Chapter 3

Social and Health Benefits of Good Air Quality

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Chapter 3

Social and Health Benefits of Good Air Quality

1. Methodology

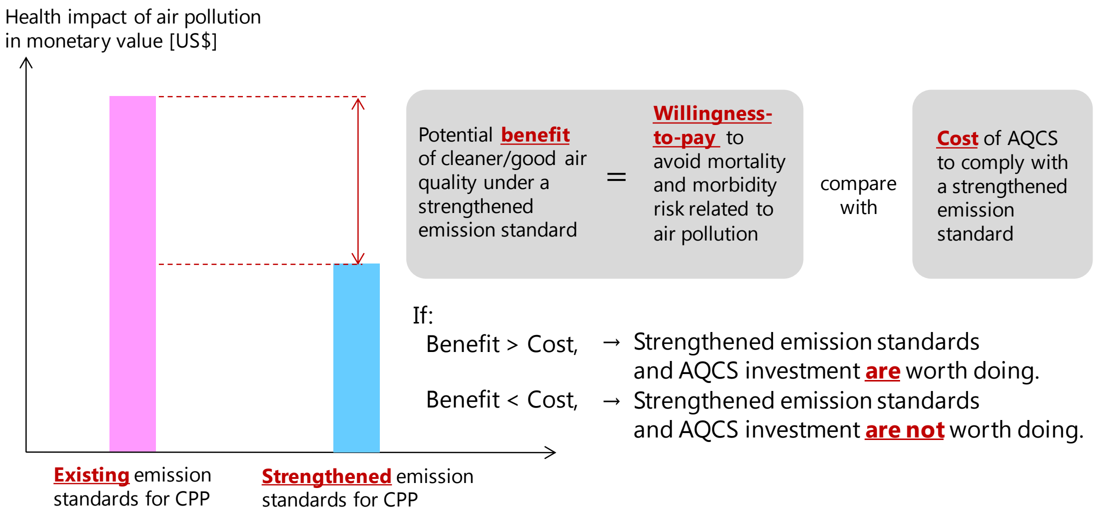
1.1. Overview

This study analyses the costs and benefits of strengthened (more-stringent) air emission standards for coal-fired power plants. Since air emission standards in ASEAN countries are laxer than those in OECD countries, the FY 2016 study (ERIA, 2017) pointed out the significance of tightening standards for air pollutants from coal-fired power plants in ASEAN to a level equivalent to those in OECD. The FY 2017 study (ERIA, 2018) calculated the typical cost of an AQCS that conforms to air emission standards as stringent as OECD countries'. This study analyses a cost–benefit comparison for tightening air emission standards by quantifying the monetary value of social benefits therefrom, of which a concrete example is mitigation of damage to the health of people living around a coal-fired power plant.

Cost is assumed as the investment amount (US$) a typical AQCS needs to comply with strengthened air emission standards. To determine benefit, we calculate the reduced health impact in monetary terms thanks to better air quality. We estimate residents' willingness-to-pay (WTP) [3] to avoid mortality and morbidity risk. For example, if a health-related benefit (WTP) from reduced air pollution is larger than the cost required for the improvement (i.e. investment amount of AQCS), tightening air emission standards and investing in AQCS can be considered economically rational.

[3] Conversion of damage quantity received by residents into economic index in terms of WTP.

Figure 3.1: Cost and Benefit Analysis in This Study



AQCS = air quality control system, CPP = coal-fired power plant.

Source: Author.

To convert the health impact of air pollution caused by coal-fired power plants into a monetary value, calculations follow these steps:

1. Identify the emission source of air pollutants and the technology and fuel used.
2. Calculate the spatial distribution of pollutants (concentration of pollutants) from the point source of pollution.
3. Estimate the health impact on residents caused by changes (increases) in the atmospheric concentration of pollutants.
4. Convert the health impact into monetary value by using mortality- and morbidity-related reference values and calculation formulas.

Calculation methods and major assumptions used in this study are as follows and equation details are described in section 1.2:

Table 3.1: Calculation Methods and Major Assumptions

1. Identification of emission source of air pollutants, etc.	• Applicable to coal-fired power plants (based on assumptions of supercritical pressure, electric output of 631 MW, and exhaust gas amount of 2,550,000 Nm^3/h) • Sites are chosen from existing coal-fired power plants in eight ASEAN countries (one power plant in each country [Table 3.2]). • Targeted air pollutants are SOx (SO_2), NOx (NO_2), and PM (PM2.5/PM10). Neither changes in the state of pollutant due to chemical reaction nor secondary particulates are considered. • Emission amount of air pollutants is calculated based on reference values for emission amounts of air pollutants in the surveyed country and in developed countries. (Actual values recorded at each power plant are not used). • The following are examined: (i) A case where the most-stringent air emission standards amongst developed countries' are adopted for SOx, NOx, and PM (ii) A case where half the existing standard values of air pollutant emission standards in the surveyed country are adopted Calculate the potential benefit of cleaner/good air quality, i.e. willingness-to-pay to avoid mortality and morbidity risk related to coal-fired power plants, by using the difference between values for each case above (i)/(ii) and the existing reference values for emission amounts of air pollutants in the surveyed country.
2. Calculation of spatial distribution of air pollutants	• Use an estimation method (Conservation of Clean Air and Water in Western Europe [CONCAWE]-plume Method) referred to in 'Guidebook for power plant–related environmental

	impact assessment' (in Japanese) by the Ministry of Economy, Trade and Industry (2019) ● The area to be surveyed is within a 20 km radius from the power plant stack.
3. Estimation of health impact on residents	● Calculate the number of cases of premature mortality caused by exposure to air pollutants (a) by using the equation presented in World Health Organization (2004) (Table 3.16 and Table 3.17 of this study).
4. Conversion of health impact into monetary value	● Calculate reference values (b), which are the basis for conversion into monetary value, for each country to be surveyed by using an equation presented by OECD (2017). Value of statistical life, which is a concept based on willingness-to-pay, is used to calculate (b) (Figure 3.12 of this study). Health impact in the surveyed country is converted into a monetary value by multiplying (a) by (b).

Source: Author.

This study covers Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam, and excludes Brunei Darussalam and Singapore, neither of which has coal-fired power plants.

Most of the coal-fired power plants in ASEAN countries use subcritical pressure technology. Future power plants are expected to use supercritical or ultra-supercritical pressure technology. We assumed a power plant using supercritical pressure technology (with electric output of 631 MW and exhaust gas of 2,550,000 Nm^3/h) as the basis for estimations. The said electricity output is an average output of supercritical pressure power plants operating in Japan as of January 2019.

Power plants selected as point sources of air pollutants are listed below. We selected one power plant from each country to calculate diffusive concentration of air pollutants within a 20 km radius therefrom. A power plant with the largest total electricity output in each country was chosen as a point source of air pollutants.

Table 3.2: Point Sources of Air Pollution (coal-fired power plants)

Country	Power Plant	Output (MWe)	Start of Operation (year)
Cambodia	Sihanoukville Stung Hav	60*2	2014
Indonesia	Suralaya	400*4	1984/1985/1988/1989
		600*3	1996/1997*2
Lao PDR	Hongsa	626*3	2015*2/2016
Malaysia	Tanjung Bin	748*3	2006/2007*2
		1000*1	2016
Myanmar	Kyaukphyu Power	660*2	-
Philippines	Calaca Semirara	300*2	1984
Thailand	Mae Moh	75*3	1978*2/1981
		150*4	1984*2/1985*2
		300*6	1990*2/1991*2/1995*2
Viet Nam	Vinh Tan-2	622*2	2014*2

Lao PDR = Lao People's Democratic Republic.

Source: Author.

The results of ERIA (2017) are adopted as air pollutant emission standards for coal-fired power plants in the surveyed countries (Table 2.).

The results of ERIA (2018) are adopted as the installation cost of AQCS. Yearly average costs are calculated based on total investment cost per MW, assuming the operating life of AQCS to be 20 years.

Table 3.3: Cost of Air Quality Control System Installation for Seven ASEAN Countries

	Yearly Average Installation Cost per MW, 2010 (US$)
Low case	0.02860
High case	0.04385

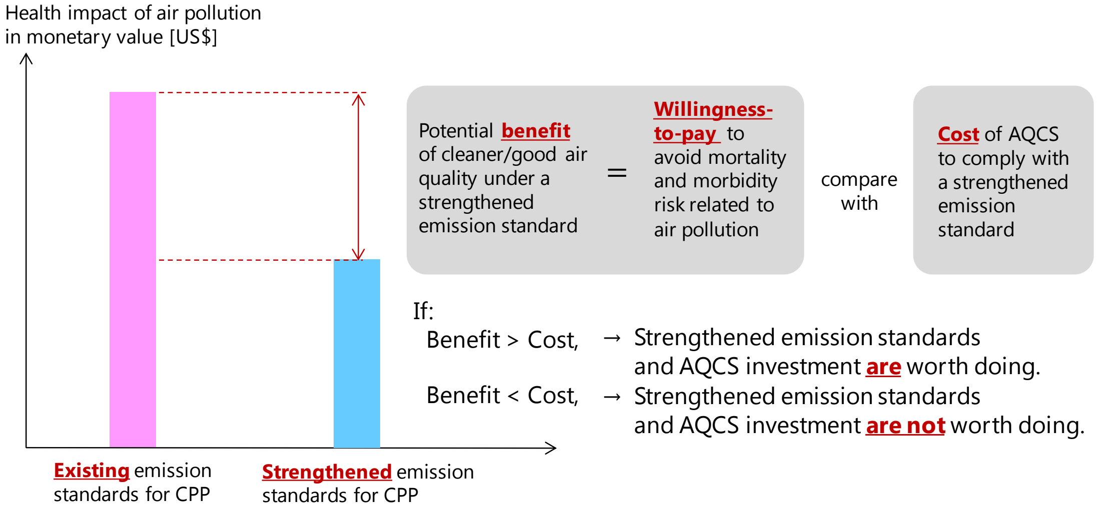
Note: We calculate the average installation cost of an air quality control system based on Table 2. and the calculation formula used in the FY 2017 study (ERIA,2018). Source: Author.

2. World Health Organization Method and Results

2.1. Standard Data to be Referenced

Two cases each are examined for SOx, NOx, and PM: (i) where the most stringent reference value amongst air pollutants emission standards is adopted, and (ii) where half of the reference value of existing air pollutant emission standards in the surveyed country is adopted.

Figure 3.2: Cost and Benefit Analysis in This Study



AQCS = air quality control system, CPP = coal-fired power plant.
Source: Author.

The cost–benefit analysis for tightening air emission standards is conducted by comparing monetary value converted from health impacts on residents, which are avoidable when air emission standards are strengthened (tightened) to a certain level, and installation costs of air pollutant-removal equipment. The cases where air emission standards are tightened to a certain level correspond to cases (i) and (ii). We assumed that an amount of air pollutants equivalent to that specified in standards is emitted and examined the health impact on residents under such conditions. As detailed in section 3.2.4, the health impact converted into monetary value is based on WTP. Therefore, 'potential benefit/social benefit of good air quality' can also be expressed as 'WTP to avoid mortality and morbidity risk related to coal-fired power plants'.

Table 3.4: Most Strengthened Emission Standard for Case (i)

	SOx (mg/m^3)	NOx (mg/m^3)	PM (mg/m^3)
Most strengthened standard	133	50	10

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.
Note: Air pollutant standards come from developed countries. SOx: Japan; NOx: Republic of Korea; PM: Germany.
Source: Author.

Table 3.5: Half of Existing Emission Standard for Case (ii)

	SOx (mg/m^3)	NOx (mg/m^3)	PM (mg/m^3)
Cambodia	250	500	200
Indonesia	375	375	50
Lao PDR	426.5	335	60
Malaysia	250	250	25
Myanmar	100	200	25
Philippines	350	500	75
Thailand	240	191.5	40
Viet Nam	250	325	100

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.

Source: Author.

The health impact that is avoidable when the air emission standard is tightened to a certain level can be calculated from the difference between an existing air emission standard value and the standard values in cases (i) and (ii). In case (i), the difference between the value of an existing air pollutant emission standard and the value of the most stringent air pollutant emission standard for SOx, NOx, and PM amongst developed countries is used for the calculation, and in case (ii), the difference between the value of an existing air pollutant emission standard and half of the value of air pollutant emission standard of the surveyed country. In this way, whenever the health impact is converted into a monetary value, the same equations and factors, except standard values, can be used equally for calculations for case (i), case (ii), or the existing air emission standard. The difference between such standard values is incorporated into the equation for the air pollutant diffusion forecast as emission rate of air pollutant (section 3.2.2). The difference will be 'Q_p' in equation (5). In the said equation, the emission rate of air pollutants is indicated in $\mu g/Nm^3/h$ per MW to make the comparison with the installation cost of AQCS (indicated as a yearly average cost/ MW) easier. The differences in the standard values used in case (i) and case (ii) (emission rate of air pollutants) are shown below:

Table 3.6: Emission Rate of Air Pollutants for Case (i)

Country	SOx (µg/Nm^3/h/MW)	NOx (µg/Nm^3/h/MW)	PM (µg/Nm^3/h/MW)
Cambodia	582	1,506	618
Indonesia	978	1,109	143
Lao PDR	1,141	983	174
Malaysia	582	713	63
Myanmar	106	555	63
Philippines	899	1,506	222
Thailand	550	528	111
Viet Nam	582	951	301

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.

Source: Author.

Table 3.7: Emission Rate of Air Pollutants for Case (ii)

Country	SOx (µg/Nm^3/h/MW)	NOx (µg/Nm^3/h/MW)	PM (µg/Nm^3/h/MW)
Cambodia	396	792	317
Indonesia	594	594	79
Lao PDR	676	531	95
Malaysia	396	396	40
Myanmar	158	317	40
Philippines	555	792	119
Thailand	380	304	63
Viet Nam	396	515	158

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.

Source: Author.

If the conditions conform to equation (1) below, the residents in the surveyed ASEAN countries may be considered to be willing to pay the installation costs of AQCS to avoid a health impact caused by coal-fired power plant–derived air pollution.

$$WTP_{ES} - WTP_{SS} > C_{AQCS} \quad (1)$$

Where,

WTP_{ES}: WTP to avoid mortality and morbidity risk related to coal-fired power generation with existing emission standards (US$)

WTP_{SS}: WTP to avoid mortality and morbidity risk related to coal-fired power generation with strengthened emission standards (US$)

$WTP_{ES} - WTP_{SS}$: Potential benefit of cleaner/good air quality with strengthened emission standards for coal-fired power plants: i.e. WTP to avoid mortality and morbidity risk related to coal-fired power plants (US$)

C_{AQCS}: AQCS installation cost in each ASEAN country (US$)

2.2. Calculation of Spatial Distribution of Air Pollutants

(a) Diffusion forecast of air pollutants

METI (2019) cites a forecast method described in Environmental Research and Control Center (2000) as a referential method relating to thermal power plants and nuclear power plants. For exhaust gases generated by operation of power generation facilities, except nuclear power plants, the referential method is used to calculate concentration changes and diffusion conditions of air quality.

Because a yearly average of ground-level pollutant concentration is sought in the course of the forecast, the survey area is, in principle, set within a 20 km radius from a power plant, because such an area includes a location where the ground-level pollutant concentration becomes relatively high.

In consideration of the assessment's validity and the forecast's accuracy, it would be appropriate to focus mainly on the forecast of the yearly average value that has a longer time scale. The yearly average value is forecast as follows:

- Calculation method. The diffusion forecast of exhaust gas from a thermal power plant is made by calculating values that are simulated based on diffusion from an effective height of a stack in consideration of ascension of smoke. The effective height of the stack is obtained by adding the actual stack height to the ascension height of smoke, which is obtained by a calculation formula for smoke ascension height.
- Conditions of forecast. The conditions of the smoke source required for diffusion forecast, such as the exhaust gas amount and emission amount of air pollutants, are calculated from a model that is simulated based on a yearly utilisation ratio and daily load patterns of the smoke source to be surveyed.

In the case of large-scale high smoke sources such as power plants, meteorological conditions that affect the exhaust gas diffusion are often different from those at ground level because of the high effective height of the stack. Therefore, the diffusion field in the upper layer is set by considering various meteorological observations, amongst others. To estimate wind velocity in the upper layer, based on the result of ground-based meteorological observation, the power law of vertical wind velocity distribution is used. The power law to indicate vertical wind velocity distribution is defined below:

$$V_z = V_r \left(\frac{Z}{Z_r}\right)^{1/n} \tag{2}$$

Where,

V_z: Wind velocity in upper layer (m/s)

V_r: Wind velocity at reference height (m/s)

Z: Height of upper layer (m)

Z_r: Reference height (m)

The National Astronomical Observatory of Japan (2008) shows the relationships between the situations of ground surface and ‘n’:

Table 3.8: Relationship Between the Situations of Ground Surface and n

Situations of Ground Surface	n
Plain field, grassland	7
Forest, urban area without high-rise building, residential area	4
Suburb of a large city and its circumference, urban area	3
Central zone of a large city and its vicinity	2

Source: National Astronomical Observatory of Japan (2008).

Wind force scales are in accordance with the Beaufort wind force scale, which has been adopted by the World Meteorological Organization as a standard expression method of wind force. The wind force scale at ground level is commonly between 1 and 4 (wind velocity from 0.3 to 7.9 m/s). If the wind velocity at ground level is assumed to be 8 m/s, the velocity at the top of a stack 200 m high will be 12.3–35.8 m/s, depending on ground surface conditions. A coal-fired power plant is rarely located in a central zone of a large city. If such a circumstance is excluded from the above range of wind velocity, the wind velocity at the top of a stack 200 m high will be 12.3–21.7 m/s depending on ground surface conditions.

Table 3.9: Beaufort Wind Scale

Wind Scale	Corresponding Wind Velocity (m/s)
0	0.0 or more, less than 0.3
1	0.3 or more, less than 1.6
2	1.6 or more, less than 3.4
3	3.4 or more, less than 5.5
4	5.5 or more, less than 8.0
5	8.0 or more, less than 10.8
6	10.8 or more, less than 13.9
7	13.9 or more, less than 17.2
8	17.2 or more, less than 20.8
9	20.8 or more, less than 24.5
10	24.5 or more, less than 28.5
11	28.5 or more, less than 32.7
12	32.7 or more

Source: Japan Meteorological Agency (2018).

The stack height of a power plant is 100–200 m and wind conditions at such a height are rarely calm. If calculated based on power law and the values of Table 3.9, the wind velocity at a height of 200 m from the ground will be 0.6–1.8 m/s, depending on ground surface conditions, even if wind conditions 10 m from the ground are calm (wind velocity of up to 0.4 m/s). This study, therefore, examines conditions with a certain level of wind.

Peculiar meteorological conditions (formation of inversion layer, occurrence of downwash, and occurrence of fumigation due to development of inner boundary layer) are not considered because they are infrequent. The effective stack height and concentration are calculated using the method below in accordance with the Environmental Research and Control Center (2000).

(b) Calculation of effective stack height

Stacks discharge exhaust gas, which is generally generated by combustion. Therefore, when exhaust gas is discharged from a stack, it has an inertia effect caused by discharging speed and a buoyance effect caused by the heat quantity of the exhaust gas. Due to such effects, exhaust gas continues to ascend after it is discharged from a stack, whilst it wafts in the wind and gradually mixes with surrounding air. Interfusion of air lowers the power to ascend and the exhaust gas reaches its ultimate height. The height of exhaust gas ascension after it is discharged from the stack is expressed by ΔH, the actual height of the stack by H_o, and the height of the emission source (effective stack height, H_e) by the equation below:

$$H_e = H_o + \Delta H \tag{3}$$

As for exhaust gas discharged from the stack, buoyance force is a dominant factor to determine the effective stack height. (The dominant factor that determines ΔH is buoyance force and is referred to as 'buoyant plume'.) The Conservation of Clean Air and Water in Western Europe (CONCAWE) formula (METI, 2019) is adopted for conditions with a certain level of wind. The equation was developed by a research group of a Western European petroleum-related company using a regressive approach from many actual measurement values. Amongst various estimation formulae, only the CONCAWE formula has been verified through domestic and overseas research studies as coinciding with the actual state of smoke.

$$\Delta H = 0.175 * Q_H^{1/2} * u^{-3/4} \tag{4}$$

Where,

ΔH: Ascending height of exhaust gas (m)

Q_H: Discharged heat quantity (cal/s)

u: Wind velocity at the top of stack (m/s)

and

$$Q_H = \rho C_p Q \Delta T \tag{5}$$

Where,

ρ: Density of exhaust gas at 0°C ($1.293*10^3$ g/m^3)

C_p: Specific heat under constant pressure (0.24 cal/K/g)

Q: Exhaust gas amount per unit time (Nm^3/s)

ΔT: Temperature difference (T_G-15°C) between exhaust gas temperature (T_G) and ambient temperature

The effective stack height was calculated using the CONCAWE formula, assuming an exhaust gas amount from a coal-fired power plant of 2,550,000 Nm^3/h and an actual stack height of 200 m.

(c) Calculation of concentration

Due to the same reasons as above, calculations are made only for conditions with wind. Exhaust gas from a stack of a power plant is smoke from a point source. Therefore, it is appropriate to use a normal distribution-type plume formula as a diffusion formula to be used for diffusion simulation and to use Pasquill-Gifford stability as a diffusion parameter. A plume formula suits conditions with a wind velocity of 0.5 m/s or more. The equation for diffusion at a certain point (horizontal distance 'R' and height 'z') is shown below. Assuming the concentration to be constant within one single wind direction, a plume that is irrelevant to the horizontal diffusion parameter is defined by the following equation:

$$\mathrm{C(R,z)} = \sqrt{\frac{1}{2\pi}} * \frac{Q_p}{\frac{\pi}{8}R\sigma_z u} * \left[exp\left\{-\frac{(z-H_e)^2}{2{\sigma_z}^2}\right\} + exp\left\{-\frac{(z+H_e)^2}{2{\sigma_z}^2}\right\}\right] \quad (6)$$

Where,

R: Horizontal distance between point source of smoke and calculated point (m)

z: z-coordinate of calculated point (m) (Origin of coordinate is set at a point on the ground surface just below the smoke source, x-axis is set in a downwind direction, y-axis is set horizontally in a direction orthogonal to x-axis, and y-axis is set in a height direction.)

σ_z: Diffusion parameter representing spread of smoke in z-axis direction

Q_p: Strength of point source of smoke (Nm^3/s)

u: Wind velocity (m/s)

H_e: Effective stack height (m)

As a diffusion parameter to be used in combination with the plume formula, the Pasquill-Gifford chart is popular. It creates diffusion parameter 'σ_z' ('σ_y' is also a diffusion parameter but is not used in this study) as a function of the downwind distance 'x' for each of the Pasquill-Gifford stability classes A through G. The approximation formula of the Pasquill-Gifford chart is mentioned below:

$$\sigma_z(x) = \gamma_z * x^{\alpha z} \quad (7)$$

Table 3.10: Pasquill-Gifford Stability Classes

Atmospheric Stability	α_z	γ_z	Downwind Distance x(m)
A	1.122	0.0800	0–300
	1.514	0.00855	300–500
	2.109	0.000212	500–
B	0.964	0.1272	0–500
	1.094	0.0570	500–
C	0.918	0.1068	0–
D	0.826	0.1046	0–1,000
	0.632	0.4000	1,000–10,000
	0.555	0.811	10,000–

E	0.788 0.565 0.415	0.0928 0.433 1.732	0–1,000 1,000–10,000 10,000–
F	0.784 0.526 0.323	0.0621 0.370 2.41	0–1,000 1,000–10,000 10,000–
G	0.794 0.637 0.431 0.222	0.0373 0.1105 0.529 3.62	0–1,000 1,000–2,000 2,000–10,000 10,000–

Source: Environmental Research and Control Center (2000).

As for atmospheric stability, stability class D is most common in Japan. Because of the larger amount of insolation in Southeast Asia, class C, which is less stable by one level than that of Japan, is adopted in this study as a yearly average value.

R from 100 m to 20,000 m is calculated by using the normal distribution-type plume formula, and the average concentration of SOx, NOx, and PM is calculated for zones with a horizontal distance of 1,500–20,000 m from the point source of smoke. To simplify the calculation, the concentration of air pollutants in the area within a 20 km radius from a power plant is assumed to be equal to the said average concentration. As detailed in section 3.2.3, the number of cases of premature mortality is calculated for each air pollutant by using such an average concentration for each air pollutant. Diffusive concentrations (average values) in the surveyed countries are as follows:

Table 3.11: Average Concentration of Air Pollutants for Case (i)

Country	Average Concentration (mg/m^3)		
	SOx	NOx	PM
Cambodia	9.873E-06	2.556E-05	1.049E-05
Indonesia	1.660E-05	1.883E-05	2.421E-06
Lao PDR	1.937E-05	1.668E-05	2.959E-06
Malaysia	9.873E-06	1.211E-05	1.076E-06
Myanmar	1.802E-06	9.415E-06	1.076E-06
Philippines	1.525E-05	2.556E-05	3.766E-06
Thailand	9.335E-06	8.958E-06	1.883E-06
Viet Nam	9.873E-06	1.614E-05	5.111E-06

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.

Source: Author.

Table 3.12: Average Concentration of Air Pollutants for Case (ii)

Country	Average Concentration (mg/m^3)		
	SOx	NOx	PM
Cambodia	6.725E-06	1.345E-05	5.380E-06
Indonesia	1.009E-05	1.009E-05	1.345E-06
Lao PDR	1.147E-05	9.012E-06	1.614E-06
Malaysia	6.725E-06	6.725E-06	6.725E-07
Myanmar	2.690E-06	5.380E-06	6.725E-07
Philippines	9.415E-06	1.345E-05	2.018E-06
Thailand	6.456E-06	5.151E-06	1.076E-06
Viet Nam	6.725E-06	8.743E-06	2.690E-06

NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide.

Source: Author.

2.3. Calculation of Number of Cases of Premature Mortality

This study refers to equations provided by the World Health Organization (WHO) (2004) to calculate the number of cases of premature mortality from all causes from exposure to air pollutants. The WHO has coordinated the preparation of practical guidance to estimate disease burden at national or local levels for selected environmental and occupational risk factors. The guidance is compiled in the *Environmental burden of disease series* and contains the scientific basis for the estimates, as well as a step-by-step approach and a numerical example to assist scientists in estimating the size of an environmental health problem in a selected area (WHO, 2019). WHO (2004) is part of the series and provides the method of the quantitative assessment of the health impact of outdoor air pollution, using PM10 or PM2.5 measurements, for a given city or region.[4]

This study estimates the effects of all-cause mortality associated with short-term exposure for the full population based on equations in WHO (2004). According to the WHO (2004: 9), 'It is important to note that estimation of the effects of short-term exposure would, to a certain extent, double-count those cases estimated to result from long-term exposure, and the burden specifically estimated for children under age 5'. Therefore, this study only focuses on short-term exposure to air pollutants to avoid double-count and simplify our estimation.

To quantify the effect of all-cause mortality associated with short-term exposure for the full population, the relative risk (RR)[5] can be specified as follows:

$$RR = exp[\beta(X - X_o)] \tag{8}$$

Where,

β: Concentration–response functions from the epidemiological literature that relates ambient concentrations of air pollutants to selected health effects

X: Current pollutant concentration (μg/m^3)

X_o: Target or threshold concentration of pollutants (μg/m^3)

The results of $X - X_o$ are in Table 3.11 and Table 3.12.

'β' refers to values from the Health Effects Institute (HEI) (2010). HEI (2010) enumerates and classifies more than 400 studies identified through a 2007 literature survey. A systematic and

[4] The evidence in WHO (2004) is being revised.

[5] A measure of the risk of a certain event happening in one group compared with the risk of the same event happening in another group (National Cancer Institute, 2019).

quantitative assessment of 82 time-series studies estimates the effect of short-term exposure to air pollution on daily mortality and hospital admissions for cardiovascular and respiratory disease. ADB (2014) reviews the summary estimates presented in HEI (2010) and examines whether they can be applied with reasonable reliability to Asian countries. ADB (2014) concludes that they are confident that HEI's estimates are the best available estimates to date in the literature on Asia and that the combined analysis from the 82 studies is applicable to Asian countries.

Table 3.13: Concentration–Response Functions

Pollutant	Outcome	Percent Change (95% CI), Fixed Effect, per 10μg/m^3
SO_2	Mortality, all causes, all ages	0.35
NO_2	Mortality, all causes, all ages	0.83
PM10	Mortality, all causes, all ages	0.14

NO_2 = nitrogen dioxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: HEI (2010).

Once the relative risks have all been determined, the attributable fractions (AFs) of health effects from air pollution for the exposed population can be calculated by

$$\mathrm{AF} = \frac{RR - 1}{RR} \tag{9}$$

To calculate the expected number of mortality cases due to air pollution (E), the AF is applied to the total number of deaths:

$$E = AF \times B \times P \tag{10}$$

Where,

E: Expected number of deaths due to outdoor air pollution

B: Population incidence of the given health effect (i.e. deaths per 1,000 people)

P: Relevant exposed population for the health effect

The WHO (2004) states that the AF is based on relative risks derived from epidemiological studies and from the change in PM being evaluated, B is obtained or approximated from available health statistics, and P from census or other data for the area under study. Table 3.14 shows the values of B for eight countries, and Table 3.15 the values of P.

Table 3.14: Crude Death Rate in Eight ASEAN Countries

Country	Deaths/1,000 population, 2017 est.
Cambodia	7.5
Indonesia	6.5
Lao PDR	7.4
Malaysia	5.1
Myanmar	8.19
Philippines	6.1
Thailand	8
Viet Nam	5.9

Lao PDR = Lao People's Democratic Republic.

Source: Central Intelligence Agency (2019).

Table 3.15: Population Within a 20 km Radius of Specific Coal-fired Power Plants

Country	Population	Census Data (as of)
Cambodia	109,724	3 March 2008
Indonesia	558,901	1 May 2015
Lao PDR	28,048	1 March 2015
Malaysia	478,187	6 July 2010
Myanmar	165,352	29 March 2014
Philippines	808,301	1 August 2015
Thailand	38,464	1 September 2010
Viet Nam	140,708	3 March 2008

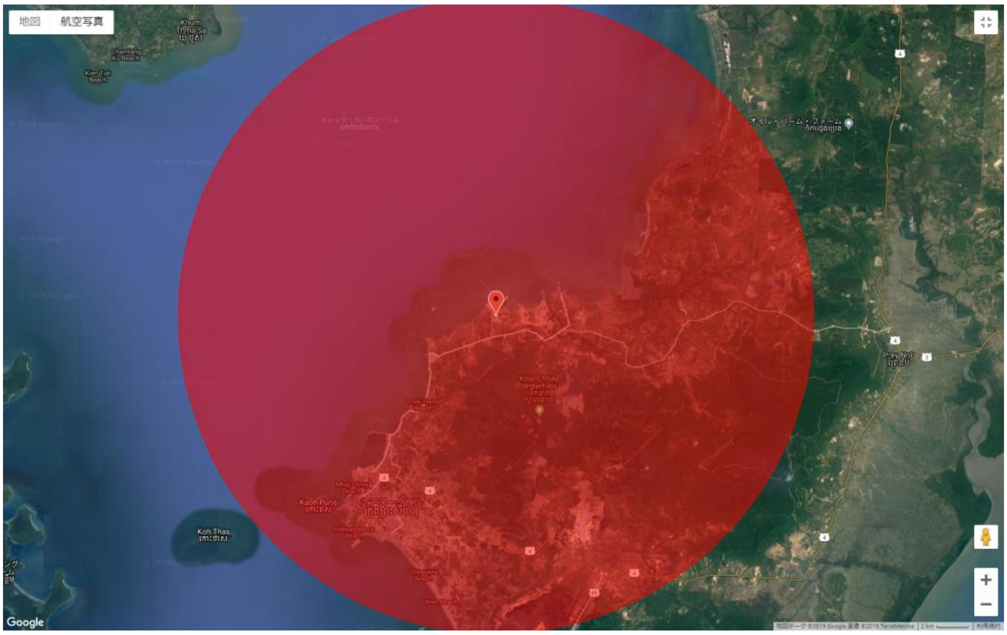
Lao PDR = Lao People's Democratic Republic.

Source: City Population, Asia (2019).

Areas within a 20 km radius from specific coal-fired power plants (Table 3.2) are shown in Figure 3.3 through Figure 3.10 for each power plant. This study does not consider absorption of air pollutants by seawater and cross-border transfer of air pollutants by atmospheric circulation.

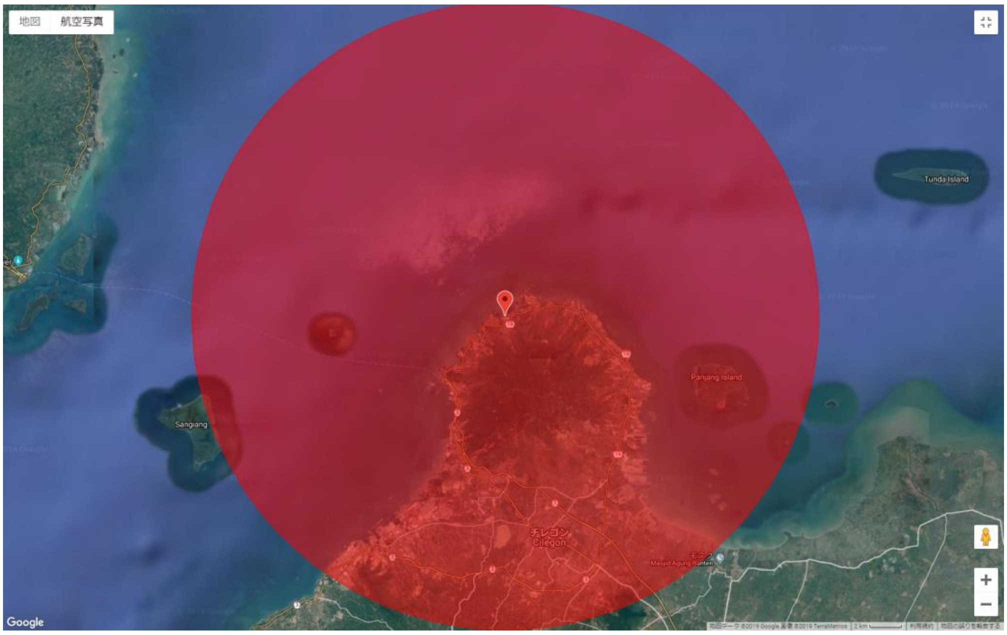
This study assumes that those who suffer health impacts are limited only to residents of the surveyed country, even if such a zone of a 20 km radius may expand to a part of another surveyed country's territory (e.g. Malaysia).

Figure 3.3: Point Source of Air Pollutants, Cambodia



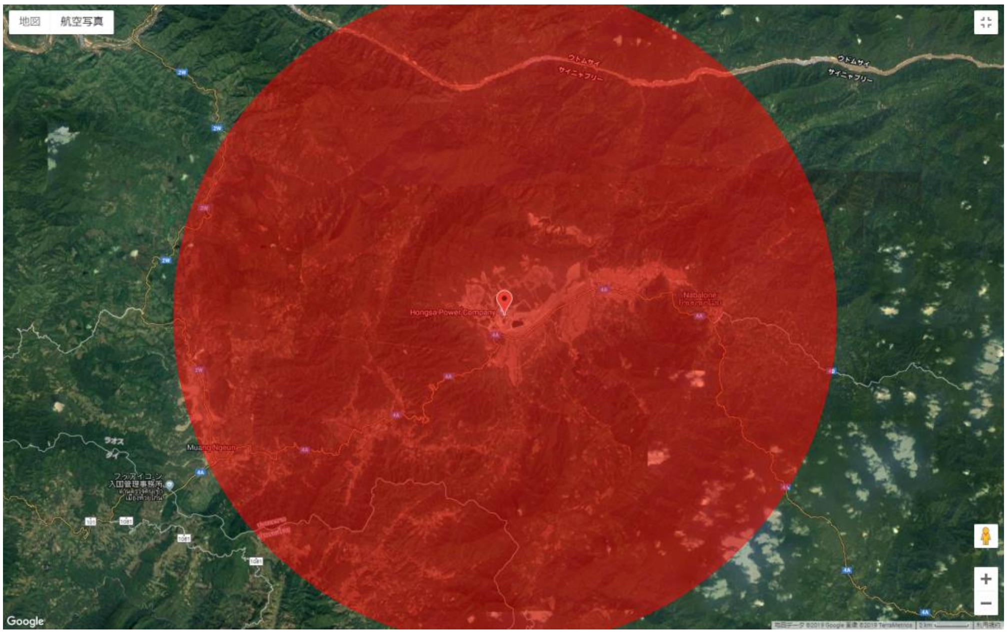
Source: Google Maps.

Figure 3.4: Point Source of Air Pollutants, Indonesia



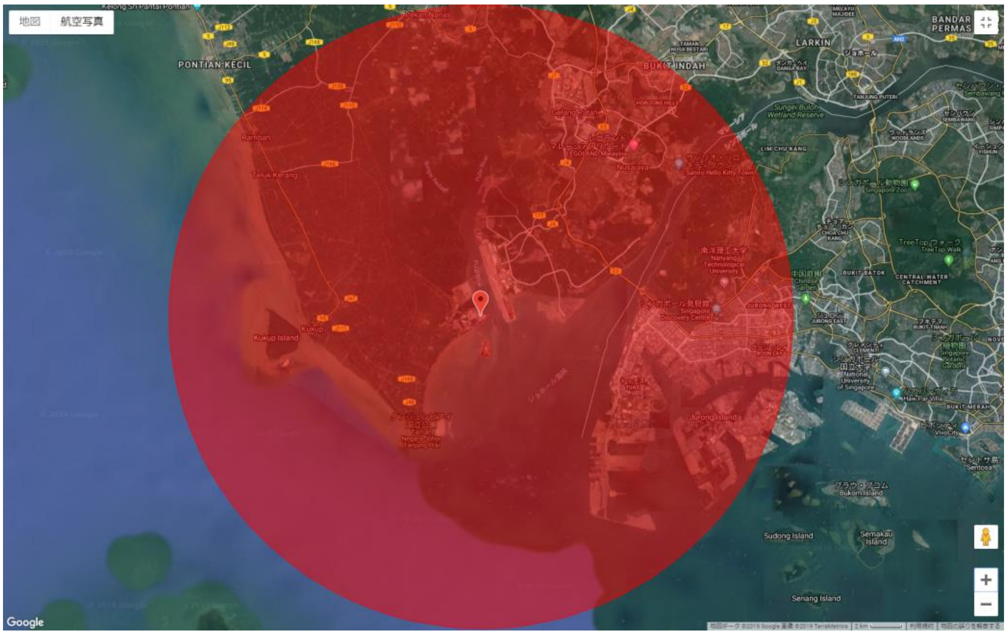
Source: Google Maps.

Figure 3.5: Point Source of Air Pollutants, Lao People's Democratic Republic



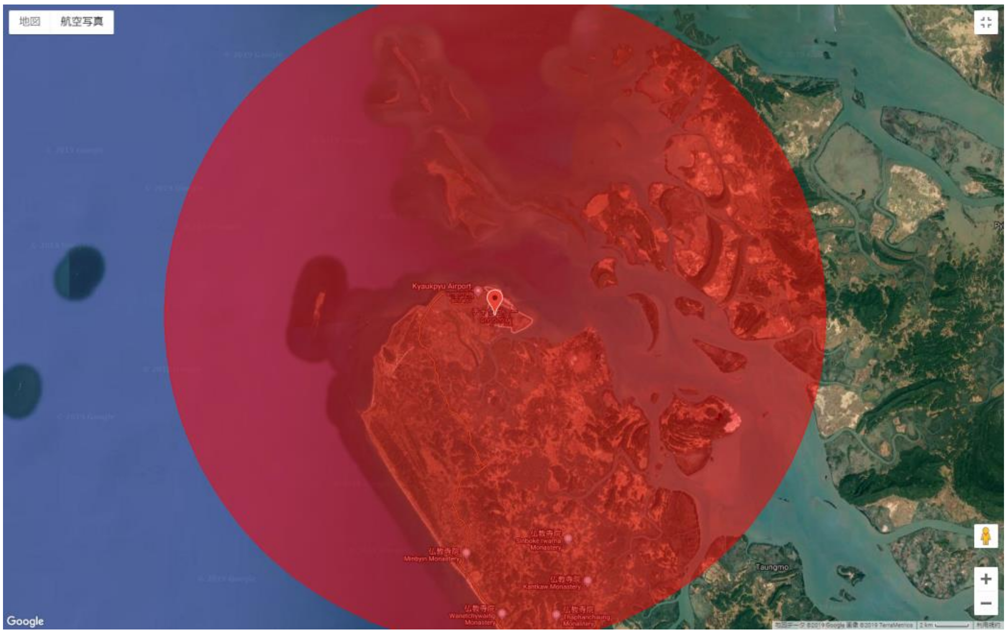
Source: Google Maps.

Figure 3.6: Point Source of Air Pollutants, Malaysia



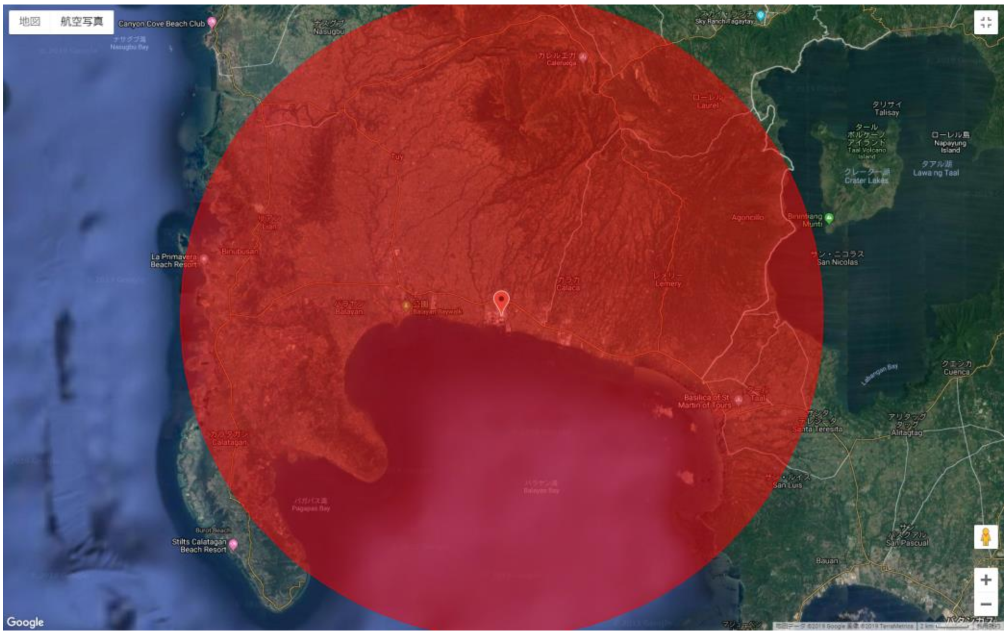
Source: Google Maps.

Figure 3.7: Point Source of Air Pollutants, Myanmar



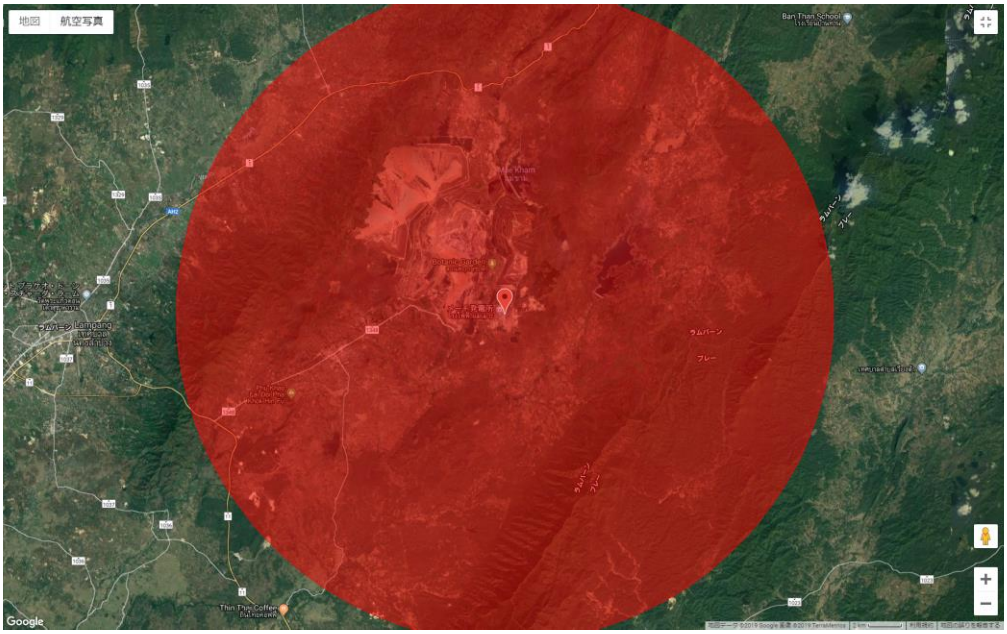
Source: Google Maps.

Figure 3.8: Point Source of Air Pollutants, Philippines



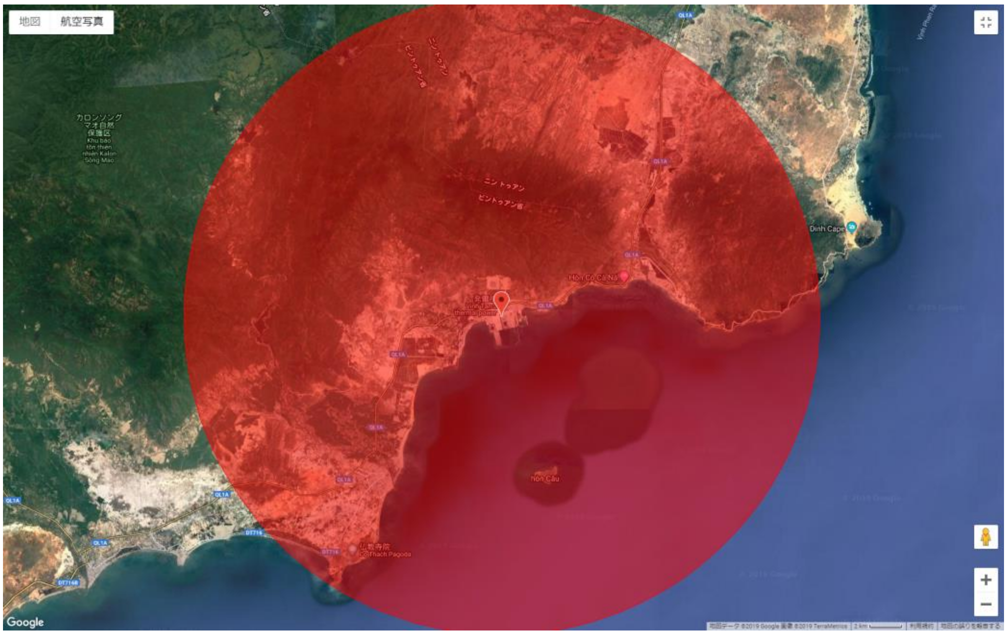
Source: Google Map

Figure 3.9: Point Source of Air Pollutants, Thailand



Source: Google Maps.

Figure 3.10: Point Source of Air Pollutants, Viet Nam



Source: Google Maps.

To calculate the number of yearly premature mortalities using equation (10), the load factor of coal-fired power plants is set at 70%. The yearly numbers of cases of premature mortalities in the surveyed countries for each type of air pollutant are shown in Table 3.16. By multiplying the values in Table 3.16 and Table 3.17 by the estimated value of statistical life (VSL) (section 3.2.4), we can obtain the cost of mortality or morbidity due to air pollution caused by coal-fired power generation, i.e. WTP to avoid mortality and morbidity risk related to coal-fired power plants.

Table 3.16: Expected Number of Deaths Due to Outdoor Air Pollution, Case (i)

Country	Cases of Mortality		
	SO_2	NO_2	PM10
Cambodia	0.01744	0.10704	0.00741
Indonesia	0.12941	0.34817	0.00755
Lao PDR	0.00863	0.01762	0.00053
Malaysia	0.05167	0.15025	0.00225
Myanmar	0.00524	0.06489	0.00125
Philippines	0.16141	0.64131	0.01594
Thailand	0.00616	0.01403	0.00050
Viet Nam	0.01759	0.06820	0.00364

NO_2 = nitrogen dioxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: Author.

Table 3.17: Expected Number of Deaths Due to Outdoor Air Pollution, Case (ii)

Country	Cases of Mortality		
	SO_2	NO_2	PM10
Cambodia	0.01188	0.05633	0.00380
Indonesia	0.07865	0.18652	0.00419
Lao PDR	0.00511	0.00952	0.00029
Malaysia	0.03520	0.08347	0.00141
Myanmar	0.00782	0.03708	0.00078
Philippines	0.09963	0.33753	0.00854
Thailand	0.00426	0.00807	0.00028
Viet Nam	0.01198	0.03694	0.00192

NO_2 = nitrogen dioxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: Author.

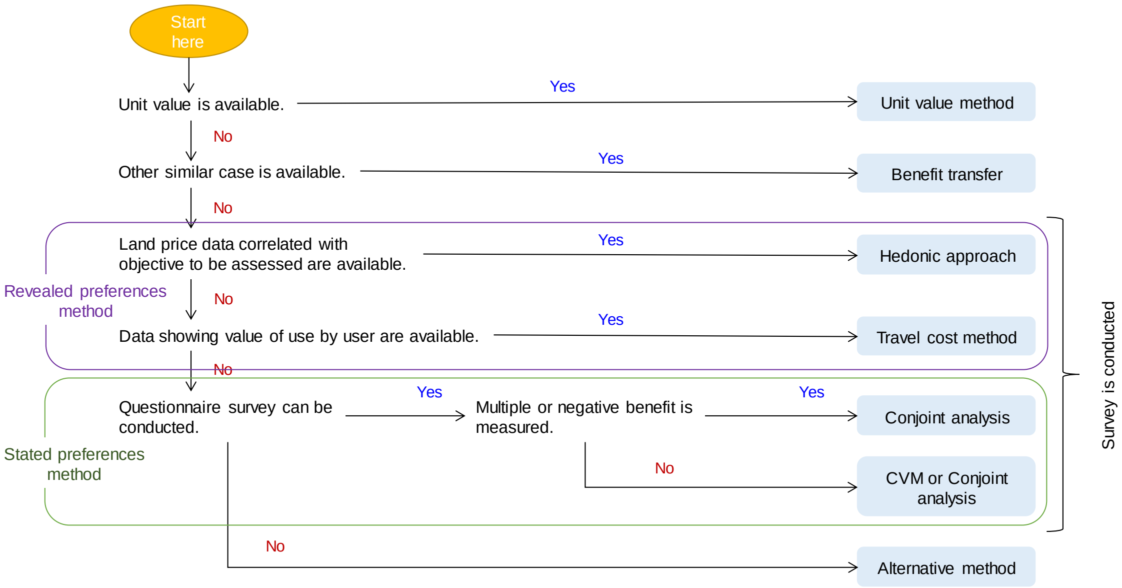
2.4. Cost of Mortality and Morbidity

Environmental economics analyses environmental issues and assesses the impact of environmental disruption from an economics point of view, i.e. it prices the environment that is not traded in the market. Multiple methods have been developed to assess the environment's monetary value. The following listed external economic evaluation methods have different features. When conducting an economic evaluation, it is necessary to comprehensively consider types of available data, characteristics of items to be evaluated, costs required for the survey, and so on (Ministry of Land, Infrastructure, Transport and Tourism, 2004).

WTP is the core of the method to evaluate the environmental benefits and costs in monetary terms. WTP means the upper limit of an amount of money that a person is willing to pay to avoid certain damage (Itsubo and Inaba, 2018), or an amount of money that a person is willing to pay to perform a certain business (in the case where things may get worse if such a business is not performed) (Ministry of Land, Infrastructure, Transport and Tourism, 2004).

To understand WTP with regard to the value that is not traded through monetary transactions (i.e. for the purpose of this study, the value of the environment), researchers commonly interview people influenced by the environment either adversely or positively, through a questionnaire survey, amongst other methods. However, no questionnaire survey or the like has ever been conducted in the countries surveyed in this study, and we do not have the human resources, funding, and time to undertake such a survey. Therefore, we calculate WTP in the surveyed countries using benefit transfer – 'a method to apply a basic original unit taken from other cases of economic assessment to a business to be evaluated' (Ministry of Land, Infrastructure, Transport and Tourism, 2004: 12). This method allows the conduct of a simplified economic assessment but is difficult to apply if conditions are not approximate between cases.

Figure 3.11: An Example of Setting Flow of Evaluation Methods



CVM = contingent valuation method.

Source: Ministry of Land, Infrastructure, Transport and Tourism (2004).

Economic evaluations of air pollution in ASEAN countries include Thanh and Lefevre (2000) and Quah and Boon (2003), which used the benefit transfer method:

> Benefit transfer suggests the possibility that some results of valuation study in other countries can be adopted for the valuation in country under consideration, given proper adjustments. In practice, almost all health impacts valuation studies inherently bear an element of benefit transfer. This is because contingent valuation studies to determine WTP values and epidemiological studies to obtain E–R functions are usually carried out separately, with different population groups, but their results are used jointly in health impact valuation studies (i.e. transfer of value of WTP from one population group to another). This element of transfer can easily be accepted when the population sample of the contingent valuation study and that of the epidemiological study are considered to be close to identical (e.g. within one country). Problems arise when the population at risk and the sample population for whom WTP is known do not have similar characteristics and their preferences are not identical. This is the case when transferring values of WTP between two different countries, such

> as the United States and Thailand. However, various approximations can be made for such a transfer (Thanh and Lefevre, 2000: 146–7).
>
> The Benefit Transfer Approach (BTA) involves the use of the estimates of environmental loss of a project to estimate the economic value of environmental impact of a similar project on the assumption that the latter project will have similar impact (Pearce, Whittington, Georgiou & James, 1994) … Similarly, for the transfer of unit economic values of the mortality and morbidity, it is also assumed that the stated preferences of people in the developed countries are similar to that of the people in Singapore. The assumption is not really farfetched since Singapore is now recognized by the World Bank and IMF as more or less a developed country… On the other hand, transfer of values may also neglect factors that would cause people to value health differently. For example, the concept of what constitutes full health may vary with culture, not only with income. In general, there are numerous environmental factors specific to location and culture; and these factors limit the reliability of the BTA in assessing environmental problems. In spite of these limitations, the cost advantages, in terms of time and resources, of benefits transfer will continue to encourage its use (Quah and Boon, 2003: 79).

Because this study examines environmental impacts that appear in the form of air pollution caused by coal-fired power generation, WTP can be interpreted as an amount of money that people are willing to pay to avoid mortality and morbidity risks posed by air pollution derived from coal-fired power generation. The value obtained by dividing the amount of WTP by mortality (or morbidity) is VSL. The value of mortality (or morbidity) is small. After the 1980s in Western countries, mainly the United States and the United Kingdom, a method using VSL has become mainstream for cost–benefit analysis to determine the pros and cons of political measures.

VSL can be defined as follows:

$$VSL = \frac{WTP_{\Delta R}}{\Delta R} \tag{11}$$

Where,

VSL: Value of statistical life

$WTP_{\Delta R}$: WTP for reduced amount of risk (ΔR)

ΔR: Reduced amount of risk

The purpose of VSL is not to calculate the price of human life; it is an expedient method based on WTP to reduce mortality or morbidity and estimate the benefit gained from saving one person. VSL varies depending on organisations that make such calculations. In this study, we use the base VSL calculated by the OECD and obtain the VSLs of the surveyed countries through benefit transfer calculated by using the OECD equation.

OECD (2017) cites the following survey results of OECD (2012) as VSL that serves as a reference value:

> The survey finds an average WTP of US$30 for a reduction in the annual risk of dying from air pollution from 3 in 100 000 to 2 in 100 000. This means that each individual is willing to pay US$30 to have this 1 in 100 000 reduction in risk. In this example, for every 100 000 people, one death would be prevented with this risk reduction. Summing the individual WTP values of US$30 over 100 000 people gives the VSL value – US$3 million in this case. It is important to emphasise that the VSL is not the value of an identified person's life, but rather an aggregation of individual values for small changes in risk of death (OECD, 2012; 2017: 15).

OECD (2012) shows the multiyear research effort, including its meta-analysis of VSLs starting with 1,095 values from 92 published studies. In units of 2005 US dollars, the recommended range for OECD countries is US$$_{2015}$1.5 million–US$4.5 million, the recommended base value in 2005 is US$$_{2005}$3 million. Using this base value, it is possible to calculate country-specific VSL values for countries within and outside the OECD and for years beyond 2005 (OECD, 2017).

The result for any given country, C, for any given year, here 2013, is thus as follows:

$$VSL\ C_{2013} = VSL\ OECD_{2005} \times (Y\ C_{2005}/Y\ OECD_{2005})^{\beta} \times (1 + \%\Delta P + \%\Delta Y)^{\beta} \tag{12}$$

Where,

$VSL\ OECD$: OECD's base value for the OECD group of countries as a whole, US$3 million (2005 US$)

$Y\ C$: Gross domestic product (GDP) per capita at the purchasing power parity (PPP)

$Y\ OECD$: The average GDP per capita of OECD countries at PPP

β: Income elasticity of VSL. It measures the percentage increase in VSL for a percentage increase in income.

$\%\Delta P$: The percentage increase in consumer price from 2005 to 2013 This is measured by the consumer price index (CPI).

$\%\Delta Y$: The percentage change in real GDP per capita growth from 2005 to 2013. This is derived from real GDP per capita annual growth.

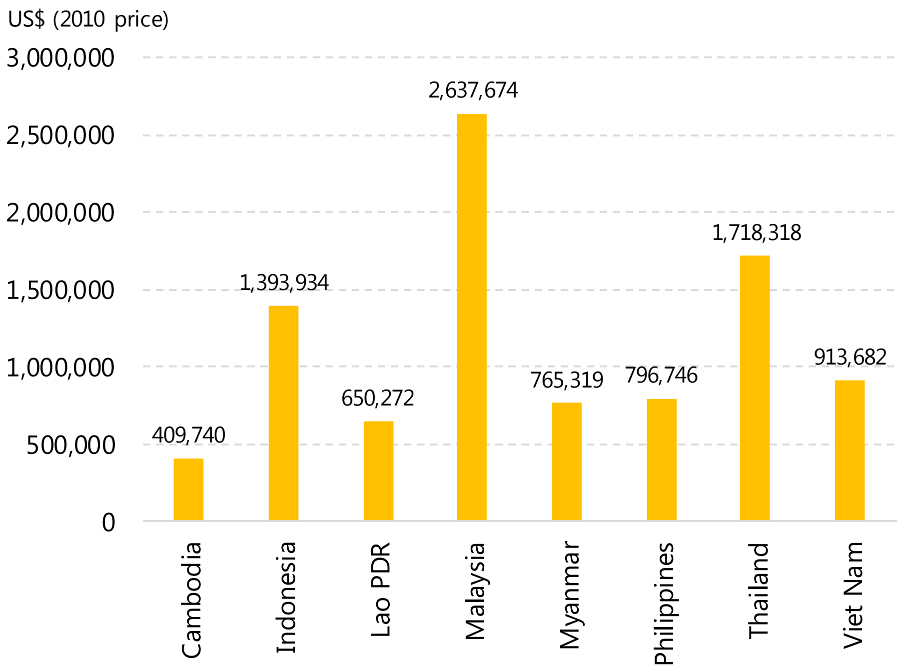
OECD (2017) refers to the use of 1 as an income elasticity of non-OECD countries. Therefore, in this study, 1 is assigned to β of equation (12). OECD (2017: 17) states:

> [T]he assumption of an income-elasticity with a value of < 1 means this: as incomes rise, the willingness-to-pay for a marginal reduction in the risk of death from a given risk also rises but not quite in proportion to the rise in incomes. And this assumption is empirically well grounded in the case of the advanced economies – as is the estimate of 0.8. Here, a step-change in life circumstances away from deep poverty alters the 'willingness-to-pay' more sharply than does a gradual but modest rise in incomes in the already high-income countries. There is therefore a case for adopting the more common assumption in the development literature of an income elasticity of 1 for the non-OECD countries under study.

Estimated values of the eight ASEAN countries were calculated based on equation (12). Data for GDP per capita at PPP, CPI, and GDP per capita growth are based on *World Development*

Indicators (World Bank, 2019). VSLs of ASEAN countries are estimated using equation (12), based on the VSL of the OECD standard ($3 million as of 2005).[6] Corrections of prices are made using the GDP deflators of IEEJ (2019). Estimated VSLs of the surveyed countries in this study are as follows:

Figure 3.12: Estimated Values of Statistical Life of Eight ASEAN Countries



Lao PDR = Lao People's Democratic Republic.

Source: Author.

The cost of mortality due to coal-fired power generation–derived air pollution in each country can be obtained by multiplying the estimated VSL of the country, which is obtained through equation (12), by the calculated number of mortal cases (Table 3.18, Table 3.19). Examinations are made for (i) a case where the most stringent standard amongst the emission standards of developed countries for air pollutants is adopted for SOx, NOx, and PM; and (ii) a case where half the values of the existing air emission standard of the surveyed country for air pollutants are adopted. The costs of mortality are as follows:

[6] There are variations in VSLs. For example, the US Environmental Protection Agency recommends that the central estimate of US$7.4 million (in 2006) be used in all benefits analyses that seek to quantify mortality risk reduction benefits regardless of age, income, or other population characteristics of the affected population until revised guidance becomes available (US EPA, 2019). The estimated VSL in Japanese researches (Matsuoka et al., 2002) shows $3.14 million~US$4.32 million (2002) as the estimated VSL for mortality risk due to air pollution, and used the contingent valuation method (Chen, Ohno, Morisugi, and Sao, 2010).

Table 3.18: Costs of Mortality for Eight ASEAN Countries

Country	Case (i), US$ (2010)	Case (ii), US$ (2010)
Cambodia	54,038	29,507
Indonesia	676,236	375,478
Lao PDR	17,410	9,701
Malaysia	538,558	316,736
Myanmar	54,631	34,962
Philippines	652,262	355,113
Thailand	35,554	21,678
Viet Nam	81,710	46,451

Lao PDR = Lao People's Democratic Republic.

Source: Author.

The cost of morbidity is then examined. A standard and commonly agreed method by which to measure the cost of morbidity is not yet available. Therefore, in this study, we set the cost of morbidity at 10% of the cost of mortality, obtained by multiplying the estimated VSL of the surveyed country by the number of mortal cases based on the conclusion of OECD (2015: viii): 'Recent practice and available evidence provide a rationale for using an additional 10% of the overall cost of mortality as a best estimate for the additional cost of morbidity'. The costs of morbidity of the surveyed countries are as follows:

Table 3.19: Costs of Morbidity for Eight ASEAN Countries

Country	Case (i), US$ (2010)	Case (ii), US$ (2010)
Cambodia	5,404	2,951
Indonesia	67,624	37,548
Lao PDR	1,741	970
Malaysia	53,856	31,674
Myanmar	5,463	3,496
Philippines	65,226	35,511
Thailand	3,555	2,168
Viet Nam	8,171	4,645

Lao PDR = Lao People's Democratic Republic.

Source: Author.

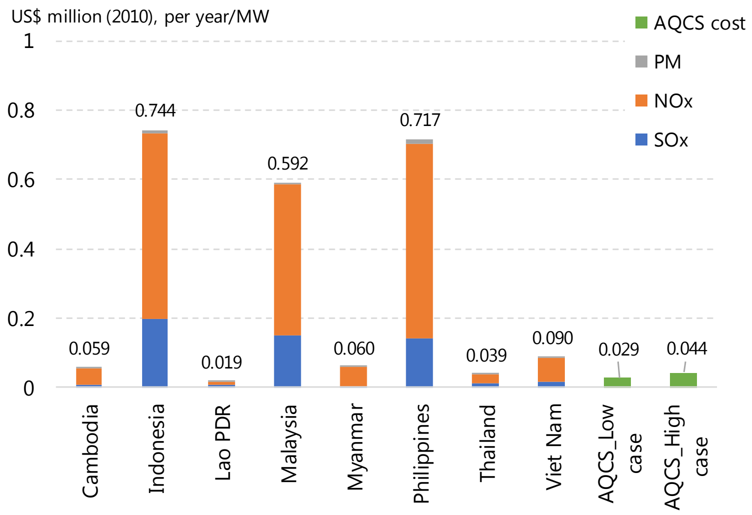
OECD (2016), a report about the cost of morbidity (and not adopted in this study), recommends a common core set of pollutant–health (morbidity) combinations to be applied in China and India, but highlights the difficulties of doing so. The following are five pollutant–health pairs for consideration in the report (OECD, 2016: 39–40):

- Respiratory hospital admissions and cardiovascular hospital admissions in relation to PM and to ozone. Whilst strongly based on evidence, experience from HIAs [health impact assessments] in Europe and the US is that these, when quantified and monetised, make little difference to the bottom line of aggregated monetised benefits.
- Restricted activity days and associated work-loss days in relation to PM and/or ozone. These are widely used in HIAs internationally and, when applied, suggest a noticeable effect on aggregate monetised benefits – small relative to mortality but one of the higher morbidity effects. However, they rest on a narrow evidence base – a series of studies in California in the 1980s. The health outcomes are strongly socio-culturally determined and there may be difficulty in obtaining credible background rates. These various difficulties point to major uncertainties about transferability.
- Chronic bronchitis in adults in relation to PM only. This has been a long-standing pollutant–health combination quantified in HIAs in the US, Europe, and elsewhere. There are studies, in the US and Europe, from which concentration–response functions can be derived and, when applied to HIAs, give monetised results, which typically are amongst the most influential of morbidity impacts. In Europe and the US, however, a recent expert review has questioned the overall evidence base relating air pollution to prevalence and incidence of chronic bronchitis in adults, concluding that the case for causality is not as strongly established as had previously been thought. Consequently, in Europe this pathway is not included amongst those that can be quantified with greater confidence, and it is not part of the primary analysis in the most recent regulatory impact assessments of the US EPA.
- Acute bronchitis in children 6–12 or 6–18 years old, defined as ‘bronchitis in the past 12 months’ (Hoek et al., 2012), is based on responses to symptoms questionnaires.
- Acute lower respiratory illnesses in children aged <5 years relate to children only, and may be expected not to have a major influence on final monetised results, compared with the monetised impacts on mortality.

2.5. Results

Based on all assumptions and calculations, we compared the health benefit in monetary terms thanks to less air pollution caused by coal-fired power generation under strengthened air emission standards and the cost of AQCS installation. The results follow.

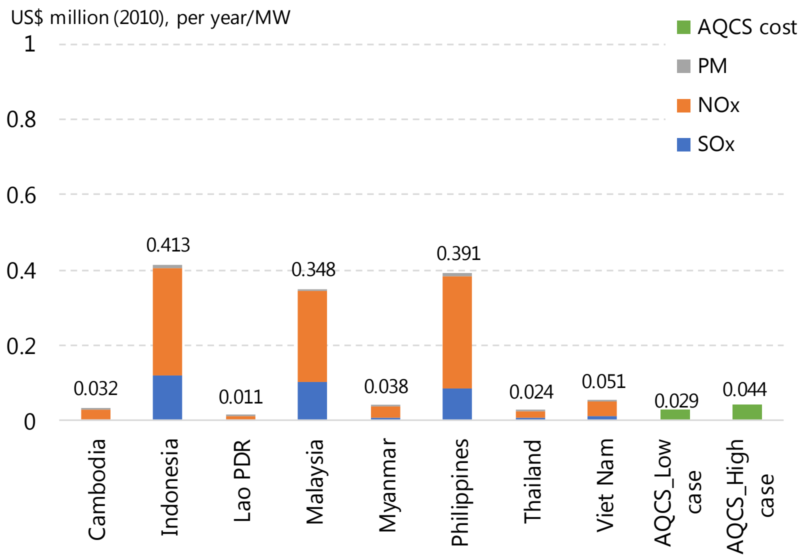
Figure 3.13: Results for Case (i)



AQCS = air quality control system, Lao PDR = Lao People's Democratic Republic, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: Author.

Figure 3.14: Results for Case (ii)



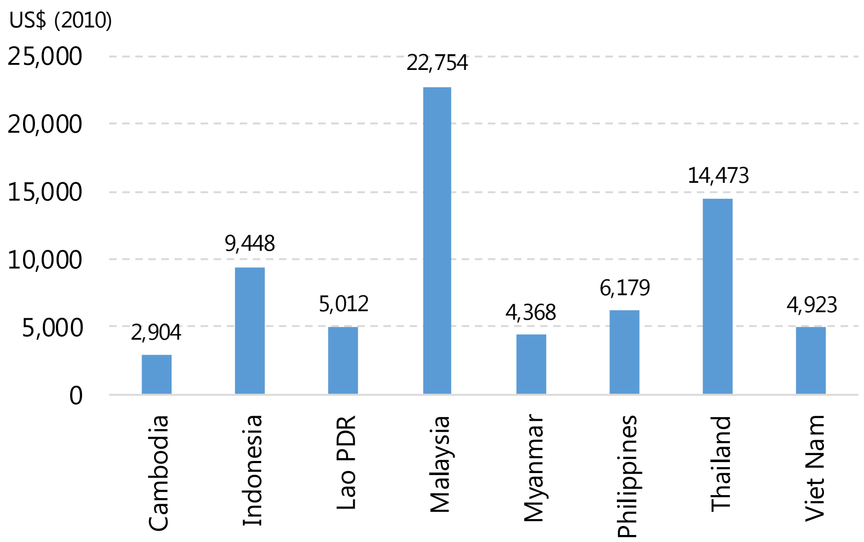
AQCS = air quality control system, Lao PDR = Lao People's Democratic Republic, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: Author.

Amongst the reference values of emission standards for air pollutants in ASEAN, those for NOx are set at a notably easier level than those in developed countries (Table 2.). This fact explains the reason for a significant difference in the level of health impacts between NOx and SOx/PM, and this study's results confirm it. Lax standards for NOx result in inadequate installation of denitrification facilities in the surveyed countries (Table 2.1).

The following two points can be considered as reasons for the substantial difference in the health benefits amongst countries. First, as indicated in equation (12), the estimated VSL of each country is calculated based on GDP per capita at PPP and real GDP per capita growth. However, the surveyed countries have substantial differences in GDP per capita (Figure 3.14), which have a substantial impact on the calculated values of health benefits. To obtain the expected number of deaths due to outdoor air pollution (Table 3.16 and Table 3.17), we use the population in the zone covered by the red circle (Figure 3.3 through Figure 3.10). The figures show that conditions in locations of the modelled power plants are different amongst countries: they are deep in the mountains or relatively close to a populated area. As a result, differences are created in the population amongst the 20 km radius zones, and such differences affect the calculation results of the expected number of deaths, i.e. the health benefit.

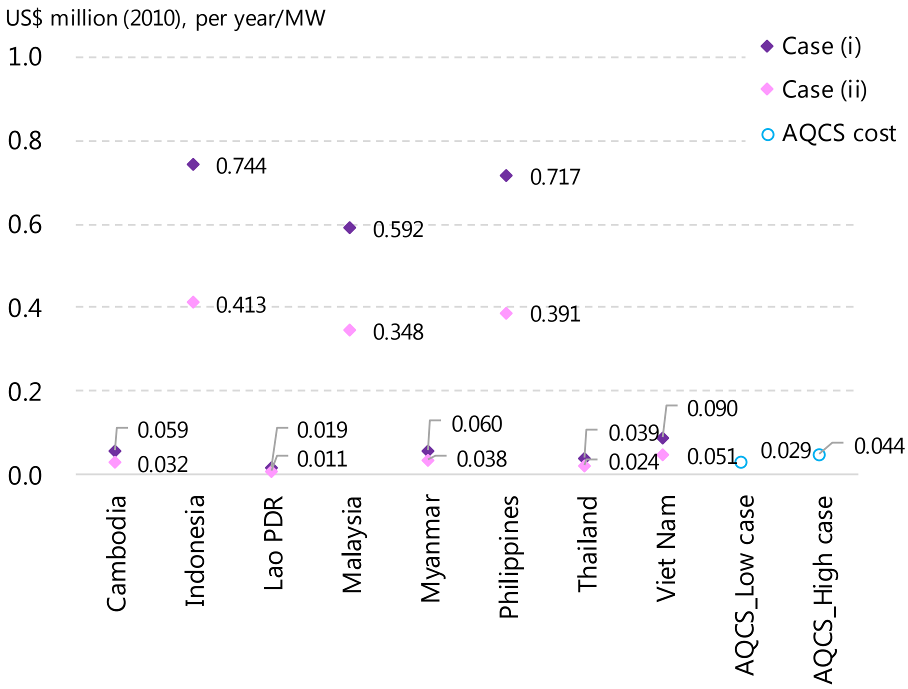
Figure 3.15: GDP per Capita for Eight ASEAN Countries in 2013



Lao PDR = Lao People's Democratic Republic.

Source: World Bank (2019).

Figure 3.16: Results for Cases (i) and (ii)



AQCS = air quality control system, Lao PDR = Lao People's Democratic Republic.

Source: Author.

The calculation results of case (i) and case (ii) can be summarised as follows:

Case (i)

- In the surveyed countries, except Lao PDR and Thailand, the benefit from tightening air pollutant emission standards exceeds the cost thereof. In Thailand, the benefit and the cost are at almost equivalent levels, whilst the cost exceeds the benefit only in the high case of AQCS installation cost.
- The FY 2017 study (ERIA, 2018) shows that the impact of the installation cost of AQCS on electricity prices is less than 10% in Cambodia, Indonesia, Malaysia, Philippines, Thailand, and Viet Nam. In the six countries, except Thailand, the benefit from strengthening emission standards exceeds the cost thereof. It is safe to say that tightening regulations is adequately beneficial.

Case (ii)

- The benefit from tightening air pollutant emission standards exceeds the cost thereof in Indonesia, Malaysia, the Philippines, and Viet Nam. The reference values in case (ii) are substantially laxer than those in case (i) (Table 3.4 and Table 3.5). If reducing air pollutant emissions by strengthening standards is limited to the level of case (ii), the benefit is small. However, it is still adequately beneficial to tighten emission standards in Indonesia, Malaysia, the Philippines, and Viet Nam.

- In Cambodia, Lao PDR, Myanmar, and Thailand, the benefit either exceeds or falls below the cost, depending on AQCS installation cost: it is not worth investing in AQCS installation if standards are lax. If AQCS is installed, emission standards should be tightened to a level equivalent to regulatory standards of developed countries. Many ASEAN economies are expected to continue growing. Therefore, even in Cambodia and Lao PDR, where the cost exceeds the benefit in case (ii), the benefit may increase with future economic growth. The installation cost of AQCS may be sufficiently paid off by its health benefit.

3. Life-cycle Impact Assessment Method Based on Endpoint (LIME) 3: Method and Result

3.1. Overview of the Method

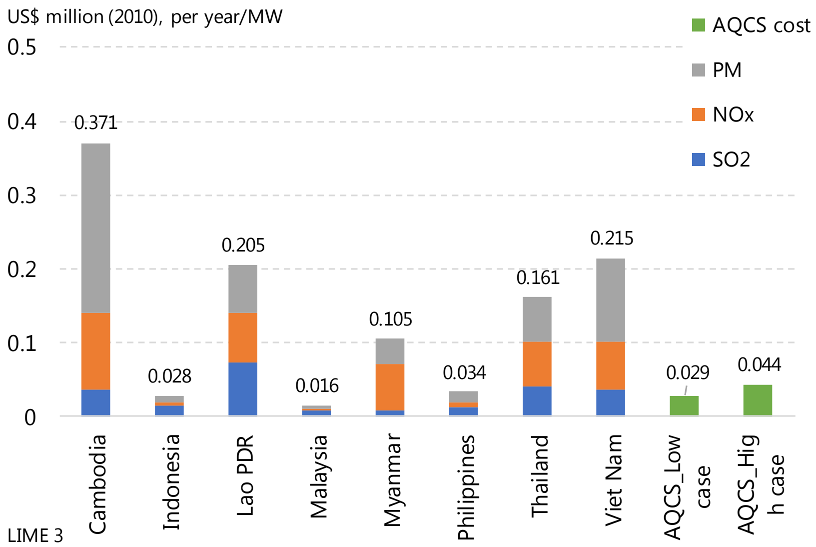
LIME 3 is the latest method modelling for a global scale, developed by Japanese experts and published in September 2018. LIME is a type of life-cycle impact assessment and complies with ISO14044 (2006). It has been used for environmental evaluation of companies' products or the companies themselves, environmental performance, and cost–benefit analysis, amongst others. LIME 1 and LIME 2 reflected domestic environmental conditions and ideas in Japan. LIME 3 provides damage factors and weighting factors in 193 countries for 11 global environmental issues in four areas of protection (human health, social assets, biodiversity, primary production). Damage factors are used to calculate damage in each area of protection. Fate analysis, impact analysis, and damage analysis were conducted before calculation of damage factors in LIME 3. Weighting factors are used to calculate economic value and are based on a conjoint analysis to give a weighting between the four areas of protection. A conjoint analysis is suitable for measuring the value of each of the multiple attributes of the environment and is based on a questionnaire administered in all G20 countries.

Whilst the WHO methodology is suitable for estimating the level of local health impact due to air pollution, the calculation using LIME 3 provides the health impact of avoiding air pollution at the world level or the macroscopic impact. To supplement the calculation using the WHO method, we show the results of the LIME 3 method (Appendix 1).

3.2. Results

The results of the calculation using LIME 3 are in Figure 3.17.

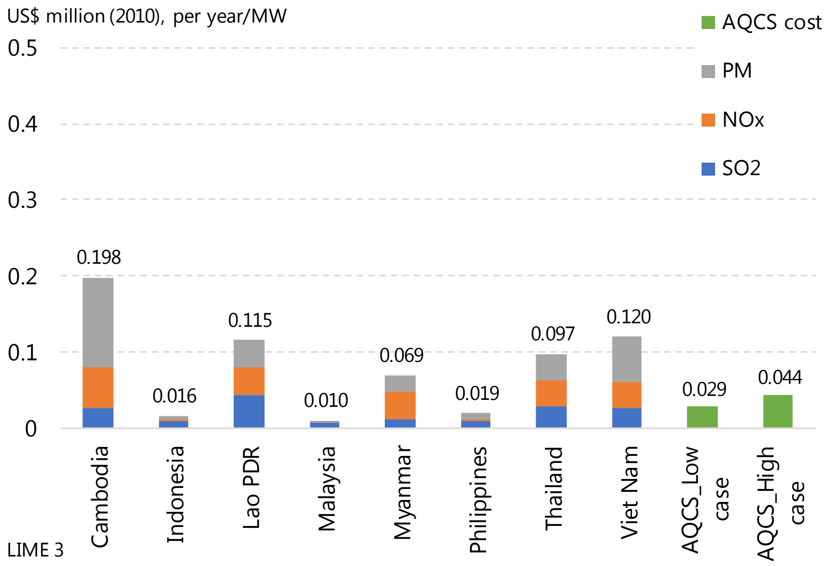
Figure 3.17: Results of LIME 3 for Case (i)



AQCS = air quality control system, Lao PDR = Lao People's Democratic Republic, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Note: Case (i) = most strengthened emission standard. Case (ii) = half of existing emission standard. Source: Author.

Figure 3.18: Results of LIME 3 for Case (ii)



AQCS = air quality control system, Lao PDR = Lao People's Democratic Republic, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Note: Case (i) = most strengthened emission standard. Case (ii) = half of existing emission standard.

Source: Author.

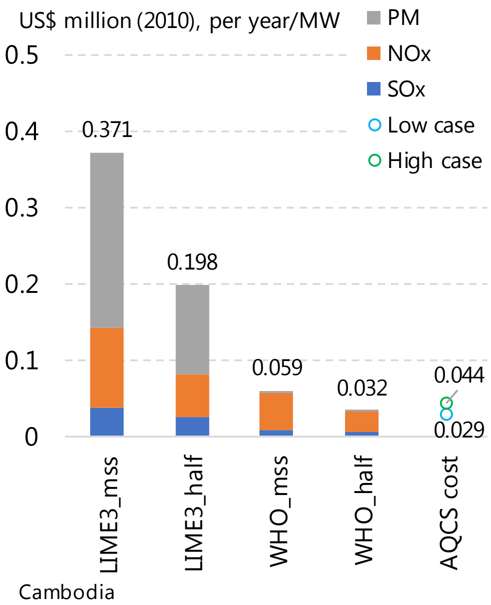
Although it varies depending on AQCS installation cost, the benefit from tightening emission standards may sometimes fall below the cost thereof in Indonesia, Malaysia, and the Philippines, which all have damage factors that are smaller than those of the other countries. The reason is that cross-border transfer and absorption into seawater of air pollutants are considered, because the concentration forecast of air pollutants is calculated in LIME 3 by using a model that can simulate the atmospheric chemistry process and aerosol process in the troposphere and stratosphere. The damage factor, therefore, is smaller in countries with many islands. Thus, the calculation result is smaller.

Whilst Cambodia, Lao PDR, Myanmar, Thailand, and Viet Nam have different levels of air pollutant emissions, strengthening emission standards has an adequate benefit in case (i) and case (ii).

4. Results of Methodologies

Results based on the WHO and LIME 3 methodologies are shown by country in the following figures. Estimation results vary substantially depending on the methodologies used, and are obtained based on various assumptions. Estimation results also vary depending on changes in the calculation method for a concentration forecast of air pollutants adopted as an assumption, factors or coefficients for conversion of health impact into monetary units, and reference VSLs, amongst others.

Figure 3.19: Results for Cambodia

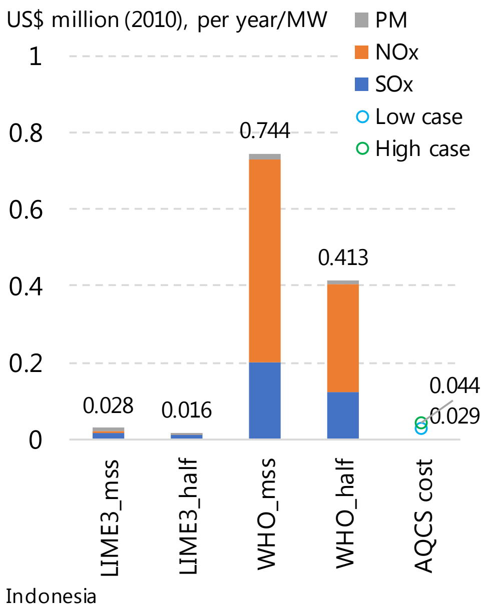


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.03724	0.10346	0.23008
LIME 3_half of ext. standard	0.02537	0.05445	0.11799
WHO_most strengthen standard	0.00786	0.04824	0.00334
WHO_half of ext. standard	0.00535	0.02539	0.00171
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.20: Results for Indonesia

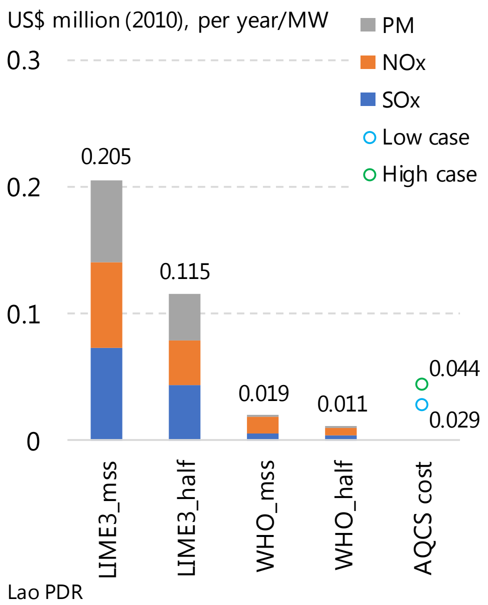


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.01475	0.00469	0.00874
LIME 3_half of ext. standard	0.00897	0.00251	0.00486
WHO_most strengthen standard	0.19843	0.53386	0.01158
WHO_half of ext. standard	0.12060	0.28599	0.00643
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.21: Results for Lao People's Democratic Republic

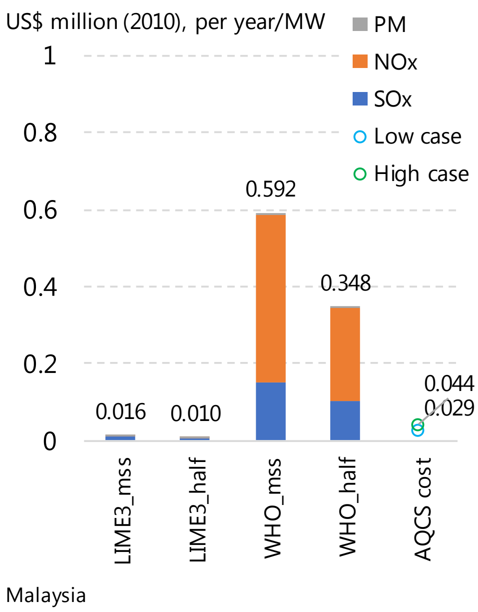


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.07307	0.06752	0.06489
LIME 3_half of ext. standard	0.04328	0.03648	0.03540
WHO_most strengthen standard	0.00617	0.01260	0.00038
WHO_half of ext. standard	0.00366	0.00681	0.00021
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.22: Results for Malaysia

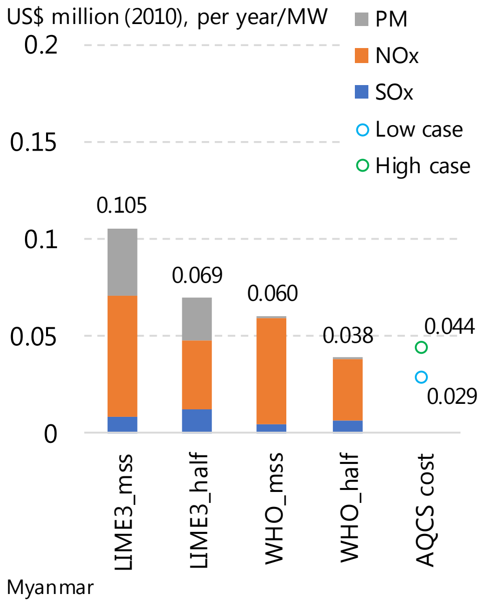


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.00878	0.00301	0.00389
LIME 3_half of ext. standard	0.00598	0.00167	0.00243
WHO_most strengthen standard	0.14993	0.43595	0.00654
WHO_half of ext. standard	0.10213	0.24219	0.00409
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.23: Results for Myanmar

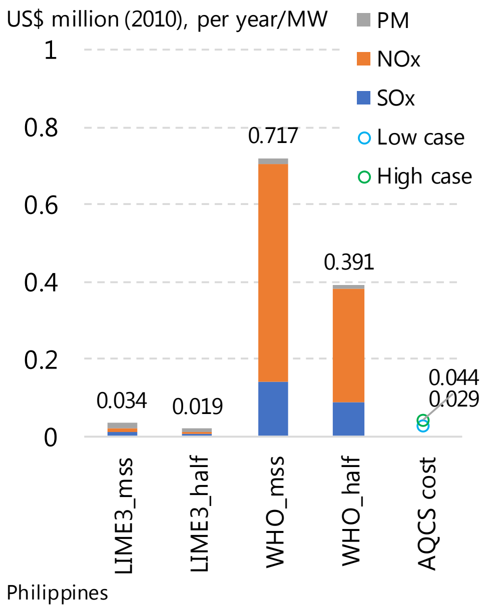


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.00803	0.06307	0.03412
LIME 3_half of ext. standard	0.01199	0.03604	0.02133
WHO_most strengthen standard	0.00441	0.05463	0.00105
WHO_half of ext. standard	0.00658	0.03122	0.00066
AQCS installation cost	0.02860	~	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.24: Results for the Philippines

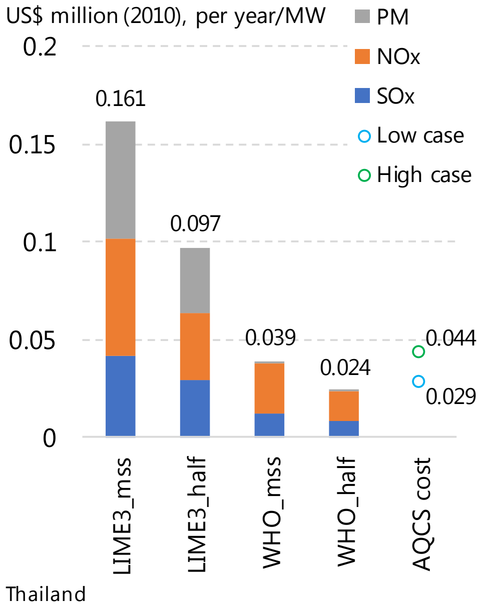


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.01356	0.00636	0.01360
LIME 3_half of ext. standard	0.00837	0.00335	0.00729
WHO_most strengthen standard	0.14146	0.56206	0.01397
WHO_half of ext. standard	0.08732	0.29582	0.00748
AQCS installation cost	0.02860	~	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.25: Results for Thailand

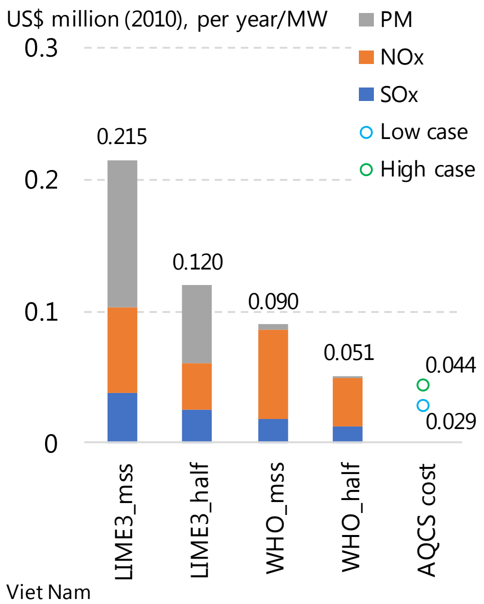


(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.04161	0.06001	0.05971
LIME 3_half of ext. standard	0.02878	0.03451	0.03412
WHO_most strengthen standard	0.01165	0.02652	0.00094
WHO_half of ext. standard	0.00806	0.01525	0.00054
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.

Figure 3.26: Results of Viet Nam



(US$ million, 2010)	SOx	NOx	PM
LIME 3_most strengthen standard	0.03724	0.06534	0.11209
LIME 3_half of ext. standard	0.02537	0.03539	0.05899
WHO_most strengthen standard	0.01768	0.06854	0.00366
WHO_half of ext. standard	0.01204	0.03713	0.00193
AQCS installation cost	0.02860	～	0.04385

AQCS = air quality control system, LIME = Life-cycle Impact Assessment Method Based on Endpoint, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxide, WHO = World Health Organization.

Source: Author.