Chapter 2

Coal Power Plants in ASEAN

October 2019

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Chapter 2

Coal Power Plants in ASEAN

1. Coal Use in the Power Sector

1.1. Power Generation Output

According to *Energy Outlook and Energy Saving Potential in East Asia 2019* (ERIA, 2019), electricity generated in ASEAN countries[1] will continue to increase until 2040 under the business as usual (BAU) scenario and advanced policy scenario (APS). Coal-fired power generation is forecast to increase under both scenarios.

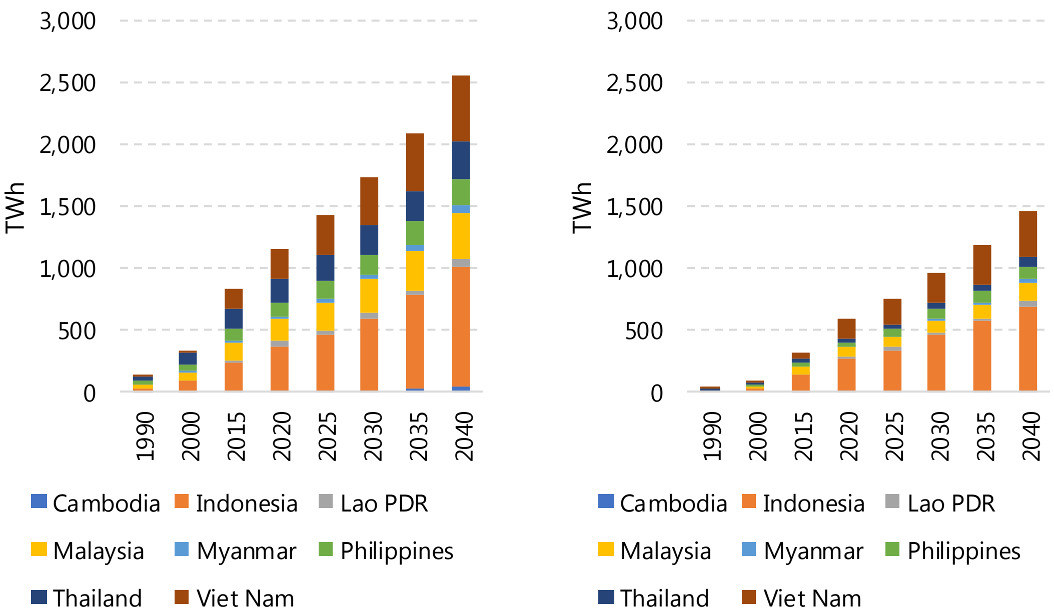
In the BAU scenario, electric energy generated in ASEAN will increase from 829.76 TWh in 2015 to 2,565.96 TWh in 2040 (Figure 2.1), of which coal-fired power generation increases from 318.97 TWh in 2015 to 1,465.13 TWh in 2040, or from 38.4% of all electricity generated in 2015 to 57.1% in 2040.

In the APS, which assumes stronger political measures for energy saving, power generation will increase from 829.76 TWh in 2015 to 2,128.95 TWh in 2040 (Figure 2.2), of which coal-fired power generation increases from 318.97 TWh in 2015 to 900.91 TWh in 2040, or from 38.4% of all electricity generated in 2015 to 42.3% in 2040.

[1] Excluding Brunei Darussalam and Singapore, which do not generate coal-fired power.

Figure 2.1: Power Generation Output in ASEAN, Business as Usual

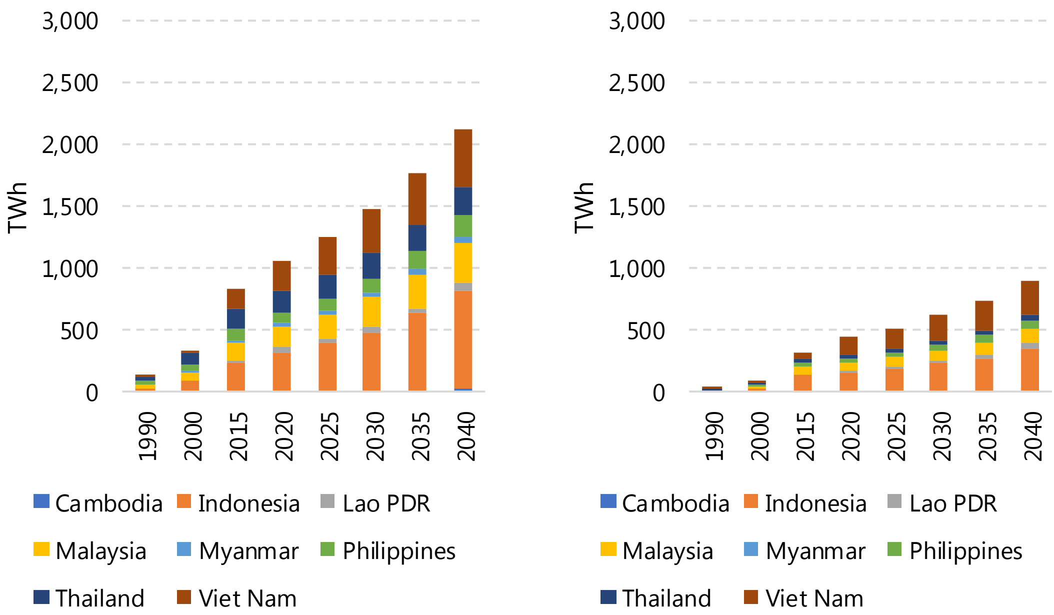
Left: Total generation. Right: Coal generation



Lao PDR = Lao People’s Democratic Republic.
Source: ERIA (2019).

Figure 2.2: Coal-fired Power Generation Output, ASEAN, Advanced Policy Scenario

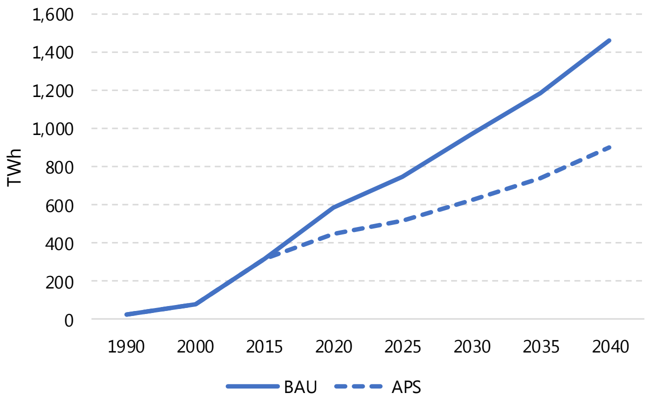
Left: Total generation. Right: Coal generation



Lao PDR = Lao People’s Democratic Republic.
Source: ERIA (2019).

In ASEAN countries where power demand increases significantly and affordability of electricity is important, utilisation of coal-fired power generation is expected to continue under both scenarios (Figure 2.3).

Figure 2.3: Coal-fired Power Generation Output, ASEAN, Business as Usual and Advanced Policy Scenario

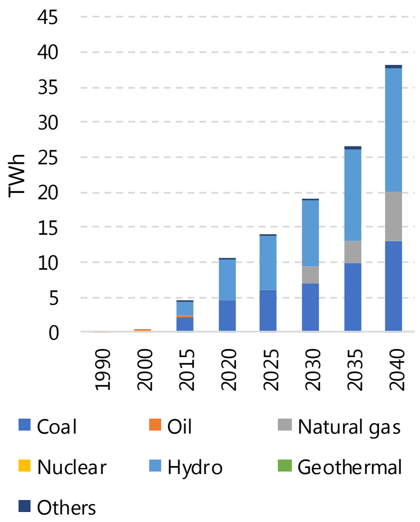


APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

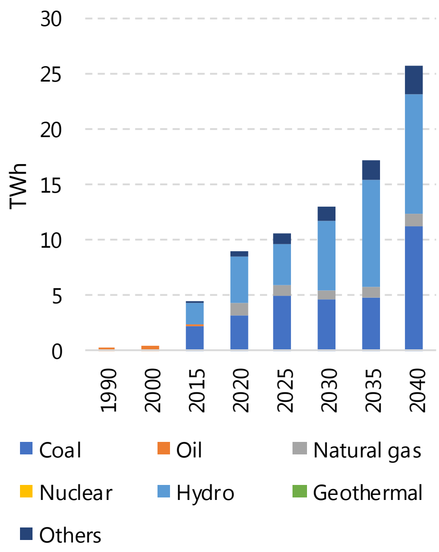
(a) Cambodia

In BAU, power generation will increase from 4.40 TWh in 2015 to 38.20 TWh in 2040, and in APS, from 4.40 TWh to 25.73 TWh (Figure 2.4).

Figure 2.4: Power Generation Output by Fuel, Cambodia



Business as Usual

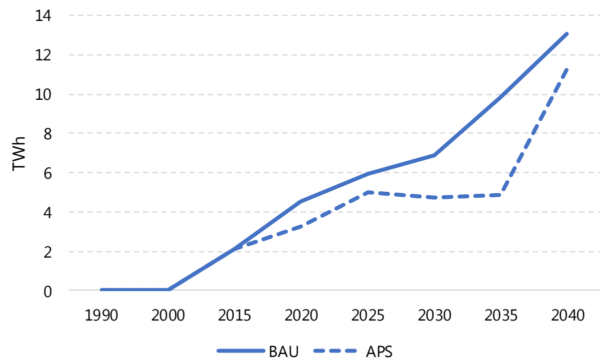


Advanced Policy Scenario

Source: ERIA (2019).

Coal-fired power generation will grow under BAU and APS (Figure 2.5). In BAU, coal-fired power generation will increase from 2.13 TWh in 2015 to 13.04 TWh in 2040. In APS, coal-fired power generation will decrease from 2025 through 2030, but then increase to 11.29 TWh in 2040 in both BAU and APS.

Figure 2.5: Coal-fired Power Generation Output, Cambodia, Business as Usual and Advanced Policy Scenario

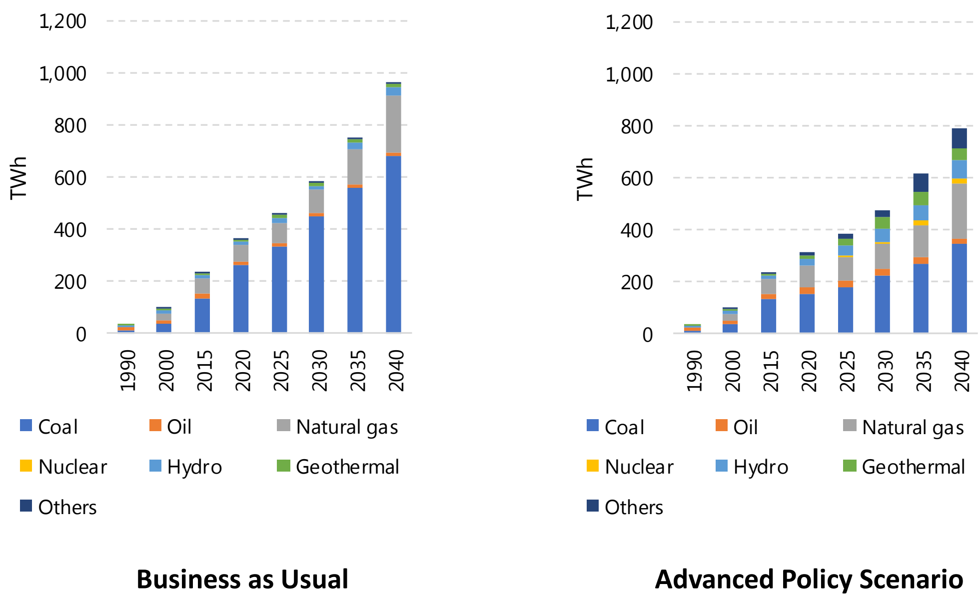


APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

(b) Indonesia

In BAU, power generation will increase from 233.33 TWh in 2015 to 968.73 TWh in 2040, and in the APS, from 233.33 TWh to 792.47 TWh (Figure 2.6).

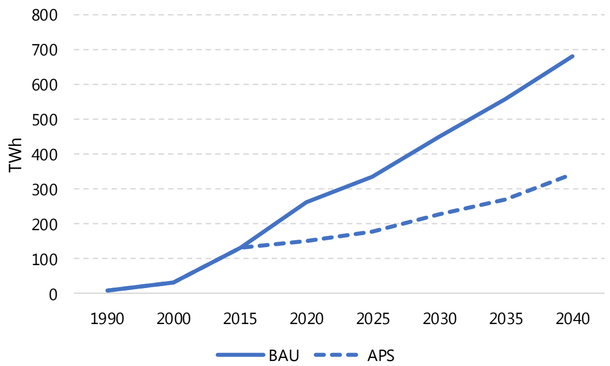
Figure 2.6: Power Generation Output, by Fuel, Indonesia



Source: ERIA (2019).

Coal-fired power output is forecast to grow in BAU from 130.51 TWh in 2015 to 681.30 TWh in 2040, and in the APS from 130.51 TWh to 344.12 TWh (Figure 2.). Output is expected to continue growing under both scenarios.

Figure 2.7: Coal-fired Power Generation Output, Indonesia, Business as Usual and Advanced Policy Scenario

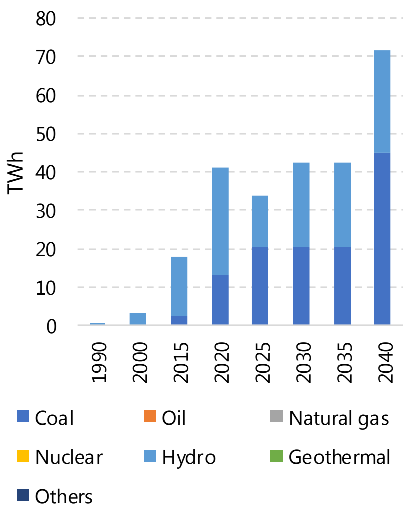


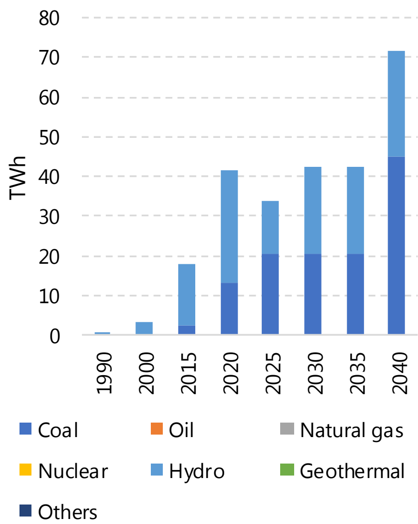
APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

(c) Lao People's Democratic Republic

In BAU and the APS, power generation will increase from 2.26 TWh in 2015 to 45.17 TWh in 2040 (Figure 2.8).

Figure 2.8: Power Generation Output, by Fuel, Lao People's Democratic Republic



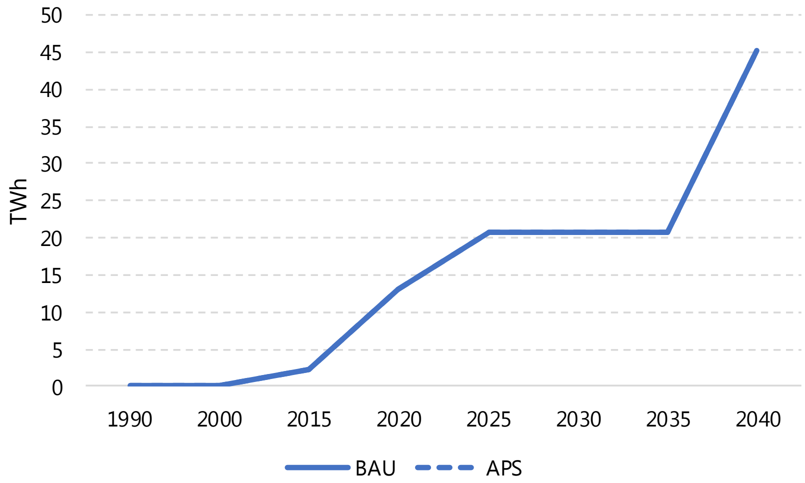


Business as Usual **Advanced Policy Scenario**

Source: ERIA (2019).

Coal-fired power output will increase from 2.26 TWh in 2015 to 45.17 TWh in 2040 in BAU and the APS (Figure 2.9)

Figure 2.9: Coal-fired Power Generation Output, Lao People's Democratic Republic, Business as Usual and Advanced Policy Scenario

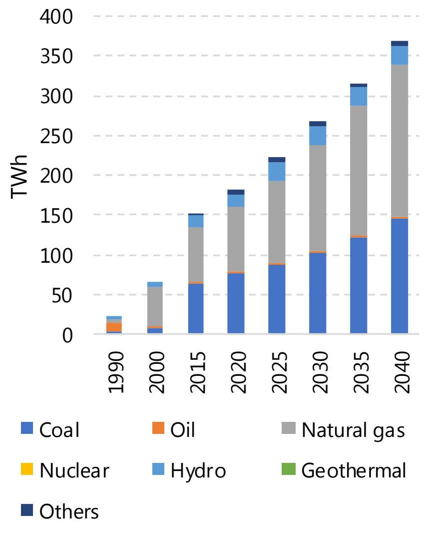


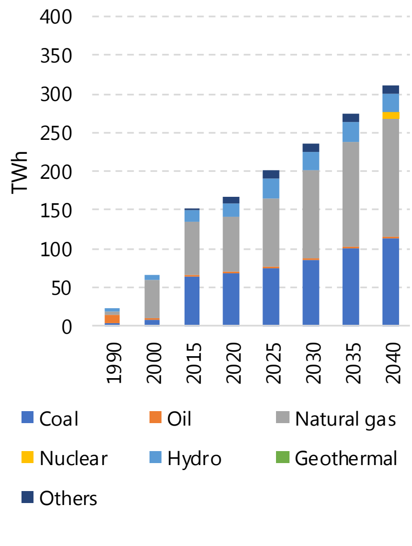
APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

(d) Malaysia

In BAU, power generation will increase from 150.37 TWh in 2015 to 368.13 TWh in 2040, and in the APS, from 150.37 TWh to 312.18 TWh (Figure 2.10).

Figure 2.10: Power Generation Output, by Fuel, Malaysia

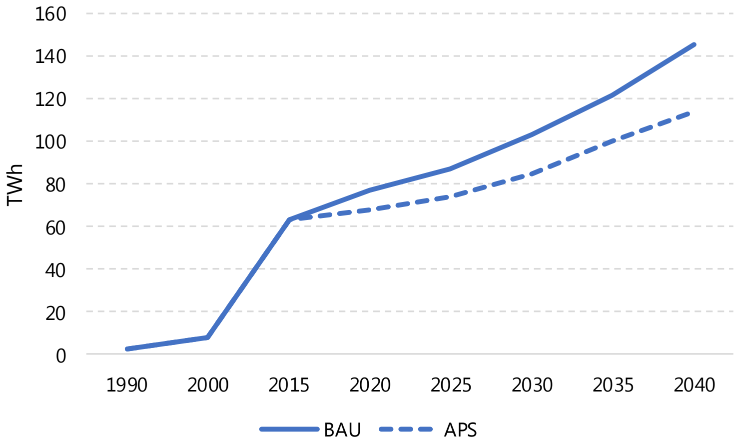




Source: ERIA (2019).

Coal-fired power output will increase in BAU from 63.47 TWh in 2015 to 145.83 TWh in 2040, and in the APS, from 63.47 TWh to 113.92 TWh (Figure 2.11). Starting in 2040, output is expected to increase in BAU and the APS.

Figure 2.11: Coal-fired Power Generation Output, Malaysia, Business as Usual and Advanced Policy Scenario

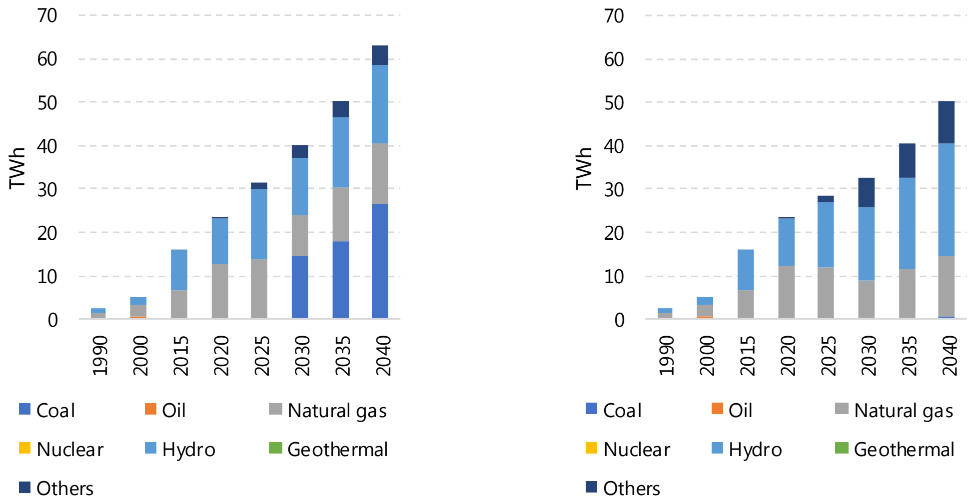


BAU = business as usual, APS = advanced policy scenario.
Source: ERIA (2019).

(e) Myanmar

In BAU, power generation will increase from 15.97 TWh in 2015 to 63.00 TWh in 2040, and in the APS, from 15.97 TWh to 50.40 TWh (Figure 2.12)

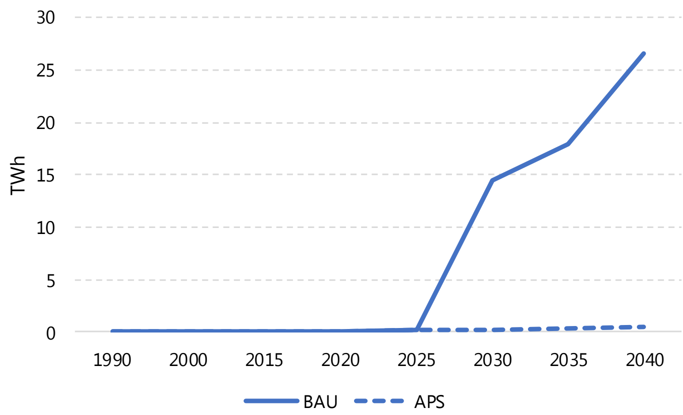
Figure 2.12: Power Generation Output, by Fuel, Myanmar



Source: ERIA (2019).

Coal-fired power output in BAU is forecast to increase from 0.00 TWh in 2015 to 26.61 TWh in 2040, and in the APS, from 0.00 TWh to 0.52 TWh (Figure 2.13). Starting in 2040, output is expected to increase in BAU and the APS.

Figure 2.13: Coal-fired Power Generation Output, Myanmar, Business as Usual and Advanced Policy Scenario

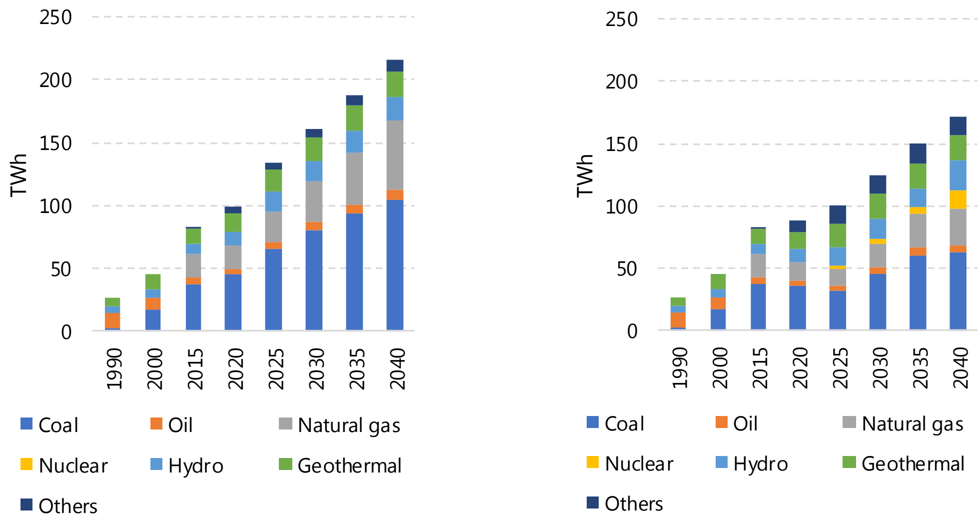


APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

(f) Philippines

In BAU, power generation will increase from 82.41 TWh in 2015 to 215.33 TWh in 2040, and in the APS, from 82.41 TWh to 172.26 TWh (Figure 2.14).

Figure 2.14: Power Generation Output, by Fuel, Philippines

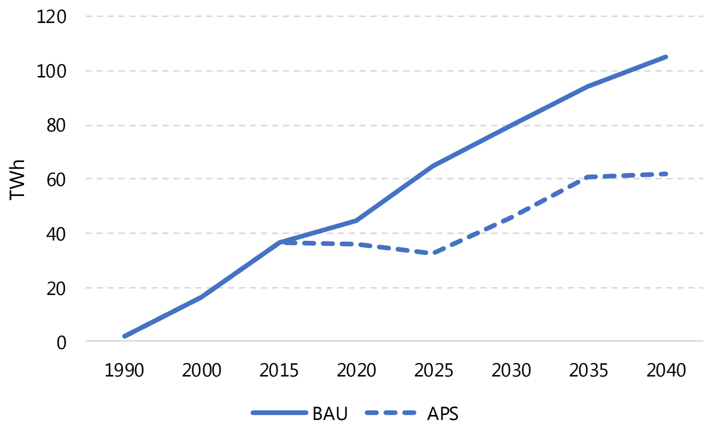


Business as Usual **Advanced Policy Scenario**

Source: ERIA (2019).

Coal-fired power output in BAU will increase from 36.69 TWh in 2015 to 104.96 TWh in 2040, and in the APS, decrease from 2020 through 2025 but increase to 62.16 TWh in 2040 (Figure 2.15). Starting in 2040, output is expected to increase in BAU and the APS.

Figure 2.15: Coal-fired Power Generation Output, Philippines, Business as Usual and Advanced Policy Scenario

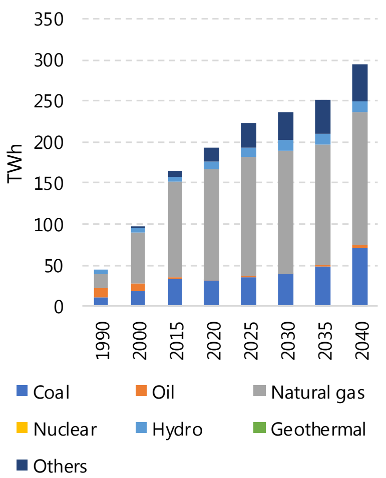


APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

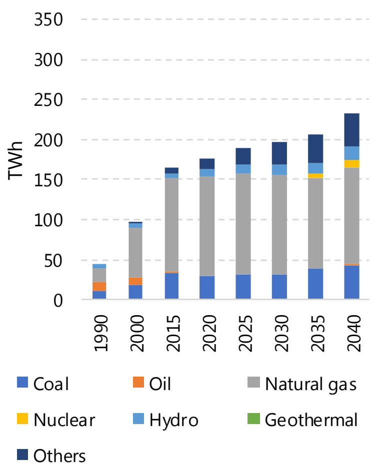
(g) Thailand

In BAU, power generation will increase from 165.71 TWh in 2015 to 294.57 TWh in 2040, and in the APS, from 165.71 TWh to 233.22 TWh (Figure 2.16).

Figure 2.16: Power Generation Output, by Fuel, Thailand



Business as Usual

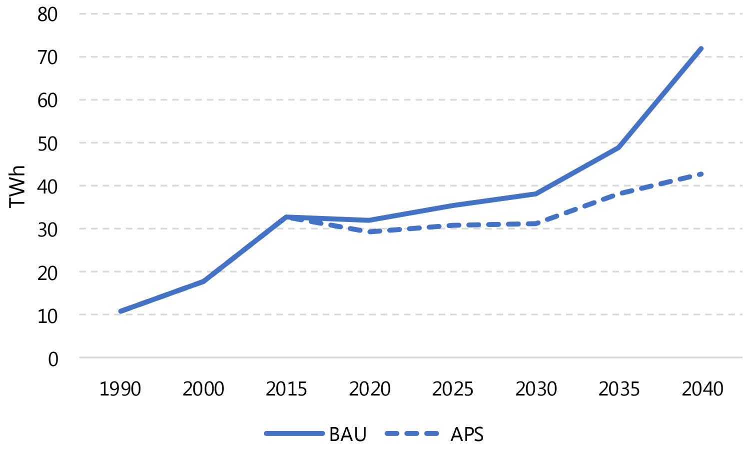


Advanced Policy Scenario

Source: ERIA (2019).

Coal-fired power output will grow in BAU from 32.92 TWh in 2015 to 71.82 TWh in 2040, and in the APS, decrease from 2015 through 2020 but increase to 42.96 TWh in 2040 (Figure 2.17). Starting in 2040, output is expected to increase in BAU and the APS.

Figure 2.17: Coal-fired Power Generation Output, Thailand, Business as Usual and Advanced Policy Scenario

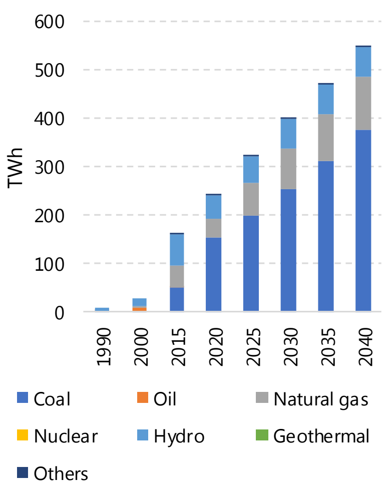


APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

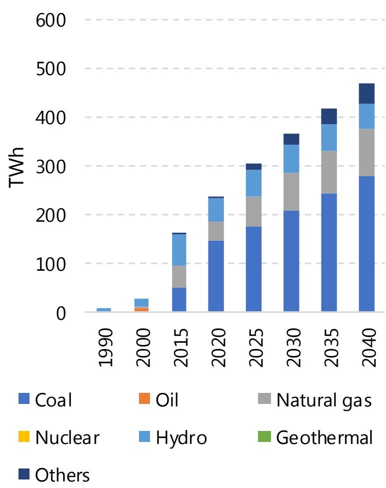
(h) Viet Nam

Power generation will increase in BAU from 159.81 TWh in 2015 to 546.15 TWh in 2040, and in the APS, from 159.81 TWh to 470.84 TWh (Figure 2.18).

Figure 2.18: Power Generation Output, by Fuel, Viet Nam



Business as Usual

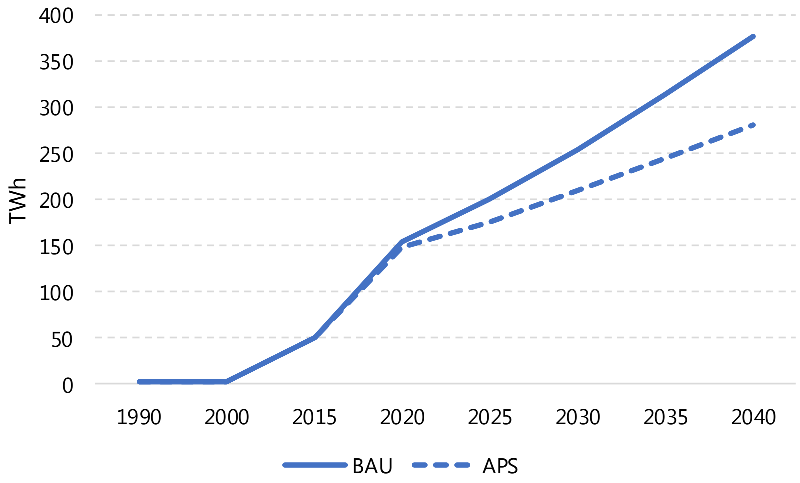


Advanced Policy Scenario

Source: ERIA (2019).

Coal-fired power output will grow in BAU from 51.00 TWh in 2015 to 376.39 TWh in 2040, and in the APS, from 51.00 TWh to 280.77 TWh (Figure 2.19). Starting in 2040, output is expected to increase in BAU and the APS.

Figure 2.19. Coal-fired Power Generation Output, Viet Nam, Business as Usual and Advanced Policy Scenario



APS = advanced policy scenario, BAU = business as usual.
Source: ERIA (2019).

1.2. AQCS Installation Status at Coal-fired Power Plants

AQCS installation status is summarised in Table 2.1 (ERIA, 2018):

- A power plant that has been operating for 30 years or longer is classified as ageing. Power plants are sorted into two groups: those that started in or before 1989 and those in or after 1990.
- Whether AQCS is installed (with) or not installed (without) is indicated for each power plant by figures representing the aggregated processing capacity of three reduction system types: PM, SO_2, and NOx.

The capacity of coal-fired power plants (MW) in ASEAN countries that started operation in or before 1989 is 4,198 MW, and in or after 1990, 59,616 MW.

Amongst coal-fired power plants that started operation in or before 1989, the capacity of those that have AQCS is 3,743 MW (89.2%) for PM, 3,633 MW (86.5%) for SO_2, and 600 MW (14.3%) for NOx. Amongst those that started operation in or after 1990, the capacity of those that have AQCS is 49,062 MW (82.2%) for PM, 53,832 MW (90.2%) for SO_2, and 23,122 MW (38.8%) for

NOx. The level of countermeasures against NOx has been improved but is still lower than for PM and SO_2.

Amongst coal-fired power plants that started operation in or after 1990, the capacity of those that do not have AQCS is 10,555 MW for PM, 5,785 MW for SO_2, and 36,495 MW for NOx. It is safe to say that the potential for improvement is substantial (Figure 2.20).

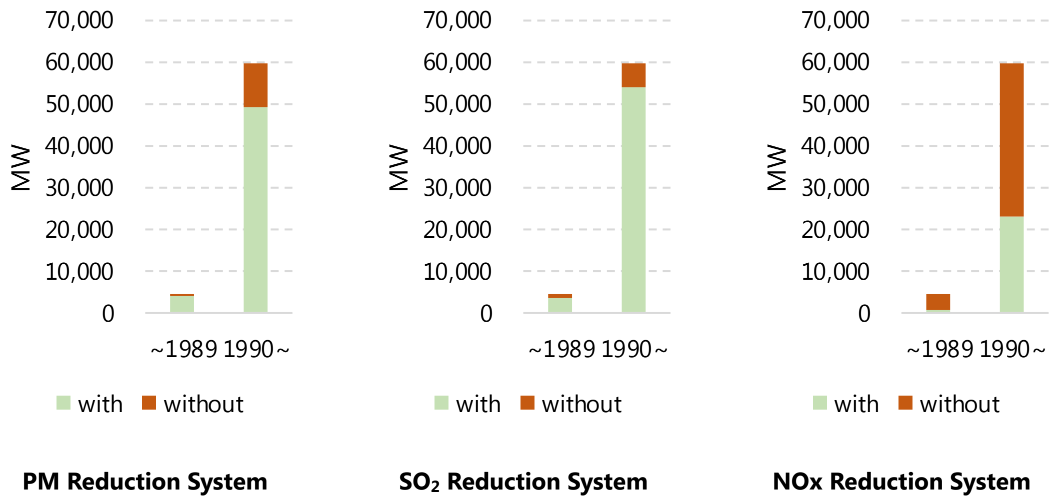
Table 2.1: Air Quality Control System Installation Status at Coal-fired Power Plants in ASEAN Countries

Country	AQCS Installation Status	Coal-fired Power Plant (MW)					
		~1989			1990~		
		PM	SO_2	NOx	PM	SO_2	NOx
Cambodia	with	0	0	0	390	390	0
	without	0	0	0	10	10	400
Indonesia	with	1,600	1,600	0	16,092	18,206	7,260
	without	130	130	1,730	7,251	5,137	16,083
Lao PDR	with	0	0	0	1,878	1,878	0
	without	0	0	0	0	0	1,878
Malaysia	with	600	600	0	9,489	9,489	6,504
	without	0	0	600	0	0	2,985
Myanmar	with	0	0	0	0	0	0
	without	0	0	0	8	8	8
Philippines	with	393	393	0	6,121	6,897	2,037
	without	105	105	498	776	0	4,860
Thailand	with	600	600	600	4,238	4,693	4,238
	without	0	0	0	455	0	455
Viet Nam	with	550	440	0	10,854	12,279	3,083
	without	220	330	770	2,055	630	9,826
ASEAN	with	3,743	3,633	600	49,062	53,832	23,122
	without	455	565	3,598	10,555	5,785	36,495

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

Source: ERIA (2018).

Figure 2.20: Air Quality Control System Installation Status at Coal-fired Power Plants in ASEAN



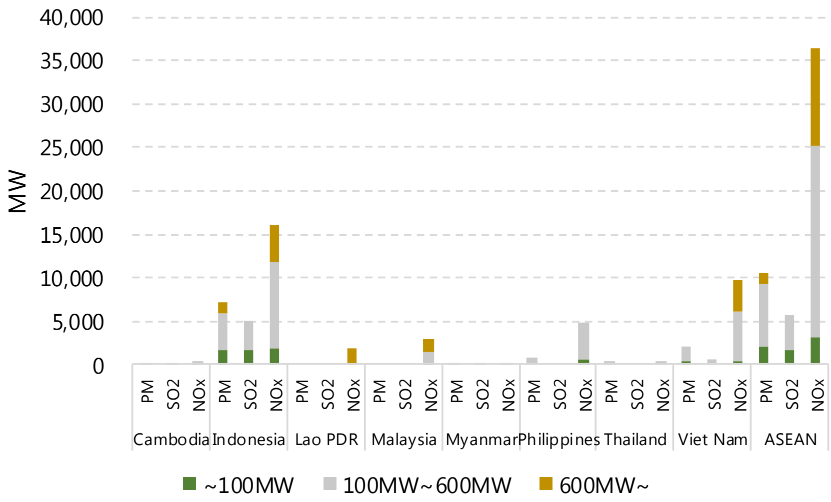
NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: ERIA (2018).

Some coal-fired power plants without AQCS that started operation in or after 1990 are not equipped with PM or NOx control, whilst all coal-fired power plants with a capacity of over 600 MW have SOx control (Figure 2.21). The potential for improvement is substantial in coal-fired power plants over 600 MW. Total capacity of 17 coal-fired power plants over 600 MW without NOx control is 11,269 MW.

AQCS installation status varies country to country. In Indonesia, Lao PDR, Malaysia, and Viet Nam, AQSC is not installed even in some large (over 600 MW) coal-fired power plants, while AQSC is installed in all large coal-fired power plants in the Philippines and Thailand.

Figure 2.21: Capacity of Coal-fired Power Plants Without AQCS In and After 1990



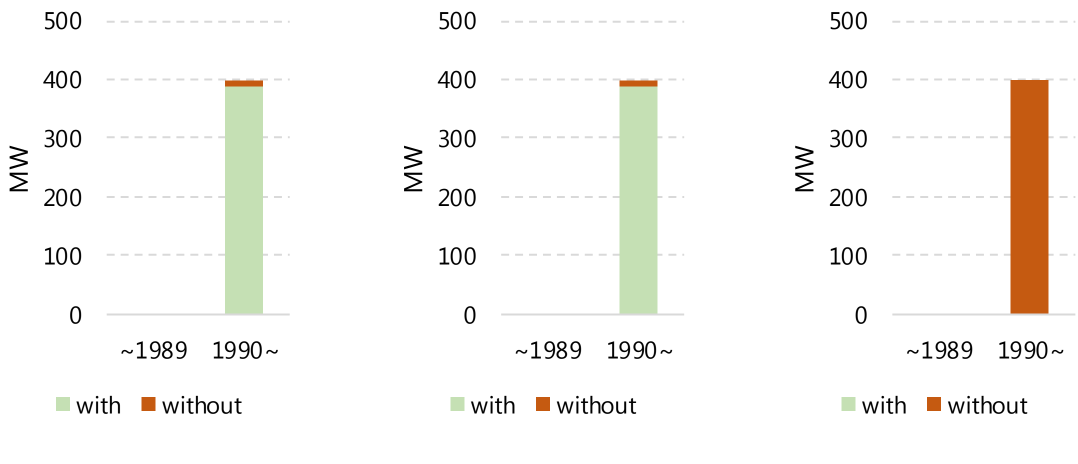
NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: ERIA (2018).

(a) Cambodia

Whilst no operating coal-fired power plant started operation in or before 1989, installed capacity of operating coal-fired power plants that started operation in or after 1990 is 400 MW. Amongst them, the capacity of those that do not have AQCS is 10 MW for PM, 10 MW for SO_2, and 400 MW for NOx.

Figure 2.22: Air Quality Control System Installation Status at Coal-fired Power Plants, Cambodia



PM Reduction System **SO_2 Reduction System** **NOx Reduction System**

NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

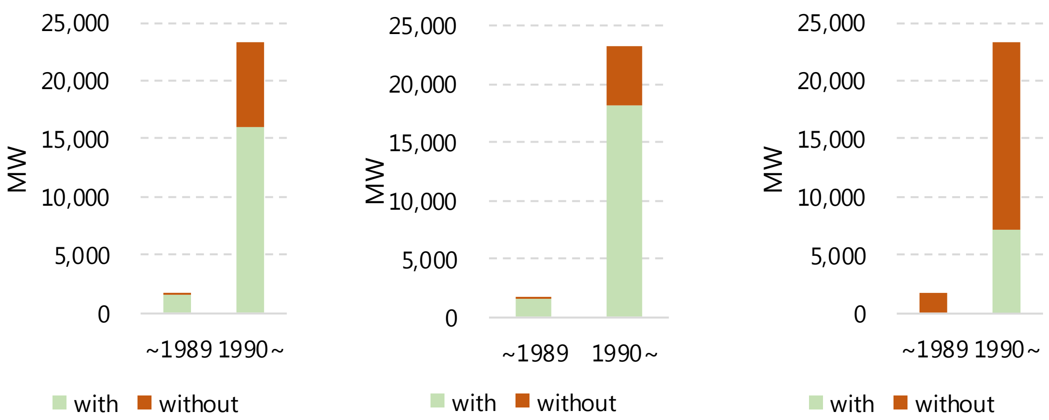
Source: ERIA (2018).

(b) Indonesia

Installed capacity of operating coal-fired power plants that started operation in or before 1989 is 1,730 MW. Amongst them, the capacity of those that do not have AQCS is 130 MW for PM, 130 MW for SO_2, and 1,730 MW for NOx.

Installed capacity of operating coal-fired power plants that started operation in or after 1990 is 23,343 MW. Amongst them, the capacity of those that do not have AQCS is 7,251 MW for PM, 5,137 MW for SO_2, and 16,083 MW for NOx.

Figure 2.23: Air Quality Control System Installation Status at Coal-fired Power Plants, Indonesia



PM Reduction System **SO_2 Reduction System** **NOx Reduction System**

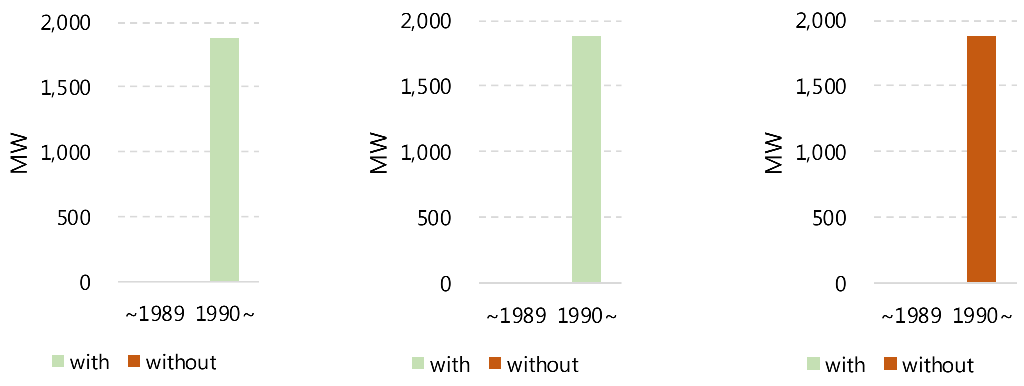
NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: ERIA (2018).

(c) Lao People's Democratic Republic

Whilst no operating coal-fired power plant started operation in or before 1989, the installed capacity of operating coal-fired power plants that started operation in or after 1990 is 1,878 MW. Amongst them, the capacity of those that do not have AQCS for NOx is 1,878 MW, whilst all coal-fired power plants have AQCS for PM and SO_2.

Figure 2.24: Air Quality Control System Installation Status at Coal-fired Power Plants, Lao People's Democratic Republic



PM Reduction System **SO_2 Reduction System** **NOx Reduction System**

NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

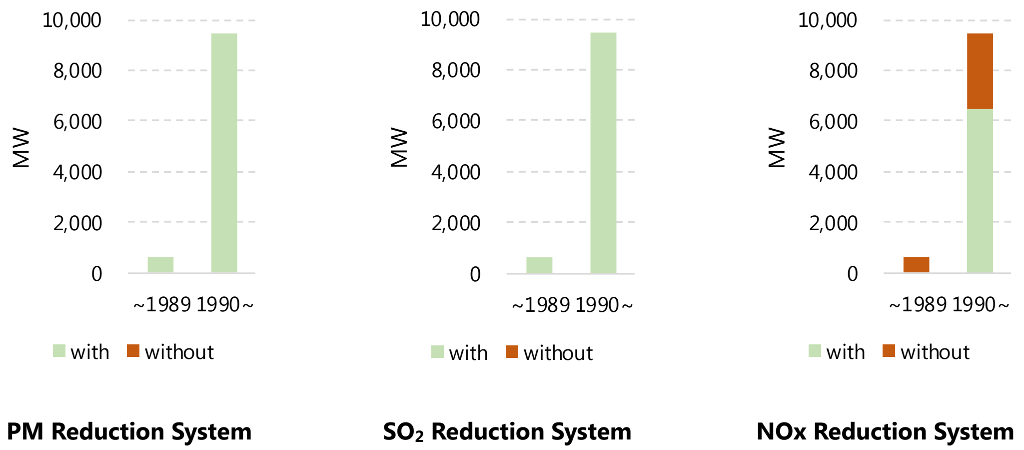
Source: ERIA (2018).

(d) Malaysia

Installed capacity of operating coal-fired power plants that started operation in or before 1989 is 600 MW. Amongst them, the capacity of those that do not have AQCS for NOx is 600 MW. All such coal-fired power plants have AQCS for PM and SO_2.

Installed capacity of operating coal-fired power plants that started operation in or after 1990 is 9,489 MW. Amongst them, the capacity of those that do not have AQCS for NOx is 2,985 MW, whilst all such coal-fired power plants have AQCSs for PM and SO_2.

Figure 2.25: Air Quality Control System Installation Status at Coal-fired Power Plants, Malaysia



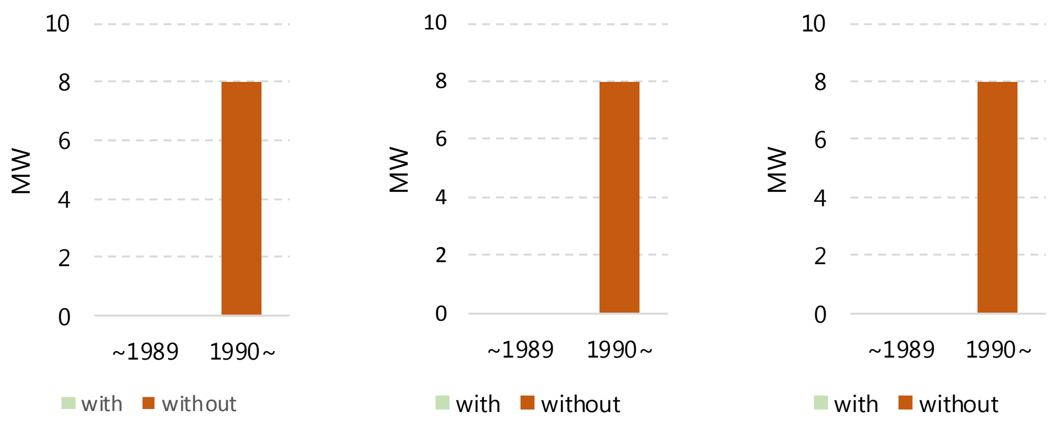
NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: ERIA (2018).

(e) Myanmar

Whilst no operating coal-fired power plant started operation in or before 1989, the installed capacity of the operating coal-fired power plant that started operation in or after 1990 is 8 MW. It has no AQCS installed.

Figure 2.26: Air Quality Control System Installation Status at the Coal-fired Power Plant, Myanmar



PM Reduction System **SO_2 Reduction System** **NOx Reduction System**

NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

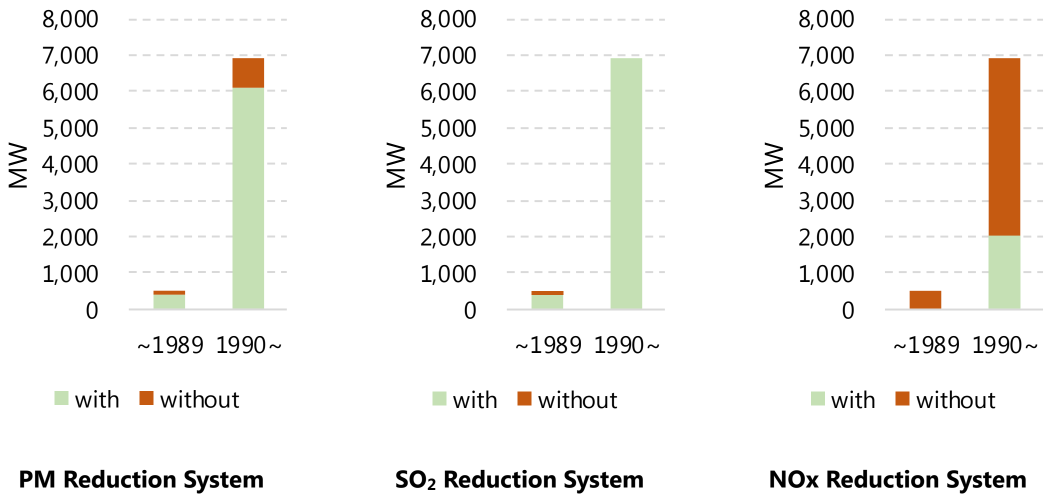
Source: ERIA (2018).

(f) Philippines

Installed capacity of operating coal-fired power plants that started operation in or before 1989 is 498 MW. Amongst them, the capacity of those that do not have AQCS is 105 MW for PM, 105 MW for SO_2, and 498 MW for NOx.

Installed capacity of operating coal-fired power plants that started operation in or after 1990 is 6,897 MW. Amongst them, the capacity of those that do not have AQCS is 776 MW for PM and 4,860 MW for NOx. All coal-fired power plants have AQCS for SO_2.

Figure 2.27: Air Quality Control System Installation Status at Coal-fired Power Plants, Philippines



NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

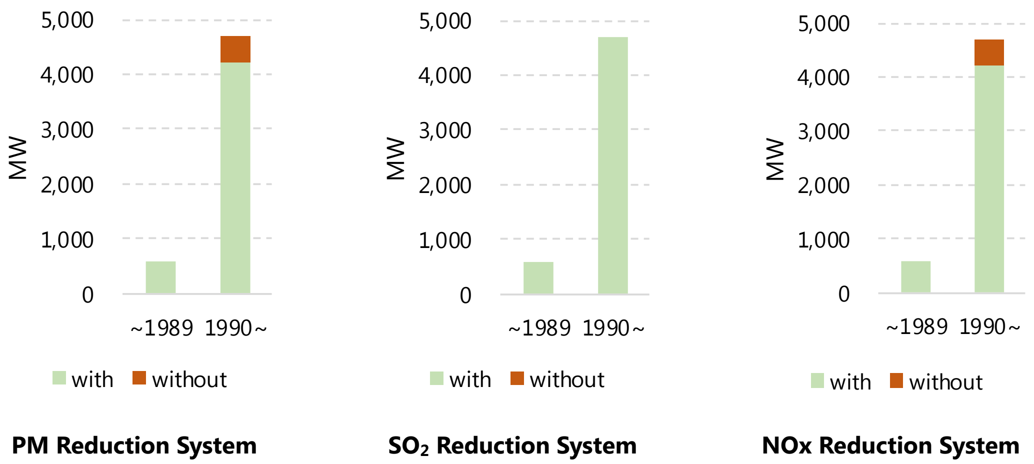
Source: ERIA (2018).

(g) Thailand

Installed capacity of operating coal-fired power plants that started operation in or before 1989 is 600 MW. All have AQCS.

Installed capacity of operating coal-fired power plants that started operation in or after 1990 is 4,693 MW. Amongst them, the capacity of those that do not have AQCS is 455 MW for PM and 455 MW for NOx. All coal-fired power plants have AQCS for SO_2.

Figure 2.28: Air Quality Control System Installation Status at Coal-fired Power Plants, Thailand



NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

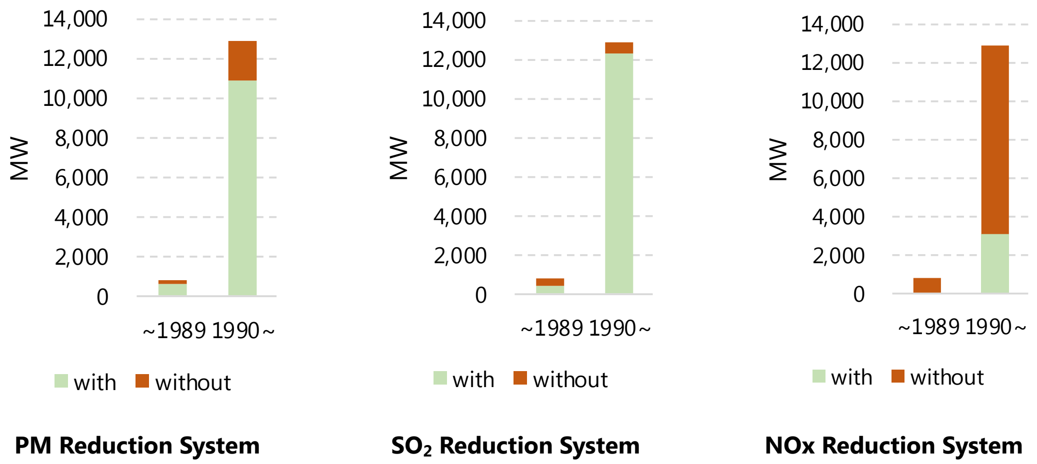
Source: ERIA (2018).

(h) Viet Nam

Installed capacity of operating coal-fired power plants that started operation in or before 1989 is 770 MW. Amongst them, the capacity of those that do not have AQCS is 220 MW for PM, 330 MW for SO_2, and 770 MW for NOx.

Installed capacity of operating coal-fired power plants that started operation in or after 1990 is 12,909 MW. Amongst them, the capacity of those that do not have AQCS is 2,055 MW for PM, 630 MW for SO_2, and 9,826 MW for NOx.

Figure 2.29: Air Quality Control System Installation Status at Coal-fired Power Plants, Viet Nam



NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: ERIA (2018).

2. Air Quality Control System of Coal-fired Power Plants

2.1. Air Emission Standards for Coal-fired Power Plants

Table 2.2 shows the emission standards of SOx, NOx, and PM for new coal-fired power plants in selected ASEAN countries, with some Organisation for Economic Co-operation and Development (OECD) countries as a reference. In case they differed depending on plant scale, the large-scale case was adopted. In case they differed depending on the period, the daily basis (24 hours) was adopted. SOx and NOx have different units from one country to another. In the countries where parts per million (ppm) is used, SOx and NOx are converted into mg/m^3 or SO_2 and NO_2.

Table 2.2: Emission Standards for Coal-fired Power Plants

Country	SOx	NOx	PM
Germany	SOx: 150 mg/m^3	NOx: 150 mg/m^3	10 mg/m^3
Japan	SOx: 50 ppm *1 (SO_2: 133 mg/m^3)	NOx: 200 ppm (NO_2: 383 mg/m^3)	100 mg/m^3
Republic of Korea	SOx: 50 ppm (SO_2: 133 mg/m^3)	NOx: 50 ppm (NO_2: 96 mg/m^3)	10 mg/m^3
Cambodia	SO_2: 500 mg/m^3	NO_2: 1,000 mg/m^3	400 mg/m^3
Indonesia	SO_2: 750 mg/m^3	NO_2: 750 mg/m^3	100 mg/m^3
Lao PDR	SO_2: 320 ppm (SO_2: 853 mg/m^3)	NOx: 350 ppm (NO_2: 670 mg/m^3)	120 mg/m^3
Malaysia	SOx: 500 mg/m^3	NOx: 500 mg/m^3	50 mg/m^3
Myanmar	SOx: 200 mg/m^3	NOx: 400 mg/m^3	50 mg/m^3
Philippines	SO_2: 700 mg/m^3	NO_2: 1000 mg/m^3	150 mg/m^3
Singapore	SO_2: 500 mg/m^3	NO_2: 700 mg/m^3	100 mg/m^3
Thailand	SO_2: 180 ppm (SO_2: 480 mg/m^3)	NOx: 200 ppm (NO_2: 383 mg/m^3)	80 mg/m^3
Viet Nam	SO_2: 500 mg/m^3	NO_2: 650 mg/m^3 *2	200 mg/m^3

Lao PDR = Lao People's Democratic Republic. NOx = nitrogen oxides, NO_2 = nitrogen dioxide, PM = particulate matter, ppm = parts per million, SOx = sulphur oxides, SO_2 = sulphur dioxide.

Notes:

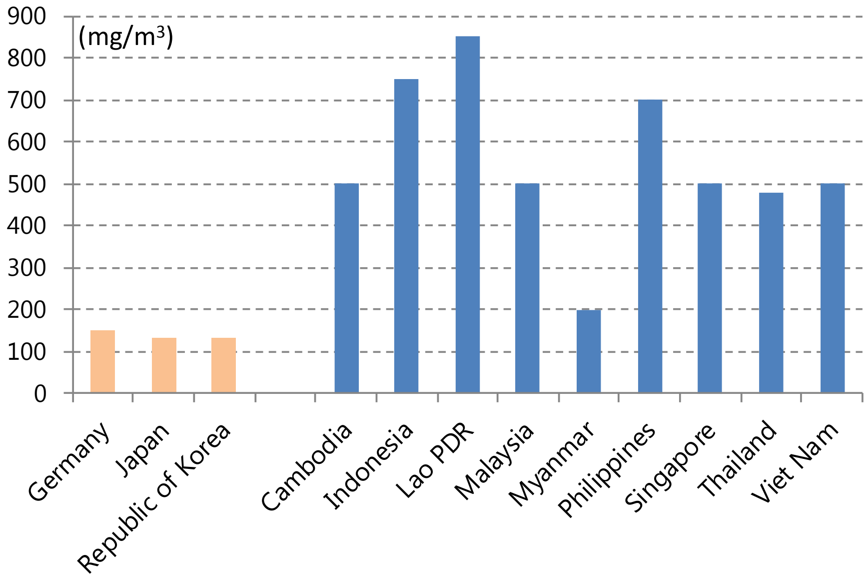
*1. Based on a coal-fired power plant's location, sulphur content of fuel, stack height, etc., the emission standard varies plant by plant. The value is an example of a specific coal-fired power plant based on agreement between the plant and the local government.

*2. Coal volatile content >10%.

Source: ERIA (2017).

The following figures compare national emission standards based on SOx, NOx, and PM. The SOx emission limit is higher (looser) in the selected ASEAN countries than in the selected OECD countries. NOx is lower in the selected OECD countries. For PM, the regulation values in the selected ASEAN countries, except Cambodia, are approximately the same as those in Japan.

Figure 2.30: Comparison of Emission Standards in Selected Countries (SOx)

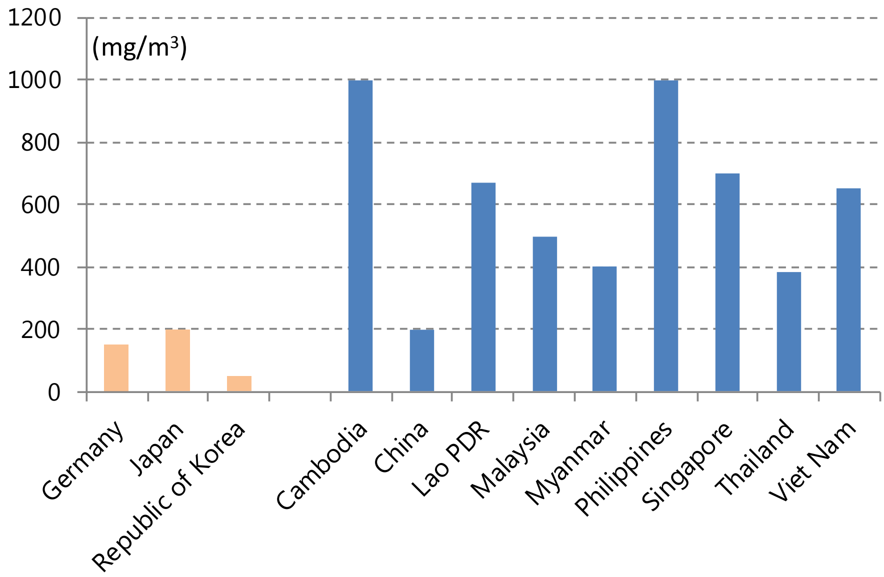


Lao PDR = Lao People's Democratic Republic, SOx = sulphur oxides.

Note: The emission standard of coal-fired power plant for SOx in Japan varies from power plant to power plant based on location, sulphur content of fuel, stack height etc. The data here is an example of a specific coal-fired power plant in Japan.

Source: ERIA (2017).

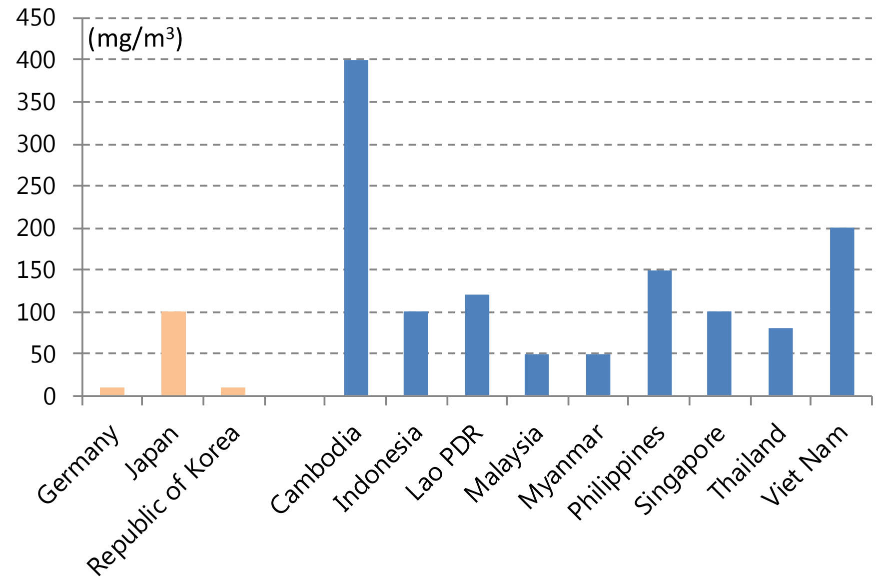
Figure 2.31: Comparison of Emission Standards in Selected Countries (NOx)



Lao PDR = Lao People's Democratic Republic, NOx = nitrogen oxides.

Source: ERIA (2017).

Figure 2.32: Comparison of Emission Standards in Selected Countries (PM)



Lao PDR = Lao People's Democratic Republic, PM = particulate matter.

Source: ERIA (2017).

2.2. Management System of Air Quality

Without an effective air quality management system, no country can achieve good air quality. We surveyed the air quality management systems of coal-fired power plants in selected ASEAN countries as well as some OECD countries as a reference. We divided management systems into the following elements:

(a) General

- Existence of legislation (national or local)
- Authority to suspend operation
- Relation to local community

(b) Management process

- Monitoring of emission by operator and/or authority
- Data archive requirement
- Reporting to authority
- Inspection by authority
- Public announcements
- Penalty, fine

The following are the survey results:

2.2.1.1. General

At the central government level, environment-related laws have been enacted, regulated air pollutants identified, and emission standards stipulated. Cambodia, Indonesia, and Thailand are known to authorise local governments to enact emission standards. Like Japan, Cambodia set emission standards voluntarily with coal-fired power plant operators.

Authority to suspend operation varies as follows:

- Central government: Malaysia, Myanmar, Thailand
- Central and local governments: Indonesia, Lao PDR
- Local government: Cambodia (based on agreement with coal-fired power plants)

Periodic meetings with the community after starting to operate a coal-fired power plant:

- Lao PDR: Dependent on an agreement with the coal-fired power plant

- Thailand: Implemented every 3 months
- Other countries: Not obligated

Management process

Local governments implement regular monitoring in Cambodia, Lao PDR, and Myanmar. They started operating coal-fired power plants only after the 2000s. Thailand is the only country where the requirement to archive measured data is not enacted by law.

Reports should be submitted as follows:

- Central government: Cambodia, Malaysia, Myanmar, Thailand
- Central and local governments: Indonesia, Lao PDR
- Local government: None

Inspection agencies vary as follows:

- Central government: Cambodia, Malaysia, Myanmar, Thailand
- Central and local governments: Indonesia, Lao PDR
- Local government: None

Public announcement varies from one country to another:

- Cambodia: Central government publishes it through public screen monitors.
- Indonesia: Central government is developing an online system.
- Lao PDR: Local government publishes the status.
- Malaysia: Central government uses its website.
- Myanmar: Coal-fired power plant publishes the status through an LED screen in front of the plant.
- Thailand: Coal-fired power plant operator issues an annual report.

Every country has implemented a system but, compared with OECD countries, there is room for improvement in two fields:

(1) Reporting frequency (Table 2.)

Coal-fired power plants in Cambodia, Lao PDR, Malaysia, and OECD countries automatically send data to the authorities, whilst plants in some ASEAN countries send data in any period enacted by law.

(2) Public announcements (Table 2.)

The public can see the measured data on a website in Malaysia and in OECD countries. Indonesia is developing an online reporting system. The public cannot, however, access real-time data in some ASEAN countries.

The following tables compare monitoring in ASEAN and selected OECD countries.

Table 2.3: Monitoring

Cambodia	Prefecture governors continuously monitor the status of air pollution.
Indonesia	Irregular monitoring by local government.
Lao PDR	Provincial authorities continuously monitor the status of air pollution. Local governments have observing stations.
Malaysia	Department of Environment monitors the status of air pollution.
Myanmar	The Ministry of Electricity and Energy, state and regional governments continuously monitor the status of air pollution. The owner or occupiers of any business have the duty to monitor environmental pollution.
Thailand	Coal-fired power plants submit environmental impact assessments to the Ministry of Environment, Ministry of Natural Resources, and Ministry of Energy. Report: Coal-fired power plant → central government → local government. Local government has the power to check emission data but rarely does so.
Australia	Areas with populations greater than 25,000 are required to install monitoring stations. E.g. in New South Wales, the Office of Environment and Heritage operates the air quality monitoring network. Data from the network is presented online every hour as the air quality index, stored in a searchable database.
Germany	Monitoring networks are operated by (1) the German Federal Environment

	Agency, which measures stations far from cities; and (2) state networks that monitor air quality in populated areas. The data from the two monitoring networks provide the foundation of the country's air quality.
Japan	Prefecture governors continuously monitor the status of air pollution. Local governments have observing stations.
United States	E.g. PM: Operator of a facility installs, calibrates, maintains, and operates opacity monitoring systems, and records the output of the system for measuring the opacity of emissions discharged into the atmosphere.

Table 2.4: Reporting to Authority

Cambodia	The power plant operator submits data on air pollution emissions to the government every month, although coal-fired power plants automatically send data through to a telemeter. The Ministry of Environment conducts an integrated survey of quantity of air pollution emission every 3 years. Archive requirement: All coal-fired power plant operators should store important emission data permanently every 6 months.
Indonesia	Government regulation 21, year 2012, article 9. The power plant is obliged to do the following: a. Report every 3 months to the regent or mayor, with a copy to the governor and environment minister, the results of emission monitoring and measurement of power plants equipped with continuous emission monitoring systems. b. Report every 6 months to the regent or mayor, with a copy to the governor and environment minister, the results of emission monitoring and measurement of power plants that manually measure emissions. c. Report to the regent or mayor, with a copy to the governor and environment minister, annual total emissions (tons/year) emitted for NOx, SOx, and CO_2. Archive requirement: Most coal-fired power plant owners keep important data permanently.
Lao PDR	The Ministry of Natural Resource and Environment (MoNRE) or provincial authorities (environmental management units) jointly with coal-fired power

	plant operators report the status of air pollutant emissions. MoNRE conducts integrated surveys of the quantity of air pollutant emissions every 6 months. As agreed between the coal-fired power plant operator and local government, the operator submits a report to the local government every month, although the plant automatically and continuously sends data through a telemeter. Archive requirement: The data should be kept for 3 years.
Malaysia	Continuous emission monitoring systems Archive requirement. The Environmental Quality (Clean Air) Regulations 2014 require that records be kept for at least 3 years.
Myanmar	The project proponent submits monitoring reports to the Ministry of Electricity and Energy not less frequently than every 6 months, as scheduled in the environmental management plan, or periodically as prescribed by the ministry. The Ministry of Electricity and Energy requires operators to report the status of air pollutant emissions. Archive requirement: Coal-fired power plant operator keeps important data permanently as paper and electronic files.
Thailand	The operator must submit data twice a year. Archive requirement: None
Australia	E.g. New South Wales law does not require licensees to report emission data to Environment Protection Authority periodically. Instead, licensees must publish pollution monitoring data. Archive requirement: Unknown
Germany	The operator supplies monitoring results to the authority regularly and at least annually. Archive requirement: Publications are lodged in the archives of the German Patents Office for safe custody and reference.
Japan	Governors may require operators to report the status of air pollutant emissions. As agreed, operators submit reports to local government every month, although coal-fired power plants automatically and continuously send data through a telemeter. Archive requirement: The data should be kept for 3 years. Generally, most operators keep important data permanently.

United States	Performance test data from continuous monitors must be reported to the administrator. The owner or operator of the facility submits a signed statement. Archive requirement: It is subject to '40 CFR §60.52Da Record-keeping requirements'.

Table 2.5: Inspection

Cambodia	The Ministry of Environment or other government agency should inspect each coal-fired power plant through the telemeter. Independent inspector: The Air Pollution Control Act requires operators to have a special environmental technician to control plant emissions.
Indonesia	Law 32, year 2009, article 72. The Ministry of Environment or the governor, regent, or mayor is obliged to conduct supervision, and may conduct on-site inspection. Law 30, year 2009, article 46. The Ministry of Energy and Mineral Resources or regional government, with authority to guide and supervise the electricity supply business' compliance with environmental protection laws, may conduct on-site inspections.
Lao PDR	The environmental management unit conducts official inspections jointly with provincial authorities. Independent inspector: Based on concession agreement for coal-fired power plant.
Malaysia	Department of Environment is in charge of inspection. Independent inspector: Not required by law.
Myanmar	A screening team, organised by the Ministry of Electricity and Energy, frequently inspects coal-fired power plants. An inspection team is organised by ministries and other organizations. Independent inspector: Not required by law.
Thailand	The Department of Estate, Ministry of Industry inspects every industrial plant. In the case of large coal-fired power plants, site visits are not be carried out. In case of a severe accident, the Ministry of Environment inspects the plant. Local government has the power to inspect plants but there has been no precedent for this. Independent inspector: Not required by law.

Australia	E.g. New South Wales: Protection of the Environment Operations Act 1997 The operator must notify the government of pollution incidents. Audits may be required as a condition of license if the Environment Protection Authority reasonably suspects wrongdoing. Independent inspector: Not required by law.
Germany	The law requires environmental inspections to be done at least every 1–3 years. Each inspection plan includes a general assessment of significant environmental issues. Independent inspector: Not required by law.
Japan	Governors may conduct official inspections. On-site inspection by the Ministry of Economy, Trade and Industry: Irregular, every 5 or 6 years. On-site inspection by a local government: Depends on the agreement between the coal-fired power plant operator and local government; generally once a year, typically during Environment Month. Independent inspector: Not required by law.
United States	Environmental Protection Agency (EPA) policy. Incentives for self-policing (discovery, disclosure, correction, and prevention) On-site visit by EPA, civil investigations, record reviews, information requests. Independent inspector: Not required by law.

Table 2.6: Public Announcement

Cambodia	The Ministry of Environment or other government agency collects environment data from various facilities and displays the status of air pollution on public screen monitors.
Indonesia	The Ministry of Environment and Forests is developing a public online reporting system. The Directorate General of Electricity is developing information systems to monitor power plant emissions through a pilot project at Cirebon 1 x 660 MW.
Lao PDR	Provincial authorities and environmental management unit make public the status of air pollution within prefectures.
Malaysia	Announcements are published through the official portal of the Department of Environment and through newspapers. The Air Pollutant Index is regularly updated.

Myanmar	Coal-fired power plants display the status of air pollution on LED screens in front of the plants. (For example, Tigyit Coal-fired Thermal Power Plant.)
Thailand	Information is distributed through operators' annual reports. Local governments do not publish emission data.
Australia	E.g. New South Wales: - The law requires licensees to publish pollution monitoring data instead of reporting. - Failure to publish monitoring data and publication of false or misleading data are penalised. - A summary of monitoring data must be posted on a website monthly, or less than monthly when necessary.
Germany	All data on air quality are published on the Internet shortly after they are gathered, providing information on current pollution level. The EU Pollutant Release and the Transfer Register (E-PRTR) provides to the public environmental information and includes data on emissions as reported by Member State.
Japan	Local governments collect environmental data from various facilities and publish the status of air pollution on a screen monitor in their city hall. Everyone can see the situation any time. Local governments publish environmental reports periodically.
United States	Anyone can access air monitoring results from https://www.epa.gov/outdoor-air-quality-data

Table 2.7: Penalties

Cambodia	Violation of the air pollution control act is penalised with a fine, cancellation of the license, and shutdown of the coal-fired power plant. Compensation for damage and losses: Strict liability
Indonesia	Penalties under Law No. 32, year 2009: - Administrative sanction - Fine and imprisonment Anyone who violates the emissions quality standards is imprisoned for 3 years and fined a maximum of IDR3 billion (approximately US$210,000). A violation is deemed a criminal offence if the offender does not comply with administrative sanctions or commits the offence more than once. Compensation for damage and losses: Strict liability

	Law 32, year 2009, article 54. Anyone who pollutes and damages the environment must take steps towards environmental recovery.
Lao PDR	Based on a concession agreement. Compensation for damage and losses: Strict liability
Malaysia	Any person who contravenes or fails to comply with any provision of Environmental Quality (Clean Air) Regulations 2014 will be fined not more than MYR100,000 (approximately US$24,000) or imprisoned for not more than 2 years or both. Compensation for damage and losses: Environmental Quality Act 1974, section 46E. Compels 'the person so convicted to pay the other person the costs and expenses incurred or compensation for loss or damage to the property and any other costs, in the amount as the court considers fit'.
Myanmar	Penalties. US$2,500 to US$10,000 or equivalent in kyat Specific administrative punishment by the Ministry of Electricity and Energy: - Issue enforcement notice - Suspension of approval of environmental management plan (EMP), EMP-construction phase (EMP-CP), or EMP-operational phase (EMP-OP) in whole or in part - Revocation of approval of EMP, EMP-CP, or EMP-OP in whole or in part Compensation for damage and losses: Failure to take reasonable steps to prevent an imminent threat of damage to the environment, society, human health, livelihoods, or property, where applicable, based on the EMP, EMP-CP, or EMP-OP.
Thailand	Industry Act. The Ministry of Industry can impose fines of up to THB200,000 (approximately US$6,000). Compensation for damage and losses: The central government requires the coal-fired power plant to pay compensation but there has been no precedent for this. (It is difficult to determine who is responsible for air pollution and to evaluate damage and losses.) Operators pay damages and losses voluntarily, i.e. hospital expenses, medical examinations, etc.
Australia	E.g. New South Wales Environmental offences and penalties Compensation for damage and losses: Strict liability
Germany	Severe cases of noncompliance can result in criminal liability. Criminal

	sanctions include imprisonment and fines of up to EUR50,000. Compensation for damage and losses: Strict liability
Japan	Punishment for violating the Air Pollution Control Act includes disclosure of the offending operator’s name, imprisonment, and a fine. Compensation for damage and losses: Strict liability
United States	If a civil defendant is found liable or agrees to settle: monetary penalty, injunctive relief, additional actions to improve the environment If a criminal defendant is convicted or pleads guilty: monetary fine, restitution, incarceration Compensation for damage and losses: Strict liability

3. Cost of Air Quality Control System and Implications for Electricity Prices

3.1. Cost of Air Quality Control System

An FY 2017 survey (ERIA, 2018) covered the cost of AQCS and its implications for electricity prices in ASEAN countries. Some respondents thought that raising government emission standards could induce private generation companies to install an AQCS if it added only 10%–20% to the price of electricity. Respondents noted that governments are extremely cautious when it comes to increasing electricity prices caused by installing AQCS.

Table 2.8 indicates the AQCS capital expenditure (CAPEX) range surveyed by Mitsubishi Hitachi Power Systems (MHPS). AQCS equipment is high quality, high performance, and highly efficient, and fulfils the loan criteria of the World Bank.

Table 2.8: Surveyed Air Quality Control System Cost (CAPEX) (US$/kW)

	PM	PM	SOx	NOx
	Fabric Filters	ESP	FGD System	SCR System
Low case	35	20	80	50
High case	45	60	100	70

ESP = electrostatic precipitator, FGD = flue-gas desulfurization scrubber, NOx = nitrogen oxides, PM = particulate matter, SCR = selective catalytic reduction, SOx = sulphur oxides.

Source: MHPS (2018).

Table 2.9: World Bank Emission Standards (mg/Nm^3) (Reference)

Air pollutant	SO_2	NOx	PM
Emission standard	200	200	30

NOx = nitrogen oxides, PM = particulate matter, SO_2 = sulphur dioxide.

Source: MHPS (2018).

3.2. Impact on Electricity Prices

This section estimates the impact of AQCS installation on electricity prices in ASEAN countries per scenario and AQCS cost range. The coal-fired power plants within scope and the state of existing AQCS installation are detailed separately. The CAPEX depreciation equivalent cost, estimated loan interest cost, and estimated operation and maintenance cost (O&M) were used to calculate the cost of AQCS installation. The impact is divided into the first 10 years and the subsequent 10 years. The cost assumptions are detailed below:

Depreciation equivalent	10 years straight-line, 100% depreciation rate
Loan interest	Currency: US$
	Repayment term: 10 years
	Rate: OECD's commercial interest reference rates[2]
O&M	15% of CAPEX (per year)
Calculation of impact	AQCS installation cost per kWh/electricity price

The impact on electricity prices in ASEAN countries is analysed based on the MHPS's AQCS cost (CAPEX) survey. Cost figures also take finance cost and O&M cost into account. Two scenarios (Table 2.10) were developed to analyse the impact AQCS installation would have on electricity prices.

[2] This study used 3.64%, the average rate from 15 January to 14 June 2018.

Table 2.10: Impact of Air Quality Control System Installation on Electricity Prices: Two Scenarios

Scenario 1 - Installation in plants where AQCSs are not installed. Scenario 2 - More-stringent emission standards will be introduced. - Existing AQCSs cannot comply with more-stringent emission standards. - High-quality, high-performance, and highly efficient AQCSs will be installed in all power plants.

AQCS = air quality control system.

Source: Author.

Table 2.11 shows the impact of AQCS installation cost on electricity prices in seven ASEAN countries, as found in this study. Whilst Lao PDR reaches a maximum of 28%, many cases show less than 10% impact.

The impact of AQCS installation cost on electricity prices may not, therefore, be significant. Raising electricity prices, however, is a politically difficult and sensitive issue and should be implemented carefully.

Table 2.11: Impact on Electricity Prices

Country	Scenario	AQCS cost range	First 10 years				Subsequent 10 years			
			Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Cambodia	Scenario 1	Low case	0.5%	0.5%		-	0.3%	0.3%		-
		High case	0.6%	0.7%		-	0.4%	0.4%		-
	Scenario 2	Low case	1.3%	1.4%		-	0.7%	0.8%		-
		High case	2.0%	2.1%		-	1.1%	1.2%		-
Indonesia	Scenario 1	Low case	-	-	-	-	-	-	-	-
		High case	-	-	-	-	-	-	-	-
	Scenario 2	Low case	7.6%	5.3%	6.1%	6.5%	4.3%	3.0%	3.5%	3.7%
		High case	11.6%	8.2%	9.3%	10.0%	6.6%	4.6%	5.3%	5.7%
Lao PDR	Scenario 1	Low case	-	-	-	-	-	-	-	-
		High case	-	-	-	-	-	-	-	-
	Scenario 2	Low case	-	-	-	18.2%	-	-	-	10.3%
		High case	-	-	-	27.9%	-	-	-	15.8%
Malaysia	Scenario 1	Low case	0.5%	0.4%	0.5%	0.4%	0.3%	0.2%	0.3%	0.3%
		High case	0.7%	0.5%	0.7%	0.6%	0.4%	0.3%	0.4%	0.4%
	Scenario 2	Low case	4.9%	3.5%	4.4%	4.1%	2.8%	2.0%	2.5%	2.3%
		High case	7.5%	5.3%	6.7%	6.3%	4.3%	3.0%	3.8%	3.6%
Philippines	Scenario 1	Low case	0.5%	0.6%	0.8%	0.6%	0.3%	0.3%	0.4%	0.3%
		High case	0.8%	0.9%	1.2%	0.9%	0.4%	0.5%	0.7%	0.5%
	Scenario 2	Low case	1.8%	2.2%	2.8%	2.2%	1.0%	1.2%	1.6%	1.2%
		High case	2.8%	3.3%	4.3%	3.4%	1.6%	1.9%	2.4%	1.9%
Thailand	Scenario 1	Low case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		High case	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
	Scenario 2	Low case	1.1%	1.0%	1.2%	1.1%	0.6%	0.6%	0.7%	0.6%
		High case	1.6%	1.6%	1.8%	1.7%	0.9%	0.9%	1.0%	1.0%
Viet Nam	Scenario 1	Low case	1.1%	1.1%	1.8%	1.4%	0.6%	0.6%	1.0%	0.8%
		High case	1.6%	1.6%	2.7%	2.1%	0.9%	0.9%	1.6%	1.2%
	Scenario 2	Low case	3.4%	3.4%	5.8%	4.4%	1.9%	1.9%	3.3%	2.5%
		High case	5.2%	5.2%	8.8%	6.7%	3.0%	3.0%	5.0%	3.8%

AQCS = air quality control system, Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).

a) Cambodia

(1) CAPEX

Table 2.12 shows the AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the low case was US$$21.0 million and the high case US$29.6 million. In scenario 2, the low case was US$60.0 million and the high case US$92.0 million.

Table 2.12: Capital Expenditure of Air Quality Control System Installation, Cambodia

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
	PM	SOx	NOx	PM (ESP)	SOx	NOx	Total	PM (ESP)	SOx	NOx	Total
(US$/kW)				(20)	(80)	(50)		(60)	(100)	(70)	
Scenario 1	10	10	400	0.2	0.8	20.0	**21.0**	0.6	1.0	28.0	**29.6**
Scenario 2	400	400	400	8.0	32.0	20.0	**60.0**	24.0	40.0	28.0	**92.0**

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.13 shows AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$24.3 million per year, and in the subsequent 10 years US$13.8 million.

Table 2.13: Air Quality Control System Installation Cost, Cambodia

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	Total	Depreciation equivalent	Loan interest	O&M	Total
Scenario 1	Low case	21.0	2.1	0.3	3.2	**5.6**			3.2	**3.2**
	High case	29.6	3.0	0.4	4.4	**7.8**			4.4	**4.4**
Scenario 2	Low case	60.0	6.0	0.9	9.0	**15.9**			9.0	**9.0**
	High case	92.0	9.2	1.3	13.8	**24.3**			13.8	**13.8**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.14 shows the AQCS installation cost divided by the annual electricity sales volume.

Table 2.14: Air Quality Control System Installation Cost per kWh, Cambodia

Scenario	CAPEX	Electricity sales (2017) (GWh)	First 10 years (per year) Installation Cost (US$ million)	First 10 years (per year) Cost per kWh (US cent/kWh)	Subsequent 10 years (per year) Installation Cost (US$ million)	Subsequent 10 years (per year) Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	6,782	5.6	**0.082**	3.2	**0.046**
	High case		7.8	**0.115**	4.4	**0.066**
Scenario 2	Low case		15.9	**0.234**	9.0	**0.133**
	High case		24.3	**0.359**	13.8	**0.204**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.15 shows the impact AQCS installation cost has on electricity price per scenario and AQCS cost range. The AQCS installation cost has a maximum impact of 2.1% on electricity prices in the first 10 years, and 1.2% in the subsequent 10 years.

Table 2.15: Impact of Air Quality Control System Installation on Electricity Price, Cambodia

		First 10 years (per year) Residential	First 10 years (per year) Industrial Commercial	Subsequent 10 years (per year) Residential	Subsequent 10 years (per year) Industrial Commercial
Electricity price (2017)	KHR/kWh	720			
	US cent/kWh	17.8	16.7	<--	<--
Impact					
Scenario 1	Low case	0.5%	0.5%	0.3%	0.3%
	High case	0.6%	0.7%	0.4%	0.4%
Scenario 2	Low case	1.3%	1.4%	0.7%	0.8%
	High case	2.0%	2.1%	1.1%	1.2%

Note: Price: Electricity supplied by Electricite Du Cambodge in Phnom Penh and Takhmao.

US$1 = KHR4,051 (2017)

Source: ERIA (2018).

b) Indonesia

(1) CAPEX

Table 2.16 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the cost was 0. In scenario 2, the low case was US$3,892.7 million and the high case US$5,968.7 million.

Table 2.16: Capital Expenditure of Air Quality Control System Installation, Indonesia

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
(US$/kW)	PM	SOx	NOx	PM (ESP) (20)	SOx (80)	NOx (50)	Total	PM (ESP) (60)	SOx (100)	NOx (70)	Total
Scenario 1	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenario 2	25,951	25,951	25,951	519.0	2,076.1	1,297.6	3,892.7	1,557.1	2,595.1	1,816.6	5,968.7

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018).

(2) AQCS installation cost

Table 2.17 shows AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$1,578.3 million per year, and in the subsequent 10 years US$895.3 million.

Table 2.17: Air Quality Control System Installation Cost, Indonesia

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	Total	Depreciation equivalent	Loan interest	O&M	Total
Scenario 1	Low case	0.0	0.0	0.0	0.0	0.0			0.0	0.0
	High case	0.0	0.0	0.0	0.0	0.0			0.0	0.0
Scenario 2	Low case	3,892.7	389.3	56.1	583.9	1,029.3			583.9	583.9
	High case	5,968.7	596.9	86.1	895.3	1,578.3			895.3	895.3

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.18 shows the AQCS installation cost divided by the annual electricity sales volume.

Table 2.18: Air Quality Control System Installation Cost per kWh, Indonesia

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 2	Low case	216,013	1,029.3	0.476	583.9	0.270
	High case		1,578.3	0.731	895.3	0.414

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.19 shows the impact the AQCS installation cost has on electricity prices per scenario and AQCS cost range. The AQCS installation cost has a maximum impact of 11.6% on electricity prices in the first 10 years, and 6.6% in the subsequent 10 years.

Table 2.19: Impact on Electricity Prices, Indonesia

		First 10 years (per year)				Subsequent 10 years (per year)			
		Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Electricity price (2016)	US cent/ kWh	6.28	8.94	7.83	7.33	<--	<--	<--	<--
Impact									
Scenario 2	Low case	7.6%	5.3%	6.1%	6.5%	4.3%	3.0%	3.5%	3.7%
	High case	11.6%	8.2%	9.3%	10.0%	6.6%	4.6%	5.3%	5.7%

Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).

c) Lao PDR

(1) CAPEX

Table 2.20 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the cost was 0. In scenario 2, the low case was US$281.7 million and the high case US$431.9 million.

Table 2.20: Capital Expenditure of Air Quality Control System Installation, Lao People's Democratic Republic

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
(US$/kW)	PM	SOx	NOx	PM (ESP) (20)	SOx (80)	NOx (50)	**Total**	PM (ESP) (60)	SOx (100)	NOx (70)	**Total**
Scenario 1	0	0	0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Scenario 2	1,878	1,878	1,878	37.6	150.2	93.9	**281.7**	112.7	187.8	131.5	**431.9**

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.21 shows Lao PDR's AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$114.2 million per year, and in the subsequent 10 years US$64.8 million per year.

Table 2.21: Air Quality Control System Installation Cost, Lao People's Democratic Republic

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	**Total**	Depreciation equivalent	Loan interest	O&M	**Total**
Scenario 1	Low case	0.0	0.0	0.0	0.0	**0.0**			0.0	**0.0**
	High case	0.0	0.0	0.0	0.0	**0.0**			0.0	**0.0**
Scenario 2	Low case	281.7	28.2	4.1	42.3	**74.5**			42.3	**42.3**
	High case	431.9	43.2	6.2	64.8	**114.2**			64.8	**64.8**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.22 shows the AQCS installation cost divided by the annual electricity sales volume. Because electricity sales are low relative to AQCS installation cost, the cost per kWh is higher than in other countries.

Table 2.22: Air Quality Control System Installation Cost per kWh, Lao People's Democratic Republic

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	4,660	0.0	**0.000**	0.0	**0.000**
	High case		0.0	**0.000**	0.0	**0.000**
Scenario 2	Low case		74.5	**1.598**	42.3	**0.907**
	High case		114.2	**2.451**	64.8	**1.390**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.23 shows the impact of AQCS installation cost on Lao PDR's electricity price per scenario and AQCS cost range. The AQCS installation cost has a maximum impact of 27.9% on electricity prices in the first 10 years, and 15.8% in the subsequent 10 years. The impact in Lao PDR is much higher than in other countries because of Lao PDR's low average electricity prices, together with its high AQCS installation cost and low volume of electricity sales. Lao PDR has one coal-fired power plant in operation – Hongsa – and all the electricity it generates is exported. Some think it is not reasonable for Lao PDR to assume the AQCS installation cost at Hongsa. Lao PDR, however, plans to build new coal-fired power plants to supply electricity domestically. The figures here estimate the future impact of AQCS installation on electricity prices.

Table 2.23: Impact on Electricity Prices, Lao People's Democratic Republic

		First 10 years (per year)	Subsequent 10 years (per year)
		Total	Total
Electricity price (2016)	LAK/kWh US cent/ kWh	8.8	<--
Impact			
Scenario 2	Low case	18.2%	10.3%
	High case	27.9%	15.8%

Source: ERIA (2018).

d) Malaysia

(1) CAPEX

Table 2.24 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the cost in the low case was US$174.0 million and in the high case US$243.6 million. In scenario 2, the low case was US$1,603.5 million and the high case US$2,458.7 million.

Table 2.24: Capital Expenditure of Air Quality Control System Installation, Malaysia

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
	PM	SOx	NOx	PM (ESP)	SOx	NOx	**Total**	PM (ESP)	SOx	NOx	**Total**
(US$/kW)				(20)	(80)	(50)		(60)	(100)	(70)	
Scenario 1	0	0	3,480	0.0	0.0	174.0	**174.0**	0.0	0.0	243.6	**243.6**
Scenario 2	10,690	10,690	10,690	213.8	855.2	534.5	**1,603.5**	641.4	1,069.0	748.3	**2,458.7**

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.25 shows the AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$650.1 million per year and in the subsequent 10 years US$368.8 million.

Table 2.25: Air Quality Control System Installation Cost, Malaysia

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	**Total**	Depreciation equivalent	Loan interest	O&M	**Total**
Scenario 1	Low case	174.0	17.4	2.5	26.1	**46.0**			26.1	**26.1**
	High case	243.6	24.4	3.5	36.5	**64.4**			36.5	**36.5**
Scenario 2	Low case	1,603.5	160.4	23.1	240.5	**424.0**			240.5	**240.5**
	High case	2,458.7	245.9	35.5	368.8	**650.1**			368.8	**368.8**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.26 shows the AQCS installation cost divided by the annual electricity sales volume.

Table 2.26: Air Quality Control System Installation Cost per kWh, Malaysia

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	108,169	46.0	**0.043**	26.1	**0.024**
	High case		64.4	**0.060**	36.5	**0.034**
Scenario 2	Low case		424.0	**0.392**	240.5	**0.222**
	High case		650.1	**0.601**	368.8	**0.341**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.27 shows the impact of AQCS installation cost as on electricity price per scenario and AQCS cost range. The AQCS installation cost has a maximum impact of 7.5% on electricity prices in the first 10 years, and 4.3% in the subsequent 10 years.

Table 2.27: Impact of Air Quality Control System Installation on Electricity Prices, Malaysia

		First 10 years (per year)				Subsequent 10 years (per year)			
		Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Electricity price (2016)	US cent/ kWh	8.01	11.28	8.96	9.58	<--	<--	<--	<--
Impact									
Scenario 1	Low case	0.5%	0.4%	0.5%	0.4%	0.3%	0.2%	0.3%	0.3%
	High case	0.7%	0.5%	0.7%	0.6%	0.4%	0.3%	0.4%	0.4%
Scenario 2	Low case	4.9%	3.5%	4.4%	4.1%	2.8%	2.0%	2.5%	2.3%
	High case	7.5%	5.3%	6.7%	6.3%	4.3%	3.0%	3.8%	3.6%

Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).

e) Philippines

(1) CAPEX

Table 2.28 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the cost of the low case was US$311.6 million and the high case US$470.3 million. In scenario 2, the low case was US$1,117.6 million and the high case US$ 1,713.7 million.

Table 2.28: Capital Expenditure of Air Quality Control System Installation, Philippines

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
	PM	SOx	NOx	PM (ESP)	SOx	NOx	**Total**	PM (ESP)	SOx	NOx	**Total**
(US$/kW)				(20)	(80)	(50)		(60)	(100)	(70)	
Scenario 1	1,150	224	5,414	23.0	17.9	270.7	**311.6**	69.0	22.4	379.0	**470.3**
Scenario 2	7,451	7,451	7,451	149.0	596.1	372.5	**1,117.6**	447.0	745.1	521.5	**1,713.7**

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.29 shows AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$453.1 million per year, and in the subsequent 10 years US$257.0 million.

Table 2.29: Air Quality Control System Installation Cost, Philippines

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	**Total**	Depreciation equivalent	Loan interest	O&M	**Total**
Scenario 1	Low case	311.6	31.2	4.5	46.7	**82.4**			46.7	**46.7**
	High case	470.3	47.0	6.8	70.5	**124.4**			70.5	**70.5**
Scenario 2	Low case	1,117.6	111.8	16.1	167.6	**295.5**			167.6	**167.6**
	High case	1,713.7	171.4	24.7	257.0	**453.1**			257.0	**257.0**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018)

(3) AQCS installation cost per kWh

Table 2.30 shows the AQCS installation cost divided by the annual electricity sales volume.

Table 2.30: Air Quality Control System Installation Cost per kWh, Philippines

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	90,798	82.4	**0.091**	46.7	**0.051**
	High case		124.4	**0.137**	70.5	**0.078**
Scenario 2	Low case		295.5	**0.325**	167.6	**0.185**
	High case		453.1	**0.499**	257.0	**0.283**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.31 shows the impact of AQCS installation cost on the electricity price per scenario and AQCS cost range. The AQCS installation cost has a maximum impact of 4.3% on electricity prices in the first 10 years, and 2.4% in the subsequent 10 years.

Table 2.31: Impact on Electricity Prices, Philippines

		First 10 years (per year)				Subsequent 10 years (per year)			
		Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Electricity price (2016)	US cent/ kWh	17.80	14.98	11.68	14.88	<--	<--	<--	<--
Impact									
Scenario 1	Low case	0.5%	0.6%	0.8%	0.6%	0.3%	0.3%	0.4%	0.3%
	High case	0.8%	0.9%	1.2%	0.9%	0.4%	0.5%	0.7%	0.5%
Scenario 2	Low case	1.8%	2.2%	2.8%	2.2%	1.0%	1.2%	1.6%	1.2%
	High case	2.8%	3.3%	4.3%	3.4%	1.6%	1.9%	2.4%	1.9%

Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).

f) Thailand

(1) CAPEX

Table 2.32 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the low case was US$311.6 million and the high case US$470.3 million. In scenario 2, the low case was US$1,117.6 million and the high case US$1,713.7 million.

Table 2.32: Capital Expenditure of Air Quality Control System Installation, Thailand

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
	PM	SOx	NOx	PM (ESP)	SOx	NOx	Total	PM (ESP)	SOx	NOx	Total
(US$/kW)				(20)	(80)	(50)		(60)	(100)	(70)	
Scenario 1	455	0	455	9.1	0.0	22.8	31.9	27.3	0.0	31.9	59.2
Scenario 2	5,293	5,293	5,293	105.9	423.4	264.7	794.0	317.6	529.3	370.5	1,217.4

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.33 shows AQCS installation cost per scenario and AQCS cost range. In the first 10 years, cost reached a maximum of US$321.9 million per year, and in the subsequent 10 years US$182.6 million.

Table 2.33: Air Quality Control System Installation Cost, Thailand

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	**Total**	Depreciation equivalent	Loan interest	O&M	**Total**
Scenario 1	Low case	31.9	3.2	0.5	4.8	**8.4**			4.8	**4.8**
	High case	59.2	5.9	0.9	8.9	**15.6**			8.9	**8.9**
Scenario 2	Low case	794.0	79.4	11.4	119.1	**209.9**			119.1	**119.1**
	High case	1,217.4	121.7	17.6	182.6	**321.9**			182.6	**182.6**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.34 shows the AQCS installation cost divided by the annual electricity sales volume.

Table 2.34: Air Quality Control System Installation Cost per kWh, Thailand

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	182,620	8.4	**0.005**	4.8	**0.003**
	High case		15.6	**0.009**	8.9	**0.005**
Scenario 2	Low case		209.9	**0.115**	119.1	**0.065**
	High case		321.9	**0.176**	182.6	**0.100**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.35 shows the impact of AQCS installation cost on electricity price per scenario and AQCS cost range. AQCS installation cost has a maximum impact of 1.8% on electricity prices in the first 10 years, and 1.0% in the subsequent 10 years.

Table 2.35: Impact on Electricity Prices, Thailand

		First 10 years (per year)				Subsequent 10 years (per year)			
		Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Electricity price (2016)	US cent/ kWh	10.9	11.3	9.5	10.3	<--	<--	<--	<--
Impact									
Scenario 1	Low case	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High case	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
Scenario 2	Low case	1.1%	1.0%	1.2%	1.1%	0.6%	0.6%	0.7%	0.6%
	High case	1.6%	1.6%	1.8%	1.7%	0.9%	0.9%	1.0%	1.0%

Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).

g) Viet Nam

(1) CAPEX

Table 2.36 shows AQCS installation CAPEX per scenario and AQCS cost range. In scenario 1, the low case was US$652.1 million and the high case US$974.2 million. In scenario 2, the low case was US$2,051.8 million and the high case US$3,146.1 million.

Table 2.36: Capital Expenditure of Air Quality Control System Installation, Viet Nam

Scenario	Capacity (MW)			CAPEX (US$ million)							
				Low case				High case			
	PM	SOx	NOx	PM (ESP)	SOx	NOx	**Total**	PM (ESP)	SOx	NOx	**Total**
(US$/kW)				(20)	(80)	(50)		(60)	(100)	(70)	
Scenario 1	2,275	960	10,596	45.5	76.8	529.8	**652.1**	136.5	96.0	741.7	**974.2**
Scenario 2	13,679	13,679	13,679	273.6	1,094.3	683.9	**2,051.8**	820.7	1,367.9	957.5	**3,146.1**

CAPEX = capital expenditure, ESP = electrostatic precipitator, NOx = nitrogen oxides, PM = particulate matter, SOx = sulphur oxides.

Source: ERIA (2018). Autoproducers are excluded.

(2) AQCS installation cost

Table 2.37 shows AQCS installation cost per scenario and AQCS cost range. In the first 10 years, the maximum was US$831.9 million per year, and in the subsequent 10 years, US$471.9 million.

Table 2.37: Air Quality Control System Installation Cost, Viet Nam

Scenario	AQCS cost range	CAPEX	AQCS installation cost (US$ million)							
			First 10 years (per year)				Subsequent 10 years (per year)			
			Depreciation equivalent	Loan interest	O&M	Total	Depreciation equivalent	Loan interest	O&M	Total
Scenario 1	Low case	652.1	65.2	9.4	97.8	**172.4**			97.8	**97.8**
	High case	974.2	97.4	14.0	146.1	**257.6**			146.1	**146.1**
Scenario 2	Low case	2,051.8	205.2	29.6	307.8	**542.5**			307.8	**307.8**
	High case	3,146.1	314.6	45.4	471.9	**831.9**			471.9	**471.9**

AQCS = air quality control system, CAPEX = capital expenditure, O&M = operation and maintenance.

Source: ERIA (2018).

(3) AQCS installation cost per kWh

Table 2.38 shows AQCS installation cost divided by annual electricity sales volume.

Table 2.38: Air Quality Control System Installation Cost per kWh, Viet Nam

Scenario	CAPEX	Electricity sales (2016) (GWh)	First 10 years (per year)		Subsequent 10 years (per year)	
			Installation Cost (US$ million)	Cost per kWh (US cent/kWh)	Installation Cost (US$ million)	Cost per kWh (US cent/kWh)
		(a)	(b)	(c)=(b)/(a)	(d)	(e)=(d)/(a)
Scenario 1	Low case	142,800	172.4	**0.121**	97.8	**0.068**
	High case		257.6	**0.180**	146.1	**0.102**
Scenario 2	Low case		542.5	**0.380**	307.8	**0.216**
	High case		831.9	**0.583**	471.9	**0.330**

CAPEX = capital expenditure.

Source: ERIA (2018).

(4) Impact on electricity prices

Table 2.39 shows the impact of AQCS installation cost on electricity price per scenario and AQCS cost range. AQCS installation cost has a maximum impact of 8.8% on electricity prices in the first 10 years, and 5.0% in the subsequent 10 years.

Table 2.39: Impact of Air Quality Control System Installation Cost on Electricity Prices, Viet Nam

		First 10 years (per year)				Subsequent 10 years (per year)			
		Res.	Com.	Ind.	Total	Res.	Com.	Ind.	Total
Electricity price (2016)	US cent/ kWh	11.2	11.1	6.6	8.7	<--	<--	<--	<--
Impact									
Scenario 1	Low case	1.1%	1.1%	1.8%	1.4%	0.6%	0.6%	1.0%	0.8%
	High case	1.6%	1.6%	2.7%	2.1%	0.9%	0.9%	1.6%	1.2%
Scenario 2	Low case	3.4%	3.4%	5.8%	4.4%	1.9%	1.9%	3.3%	2.5%
	High case	5.2%	5.2%	8.8%	6.7%	3.0%	3.0%	5.0%	3.8%

Com. = commercial, Ind. = industry, Res. = residential.

Source: ERIA (2018).