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Benefits and Costs of Controlling Emissions from Fossil-fired Power Plants: Region IV, Philippines

Elvira M. Orbeta, Carlito M. Rufo Jr., and Anabeth L. Indab

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BENEFITS AND COSTS OF CONTROLLING EMISSIONS FROM FOSSIL-FIRED POWER PLANTS: REGION IV, PHILIPPINES[1]

Elvira M. Orbeta, Carlito M. Rufo, Jr. and Anabeth L. Indab

Abstract

The study assessed the incremental benefits and costs of different options to control PM_{10} and SO_2 emissions from fossil-fired power plants using two power plants in Region IV (Southern Tagalog), Philippines, as case studies. Benefits were estimated by modeling the changes in ambient concentrations arising from the control, estimating the improvements, and valuing these in economic terms. The study focused on adverse health effects, using dose-response function established in other studies, and economic values based on the benefit transfer technique. Control costs were estimated using the engineering cost approach. Impacts were assessed within 10 and 50 km radius from each plant. The study showed that existing controls for particulates met the emissions standard. However, the use of fuel with standard sulfur content was not sufficient to meet SO_2 emissions standard. Thus, a review of the sulfur content standard in fuel was recommended. SO_2 emissions from each of the two power plants translated to maximum predicted ambient concentrations that were significant relative to the maximum allowable ambient concentration. The value of the health effects avoided was much larger when the impact area was extended from 10- to 50-km radius, it was much larger for oil than for coal, with the value of mortality effects avoided dominating the total. Among the different options analyzed only the switch to cleaner fuel for oil and increased thermal efficiency for coal were justified. With a switch to cleaner fuel, the value of health damage avoided considering a 50-km impact area was 0.08% to 3.34% of the current average selling price of electricity, implying a 0.11% to 4.31% increase in the average cost of power service if the power plants were made to internalize the health damages.

1.0 INTRODUCTION

The Philippines has a total installed generation capacity of 10,855 MW as of 1998, almost double its capacity in 1988 (NPC 1998). Generation capacity is distributed as follows: 49.8% oil-fired, 13.4% coal-fired, 36.8% hydro and geothermal sources. About 25% of the total, mainly oil-fired, is located in two highly populated regions - the National Capital Region (NCR) and the Southern Tagalog Region (Region IV). About 2,000 MW of the oil-fired generation capacity is scheduled for retirement between 1999 and 2005. Coal, on the other hand, is projected to contribute the bulk of additional installed capacity and the leading energy source between 1998 and 2010 (DOE 1996).

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[1] Prepared by Ms. Elvira M. Orbeta of the Resources, Environment and Economics Center for Studies (REECS), principal investigator, Ms. Anabeth L. Indab, research associate and Engr. Carlito M. Rufo, Jr. air dispersion modeler for the Economy and Environment Program for Southeast Asia.

Based on ENRAP (Phase 3) [2] estimates, power generation had been the major source of sulfur oxide (SOx) emissions accounting for over 50% of total emissions between 1988 and 1992 (Orbeta and Indab 1997). During the same period, power plants generated annually about 223,000 metric tons (MT) of SOx emissions (Rufo *et al* 1997). Estimated SOx emissions were higher by 23% in 1995. Emissions were mainly from fossil-fired power plants, particularly from oil-fired power plants (Rufo *et al* 1997). Fortunately, most of these are due for retirement soon.

Power generation is associated with the problems of acid deposition and health effects arising mainly from particulate and SOx emissions (Freeman 1995). SOx together with particulates and nitrogen oxides in the air aggravate respiratory and cardiac diseases that increase the risk of pre-mature death among children and adults. The value of the health effects was estimated at about 96% for particulate. These pollutants also have non-health effects such as loss of visibility, materials soiling, and damage to crops and materials.

Existing pollution control measures are mainly for particulate control. Some oil-fired power plants have mechanical dust collectors while coal-fired thermal power plants are equipped with electrostatic precipitators (EP). To minimize sulfur oxide emissions, fuel with standard sulfur content is used. Only the latest coal-fired power plants are equipped with a flue gas desulfurization (FGD) system for the control of SOx emissions. Unless adequate pollution control is put in place, the environmental impacts from power generation are expected to worsen as the government implements its power development program.

To provide some basis for decisions regarding investments in air pollution control in the power generation sector, specifically for fossil-fired power plants in the Philippines, the study conducted a benefit-cost analysis (BCA) of different control options for PM_{10} and SO_2 emissions. It used two power plants as case studies: a coal-fired and an oil-fired power plant located in two rural areas in Region IV. The control options included a switch to cleaner fuel (i.e., lower sulfur and lower ash content); increased thermal efficiency; and end-of-pipe pollution control measures such as EP and FGD technologies. In particular, the study evaluated, in economic terms, the extent to which the alternative options might result in changes in environmental benefits and changes in costs of control. The study also provided some insights on the use of coal vs. oil – in terms of relative costs and benefits.

The report consists of six sections. Section 2 provides background information on the relevant regulations for controlling air pollution from stationary sources, the power plants selected, and scenarios analyzed. Section 3 discusses the theoretical and analytical framework of the study. Sections 4 and 5 provide an assessment of the physical impacts and valuation of the benefits and costs of the different control options, respectively. Section 6 provides a brief summary and conclusion of the study.

[2] The Environment and Natural Resources Accounting Project (ENRAP), funded by USAID is implemented by the International Resources Group in cooperation with the Edgevale Associates and the Resources, Environment and Economics Center for Studies for the Philippine Department of Environment and Natural Resources.

2.0 BACKGROUND

2.1 Relevant Air Pollution Regulations

The Department of Environment and Natural Resources (DENR), through its Environment and Management Bureau (EMB), is responsible for establishing and monitoring environmental standards in the Philippines. Command and control mechanisms are used to regulate air emissions. These mechanisms are stipulated in the Air Quality Standards of the Philippines (Presidential Decree No. 984, DAO # 14 and 14-A, s. 1993). The measures include licensing, specification of fuel sulfur content, implementation of emission and ambient standards, and imposition of penalties and corrective measures for non-compliance.

Stationary sources including power stations are required to secure a license to construct and operate pollution control facilities. The license is renewed annually and is subject for review by the Department. Major sources of SOx are required to install appropriate control facilities within five years after the signing of the Revised Air Quality Standard (DAO # 14-A, s. 1993).

As a supplementary approach to controlling sulfur compound emissions, the revised standard specified the maximum sulfur content levels for liquid and solid fuel. The initial specifications were as follows: within Metro Manila - 2.5% for coal, 3.5% for fuel oil and 0.7% for industrial diesel; outside Metro Manila - 0.3% and 0.1% higher for fuel oil and industrial diesel, respectively. Starting in 1996, lower sulfur contents in fuels were required: 3% for fuel oil, 0.5% for industrial diesel, and 1.0% for coal. For industrial diesel, the Clean Air Act of 1999 specified further reduction to 0.3 % by 2001.

The air quality standard applied to power generating plants distinguishes between the location and age of the plant. Power plants in non-urban areas are mandated to comply with the national ambient air quality standards for source specific air pollutants from industrial sources as per DENR MC 29, s.1994 while those in urban areas are required to meet the emissions standards stipulated in DAO 14, s.1993. DENR MC 29, s.1994 requires power plants in non-urban areas to undertake the following activities: a) study plume dispersion of its emissions to pinpoint ambient air sampling sites and appropriate buffer zones; b) provide automatic air sampling instruments, which are to be installed and operated continuously in selected sampling sites; c) submit monthly air sampling results; and d) institute measures to reduce emissions whenever standards are exceeded. Appendix 1 shows the TSP, PM_{10} and SO_2 emissions, and ambient standards applicable to fossil-fired power generation.

The DENR Regional Offices monitor compliance to environmental standards, except for stationary sources located along Laguna de Bay which are under the jurisdiction of the Laguna Lake Development Authority (LLDA). Samples are taken at an elevation of at least 2 meters above the ground, either at the property line or at a downwind distance of 5 to 25 times the stack height, whichever is more stringent.

Likewise, DENR establishes norms for Environmental Impact Assessment (EIA) of environmentally critical projects such as power generation. It also issues Environmental Compliance Certificates. The EIA system requires project proponents to identify and predict potential environmental impacts as well as propose the necessary mitigating measures. For non-compliance, a penalty of 20[3] pesos per kilogram of SO_2 discharged beyond the allowable emission limit, or a maximum of 5,000 pesos per day. In addition, non-complying sources are required to institute, within a given period of time, any one or a combination of the following corrective measures: 1) use a specified sulfur content of fuel; 2) erect or alter the height or dimensions of the stack to reduce ground level concentrations of SO_2 to a specified level not exceeding 180 μg/Ncm (24-hr. sampling) above background level; or 3) alter the method of operation or industrial process. The penalty and other requirements for non-compliance, however, were never implemented for some reason.

2.2 Power Plants Selected

Table 1 briefly describes the oil- and coal-fired power plants that were selected as case studies. These power plants were chosen because of their relative importance to the total generating capacity and the particular plant type to which they belonged. The coal- and oil-fired power plants were located in two non-urban areas in Region IV. As such, both power plants were subject to the national ambient air quality standard as per DENR MC 29 s. 1994. Three municipalities were within 10-km radius from each power plant. On the other hand, there were over 50 municipalities within a 50-km radius. There were four major land uses within the areas of influence of the two power plants, namely: built-up, areas planted to agricultural crops, forestland, and water bodies (i.e., swamp, marsh, lake, sea). The oil-fired power plant had a larger built-up area surrounding it than the coal-fired power plant. The major agricultural crops within the influence areas included rice and annual crops such as sugarcane.

Table 1. Description of power plants studied

Item	Oil-fired	Coal-fired
Installed capacity	300 MW and 350 MW; 12% to total oil capacity[1]; 6.0% to total generating capacity[1]	2 x 300 MW; 41% to total coal capacity[1]; 5.5% to total generating cap.[1]
Date established	Unit 1 – 1975; Unit 2 – 1979; both units were rehabilitated in 1995	Unit 1 – 1984; Unit 2 – 1995
Location	A rural area approximately 70 km southeast of Metro Manila	A rural area approximately 270 km southwest of Metro Manila
Land-use w/in area of influence	Built-up, orchard, forest, scrub, agri. Crops, grassland, and water body	Built-up areas, agriculture crops such as sugarcane and rice, forest, scrub, grassland and water body

[1] as of 1998
Sources: EIA documents, plant profiles, and personal interviews

Technical plant details required in the estimation of emissions and air dispersion modeling are discussed in subsequent sections.

2.3 Control Scenarios Analyzed

Two sets of scenarios were analyzed: 1) base case and 2) with "additional" control scenarios. The base case scenario is defined in terms of the existing power

[3] USD1= P40

generation capacity and emission control technologies of the two power plants selected as case studies. The oil-fired power plant used utility boilers firing residual oil while the coal-fired power plant was a tangentially fired pulverized coal system using bituminous coal. For the control of particulates, the oil-fired power plant uses cyclones while the coal-fired power plant uses electrostatic precipitators. To reduce SO_2 emissions, the two power plants use fuel with sulfur content within the prescribed standard of 3% for bunker oil fuel (BOF) and 1% S for coal.

The additional control scenarios included: 1) a switch to cleaner fuel, 2) increased generating efficiency, 3) end-of-pipe (EOP) control measures such as an EP for PM_{10} and FGD for SO_2, and 4) combination of EOP and cleaner fuel (Table 2). The switch to cleaner fuel and increased efficiency options were implemented in conjunction with the existing control. Cleaner fuel assumed sulfur content levels of 0.5% for coal and 1% for bunker oil. The target level for coal was based on the estimated level required to meet the emission standard of 700 mg/Ncm[4] for new steam generating plants (DOE 1996). It is available from current sources, namely, Australia, China, and Indonesia. For bunker oil fuel, the level was based on the lowest level currently used by some oil-fired power plants in Asia (e.g., Korea). For FGD, the particular type assumed was based on technical recommendations for the two power plants.

Table 2. Alternative scenarios for PM_{10} and SO_2 control

Oil-fired Power Plant	Coal-fired Power Plant
PM_{10}	
Base case: Cyclone with fuel within standard (i.e., 3% S bunker oil fuel (BOF))	Base case: EP with fuel within standard (i.e., <1% S coal)
Cleaner fuel (1% S BOF)[1]	Cleaner fuel (12% ash and 0.5% S)[1]
Electrostatic precipitator (EP)[2]	Increased thermal efficiency[2]
SO_2	
Base case: No EOP control, use of fuel within standard (i.e., 3% S)	Base case: No EOP, use of fuel within standard (i.e., <1% S)
Cleaner fuel (1% S)	Cleaner fuel (0.5% S)
Flue gas desulfurization (lime)[2]	FGD (seawater)[2]
FGD with cleaner fuel (1% S)	FGD with cleaner fuel (0.5% S)
	Increased thermal efficiency[2]

[1] Implemented in conjunction with existing pollution control.
[2] Assumed the use of fuel with standard sulfur content.

3.0 THEORETICAL AND ANALYTICAL FRAMEWORK

Externalities are effects of production or consumption on third parties. The effects are either positive (a benefit) or negative (a cost). Air pollution is a negative externality resulting from the failure of polluters to internalize the cost imposed on those who bear the burden (Tietenberg 1996). Emissions from power generation impose external costs since utilities are not obligated to pay damages either as

[4] NCM refers to normal cubic meter. The standard in microgram/Ncm is measured at 25 degrees Centigrade and one atmosphere pressure.

compensation to affected individuals or as pollution charge to government. These costs are mostly transmitted through the environment (e.g., health effects).

External costs lead to inefficient allocation of society's resources. The effects on the economy are manifested through: 1) excess pollutant discharges and 2) excess production of goods that create externalities. For pollutant discharges (considered a "bad"), the requirement for attaining economic efficiency is that the marginal benefit (MB) of reducing the bad should be equal to the marginal cost of controlling emissions (MCC). For industry, the marginal benefit is the avoided marginal cost of control. For society, the benefit is the marginal reduction in damage costs (MD) resulting from emission controls. The latter is measured by the sum of the marginal willingness to pay (MWTP) of affected individuals to avoid damage. Efficiency is achieved when MCC equals MD.

Benefit-cost analysis (BCA) is used to measure efficiency in resource allocation. For the control of air pollutants, efficient allocation is defined as one that maximizes the present value of the stream of net benefits from pollution reduction. BCA is an appropriate measure as long as the benefits are expressed in terms of the affected individuals' willingness to pay (WTP) and costs are expressed in terms of the opportunity cost of using society's resources (Boardman *et al* 1996). For this study, the benefits were expressed in terms of the value of health effects avoided, which composed the bulk of benefits from controlling emissions from thermal power plants. Impacts were limited to local and medium-scale boundaries (i.e., within 10- and 50-km radius, respectively from the power plant). Abatement costs, on the other hand, were expressed in terms of the capital and operation and maintenance costs over the expected lifetime of the pollution control equipment.

A BCA of emission control involves three major steps: an assessment of the physical impact of the different control options, valuation of the benefits and costs of control, and recommendation of the option with the largest net present value (NPV). Table 3 enumerates the steps, methodology, and data used in the analysis. Details are provided in succeeding sections of the study.

4.0 ASSESSMENT OF PHYSICAL IMPACTS

4.1 Emissions and Predicted Ambient Concentrations

4.1.1 Emissions and efficiency of control

Particulate matters and sulfur compounds are produced when coal and oil are burned for power generation. Particulate matter includes solid and liquid compounds. Solid particles are produced mainly from coal burning, with a ratio of 50:1 relative to particles from oil. They consist of ash particles (calcium silicates), carbon particles, and metal oxides (calcium and ferric oxide).

Sulfur compound (sulfur dioxide and sulfur trioxide) emissions are dependent primarily on the sulfur content of fuel. Approximately 97% of sulfur compounds enter the atmosphere mainly as SO_2. Sulfuric acid (H_2SO_4), a highly corrosive oily strong acid and very harmful to humans, is produced as sulfur compounds react with water vapor and oxygen in the air. It appears as a fine mist of liquid droplets in the air.

Sulfate particles on the other hand, are produced as metal oxides react with sulfuric acid. Sulfate particles and H_2SO_4 droplets are formed within a few days from the time of emission as pollutants are transported hundreds of miles from the source by winds.

Aside from fuel quality, emission levels are also directly related to the volume of fuel used, power generated, and the pollution control option employed. A rapid assessment approach wherein process rate (i.e., fuel consumption) is multiplied by appropriate emission factors was used to estimate emissions. Appendix 2 provides details on the assumptions used with respect to fuel consumption, power generation rate, operating hours, thermal efficiency, and end-of-pipe control.

Table 4 shows the emission estimates and incremental reduction achieved under the alternative control measures. The incremental emission reduction per unit of power generated was relatively larger for the oil-fired than the coal-fired power plant and for SO_2 than PM_{10}. For the oil-fired power plant, uncontrolled annual emission was estimated at 2,324 MT for PM_{10} and 37,383 MT for SO_2. Under the base case, cyclones reduced PM_{10} emissions by about 30%. A switch to cleaner fuel was expected to reduce PM_{10} and SO_2 emissions by 42% and 67%, respectively. An EP was projected to reduce PM_{10} emissions by 99.5% while retrofitting an FGD was estimated to cut SO_2 emissions by 70% and by an additional 20% when used in conjunction with cleaner fuel. Appendix 3 converts the emission estimates into flow rates (grams/second) as required in the air dispersion modeling.

For the coal-fired power plant, uncontrolled annual emission was about 82,091 MT for PM_{10} and 18,968 MT for SO_2. Under the base case, an EP reduced PM_{10} emissions by 98.7%. Increasing the efficiency of the two units of the coal-fired power plant to their respective maximum achievable level (i.e., 38% for unit 1 and 36% for unit 2) was expected to reduce emissions further by 0.1% and switching to a cleaner fuel (i.e., from the existing quality to that with 12% ash and 0.5% S coal), by 0.2%. The two measures were also expected to further cut SO_2 emissions by 7% and 30%, respectively. An FGD was expected to reduce SO_2 emissions by 70% and by an additional 9% when used together with cleaner fuel.

4.1.2 Emission rates and predicted ambient concentrations vis-à-vis standards

A Gaussian plume air dispersion model, the Industrial Source Complex Long Term 3 (ISCLT3) designed by the United States Environmental Protection Agency (USEPA), was used to predict annual average ambient concentrations of PM_{10} and SO_2 within a radius of 10-and 50-km from the power plants. The model utilizes meteorological data (wind velocity and direction, mixing height, etc.) and the characteristics of the emission source (i.e., stack height, elevation and diameter, flue gas temperature, velocity, etc.). It generates isophlets that depict the maximum predicted annual average ambient concentration within a specified area (e.g., 10- and 50-km radius from the plant) due to emissions from the power plant. The predicted ambient concentrations are above the natural background level, so that any health effect estimated is attributed to the individual power plant. Appendix 4 briefly describes the air dispersion model, input specifications, and data used.

Table 3. Steps for BCA, methodology used, and data requirement

Step	Methodology	Data Requirement	
		Type	Source
I. Assessment of physical impacts of pollution control options			
1. Estimate reduction in emissions	Rapid assessment method	Emission factors and efficiency of pollution control measures	U.S. EPA AP 42 (1995); p.c. w/ plant officials
		Fuel consumption	Power plant records
2. Predict changes in ambient concentration	Air dispersion modeling	Meteorological data	PAGASA
		Emission source parameters	Power plant records
		Air dispersion model	U.S. EPA
3. Estimate adverse health effects such as mortality and morbidity effects	Damage function approach	Dose- response coefficients from other studies	Ostro 1994 and 1996
		Changes in ambient concentration	Derived from air dispersion modeling
		Population at municipal level within 10- and 50-km radius from the power plant	NSO
		Topographic maps	NAMRIA
II. Valuation of benefits and costs			
1. Health benefits a. Mortality b. Morbidity	Benefits transfer method	Willingness-to-pay values; Cost-of-illness values	Rowe *et al* 1995; Dixon, J. (World Bank, 1999); ADB 1996
		Economic indicators	PIDS, NEDA, NSCB
2. Control costs	Engineering cost; cost transfer approach	Control costs	Colenco 1993
3. Comparison of benefits and costs	NPV, B/C ratio		
4. Sensitivity analysis	Partial approach (vary single assumption at a time)	Range of dose-response functions and monetary values	Ostro 1994 and 1996; Rowe *et al* 1995
III. Recommendation of best option	Use BCA decision rule		

Table 4. Emissions and incremental reduction of PM_{10} and SO_2 by scenario: oil- and coal-fired power plants

Scenario	Oil			Coal		
	Annual Emission (MT)	Inc. Reduction[1] (per GWh)	Efficiency[4]	Annual Emission (MT)	Inc. Reduction[1] (per GWh)	Efficiency[4]
PM_{10}						
No EOP control	2,324	*0.94*[3]		82,091	*27.04*[3]	
Base case: existing EOP w/ fuel within standard	1,627	0.28	30.0	1,074	26.68	98.7
EP	12	0.93	99.5	NA	-	-
Cleaner fuel[2]	659	0.39	71.6	865	0.07	98.9
Increased efficiency[2]	NA	NA	-	1,023	0.02	98.8
SO_2						
Base case: no EOP control	37,383	*15.05*[3]		18,968	*6.25*[3]	
Cleaner fuel	12,461	10.03	66.7	13,328	1.86	29.7
FGD	11,215	10.53	70.0	5,690	4.37	70.0
FGD with cleaner fuel	3,738	13.55	90.0	3,998	4.93	78.9
Increased efficiency[2]	NA	NA	-	17,604	0.45	7.2

[1] The reduction was relative to the base case level of emission, except for PM_{10}, no EOP, and base case figures.
[2] The option was applied in conjunction with existing level of pollution control.
[3] Emissions in MT/GWh
[4] Pollutant-removal efficiency

Table 5 shows the emission rates and maximum predicted annual ambient ground concentrations of PM_{10} and SO_2 within 10- and 50-km radius due to emissions from the oil- and coal-fired power plants. For particulates, the relevant emissions and ambient concentration standards were already met by the existing control (i.e., under the base case) measure implemented by the two power plants. The estimates assumed that the EOP controls were performing based on designed efficiencies.

Table 5. Emission rates and maximum predicted ambient ground concentration[1]: 10-and 50-km radius, oil-and coal-fired power plants

Scenario	Emission Rate (mg/Ncm)[2]				Ambient Conc. (μg/Ncm)[3]			
	Oil		Coal		10 km		50 km	
	Unit 1	Unit 2	Unit 1	Unit 2	Oil	Coal	Oil	Coal
TSP/PM_{10}	TSP				PM_{10}			
No EOP	225	206	18,367	57,817				
Base case	158	144	166	67	2.0	1.0	1.4	NA
EP	2	2	NA	NA	0.01	NA	0.01	0.9
Cleaner fuel	90	82	140	38	0.6	0.8	0.6	0.7
Inc. thermal efficiency	NA	NA	160	61	NA	1.0	NA	0.9
SO_2								
Base case: No EOP control	3,443	3,037	1,074	2,846	45.1	16.7	32.2	15.0
Cleaner fuel	1,148	1,012	845	1,792	15.0	13.5	10.7	12.2
FGD	1,033	911	322	854	13.5	11.6	9.7	10.4
FGD with cleaner fuel	344	304	254	538	4.5	8.3	3.2	7.4
Inc. thermal efficiency			1,033	2,559	NA	15.5	NA	13.9

[1] annual average
[2] The emission standards for old sources were 300 mg/Ncm for TSP and 1,500 mg/Ncm for SO_2.
[3] The ambient standards for source specific air pollutants from industrial sources of 200 μg/Ncm for PM_{10} and 40 μg/Ncm for SO_2 were based on an averaging time of 1 hr.

For SO_2, although the emission rates under the base case exceeded the emission standard (1,500 mg/Ncm), the predicted ambient concentrations were generally within the relevant ambient standard (40 μg/Ncm). Nonetheless, the ambient concentrations (which accounted only for emissions from the power plant) were significant relative to the maximum allowable ambient concentration within a 10-km radius. For the oil-fired, the emission rates were more than double the standard while the maximum predicted concentrations within a 10-km radius were slightly above the standard (45 μg/Ncm or 113% of what was allowed). The coal-fired power plant met the emission standard when the sulfur content of fuel used was less than 0.6%. The predicted ambient concentration for SO_2 was 43% of what was allowable. A switch to cleaner fuel (in this case, 0.5% S for coal and 1% S for BOF) was sufficient to meet the emissions standard. For new plants, a 0.45%S for coal was required to meet the emissions standard of 700 microgram/Ncm (DOE 1996). The measure translated to a maximum predicted ambient concentration of 15 μg/Ncm and to as low as 5 μg/Ncm when implemented together with an FGD.

4.2 Health Effects

Epidemiological studies indicated strong relationships between ambient concentrations of air pollutants such as particulates and sulfur oxides and adverse health outcomes such as mortality and morbidity. These relationships were found to be significant for alternative measures of PM such as TSP, $PM_{2.5}$, and sulfates (Ostro 1996). A high concentration level of particulates and SOx together in the air was considered deadly, deadlier than when only one of these pollutants was present. These pollutants aggravated respiratory and cardiac diseases, increasing the risk of pre-mature death among children and adults (OECD 1986). Appendix 5 summarizes the health and non-health effects of PM_{10} and SO_2 emissions.

Estimation of the health effects of improving air quality followed a bottom-up approach (Freeman 1993, Markandya 1995). The emissions under the various scenarios were determined and inputted to an air dispersion model to generate the corresponding changes in ambient concentration (as discussed in the previous section). These changes were then multiplied with the population at risk of exposure. Dose-response coefficients were applied to determine the health outcomes (e.g., number of excess pre-mature death due to PM_{10} exposure). Data were disaggregated at grid level.

4.2.1 Dose-response coefficients

Dose-response coefficients indicate the relationship that may exist between the ambient concentration of various air pollutants and the incidence of morbidity and mortality cases. For mortality effects, dose-response functions express the change in the probability that individuals will die prematurely as a result of changes in environmental conditions, holding other factors constant, as cases of "excess premature mortality" per unit of time (e.g., per year). Similarly, the change in the probability that individuals will suffer a certain illness due changes in pollutant concentration is reflected by dose-response functions as excess morbidity cases.

Table 6 summarizes the dose-response coefficients used to estimate the health effects of annual average changes in PM_{10} and SO_2 concentrations. The coefficients were derived from various epidemiological studies conducted in developed countries such as the US, Canada, and the UK (Ostro1994, 1996). The low, central, and high estimates indicated the likely ranges within which the actual damages were likely to fall as well as the range of uncertainty in the estimates. Since no threshold level below which no effects related to exposure had been identified for these pollutants, the study assumed a threshold level of zero.

Table 6. Dose-response coefficients used to estimate annual health effects (per $\mu g/m^3$ change in PM_{10} and SO_2 ambient concentration)

Health Effect	Unit	Coefficient		
		Low	Central	High
PM_{10}				
Mortality	% inc. cases	1.23E-01	2.70E-01	4.20E-01
Morbidity				
Respiratory hospital admissions (RHA)	Cases	6.57E-06	1.20E-05	1.56E-05
Emergency room visit (ERV)	Cases	1.28E-03	2.36E-03	3.43E-03
Restricted activity day (RAD)	Cases	4.04E-02	5.75E-02	9.03E-02
Acute bronchitis, children	Cases/ child<15	8.00E-04	1.60E-03	2.38E-03
Asthma attacks (AA)	Cases/ Asthmatic	3.30E-02	5.90E-02	1.96E-01
Respiratory symptoms	Cases	9.10E-02	1.80E-01	2.73E-01
Chronic bronchitis, adult	Cases/ adult>15	3.06E-05	6.12E-05	9.18E-05
SO_2				
Mortality	% increase in cases	2.00E-02	4.80E-02	1.21E-01
Respiratory symptoms, children	Prob. of cough/child	1.00E-05	1.81E-05	2.62E-05
RS/ chest disc., adult	Prob. of chest disc./adult	5.00E-03	1.00E-02	1.50E-02

Source: Ostro 1994 and 1996

4.2.2 Population at risk of exposure

Population at risk refers to all individuals potentially exposed to changes in air quality in a specific geographic boundary at a given time period (Rowe *et al* 1995). It refers to the total population in the impact areas located in varying distances downwind from the source of air emissions.

Markandya (1995) noted that health impact estimation for air pollutants, at the very least, should have a regional coverage. This is because although the impact may be relatively small farther from the source, extending the coverage could increase the aggregate external cost due to the potentially large number of population present in the area. Rowe *et al* (1995), in modeling the externality of a 300-Kwh coal power plant in New York, used the following impact area categories based on distance from the plant:1) local area-within 30 km; 2) regional area–beyond 30 km but within 100 km;

and 3) distant area-beyond 100 km but within 500 km. The study used two categories: a) 10-km radius (i.e., the maximum impact area) and b) 50-km radius.

Three years of census data (1980, 1990, and 1995), disaggregated by age group at the municipal level, were used as bases for projecting and distributing population at risk within the geographic area considered. Distribution of the population by grid involved delineation of the municipal boundaries, identification of built-up areas, and determination of population density by grid. The grid size used was 500 x 500 m or 0.025 km^2 (i.e., 2.5 ha each) for areas within 10-km radius and 9 km^2 for areas within the 50-km radius.

Table 7 shows the population at risk of exposure to PM_{10} and SO_2 emissions from the oil- and coal-fired power plants within 10-and 50-km radius for 1998 and 2010. The impact areas of the two power plants covered three municipalities, each within the 10-km radius. Within the 50-km radius, the number of municipalities affected increased to 57 for the oil-fired and 45 for the coal-fired. The estimated population at risk to emissions from the coal-fired power plant within the 10-km radius was slightly higher than from the oil-fired power plant. Within the 50-km radius, however, the projected population at risk to the oil-fired power plant was 50% more than the coal-fired. Increasing the impact area from 10-km radius to 50-km radius significantly increased the estimated size of population at risk (e.g., by over 600 times by 2010 for the coal-fired power plant). Based on the population distribution by age group in the municipalities affected, more individuals over 15 years old were projected to be at risk of exposure. The percentage was a little higher for the coal-fired power plant.

Table 7. Number of municipalities and estimated population at risk of exposure within 10- and 50-km radius: oil- and coal -fired power plants, 1998 and 2010

	10-km		50-km	
	Oil	Coal	Oil	Coal
Municipalities (no.)	3	3	57	45
Year/ Age Group				
1998	10,228	10,796	9,091,964	4,504,728
Below 15	43%	34%	36%	29%
Above 15	57%	66%	64%	71%
2010	14,750	15,384	19,417,062	9,926,660
Below 15	43%	29%	29%	23%
Above 15	57%	71%	71%	77%

Tables 8 and 9 show the percentage of population at risk of exposure to various ambient concentration levels of PM_{10} and SO_2 predicted under the various scenarios. Under the base case, 77% of the population within a 10-km radius from the oil-fired power plant was potentially exposed to ambient concentrations of PM_{10} ranging from 0.01 to 0.29 μg/Ncm. For the coal-fired, the dominant PM_{10} concentration levels to which the population was potentially exposed to were <0.01 (40%) and 0.3 to 0.59 μg/Ncm (40%). For SO_2, 88% of the population within 10-km from the oil-fired power plant was potentially exposed to ambient concentrations ranging from 1 to 5.9 μg/Ncm under the base case. For the coal-fired, 38% was potentially exposed to <1 μg/Ncm, 35% to 1-5.9 μg/Ncm and 27% to as much as 10.9 μg/Ncm. With additional or more advanced control measures, a higher percentage of the population was potentially exposed to lower ambient concentration levels. Within a 50-km radius, although the ambient concentrations of the pollutants were lower, the projected size of population at risk was significantly larger than that within the 10-km radius. The difference was about 10 M for the coal-fired and double for the oil-fired power plant.

Table 8. Percentage of projected population at risk of exposure to different ambient concentration levels of PM_{10}: oil- and coal-fired power plants, 2010

Pollutant Concentration	Population at Risk of Exposure (%)					
	Oil			Coal		
	Base case	Cyclone w/ CF	EP	Base case	Inc. T. E.	EP w/ CF
10-km						
Popn. At risk			14,750			15,384
Conc. (μg/Ncm)						
< 0.01	-	-	90.5	40.4	40.4	40.4
0.01 – 0.29	76.9	87.0	9.5	17.2	18.0	29.2
0.3 – 0.59	9.1	13.0	-	38.7	39.4	30.4
0.6 – 0.89	8.6	-		3.7	2.2	-
0.9 – 1.0+	-	-		-	-	-
50-km						
Popn. at risk			19,417,062			9,926,660
Conc. (μg/Ncm)						
< 0.01	-	-	-	83.8	83.8	83.8
0.01 – 0.29	92.4	99.7	100.0	10.4	10.5	12.6
0.3 – 0.59	7.2	0.3	-	5.4	5.3	3.4
0.6 – 0.89	0.2	-	-	0.3	0.4	0.2
0.9 – 1.0+	0.3	-	-	0.1	-	-

Table 9. Percentage of projected population at risk of exposure to different ambient concentration levels of SO_2: oil- and coal-fired power plants, 2010

Pollutant Concentration	Population at Risk of Exposure (%)								
	Oil				Coal				
	Base case	CF	FGD	FGD w/ CF	Base case	CF	FGD	FGD w/ CF	Inc. T.E.
10-km									
Popn. at risk				14,750					15,384
Conc. (μg/Ncm)									
< 1.0	0.31	-	-	-	38.0	38.0	37.9	37.9	37.9
1.0 – 5.9	75.6	93.1	94.7	100.0	35.2	49.7	54.5	62.1	41.5
6 – 10.9	5.9	5.3	4.3	-	26.8	12.3	7.6	-	20.6
11 – 15.9	9.8	1.7	1.0	-	-	-	-	-	-
16 – 20+	8.4	-	-	-	-	-	-	-	-
50-km									
Popn. at risk				19,417,062					9,926,660
Conc. (μg/Ncm)									
< 1.0	-	-	-	-	83.4	83.4	83.4	83.4	83.4
1.0 – 5.9	88.8	99.5	99.5	100.0	14.5	15.8	16.2	16.4	14.9
6 – 10.9	10.7	0.5	0.5	-	1.7	0.7	0.3	0.2	1.5
11 – 15.9	0.1	-	-	-	0.4	0.1	0.1	-	0.2
16 – 20+	0.5	-	-	-	-	-	-	-	-

4.2.3 Avoided premature mortality and morbidity effects

The total health effect of pollution control is determined by the pollution control measure, the pollutant's ambient concentration, size of the impact area, size and distribution of the population at risk of exposure, and the dose-response coefficients used. Tables 10 and 11 show the projected incremental health benefits over the period of analysis for the oil- and coal-fired power plants using the central dose-response coefficients shown in Table 6. The results show that extending the impact area from 10-km to 50-km increased significantly the magnitude of the health effects avoided or the benefits of reducing emissions from the power plants. For example, a switch to cleaner fuel by the oil-fired power plant was projected to reduce premature mortality by 2 compared with 1,102 considering a 10-km and 50-km impact area, respectively. It was also projected to reduce the incidence of morbidity effects (Tables 10 and 11). The incremental benefit per unit of power generated was also higher for the oil-fired than for the coal-fired power plant mainly due to the large difference in the size of potential population exposed (Appendices 6 and 7).

Table 10. Total incremental health benefits of controlling PM_{10} emissions by Scenario: oil-and coal-fired power plant (central estimate)

Health Effect	Unit	Incremental Health Benefits (# incidence reduced)[1]			
		Oil		Coal	
		Cyclone w/ CF	EP	EP w/ CF	Inc. T. E.
10 km					
Mortality	Cases	0	1	0	0
Morbidity					
RHA	Cases	0	0	0	0
Emergency room visit	Cases	47	92	19	5
Restricted activity days	Days	632	1,215	308	76
Acute bronchitis, children	Cases	16	29	4	1
Asthma attacks	Cases	48	93	19	5
Respiratory symptoms	Days	2,952	5,750	1,138	282
Chronic bronchitis, adult	Cases	1	1	0	0
50 km					
Mortality	Cases	196	310	12	3
Morbidity					
RHA	Cases	160	254	10	2
Emergency room visit	Cases	31,284	49,533	1,900	470
Restricted activity days	Days	469,311	745,541	34,174	8,453
Acute bronchitis, children	Cases	11,992	19,442	265	66
Asthma attacks	Cases	31,511	49,892	1,914	474
Respiratory symptoms	Days	1,886,879	2,984,895	108,860	26,926
Chronic bronchitis, adult	Cases	550	873	40	10

[1] Over the period 1999-2010 for the oil-fired and 1999-2013 for the coal-fired power plant.

Table 11. Total incremental health benefits of controlling SO_2 emissions by scenario: oil-and coal-fired power plant (central estimate)

Health Effect	Incidence Avoided (# cases) [1]						
	Oil			Coal			
	CF	FGD	FGD w/ CF	CF	FGD	FGD w/ CF	Inc. T. E.
10 km							
Mortality	2	2	2	0	1	1	0
Morbidity							
RS, children	5	5	6	0	1	2	0
RS/Chest Disc. Adult	3,831	3,752	4,825	946	1,345	3,423	348
50 km							
Mortality	906	891	1,145	33	51	85	12
Morbidity							
RS, children	2,050	2,009	2,584	46	71	117	17
RS/Chest disc., adult	2,331,831	2,307,055	2,966,299	99,856	154,964	257,035	36,929

[1] Over the period 1999-2010 for the oil-fired and 1999-2013 for the coal-fired power plant.

5.0 VALUATION OF BENEFITS AND COSTS

5.1 Health Benefits

5.1.1 Valuation method

Valuation of the health benefits of pollution control is based on the willingness to pay (WTP) approach. WTP estimates reflect an individual's preference. It is the "maximum amount a person would be willing to pay to obtain an improvement or to avoid a deterioration in environmental conditions affecting health status" (ADB 1996).

WTP values may be inferred from observed behavior or elicited through surveys. The valuation methods include direct elicitation approach, wage-differential approach, and human capital or foregone productivity approach. The first approach is used mainly in the estimation of the value of mortality effects avoided or the value of statistical life (VSL). Wage-differential or labor market studies estimate WTP based on additional compensation demanded in the labor market for riskier jobs.

The foregone productivity approach and cost of illness (COI) are used to approximate WTP for changes in the risk of suffering morbidity effects. The COI approach measures the avoided medical cost and avoided cost of work loss days or foregone earnings associated with illness. It excludes the pain and suffering associated with the illness. Values derived using the approach are estimated as half the WTP for any given health effect (US-EPA 1997 and ADB 1996). Appendix 8 shows the features, data requirement, underlying assumptions, and limitations of the different valuation methods commonly used. Appendix 9 provides a range of estimated values of premature mortality and morbidity effects derived by various studies.

In view of the technical, financial, and time requirements for generating WTP estimates, a benefits transfer approach was used to value the health benefits. The approach is a secondary economic valuation method that relies on the value estimates of one or more primary studies in comparable sites to estimate monetary values for environmental impacts (ADB 1996). To make the borrowed estimates applicable, adjustments were made to address differences in income of the population (purchasing power) and differences in the units of currency (ADB 1996). With the approach, it was assumed that individuals in the area where the values were to be applied were willing to set aside the same relative monetary share of their available monetary income to prevent or reduce a comparable amount of environmental impact. As suggested by the results of the Alberini *et al* (1997) study in Taiwan, the benefits transfer approach is considered reasonable in the absence of country-specific data.

Table 12 summarizes the adjusted WTP and COI values used in the study. The values are based on Appendix 9. The values for respiratory hospital admission (RHA), emergency room visits (ERV), reduced activity days (RAD), and acute bronchitis were adjusted further using the average daily wage rate in the area, which was assumed to represent the value of a day's foregone productivity.

Table 12. Unit values for mortality and morbidity effects

Health Effect	Value per Case (1990 Pesos)[1]			Type of Estimate
	Low	Central	High	
Mortality (all causes)	1,029,340	1,998,130	3,996,250	WTP
Morbidity				
Respiratory hospital admissions (RHA)	5,400	10,800	16,195	Adjusted COI
Emergency room visits (ERV)	225	450	670	Adjusted COI
Child bronchitis	170	340	510	Adjusted COI
Restricted activity day (RAD)	40	75	110	WTP & Adj. COI
Asthma attack day	10	20	35	WTP
Acute resp. symptom day	3	6	9	WTP
Adult chronic bronchitis	76,790	127,150	203,450	WTP

[1] Adjusted from the original values using the following steps: a) convert original WTP value as a percentage of the per capita GDP of the country where the values were obtained; b) apply the percentage to the per capita GDP of the country where the value was used to get the equivalent value for the country; and c) convert to local currency using the official exchange rate. Values were rounded to the nearest ten.

The total value of emission reduction to society is the sum of the WTP values of all individuals who benefit from improvements in air quality. Since the benefits conferred on individuals by the improvement in air quality and the WTP of individuals for such improvements are not known, the benefits estimated are in fact values of statistical health and welfare effects avoided (US-EPA 1997).

5.1.2 Value of health effects avoided

Table 13 shows central estimates of the discounted total and per unit incremental benefits or the value of environmental damage avoided with reductions in PM_{10} and SO_2 emissions from the oil- and coal-fired power plants. The estimates were derived using the central estimates of the dose-response coefficients and unit monetary values for premature mortality and morbidity effects. As with the physical effects, the incremental benefits were much larger when the impact area was extended from 10 to 50-km radius. The projected benefits were much larger for oil than for coal, particularly within the 50-km radius, primarily because of the large difference in the size of the population at risk of exposure to the two power plants. Of the total value of health benefits, the value of mortality effects avoided or VSL dominated for both pollutants and type of power plants (Appendix 10).

A switch to cleaner fuel, for example, generated a total incremental benefit from reductions in both PM_{10} and SO_2 emissions of about ₱4.15 million (or ₱70.12/GWh) at a 10-km radius impact area compared with ₱1.13 billion (or ₱37,767/GWh) only at a 50-km radius for the oil-fired power plant. For coal, the incremental benefit from the same measure ranged from ₱0.48 M to ₱43.38 M or ₱10.47 to 952.56/GWh. Of the total health benefits, the VSL accounted for an average of 76 to 78% for PM_{10} and 99% for SO_2 emission reductions.

At the 50-km impact area, the value of health damage avoided with a switch to cleaner fuel represented 0.08% to 3.34% of the current average selling price of electricity of about ₱1,131,043/GWh (1990 prices, NPC). If the power plants were made to internalize the health damages, the cost of power service, which was about ₱910,742/GWh (1990 prices, NPC), would increase by about 0.11% to 4.31%.

Table 13. PV of incremental health benefit of controlling PM_{10} and SO_2 emissions by scenario: oil- and coal-fired power plants (central estimate, 1990 Pesos)

Scenario	Incremental Benefit			
	PV (Million Pesos)[1]		Per Gigawatt-Hour (Pesos)	
	Oil	Coal	Oil	Coal
10 km				
PM_{10}				
EP	14.39	NA	24.97	NA
Cleaner fuel[2]	4.15	0.15	12.78	3.24
Inc. thermal efficiency[2]	NA	0.04	NA	0.80
SO_2				
Cleaner fuel	4.15	0.33	57.34	7.23
FGD	56.75	0.47	56.20	10.97
FGD w/ cleaner fuel	57.19	0.77	72.26	18.16
Inc. thermal efficiency	NA	0.12	NA	2.65
50 km				
PM_{10}				
EP	375.97	NA	13,258	NA
Cleaner fuel[2]	1,127.81	13.56	8,297	297.70
Inc. thermal efficiency[2]	NA	3.35	NA	73.63
SO_2				
Cleaner fuel	1,127.81	29.82	29,470	654.86
FGD	855.36	43.70	29,284	1,028.08
FGD w/ cleaner fuel	1,083.99	72.49	37,651	1,705.44
Inc. thermal efficiency	NA	11.04	NA	242.31

[1] PV of total health benefits over the period 1999-2010 for the oil-fired and 1999-2013 for the coal-fired power plant discounted to 1999 at r=15% in 1990 prices

[2] Used in conjunction with existing pollution control equipment

5.2 Costs of Pollution Control

5.2.1 Valuation method

The opportunity cost concept is used in benefit-cost analysis to value the inputs (e.g., land, labor, capital) required to implement a policy (e.g., pollution reduction to meet environmental standards) (Boardman *et al* 1996). Opportunity cost measures the value that society must forego for the use of such inputs. It is the value of the next best alternative for that input. The costs of reducing pollution to meet standards consist of the capital and operating and maintenance (O&M) costs (including monitoring costs) of the pollution control equipment valued in terms of the opportunity cost of the financial resources used.

For BCA, the rule is to be consistent with the time scale, prices, and rates used (Boardman *et al* 1996). The relevant period covered by discounting is the entire lifetime of a project or an investment. In the case of power plants, the design lifetime of the main technology may be used (e.g., 25 years for a coal power plant, Markandya 1995) or the economic life of the pollution control device (e.g., 10 to 15 years for an EP or an FGD, Adamson *et al* 1996). Although the environmental impact could extend beyond the lifetime of the plant or the lifetime of an investment, the same time scale should be used for both the benefits and costs for consistency. With respect to prices and discount rates, when real (nominal) prices are used in the valuation of benefits and costs, real (nominal) discount rate should be used. The same discount rate should be applied to both benefits and costs.

5.2.2 Cost of emission reduction

Engineering costs are used as bases in computing the annualized capital and O&M costs for cyclone and EP to control PM_{10}. For SO_2, the costs of FGD technologies applied (i.e., limestone for oil and seawater for coal) were based on estimates made by another study for the two power plants. The cost of switching to a cleaner fuel was based on fuel consumption and computed as the difference between the existing fuel cost and the cost of using cleaner fuel. It does not entail any capital cost. The cost of increasing thermal efficiency for the coal-fired power plant was based on plant data. It was estimated as the difference between the power generation cost at the existing thermal efficiency level and the cost at the design level.

For discounting, the expected lifetime of the relevant pollution control equipment (i.e., 15 years) and a discount rate of 15% (currently applied by government for evaluating investments) were used. The incremental control costs were relative to the costs of the existing level of pollution control. Appendix 11 provides the removal efficiency and estimated annualized capital and O&M costs of various measures for controlling PM_{10} and SO_2 emissions. Appendix 12 shows the assumptions used in deriving the total annual cost for each control measure.

Table 14 shows the discounted incremental cost of reducing PM_{10} and SO_2 emissions for the oil- and coal-fired power plants. The incremental cost of switching to cleaner fuel is about ₱26,000/GWh for coal, 24% lower than for oil. Increasing the thermal efficiency of the coal-fired power plant from existing to design levels generated an incremental saving of about ₱2,520/GWh in terms of reduced fuel consumption and correspondingly lower generation cost. Retrofitting an FGD entailed an incremental cost of ₱49,000/GWh (63% lower than for oil), and 20% more when used in combination with cleaner fuel.

Table 14. PV of incremental cost of emission reduction: oil- and coal-fired power plants (1990 Pesos)

Scenario	PV of Incremental Cost[1]			
	Total (Million Pesos)		Per GWh (Pesos)	
	Oil	Coal	Oil	Coal
PM_{10}				
EP	821	NA	27,545	NA
Cleaner fuel[2]	1,011	1,173	33,906	25,758
Increased thermal efficiency[3]	NA	115	NA	2,520
SO_2				
Cleaner fuel	1,011	1,173	33,906	25,758
FGD	3,948	2,219	132,447	48,713
FGD w/ cleaner fuel	4,959	3,392	166,352	74,471
Increased thermal efficiency[3]	NA	115	NA	2,520

[1] The base case for PM_{10} control was cyclone for the oil-fired power plant and EP for the coal-fired power plant. For SO2, the base case was use of fuel with standard S. Values discounted to 1999 at n=15 and r=15%.
[2] Cost of cleaner fuel was the difference between the cost of existing fuel and the cost of cleaner fuel.
[3] Estimated savings from reduced cost of production.

5.3 Comparison of Benefits and Costs

The decision rule in CBA is to choose the project or investment (in this case, investment on alternative pollution control options) that has a positive net benefit, assuming there are no constraints on inputs (Boardman *et al* 1996). Efficiency in resource allocation is maximized by the option with the largest net positive benefit.

With the central bound estimate, only the switch to cleaner fuel considering a 50-km impact area for oil and increasing thermal efficiency for coal generated a positive incremental net benefit (Table 15). Both these measures controlled PM_{10} and SO_2 emissions. The incremental net benefit was about ₱117 M to ₱131 M, respectively.

5.4 Sensitivity Analysis

Sensitivity analysis aims to determine the potential effect on results when assumptions other than those used in the estimates are used. It addresses uncertainties with respect to both prediction and valuation of impacts. The potential sources of uncertainty and error include the dose-response functions; estimate of changes in emissions and ambient concentration; and monetary values assigned per unit impact (Rowe *et al* 1995). The practice is to vary the values around the best estimate of the value of the source of uncertainty and observe the impact on NPV.

For the study, the effects of varying the discount rate and the unit monetary values used on the net benefits were analyzed. Table 16 shows the effects of varying the assumed discount rate by + and –3 percent from the assumed central estimate of

15 percent on the net benefits. Appendix 13 provides the incremental benefits derived using central estimates of the dose-response coefficients and monetary values and control costs at varying discount rates. The results were generally the same. Only the switch to cleaner fuel and increased thermal efficiency for the oil- and coal-fired power plants were justified. Since the IRRs (the interest rate at which NPV=0) of these two measures were above the social discount rate (i.e., 15%), these options were recommended.

Table 15. PV of incremental net benefit of PM_{10} and SO_2 emission reduction: oil- and coal-fired power plants (central estimate)

Scenario	Incremental Net Benefits[1] (1990 Million Pesos)	
	Oil	Coal
10-km		
PM_{10}		
EP	(806.67)	NA
Cleaner fuel	(1,006.49)[2]	(1,170.50)[2]
Increased thermal efficiency	NA	117.08
SO_2		
Cleaner fuel	(1,006.49)[2]	(1,170.50)[2]
FGD	(3,891.17)	(2,204.76)
FGD w/ cleaner fuel	(4,901.37)	(3,377.58)
Increased thermal efficiency		117.08
50-km		
PM_{10}		
EP	(445.09)	NA
Cleaner fuel	117.17[2]	(1,127.60)[2]
Increased thermal efficiency	NA	131.32
SO_2		
Cleaner fuel	117.17[2]	(1,127.60)[2]
FGD	(3,092.56)	(2,161.53)
FGD w/ cleaner fuel	(3,874.57)	(3,305.86)
Increased thermal efficiency	NA	131.32

[1] Central estimate; discounted to 1999 at n=15 and r=15%; includes salvage value

[2] The value accounted for the inc. net benefits from both PM_{10} and SO_2 reduction with cleaner fuel.

Table 17 shows the effect of varying the unit monetary values used for valuing the health effects. The values were generated using the central dose-response coefficients of the different health effects and the low and high bound estimates of the unit WTP and the adjusted COI values shown in Tables 6 and 12, respectively. For coal, the result was the same – the net benefits were still negative except in the increased thermal efficiency scenario. For oil, the net benefits for all the measures analyzed were positive at the 50-km impact area and when high monetary unit values were used. The switch to cleaner fuel had the largest net benefits. When low unit monetary values were applied, the net benefits were negative even at the 50-km impact area.

Table 16. Effect of alternative discount rates on the net benefits: oil- and coal-fired power plants (central estimate, 1990 million pesos)

Scenario	PV of Incremental Net Benefits					
	Oil			Coal		
	12%	15%	18%	12%	15%	18%
10-km						
PM_{10}						
EP	(847.70)	(806.67)	(772.44)	(1,326.62)	(1,170.50)	(1,046.39)
Cleaner fuel	(1,119.60)	(1,006.49)	(913.59)	134.04	117.08	113.21
Inc. thermal efficiency						
SO_2						
Cleaner fuel	(1,119.60)	(1,006.49)	(913.59)	(1,326.62)	(1,170.50)	(1,046.39)
FGD	(4,136.45)	(3,891.17)	(3,687.64)	(2,370.99)	(2,204.76)	(2,070.89)
FGD w/ cleaner fuel	(5,260.73)	(4,901.37)	(4,604.23)	(3,701.46)	(3,377.58)	(3,118.72)
Inc. thermal efficiency				134.04	117.08	113.21
50-km						
PM_{10}						
EP	(432.28)	(445.09)	(454.55)	(1,283.13)	(1,127.60)	(1,003.93)
Cleaner fuel	148.43	117.17	92.84	148.42	131.32	127.33
Inc. thermal efficiency						
SO_2						
Cleaner fuel	148.43	117.17	92.84	(1,283.13)	(1,127.60)	(1,003.93)
FGD	(3,219.80)	(3,092.56)	(2,984.98)	(2,327.69)	(2,161.53)	(2,027.70)
FGD w/ cleaner fuel	(4,082.15)	(3,874.57)	(3,700.71)	(3,629.63)	(3,305.86)	(3,047.08)
Inc. thermal efficiency				148.42	131.32	127.33

Table 17. Range of discounted incremental net benefit of controlling PM_{10} and SO_2 emissions: oil- and coal-fired power plants (1990 million pesos)

Scenario	Oil		Coal	
	Low	High	Low	High
10-km				
PM_{10}				
EP	(817.48)	(778.70)	NA	NA
Cleaner fuel	(1,009.70)	(998.38)	(1,171.76)	(1,167.98)
Increased thermal efficiency	NA	NA	115.97	119.31
SO_2				
Cleaner fuel	(1,009.70)	(998.38)	(1,171.76)	(1,167.98)
FGD	(3,935.72)	(3,662.91)	(2,211.45)	(2,191.04)
FGD w/ cleaner fuel	(4,946.27)	(4,671.34)	(3,384.41)	(3,363.55)
Increased thermal efficiency	NA	NA	115.97	119.31
50 km				
PM_{10}				
EP	(727.64)	288.93	NA	NA
Cleaner fuel	(757.46)	2,308.26	(1,138.33)	(1,082.28)
Increased thermal efficiency	NA	NA	123.34	147.32
SO_2				
Cleaner fuel	(757.46)	2,308.26	(1,138.33)	(1,082.28)
FGD	(3,764.68)	345.46	(2,189.18)	(2,104.77)
FGD w/ cleaner fuel	(4,725.57)	482.41	(3,241.33)	(3,220.44)
Increased thermal efficiency	NA	NA	123.34	147.32

[1] Discounted to 1999 at n = 15

6.0 SUMMARY AND RECOMMENDATIONS

The study assessed the incremental benefits and costs of different options to control PM_{10} and SO_2 emissions from fossil-fired power plants using as case studies two power plants, an oil- and a coal-fired power plant, in Southern Tagalog Region (Region IV), Philippines. The different control measures analyzed included switching to cleaner fuel, increased thermal efficiency, retrofitting of end-of-pipe control options such as EP and FGD, and use of cleaner fuel in conjunction with EOP measure. The benefits were estimated by modeling the changes in ambient concentrations arising from the control, estimating the improvements, and valuing these in economic terms. The study focused on adverse health effects, using dose-response function established in other studies, and economic values based on the benefits transfer technique. The incremental costs of control were estimated using the engineering cost approach. The impacts were assessed within 10-km (the maximum impact area) and 50-km radius from each plant. Sensitivity of the results to changes in the discount rate and the unit monetary values for the health effects was tested.

The following are the major findings of the study:

1. Existing controls for particulates met the emissions standard. However, the use of fuel with the existing sulfur content standard of 3% S for BOF and 1% S for coal was not sufficient to meet SO_2 emissions standard. A switch to cleaner fuel with about 1%S for BOF and 0.5% S for coal was required. SO_2 emissions from the two power plants translated to maximum predicted concentrations (excluding background concentrations) that were significant relative to the maximum allowable ambient concentration ranging from 43 to 113%. In this regard, a review of the existing sulfur content standard is recommended.
2. The value of the health effects avoided was much larger when the impact area was extended from a radius of 10 to 50-km; it was much larger for the oil-fired than the coal-fired power plants, with the value of mortality effects avoided dominating the total. With switching to cleaner fuel, the value of health damage avoided at a 50-km impact area represented 0.08% to 3.34% of the current average selling price of electricity, implying a 0.11% to 4.31% increase in the average cost of power service if the power plants were made to internalize the health damages.
3. The incremental cost of reducing PM_{10} and SO_2 emissions per unit of power generated was lower for the coal-fired than the oil-fired power plant. The incremental cost of switching to cleaner fuel was about ₱26,000/GWh for coal, which was 24% lower than that for oil. Increasing the thermal efficiency of the coal-fired power plant from existing to design levels was expected to generate an incremental saving of about ₱2,520/GWh in terms of reduced fuel consumption and, correspondingly, lower generation cost. Retrofitting an FGD entailed an incremental cost of ₱49,000/GWh (63% lower than that for oil), and 20% more when used in combination with cleaner fuel.
4. Among the control measures analyzed, only switching to cleaner fuel for oil and increased thermal efficiency for coal were justified. Retrofitting an FGD was justified for the oil-fired power plant only when high monetary unit values for the health effects avoided were used and only at a 50-km radius impact area.
5. The impact of the internalization of external costs by the power generation sector on energy pricing and subsequently on the environment is recommended for future study.

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Appendices

Appendix Table 1. National ambient air quality (NAAQ) and emission standards

Pollutant	NAAQ Standard for Source Specific Pollutants (mg/Ncm)[1]	Emission Standard (mg/Ncm)
TSP	300 (1-hr sampling)	Existing source (as of 1992)
		After 1978 - 300
		Before 1978 - 500
		New source
		Urban - 150
		Non-urban - 200
PM_{10}	200 (1-hr sampling)	50% of TSP standard based on a TSP to PM10 ratio of 0.5[2]
SO_2	70 (30-min. sampling) 40 (1-hr. sampling)	Existing source - 1,500
		New source - 700

[1] Applied to all existing geothermal and thermal power generating projects as per DENR MC 29 s. 1994; Maximum limits are not to be exceeded more than once a year. Sampling shall be done at an elevation of at least 2 meters above the ground level and conducted either at the property line or a downwind distance of 5 to 25 times the stack height, whichever is more stringent.
[2] Larssen et al 1997

Appendix Table 2. Assumptions used in the emissions estimate

Item	Oil				Coal			
Emission factor[1]								
Unit	kg/1,000 liter BOF				Kg/ton coal			
TSP	1.12 x sulfur content in fuel + 0.37				5 x ash content of fuel			
PM_{10}	63% of uncontrolled TSP emission				67% of uncontrolled TSP emission			
SO_2	19 x sulfur content in fuel				19 x sulfur content in fuel			
Plant data[2]	Unit1		Unit 2		Unit 1		Unit 2	
Fuel consumption (annual)	320 M liter BOF		336 M liter BOF		730,400 MT coal		672,600 MT coal	
Fuel specification (%)	Ash	S	Ash	S	Ash	S	Ash	S
Existing	-	3.0	-	3.0	14	0.6	21	0.8
Standard	-	3.0	-	3.0	-	1.0	-	1.0
Target		1.0		1.0	12	0.5	12	0.5
Fuel source	Shell Philippines Petroleum Corporation and barge				Local – Semirara Island; Imported – Australia, China, Indonesia			
Gross generation (GWh)	1,169.75		1,314.20		1,693.70		1,342.50	
Operating Hours	5,670		5,750		6,860		6,860	
Thermal efficiency (%)	35		34		36.5		32.4	
Pollution control (existing)								
PM_{10}	Cyclone (30%)				EP (97%)		EP (99+%)	
SO_2	No EOP control				No EOP control			

[1] Emission factors used are for a pulverized coal system for the coal-fired PP and for utility boilers using residual oil for the oil-fired PP (US-EPA 1995 AP-42).
[2] EIA and plant documents

Appendix Table 3. Annual PM_{10} and SO_2 emission rates by scenario: oil- and coal-fired power plants

Scenario	Oil			Coal		
	Total (MT)	Unit 1 (g/s)	Unit 2 (g/s)	Total (MT)	Unit 1 (g/s)	Unit 2 (g/s)
PM_{10}						
No EOP control	2,324	56	58	82,091	1,405	1,950
Base case[1]	1,627	39	40	1,074	37	7
EP	12	0	0	NA	NA	NA
Cleaner fuel[2]	659	16	16	865	31	4
Inc. thermal efficiency[2]	NA	NA	NA	1,023	36	6
SO_2						
Base case: no EOP control	37,383	893	926	18,968	359	418
Cleaner fuel	12,461	298	309	13,328	281	354
Flue gas desulfurization	11,215	268	278	5,690	107	125
FGD with cleaner fuel	3,738	89	93	3,998	84	79
Inc. thermal efficiency[2]	NA	NA	NA	17,604	344	375

Notes:
[1] Base case end-of pipe control: oil-fired - cyclone; coal-fired - EP
[2] Used in conjunction with existing level of pollution control

Appendix 4
Air dispersion modeling

The Industrial Source Complex Long Term 3 (ISCLT3) designed by the USEPA to support its regulatory modeling program was used to predict changes in annual average concentration of PM_{10} and SO_2 as a result of emissions from the oil and coal-fired power plants. The ISCLT3 uses annual averaged meteorology called stability array or STAR. It uses a Gaussian sector-average plume equation as the basis for modeling pollutant emissions on a long-term basis as follows:

$$\chi_1 = \frac{K}{\sqrt{2\pi}\, R\, \Delta\theta'} \sum_{i,j,k} \frac{QfSVD}{u_s \sigma_z}$$

where:

- K = units scaling coefficient
- Q = pollutant emission rate (mass per unit time), for the i^{th} wind-speed category, the k^{th} stability category and the l^{th} season
- f = frequency of occurrence of the i^{th} wind-speed category, the j^{th} wind-direction category and the k^{th} stability category for the l^{th} season
- $\Delta\theta'$ = sector width in radians
- R = radial distance from lateral virtual point source (for building downwash) to the receptor = $[(x+x_y)^2 + y^2]^{1/2}$ (m)
- x = downwind distance from source center to receptor, measured along the plume axis (m)
- y = lateral distance from the plume axis to the receptor (m)
- x_y = lateral virtual distance, equals zero for point sources without building downwash, and for downwash sources that do not experience lateral dispersion enhancement (m)
- S = a smoothing function
- u_s = mean wind speed (m/sec) at stack height for the i^{th} wind-speed category and k^{th} stability category
- σ_z = standard deviation of the vertical concentration distribution (m) for the k^{th} stability category
- V = the vertical term for the i^{th} wind-speed category, k^{th} stability category and l^{th} season
- D = the decay term for the i^{th} wind speed category and k^{th} stability category

Model option. The USEPA regulatory default options were used to calculate ambient concentration values for PM_{10} and SO_2. The USEPA land use procedure in distinguishing urban from rural areas, which in turn dictated the dispersion parameters used in the model, was followed. Since the aggregate area of land devoted to industrial, commercial, and residential uses within a 3-km radius from both the oil- and coal-fired power plants was less than 50% of the defined area, the respective locations of the two plants were classified as rural.

Source parameter. The source parameter data used in the air dispersion modeling were as follows:

Source Parameter Data

Stack Parameter	Oil		Coal	
	Unit 1	Unit 2	Unit 1	Unit 2
Height	90	90	120 m	150 m
Elevation	10	10	5	5
Inside diameter	4.57	4.57	4.46	4.46
Discharge temp.	428 K	422 K	413 K	403 K
Discharge velocity	17.7 m/s	10.1 m/s	21.3 m/s	31.6 m/s

Receptor location. A Cartesian grid receptor network with a 34x34 dimension was used to plot the ground-level receptors. The network had a uniform spacing of 250 meters for the 10-km radius and 3-km for the 50-km radius with a grid size of 2.5 hectares (i.e., 500x500m) and 900 hectares, respectively. The elevation of each grid was extrapolated from a mosaic of 1:50,000 topographic maps from the Philippine National Mapping and Resource Information Authority. The topographic maps had a 20-meter contour interval.

Meteorological data. Meteorological data collected by the weather stations nearest to the power plant were inputted as a stability array (STAR) file - a joint frequency distribution of wind speed and wind direction by stability category. It was generated using hourly meteorological data on ceiling height, wind direction, wind speed, dry bulb temperature, total cloud cover, opaque cloud cover. The data, reported in ASCII format, were taken from the Philippine Atmospheric, Geophysical and Atmospheric Services Administration (PAGASA). The data were converted to the USEPA - Support Center for Regulatory Air Modeling (SCRAM) surface meteorological data file format and edited for missing data parameters and restructured into a format required by the STAR program using the MET144, another program developed by the USEPA.

The location of the two power plants is classified under climate Type 1. Type 1 has two pronounced seasons, namely; dry from November to May and wet the rest of the year. For the oil-fired power plant, the annual average rainfall is 2.43 meters with annual temperatures ranging from 22.4°C (min.) to 31.1°C (max.) or 27.2°C, on the average. For the coal-fired power plant, annual average rainfall is lower at 1.9 meters. However, annual temperatures are slightly higher, i.e., 27.5°C (ave.), 32°C (max.) and 23.1°C (min.). Relative humidity for both locations is about 77% annually while the dominant wind directions are northeasterly and southwesterly winds.

Appendix Table 5. Physical effects of particulate and sulfur oxides

Pollutant	Quantified Effects	Unquantified Effects	Other Possible Effects
Particulate matter/ TSP/sulfates	*Health effects* Mortality Morbidity Respiratory Hospital Admissions Emergency Room Visits Restricted Activity Days Acute Bronchitis, children Asthma attacks Respiratory symptom days Chronic bronchitis, adult	Changes in pulmonary function	Chronic respiratory diseases other than chronic bronchitis Inflammation in the lung
		Non-health effects Household soiling Visibility Other materials damage Effects on wildlife	
Sulfur dioxide	*Health effects* Mortality Morbidity Respiratory symptoms, children RS/Chest discomfort, adult		Respiratory symptoms in non-asthmatics Hospital admissions
		Non-health effects Visibility Crop losses Materials damage Effects on fisheries Effects on forests	

Appendix Table 6. Incremental health benefits of controlling PM_{10} emissions per GWh: oil- and coal-fired power plant (central estimate)

Health Effect	Units	Incremental Incidence Reduced per GWh			
		Oil[1]		Coal[1]	
		Cyclone w/ CF	EP	EP w/ CF	Inc. T. Eff.
10-km					
Mortality	cases	0.0000	0.0000	0.0000	0.0000
Morbidity					
Respiratory Hospital Admissions	cases	0.0000	0.0000	0.0000	0.0000
Emergency Room Visits	cases	0.0016	0.0034	0.0000	0.0000
Restricted Activity Days[2]	days	0.0212	0.0445	0.0000	0.0000
Acute Bronchitis, children	cases	0.0005	0.0011	0.0008	0.0003
Asthma attacks	cases	0.0016	0.0034	0.0061	0.0027
Respiratory symptom days[2]	days	0.0991	0.2105	0.0001	0.0000
Chronic bronchitis, adult	cases	0.0000	0.0001	0.0019	0.0008
50-km					
Mortality	cases	0.0066	0.0113	0.0000	0.0000
Morbidity					
Respiratory Hospital Admissions	cases	0.0054	0.0093	0.0000	0.0000
Emergency Room Visits	cases	1.0495	1.8128	0.0000	0.0000
Restricted Activity Days[2]	days	15.7447	27.2860	0.0000	0.0000
Acute Bronchitis, children	cases	0.4023	0.7116	0.0000	0.0000
Asthma attacks	cases	1.0572	1.8260	0.0002	0.0000
Respiratory symptom days[2]	days	63.3022	109.2426	0.0801	0.0198
Chronic bronchitis, adult	cases	0.0184	0.0320	1.5022	0.3716

[1] Covers the period 1999-2010 for oil and 1999-2013 for coal.

[2] For broad categories of morbidity effects such as respiratory symptom days and RAD (a measure of illness defined as "a day on which illness prevents an individual from engaging in some or all of his or her usual activities") adjustments were made to avoid double counting for effects such as ERVs (Rowe *et al* 1995). The adjustment assumed that all ERVs were also RHAs, the latter thus was subtracted from total ERV. Since the dose-response functions for RHA, ERV and AA were for all ages, while RAD applied to adults, it was also assumed that all RHAs, ERVs and AA, were all RADs, thus were subtracted from total RAD. Adjustment to total RAD was in proportion to age distribution so only the percentage of the effects on adults was deducted. Adjusted RAD, therefore is equal to Total RAD - (% adult.population x # days per RHA x RHA) – (% adult population x net ERV) x (% adult population x asthmatic population). The assumed number of days per RHA was seven days based on Philippine experience. In the absence of Philippine data, asthmatic population was assumed at 4% of total population - the default estimate for the New York Externality Model. All RADs were also assumed as respiratory symptom days, thus was subtracted from RS.

Appendix Table 7. Incremental health benefits of controlling SO_2 emissions per GWh: oil- and coal-fired power plant (central estimate)

Health Effect	Unit	Incremental Incidence Reduced per GWh						
		Oil[1]			Coal[1]			
		CF	FGD	FGD & CF	EP w/ CF	FGD	FGD w/ CF	Inc. T. Eff.
10-km								
Mortality	cases	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
Morbidity								
Respiratory symptoms, children	days	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000
Resp. symptom/Chest discomfort, adult	days	0.1285	0.1373	0.1766	0.0205	0.0335	0.0554	0.0075
50-km								
Mortality	cases	0.0304	0.0326	0.0419	0.0007	0.0023	0.0031	0.0003
Morbidity								
Respiratory symptoms, children	days	0.0688	0.0735	0.0946	0.0003	0.0008	0.0012	0.0001
Resp. symptom/Chest discomfort, adult	days	78.2297	84.4347	108.5621	0.5725	1.7312	2.5728	0.2776

[1] Covers the period 1999-2010 for oil and 1999-2013 for coal.

Appendix Table 8. Economic valuation techniques for measuring health costs of air pollution

Economic Valuation Technique	Health Effect	Group	Data Requirement	Underlying Assumption	Limitation of the Approach
Willingness to pay approach (CV)	Mortality/ morbidity	Behavioral models	- household/individual survey data on people's perceptions and preferences	- the economic value of the health effects of air pollution is indicated by the people's preferences.	- subjective valuation of damage - designing precise questions to be asked is difficult
Wage-differential approach	Mortality/ Morbidity	Revealed preferences	- individual survey data on wage-risk combinations, worker's perceptions, and preferences on non-risk jobs	- existence of and well-functioning labor markets, workers get information on other job situation opportunities and are free to make a choice between risky and non-risky jobs	- subjective valuation of damage - workers may not be well informed - the value varies according to the type of risks and sometimes samples may be biased and give rise to biased results
Human capital Approach	Mortality	Physical linkage method	- information on premature deaths due to air pollution by age category - foregone earnings	- dose-response function can be estimated - market price reflects scarcity	- Ethically unacceptable as it reduces the value of human life to capitalized value of lost income stream, differentiation in value of life between rich and poor, and those employed and unemployed. - Overall, provides a lower bound estimate of economic value and health costs
Cost of illness (COI) approach	Morbidity	Physical linkage method	- excess morbidity cases - work loss days or restricted activity days - cost of medical treatments	- the medical costs and the loss of workdays represents the costs of temporary effects of air pollution on human health	- The method excludes the cost of untreated pain and sufferings and defensive expenditures to maintain the health conditions.

Appendix Table 9. Summary of selected willingness to pay estimates for human health effects

Health Effect	Value per Case (US$ 1992)			Type of Estimate[1]
	Low	Central	High	
Mortality, all causes				
< 65 yrs	2,000,000	4,000,000	8,000,000	WTP
> 65 yrs 2	1,500,000	3,000,000	6,000,000	WTP
All ages	1,700,000	3,300,000	6,600,000	WTP
Morbidity				
Respiratory Hospital Admission	7,000	14,000	21,000	Adjusted COI
Emergency Room Visits	265	530	795	Adjusted COI
Child Bronchitis	135	270	405	Adjusted COI
Restricted activity day	35	70	105	WTP & Adjusted COI
Asthma attack day	12	34	55	WTP
Minor restricted activity day	15	24	41	WTP
Acute respiratory symptom day	5	10	15	WTP
Adult chronic bronchitis	126,000	210,000	336,000	WTP

Notes:
[1] WTP = contingent valuation WTP estimate. Adjusted COI = COI x 2 to approximate WTP.
COI reflects medical costs and lost productivity due to illness. Adjusted COI account for additional potential pain and suffering and activity losses not reflected in the COI numbers.
[2] Mortality values based on United States data, where life expectancy at birth is about 75 years.
Source: Rowe, et al. 1995. New York State Environmental Externalities Cost Study. ESEERCO, New York.

Appendix Table 10. Distribution of incremental health benefits between mortality and morbidity effects avoided: oil- and coal-fired power plants

Scenario	Incremental Health Benefit (1990 Million Pesos)			
	Oil		Coal	
	Mortality	Morbidity	Mortality	Morbidity
10-km				
PM_{10}				
EP	0.53	0.15		
Cleaner fuel	0.30	0.08	0.11	0.032
Increased thermal efficiency			0.03	0.008
SO_2				
Cleaner fuel	1.70	0.01	0.33	0.002
FGD	1.53	0.01	0.46	0.003
FGD w/ cleaner fuel	1.96	0.01	0.77	0.005
Increased thermal efficiency			0.12	0.001
50-km				
PM_{10}				
EP	276.47	85.80	10.38	3.176
Cleaner fuel	189.21	58.11	2.57	0.786
Increased thermal efficiency				
SO_2				
Cleaner fuel	871.81	6.62	29.60	0.224
FGD	794.01	6.10	43.37	0.337
FGD w/ cleaner fuel	1,020.93	7.84	71.95	0.543
Increased thermal efficiency			10.95	0.083

Appendix Table 11. Efficiency and unit cost of alternative measures to control PM and SO_2 emissions

Control Measure	Pollution Control Efficiency		Estimated Cost			Reference
	PM	SO_2	Capital	O & M	Total	
Switching to cleaner fuel						
a) Low sulfur						
- from 3 to 2% sulfur		40%				Larssen et al 1997
b) Low grade fuel oil						
- use of grade 5		70%				Larssen et al 1997
- use of grade 4		80%				Larssen et al 1997
c) Clean coal						
- Physical	30-60% lower	10 to 40%			$1-5/ton coal	Brandon & Ramankutty 1993
* Coarse Fraction	flyash				$2-3/ton	Oskarsson et al 1997
* Fine fraction					$3-10/ton	Oskarsson et al 1997
- Advanced	70% lower	30 to 70%			$6-20/ton coal	Brandon & Ramankutty 1993
	flyash				$15-30/ton	Oskarsson et al 1997
- Sorbent injection		30 to 60%	$70-120/kW	$3-7 mills/kWh		Brandon & Ramankutty 1993
- Coal beneficiation		5-40%			$ 800-1200/ton sulfur or an additional 2% cost of generation	Brandon & Ramankutty 1993
End-of pipe pollution control						
a) Electrostatic precipitators	99%				2-5% cost	Brandon & Ramankutty 1993
	95-99%		$10 M	$ 3-5 M/yr	increment	Larssen et al 1997
	100%		$50-100/kWe	$.15-.4/kWh		Oskarsson et al 1997
- Pulverized coal	95%		$1000/kW	$9 mills/kWh		Tavoulareas & Chatpentier 1995
- Advanced	Up to 99.9%	None	$40-100/kW			Brandon & Ramankutty 1993
	99.50%		4% of plant cost	5-8% of plant cost		
			P3.2-11.3M/MW	P.056/kWh		Sinclair et al 1998
b) Mechanical collectors	90%		10-20% of the cost of installing & operating an ESP			
			P2-3.2M/MW	P0.01/kWh		Sinclair et al 1998

Bag filters	Up to 99.9%	None	$50-70/kW			Brandon & Ramankutty 1993
			$50-75/kW	$.18-.2/kWh		Oskarsson et al 1997
c) Atmospheric fluidized-bed combustion	None	70-95%	$500-1000/kW			Brandon & Ramankutty 1993
- with bagfilter	95%		$1400/kW	$11 mills/kWh		Tavoulareas & Chatpentier 1995
d) Flue-gas Desulfurization		70-95% 80-90% 90-95%	$150-270/kW	$.5-3.3 mills/kWh	or additional 8-12% cost $100 M/yr	Tavoulareas & Chatpentier 1995 Brandon & Ramankutty 1993 Larssen et al 1997
- Furnace sorbent injection, duct injection, dry scrubbers		30 to 70%				Tavoulareas & Chatpentier 1995
- Wet Scrubber/Wet Flue gas desulfurization		80-99%	$160-240/kWe	Variable: $0.15-0.20/kWh Fixed: $.14/kWh		Oskarsson et al 1997 EIA, Coal plant
- Wet scrubbers		90%				Brandon & Ramankutty 1993
- Limestone process		95%	P 628-3,393 M (in 1990 prices)	P110.6-654.9 M/yr	P0.06-0.18/kWh P13.9-35.3/kg SO_2	COLENCO, 1993
- Semi-Dry		90%	P542-3,148M (in 1990 prices)	P106-788.1 M/yr	P0.06-0.19/kWh P16.7-33.8/kg SO_2	COLENCO, 1993
- Seawater		95%	P505-924 M (in 1990 prices)	P85.7-168 M/yr	P0.05-0.12/kWh P12.0-27.3/kg SO_2	COLENCO, 1993
- Spray Dryers		70 to 90%	$140-210/kW	$2.1-3.2mills/kWh		Tavoulareas & Chatpentier 1995
- Dry Sorbent Injection		25-40%	P143-183 M (in 1990 prices)	P36.3-53.2 M/yr	P0.02-0.03 kWh P11.6-13.5/kg SO_2	COLENCO, 1993
- Sorbent injection	None	30-60%	$70-100/kW			Brandon & Ramankutty 1993
		30-70%	$75-100/kW	Fixed: $6/kW/yr ariable: $0.3/kWh		Oskarsson et al 1997

Appendix Table 12. Details on control costs for the oil- and coal-fired power plant

Item	Oil	Coal	Reference	Remarks
Plant Capacity	650 MW	600 MW	Plant profile	
Plant Cost				
Unit 1	4.56 B	2.20 B (1984)	Plant profile	For oil, it is based on P 15,200/kW (1988 peso)
Unit 2	5.32 B	9.51 B (1993)	EIA document	
Capital Cost of EP	488.86 M	431.9 M	ADB	4% of plant cost
O & M Cost per KWh	0.03	0.03	EESIS	1990 pesos
Capital Cost of Cyclone	73.32 M		ADB	15% of cost of installing and operating ESP
O & M Cost per KWh	0.0045			1990 pesos
Capital Cost of FGD	1,969.50 M	1,083.69 M	COLENCO	Type of FGD: oil - limestone; coal - seawater
Annual O & M Cost	378.01 M	191.06 M		1990 pesos
Cost of Cleaner Fuel	162.12 M	174.45 M	DOE/WB	Fuel consumption: oil: 4,125,306 barrel/yr;
Existing Fuel	1,080.83 M	825.34 M		coal:1,402,974 MT/yr
Cleaner Fuel	1,242.95 M	999.79 M		Fuel Prices (in 1990 pesos):
				Oil (per barrel): 3%S - 262; 1% S - 301.3
				Coal (per MT): Local - 492; Australian &
				Indonesian - 655; China - 783
Cost of Increased Efficiency				Increase efficiency of Unit 1 from 32% to 36%
- reduction in cost of generation			Plant profile	and Unit 2 from 36% to 38%.
Unit 1	2.38%			
Unit 2	0.70%			

Notes:

1. The costs were adjusted to 1990 price using CPI.
2. The capital costs were annualized by dividing the adjusted 1990 price with the annuity factors.
3. The cost of cleaner fuel was based on the difference between the cost of fuel with a lower sulfur and ash content and the cost of fuel with the existing fuel quality. For the cost of cleaner coal, the combination of the type of coal with a 0.5% S and 12% ash was first determined and then the corresponding price (based on the source) was applied.
4. The cost of inc. thermal efficiency was based on the trend of the plant's thermal efficiency and cost of energy generation.. The percentage decline in cost of power generation was estimated vis-a-vis the percentage increase in the plant's efficiency based on a time-series data.
5. The annualized capital and annual O & M costs were estimated and then added up and discounted at different levels of r (i.e. 12%, 15% and 18%) to get the total present value for the period 1999-2010/2013.

Appendix Table 13. PV of incremental benefits and costs at various discount rates by scenario: oil- and coal-fired power plants (Central Estimate, 1990 million pesos)

Scenario	Oil						Coal					
	Incremental Benefit*			Incremental Cost			Incremental Benefit*			Incremental Cost		
	r = 12%	r = 15%	r = 18%	r = 12%	r = 15%	r = 18%	r = 12%	r = 15%	r = 18%	r = 12%	r = 15%	r = 18%
10 km												
PM_{10}												
EP	19.60	14.39	10.67	867.30	821.06	783.11	4.16	2.62	1.75	1,330.77	1,173.12	1,048.14
Cleaner fuel	5.17	4.15	3.39	1,124.77	1,010.64	916.98	3.83	2.30	1.43	130.21	114.79	111.78
Increased thermal efficiency												
SO_2												
Cleaner fuel	5.17	4.15	3.39	1,124.77	1,010.64	916.98	4.16	2.62	1.75	1,330.77	1,173.12	1,048.14
FGD	77.58	56.75	41.90	4,214.04	3,947.92	3,729.54	20.27	13.78	9.52	2,391.26	2,218.55	2,080.41
FGD w/ cleaner fuel	78.08	57.19	42.28	5,338.81	4,958.56	4,646.52	20.57	14.09	9.82	3,722.03	3,391.67	3,128.54
Increased thermal efficiency							3.83	2.30	1.43	130.21	114.79	111.78
50 km												
PM_{10}												
EP	435.02	375.97	328.56	867.30	821.06	783.11	47.64	45.52	44.20	1,330.77	1,173.12	1,048.14
Cleaner fuel	1,273.20	1,127.81	1,009.82	1,124.77	1,010.64	916.98	18.21	16.53	15.55	130.21	114.79	111.78
Increased thermal efficiency												
SO_2												
Cleaner fuel	1,273.20	1,127.81	1,009.82	1,124.77	1,010.64	916.98	47.64	45.52	44.20	1,330.77	1,173.12	1,048.14
FGD	994.24	855.36	744.62	4,214.04	3,947.92	3,729.54	63.56	57.02	52.70	2,391.26	2,218.55	2,080.41
FGD w/ cleaner fuel	1,256.66	1,083.99	945.80	5,338.81	4,958.56	4,646.52	92.40	85.81	81.46	3,722.03	3,391.67	3,128.54
Increased thermal efficiency							18.21	16.53	15.55	130.21	114.79	111.78

* The incremental benefit includes the estimated salvage value of the particular pollution control equipment.

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