on the possibility of getting ill with acute and chronic respiratory symptoms. This was inserted as a categorical variable using the control sites (Muang and Muang Pan Districts) as the reference in relation to the Mae Moh District where people had been exposed to sulfur dioxide emissions. The study aimed at presenting the adjusted odds ratios of having respiratory symptoms among adults and children. The empirical results of adjusted odds ratio coefficients were the ratios of the probability or risk of getting a specified respiratory symptom by the population of the Mae Moh District as compared to the population in the control group, controlling for changes in other variables. In the logistic regression model, these odds ratios are Pi/(1-Pi) or $e^{ß1i}$ where $ß_{1i}$ is the coefficient attached to the site variable. Using natural logarithm gives the following mathematical relation:

$$Ln\frac{P_i}{(1-P_i)} = Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n \quad (2)$$

The results of the CPH study, as shown in Table 4, revealed that Mae Moh populations were at higher risk of having respiratory symptoms than those living in the control site. Chronic cough exhibited the highest adjusted odds ratio (OR) of 3.0 and 3.7 times the risk both in adults and children, respectively. For the adult group, the adjusted odds ratios of all other symptoms including chronic phlegm, wheezing, bronchitis, asthma, cough and phlegm were approximately 2.0 and over – all were statistically significant at 95 per cent confidence level. Slightly different from the adults, the probability of children in Mae Moh and the control site having bronchitis was statistically indifferent at 95 per cent level. Except for the very high adjusted odds ratio of 3.7 for chronic cough, the odds ratios for children for other symptoms were less significant.

The base population study conducted by the College of Public Health (2001 & 2002) ended at assessing the health risks of the Mae Moh population compared to the control group in terms of adjusted odds ratios. In this research study, we attempt to make use of these empirical results in further developing the dose response relationships, i.e., the probability of having a specified respiratory symptom (response) from exposure to a specified pathogen, i.e., the concentration of sulfur dioxide (dose) for the Mae Moh population.

Estimation Methods

We attempt to estimate exposure response coefficients based on the results of adjusted odds ratios obtained from the CPH study. Measures of risk reported as odds ratios of having respiratory symptoms or illnesses among the Mae Moh adult and children populations as compared to those living in the control sites are assumed to be directly related to average annual ambient sulfur dioxide concentrations in the Mae Moh District during the study period. The basic assumption is that improving air quality should reduce the number of occurrences of acute and chronic respiratory illness that occur each year given that all other factors do not change significantly.

One of the shortcomings of the analysis is that we have hypothesized that the major air pollutant causing the respiratory symptoms and illnesses in the Mae Moh District is ambient sulfur dioxide. However, the data on the levels of PM_{10} (particulate matter up to 10 micrometers) in the Mae Moh District and the control sites during the study period are also quite different, with the average annual levels of 73.2 and 22.8 $\mu g/m^3$, respectively. It is possible that the health impacts may be a result of the interaction between SO_2 and PM_{10} rather than SO_2 alone.

Due to the significant difference in ambient SO_2 levels from 1994 to 2000, we assume the relationship between the levels of ambient sulfur dioxide concentration (dose) and health outcomes to be in natural logarithmic or log-linear functional form. This is because dose response relationships are not usually linear over the whole range of a dataset, but have a sigmoid form approaching the maximum and minimum value (Wiwatanadate 2004). This should help predict health outcomes when doses are outside the range.

Given the recorded data on the frequency of medical visits per 1,000 population in the control sites and the exposure response coefficients developed for all the health outcomes, we then compute the health effects of the Mae Moh population in relation to the baseline incidence (control sites) due to changes in annual ambient sulfur dioxide concentrations. Note that only the risks of having symptoms and illnesses that are statistically significant at 95 per cent confidence level were considered.

In the “with FGD” scenario, the actual doses of annual ambient sulfur dioxide from 1994 to 2004 were used. As the ambient sulfur dioxide has been effectively controlled at a very low level since the FGDs were completely installed in 2000 (annual average of 1-3 $\mu g/m^3$), it is logical to assume that the dose of ambient sulfur dioxide would remain at this low level during the remaining study period. The total frequency of morbidity cases can be predicted allowing for population growth.

In the “without FGD” scenario, we used the “worst case” situation based on the 1994 estimates (where the annual ambient sulfur dioxide reached the highest) in calculating the estimated number of morbidity cases per 1,000 population in relation to the baseline incidence in the control group. Again, the total frequency of morbidity cases in this “without” scenario can be predicted allowing for population growth.

The health benefits associated with a reduction in ambient sulfur dioxide through the FGD control technology can be estimated from the improvements in human health in terms of changes in morbidity cases in the “with” and “without” scenarios over the lifetime of the FGDs. Note that this study considers **only** those respiratory symptoms and illnesses indicated in the CPH study. There are other forms of respiratory illnesses and other health outcomes not indicated in the CPH study, such as emphysema and chronic obstructive pulmonary disease (COPD). By not including these potential morbidity impacts, this study may underestimate the true health benefits associated with FGD investments.

Aside from the reductions in health morbidity, the risk of premature mortality is normally assumed by health scientists to be related to exposure to air pollutants (e.g., Ostro 1992; Zmirou et.al. 1998). In this study, we investigated the data on the proportion of mortality caused by respiratory illnesses among the Mae Moh population in comparison with those of the control sites and also other districts in Lampang

Province. However, there was inadequate evidence to support any differences in mortality rates among the different districts. Unfortunately, the disaggregate data on mortality rates (caused by respiratory illnesses) by age at the district level were not available for further investigation on premature mortality. Therefore, this study does not directly attempt to estimate the magnitude of the health benefits of FGDs in terms of reductions in premature mortality.

Valuing Health Benefits: Reduced Morbidity Risks

To economists, the value of avoiding an illness occurrence normally consists of three components: (1) the medical costs; (2) the value of work time lost (in terms of productivity) and/or leisure time; and (3) the willingness to pay to avoid the pain and suffering associated with the illness or the threat of the illness (i.e., disutility from illness). These economic costs should be included in the value of avoiding an illness occurrence.

This study employs the cost of illness (COI) approach to valuing morbidity. The first two components, medical costs and productivity loss (incurred in adult population) are estimated. Medical costs are referred to as the direct costs of illness and productivity loss as indirect costs. It should be noted that medical costs are computed based on the full social cost of providing the medicine and treatment to the patients as there have been several public health welfare and insurance programs taking effect including the compensation scheme by EGAT for free medical care for the Mae Moh population. The medical costs incurred by the Mae Moh Hospital are used as the basis in calculating the unit cost for each respiratory symptom and illness examined in this study. The unit costs are compared with the figures from other similar-sized hospitals to check for reliability. Work time lost by adult patients is computed for those hospitalized by using the real wage rate.

To deal with the disutility of illness component without using the contingent valuation method or stated preference approach, this study uses the ratio of willingness to pay (WTP) to avoid morbidity risks at two times the sum of COI as suggested by ADB (1996). The WTP, calculated at two times the sum of COI across all reduced morbidity risks, therefore, represents the health benefits associated with FGD control technology.

3.3.2 Estimation Methods for Crop Benefits

Evidence suggests that high concentrations of sulfur dioxide may cause irregular growth of vegetation, and reduce crop quality, crop yields, and productivity of forests (Jacobson and Hill 1970; Grodzinski et al. 1990). However, as Emberson et al. (2003) pointed out, there are relatively few studies on assessing the extent of air pollution impacts in developing countries, especially in Asia, as compared to Europe and North America.

Interviews with local agricultural officials in the Lampang Province and Thai soil scientists suggest that there is no clear indication of the real impacts of sulfur dioxide on crop growth. Several factors have to be taken into account in estimating the damages, for instance, the concentrations of sulfur dioxide, the types of crops, and the duration of crop exposure to the pollutant. Interviews with people who experienced sulfur dioxide emissions from the Mae Moh power plant in the past suggest that the impacts of sulfur dioxide on crops are quite obvious. However, scientific knowledge such as the magnitude of the impacts, the areas affected, and the dose response function related to agricultural production in Thailand is scarce.

Aside from the damage functions or crop response models, there are other simple methods that can be used to estimate the impacts of high ambient sulfur dioxide on agricultural crops. For instance, we can compare the pre-FDG pattern of crop yields with post-FGD yields in the study region as being representative of the "with FGD" and "without FGD" situations, respectively, and assume that the positive difference in net returns are the benefits attributable to FGD abatement technology. An alternative statistical approach would be to compute and test for percentage differences of pre-FGD crop productivities at Mae Moh and those obtained in other control sites. However, neither of these approaches will work well due to severe limitations in the local dataset especially when we need extensive disaggregate data on the range of crop species at the local level.

In this study, we employ the exposure response relationship which relates yield losses with SO_2 concentrations for *Lolium perenne* (rye grass), as developed by the OECD (1981). This relationship is used to assess the reduction in crop damages associated with changes in ambient sulfur dioxide concentrations due to FGD installation at the Mae Moh power plant. Similar to the estimation of health benefits in the "without FGD" scenario, we use the 1994 annual ambient sulfur dioxide figure which is the "worst case" situation in calculating yield losses over the study period. Forecasted changes in cropping patterns and land uses in the future are taken into account in the calculations. Note that all the calculations are shown in 1994 constant prices.

The OECD (1981) exposure response relationship can be described as follows:

$$Y = -116.25 + 29.62 \log_e X \qquad (3)$$

where Y is the percentage yield loss, and X is the annual mean SO_2 concentration in $\mu g/m^3$.

To calculate the percentage yield reduction (Y), the following formula by the OECD (1981) is suggested:

$$Y = \frac{100e(3.8S - 9.2)}{1 + e(3.8S - 9.2)} \qquad (4)$$

where S = log $_{10}$ SO_2 concentration in $\mu g/m^3$.

One of the main criticisms of the OECD response function is that there is no threshold for the adverse effects of SO_2, while more recent studies suggest that below a certain concentration, the effect of SO_2 is minimal or variable (i.e., could be either positive or negative) (CLAG 1996; Bell et al. 1993 cited in Emberson et al. 2003). However, the studies on sulfur deposition in Thailand by Milindalekha et al. (2001) and Towprayoon et al. (2001) suggest that the northern region is very sensitive to sulfur deposition. Therefore, even with the FGDs taking full effect after the year 2000 and the ambient SO_2 being substantially reduced to a very low level, we assume from expert opinion that acid sulfate soil is likely to remain for approximately another 10 years (2001-2010), and this could still have a minimal adverse effect on crop productivity. However, the threshold effect can be taken into account for the remaining period. In other words, in the "with FGD" scenario, we consider *no yield reduction* from low SO_2 concentrations where the average annual ambient SO_2 is less than 5 $\mu g/m^3$ in the years 2011 to 2024.

3.3.3 Estimation Methods for Forest Benefits

It is well established that fumigation with SO_2 causes a decrease in photosynthesis as SO_2 enters the plant through the stomata where it reacts with wet surfaces of spongy mesophyll tissue – this can have an inhibitory effect on photosynthesis. As a consequence, significant growth reduction may occur following SO_2 exposure even if symptoms are not apparent (EGAT 1991). In the case of the Mae Moh power plant, we hypothesize that chronic exposures to SO_2 over the years may have a deteriorative effect on forest productivity.

The main aim in evaluating the damage to forests in this study is to estimate the differences in the value of the forests and forest productivity with and without FGD controls. Potential damages are considered both in terms of impacts on commercial plantations and natural forests where non-timber forest products (NTFPs) can be derived. According to the Thai National Forest Policy, forest areas are divided into natural forests under strict conservation in which logging has been legally banned since 1989; and commercial forest plantations where harvesting is legally permitted. In this study, we focus on investigating the potential benefits attributed to FGD in terms of improvements of timber productivity in commercial plantations and increase in benefits derived from non-timber forest products (NTFPs) in both natural and commercial forest areas.

Timber Forest Products

To investigate the cumulative impacts of SO_2 emissions on timber benefits in this study, academics and experts in forestry suggested analyzing the differences in the growth of teak (*Tectona grandis*) plantations under the Forest Industry Organization (FIO) in the control site and the affected site. The FIO is a state enterprise under the supervision of the Ministry of Agriculture and Cooperatives operating sawmills, wood-product factories, plantations, and forest villages. The FIO has established and operated large-scale plantations since 1968 in an attempt to increase industrial wood supplies for domestic consumption. The teak plantations under FIO operations are classified by the site index. The site index represents a combination of the main physical factors that affect productivity e.g., soil quality and amount of rainfall.

Teak is the only species considered in this analysis because there are numerous teak forest plantations that have high commercial value in the Mae Moh power plant area. Besides, teak seedlings have large leaves and therefore, greater absorptive surface. In addition, the site index and the relevant assumption of homogeneous FIO management techniques would allow us to compare and test for the likely impacts of SO_2 on growth in terms of girth at breast height (GBH) and volume of teak woods in the different plantations. In this study, data from annual inventories of each teak plantation unit compiled by the FIO in a Forest Information System (FIS)[4] was employed. Normally, the rotation period of teak plantations managed by the FIO is about 30 years on good sites and 35 years on poor sites.

As outlined in Section 3.2, the analysis of the impacts of SO_2 emissions from the Mae Moh power plant on forests covers the three provinces subject to high and significant acidic deposition from the power plant, i.e., Lampang, Phrae and Phayao. Note that there is no teak plantation under the FIO in Phayao Province. To analyze the impacts of SO_2 on teak growth, a few teak plantations of similar age and site index in the affected areas, i.e., Lampang and Phrae Provinces, were selected to be compared with teak growth without the effect of SO_2 emissions in the control site. The teak plantation at Mae Hor Phra, located in the Mae Taeng District, Chiang Mai Province (about 170 km from the Mae Moh power plant) was selected as the control site. By controlling for age (plantation period between 1968-1971) and site index (14-17), the four teak plantations in Lampang Province with varying distances from the power plant were selected, i.e., Mae Jang (4 km), Mae Moh (19 km), Mae Mai (36 km) and Tung Kwien (52 km). Teak plantations in Phrae Province were not selected as they were not of the same age. The analysis takes the following steps:

1) Determine the teak forests potentially affected by SO_2 emissions from the Mae Moh power plant

First, teak plantation units are selected to test for the impacts of sulfur dioxide emissions from the Mae Moh power plant. Two hypotheses are tested:

(a) Whether the growth of teak plantations is influenced by the magnitude of ambient SO_2 concentrations, measured by the differences in GBH and volume of teak between the control site (Mae Hor Phra) and those in the affected sites (Mae Jang, Mae Moh, Mae Mai and Tung Kwien) .

(b) Whether the impacts vary by distance, i.e., there is a negative relationship between growth and distance of the teak plantation from the power plant.

However, as data on teak wood yields of each plantation was not available, this analysis employs the recorded estimates of average volume and GBH of the teak stock from the FIO database as proxies. Given these data, we performed simple statistical analyses to test our hypotheses.

2) Determine growth of teak plantations (with and without FGD controls)

A previous study on the growth of teak in northern Thailand by the Royal Forest Department (undated) is taken as representative of normal growth in areas without air pollution. The growth of teak in the normal case (i.e., similar site index 14-17) is taken as the control case in the comparison of differences in site quality – this reduces errors when assessing damages.

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[4] Only data for recent years (2003 and 2004) are available. In this analysis, cross-sectional survey data on the yields of teak plantations at the selected sites in the crop year 2004 are used.

Since data on the actual growth of teak in each plantation is not available, the growth of teak plantations in the "without FGD" is calculated based on the percentage differences in the volume of teak stock in the control site and the affected plantation sites as proxies. These differences are presumed to remain the same for the "without FGD" scenario throughout the study period.

For the "with FGD" scenario, the following relevant assumptions are employed in calculating average yield:

- Since FGD investments ended in the year 2000, therefore we presume no direct effect of acid rain. However, from expert opinion, acid sulfate soil is likely to remain for another 10 years (2001-2010) and could still affect growth. In this analysis, yield reduction of teak woods (in the affected areas) is assumed to continue even after 2000 and the reduction is assumed to be 50% of the reduction in the case "without FGD".

- After 2010, the growth of teak in the "with FGD" scenario and in the control site (normal case without the SO_2 source) can be assumed to be the same.

In this study, the rotation period is assumed to be 30 years, i.e., replanting takes place right after harvesting. It is assumed that the management, harvesting and replanting costs in the control site and affected sites are the same regardless of forest conditions and there are no significant losses of teak timber through premature death, fires and illegal logging.

3) Calculate the differences in mean annual increment (MAI) in yields and total annual damage avoided by FGD controls

Given the estimates of average yield of teak plantations in the "with FGD" and "without FGD" scenarios classified by age of plantation, the mean annual increments (MAIs) for these two situations can be estimated. As shown in Equation (5), the positive difference between them (B_i) represents the benefits associated with the FGD investments. From Equation (6), the physical annual damages avoided by FGD controls by age of teak plantation (TD_i) for each specified year can be computed by multiplying the decrease in the MAI per area unit (cubic meter per rai per year, B_i) and the total size of teak plantations in the affected zones by age of plantation (A_i). Again, for each plantation we assume the rotation period to be 30 years and that replanting takes place right after harvesting. So at this stage we have figures on the annual decrease in the volume of teak growth (cubic meter) by age of teak plantation. The total annual damage avoided by FGD investments (TTD) for each year over our study period (1994-2024) can then be calculated by adding TD_i as shown in Equation (7).

$$B_i = (MAI_i)_w - (MAI_i)_{w/o} \tag{5}$$

$$TD_i = B_i * A_i \tag{6}$$

$$TTD = \sum_{i=1}^{30} TD_i \quad (7)$$

where
i = age of teak plantation,
w = with FGD controls,
w/o = without FGD controls

4) Calculate the monetary valuation of the benefits associated with FGD controls

The monetary values of teak benefits are calculated using FIO data on the values of teak stands (unit stumpage prices) between 1995 and 2003, converted into 1994 constant prices. The monetary benefits associated with FGD investments are calculated by multiplying the total annual damage avoided by FGD controls (TTD) with unit stumpage prices.

Non-Timber Forest Products

The assessment of forest benefits in terms of non-timber forest products focuses mainly on subsistence values relevant to local community livelihoods. The FAO (1995) pointed out that non-timber forest products (NTFPs) such as fruits, vegetables, fungi, honey, and forest wildlife are an important source of nutrition to rural communities. The study by Boonchote and Pasandhanatorn (1998) indicated that about 80% of households in northern Thailand received benefits from NTFPs. In this study, it is logical to assume that SO_2 emitted from the Mae Moh power plant causes a decrease in NTFP productivity in the same way that it results in a decrease in forest and agricultural productivity. Similar to the estimation of teak benefits from FGD investments, the areas affected by SO_2 emissions from the Mae Moh power plant in terms of NTFPs include the three provinces, i.e., Lampang, Phrae and Phayao.

In this analysis, we employ the exposure response relationship (OECD 1981) to estimate the average reductions in NTFPs in the affected areas using the procedure outlined in 3.3.2. The percentage of reductions is applied to the value of benefits of NTFPs obtained by the communities in the affected areas. The subsistence values of NTFPs per household in forest communities in Lamphun (Suthduk 2000) and Chiang Mai provinces (Somboonchai 2002) are used as the benefits in the case without the impacts of SO_2 emissions. Note that Lamphun and Chiang Mai are also in the north of Thailand with similar forest characteristics and socio-economic conditions as the affected areas but without the major source of SO_2 pollutant. The total benefits are calculated assuming 80% of the households in the affected areas rely upon NTFPs as suggested by Boonchote and Pasandhanatorn (1998). However, households in the Muang District are excluded because access to forests is rather difficult and people rarely rely on NTFP collections.

3.3.4 Estimation of Costs of Carbon Dioxide (CO_2) Emissions

The benefit transfer of the value of shadow cost or the social value of carbon dioxide reductions is employed to assess the costs in CO_2 emissions in this study. Only the amount of CO_2 emissions from the desulfurization process is assessed as the social cost of the investments in the FGD technology.

In order to estimate the amount of CO_2 emissions, three relevant chemical equations describing the FGD process are considered. These are given below.

$$S + O_2 \rightarrow SO_2 \tag{8}$$

$$CaCO_3 + SO_2 + \frac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4.2H_2O + CO_2 \uparrow \tag{9}$$

$$CaCO_3 + SO_2 + 0.5O_2 \rightarrow CaSO_4 + CO_2 \tag{10}$$

The calculation of the amount of CO_2 emissions takes the following steps:

- Calculate all fuel mass used ($\dot{m}f$) in the power production ($\dot{W}$) on an hourly or yearly basis. These are computed from lignite characteristics such as sulfur content, heat factor (HHV) and plant efficiency (η).

$$\dot{m}f = \frac{\dot{W}}{\eta(HHV)} \tag{11}$$

- From the chemical process in Equation (8), compute the mass of SO_2 pollutant using the average weight of sulfur in solid fuel.
- Calculate the amount of SO_2 absorbed by the FGD plants using the results of the previous step and efficiency rate of the FGD plants.
- Calculate the amount of limestone ($CaCO_3$) required in the chemical process as illustrated in Equation (9).
- Finally, compute the product from the chemical process illustrated in Equation (10), i.e., gypsum or calcium sulfate ($CaSO_4$) and CO_2 emissions.

In assessing the costs for carbon dioxide emissions, an estimate of carbon tax generated by the optimum emissions control path by Nordhaus and Boyer 2000 is employed. The estimated carbon tax for the optimum path is equal to the estimated marginal damages. The optimal policy has a carbon tax starting at a relatively low cost of US$ 5.9 per ton carbon in the 1990-1999 period which gradually rises to US$ 9.13 in 2005, US$ 12.73 in 2015, and US$ 16.73 in 2025. In our calculations, these taxes are converted to 1994 constant prices to account for the expected changes in the price level over time.

4.0 ASSESSING THE BENEFITS OF FGD POLLUTION CONTROL TECHNOLOGY

From the previous section, we know that damage reductions to human health and ecosystems can be assessed as benefits of FGD abatement technology. However, the relevant measure is the change in damage reductions brought about by installing FGD controls, in other words, incremental benefits between the "with" and "without" scenarios. In this analysis, the environmental benefits are separated into two main categories, direct and indirect benefits. Direct or primary benefits include improvements in human health, increase in crop yields, and forest benefits. Gypsum as a byproduct of the abatement process is considered as an indirect benefit.

The benefit assessments presented in this section basically follow the estimation procedures outlined in the previous section.

4.1 Measuring Incremental Benefits on Human Health

Extending the analysis from the CPH study, this analysis attempts to link health outcomes in terms of respiratory symptoms and illnesses in children and adults to their exposure to sulfur dioxide emitted from the Mae Moh power plant, assuming non-linear dose response relationships. Table 5 shows the calculations of adjusted odds ratios or risks of having respiratory symptoms and illnesses of people living in the Mae Moh District as compared with those living in the control sites (i.e., Muang and Muang Pan Districts). The incremental reductions in the morbidity risks of these respiratory symptoms and illnesses are estimated based on the extent to which these risks would be reduced by the FGD controls installed in the plant. We used the highest ambient sulfur dioxide reading of 1994, the worst case concentration in the "without FGD" scenario throughout the study period, while the low concentrations after the complete installation in the year 2000 are expected to remain constant in the "with FGD" scenario. The differences in the frequency of medical visits per 1,000 people are converted to population at risk over the study period.

The costs of illness can then be estimated using data from the community hospitals and survey as summarized in Table 6. The medical costs are relatively low as most medicines are locally made. Table 7 presents the components in costs of illness, including the medical costs, transportation costs and wages lost (in the case of adult patients), all expressed in 1994 prices.

As summarized in Table 8, the present value of incremental benefits of health improvements in terms of willingness to pay for avoiding morbidity risks over the study period is about 3,730 million baht at a six per cent discount rate. The medical costs over the study period account for about 45 per cent of the total costs of illness, while transportation costs and opportunity costs of wages lost contribute approximately 24 and 31 per cent, respectively.

4.2 Measuring Incremental Benefits on Agriculture

This analysis employs the OECD (1981) exposure response relationship as outlined in the previous section. One of the limitations we have to bear in mind is that the same exposure response relationship is applied across all crops regardless of species. The other disadvantage in assessing agricultural benefits in this study is the low availability and incompleteness of data at the local level. As a consequence, simple forecasts and expert opinions are used extensively – this may result in high inaccuracies in the estimates.

Modeling benefits centers around quantifying the incremental benefits that would result from the FGD controls. The increases in crop yields corresponding to the ambient sulfur dioxide concentrations in the "with FGD" scenario in relation to those in the "without FGD" are the benefits brought about by the FGD controls. Similar to the estimation of health impacts, the highest ambient sulfur dioxide occurrence in 1994 is employed as the concentration in the "without FGD" scenario for the study period, while the low concentrations after all the FGDs take full effect are expected to remain constant in the "with FGD" situation.

In monetizing the impacts, agricultural benefits are normally measured by changes in net returns corresponding to the changes in crop yields. However, in this analysis it is logical to assume that costs of production per unit of area planted, including those of agricultural management and technology employed in the two scenarios, remain the same, only gross returns are expected to rise with the FGD controls. Therefore, the incremental agricultural benefits are measured on the basis of gross returns. Table 9 presents the estimates of the increases in gross returns as the result of FGD technology. From the calculations, agricultural benefits brought about by FGD abatement technology over the study period are approximately only 80 million baht in present value at a six per cent discount rate.

4.3 Measuring Increase in Forest Productivities

As discussed in the previous section, the benefits assessment of FGD control technology in relation to forest resources is divided into two categories, i.e., timber forest products in terms of changes in teak productivities, and non-timber forest products as a source of subsistence livelihood for the local communities.

4.3.1 Teak Plantations

Even though there seems to be inconclusive evidence of the adverse effects of sulfur dioxide on forest resources in Thailand, this study attempts to investigate this hypothesis as there are several international studies (eg., Dreisinger 1965; De Cormis 1969 cited in Kasetsart University 1996) that indicate otherwise. An analysis of teak productivities under FIO operations, controlling for age of plantations and other differences in site quality between the control site and an average of those selected plantations in the affected sites, is performed using the t-statistic. The analysis employs the FIO database i.e., average volume and girth at breast height (GBH) of teak stocks to test for the likely impacts of sulfur dioxide on the growth and productivity of teak.

As outlined in Section 3.3.3, we selected a teak plantation at Mae Hor Phra in Chiang Mai Province as the control site, and four teak plantations in the affected areas with varying distances from the power plant (i.e., Mae Jang, Mae Moh, Mae Mai, and Tung Kwien in Lampang Province). First, we tested for the differences in GBH and volume of teak between the control site and those in the affected sites. The statistical results suggest that there are significant differences in GBH and volume of teak stocks per unit of area planted between the control site and an average of the four sites in the affected areas. The Fisher's Least Significant Difference (LSD) statistical results further suggest that the magnitude of the fumigation effects and the distance of the forest plantation unit from the power plant are significantly related. Based on these results and the location of commercial teak plantations in the affected areas in Lampang and Phrae Provinces, the impact analysis divides the affected areas into two zones, i.e., within 40 kilometers from the Mae Moh power plant as Zone 1 and 41-100 kilometers away as Zone 2. Table 10 presents the total areas of commercial teak plantations under FIO operations from 1994 to 2004 by age of plantations.

The percentage differences in average yields of teak stocks between the control site and those of Zone 1 and Zone 2 are employed in calculating the average yield of teak. A previous study on the growth of teak in northern Thailand by the Royal Forest Department is taken as representative of normal growth in the control site without air pollution (Table 11). We found that, on average, the productivity of teak trees planted within 40 kilometers was approximately 40 per cent less than the average yield of teak in the control site. For teak plantations located further from the power plant i.e., in Zone 2, the difference in average yield was about 30 per cent.

The relevant assumptions and estimation procedures discussed in the previous section are employed to estimate the mean annual increment in teak growth in the two scenarios over the study period allowing for a 30-year rotation. The improvements in teak MAI in the "with FGD" situation as compared with the "without FGD" case represents the incremental benefits associated with FGD controls per unit of area planted. The total increase in teak productivity brought about by FGDs can be assessed for all the commercial teak forests in the affected areas in Lampang and Phrae Provinces. The average real stumpage value of 3,336.70 baht per cubic meter (in 1994 constant prices) is directly used to monetize the impacts, assuming the same management is used in the two situations – the results are shown in Table 12. The present value of increase in teak productivity associated with the investments in FGD systems over the study period is about 706 million baht at a six per cent discount rate.

4.3.2 Non-Timber Forest Products

The incremental benefits in terms of non-timber forest products (NTFPs) are assessed using a similar approach as performed for agriculture. Following the procedure discussed in Section 3.3.3, we found that the benefits of NTFPs would increase by approximately 15 to 60 baht per household according to the improvement in air quality. The present value of estimates of incremental benefits of NTFPs brought about by FGD controls is approximately 174 million baht at a six per cent discount rate (Table 13).

4.4 Measuring Indirect Benefits

Table 14 shows the actual data on gypsum produced as a byproduct of the FGD abatement process. Unfortunately, approximately only three per cent of the gypsum produced has commercial value. This is due to the relatively low quality of the produce. Notice that the unit price is quite low; EGAT reports the sale price is constant at 20 baht per ton. From the calculations, the present value of the sale of gypsum over the study period is approximately 10 million baht at a six per cent discount rate.

4.5 Summary of Benefits

To summarize, the present value of total benefits (PVB) attributable to the FGD investments in real terms at a six per cent discount rate is approximately 4,700 million baht. Improvements in human health account for about 3,730 million baht or almost 80 per cent of the total benefits, the most relevant gain achieved from the abatement process. The results are consistent with various international valuation studies on the impacts of air pollution where health impacts are normally found to be the most significant category. Meanwhile, the benefits from an increase in forest productivity in terms of timber and non-timber forest products contribute about 18.7 per cent of the total benefits or about 880 million baht in present value. This may be reasonable as the affected areas are endowed with rich natural forests and commercial forest plantations. As described earlier, about 70 per cent of the Mae Moh District and Lampang Province are mountainous.

Of all the direct benefits assessed, the agricultural benefits brought about by FGD investments seem to be of least importance, with a present value of only 80 million baht or 1.7 per cent of the total benefits. This may also be supported by the fact that agriculture is not a major income contributor for the Mae Moh and Lampang population, unlike other provinces in the northern region.

One of the unfortunate outcomes of the FGD abatement process is the low quality gypsum obtained as the main byproduct of the desulfurization process. Only three per cent of the huge amount of gypsum produced can be sold and at a very low price due to its poor quality. In this analysis, the present value of benefits derived from gypsum is about 10 million baht or only 0.2 per cent of the total benefits.

Figure 5 and Table 15 summarize the benefits achieved from retrofitting the six units of FGD plants at the Mae Moh lignite-fired power plant.

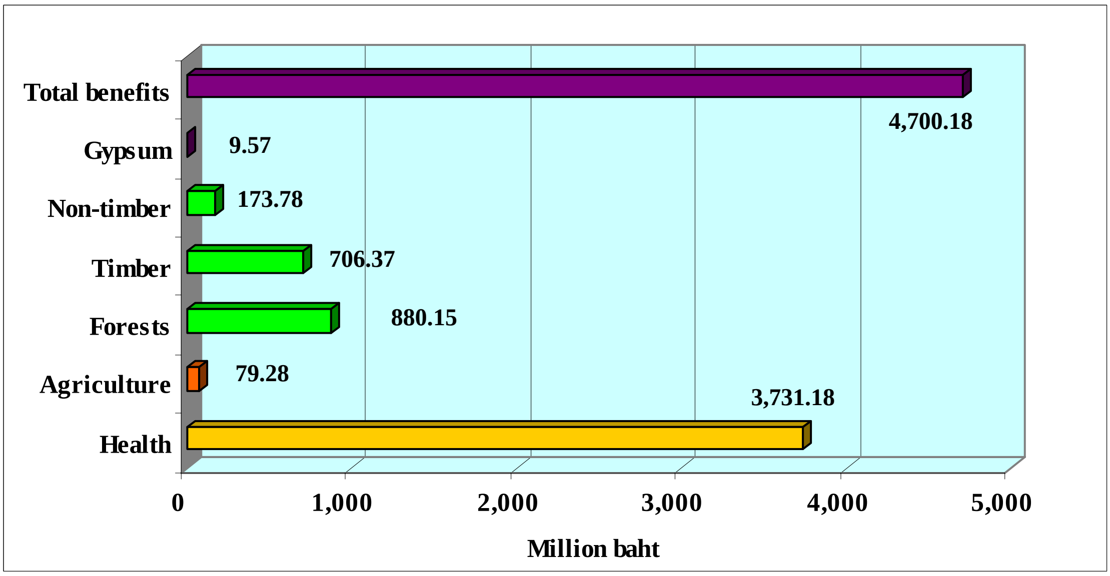

Figure 5. Summary of the present value of benefit components attributable to the FGD controls

5.0 ASSESSING THE COSTS OF FGD POLLUTION CONTROL TECHNOLOGY

In the previous section, we began our formal study of benefit-cost analysis with the estimation of environmental benefits attributable to the investments in FGD controls. Equally important is the analysis of economic costs associated with the investments. Just as for benefits, the cost analysis is based on incremental costs to allow for a comparison between the "without FGD" scenario and the expenditure incurred due to the installation of the FGD controls. In this analysis, the incremental costs associated with the FGD controls are divided into two categories, i.e., direct costs and indirect costs. Direct costs comprise the capital costs, operating costs and input costs of the abatement process. The implicit indirect costs of CO_2 emissions that would negatively affect society's well-being in the long-run are also captured in the analysis. The actual and estimated figures of all the cost components are shown in Table 16, expressed in 1994 constant prices.

The composition of the FGD abatement costs is summarized in Table 17 and Figure 6, all illustrated in present values as at 1994, using a discount rate of six per cent. Capital costs account for approximately 52 per cent, the highest proportion of the total costs. The operating and maintenance (O&M) costs and costs of inputs in the abatement process contribute about 15 and 27 per cent of the total costs, respectively. The global damages from CO_2 emissions account for about six per cent. Note that if the social cost of CO_2 emissions is not taken into consideration, the proportion of capital investments would be 55 per cent, while O&M and input costs would account for 16 and 29 per cent of the total expenditures, respectively.

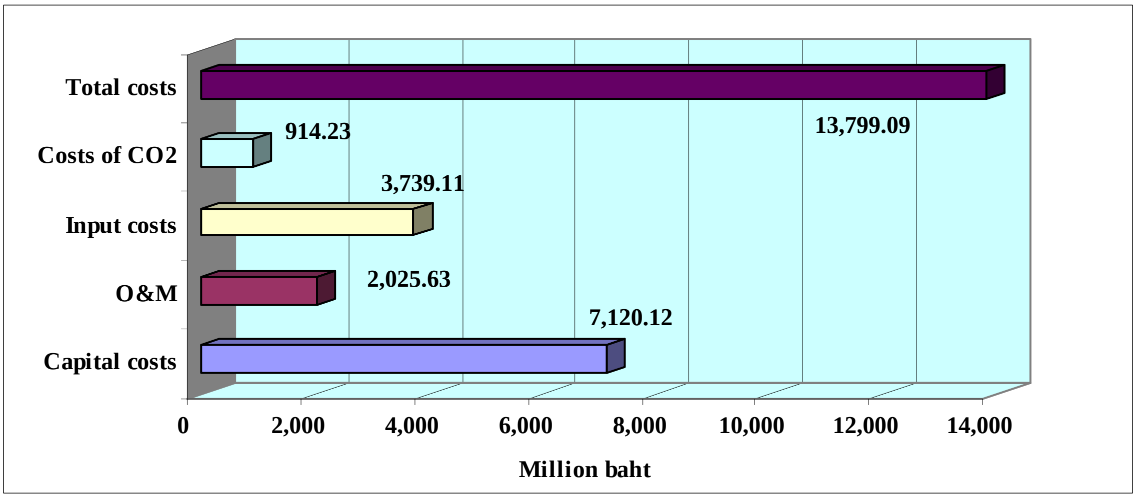

Figure 6. Summary of the present value of cost components attributable to the FGD controls

6.0 BENEFIT-COST ANALYSIS OF FGD POLLUTION CONTROL TECHNOLOGY IN THE CASE OF THE MAE MOH POWER PLANT

Benefit-cost analysis begins with the critical tasks of identifying and monetizing benefits and costs attributable to the FGD abatement technology, the subject of the previous two sections. In this section, the estimates of benefits and costs are systematically linked and compared in a formal benefit-cost analysis to arrive at a decision.

6.1 Base Case Analysis

As summarized in the previous two sections, the present value of benefits (PVB) associated with FGD controls at the Mae Moh power plant over their lifetime is about 4,700 million baht which is significantly less than the 13,800 million baht of the present value of costs (PVC) (Table 18). In this case, the net present value of benefits (NPV), the differential of the present value of benefits and the present value of costs (PVB-PVC), is approximately minus 9,100 million baht in real terms. From a benefit-cost perspective, this is not satisfactory as the costs incurred outweigh the benefits, thereby reducing social welfare. From a pure economic viewpoint, the net loss is borne by society.

The benefit-cost ratio (BCR) is another common measure for evaluating a given project or policy option. The ratio compares the time-adjusted values of incremental benefits and incremental costs, i.e., PVB/PVC to unity. If the ratio exceeds 1, it implies that the benefits associated with a given option outweigh the costs incurred. In this analysis, the BCR result at the six per cent discount rate equals to 0.34 – this implies that for every baht of costs incurred, there is only 0.34 baht in realized benefits. However, if the global damage cost of CO_2 emissions is left out, the net present value of benefits (NPV) and BCR at six per cent discount rate would be slightly different, i.e., minus 8,185 million baht and 0.36, respectively.

Overall, the results of the benefit-cost analysis of the FGD investments from the base case seem to suggest that the FGD abatement technology at the Mae Moh power plant has not fulfilled allocative efficiency criteria. Allocative efficiency refers to a situation whereby resources are allocated in a way to maximize the net benefits to a society. However, in this analysis, the capital and operating costs of the FGD systems are likely to outweigh the benefits over their lifetime. This may be due to the very expensive FGD wet scrubbing type controls installed at the Mae Moh power plant. The high costs as compared to the benefits in terms of present value seem to stem from the fact that FGDs involve very large capital costs incurred mainly in the early stages. If the investments had been spread out over a longer period, the opportunity cost of capital might not have been so high. Therefore, optimal timing of investments or staggered investments especially in such expensive technologies should be taken into consideration in planning for future environmental management programs in order to achieve efficient allocative outcomes.

6.2 Sensitivity Analysis

In this section, the NPV and BCR are recalculated assuming the following scenarios:

1) Risk of premature mortality is taken into consideration.

2) Estimated potential compensation payments are used as an alternative measure of the benefits of FGD investments.

3) Medical costs, agricultural prices and forest stumpage prices are assumed to increase by 10 per cent.

4) Only operating and maintenance costs are considered as relevant costs, while capital costs are excluded as sunk costs.

Scenario 1: Risk of premature mortality is taken into consideration

It should be emphasized that only an increase in health morbidity benefits associated with reductions in ambient sulfur dioxide due to FGD investments is considered in the base case analysis for the health impact. Even though there have been claims that hundreds of local residents in Mae Moh have lost their lives as a result of the toxic substances from the Mae Moh power plant, there has been no strong scientific evidence to support these claims. This assumption leads to the low benefits from investments in FGD emission control technology. However, most of the health science literature on air pollution strongly indicates a relationship between the risk of premature mortality and exposure to air pollution concentrations (eg., Ostro 1992; US EPA 1997, 1999; Lvovsky et al. 2000; HEI 2004). Various studies have obtained different estimates for mortality risk from exposure to air pollutants. From literature reviews, premature deaths appear to account for approximately 40 to 90 per cent of the total health costs.

Even though there seems to be great uncertainty in applying these parameters, it may in fact help overcome the conservative assumption of no mortality health costs and also provide further insights into the financial decisions of the FGD investments. Note that if a lower share of mortality cost of 40 per cent is used, the costs still dominate and the analysis still yields a negative NPV of approximately 6,600 million baht and a BCR of 0.52. On the other hand, if a high estimate of 90 per cent mortality cost is used, the NPV becomes a positive value at about 24,500 million baht and the BCR rises to 1.77. A quick assessment of the threshold value of mortality benefits that would be needed to equate the total benefits and total costs of FGDs indicates the share of mortality benefits to be approximately 71 per cent of the total health benefits in the case of Mae Moh plant.

Scenario 2: Estimated potential compensation payments are used as an alternative measure of the benefits of FGD investments

Since the first severe air pollution incident in 1992, the Mae Moh power plant has been claimed to pose an environmental threat to the communities surrounding the plant. At that time, thousands of local residents were found suffering from acute breathing ailments. Agricultural crops and trees were damaged. In 1992, EGAT's compensation for health damages was nine million baht which was approximately 7,800 baht (US$ 312) per case. It should be noted that the payments might reflect only the acute respiratory illnesses, and therefore underestimate the true economic costs of longer-term health deterioration due to air pollution.

Pollution problems in the Mae Moh areas recurred in 1996 and then again in 1998 and 1999 when severe air pollution caused damage to human health and ecological systems. As a result, the network of occupational health sufferers of Thailand was established to defend people and the environment adversely affected by the power plant. In 1998, the first lawsuit was filed against EGAT claiming SO_2 emissions had caused heavy pollution and damaged the plaintiffs' crops, vegetables and fruit trees. A series of lawsuits has been subsequently filed for health deterioration and environmental damages. Two other lawsuits filed in late 2003 by the affected local communities have claimed 1.08 billion baht (US$ 26.25 million) in compensation. Another lawsuit, filed in February 2004 by the local residents in Mae Moh District, asked the Chiang Mai Supreme Administrative Court to order the closure of the power plant. In relation to the first case filed in 1998, the Lampang provincial court, in May 2004, finally awarded approximately 3.22 million baht to 95 villagers for crop damages and in the subsequent month, a payment of 1.54 million baht was awarded to 64 farmers.

In this sensitivity analysis, the compensation payments EGAT might be expected to pay for health and crop damages over a period of 30 years without the FGD investments are calculated as a proxy for environmental damage costs or as a measure of the benefits of the FGDs. For adverse health impacts, the compensation EGAT actually paid in 1992 is used to estimate the total morbidity health damage costs by considering the incremental number of population at risk in the "without FGD" scenario as compared with those residing in the areas without being exposed to high ambient sulfur dioxide concentrations. By allowing for population growth, the present value of total compensation for potential morbidity health damages EGAT might be expected to pay would be approximately 9,670 million baht (in 1994 prices) at a six per cent discount rate. This is about 2.5 times greater than that estimated using the COI and WTP approaches in the base case.

In relation to crop damages, the average compensation actually awarded by the courts is used as a basis in the calculations. Due to crop diversity, the per-farmer compensation awarded is employed, and the total compensation payments are computed according to the number of agricultural households in the areas potentially affected by the air pollution. As agricultural land is assumed to be relatively limited, the compensation payments in real terms can be assumed to remain constant over the study period. Based on the calculations, at the six per cent discount rate, the present value of total compensation that EGAT might be expected to pay over a period of 30 years is approximately 7,130 million baht in real terms.

Based on actual compensations EGAT has paid for human health morbidity and crop damages, the estimated PV of the total amount of compensation payments EGAT might be expected to pay would be about 16,800 million baht which exceeds the total costs of FGD investments by approximately 3,000 million baht over the period of 30 years. This would bring the BCR up to about 1.22. However, these calculations may indicate only the minimum value of environmental damages as the premature health mortality risks and environmental costs on ecosystems such as teak forests and those of non-timber forest products are not taken into account in this compensation scheme.

Scenario 3: Medical costs, agricultural prices and forest stumpage prices are assumed to increase by 10 per cent

As summarized below, the estimated NPV and BCR of the FGD investments are only slightly increased from the base case when we assume that all the prices in the direct benefit components, i.e., health, agriculture and forest products simultaneously increase by 10 per cent. This is not surprising. Given significant high investment costs, a small change in a series of benefit categories would suggest a relatively small impact on the benefit-cost analysis. The NPV at the six per cent discount rate is still about minus 8,840 million baht with a BCR of 0.36.

Scenario 4: Only operating and maintenance costs are considered as relevant costs while capital costs are excluded as sunk costs

The next experiment is to exclude the capital investment costs, which are considered sunk costs. The results are somewhat different from those of the base case. However, they still constitute a net loss to society as indicated by a negative NPV of approximately 1,980 million baht at the six per cent discount rate and a BCR of 0.70.

The NPV and BCR results in the base case and sensitivity analysis of the investments in FGDs at the Mae Moh plant are summarized as follows:

Description	NPV (1994 million baht)	BCR
• Base case	-9,098.91	0.34
(1) Premature mortality is incorporated (*assuming mortality benefits contribute about 70.9% of total health benefits*).	**0.00**	**1.00**
(2) Compensation payments as an alternative measure of the benefits of FGDs.	**3,015.48**	**1.22**
(3) Medical costs, agricultural prices and stumpage prices increase by 10%.	-8,840.66	0.36
(4) Capital investment costs are not taken into consideration.	-1,978.79	0.70

7.0 SUMMARY AND POLICY IMPLICATIONS

EGAT has done considerable work to improve the environmental performance of the Mae Moh power plant since the first severe occurrence of sulfur dioxide emissions in 1992. The high investments in the FGD systems from 1994 to 2000 has greatly helped in controlling ambient sulfur dioxide concentrations at a rate far below the national standard especially in recent years. Health and other environmental concerns associated with sulfur dioxide problems such as in the past are unlikely to recur provided that the systems are fully controlled and well-maintained. Clearly, the FGD investments have been successful in terms of technological effectiveness.

7.1 Summary, Discussions and Implications

The primary objective of this study has been to conduct an economic assessment of the investments in FGDs at the Mae Moh lignite-fired power plant. Assuming the expected lifetime of 25 years, the study period starts from 1994 and ends in 2024. The estimation of incremental benefits and incremental costs associated with the FGD investments seems to suggest that EGAT has over-invested in the FGD controls at the Mae Moh power plant. The results of the present values of total benefits and total costs in real terms at a six per cent discount rate are approximately 4,700 and 13,800 million baht, respectively.

A breakdown of the cost data shows that capital investment costs represent about 52 per cent of the total costs, while input costs and operating expenses absorb about 27 and 15 per cent, respectively. The global damage costs of CO_2 emissions as a byproduct of the abatement process account for about six per cent of the total costs. It should be noted that the investment costs of FGD abatement technology are significantly high, with the initial capital costs being over half of the total costs. These very large capital costs incurred immediately at the early stage translate into high opportunity costs of the investments.

As part of the benefits assessment, improvements in human health form the greatest proportion of the total gains, accounting for about 79.4 per cent. The benefits from an increase in forest productivity in terms of timber and non-timber forest products contribute about 18.7 per cent, while crop benefits represent only 1.7 per cent of the total. Gypsum represents a very small side benefit of about 0.2 per cent of the total due to its low quality.

The results of the benefit-cost analysis in the base case indicate a negative NPV of approximately 9,100 million baht and a BCR of 0.34 which directly implies a net loss to society. Questions may arise on EGAT's decision to invest in the FGDs as the benefits do not seem to justify the costs. As a matter of fact, the justification for investing in pollution abatement does not depend entirely on economic grounds. When faced with high and uncertain environmental risks in terms of future adverse impacts of SO_2 emissions from a power plant, the application of the precautionary principle by implementing FGD technology to prevent or minimize society's risk is justified. The negative NPV of 9,100 million baht may reflect the "risk premium" to ensure that the air pollution caused by the Mae Moh power plant does not take place again.

Furthermore, the FGD investments represent a strategic approach in establishing public trust in the lignite-fired power plant. The public's belief that the best technology was implemented to help reduce environmental risks to their health and environment would augur well for Mae Moh plant operations. In fact, the net revenues from electricity production at the Mae Moh power plant appear to far exceed the FGD investment costs over their remaining lifetime.

Another interesting point when we further assess the FGD investments in a broader perspective, i.e., to compare the unit costs of fuel used in electricity production from various alternatives, is that we find that even with expensive technology such as FGDs in the lignite-fired power plant, the costs are still relatively cheaper as compared with electricity produced by other sources such as natural gas and fuel oil. The additional calculations on the unit cost of FGD abatement per kilowatt-hour of electricity produced from lignite at the Mae Moh power plant over the lifespan of 25 years is only 0.011 baht per kilowatt-hour. This would make the average cost of electricity produced from lignite increase to approximately 0.511 baht per kilowatt-hour (in the year 1998 – during FGD construction) which is still cheaper compared to other sources.[5] It should be noted that the comparisons are made in terms of average fuel cost of alternative fuels used in electricity production. Given that the fixed investment costs of all existing power plants are sunk costs, it is rational for EGAT to invest in FGD abatement technology as the additional abatement cost is still low.

In this study, the unsatisfactory results of the benefit-cost analysis of the FGD investments may stem from the fact that relevant impacts may not have been fully accounted for. As illustrated in the sensitivity analyses, the incorporation of the impacts

[5] Average costs of fuels used in electricity production from natural gas, fuel oil and diesel were 0.93, 1.10, and 2.72 baht per kilowatt-hour, respectively, in 1998. (http://www.eppo.go.th/doc/doc-AlterFuel.html).

of high ambient sulfur dioxide on prospective premature mortality could make the investments economically sound. Moreover, this study focuses on the primary pollutant of sulfur dioxide emissions. However, gaseous sulfur dioxide can be converted into sulfate particles by oxidation process in the atmosphere. These sulfate particles may have caused adverse health impacts in the region. This study focuses on the primary effect of gaseous SO_2 and does not consider the secondary impacts of SO_2 in the form of SO_4 particles (after oxidation) – therefore our estimates of the benefits of FGD investments at the Mae Moh plant may be less than if we had included these secondary impacts. Another plausible explanation that would support installing FGDs in the Mae Moh power plant is that the damage costs to human health and crop productivity are perceived by the affected parties as significantly high. Based on actual compensation for past pollution incidents, the projected PV of compensation payments EGAT might be expected to pay for over a period of 30 years without any pollution control measure would exceed the total investment costs in FGDs by about 3,000 million baht in real terms.

On economic grounds, the poor NPV and BCR results of FGD investments would imply that it might not have been necessary to install FGDs on all the power generating units at the Mae Moh power plant i.e., a more satisfactory outcome in terms of economic efficiency might have been achieved. In addition, when environmental protection measures involve high capital investment costs, policy-makers or environmental managers should consider the optimal timing of the investments as the opportunity cost of initial investments is relatively high. Alternatively, the implementation of less expensive abatement technology such as dry FGDs could also have been considered. Aside from the benefit-cost approach, it may also be worth considering other cost effectiveness criteria in planning for environmental protection. In other words, if we have to choose an appropriate abatement technology, attention should be paid to choosing the cheapest available technology that would comply with regulations or pre-established incremental risk reductions to be achieved. Finally, the unsatisfactory results of a negative NPV and a BCR of less than one in the case of the FGD investments suggest the need for a careful environmental benefit-cost analysis to guide decision-making before actually implementing environmental protection measures.

7.2 Limitations

It is important to explicitly acknowledge some potential limitations of this study. The first limitation would be the potential impacts that are not addressed in this study. The second deals with the inherent difficulties in environmental benefit estimation.

Issues of Potential Impacts

In implementing FGD technology to reduce the risks of exposure to SO_2 emissions, the primary benefits would include improved human health in terms of reduced morbidity and premature mortality, and protection of the ecosystem. In this study, the estimation of environmental benefits includes only three main categories, i.e., morbidity health benefits and increase in crop and forest productivities. In fact, there may be many other tangibles and intangibles involved that have not been quantified, for instance property damage and aesthetic qualities. The base case analysis, therefore, reflects the lower bound of environmental benefits brought about by the FGD abatement process. In other words, the analysis may underestimate the true economic value of the FGD technology.

Potential impacts such as premature mortality are not included in the main analysis. Increased acidic deposition in the atmosphere through the release of sulfate particles which could impact people and ecosystems in more distant areas are not fully assessed due to lack of scientific research and relevant data. The uncertainty of the extent of these damages may have a crucial impact on the benefit-cost analysis.

Measurement Problems

Aside from the uncertainties and possible omissions in estimating the benefits of the FGD controls, capturing and quantifying the intangible values of these benefit components is difficult. There are few models for assessing ecological risks at local or regional levels. Solving this problem can be the objective of future research. As the benefit estimation process in this study relies mainly upon secondary data, difficulties are often magnified by datasets that are unavailable, unreliable or incomplete. This is very problematic as it limits the use of available valuation techniques and affects the accuracy of the estimates.

Recognizing these uncertainties and shortcomings is important in interpreting and using the results. This study attempts to provide the data and analysis needed for assessing the economic viability of the FGD control technology at the Mae Moh lignite-fired power plant. With the limitations of the dataset and methodology employed in this analysis, the estimates cannot be used as references in any legal claims. In fact, the analysis can only be viewed as an additional source of information that policy-makers or environmental managers may use to make better and more informed decisions regarding the economic effectiveness of environmental protection measures.

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APPENDIX A

TABLES 1 – 18

Table 1. Production capacity of the Mae Moh power generation units and FGD plants

Generation Unit	Installed capacity (megawatt)	Production of electricity (million KWh)	Lignite input (million ton)	Year of commission	FGD construction year	FGD operation date	Efficiency rate in SO_2 removal
1	75	1,480	0.5	1978	-	-	-
2	75		0.5	1979	-	-	-
3	75		0.5	1981	-	-	-
4	150	985	1	1984	1997	February 14, 2000	97%
5	150	985	1	1984			
6	150	985	1	1985		December 7, 7,1999	
7	150	985	1	1985			
8	300	1,970	2	1989	1994	November 26, 1997	95%
9	300	1,970	2	1990	1994	September 17, 1997	
10	300	1,970	2	1991	1994	March 28, 1998	
11	300	1,970	2	1992	1994	January 30, 1998	
12	300	1,970	2	1995	1993	May 2, 1995	92%
13	300	1,970	2	1995	1993	September 18, 1995	
Total	2,625	17,240	17.5				

Table 2. Sulfur dioxide generated and emitted from Mae Moh power plant

Year	**Power Generation (GWh/year)**	**SO_2 generated (ton)**	**SO_2 emission (ton)**	**% SO_2 emission**	**SO_2 removal (ton)**
1992	14,856	505,959.52	505,959.52	100.00	0.00
1993	13,595	518,521.70	518,521.70	100.00	0.00
1994	14,097	530,809.85	530,809.85	100.00	0.00
1995	13,581	540,777.60	534,379.42	98.82	6,398.18
1996	17,154	638,809.60	538,821.62	84.35	99,987.93
1997	19,376	718,559.89	568,436.59	79.11	150,123.30
1998	17,106	670,989.84	351,482.82	52.38	319,500.02
1999	15,784	574,086.22	98,807.74	17.21	475,278.48
2000	15,547	589,171.14	92,783.38	15.75	496,387.76
2001	17,338	680,878.00	27,615.00	4.06	653,263.00
2002	16,924	651,769.60	19,553.09	3.00	632,216.51
2003	17,177	795,963.67	20,145.45	2.53	775,818.22
2004	17,597	829,398.22	23,542.69	2.84	805,855.53

Table 3. Highest monthly maximum 1-hour average & maximum 24-hour average ambient SO_2 concentration by air quality monitoring station (AQMS)

AQMS	**Distance from power plant (km.)**		**Highest Recorded Concentration (μg/m^3)**			
	Unit 1-3	**Unit 4-13**	**Max 1-hour average**		**Max 24-hour average**	
			Pre-FGD	**Post-FGD**	**Pre-FGD**	**Post-FGD**
Meteorological main station	1.5	2	4,184(1993)	403(2003)	378(1993)	34(2003)
Ban Koh Or	1.8	3.2	3,754(1992)	346(2003)	352(1996)	29(2001)
Ban Sadet	14.3	4.0	1,569(1995)	128(2003)	194(1995)	8(2001)
Ban Mae Chang School	7.9	4.6	2,251(1996)	160(2001)	303(1993)	18(2003)
Ban Sop Prad	8.5	5.5	3,380(1992)	252(2003)	389(1992)	20(2004)
Ban Sop Moh	6.3	5.8	2,418(1996)	487(2003)	385(1997)	29(2001)
Ban Huai King	4.8	7.1	2,620 (1991,1992)	155(2003)	233(1992)	19(2002)
Ban Hua Fai	7.9	10.0	2,827(1995)	231(2004)	314(1995)	18 (2001,2004)
Mae Moh Government Centre	8.0	10.0	2,484(1995)	131(2003)	374(1995)	31(2003)
Ban Mai Ratanakosin	12.8	11.3	1,792(1997)	115(2003)	277(1995)	17(2004)
Ban Thasi	13.0	14.7	2,651(1995)	126(2001)	324(1995)	16(2001)
Pratupha Army Camp	21.5	22.0	1,635(1995)	123(2004)	231(1998)	24(2003)

Table 4. Adjusted odds ratio and 95% confidence interval (given in parenthesis) of respiratory symptoms and illnesses in adults (age 15 and over) and children (age less than 15) in Mae Moh District in relation to the control site, 1994-2000

Population	Sample size	Cough	Chronic cough	Phlegm	Chronic phlegm	Wheezing	Asthma	Bronchitis
Adults	4,957	2.1 (1.9-2.3)	3.0 (2.4-3.8)	1.9 (1.7-2.1)	2.8 (2.3-3.6)	2.7 (2.3-3.1)	2.2 (1.6-3.0)	2.3 (1.2-2.8)
Children	3,294	1.7 (1.5-1.8)	3.7 (2.3-5.8)	1.6 (1.5-1.8)	2.5 (1.7-3.7)	2.3 (2.0-2.8)	1.3 (1.0-1.7)	

Source: College of Public Health, 2002

Table 5. Calculations of dose response relationships between adjusted odds ratios in terms of risks of having respiratory symptoms and illnesses and annual ambient SO_2 in natural logarithm

Year	Annual ambient SO_2 (microgram/m^3)	ln SO_2	Adult								Children				
			Phlegm 1.9	Cough 2.1	Asthma 2.2	Bronchitis 2.3	Bronchitis 2.3	Wheeze 2.7	CP[1] 2.8	CC[2] 3.0	Phlegm 1.6	Cough 1.7	Wheeze 2.3	CC[1] 3.7	CP[2] 2.5
1994	27.11	3.2999	2.4098	2.6635	2.7903	2.9171	2.9171	3.4245	3.5513	3.8049	2.0293	2.1561	2.9171	4.6928	3.1708
1995	27.89	3.3283	2.4305	2.6864	2.8143	2.9422	2.9422	3.4539	3.5818	3.8377	2.0467	2.1747	2.9422	4.7331	3.1980
1996	24.67	3.2056	2.3409	2.5873	2.7105	2.8338	2.8338	3.3266	3.4498	3.6962	1.9713	2.0945	2.8338	4.5586	3.0802
1997	23.08	3.1390	2.2923	2.5336	2.6542	2.7749	2.7749	3.2574	3.3781	3.6194	1.9303	2.0510	2.7749	4.4639	3.0161
1998	13.83	2.6268	1.9183	2.1202	2.2212	2.3221	2.3221	2.7260	2.8269	3.0289	1.6154	1.7164	2.3221	3.7356	2.5241
1999	4.87	1.5831	1.1561	1.2778	1.3386	1.3995	1.3995	1.6428	1.7037	1.8254	0.9735	1.0344	1.3995	2.2513	1.5212
2000	2.80	1.0296	0.7519	0.8310	0.8706	0.9102	0.9102	1.0685	1.1081	1.1872	0.6332	0.6727	0.9102	1.4642	0.9893
Average	**17.75**	**2.6018**													

Notes: [1]Chronic phlegm
[2]Chronic cough

Table 6. Medical costs and other relevant costs employed in estimating health impacts, 1994 prices

Cost/Health effect[1]	**Costs/visit**[2] **(Baht)**	
	1994-2004	**2005-2027**
Out-patient (medical costs)		
Asthma attacks	196.06	242.07
Bronchitis	88.41	134.42
Respiratory symptoms	65.95	111.96
In-patient (medical costs)		
Asthma attacks	1,406.41	1,847.61
Bronchitis	1,094.91	1,536.11
Respiratory symptoms	1,127.05	1,568.24
Transportation costs	77.30	77.30
Wage	110.00	110.00

Notes: [1] From the Mae Moh hospital database (2002-2004), percentage of hospital admissions for asthma attacks, bronchitis and respiratory symptoms were 2.72, 5.40 and 1.25 per cent, respectively.

[2] There was an increase in actual medical costs in 2005.

Table 7. Components in costs of illness that can be reduced by FGD controls at the Mae Moh power plant (1994, million baht)

Year	Adult				Children			Total COI	Total WTP
	Medical costs	Transportation cost (TC)	Wage lost	Total	Medical costs	TC	Total		
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	3.96	2.85	4.30	11.11	0.53	0.48	1.01	12.12	24.24
1998	13.48	9.68	14.66	37.82	1.74	1.69	3.43	41.25	82.50
1999	41.12	29.54	44.74	115.40	4.87	4.73	9.60	125.00	250.00
2000	57.11	41.03	62.13	160.27	6.82	6.63	13.45	173.72	347.44
2001	52.93	38.02	57.58	148.53	6.20	6.03	12.23	160.76	321.52
2002	53.54	38.46	58.24	150.24	6.19	6.02	12.21	162.45	324.90
2003	54.16	38.90	58.91	151.97	6.10	5.93	12.03	164.00	328.00
2004	54.70	39.29	59.50	153.49	6.17	5.99	12.16	165.65	331.30
2005	83.04	39.69	60.08	182.81	10.23	6.05	16.28	199.09	398.18
2006	83.87	40.08	60.70	184.65	10.34	6.11	16.45	201.10	402.20
2007	84.70	40.48	61.32	186.50	10.44	6.18	16.62	203.12	406.24
2008	85.55	40.89	61.92	188.36	10.54	6.24	16.78	205.14	410.28
2009	86.41	41.30	62.55	190.26	10.65	6.30	16.95	207.21	414.42
2010	87.27	41.71	63.16	192.14	10.76	6.36	17.12	209.26	418.52
2011	88.14	42.13	63.79	194.06	10.86	6.43	17.29	211.35	422.70
2012	89.03	42.55	64.43	196.01	10.97	6.49	17.46	213.47	426.94
2013	89.92	42.97	65.08	197.97	11.08	6.56	17.64	215.61	431.22
2014	90.81	43.40	65.73	199.94	11.19	6.62	17.81	217.75	435.50
2015	91.72	43.84	66.39	201.95	11.30	6.69	17.99	219.94	439.88
2016	92.64	44.28	67.05	203.97	11.42	6.75	18.17	222.14	444.28
2017	93.57	44.72	67.72	206.01	11.53	6.82	18.35	224.36	448.72
2018	94.50	45.17	68.40	208.07	11.65	6.89	18.54	226.61	453.22
2019	95.45	45.62	69.08	210.15	11.76	6.96	18.72	228.87	457.74
2020	96.40	46.07	69.77	212.24	11.88	7.03	18.91	231.15	462.30
2021	97.37	46.53	70.47	214.37	12.00	7.10	19.10	233.47	466.94
2022	98.34	47.00	71.17	216.51	12.12	7.17	19.29	235.80	471.60
2023	33.07	15.81	23.94	72.82	4.08	2.41	6.49	79.31	158.62
2024	33.40	15.97	24.18	73.55	4.12	2.44	6.56	80.11	160.22

Table 8. Summary of health benefits by component of cost avoided (1994-2024)

Unit: 1994, million baht

Discount value (%)	Medical costs	Transportation costs	Wages lost	Total cost of illness (COI)	Willingness to pay (WTP)
0	2,273.74 (44.85)	1,209.08 (23.85)	1,586.99 (31.30)	5,069.81 (100.00)	10,139.62
6	811.53 (43.50)	456.02 (24.44)	598.04 (32.06)	1,865.59 (100.00)	3,731.18

Note: Percentage of total cost of illness is given in parenthesis.

Table 9. Agricultural benefits in the Mae Moh basin brought about by FGD controls

Year	**Total agricultural benefits (1994, million baht)**
1994	0.00
1995	0.00
1996	0.00
1997	1.69
1998	4.69
1999	6.16
2000	6.71
2001	8.67
2002	7.82
2003	7.54
2004	8.45
2005	8.00
2006	8.00
2007	8.00
2008	8.00
2009	8.00
2010	8.00
2011	8.11
2012	8.11
2013	8.11
2014	8.11
2015	8.11
2016	8.11
2017	8.11
2018	8.11
2019	8.11
2020	8.11
2021	8.11
2022	8.11
2023	2.70
2024	2.70
Total	**202.45**
PV (6%)	**79.28**

Table 10. Areas of commercial teak forest plantations (rai) by distance from the Mae Moh power plant (0-40 km. and 41-100 km.)

Year planted	Distance (0-40 km)			Distance (41-100 km)		
	Lampang	Phrae	Total	Lampang	Phrae	Total
1968	1,584	-	1,584	1,954	-	1,954
1969	1,620	-	1,620	1,908	-	1,908
1970	1,673	-	1,673	1,989	-	1,989
1971	2,295	-	2,295	2,061	-	2,061
1972	3,525	-	3,525	2,330	-	2,330
1973	3,000	-	3,000	2,317	-	2,317
1974	2,229	264	2,493	2,450	986	3,436
1975	2,367	-	2,367	3,620	1,166	4,786
1976	2,058	-	2,058	2,080	1,045	3,125
1977	2,726	2,123	4,849	5,010	839	5,849
1978	2,448	2,950	5,398	3,907	9,490	13,397
1979	3,659	2,096	5,755	5,450	15,762	21,212
1980	3,974	-	3,974	5,070	5,243	10,313
1981	3,525	-	3,525	1,924	5,748	7,672
1982	2,320	-	2,320	1,734	3,324	5,058
1983	2,705	-	2,705	1,796	4,580	6,376
1984	2,793	-	2,793	2,075	6,867	8,942
1985	2,244	-	2,244	1,909	4,850	6,759
1986	-	-	-	898	1,224	2,122
1987	-	-	-	1,828	1,330	3,158
1988	-	-	-	141	240	381
1989	-	-	-	-	188	188
1990	-	-	-	-	410	410
1991	-	-	-	-	665	665
1992	-	-	-	-	1,120	1,120
1993	-	-	-	-	780	780
1994	-	-	-	-	990	990

Note: There is no commercial teak plantation reported for Phayao Province.

Table 11. Average productivity of teak woods in northern Thailand by age of plantation

Age of plantation (year)	**Volume (normal growth without air pollution) (m^3/rai)**
0	0.00
1	0.50
2	1.00
3	1.50
4	2.00
5	2.50
6	3.00
7	3.50
8	4.00
9	4.50
10	5.00
11	5.73
12	6.46
13	7.20
14	7.93
15	8.67
16	9.37
17	10.07
18	10.77
19	11.47
20	12.17
21	12.68
22	13.18
23	13.69
24	14.19
25	14.70
26	15.19
27	15.68
28	16.17
29	16.66
30	17.15

Table 12. Summary of potential benefits of FGD investments in reduction of damages to teak plantations

Year	Zone 1 (m^3)	Zone 2 (m^3)	Total (m^3)	Total benefits (1994 million baht)
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	4,032.05	6,846.63	10,878.68	36.30
1998	3,905.04	6,793.05	10,698.09	35.70
1999	3,766.39	6,542.87	10,309.26	34.40
2000	6,135.46	10,423.77	16,559.23	55.25
2001	5,961.09	10,093.62	16,054.71	53.57
2002	5,821.11	9,876.66	15,697.77	52.38
2003	5,722.70	9,741.08	15,463.78	51.60
2004	5,606.60	9,526.63	15,133.23	50.50
2005	5,485.19	9,217.13	14,702.32	49.06
2006	5,390.11	8,994.18	14,384.29	48.00
2007	5,383.70	8,924.55	14,308.25	47.74
2008	5,385.73	8,809.58	14,195.31	47.37
2009	5,461.68	8,833.63	14,295.31	47.70
2010	5,539.65	8,865.00	14,404.65	48.06
2011	11,236.83	18,054.21	29,291.04	97.74
2012	11,463.99	18,170.35	29,634.34	98.88
2013	11,802.28	18,267.65	30,069.93	100.33
2014	12,072.05	18,426.17	30,498.22	101.76
2015	12,294.02	18,671.40	30,965.42	103.32
2016	12,501.48	19,003.59	31,505.07	105.12
2017	12,663.78	19,204.95	31,868.73	106.34
2018	13,072.09	19,596.86	32,668.95	109.01
2019	13,414.63	20,402.07	33,816.70	112.84
2020	13,794.54	21,748.57	35,543.11	118.60
2021	14,004.89	22,310.84	36,315.73	121.17
2022	14,128.44	22,700.17	36,828.61	122.89
2023	4,621.88	7,545.13	12,167.01	40.60
2024	4,600.35	7,598.26	12,198.61	40.70
Sum				**2,036.93**
PV (6%)				**706.37**

Note: Real stumpage value = 3,336.70 baht/m^3

Table 13. Benefits of non-timber forest products brought about by FGD controls

Year	Total household	% yield reduction	Benefit saved (baht/household)	Total benefits (1994 million baht)
1994	313,549	0.0000	0.00	0.00
1995	322,377	0.0000	0.00	0.00
1996	330,506	0.0000	0.00	0.00
1997	322,165	1.7641	15.71	4.05
1998	328,583	0.7654	40.55	10.66
1999	327,247	0.1376	56.16	14.70
2000	334,015	0.0552	58.21	15.55
2001	338,147	0.0317	58.80	15.91
2002	344,807	0.0619	58.05	16.01
2003	349,541	0.0101	59.33	16.59
2004	352,408	0.0101	59.33	16.73
2005	355,297	0.0101	59.33	16.86
2006	358,211	0.0101	59.33	17.00
2007	361,148	0.0101	59.33	17.14
2008	364,109	0.0101	59.33	17.28
2009	367,095	0.0101	59.33	17.42
2010	370,105	0.0101	59.33	17.57
2011	373,140		59.58	17.79
2012	376,200		59.58	17.93
2013	379,285		59.58	18.08
2014	382,395		59.58	18.23
2015	385,531		59.58	18.38
2016	388,692		59.58	18.53
2017	391,879		59.58	18.68
2018	395,093		59.58	18.83
2019	398,332		59.58	18.99
2020	401,599		59.58	19.14
2021	404,892		59.58	19.30
2022	408,212		59.58	19.46
2023	411,559		19.84	6.53
2024	414,934		19.84	6.59
Total				**449.94**
PV (6%)				**173.78**

Table 14. Production and sale of gypsum

Year	Production (ton)	Sale (ton)	% Sale	Revenue (1994 million baht)
1994	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	526,711.00	0.00	0.00	0.00
1998	1,104,600.40	23,499.00	2.13	0.47
1999	1,365,213.59	66,214.00	4.85	1.32
2000	1,503,266.08	49,307.00	3.28	0.99
2001	2,044,969.93	46,052.00	2.25	0.92
2002	2,010,904.63	69,280.61	3.45	1.39
2003	2,236,281.45	60,772.76	2.72	1.22
2004	2,125,653.79	63,019.42	2.96	1.26
2005	1,063,774.28	36,895.10	3.47	0.74
2006	1,354,115.42	42,519.22	3.14	0.85
2007	1,354,115.42	42,519.22	3.14	0.85
2008	1,354,115.42	42,519.22	3.14	0.85
2009	1,354,115.42	42,519.22	3.14	0.85
2010	1,354,115.42	42,519.22	3.14	0.85
2011	1,354,115.42	42,519.22	3.14	0.85
2012	1,354,115.42	42,519.22	3.14	0.85
2013	1,354,115.42	42,519.22	3.14	0.85
2014	1,354,115.42	42,519.22	3.14	0.85
2015	1,354,115.42	42,519.22	3.14	0.85
2016	1,354,115.42	42,519.22	3.14	0.85
2017	1,354,115.42	42,519.22	3.14	0.85
2018	1,354,115.42	42,519.22	3.14	0.85
2019	1,354,115.42	42,519.22	3.14	0.85
2020	1,354,115.42	42,519.22	3.14	0.85
2021	1,354,115.42	42,519.22	3.14	0.85
2022	1,354,115.42	42,519.22	3.14	0.85
2023	1,354,115.42	42,519.22	3.14	0.28
2024	1,354,115.42	42,519.22	3.14	0.28
Total				**23.32**
PV (6%)				**9.57**

Note: Quantity of gypsum produced from 2005-2024 is forecasted. The average percentage of sales from 1996-2004 of 3.14 % is employed to forecast the sale of gypsum after 2004.

Table 15. Benefits brought about by FGD abatement technology at Mae Moh power plant (6% discount rate)

Benefits	Present value (1994, million baht)	% of total benefits
Health	3,731.18	79.38
Agriculture	79.28	1.69
Forests	880.15	18.73
Gypsum	9.57	0.20
Total	**4,700.18**	**100.00**

Table 16. Costs of FGD abatement technology

Unit:1994, million baht

Year	Capital costs	Operating & maintenance costs	Input costs	Costs of CO_2	Total costs	Total costs (excluding CO_2)
1994	1,421.08	0.00	0.00	0.00	1,421.08	1,421.08
1995	1,351.16	0.00	0.00	0.00	1,351.16	1,351.16
1996	1,284.79	0.00	0.00	0.00	1,284.79	1,284.79
1997	2,410.00	13.47	0.00	48.79	2,472.26	2,423.47
1998	1,103.70	57.12	156.07	67.49	1,384.38	1,316.89
1999	1,084.48	81.97	175.77	79.56	1,421.78	1,342.22
2000	0.00	115.59	373.38	62.07	551.04	488.97
2001	0.00	170.11	455.67	80.99	706.77	625.78
2002	0.00	236.96	378.63	81.99	697.58	615.59
2003	0.00	185.09	449.31	86.33	720.73	634.40
2004	0.00	482.35	476.32	91.45	1,050.12	958.67
2005	0.00	212.01	384.85	85.05	681.91	596.86
2006	0.00	212.01	384.85	86.10	682.96	596.86
2007	0.00	212.01	384.85	87.11	683.97	596.86
2008	0.00	212.01	384.85	88.07	684.93	596.86
2009	0.00	212.01	384.85	88.97	685.83	596.86
2010	0.00	212.01	384.85	89.84	686.70	596.86
2011	0.00	212.01	384.85	90.66	687.52	596.86
2012	0.00	212.01	384.85	91.46	688.32	596.86
2013	0.00	212.01	384.85	92.21	689.07	596.86
2014	0.00	212.01	384.85	92.93	689.79	596.86
2015	0.00	212.01	384.85	93.63	690.49	596.86
2016	0.00	212.01	384.85	94.60	691.46	596.86
2017	0.00	212.01	384.85	95.54	692.40	596.86
2018	0.00	212.01	384.85	96.44	693.30	596.86
2019	0.00	212.01	384.85	97.30	694.16	596.86
2020	0.00	212.01	384.85	98.13	694.99	596.86
2021	0.00	212.01	384.85	98.93	695.79	596.86
2022	0.00	212.01	384.85	99.70	696.56	596.86
2023	0.00	70.60	128.15	33.48	232.23	198.75
2024	0.00	70.60	128.15	33.72	232.47	198.75
Total	**8,655.21**	**5,300.04**	**9,648.75**	**2,332.54**	**25,936.54**	**23,604.00**
PV (6%)	**7,120.12**	**2,025.63**	**3,739.11**	**914.23**	**13,799.09**	**12,884.86**

Table 17. Costs of FGD abatement technology at the Mae Moh power plant (6% discount rate)

Costs	Present value (1994, million baht)	% of total costs	% of total costs (excluding CO_2)
Capital costs	7,120.12	51.60	55.26
O&M	2,025.63	14.68	15.72
Input costs	3,739.11	27.10	29.02
Costs of CO_2	914.23	6.62	-
Total costs	**13,799.09**	**100.00**	**-**
Total costs (excluding CO_2)	**12,884.86**	**-**	**100.00**

Table 18. Summary of total benefits and total costs associated with FGD investments

Unit: 1994, million baht

Year	Total benefits	Total costs (excluding CO_2)	Net benefits (excluding CO_2)	Total costs	Net benefits
1994	0.00	1,421.08	-1,421.08	1,421.08	-1,421.08
1995	0.00	1,351.16	-1,351.16	1,351.16	-1,351.16
1996	0.00	1,284.79	-1,284.79	1,284.79	-1,284.79
1997	66.36	2,423.47	-2,357.11	2,472.26	-2,405.90
1998	134.01	1,316.86	-1,182.84	1,384.35	-1,250.34
1999	306.61	1,342.22	-1,035.61	1,421.77	-1,115.16
2000	425.92	488.97	-63.05	551.04	-125.12
2001	400.59	625.78	-225.19	706.78	-306.19
2002	402.50	615.59	-213.09	697.58	-295.08
2003	404.97	634.41	-229.44	720.74	-315.77
2004	408.24	958.67	-550.43	1,050.12	-641.88
2005	472.92	596.86	-123.94	681.91	-208.99
2006	476.05	596.86	-120.81	682.96	-206.91
2007	479.94	596.86	-116.92	683.97	-204.03
2008	483.78	596.86	-113.08	684.93	-201.15
2009	488.35	596.86	-108.51	685.83	-197.48
2010	493.00	596.86	-103.86	686.70	-193.70
2011	547.19	596.86	-49.67	687.52	-140.33
2012	552.70	596.86	-44.16	688.32	-135.62
2013	558.57	596.86	-38.29	689.07	-130.50
2014	564.46	596.86	-32.40	689.79	-125.33
2015	570.53	596.86	-26.33	690.49	-119.96
2016	576.88	596.86	-19.98	691.46	-114.58
2017	582.69	596.86	-14.17	692.40	-109.71
2018	590.00	596.86	-6.86	693.30	-103.30
2019	598.51	596.86	1.65	694.16	-95.65
2020	609.01	596.86	12.15	694.99	-85.98
2021	616.36	596.86	19.50	695.79	-79.43
2022	622.90	596.86	26.04	696.56	-73.66
2023	208.73	198.75	9.98	232.24	-23.51
2024	210.49	198.75	11.74	232.48	-21.99
Total	**12,852.26**	**23,603.98**	**-10,751.73**	**25,936.54**	**-13,084.28**
PV (6%)	**4,700.18**	**12,884.86**	**-8,184.68**	**13,799.09**	**-9,098.91**