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Study on the Biomass and Coal Co-combustion in the ASEAN Region

Edited by

Otaka Yasuo

Yamada Fumiko

Han Phoumin

Economic Research Institute for ASEAN and East Asia

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Contents

List of Figures

List of Tables

List of Project Members

Working Group Members

Mr Chheang Bunthy Deputy Director, Generation, Transmission and Sub-Transmission Department, Electricity Authority of Cambodia (EAC), Cambodia
Mr Sok Chandareth, Chief of Energy Statistic Office, Ministry of Mines and Energy, Cambodia
Mr Han Vanra, Deputy Chief of Independent Power Producers Operation Office, Electricity De Cambodia (EDC), Cambodia
Ms Elis Heviati, Deputy Director for Investment and Cooperation of Bioenergy, Directorate of Bioenergy, Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources, Indonesia
Mr Jensen M. Alvarez, Senior Science Research Specialist, Biomass Energy Management Division, Renewable Energy Management Bureau, Department of Energy, Philippines
Mr Litz M. Manuel-Santana, Vice President and Head, External Affairs, MERALCO PowerGen Corporation, Philippines
Mr Chawit Chongwilaiwan, Head, Hydro Power Project Feasibility Study Section, Hydro Power Plant Planning and Feasibility Study Department, Power Plant Development Planning Division, Electricity Generating Authority of Thailand (EGAT), Thailand
Dr Yaowateera Achawangkul, Mechanical Engineer, Senior Professional Level, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand

ERIA Project Organiser

Dr Han Phoumin, Energy Economist, Energy Unit, Research Department, Economic Research Institute for ASEAN and East Asia (ERIA)

JCOAL Study Team

Dr Murakami Kazuyuki, Principal Deputy Director, International Collaborations Department
Mr Otaka Yasuo, Deputy Director, Resources Development Department
Mr Uehara Masafumi, Assistant Secretary General
Ms Yamada Fumiko, Assistant Director, International Collaborations Department
Mr Ozawa Masahiro, Chief Engineer, International Collaborations Department

Abbreviations and Acronyms

AMS	ASEAN Member State
ASEAN	Association of Southeast Asian Nations
CEL	Cambodia Energy Limited
CFB	circulating fluidised bed
CO_2	carbon dioxide
DOE	Department of Energy (Philippines)
EFB	empty fruit bunch
GDP	gross domestic products
ICI	Indonesian Coal Index
IPP	independent power producer
LHV	low heating value
MESTECC	Ministry of Energy, Science, Technology, Environment and Climate Change
PKS	kernel shell
PLN	Perusahaan Listrik Negara
USC	ultra supercritical

Chapter 1

Introduction

1. Background and Objectives of the Project

1.1. Project Background

Electricity demand in the region of the Association of Southeast Asian Nations (ASEAN) is rising as its economy grows steadily. To address the surging demand, the development of power plants is expected to proceed towards a well-balanced optimal generation mix with coal, gas, and renewables.

As the Joint Ministerial Statement of the 36th ASEAN Ministers on Energy Meeting[1] held on 29 October 2018 in Singapore puts it, ASEAN member states (AMSs) share the view that coal is strategically important, having advantages over gas in terms of generation cost and abundant availability in the East Asia Summit region. Accordingly, most ASEAN governments foresee that coal will remain as a major generation source in the long run, even if they are also committed to reduce emissions to address climate change issues by introducing renewable energy and by facilitating the cleanest-possible use of coal, for which, as the Declaration says, the use of clean coal technology is vitally important.

During the development period in the ASEAN region, regardless of the generation source, the development of large power plants to supply electricity to urban and/or industrial areas was initiated to bolster overall national development. Now that the fruits of national development are to be shared broadly with all the people in each member state and the region, the respective governments are pressed to facilitate the development of smaller-scale power plants – from 100 MW or less – in the areas that are yet to enjoy the benefits of electricity. However, the high-efficiency ultra-supercritical (USC) boiler that is deemed to be the most environmentally compliant among the broadly available technologies may not be applicable to such smaller-scale power generation. Circulating fluidised bed (CFB) combustion technology at small scale enables appropriate combustion even on low rank coals. To stress a point, the CFB is more advantageous than the USC in small-scale power generation.

Full-fledged biomass utilisation is one important issue for the AMSs, in which agriculture and forest remain the crucial industrial sectors. Most of the residue is treated as waste either through incineration or landfill, which may cause environmental degradation into the future if continued. Shedding light on the other aspect, these wastes vary in terms of types, grades, and characteristics and are sufficient in quantity. In summary, such biomass resources are ready for utilisation and are expected to be a most promising renewable fuel for small-scale power generation in addressing the issues of carbon dioxide (CO_2) emissions reduction and rural electrification that are crucial to rural development. That being said, biomass resources

[1] https://asean.org/storage/2018/10/JMS-of-the-36th-AMEM-Final.pdf

are intermittent just like the rest of the renewable resources since they are basically seasonal.

Coal, a generation source that is easily available, may be complementary with biomass resources and vice versa as biomass resources may significantly reduce CO_2 emissions that may not be achieved if a smaller-scale power plant is operated on coal only.

1.2. Objectives

The Study on Biomass and Coal Co-combustion in the ASEAN Region ('the Study') was conducted to finally provide a proposal to reduce CO_2 emissions and to better secure energy through coal and biomass co-combustion on CFB boiler in the ASEAN region. For this reason, two models from the member states – one coal producer and the other coal importer, both of which have high demand for coal and have abundant biomass resources – were selected.

Said proposal shall comprise the optimal combination of coal and biomass resources in terms of type, volume, and the most suitable technology for identified AMSs considering fuel availability, environmental performance, and economy.

2. Methodologies of the Project

2.1. Case selection

The AMSs are generally rich in biomass resources. There are two types of member states that are clear on coal utilisation for power generation in parallel with renewables and other resources: (i) a biomass-rich and coal-producing country, and (ii) a biomass-rich and coal-importing country.

Accordingly, the Study focuses on the following two cases in pursuit of the optimal proposal of biomass and coal co-combustion on CFB boiler.

Case 1: Indonesia as a biomass-rich and coal-producing country
Case 2: The Philippines as a biomass-rich and coal-importing country

In the meantime, proposals will be made for the eight target member states: Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam, which maintain coal use in their respective national energy policies.

2.2. Survey on the overall situation of power generation, coal and biomass utilisation in the power sector in the ASEAN region

A literature survey through the Internet and/or direct interviews/communication on the following topics A) to C) were conducted for relevant information and data from international organisations, such as the International Energy Agency, ASEAN Centre for Energy, ASEAN governments' authorities, etc.

Also conducted is a techno-economic study on coal and biomass co-combustion in order to identify the optimal option each target member state is recommended to choose.

a) Energy and power demand and supply situation and position of coal in the national energy policy

- Analyse the statistical data of the International Energy Agency and others to quantitatively understand the energy/power demand and supply situation in the target member states.

b) Advantages and importance of coal and biomass resources

- Identify the quantitative advantages of coal in the context of energy self-sufficiency and energy prices in the ASEAN region.
- In identifying optimal biomass resources and quantitative analysis, comprehensively study available agricultural and forestry waste types, amount and method of procurement, cost, etc., in view of the diversity in agricultural and forestry products as well as part of such biomass products that are available in the market since the rest are being treated as waste.
- Study and assess coal and biomass co-combustion technology and individual applicability to each AMS and requisites to be considered.

c) Importance of coal and biomass co-utilisation in the context of energy security in the ASEAN region

- Justify under-utilised agricultural and forestry wastes that have potential as biomass generation sources. Also, coal and biomass co-utilisation for power generation will be conducive to the energy security of the AMSs and the region, based on the foregoing analytical work.

2.3. Extent of direct and indirect effects of biomass and coal combustion on each target member state for environmental compliance and other relevant aspects

a) Effects expected from biomass and coal co-combustion

- Efficient use of generation resources in the target AMS and the ASEAN region
- Expected extent of CO_2 emissions reduction that would have a positive environmental impact
- Analytical review of a proposed case of biomass and coal co-combustion as an alternative to full coal power generation and its possible impact on the existing energy policy of the target member state

b) Economic advantages of biomass and coal co-combustion in the ASEAN region

- Identify economic advantages and other effects of biomass and coal co-combustion in the ASEAN region based on the techno-economic study.

2.4. Working Group meeting in Jakarta

To discuss the applicability of biomass and coal co-combustion and gather relevant information and data from each member state concerned, a Working Group meeting was held in Jakarta. Policymakers and business experts in electricity utilities from the AMSs were invited and the directions of the study were confirmed.

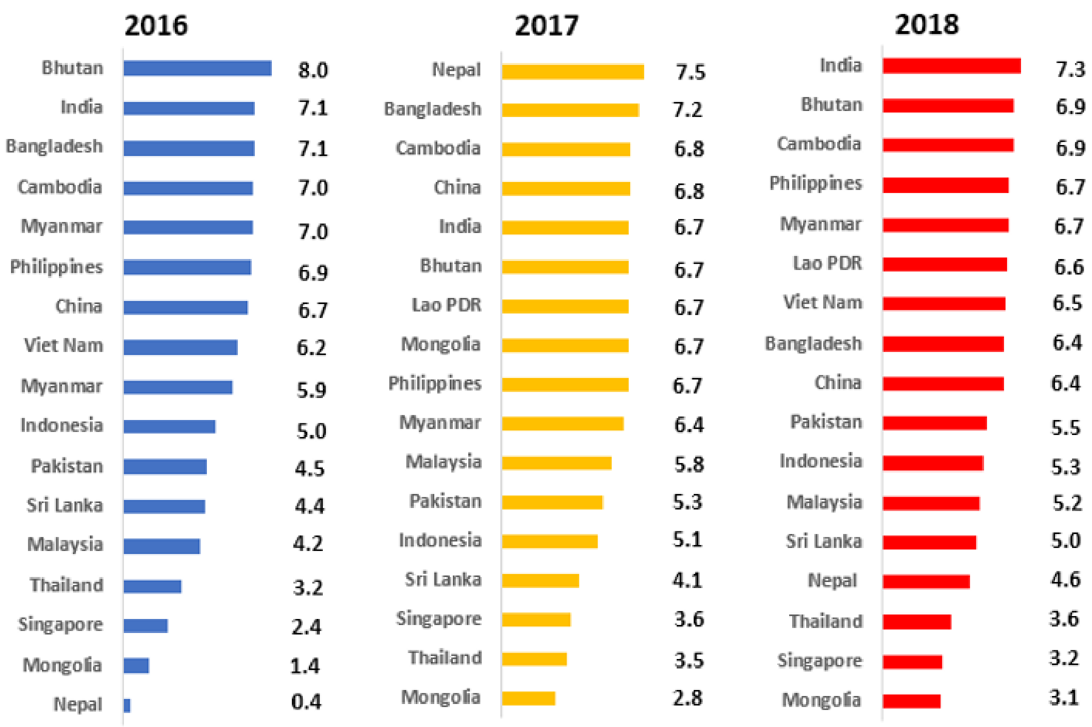
Chapter 2
Overview of the Energy and Power Situation in ASEAN

1. Energy, Power, and Environmental Situation in ASEAN

1.1. Economic growth in ASEAN

Having successfully weathered the 1997 Asian financial crisis and the 2008–2009 global economic crisis, ASEAN is now the fastest-growing and the sixth largest economy globally. Nine (9) out of 10 AMSs are in the list of 17 countries with highest growth in Asia for 2016–2018 (Figure 2.1).

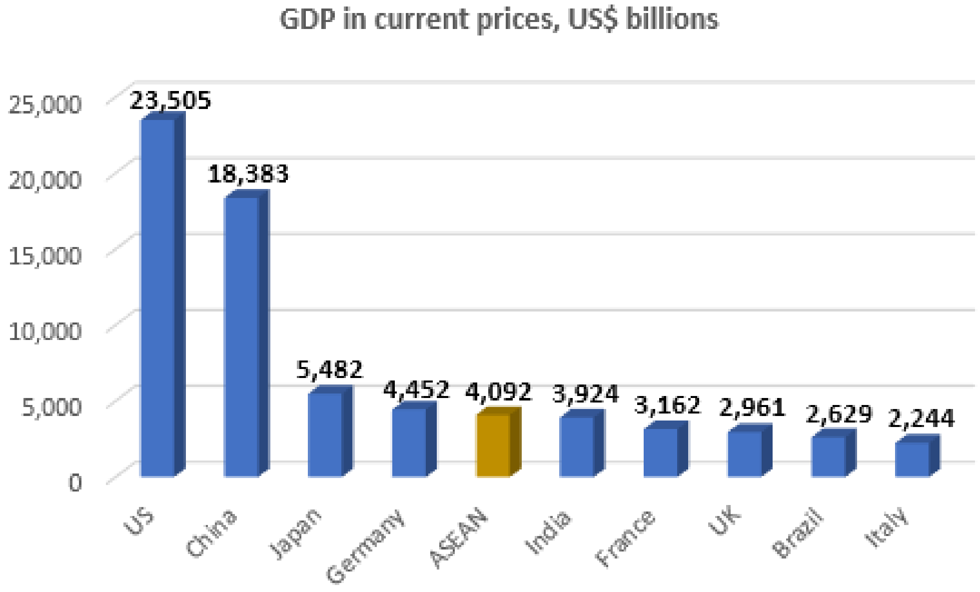
Figure 2.1. GDP Growth Projection for Asia, 2018



Source: The World Bank (2018).

ASEAN is forecasted to be the fifth-largest market by gross domestic product (GDP) size by 2022, when its GDP is expected to exceed US$4 trillion.

Figure 2.2. Top 10 Markets Worldwide in 2022, by GDP Size

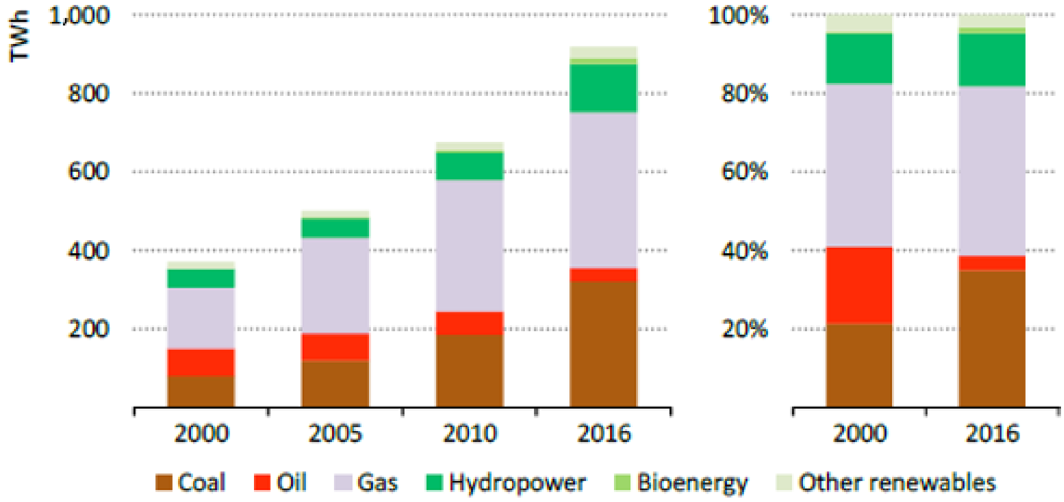


UK = United Kingdom, US = United States.
Source: PwC (2018).

1.2. Power demand growth and power generation mix

The electricity demand in the region, accordingly, has more than doubled in 2000–2016. Coal, as an abundant, affordable, and available electricity source, bolsters demand and economic growth.

Figure 2.3. Growth of Power Generation Mix in ASEAN



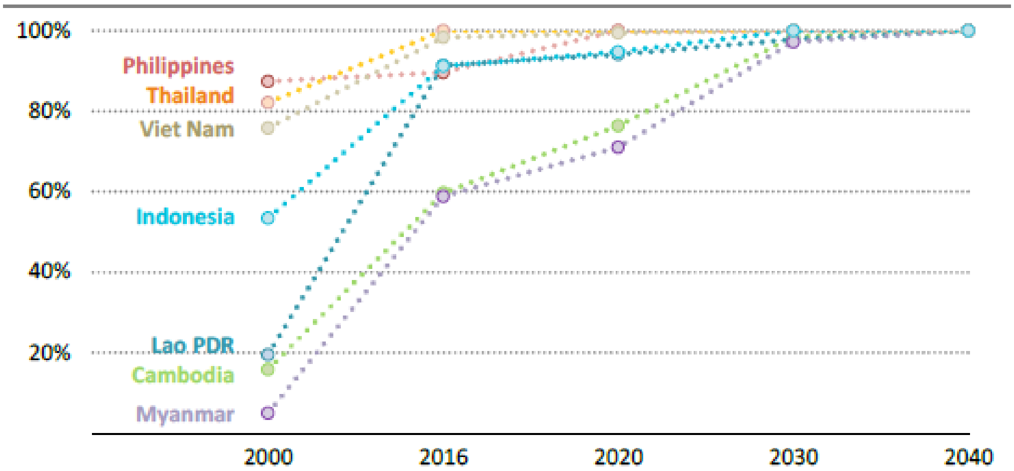
Source: IEA (2017).

Improvement of electricity access in the ASEAN region

While ASEAN as a collective group of states has made such outstanding progress during the past decades and is anticipated to continuously lead the economic path right on track, regional variations or even disparity remains in the socio-economic status of each member state, which affects national energy policy and planning.

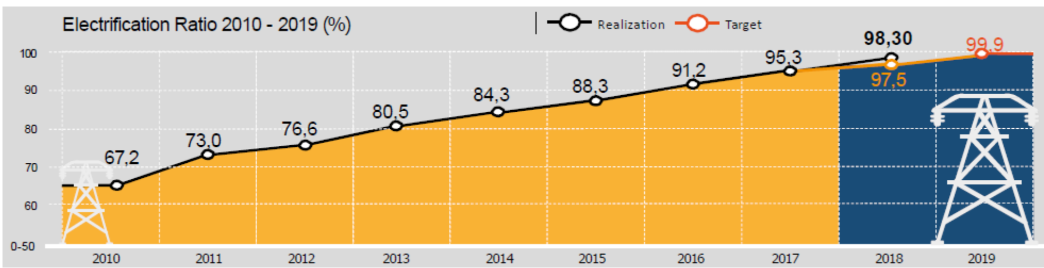
Especially in the past decade, the AMSs have been strenuously endeavouring to extend access to electricity. However, due to geographical and other country-specific reasons, the gap of electrification rate between each AMS used to be quite wide in 2000, but the gap had narrowed as of 2016. The Philippines and Thailand were getting close to 100% electrification following Brunei, Malaysia, and Singapore. Viet Nam was awarded by the World Bank as an emerging economy with the highest rural electrification ratio in the world of more than 99%.

Figure 2.4. Narrowing the Gap in Electricity Access



Source: IEA (2017).

Figure 2.5. Improvement of Electrification Access in Indonesia



Source: Indonesia Country Report Presentation at the ERIA Working Group Meeting.

Indonesia is another success story. An archipelagic country with 17,508 islands, it has also been struggling for years to increase electricity access towards 100% electrification. In 2015, the national electrification rate was 88.3% and was expected to reach 99.9% in 2019 (Figure 2.5).

Cambodia and Myanmar have seen an outstanding growth in their respective economies and their electrification ratio during the last decade. However, in Myanmar, a mere 34% of households have access to basic electricity services nationwide and 16% in rural areas. In Cambodia, a large part of households – about 6.62 million people – have yet to have access to electricity. They are continuously struggling to further boost the electrification ratio to catch up with the rest of the AMSs.

Towards full electrification: the issue of rural electrification and policy efforts to fill in the gap

While most AMSs appear to be on the same smooth path towards full electrification, they face a common issue – rural electrification – even after achieving over an 80%–90% electrification rate. Their respective governments are trying to enhance their policy efforts to fill in the gap between regions or between the urban and rural areas to expedite rural electrification.

The Government of Cambodia set a two-step target in rural electrification: (i) by the year 2020, all the villages would have electricity of some type; and (ii) by 2030, at least 70% of households would have access to grid-quality electricity (Department of Rural Electrification Fund, 2018). The government announced that Cambodia would push ahead with plans to use hydropower and coal to achieve these. These are the major power sources to electrify the entire country by 2020, while renewables are also expected to play some roles (Thomson Reuters Foundation News, 2018).

In the meantime, the Government of Myanmar approved in its National Electrification Plan an ambitious target of universal access to electricity (7.2 million new connections) by 2030. In off-grid areas (those not likely to be connected to the national grid before 2026), the plan predicts that as many as 2.4 million new household connections could be made through solar home systems and mini-grids by 2021, plus tens of thousands more community connections and public lighting connections.

Archipelagic Indonesia has more than 73,000 villages, out of which about 2,500 villages are targeted under the government's special electrification programme 'Indonesia Terang' supported by the Japan International Cooperation Agency. The programme, separate from the major electricity development plan of the Perusahaan Listrik Negara (PLN), focuses on three types of renewables: micro hydro, wind, and solar photovoltaic. The programme for 10,300 villages is more for the six provinces of Papua, West Papua, Maluku, Maluku Utara, East Nusa Tenggara, and West Nusa Tenggara, where 6,689 villages are awaiting electrification. It is unique and quite sustainable as it emphasises a shorter time to prepare and develop the project, including managing both local government and community.

As shown in the list of Philippines household electrification rates by region (Table 2.1), the Philippine government has mandated off-grid missionary electrification to the National Power Corporation and has been supporting Missionary Electrification through electricity subsidies. Recently, the Department of Energy (DOE) announced that the subsidies would be removed and private sector participation in the field would be stimulated to further expedite rural electrification.

Table 2.1. Philippines Household Electrification Level, by Region (as of December 2016)

Region	Total HH	Served HH	Unserved HH	Electrification Level (%)
CAR	392,000	348,471	43,529	88.9
I	1,184,431	1,100,259	84,172	92.9
II	785,900	721,354	64,546	91.8
III	2,687,073	2,593,462	93,611	96.5
IV-A	3,506,353	3,376,855	129,498	96.3
IV-B	648,149	533,017	115,132	82.2
NCR	3,512,439	3,451,303	61,136	98.3
V	1,087,469	964,270	123,199	88.7
Luzon Total	**13,803,814**	**13,088,991**	**714,823**	94.8
VI	924,701	863,878	60,823	93.4
VII	1,430,541	1,371,853	58,688	95.9
VIII	889,968	776,180	113,788	87.2
NIR	831,100	755,480	75,620	90.9
Visayas Total	**4,076,309**	**3,767,391**	**308,918**	**92.4**
ARMM	514,592	199,373	315,219	38.7
CARAGA	607,700	570,025	37,675	93.8
IX	655,300	476,510	178,790	72.7
X	1,039,243	837,560	201,683	80.6
XI	1,076,655	771,250	305,405	71.6
XII	947,816	649,234	298,582	68.5
Mindanao Total	**4,841,306**	**3,503,952**	**1,337,354**	**72.4**
Philippines	**22,721,430**	**20,360,334**	**2,361,096**	**89.6**

ARMM = Autonomous Region of Muslim Mindanao, CARAGA = Caraga Administrative Region, HH = household, NCR = National Capital Region, NIR = Negros Island Region.
Source: DOE (2017).

This report deliberates on the roles and possibilities expected of biomass–coal combustion to accelerate the smooth implementation of rural electrification by AMS governments to immediately realise full electrification.

1.3. Commitment to climate change and environmental compliance

All AMSs had ratified the Paris Agreement and made voluntary commitments. Undoubtedly, it is important for them to develop power and further electrification while mitigating CO_2 emissions to the extent possible for both global and local communities. Their national target of climate change, electrification, renewables, and efficiency are indicated in Table 2.2.

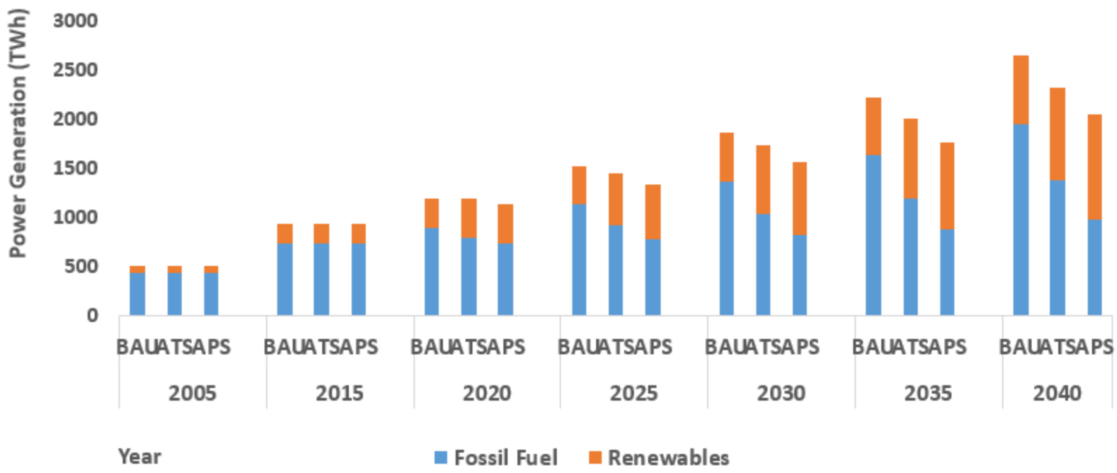
Table 2.2. National Energy and Climate Targets of ASEAN Member States

	Climate Change	Electrification	Renewables	Efficiency
Brunei	Reduce CO^2 emissions from morning peak-hour vehicle use by 40% from BAU level by 2035.		Increase share of new and renewable energy in generation mix to 10% in 2035.	Reduce total energy consumption by 63% from BAU levels by 2035.
Cambodia	Reduce GHG emissions by 27% from baseline emissions by 2030 with international support.	Universal electrification for all villages by 2020 and 70% electrification for households by 2030.	Increase share of new and renewable energy in generation mix to 25% in 2035	
Indonesia	Reduce GHG emission 29% from BAU and 41% with international support by 2030.	Achieve electrification ratio of 99.7% by 2025.	Increase share of new and renewable energy in primary energy supply to reach 23% by 2025 and 31% by 2050.	Reduce energy intensity by 1% per year to 2025.
Lao PDR		Achieve electrification rate of 98% by 2025.	Achieve 30% share of renewables in primary energy supply by 2025.	Reduce final energy consumption from BAU level by 10%.
Malaysia	Reduce GHG intensity of GDP by 35% by 2030 from 2005 level, increase to 45%reduction with enhanced international support.		Increase share of new and renewable energy in generation mix to 9% in 2020, 20% in 2030.	Promote energy efficiency in the industry, buildings and domestic sectors with methods of standard setting, labelling, energy audits and building design.
Myanmar		Achieve total electrification rate of 100% by 2030.	Increase share of new and renewable energy in generation mix to 15% in 2020.	Reduce primary energy demand by 8% by 2030 from 2035 level.
Philippines	Reduce GHG emissions by 70% from BAU level by 2030 with the condition of international support.	Achieve 100% electrification by 2022.	Increase of new and renewable energy in generation mix to 35% in 2030.	Reduce 40% energy intensity by 2030 from 2010 level. Decrease energy consumption by 1.6% per year against baseline forecasts by 2030.
Singapore	Reduce GHG emissions by 16% below BAU level by 2020, stabilize emissions with the aim of peaking around 2030.		Increase share of new and renewable energy in generation mix to 8%.	Improve energy intensity by 36% by 2030 from 2010 level.
Thailand	Reduce GHG emissions by 20% from BAU level by 2030, increase to 25% with enhanced interntional support.		Increase share of new and renewable energy in generation mix to 20.11%, and share of renewables in transport fuel consumption to 25.04% by 2036.	Reduce energy intensity by 30% by 2036 from 2010 level.

BAU = Business-As-Usual Scenario, CO_2 = carbon dioxide, GDP = gross domestic product, GHG = greenhouse gas.
Source: The Study Team, based on SEO 2017 and ASEAN Action Plan for Energy Cooperation 2016–2025.

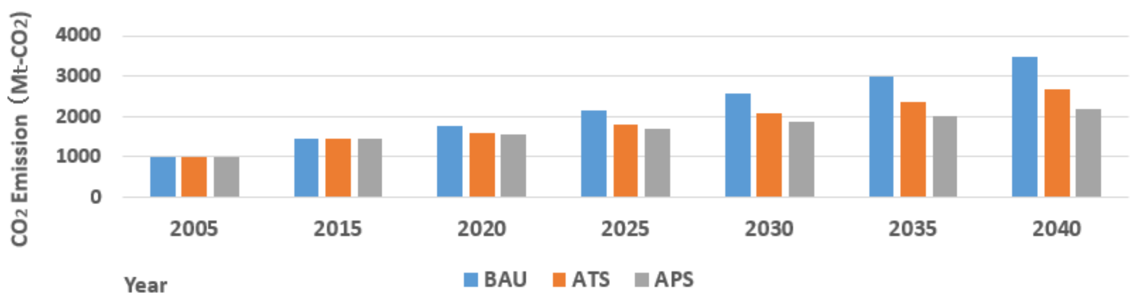
The 5th ASEAN Energy Outlook clearly shows how the AMSs have been firmly addressing the issue of CO_2 emissions in the power sector (Figure 2.7). ATS stands for data of the AMS Targets Scenario, while APS stands for data of the ASEAN Progressive Scenario. From 2005 to 2015, CO_2 emissions clearly did not increase as much as power generated in the same period. From 2015 to 2040, CO_2 emissions are predicted to be 2.4 times, while in the APS it will be 1.5 times only.

Figure 2.6. Growth of Power Generation in ASEAN



APS = ASEAN Progressive Scenario, ATS = AMS Targets Scenario, BAU = Business-as-Usual Scenario.
Source: ACE (2015).

Figure 2.7. CO_2 Emissions in ASEAN



ATS = AMS Targets Scenario, APS = ASEAN Progressive Scenario, BAU = Business-as-Usual Scenario.
Source: ACE (2015).

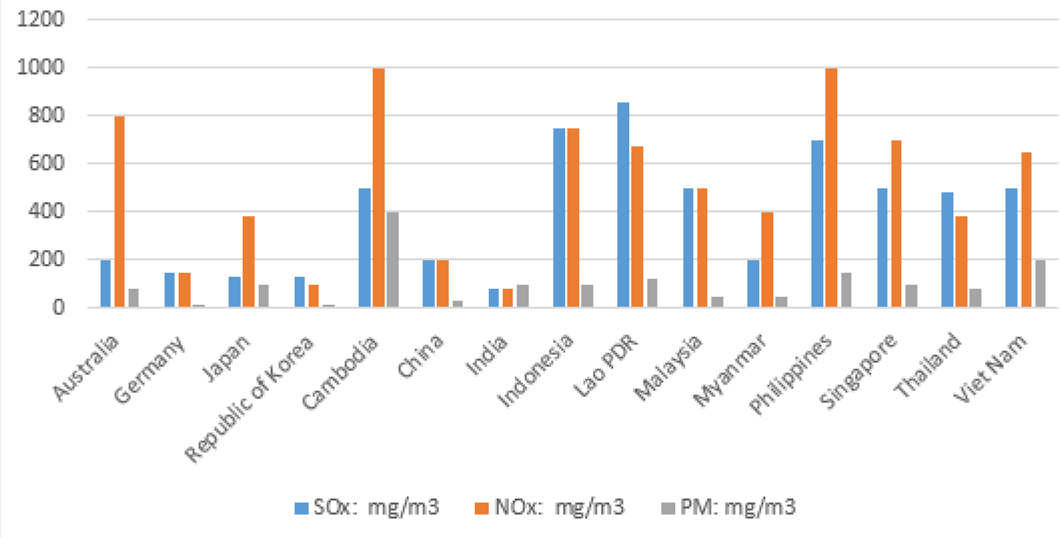
It is worthy to note that between 2005 and 2015, regardless of the scenario, the increased volume of CO_2 emissions is kept lower against the power generation growth, which has been realised through the efforts of the AMSs to improve efficiency.

Issue of environmental compliance and public acceptance

When considering the global environment, it is important to reduce and control CO_2 emissions. However, on regional and living environments, other pollutants that affect the local and living environments such as sulphur oxide (SOx), nitrogen oxide (NOx), dust, etc. should be considered and significantly improved.

For this reason, environmental regulations in each country are gradually tightened. Figure 2.1-8 shows the environmental regulation values of recent coal-fired power plants in major countries. In Germany, Japan, and South Korea, each environmental regulation value is as low as 100–150 mg/m^3 for SOx, 50–200 mg/m^3 for NOx, and 10–100 mg/m^3 for vehicle dust. In China and India, environmental regulations have been greatly strengthened due to the deterioration of the air quality for several years. Environmental efforts have been tightened with values of 100 mg/m^3 or less. On the other hand, in the ASEAN region, SOx is high at 200–850 mg/m^3, NOx at 380–1,000 mg/m^3, and medium dust at 80–400 mg/m^3.

Figure 2.8. Emission Standards for Newly Constructed Coal-fired Power Plants in Selected Countries (SOx, NOx, and PM)



NOx = nitrogen oxide, PM = particulate matter, SOx = sulphur oxide.
Source: *Myanmar Times* (2018).

In light of the above, promoting the policy improvement of the environment in the ASEAN region is deemed important.

It is technically possible to install and strengthen each countermeasure equipment for environmental improvement. However, increase in equipment costs leads to increased electricity prices. It is assumed that it will be difficult for countries and regions to respond and adopt this measure. Therefore, depending on the fuel used, a more optimal measure is desired.

Currently, the distribution of electricity is essential in improving the quality of life and the living standards of people. Achieving universal access to electricity is one important policy issue for ASEAN countries to continue to steadily grow even for those that still have non-electrified areas. Since coal is widely distributed worldwide, a stable and relatively inexpensive supply is possible. We have clearly stated that we will continue to use clean coal to generate power. ASEAN countries continue to use coal for their development, notwithstanding the adverse international public opinion on coal-fired power over global warming issues by environmental groups concerned about air pollution in each country/region. To do so, it is important that coal-fired plants are highly accepted publicly.

Specifically, while responding logically to the various criticisms mentioned above, environment-friendly technologies are being developed for coal-fired power plants already in operation and for those to be developed in the future. It is necessary to introduce environment-friendly technologies.

In the past, environmental measures for coal-fired power plants in the ASEAN region were limited to the installation of dust collectors, which led to opposition to construct coal-fired power plants. However, in recent years, in addition to the improvement in the performance of dust collectors, the technological development of SOx and NOx measures have progressed, leading to significant environmental improvements.

Since the volume of emitted air pollutants change depending on the fuel, fuel pre-treatment may help save an excessive increase in environmental protection costs.

While the main thing is that the envisaged coal is practically available, it is also important to pay extra care to the amount of ash, flammability, ash properties, and water content by which unnecessary introduction of excessive equipment would be avoided. Thus, the introduction of biomass co-combustion is expected to provide appreciable advantages in terms of saving fuel and improving environmental compliance as well as enhancing public acceptance.

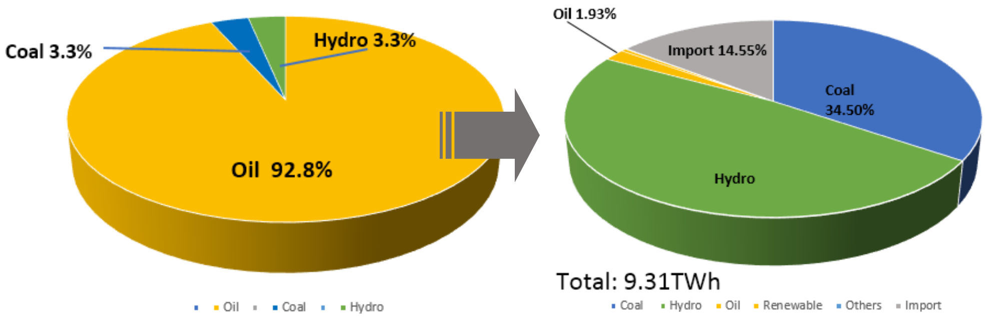
2. National Energy and Power Situation in ASEAN

2.1. Energy policy and generation mix of the AMSs

Cambodia

As of now, the major generation sources are hydro and coal. Generation mix in 2010 shows how the country was ever dependent on oil when it accounted for over 90% of the generation mix. It is admirable that the government has initiated diversification of generation sources, so the generation mix has been drastically changed to have two sources as the backbone of power generation (Figure 2.9).

Figure 2.9. Generation Mix of Cambodia, 2010 and 2015



Source: EAC (2018).

According to the transition of power generation from 2007 to 2017, power generation increased at 17.3% annually. If it increases at this ratio, power generation will be 23,774 GWh in 2025, 3.6 times of 6,634 GWh in 2017. Table 3 shows the construction plan for coal-fired power plants. Power generation from coal-fired power plants is planned to be expanded to 700 MW by the Sihanoukville Cambodia International Investment Development Group (CIIDG), which is currently at 405 MW. An additional 295 MW capacity will be constructed.

The Cambodia Energy Limited (CEL) is planning a 135 MW CEL Ⅱ in Sihanoukville in addition to the current 100 MW, totalling 235 MW. Toshiba already signed an EPC contract for CEL Ⅱ, whose scheduled commercial operation date is in late 2019 (Table 2.3).

Table 2.3. Construction Plan of Coal-fired Power Plants

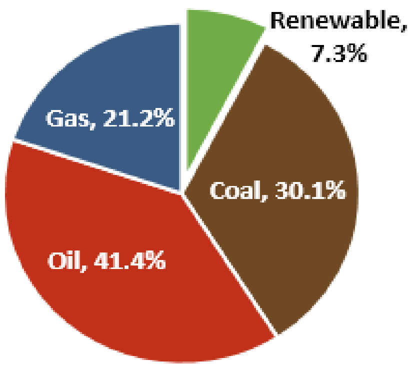
	Name of Power Plant	Condition	Capacity (MW)
Coal	Sihanoukville CIIDG Power Station (Phase 1)	Existing	405
	Sihanoukville CIIDG Power Station (Phase 2)	Expand	700
	Sihanoukville CEL Power Station	Existing (CEL)	100
		Expand (CEL Ⅱ)	135

CEL = Cambodia Energy Limited, CIIDG = Cambodia International Investment Development Group.
Source: EAC (2018).

Indonesia

Having been successful in getting out of oil dependency during the fuel crisis in the early 2000s, Indonesia remains highly dependent on fossil fuel. More than 90% of national energy consumption is sourced from fossil fuels – oil, gas, and coal – while fossil fuel reserves are declining gradually.

Figure 2.10. Primary Energy Mix of Indonesia, 2017

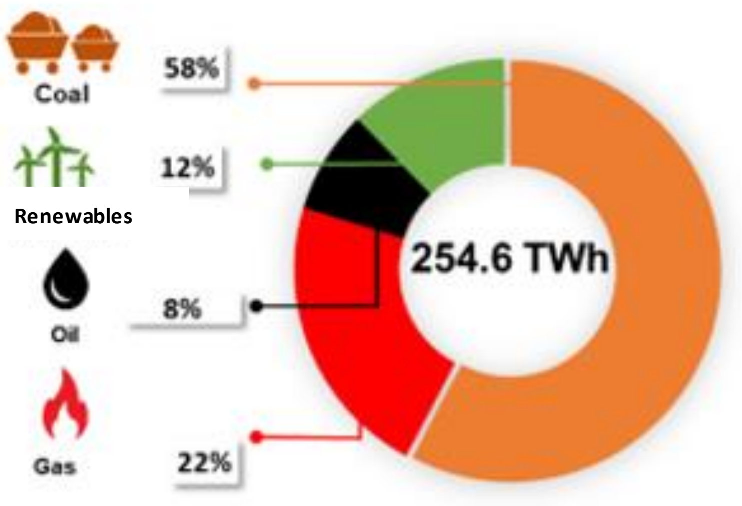


Source: MEMR (2018).

The government is now trying to ensure energy diversification by developing new and renewable energy, including bioenergy, waste-to-energy, etc.[2]

[2] According to presentations during the working group meeting, the total capacity of bioenergy power plants had reached 1,858.5 MW as of 2018. The government identified 12 waste-to-energy project sites with expected generated amount to be 207–242 MW.

Figure 2.11. Generation Mix of Indonesia, 2017



Source: MEMR (2018).

That said, coal remains the backbone of Indonesia's national electricity mix. The power generation in 2027 will be 501,917 GWh, which is about 2.5 times of the present capacity. The ratio of coal is 293,902 GWh, accounting for 59% of the total generation. In addition, the total capacity of power generation facilities to be built between 2018 and 2027 is 56 GW. Coal power is 27 GW, which is 48% of the total power capacity (Tables 2.4 and 2.5).

Table 2.4. Power Generation Plan of Indonesia, 2018–2027 (GWh)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Coal	169,632	176,517	194,250	220,081	234,455	248,560	264,618	236,841	264,429	293,902
Gas (LNG, etc.)	57,049	68,137	76,069	73,548	80,047	83,660	85,745	96,548	98,120	103,476
Geothermal	14,700	16,532	17,471	19,299	22,382	23,666	26,179	50,782	50,006	49,201
Hydro	18,944	17,594	18,051	19,784	20,028	23,749	27,967	43,135	44,385	46,700
Oil/diesel	11,634	11,429	7,053	3,639	1,679	1,713	1,834	1,826	1,893	2,007
Other renewables	419	2,494	2,906	3,180	3,204	3,260	3,545	6,319	6,591	6,631
Import	1,433	1,559	907	612						
Total	**273,811**	**294,262**	**316,707**	**340,143**	**361,795**	**384,608**	**409,888**	**435,451**	**465,424**	**501,917**

LNG = liquefied natural gas.
Source: PLN (2018).

Table 2.5. Power Plant Construction Plan, 2018–2027 (GW)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	合計
Coal	1,066	1,701	5,800	4,300	4,573	2,978	3,140	775	2,175	300	26,808
Geothermal	210	150	221	235	405	445	355	2,537	20	5	4,583
Gas	1,050	2,358	1,639	1,315	910	1,330	680	100	680	375	10,437
Gas engine	990	964	641	273	320	371	133	103	23	15	3,833
Diesel	30	5	0	0	0	0	0	0	0	0	35
Micro Hydro	109	203	365	103	31	0	0	0	0	0	811
Hydro	66	287	193	755	315	196	115	2,041	0	64	4,032
Solar	0	0	0	0	0	0	520	2,420	0	500	3,440
Others	128	160	261	335	245	240	309	300	0	70	2,048
Total	**3,649**	**5,828**	**9,120**	**7,316**	**6,799**	**5,560**	**5,252**	**8,276**	**2,898**	**1,329**	**56,027**

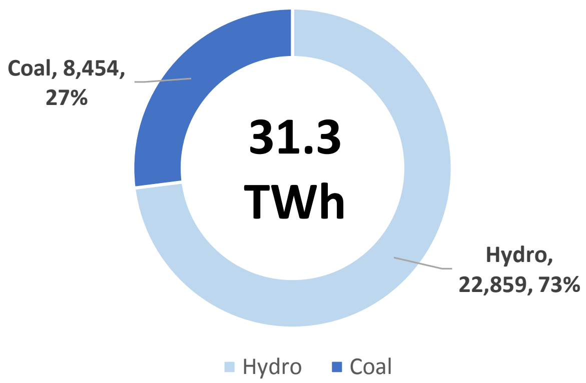
Source: PLN (2018).

Lao PDR

The Lao PDR has large hydropower potential varying from 18,000 MW to 26,000 MW, of which only 18% had been developed as of 2015.

The country has been engaging in electricity export for decades, as it is one of the major sources of state revenue. Total installed capacity is 6,308 MW, of which 2,100 MW is for domestic supply. In view of the supply situation and the relatively well-developed transmission lines, it looks as if the Lao PDR has no issues about national power supply. However, the country is not always a power exporter. The Electricité Du Laos (EDL), the national power company, indicates that it exports during the rainy season and imports during the dry season as most of its generation sources are run-off-river type hydro. The EDL considers diversifying its generation sources to others, including thermal power, to address the issue and ensure sustainable power supply. The policy direction might be the right choice for the government in light of the demand that is growing by 14% every year (EDL, 2017).

Figure 2.12. Power Generation Capacity and Power Generation of the Lao PDR, 2017



Source: EDL (2017).

Figure 2.12 shows that hydropower and coal will remain as the two pillars of power generation in the Lao PDR. The hydropower-installed capacity in 2030 is expected to be 17,486 MW, three times that of 2017. In the meantime, by the expansion of the current mine mouth Hongsa Power Plant and the other two new coal power plants, coal power–installed capacity will increase to 3,378 MW in 2025 – 1.8 times compared to that in 2017 – though the ratio of coal in the electricity mix will go down from 27% in 2017 to 15% in 2035.

Table 2.6. Future Power Generation Plan (MW)

	2017	2020	2025	2030
Coal	1,878	1,878	3,378	3,378
Hydro	5,172	8,735	13,580	17,486
Others	26	70	725	1,031
Total	7,076	10,683	17,683	21,895

Source: EDL (2017).

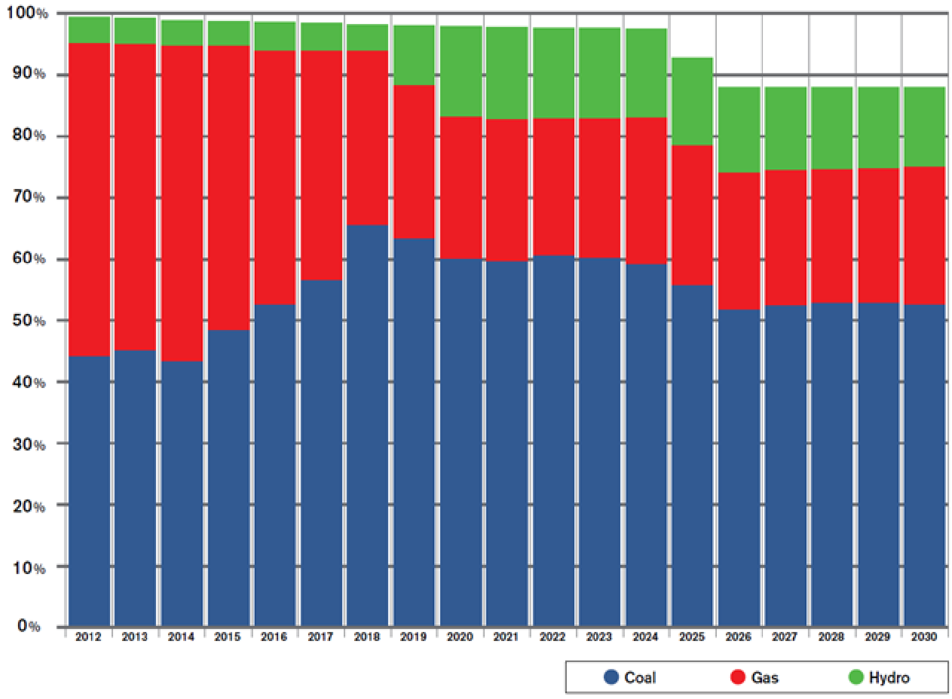
Malaysia

After the Asian financial crisis of 1997–1998, Malaysia's economy has been growing at an average of 5.4% since 2010. The country is expected to achieve its transition from an upper middle–income economy to a high-income economy by 2030 (Ministry of Economic Affairs, 2018).

As of now, about 56% of Malaysia's fuel mix is coal due to its price advantage and its ability to provide a balanced fuel mix in the system. Now the government is considering reducing dependence on fossil fuel, especially coal, and increase renewable energy instead. The target share of renewables in the national generation mix is 9% in 2020, 20% in 2030, which was revised after the new government came to power. The current share of renewable is 1%, but the government and other relevant institutions are ready to work on the plan to achieve the challenging target.

While Malaysia is keen to aggressively enhance renewable energy in its national energy mix, the government sticks to the balance of generation mix in view of the limited reliability of renewables in terms of supply stability, this being essentially intermittent.

Figure 2.13. Peninsular Malaysia and Sabah's Projected Generation Mix (%)



Source: Energy Commission (2017).

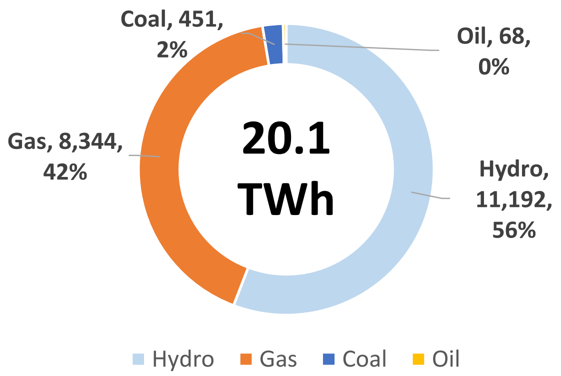
Myanmar

Having undergone political reforms in 2011–2015 followed by the transfer to the democratic government, Myanmar is naturally the least electrified and consumes the least of all AMSs. Myanmar stood at the beginning stages of a market economy only in 2014. Electricity consumption has increased rapidly since 2013 at an annual average growth rate of 15.8%.

In 2015, the National Energy Management Committee of the Government of Myanmar announced the Myanmar Energy Master Plan[3] to address all national energy issues including realisation of the universal access to electricity by 2030. Before the masterplan, the National Energy Policy was formulated in 2014. The policy indicates the national plan for coal-fired power plants with a total capacity of 2,785 MW to fulfil the surging demand. So far, Myanmar has an aged coal-fired power plant, Tigyit, at a rather inconvenient location; the plant is quite far from any of the seaport. Other plants are all small scale at 50–150 MW. Myanmar did not see much progress in new coal-fired power development since 2014 due to the anti-coal sentiment and campaigns in the country.

[3] The masterplan was financed under the Japan Fund for Poverty Reduction and administered by the Asian Development Bank.

Figure 2.14. Power Generation Capacity and Power Generation of Myanmar, 2018



Source: MOEE (Myanmar) (2019).

Philippines

Power generation output increased by 21.1% from 82.4 TWh in 2015 to 99.8 TWh in 2018. Being sourced from coal is 52.1% of the country's electricity, followed by gas (21.4%), and renewables (14.0%) (Figure 2.15).

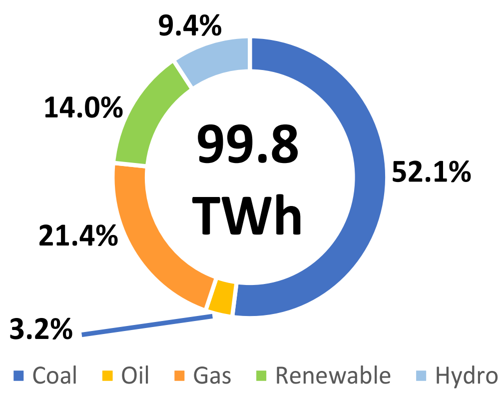
The future power demand in the Philippines is predicted to be 16,323 MW in 2020; 28,158 MW in 2030; and 49,287 MW in 2040. It will increase 1.3 times, 2.3 times, and 4.0 times, respectively, compared to 2015. However, it had already increased by 22,730 MW in 2017, and it would be 2.2 times in 2040 (Table 2.7, Figure 2.15).

Table 2.7. Prediction of Future Power Demand (MW)

	2015	2019	2020	2025	2030	2035	2040
Luzon	8,928	10,895	11,451	14,501	18,432	23,457	29,852
Visayas	1,768	2,298	2,465	3,427	4,765	6,624	9,210
Mindanao	1,517	2,229	2,407	3,456	4,961	7,122	10,225
Total	**12,213**	**15,422**	**16,323**	**21,384**	**28,158**	**37,203**	**49,287**

Source: Department of Energy (2016).

Figure 2.15. Generation Mix of the Philippines, 2018

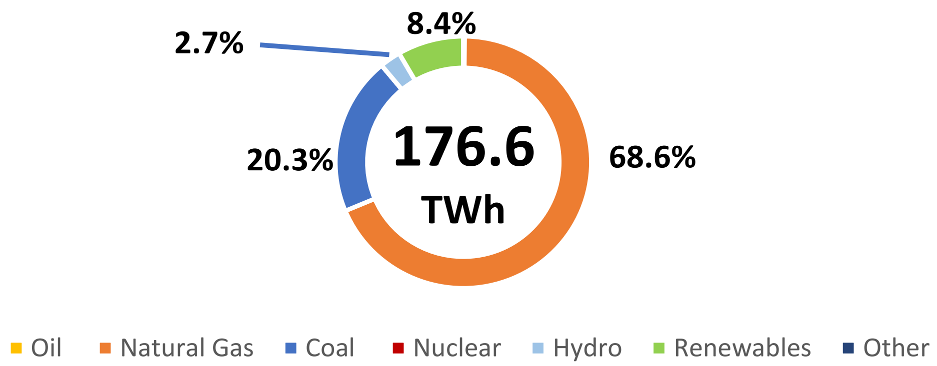


Source: Department of Energy (2018).

Thailand

Figure 2.16 shows the current generation mix of Thailand.

Figure 2.16. Generation Mix of Thailand, 2017



Source: BP (2018).

In January 2019, the Government of Thailand announced the revised Power Development Plan (PDP) 2018–2037. This clearly reflected a policy revision, if not a change of direction, in the then-forthcoming national power development planning and implementation reflecting Thailand's renewable energy policy, the Alternative Energy Development Plan 2018.

Table 2.8 compares the previous 2015 PDP and the amended PDP.

Table 2.8. Comparison of 2015 PDP and 2019 Amended PDP

Type of energy source	2036 Targets (%) under 2015 PDP	2037 Targets (%) under 2019 Amended PDP
Natural Gas	37	53
Coal	23	12
Hydropower from neighbouring country	15	9
Alternative Energy	20	20
Nuclear	5	-
Others	0.1	0.06
Energy efficiency	0	6

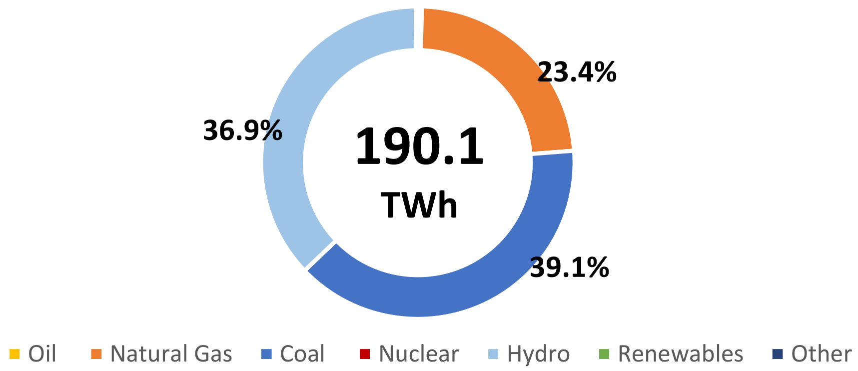
PDP = power development plan.
Source: EGAT (2015, 2019).

Having once shifted to increase coal-fired power generation in its generation mix to pull out from excessive dependency on gas, Thailand is now shifting again its policy direction to restructure its electricity mix by making an impressive 'comeback' to gas (from 37% to 53%). Coal's share has been reduced to 12% from 23%, and even hydropower will decrease to 9% from 15%.

The total installed capacity is 46,090 MW as of December 2017. The planned addition is 56,431 MW, while the capacity to be retired is 25,310 MW. The total installed capacity at the end of 2037 is expected to be 77,211 MW.[4] Renewable energy is projected to reach 28,004 MW in terms of installed capacity. Biomass is forecasted to account for 17% (4,690 MW) of all renewable installed capacity in 2037.

Viet Nam

Figure 2.17. Generation Mix of Viet Nam, 2017



Source: BP (2018).

The power generation plan is contained in the PDP. The power plan up to 2030 was published in the revised version of PDP 7 (2011–2020) on 18 March 2016. The revised version sets the annual economic growth rate at 7%. Power generation in 2030 is 572,000 GWh, 3.2 times that of the present. Coal accounts for 53% (Table 2.9).

Table 2.9. Future Power Generation Plan of Viet Nam

Power generation capacity (MW)

	2020	2025	2030	
Coal	25,620	47,575	55,167	43%
Hydro	18,060	20,458	21,886	17%
Gas	8,940	15,054	19,037	15%
Renewables	5,940	12,063	27,195	21%
Nuclear	0	0	4,662	4%
Import	1,440	1,351	1,554	1%
Total	**60,000**	**96,500**	**129,500**	**100%**

Power generation （GWh）

	2020	2025	2030	
Coal	130,645	2,200,000	304,304	53%
Hydro	66,780	696,000	70,928	12%
Gas	43,990	764,000	96,096	17%
Renewables	17,225	276,000	61,204	11%
Nuclear	0	0	32,604	6%
Import	6,360	64,000	6,864	1%
Total	**265,000**	**4,000,000**	**572,000**	**100%**

Source: Office of the Prime Minister, Viet Nam (2016).

[4] http://gizenergy.org.vn/media/app/media/PDF-Docs/Legal-Documents/PDP%207%20revised%20Decision%20428-QD-TTg%20dated%2018%20March%202016-ENG.pdf#search=%27Vietnam+428%2FQDTTg%27

2.2. Coal resources, production, utilisation, and plans for power plants

Cambodia

Coal resources and reserves

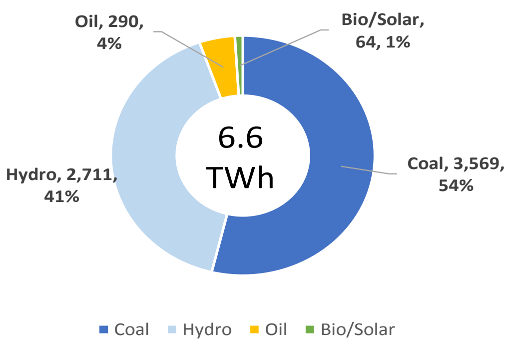
Cambodia coal was discovered in Otdar Meanchery province, Stung Treng province in the north, and in Kampong Thom province, the Kratie province in the central area, and Battambang province in the west area. In addition, although the presence of coal has been confirmed in Kompot province in the south and in Kaoh Kong province in the southeast, coal exploration in Cambodia has only begun, and data on coal resources is not enough. The coal reserves of Stung Treng province and Otdar Meanchery province total 18 million tons and 5 million tons, respectively (official figure is only 23 million tons). The underground coal mine of Yun Khean Minerals located in Anlong Veng of Otdar Meanchery province was developed with the support of China, but its operation is currently suspended.

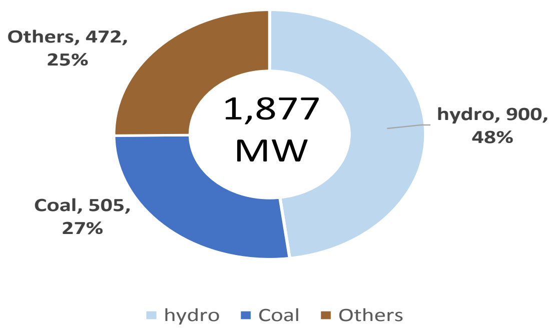
Current situation of the power sector

- Corporate structure of the power business
  The electricity business in Cambodia is governed by the Ministry of Mines and Energy (MME). The electricity supply is implemented by the Electricité Du Cambodge (EDC), which is the state-owned Cambodia Electric Power Corporation and is the distributor and producer of electricity in Cambodia. The EDC supplies its own power and purchased power from the independent power producers (IPPs) in the metropolitan areas and major regional cities. Outside of the EDC electricity supply area, rural electricity enterprises and public electricity utilities, which are provincial electricity companies, are supplying electricity. The IPPs began to operate in 1997.

- Power generation capacity
  Power generation capacity in Cambodia in 2017 was 1,877 MW, consisting of 48% hydropower and 27% coal. The power generation in 2017 was 6,634 GWh, consisting of 54% coal, 41% hydropower, 4% oil, and 1% biomass-solar. The business model was 98% IPP, 1% EDC, and 1% others. The operating ratio of hydropower decreased during the dry season; coal had a small installed electricity capacity but the amount of power generation was large. Domestic power generation alone could not support domestic demand; therefore, 1,439 GWh of power was imported from neighbouring countries in 2017. Cambodia imported electricity mainly from Viet Nam (76%), Thailand (20%), and the Lao PDR (4%). Domestic consumption amounted to 8,073 GWh in 2017 (Figure 2.18).

Figure 2.18. Power Generation Capacity and Power Generation of Cambodia, 2017





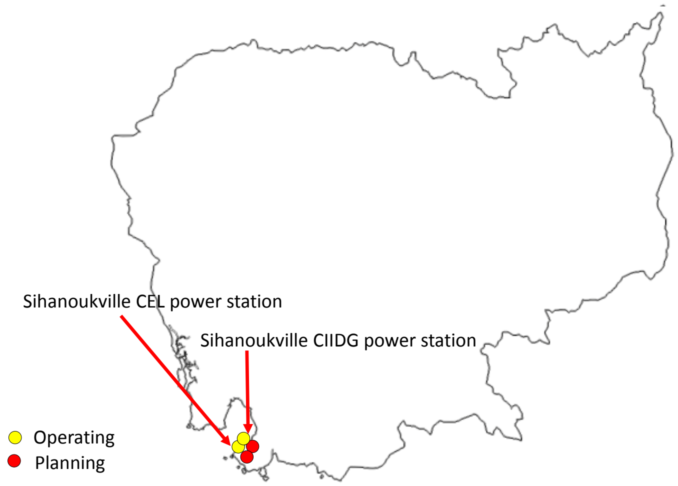
Source : EAC (2017).

Current situation of coal-fired power plants

Two coal-fired power plants are currently operating in Cambodia. Both are located in Sihanoukville province southwest of Cambodia. Coal is imported from Indonesia. Cambodia uses coal, 2 million tons of which are imported annually with the quality of 5,800 Kcal/kg as calorific value, 5% ash content, and 20% total moisture. The details are as follows:

- Sihanoukville CIIDG power station
  This power plant is an IPP power plant operated by the Cambodia International Investment Development Group (CIIDG) with the support of Chinese companies. Power capacity installed was 135 MW in 2014, 135 MW in 2015, and 135 MW in 2017. Total power capacity was 405 MW.
- Sihanoukville CEL power station
  It is the first coal-fired power plant in Cambodia with 100 MW. It is an IPP power plant currently operated by the Malaysian-owned Cambodia Energy Limited (CEL). The owner is a Malaysian company Leader Universal Holdings Bhd It is called CEL.

Figure 2.19. Operating and Planning Coal-fired Power Plants in Cambodia



Source: Created by the Authors from the data of the Ministry of Mine and Energy.

Indonesia

Coal resources and reserves

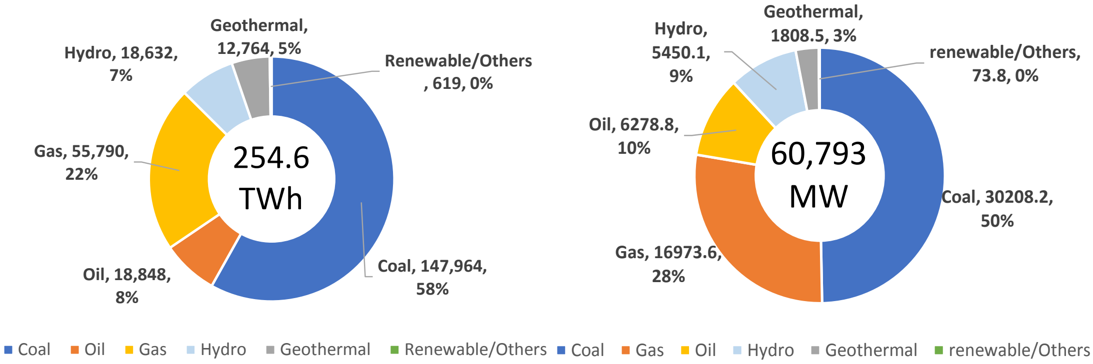
Indonesia is one of the world's leading coal-producing and coal-exporting countries. Coal is mainly distributed in Sumatra Island and Kalimantan Island. Coal resources total 125,177 million tons and reserves are 24,239 million tons. Coal production was 461 million tons, domestic consumption was 97 million tons, and 364 million tons of coal were exported in 2017.

Current situation of the power sector

- Corporate structure of the power business
  The electricity business is governed by the Directorate General of Electricity, Ministry of Energy and Mineral Resources. Electricity supply is managed and distributed by the state-owned power company PLN (Perusahaan Listrik Negara), which is also the power generator. It also manages the transmission to the gird. Among the PLN subsidiaries, PT. Indonesia Power and PT. Pembangkitan Jawa-Bali have power plants and are operating the power business under the PLN. In addition, many IPP power plants have been built, and the PLN purchases power from these power plants.

- Power generation capacity and power generation
  Power generation capacity of Indonesia in 2017 was 60,793 MW, consisting of 50% coal, 28% gas, 10% oil, 9% hydropower, 3% geothermal, and 0.1% renewables/Others. The power generated in 2017 was 254,617 GWh, consisting of 58% coal, 22% gas, 8% oil, 7% hydropower, 5% geothermal, and 0.02% renewables/Others. Coal has more than half of the total power generation facilities and power generation (Figure 2.20).

Figure 2.20. Power Generation Capacity and Power Generation of Indonesia, 2017

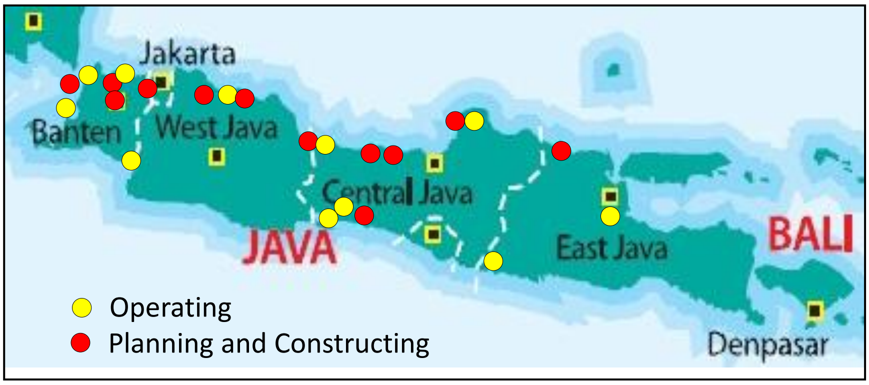


Source: MEMR (2018).

Current situation of coal-fired power plants

Many large coal-fired power plants are being built on Java Island. Coal is transported from Sumatra and Kalimantan by barges and coal vessels to power generation companies. A mine mouth coal-fired power plant is being constructed next to the coal mines in Sumatra and Kalimantan. A large-scale coal-fired power plant will be constructed in Java in the future (Figure 2.21).

Figure 2.21. Operation, Planning, and Construction of Coal-fired Power Plants in Java Island



Source: Created by the Authors from PLN (2018).

Lao PDR

Coal resources and reserves

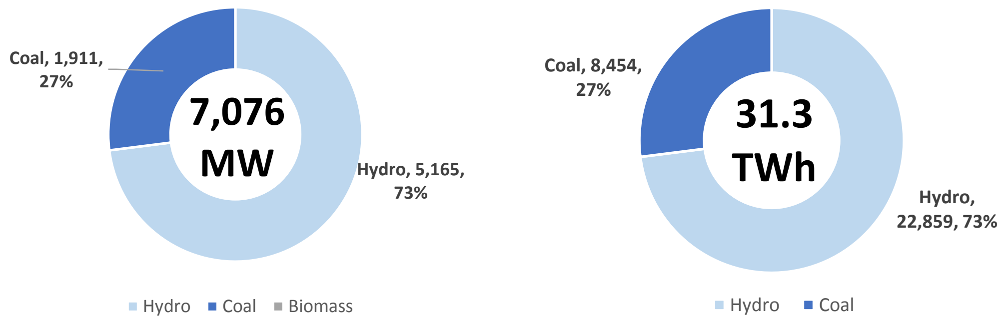
The Lao PDR is a coal-producing country whose yearly production reaches about 800,000 tons (excluding lignite in the mine mouth power plant). The coal field is divided into the northern and southern areas. The northern area has the same layer as tertiary brown coal in Thailand. The southern area is lined with Viet Nam's anthracite coal. The coal reserve is 739 million tons, 90% of which is lignite and subbituminous coal, and anthracite is only 10%. The excavated coal is partially exported to Thailand. About 15 million tons of coal is excavated annually from the lignite coal mine located next to the Hongsa Power Plant, which was built near the Thailand border in northern Lao PDR. Thus, coal production in the country is 15.8 million tons. Coal production and consumption are almost the same.

Current situation of the power sector

a) Corporate structure of the power business
The electricity business in the Lao PDR is governed by the Ministry of Energy and Mines. Electricity supply is managed by the state-owned company, Électricité du Laos (EDL) or the Laos Electric Power Company, which is a100% state-owned enterprise. The EDL manages the domestic supply of electricity and imports and exports work from neighbouring countries. The EDL also participates in the IPP business. In 2010, EDL separated the power generation business and established the EDL Generation Public Company (EDL-Gen), 25% of whose shares were released to the private sector (75% owned by the EDL). After that, the power generation facilities in operation were transferred from the EDL to EDL-Gen sequentially including the IPP business.

b) Power generation capacity and power generation
The power generation capacity of the Lao PDR in 2017 was 7,076 MW, consisting of 73% hydropower and 27% coal. The business form was IPP for overseas, 67%; IPP for domestic, 21%; EGL-Gen, 9%; and EDL, 3%. Power generation in 2017 was 31,315 GWh, 16% of which was used domestically, while the remaining 84% was exported to neighbouring countries.

Figure 2.22. Power Generation Capacity and Power Generation of the Lao PDR, 2017

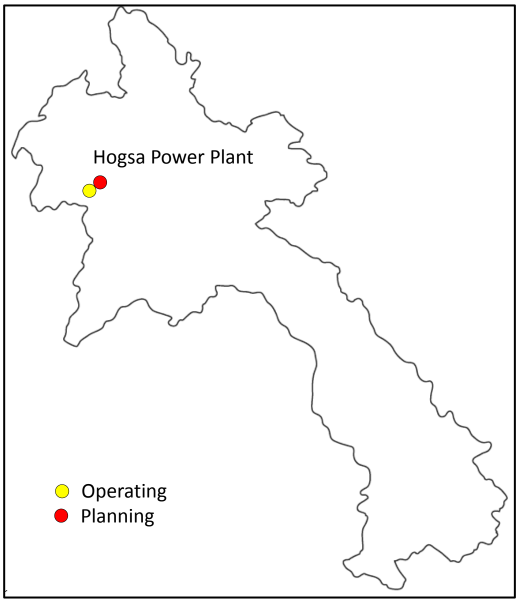


Source: EDL (2017).

Current situation of the coal-fired power plant

The Hongsa coal-fired power plant, which was built in Xaignabouri province in northern Lao PDR, is a mine mouth power plant using lignite from nearby areas. Investors are RATCH (40%), a Thai power generation company; Banpu (40%), a Thai mining company); and the Lao government (20%). The first unit (with output of 626 MW) started in June 2015, the second unit (with 626 MW output) started in November 2015, the third unit (with 626 MW output) started in March 2016, and current total capacity is 1,878 MW in operation. The amount of lignite used annually is 14.3 million tons.

Figure 2.23. Operating and Planning Coal-fired Power Plants in the Lao PDR



Source: Created by the Authors based on the data of the Ministry of Energy and Mines.

Malaysia

Coal resources and reserves

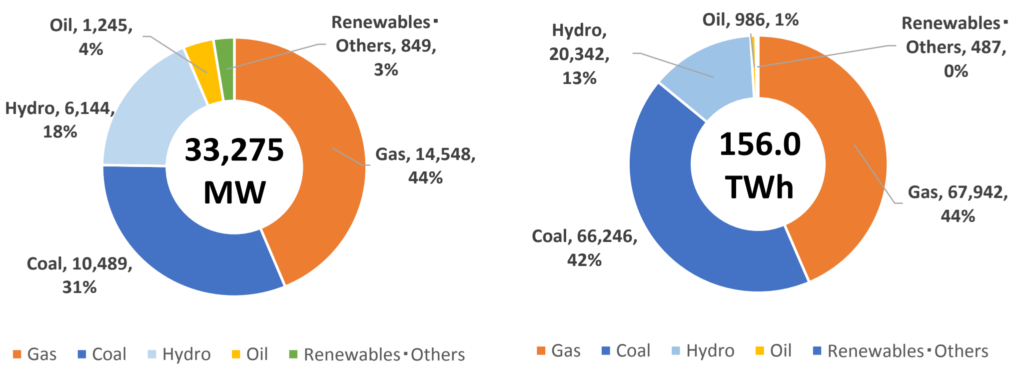
Coal resources in Malaysia total 1.8 billion tons, mainly distributed in Kalimantan Island, 1.5 billion tons in Sarawak province, and 300 million tons in Sabah province in Kalimantan Island. Yet, there is almost no coal in the Malay Peninsula. Coal is produced only in Kalimantan Island. In 2016, coal produced was 2.41 million tons.

Current situation of the power sector

- Corporate structure of the power business
  The electricity business in Malaysia is regulated by the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC). The electricity business itself has already been privatised. Power supply in the Malay Peninsula is managed by the Tenaga Nasional Berhad (TNB) or Tenaga National. The power supply in Sabah is managed by the Sabah Electricity Sdn. Bhd., and the power supply in Sarawak is controlled by the Sarawak Energy Bhd. Besides these companies, some private companies and IPPs generate power.

- Power generation capacity and power generation
  The power generation capacity of Malaysia in 2017 was 33,275 MW, consisting of 44% gas, 31% coal, 18% hydropower, 4% oil, 3% renewables/Others. The power generation in 2016 was 156,003 GWh, consisting of 44% gas, 42% coal, 13% hydropower, 1% petroleum, and 1% renewables/Others.

Figure 2.24. Power Generation Capacity and Power Generation of Malaysia, 2017

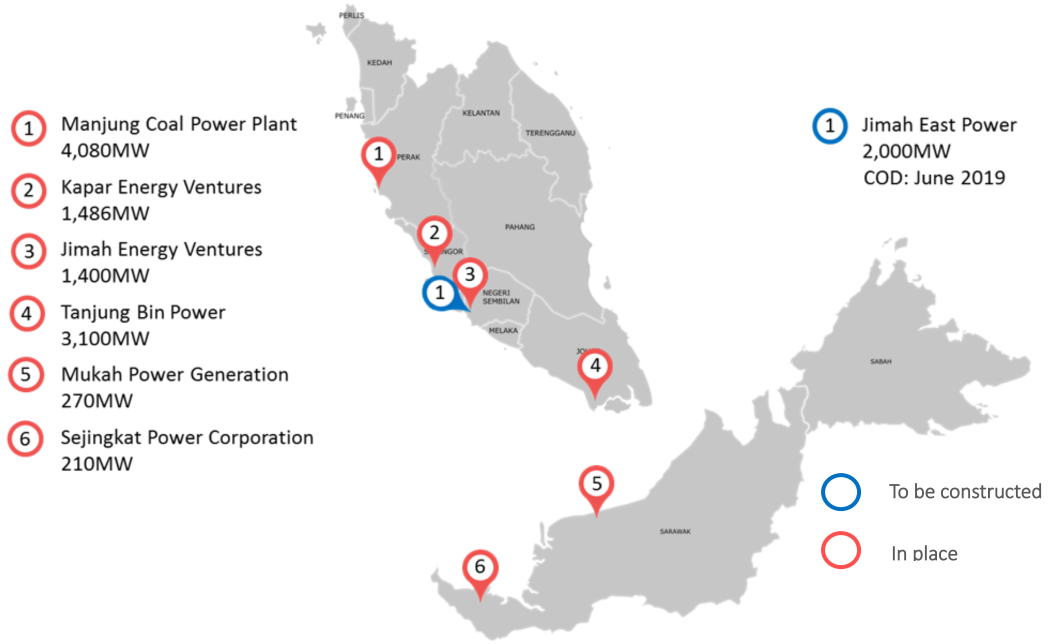


Source: MESTECC (2018).

Current situation of coal-fired power plants

Coal-fired power plants in Malaysia operate in the Malay Peninsula and Sarawak province in Kalimantan Island. One coal-fired power plant is currently under construction in the Malay Peninsula.

Figure 2.25. Coal-fired Power Plants in Operation/Under Construction/Being Planned in Malaysia



Source: Energy Commission (2019).

Myanmar

Coal resources and reserves

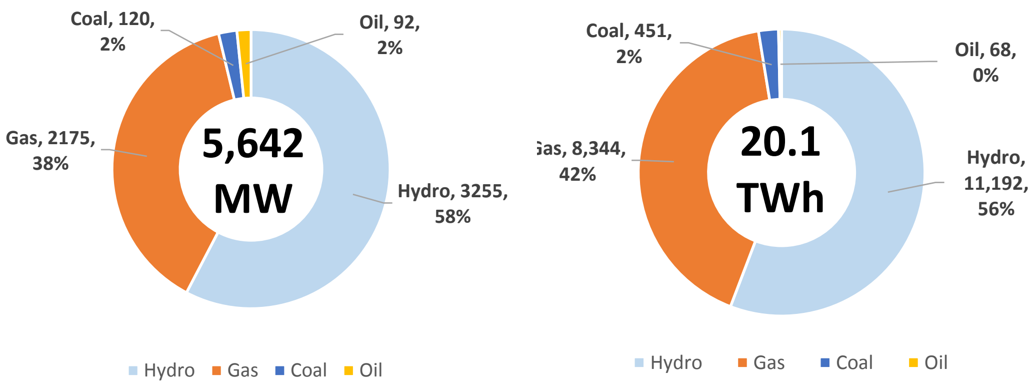
Coal resources in Myanmar total 711 million tons, and the indicated coal reserves of the major 34 coal deposits which are distributed throughout the country total 543 million tons. Coal production recorded over 1 million tons in fiscal year 2005–2007. However, since fiscal year 2008 onwards, production has been stagnant staying around 500,000 tons. The underground mining method is carried out in Kareva and some other areas. The production from underground mining is about 20% of the total coal output of Myanmar.

Current situation of the power sector

- Corporate structure of the power business
  The electricity business in Myanmar is governed by the Ministry of Electricity and Energy (MOEE), which was formed in April 2016 by merging the then Ministry of Electricity and the then Ministry of Energy. The electricity business itself is under the responsibility of the Electric Power Generation Enterprise. The distribution and retail business are managed by the Yangon Electric Supply Corporation, Mandalay Electric Supply Corporation, and Electric Supply Enterprise which are under the MOEE.

- Power generation capacity and power generation
  The installed capacity of Myanmar in March 2018 was 5,642 MW, consisting of 58% hydropower, 38% gas, 2% coal, and 2% oil. Power generation in the same period was 20,054 GWh, consisting of 56% hydropower, 42% gas, 2% coal, and 0% oil. At present, the main sources are hydropower and gas, and only 2% coal-fired power plants (Figure 2.26).

Figure 2.26. Power Generation Capacity and Power Generation of Myanmar, 2018

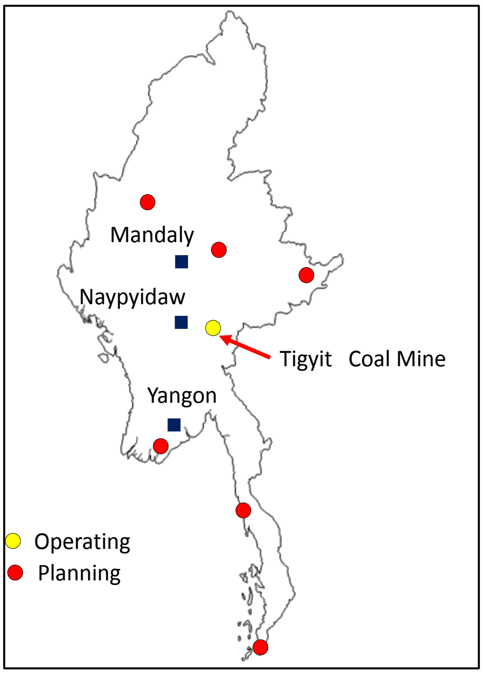


Source: MOEE, Myanmar (2018).

Current situation of the coal-fired power plant

At present, the Tigyit coal-fired power plant is the only one operating in Myanmar. The power plant was built with the support of China. The two 60 MW units installed have a total capacity of 120 MW. Coal is supplied by the coal mine located next to the power plant. Coal consumption is designed to be 320,000 tons annually, but the total coal consumption is 640,000 tons annually. Coal operation rate is low due to some malfunction in the power plant operation. Therefore, coal consumption has not reached the desired quantity. The operation of the power plant, currently under a Chinese company, is promoting the environmental equipment. Desulphurisation and denitrification equipment were installed. Figure 2.27 shows the results of environmental monitoring of the residents surrounding the power plant.

Figure 2.27. Operating and Planned Coal-fired Power Plants in Myanmar



Source: Created by the Authors based on data of MOEE Myanmar (2018).

Philippines

Coal resources and reserves

The Philippines is divided into three major areas – Luzon, Visayas, and Mindanao – and coal is distributed in these three areas. Coal resources total 2,367 million tons, and recoverable reserve is 469 million tons (Department of Energy website). Coal production in 2018 was 13.05 million tons, 99.19% of which was produced from the Semirara coal mine in the Visayas Islands. Exported are 5.05 million tons of Semirara coal, which is 38.6% of the annual production of the company. Export destinations are China (98%), India (1%), and Thailand (1%). Domestic consumption is 30.83 million tons: 25.13 million tons of which are imported, while 5.7 million tons of domestic coal are used (Department of Energy website).[5]

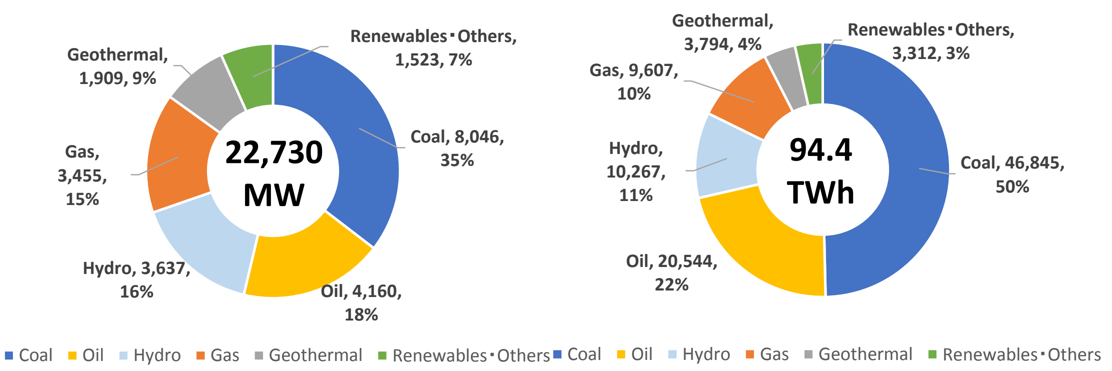
Current situation of the power sector

- Corporate structure of the power business
  The electricity business in the Philippines is regulated by the Department of Energy (DOE). Electricity in the Philippines was initially supplied by the National Power Corporation (NPC), the nationally owned power company; now power supply is mainly undertaken by the IPPs. With the enforcement of the Electric Power Industry Reform Act of 2001, the NPC has been selling power generation assets to the IPPs, and the NPC is shrinking annually. There are 20 private electric power companies such as the Manila Electric Company (MERALCO), Visayan Electric Company, Davao Light and Power Company, Inc.; 119 electric cooperatives; and 8 local government companies. MERALCO is the largest distribution company whose sales reach about 70% of the total power generation in Luzon.

- Power generation capacity and power generation
  The power generation capacity of the Philippines in 2018 was 23,815 MW, consisting of 37.1% coal, 18% oil, 15.5% hydro, 14.5% gas, 8.2% geothermal, and 6.7% renewables/Others. Power generation in 2018 was 99.765 GWh, consisting of 52.1% coal, 21.4% gas, 10.5% geothermal, 9.4% hydropower, 3.2% petroleum, and 3.6% renewables/Others. Oil and water utilisation rates are low, and coal accounts for half of all power generation (Figure 2.28).

[5] https://www.doe.gov.ph/energy-statistics?_

Figure 2.28. Power Generation Capacity and Power Generation of the Philippines, 2017

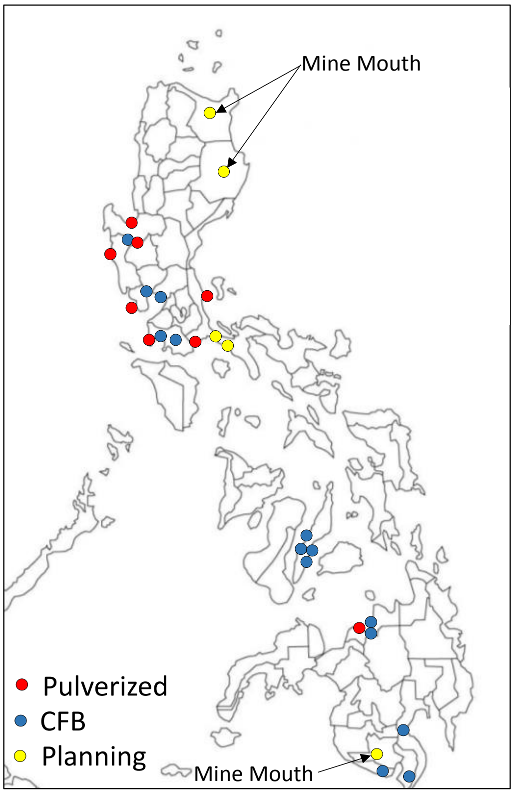


Source: Department of Energy website, https://www.doe.gov.ph/electric-power

Current situation of coal-fired power plants

The Philippines has many coal-fired power plants. The power plants are divided into pulverised coal boiler and CFB. There are many CFB boilers in Mindanao and the Visayas. Also, the coal-producing areas in Luzon and Mindanao have the potential for a mine mouth coal-fired power plant.

Figure 2.29. Operating and Planned Coal-fired Power Plants in the Philippines



CFB = circulating fluidised bed.
Source: DOE (2018).

Thailand

Coal resources and reserves

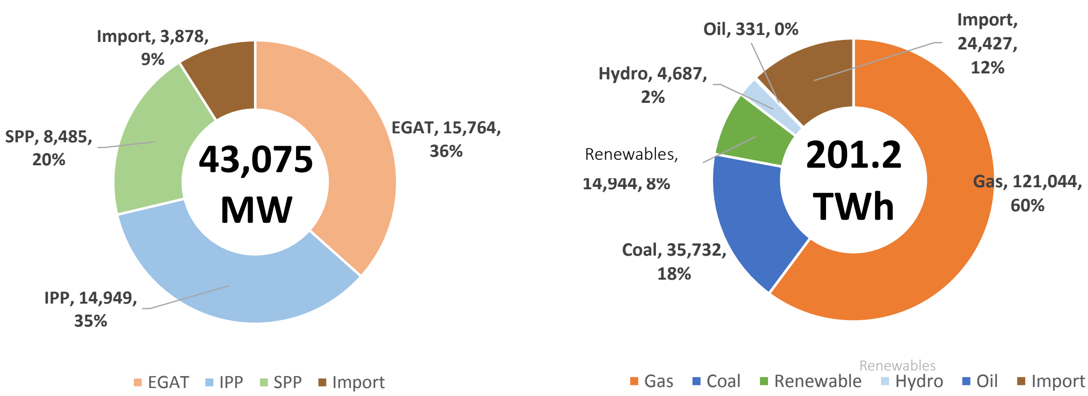
Coal resources in Thailand are distributed mainly in the northwestern area. The remaining reserves of coal in this area are estimated at 1.1 billion tons. The measured reserves and indicated reserves of coal in the undeveloped areas of the country are 785 million tons and 720 million tons, respectively, and the reserves of coal total 578 million tons. Coal produced in 2017 was 16.3 million tons, and 15.9 million tons (97%) of lignite were excavated from the Mae-Moh coal mine. Thailand imports 22.2 million tons of bituminous coal and sub-bituminous coal yearly. Coal consumption in Thailand was 38.5 million tons.

Current situation of the power sector

- Corporate structure of the power business
  The electricity business in Thailand is governed by the Ministry of Energy. The state-owned company EGAT engages in power supply from its own generation facilities and manages the entire national power supply including IPP generation and the power purchase from neighbouring countries. Power is supplied to the Metropolitan Electricity Authority and the Provincial Electricity Authority and large customers in Thailand. The IPPs started in 1992 as power producers; small power producers (SPPs) which supply less than 90 MW of electricity started in the same year.

- Power generation capacity and power generation
  The power generation capacity of Thailand in October 2018 was 43,075 MW, consisting of 36% EGAT, 35% IPP, 20% SPP, and 9% import (Figure 1.30). Power generation in 2017 was 20,165 GWh, consisting of 60% gas, 18% coal, and 2% hydropower. The 12% of the total electricity power is imported electricity.

Figure 2.30. Power Generation Capacity and Power Generation of Thailand, 2018

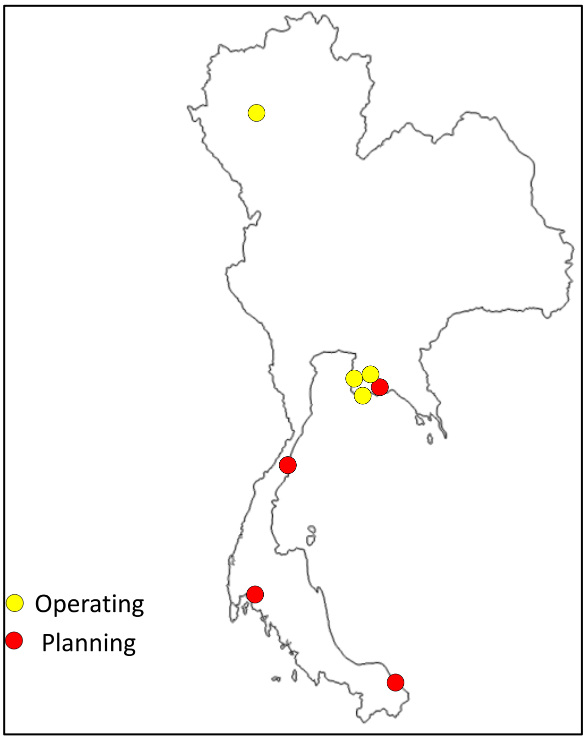


EGAT = Electricity Generation Authority of Thailand, IPP = independent power producer, SPP = small power producer.
Source: Ministry of Energy, Thailand (2015).

Current situation of the power sector

The largest coal-fired power plant in Thailand, the Mae-Moh coal-fired power plant, is located in the northern coal field of the country. The first unit was built in 1978; it has been expanded since. Currently, up to 13 units are in operation. Units 1 to 3 each have a capacity of 75 MW (total of 225 MW), Units 4 to 7 have 150 MW each (total of 600 MW), and Units 8 to 13 have 300 MW each (total of 1,800 MW). The total power generation capacity is 2,625 MW. However, since Units 1 to 3 have already been discontinued, the current installed capacity is only 2,400 MW. Coal supplied is 16 million tons yearly from the Mae-Moh coal mine next to the power plant. In addition, the IPP coal-fired power plant using imported coal operates at the coast of Thailand. Out of the 22 million tons of imported coal, 8 million tons are used for electricity.

Figure 2.31. Operating and Planned Coal-fired Power Plants in Thailand



Source: Created by the Authors from EGAT data.

Viet Nam

Coal resources and reserves

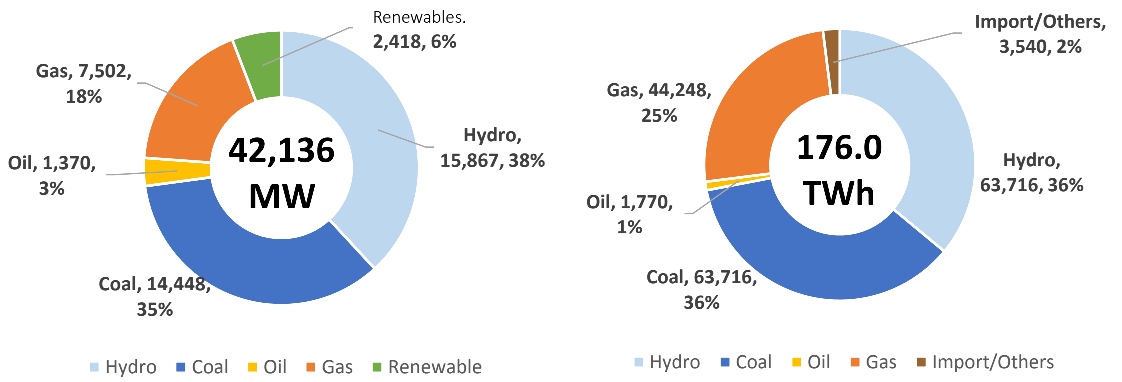
Viet Nam produces a significant amount of anthracite. The Quang Ninh area has 62.9 billion tons of coal resources and the Red River area, 42 billion tons. The coal reserve is estimated to be 3.1 billion tons. Coal produced in 2017 was 38.20 million tons (37.2 million tons of Vinacomin and 1 million tons of others) (General Statistics Office of Viet Nam, 2017). The domestic coal consumption in 2017 was over 50 million tons with 38.20 million tons of production, 2.2 million tons of export and 14.50 million tons of import.

Current situation of the power sector

- Corporate structure of the power business
  The electricity business in Viet Nam is governed by the Ministry of Industry and Trade (MOIT). The state-owned power company, Viet Nam Electricity (EVN), supplies electricity. The EVN owns and manages power generation companies, power supply control offices, power transmission companies, and power distribution companies. The power generation part of EVN was unbundled into three companies: GENCO 1, GENCO 2, and GENCO 3. The Institute of Energy under MOIT conducts energy policy and power development planning, and power investigation and research related to electricity.

- Power generation capacity
  Installed capacity of Viet Nam in 2016 was 42,136 MW, consisting of 38% hydropower, 35% coal, 18% gas, 3% oil, and 6% renewables/Others. Power generated in 2016 was 175,990 GWh, consisting of 36% hydropower, 36% coal, 25% gas, and 2% import/Others (Figure 2.32). Coal accounts over for 30% and is an important energy source.

Figure 2.32. Power Generation Capacity and Power Generation of Viet Nam, 2016

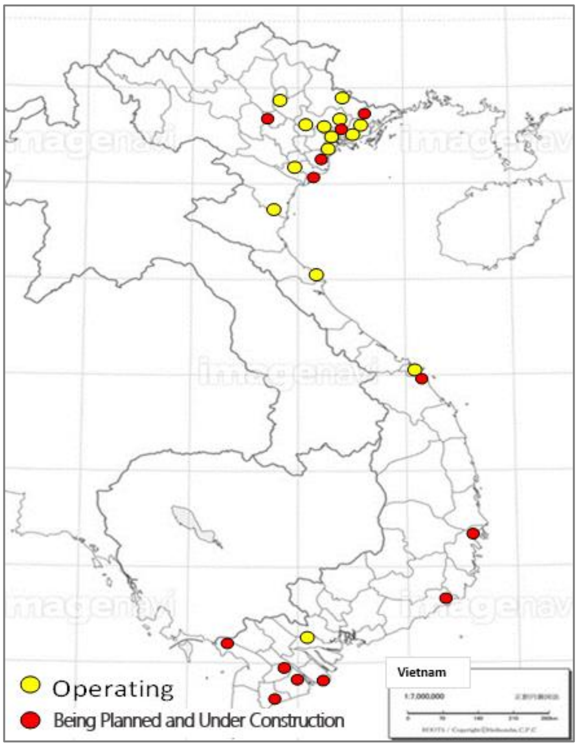


Source: Viet Nam Electricity (2017).

Current situation of the coal-fired power plant

The coal-fired power plants in Viet Nam are in the northern area where coal is produced. In the south, where the capital Ho Chi Minh City is located, coal-fired power plants are being constructed to prepare for the future increase of electricity demand and when imported coal from overseas is expected to be used (Figure 2.33).

Figure 2.33. Coal-fired Power Plants in Viet Nam: Operating, Being Planned and Under Construction



Source: Created by the Authors based on EVN (2017).

Coal demand and supply plan

The current coal consumption in Viet Nam is around 50 million tons, including domestic and imported coal. Said consumption is estimated to reach 86.1 million tons (electric power is 6,410 million tons, 74% of the total) in 2020, and 21.5 million tons (electric power is 96.5 million tons, 79% of the total) in 2025, and 158.6 million tons in 2030 (electric power 131.1 million tons, 82% of total). Domestic coal produced will be about 50 million tons, so the quantity of imported coal will increase. Imported coal is estimated at 40.3 million tons in 2020, 70.4 million tons in 2025, and 102.1 million tons in 2030. The coal ratio in the total electricity consumption will increase annually (Table 2.10).

Table 2.10. Coal Demand and Supply Plan

Coal demand (million tons)

	2020	2025	2030
Power	64.1	96.5	131.1
Fertiliser/chemical	5.0	5.0	5.0
Cement	6.2	6.7	6.9
Metallurgy	5.3	7.2	7.2
Others	5.8	6.1	6.4
Total	**86.4**	**121.5**	**156.6**

Production and import (million tons)

	2020	2025	2030
Demand	86.4	121.5	156.6
Production	46.1	51.1	54.5
Import	40.3	70.4	102.1

Source: EVN (2016).

All countries

Coal resources and reserves, production, export volume, etc.

Many countries in Southeast Asia are rich in coal resources. Indonesia, the Philippines, Malaysia, Myanmar, Thailand, Viet Nam, and the Lao PDR are using their coal to generate power. Thailand, Malaysia, the Philippines, and Viet Nam are importing coal from overseas to generate electricity in addition to their own coal. But Cambodia uses imported coal only. The total coal production in the eight countries is 547.34 Mt, consumption is 264.23 Mt, export is 372.13 Mt, and import is 90.57 Mt (Table 2.11).

Table 2.11. Coal Resources, Production and Consumption, and Export and Import (Mt)

	Coal Resources and Reserves, Mt	Coal Production and Consumption (2017), Mt	Coal Export and Import (2017), Mt
Indonesia	Coal Resources: 125,177 Coal Reserves: 24,239	Production: 461 Consumption: 97	Export: 364
Thailand	Coal Resources: 2,578	Production: 16.22 Consumption: 38.40	Import: 22.2
Viet Nam	Coal Resources: 48.800 Coal Reserves: 3.100	Production: 38.2 Consumption: 50.0	Export: 2.2 Import: 14.5
Malaysia	Coal Resources: 1.800 Coal Reserves: .500	Production: 2.41 Consumption: 31.0	Import: 28.54
Philippines	Coal Resources: 2,367 Coal Reserves: 478	Production: 13.14 Consumption: 29.32	Export: 5.93 Import: 23.33
Lao PDR	Coal Reserves: 739	Production: 15.8 Consumption: 15.8	
Myanmar	Coal Resources: 711 Coal Reserves: 543	Production: 0.57 Consumption: 0.71	
Cambodia	Coal Resources: 711 Coal Reserves: 543	Production: 0 Consumption: 2.0	Import: 2.0
Total		**Production: 547.34** **Consumption: 264.23**	**Export: 372.13** **Import: 90.57**

Source: Based on the respective governments' website.

2.3. Biomass resources

One major industry in ASEAN is agriculture. The agricultural products and the production volume in each country are different depending on the country's climate, etc. Table classifies these countries into two major groups according to relatively similar agricultural products. The first group comprises Indonesia, Malaysia, and Thailand, which are engaged in agricultural production with large plantations, such as palm. The second comprises the Philippines and others, which mainly produce rice.

In such situation, Indonesia and the Philippines are representative examples in the case studies of the next section.

Table 2.12. Agriculture Production in ASEAN, 2014

(million tons)

		Palm	Coconut	Cassava	Corn	Sugar Cane	Rice
Group 1	Indonesia	139.95	32.28	23.44	19.01	25.75	70.85
	Malaysia	95.38	0.60				1.83
	Thailand	12.43		30.02	4.80	103.70	32.62
Group 2	Philippines		14.70		7.77	28.00	18.97
	Cambodia			10.21	0.35	0.61	9.82
	Lao PDR			1.63	1.41	1.84	4.00
	Viet Nam			10.21	5.20	19.82	44.97
	Myanmar				1.69	11.13	26.42
	Total	258.90	47.48	72.82	41.59	192.26	216.25

Source: Food and Agriculture Organization (2016).

While Table 2.12 shows the yield of main agricultural products, Table 2.13 shows the amount of wastes generated yearly.

Table 2.13. Main Wastes of Agriculture Products

Biomass	Type of Waste	Biomass	Type of Waste
Palm (FFB)	Kernel shell (PKS) Fibre EFB (empty fruit bunch) Trunk POM effluent (liquid)	Corn	Cob
		Rice	Rice husk Rice straw
		Sugar cane	Bagasse
Coconut	Kernel shell Fibre	Rubber	Rubber wood small logs

Source: Authors.

Kernel shell (PKS) is used as a boiler fuel at palm oil mills. Because it has a low moisture content, relatively high calorific value, and low chlorine and potassium content, demand for PKS is increasing in Japan and South Korea. This biomass fuel is mixed with other types of fuel to reduce the CO_2 emissions from coal-fired power plants. Furthermore, large palm companies in Indonesia purchase PKS from other mills and use it as fuel in related facilities other than palm oil mills. As a result, demand for PKS is increasing, thus intensifying the competition in the procurement market and making it difficult to obtain. The increased demand is also causing a rise in the price of PKS year after year. In Indonesia, PKS presently costs US$80–US$100 per ton. In such situation, PKS cannot be available for co-combustion fuel.

For rice husk, 30%–50% of the rice husk generated by milled rice is consumed for burning. A part of the remaining rice husk is used as cement raw material. In summary, 60% of the rice husk is available for co-combustion.

Other wastes are not used much. However, bagasse and cassava may be used as biofuel feedstock. In addition, fibres of coconut are used as fuel by farmers. Assuming that the availability of other wastes is about 80%, the amount available for biomass fuel will be 124 million tons (Table 2.14).

Table 2.14. Amount Available for Biomass Fuel in Waste of Agriculture Products

(million tons)

	Palm		Coconut		Cassava	Corn	Sugar Cane	Rice	
Main waste	PKS	EFB	KS	Fiber	Peel, Chop	Cob	Bagasse	Rice Husk	Total
Yield (%)	5	23	20	30	24	23	15	20	
Amount	12.95	59.55	9.50	14.24	17.48	9.57	28.84	43.25	195.36
Availability (%)	0	80	80	50	80	80	50	60	
Available for fuel	0.00	47.64	7.60	7.12	13.98	7.65	14.42	25.95	124.36

Source: Authors.

2. The Importance and Possibilities of Biomass and Coal Co-combustion

The advantages of biomass and coal co-combustion are summarised as follows:

(1) It helps mitigate CO_2 emissions.
(2) It reduces underutilised agricultural waste.
(3) It saves the amount of coal fuel so that it saves on generation cost.
(4) Intermittency of biomass supply is substituted by co-utilisation of coal.
(5) It creates more job opportunities since biomass use is labour intensive.

(1) Biomass use in the coal-fired power plant is to be applied as direct and effective mitigation measures of CO_2 in the power sector of the countries that use coal as the main energy source, such as the ASEAN region. CO_2 emission is reduced proportionally with an increased blend ratio of biomass with coal since biomass is recognised as a carbon-neutral substance.

(2) Although the imported woodchip is mainly used in the European Union and Japan as a biomass source, agricultural wastes – such as PKS, empty fruit bunch (EFB), sugar cane, rice hulk, and food waste – in the ASEAN region are thought to be potential sources of domestic energy. This also has the advantage of reducing underutilised waste. Biomass can be used in wider types of boilers such as CFB, small size pulverised boiler, and USC of larger capacity.

(3) The effectiveness of biomass as an alternative fuel in a coal-fired power plant does not only mitigate CO_2 emissions but also improve the plant operation cost if biomass is efficiently collected from the surrounding areas. One issue in utilising agricultural waste as biomass fuel is the seasonal volume which implies unstable supply.

(4) In this regard, co-firing with coal can compensate the total energy input to the plant by optimising the coal/biomass ratio.

(5) Biomass utilisation in coal-fired power plants might bring merit to regional employment by supplying biomass through the collection and selection process in the surrounding area.

In sum, expediting the co-firing of biomass and coal in a coal-fired power plant in the ASEAN region is deemed to be crucial in addressing both CO_2 mitigation and surging energy demand.

Chapter 3
Case Studies

1. Prerequisites of Case Studies

1.1. Generation capacity

In the ASEAN region, large-scale coal-fired power plants based on energy plans are in operation or in construction, and the electrification rate in urban area has reached more than 90%. Therefore, construction of power plants in rural areas is expected to increase in the future due to improved rural electrification rate. However, the present power plants are small and medium scale because the local power grid is not developed yet and the transmission capacity is small. Additionally, if agricultural waste would be used as biomass fuel to generate electricity, the amount of waste that could be procured and supplied from areas surrounding the power plant is important.

From such situation, the generation capacity in each case study is set to 50 MW.

1.2. Boiler

(1) Fuel tolerance range

The CFB boiler used in this study is configured so that air intake from the bottom of the furnace causes the even mixture of fuels and high-temperature combustible materials inside the furnace. Following combustion, the mixture is returned to the furnace bed and blown upward. The fuel is repeatedly subjected to this process inside the furnace, making it a boiler technology that offers extremely high fuel efficiency. On the other hand, the system is highly adaptable to a wide range of fuels – from waste products to low-rank coal. Its superior fuel adaptability is a vital property for use in developing countries where there is a strong desire to use biomass fuels as a way of reducing CO_2 emissions and promoting the domestic use of low-rank fuel sources.

CFB boilers can tolerate an extremely wide range of fuels. It is possible to develop a relatively large-scale boiler to use fuels that could not be used with conventional pulverised coal combustion boiler or stoker boiler. One great attribute of the CFB boiler is that low-value or low-quality fuels can be used to produce electricity economically.

(2) Reducing operating and maintenance burden

CFB boilers have a low internal combustion temperature and they do not experience localised overheating due to fluidised combustion. As a result, they are unique in that they produce extremely low levels of ash, slag, or scale deposits on the furnace wall; the risk of high-temperature clinker generation at the bottom of the furnace is also extremely low.

As a result, long-term sustained operation, particularly during low melting point combustion, is possible and the frequency of facility maintenance inspections can be constrained. Furthermore, fly ash produced during combustion is almost completely burnt so it is often converted to be used as cement materials. Also, foreign objects mixed in the fuel are discharged via a grid; so, bottom ash can be used as a resource.

(3) Reducing environment load

As indicated in (1), CFB boilers enable the highly efficient use of biomass fuels and waste material fuels in power generation facilities and, thus, are effective as a CO_2 reduction measure (global environmental load). Also, the system enables low-NOx operation because the fuel properties and structural characteristics of the circulating fluidised bed system result in the production of very low amounts of NOx.

Inserting pulverised limestone together with the fuel into the furnace results in desulphurisation above 90%. This is a simple method that would be particularly attractive for regions lacking in technological advancement. The low global environmental load (particularly NOx and SOx) and environmental robustness are also highly environment friendly.

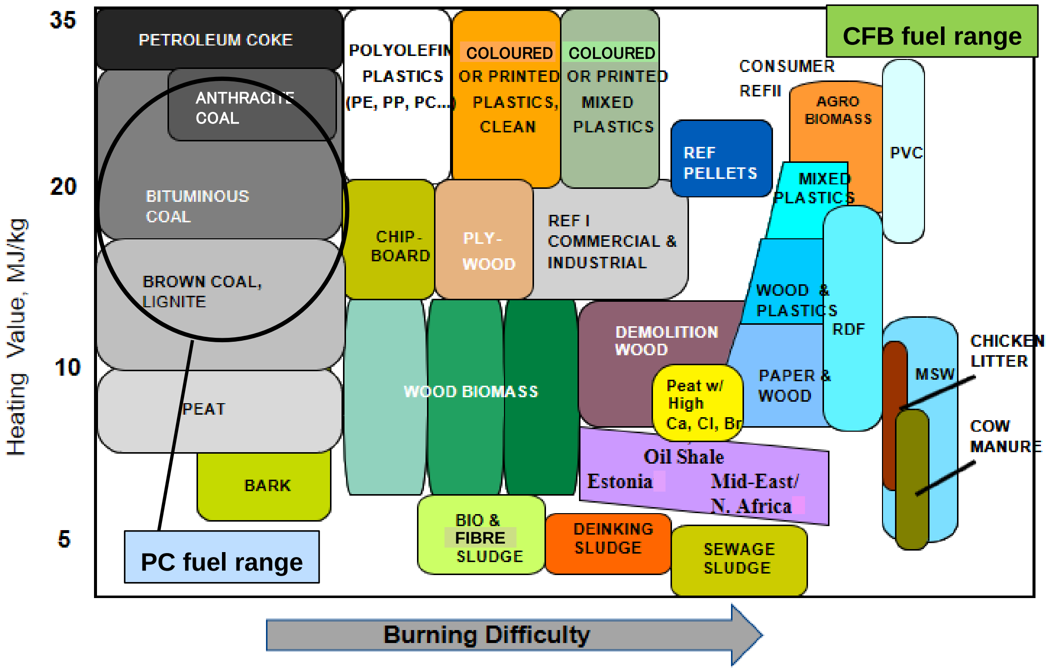
As indicated by cases in Japan, this system can resolve the problem of waste materials (garbage problem) that occurs with economic growth in developing countries. As such, this system can make social contributions to the environment.

When facing more difficult demands for environmental performance, urea can be inserted into the cyclone to conduct non-catalytic denitrification. Even when faced with the stricter urban environmental measures of an advanced nation, these requirements can be met by installing an external desulphurization unit and an external denitrification unit, systems required as permanent installations on systems of pulverised coal combustion boilers and stoker boilers.

This technology enables social contributions in the area of global emissions, local emissions, and life environment.

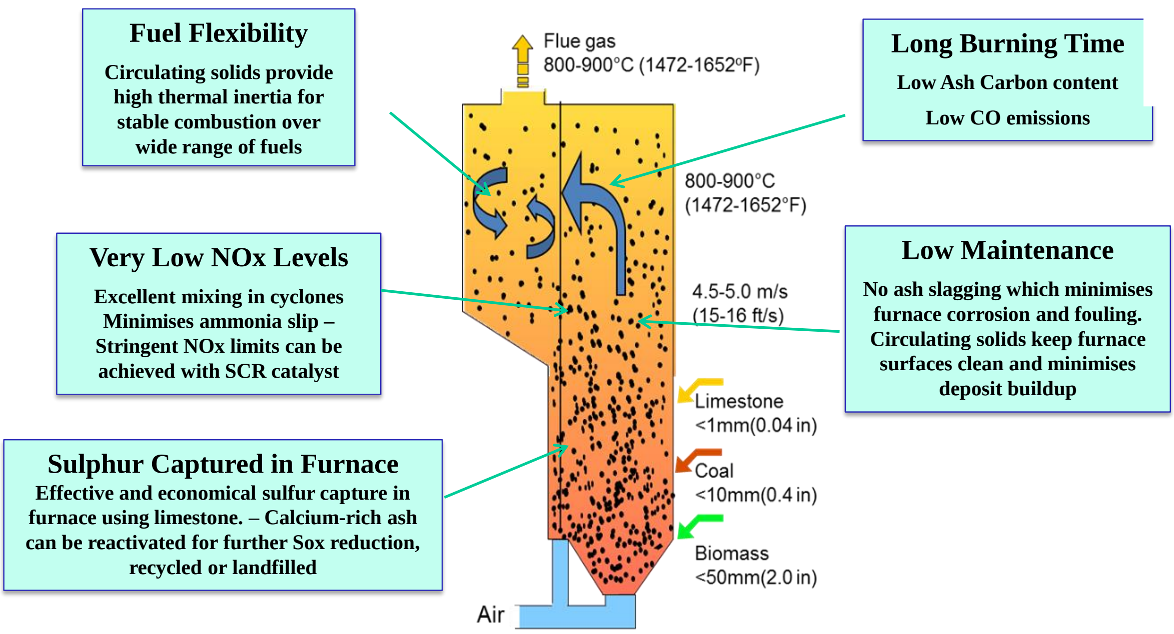
Figure 3.1 shows a conceptual image of a CFB boiler.

Figure 3.1. Adaptability of Fuels for CFB Boiler



Source: Working group meeting on this project (2019).

Figure 3.2. Conceptual Image of CFB Boiler



Source: Working group meeting on this project (2019).

1.3. Coal

Type and quality

(a) Case 1

In Indonesia, coal is produced in large amounts at a wider variety. Bituminous and higher rank sub-bituminous coal are mainly exported. Lower sub-bituminous coal and lignite are used for domestic supply. The Indonesian government is promoting the use of low-rank coal as energy and coal policy, and the development and production of lignite, lowest-rank coal, has been carried out since around 2010.

Therefore, for coal in Case 1, lignite with calorific value of 2,500 kcal/kg NAR (net as received base) is selected.

(b) Case 2

In the Philippines, 13 million tons of coal are produced annually. However, half of the coal produced is exported. Most coal-fired power plants in the Philippines use imported coal from Indonesia, which is mainly sub-bituminous coal.

Therefore, for coal in Case 2, Indonesian sub-bituminous coal with calorific value of 5,000 kcal/kg NAR is selected.

Properties of these coals are shown in Table 3.1.

Table 3.1. Properties of Raw Materials

Item		Base	Case 1		Case 2	
			Lignite	EFB	Sub-bituminous	Rice Husk
Total moisture		AR wt %	51.80	50.00	23.60	12.20
Proximate analysis		AD wt %				
	Fixed carbon		41.27	18.78	43.11	13.29
	Volatile matter		42.37	76.80	34.11	62.71
	Ash		3.30	3.22	8.78	17.60
	Moisture.		13.06	1.20	14.00	6.40
	(sum.)		(100.00)	(100.00)	(100.00)	(100.00)
Fuel ratio			0.97	0.24	1.26	0.21
Total Sulphur		AD wt %	0.18	0.12	0.52	0.08
Gross HV		AD kcal/kg	5,234	4,347	5,901	3,482
		AR Kcal/kg	2,902	2,200	5,242	3,266
Net HV		AD kcal/kg	4,944	4,043	5,731	3,187
		AR Kcal/kg	2,478	1,754	5,092	2,990
Ulitmate analysis		DRY wt %				
	C		65.08	44.79	70.94	40.64
	H		4.62	5.67	5.10	5.07
	N		1.32	1.03	1.18	0.29
	S		0.21	0.13	0.52	0.04
	O		24.97	44.78	12.05	35.16
	Cl		0.0097	0.3483		
	Ash		3.79	3.26	10.21	18.80
	(sum.)		(100.00)	(100.00)	(100.00)	(100.00)
	Na	mg/kg	1050	168	947	432
	K	mg/kg	195	10,000	212	2,115

AR: as received base
AD: air dry base

Source: Authors.

Price

Indonesian coal prices are published weekly by the Argus and Coalindo as the Indonesian Coal Index (ICI). ICI is classified into five types based on calorific value, sulphur, ash, moisture, and size. Table 3.2 shows the specification of five types of ICI; the lignite in Case 1 and the sub-bituminous coal in Case 2 correspond to ICI-5 and ICI-3, respectively.

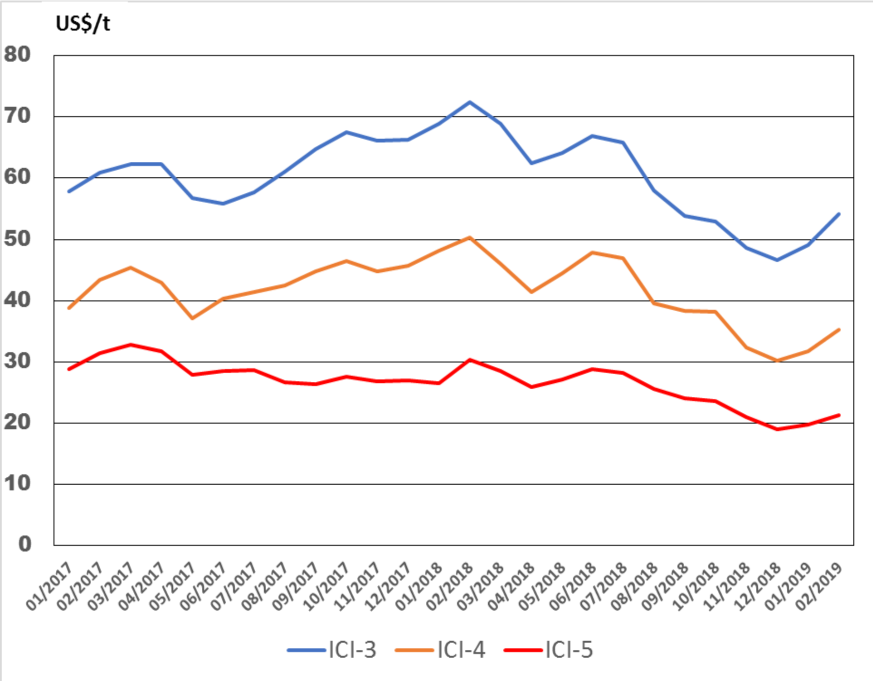
Figure 3.3 shows the price trend in the last 2 years of ICI-3, ICI-4, and ICI-5. These prices are the FOB Kalimantan in Indonesia base. Based on the price data in Figure 3.1-3, the coal price of Case 1 (Indonesia) is US$20/t and that of Case 2 (Philippines) is US$60/t, which includes US$10/t for transportation and insurance costs from Indonesia to the Philippines.

Table 3.2. Indonesian Coal Index (ICI) Specification

	Calorific Value	Sulphur, %	Ash, %	Moisture, %	Size
ICI-1	6,500 GAR/6,200 NAR	< 1	< 12	< 12	Panamax
ICI-2	5,800 GAR/5,500 NAR	< 0.8	< 10	< 18	Panamax
ICI-3	5,000 GAR/4,600 NAR	< 0.6	< 8	< 30	Panamax
ICI-4	4,200 GAR/3,800 NAR	< 0.4	< 6	< 40	Geared supramax
ICI-5	3,400 GAR/3,000 NAR	< 0.2	< 4	< 50	Geared supramax

GAR = gross as received, NAR = net as received.
Source: Argus/Coalindo (2019).

Figure 3.3. Price Trends of ICI 3, 4, 5



ICI = Indonesian Coal Index.
Source: Prepared by Authors based on Indonesian Coal Index report.

1.4. Biomass

Type and quality

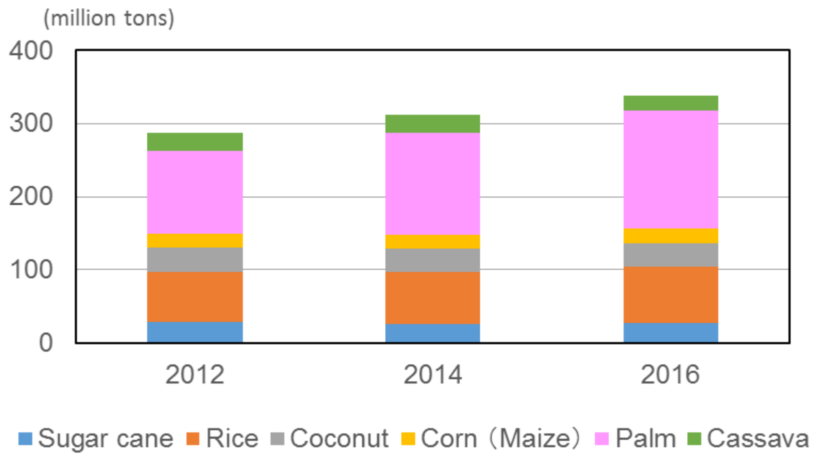
(a) Case 1

Figure 3.4 shows agricultural production in Indonesia. Palm had the largest annual production of 160 million tons in 2016. It was followed by rice (77 million tons), coconut (32 million tons), sugar cane (27 million tons), cassava (21 million tons), and corn (20 million tons).

Palm is cultivated on a large-scale plantation and is harvested and processed at a palm oil mill to produce palm oil. As described in Section 2.3, the PKS and EFB are generated as waste in palm oil mills, so that a certain amount of these wastes is

available in the market. Although the PKS is used as fuel at oil mills, it is currently traded and exported as a biomass fuel to Japan and Korea.
Therefore, for biomass in Case 1, the EFB is selected.

Figure 3.4. Agricultural Production in Indonesia



Source: FAO (2017).

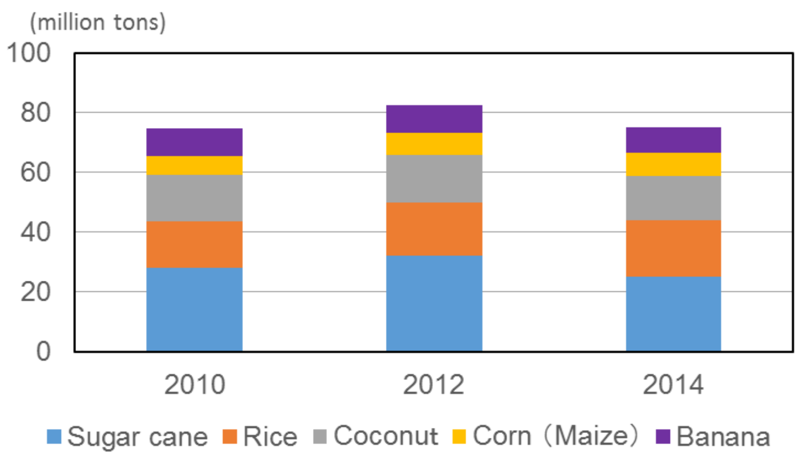
(b) Case 2

Figure 3.5 shows agricultural production in Philippines. Most produced is sugar cane at 28 million tons. This is followed by rice (19 million tons), coconut (15 million tons), and corn (8 million tons).

In the Philippines, sugar cane is already used as raw material for biofuel such as bioethanol. As mentioned, rice is the main agriculture product in other ASEAN countries. Therefore, for biomass in Case 2, rice husk, which is rice waste, is selected.

The properties of these biomass raw materials are shown in Table 3.1.

Figure 3.5. Agricultural Production in the Philippines



Source: FAO (2016).

Price

Case 1: EFB

In Indonesia, the EFB is incinerated at a palm oil mill. Since the EFB has a high potassium content resulting in incinerator ash also having a high potassium content, EFB ash after incineration is returned to the plantation to be used as fertiliser. However, incineration was banned in 2016 due to environmental issues; thus, raw EFB had to be returned to the plantation for disposal. Since the EFB is used as fertiliser in palm plantation, the palm oil mills side requested that the EFB be purchased at a price that makes up for those losses. Although the EFB disposed in plantations is effective as a fertiliser, it causes methane gas generation through corrosion and fermentation. In this case study, we assumed returning combustion ash to the plantation as fertiliser to receive free EFB.

EFB transport cost is IDR3,000/km・t according to previous JCOAL studies. Assuming that average distance from each palm oil mill to a power plant is 40 km, the purchase price of the EFB is IDR120,000/t and it is US$8.5 /t by conversion rate in Table 3.3.

Case 2: Rice husk

In general, rice collected from farmers are processed in the rice mill. After processing, milled rice (white rice), rice bran, and rice husk are generated. Average generation amounts of these products on the basis of rice are 70%, 10%, and 20%, respectively. Rice is often purchased in a wet state, and rice husk is burned to dry it before milling. About 30%–50% of the rice husk generated by milled rice is consumed for burning. The remaining 50%–70% of the rice husk is not used; it is dumped and awaits natural corrosion. A part of rice husk is used as cement raw material.

Since the purchase price of rice husk in the Philippines is currently ₱0.8–1.5/kg including transport cost, the price of rice husk in Case 2 is ₱1/kg on average and its price is US$19/ton by the conversion rate in Table 3.3.

1.5. Other conditions

Prerequisites of case studies are shown in Table 3.3.

Table 3.3. Prerequisites of Case Studies

	Case 1		Case 2	
Country Studied (Countries with similar status)	Indonesia (Malaysia, Thailand)		Philippines (Cambodia, Lao PDR, Myanmar, etc)	
Generation capacity	50 MW			
Operating duration	25 years			
Operating hours	8,000 hours / year			
Depreciation	15 years, Remaining value 10%			
Finance	Personal fund 30%, Loan 70% (Interest rate 10%)			
Corporate tax	25%		30%	
Exchange rate	¥110/US$, ¥0.00775/IDR		¥110/US$, ¥210/PHP	
Raw materials	Coal	Biomass	Coal	Biomass
Type	Lignite	EFB	Sub-bituminous	Rice husk
Properties	(Table 3.2)			
Price	20 US$/t	8.5 US$/t	60 US$/t	19 US$/t
Environment Standard (mg/Nm^3)				
SOx	750 (200)	( ): To be revisd in 2019	150 (Urban area) 200 (Other combustion equipment)	
NOx	750 (200)		700 (for SO2)	
PM	100 (50)		1000 (for NO2)	

Source: Authors.

2. Results and Estimation of Co-combustion

2.1. Fuel properties

Case 1

(a) Lignite

The lignite used in Case 1 is classified as high moisture and very low–quality coal. It is considered unsuitable for pulverised coal combustion boiler. On the other hand, it is possible to burn directly in CFB boilers without pre-drying. This lignite has a low risk of corrosion and can be used under high- temperature and high-pressure steam conditions. For 50 MW capacity, steam condition at 12.5MPa and 538°C (turbine inlet) is selected from an economic point of view.

(b) EFB

The EFB is a fuel that contains high moisture, high alkali metals and high chlorine, and therefore has a high risk of low molten salt corrosion. It is not recommended for direct combustion in large power plants. It is currently used in incinerator utilisation steam conditions (6Mpa and 460°C) in stoker furnace, etc. However, the generation of clinker in the furnace, ash adhesion to superheater pipe, problems such as molten salt corrosion, etc. occur. It is a fuel that has limited use due to its chemical composition. Therefore, in this study, we will consider the use of biomass in co-firing with coal.

Case 2

(a) Sub-bituminous coal

This coal is evaluated as a relatively high-quality sub-bituminous coal with low moisture content. The coal can be used in pulverised coal burning by technological advancement in equipment such as burners. The coal has a low risk of corrosion, and can be used under high-temperature, high-pressure steam conditions. For 50 MW, steam condition at 12.5 MPa and 538°C (turbine inlet) is selected from an economic viewpoint.

(b) Rice husk

Rice husk is a fuel that contains very high ash (mainly SiO_2) in biomass and contains high alkaline metals (mainly potassium). Compared to EFB, rice husk has no chlorine content and is relatively low risk in terms of corrosion. However, it is well known that low melting point ash is formed by the eutectic reaction of SiO_2 and K_2O. The risk, such as the problem of ash adhesion to the inside of the heater, is very high. The low-melting-point-ash formed from rice husk has a risk of melting even at 900°C or less, and is evaluated as a fuel that requires special consideration, such as selection of a low furnace temperature.

2.2. Steam conditions

The choice of steam conditions dictates the turbine efficiency which contributes significantly to the power generation efficiency at the power plant. In a 50 MW class power generation facility, the subcritical steam temperature is selected in view of the scale of the facility. It is generally selected as a non-reheat-type turbine from the economic viewpoint. In addition, this steam temperature selection requires the selection on the boiler side in consideration of the corrosion problem of the superheater weir and the like. In this study, it was necessary to consider the following three conditions of steam selection from the fuel risk (Table 3.4).

Table 3.4. Steam Conditions of Turbine at Selected Cases

Corrosion Risk	Turbine Steam Conditions		Boiler	Turbine Efficiency (%)	Application Example
	Pressure (MPaA)	Temperature (℃)	Feed water (℃)		
A: Low	12.7	538	250	40.22	Coal fired
B: Medium	10	510	230	38.62	Co-combustion High-quality fuel
C: High	8	480	185	36.07	Co-combustion Low-quality fuel

Source: Authors.

2.3. Efficiency and CO_2 reduction

Based on the consideration of fuel conditions, co-firing combustion was studied by changing the mixing ratio of biomass to coal in each of the case. The evaluations are as follows.

Efficiency

(a) Case 1
Used coal is lignite and very low quality – high moisture (51%) and low calorific value (2,478 kcal/kg NAR). Gross heat rate at coal-only fired plant is 35.3 % (low heating value [LHV]), which is a relatively good value. Although EFB as biomass also has a low quality, the gross heat rate efficiency is 34.1% at a biomass mixing rate of 25%, and 32% at a mixing rate of 50%. The decrease in efficiency is not so significant.

(b) Case 2
The results of Case 2 tend to be similar to Case 1. At coal-only fired plant, gross heat rate is 38% (LHV). Although the efficiency gradually decreases by the increase of the biomass mixing ratio, the result is as good as 32% even for biomass-only combustion. Since the raw material of Case 2 is of higher quality than Case 1, the gross heat rate and CO_2 reduction are better than Case 1.

CO_2 emission

CO_2 emission and CO_2 emission intensity in coal-fired power plants are 54.6 tons/year and 1,092 CO_2-g/kWh in Case 1, and 46.7 tons/year and 934 CO_2-g/kWh in Case 2. Since the raw materials used in Case 2 have better quality than those of Case 1, CO_2 emission and CO_2 emission intensity are lower than Case 1.

CO_2 emission is reduced by mixing biomass to coal. In Case 1, CO_2 emissions will be reduced by 81,600 tons annually if biomass is mixed with coal by 25%, and 191,200 tons annually if biomass is mixed with coal by 50%. In Case 2, CO_2 emissions will be reduced by 45,600 tons annually if biomass is mixed with coal by 25%, and 146,400 tons annually if biomass is mixed with coal by 50%.

Figure 3.6 shows the effect of CO_2 reduction by co-combustion compared to the USC and LNG power plants.

When the mixing ratio of biomass to coal is 25%, CO_2 emission intensity decreases from 1,092 to 887 CO_2-g/kWh in Case 1, and from 934 to 700 CO_2-g/kWh in Case 2. Therefore, CO_2 emission intensity is less than the USC at biomass mixing ratio of 20% (Case 2) and 30% (Case1). Additionally, at biomass mixing ratio of 50% in Case 2, CO_2 emission intensity is 486 CO_2-g/kWh, which is equivalent to LNG power plants. As a result, the co-combustion of biomass with coal clearly largely affects CO_2 reduction.

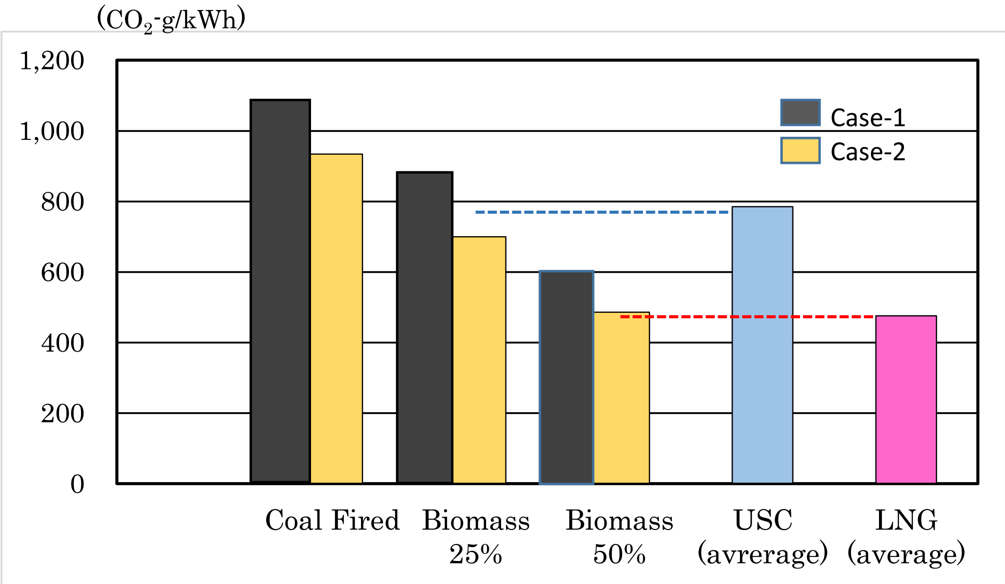
Table 3.5. Evaluation Results of Case Studies

Case 1						
Mixing ratio of raw material* (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Feed rate (t/h)	Coal	48	39	27	Not recommended	
	EFB	0	28	37		
Steam temperature (℃)		538	510	480		
Efficiency**						
Turbine (%)		40.0	38.5	36.0		
Boiler (%, LHV)		89.2	89.4	89.7		
Gross heat rate (%, LHV)		35.3	34.1	32.0		
CO_2 emission						
CO_2 amount (ton/hr)		54.6	44.4	30.7		
CO_2 intensity (g/kWh)		1,092	887	614		
CO_2 reduction (ton/year)		—	▲81,600	▲191,200		

Case 2						
Mixing ratio of raw material* (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Feed rate (t/h)	Coal	24	18	12.5	6.5	0
	Rice husk	0	10	21	33	44
Steam temperature (℃)		538	538	510	480	480
Efficiency**						
Turbine (%)		40.0	40	38.5	36	36
Boiler (%, LHV)		90.8	91.0	91.2	91.4	91.6
Gross heat rate (%, LHV)		36.0	36.0	34.8	32.6	32.6
CO_2 emission						
CO_2 amount (ton/hr)		46.7	41.0	28.4	14.8	0
CO_2 intensity (g/kWh)		934	700	486	252	0
CO_2 reduction (ton/year)		—	▲45,600	▲146,400	▲252,200	▲373,600

* Calorific value base.
**Transmission efficiency of 99%.
Source: Authors.

Figure 3.6. Effect of CO_2 Reduction by Co-combustion



Source: Authors.

2.4. Economic evaluation

Economic evaluation was considered under the following two conditions.

- IRR (internal rate of return) at tariff of US ¢ 8 /kWh
- Tariff at IRR of 10%

According to data published by the Ministry of Energy and Mineral Resources of Indonesia, the average power generation cost in Indonesia in 2018 was US ¢ 7.86/kWh, and average power generation cost in East Kalimantan province, which has many coal mines and palm plantations, is US ¢ 10.58/kWh. In addition, the power generation cost of coal-fired power plants in the Philippines is US ¢ 6.03–11.95 /kWh. From these data, we set US ¢ 8 as tariff.

Tariff is assumed at IRR 10%, which is generally the minimum rate that makes a project economically viable.

Economic evaluation results of co-combustion based on prerequisites indicated in Table 3.5 are shown in Table 3.6.

In either case, with tariff at US ¢ 8, project profit cannot be gained because of negative IRR. The tariff that may sustain IRR at 10% is US ¢ 15–16/kWh, which is much higher than the prevailing prices.

Therefore, among the preconditions for evaluation, the economics at loan interest rate of 5% were considered. Table 3.7 shows the effect of loan interest rate.

The IRR was negative even if the interest rate was 5%. Tariff slightly improved but the selling price remained high.

Large USC coal-fired power plants require high capital cost, while generation cost is less than US ¢ 10/kWh because of high generation efficiency of 40% or more.

In this case, higher selling price may be inevitable with low generation efficiency due to the poor quality of raw materials. Also, economies of scale do not hold due to the small capacity of power plants.

Thus, to establish a business, it is necessary to consider incentives for CO_2 reduction effects comparable to the USC and LNG, in addition to funds with low interest rates.

Table 3.6. Economic Evaluation Results of Case Studies

Case 1						
Mixing ratio of raw materials (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Efficiency						
Gross heat rate (%, LHV)		35.3	34.1	32.0		
CO_2 emission						
CO_2 intensity (g/kWh)		1,092	887	614		
CO_2 reduction (ton/year)		—	▲81,600	▲191,200		
Economic analysis						
IRR at US ¢ 8/kWh –tariff (%)		-2.0	-1.7	-1.5		
Tariff at 10% -IRR (US ¢ /kWh)		15.4	15.3	15.2		

Case 2						
Mixing ratio of raw materials (%)	Coal	100	75	50	25	0
	Biomass	0	25	50	75	100
Efficiency						
Gross heat rate (%, LHV)		36.0	36.0	34.8	32.6	32.6
CO_2 emission						
CO_2 intensity (g/kWh)		934	700	486	252	0
CO_2 reduction (ton/year)		—	▲45,600	▲146,400	▲252,200	▲373,600
Economic analysis						
IRR at US ¢ 8/kWh –tariff (%)		-7.3	-6.0	-4.6	-3.8	-2.0
Tariff at 10% -IRR (US ¢ /kWh)		16.8	16.6	16.3	16.1	15.5

IRR = internal rate of return, LHV = low heating value.
Source: Authors.

Table 3.7. Effect of Loan Interest Rate

Case 1							
Mixing ratio of raw materials (%)		Coal	100	75	50	25	0
		Biomass	0	25	50	75	100
Economic analysis							
Interest rate	10 %	IRR at US ¢ 8/kWh –tariff (%)	-2.0	-1.7	-1.5		
		Tariff at 10% -IRR (US ¢ /kWh)	15.4	15.3	15.2		
	5 %	IRR at 8 ¢ /kWh –tariff (%)	-1.6	-1.3	-1.1		
		Tariff at 10% -IRR (US ¢ /kWh)	13.9	13.8	13.7		

Case 2							
Mixing ratio of raw materials (%)		Coal	100	75	50	25	0
		Biomass	0	25	50	75	100
Economic analysis							
Interest rate	10 %	IRR at US ¢ 8/kWh –tariff (%)	-7.3	-6.0	-4.6	-3.8	-2.0
		Tariff at 10% -IRR (US ¢ /kWh)	16.8	16.6	16.3	16.1	15.5
	5 %	IRR at US ¢ 8/kWh –tariff (%)	-6.8	-5.5	-4.1	-3.4	-1.6
		Tariff at 10% -IRR (US ¢ /kWh)	15.2	15.0	14.7	14.5	13.9

IRR = internal rate of return.
Source: Authors.

Chapter 4
Conclusion

1. Summary of the Study

1.1. Adaptability of biomass co-combustion with coal, Case 1: Indonesia

Case 1 is on lignite/EFB co-combustion with 50 MW CFB boiler in Indonesia. This is a typical case of countries with palm plantation as the main agricultural product. EFB is recognised as unsuitable for biomass combustion in a PC boiler because of its high moisture, alkali, and chlorine contents. Therefore, co-combustion with coal is a way to use EFB as biomass energy.

The unit efficiency decreases with increasing biomass co-firing, i.e. the efficiency at 25% and 50% co-firing is 34.1% and 32%, respectively. The remarkable reduction of CO_2 emission is 19% and 44% at 25% and 44% in biomass co-firing cases.

From an economic point of view, if project profitability is to be kept at 10% IRR, US ¢ 15.2–15.4/kWh is required. In these cases, government incentives, such as feed-in tariff (FiT), are recommended.

1.2. Adaptability of biomass co-combustion with coal, Case 2: Philippines

Case 2 is on sub-bituminous/rice co-combustion with 50 MW CFB boiler in the Philippines. This is a typical case of countries with rice as the main agricultural product. Rice husk has high silica and potassium content and low chlorine. This means a relatively low melting point and adhesion inside the boiler wall is an issue.

The unit efficiency slightly decreases with increasing biomass co-firing, i.e. the efficiency at 25%, 50%, and 75% co-firing is 36%, 34.8%, and 32.6%, respectively. A remarkable reduction of CO_2 emission is expected as in Case 1.

From an economic point of view, if the project profitability is to be kept at 10% IRR, US ¢ 15.5–16.8/kWh is required. In these cases, government incentives, such as FiT, are recommended.

1.3. Input by the Working Group

The working group meeting was held at the ERIA Jakarta office on 6 February 2019 with participants from Cambodia, Indonesia, and Thailand. Each member country presented its power situation, especially biomass installation.

This meeting revealed that the main energy source of these four countries is coal; all countries are intensively increasing renewable energy to mitigate greenhouse gas (GHG) and regional environmental impact. While unused agricultural waste is found to be a potential biomass energy resource in these countries, it has not yet been realised. The capacity of a biomass-fired plant is thought to be only 50–100 MW. Co-combustion with coal at a coal-fired plant is a more considerable measure to increase the use of biomass.

2. Conclusion of the Study

The study indicates that co-combustion of agricultural waste and coal on CFBC boilers will remarkably contribute to CO_2 mitigation compared with simple coal combustion for power generation.

However, the findings on Case 1 and Case 2 reveal that their economic viability is so far not feasible under the current tariff situation unless the right incentives are in place.

In this connection, further consideration shall be given in the next study to identify tailor-made country-specific models with the optimal capacity and technologies as well as envisaged incentives.

3. Policy Recommendations in the ASEAN Region

3.1. Adaptability of biomass co-combustion

Table shows the current power situation and biomass potential of each country. All countries can potentially expand the application of biomass and coal co-combustion as a GHG mitigation measure. Biomass co-combustion is also beneficial to mitigate regional environmental impact such as SOx, NOx, and suspended particulate matter (SPM) since biomass normally has less heteroatom and ash compared to coal.

Table 4.1. Current Power Situation and Biomass Potential

Country	Capacity (GW)	Renewable Capacity (%)	Biomass Resources	Biomass Potential (MWe)	Current Tariff Incentive, FiT
Cambodia	1.87				
Indonesia	60.79	0.1	Oil palm waste (inc. POME) Sugarcane (bagasse, trash) Wood waste Rice (hull, straw) Corn (cobs, stalks) Coconut (shell, husk, fronds), Etc.	32,654	FiT is not applied. Using reference price for each system.
Philippines[6]	23.81	7.2	Rice (hull,	4,449.5	Php

[6] All data on the Philippines here were provided by the working group member from the Department of Energy, Philippines.

			straw) Corn (cobs, stalks) Coconut (shell, husk, fronds) Sugarcane (bagasse, trash) Hog and chicken manure	4	6.5969/kWh (for approval) (FiT)
Thailand	43.07	15.28			4.00-5.50 B/kWh

FiT = feed-in tariff.
Source: Authors' compilation and calculation

Another advantage of biomass co-combustion is the use of agricultural waste. As described in Section 2.3, a significant volume of agricultural waste to be applicable for co-combustion is expected in ASEAN countries.

3.2. The advantages and spillover effect of biomass co-combustion

Biomass co-combustion with coal can contribute to the increase of universal access in the ASEAN region as an applicable measure of mitigating GHG emissions. The advantages and spillover effects are as follows:

(1) Biomass use in coal-fired power plants is to be applied as direct and effective mitigation measures of CO_2 in the power sector of countries that use coal as the main energy source, such as those in the ASEAN region. CO_2 emission is reduced proportionally by increasing the blend ratio of biomass with coal since biomass is recognised as a carbon-neutral substance.

(2) Agricultural waste, for example, PKS, EFB, sugar cane, rice husk, and food waste, in the ASEAN region is thought to be a potential domestic energy resource. It can also reduce underutilised waste. Biomass can be used in a wider type of boilers such as CFB, small pulverised boiler, and USC of larger capacity.

(3) The effectiveness of biomass as an alternative fuel in a coal-fired power plant is not only to mitigate CO_2 emissions but also to reduce plant operation costs if biomass is efficiently collected from the surrounding area. Since one issue in using agricultural waste as biomass fuel is the seasonal volume change, i.e. supply stability, co-firing with coal can compensate the total energy input to the plant by optimising coal/biomass ratio with seasonal variation.

(4) Although applicable biomass resources and the current utilisation situation is different in each country, biomass co-combustion in a coal-fired power plant might increase regional employment through the collection, selection, and torrefaction processes in the surrounding areas.

Considering the above-mentioned, expediting the realisation of biomass/coal co-firing in a coal-fired power plant in the ASEAN region is deemed crucial in addressing both CO_2 mitigation and surging energy demand.

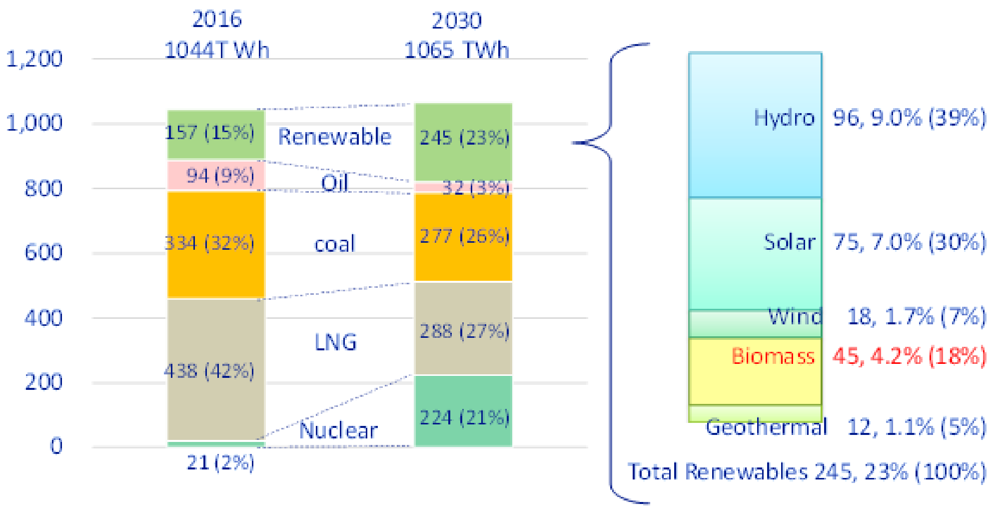
3.3. Policy recommendations to expedite biomass co-combustion

To conclude, policy recommendations are summarised below. The realisation of the following items in each country is basically to be considered by the respective country. Bilateral or multilateral collaboration can expedite the possibility of the realisation.

(1) *Authorisation by the government to use biomass as renewable energy in the energy development plan of each country.*

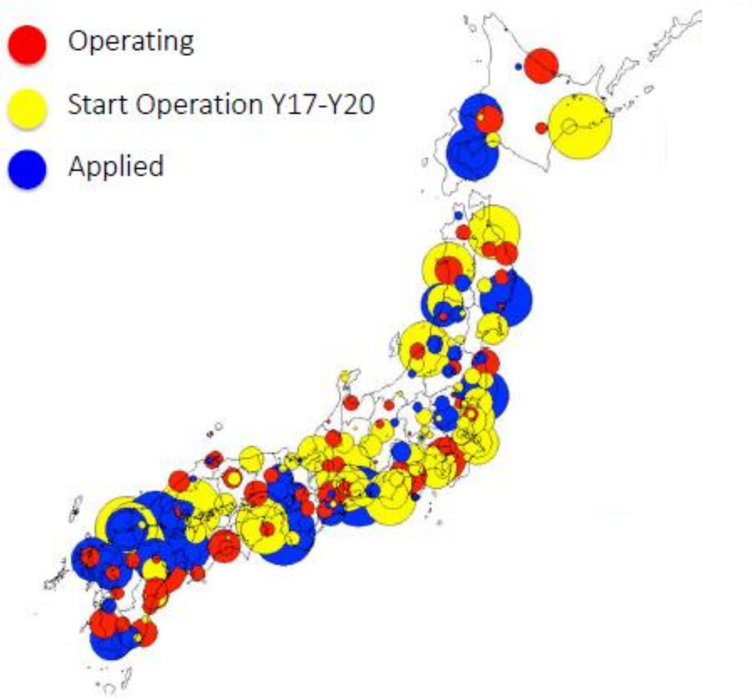
In Japan, the target of the biomass utilisation is clearly shown by the government (Figure 4.1). Expected in 2030 is 45 TW of biomass generation out of total renewables of 245 TWh. Most of the biomass generation will be accomplished by co-combustion with coal. Along with the government's target, a significant number of plants are commissioning or are being planned by the major electric power company and newly joined venture companies.

Figure 4.1. Generation Forecast in Japan, by Source



Source: METI (2017).

Figure 4.2. Biomass Plant in Japan[a]



[a] Diameter of the circle shows the capacity.
Source: Fuji Biomass Energy Sdn. Bhd. (2018).

(2) Tariff and other financial incentives for biomass co-combustion

Tariff incentives for biomass co-combustion, such as FiT, are to be considered for accelerating the investment of biomass co-combustion. If feed-in tariff has been introduced, its rate for each renewable source should be optimised according to the renewable target and energy mix. In this study, US ¢ 13–16/kWh is to be recommended as FiT for further dissemination of biomass use in the ASEAN region.

Also recommended is the establishment of a special purpose financial scheme solely for the biomass utilisation project.

(3) Development of biomass collection scheme

A continuous and stable agricultural waste collection process is essential to establish biomass co-combustion in a coal-fired plant. Depending on the agricultural waste resources, for example, the PKS is already treated commercially as an energy source. Most of the waste of cereal crops is thought to be applicable for biomass energy. To utilise such biomass sources, an integrated collection function should be located at the centre of the collection area and transportation system. If a cooperative association is established by local farmers, business owners, and related organisations to handle the collection and transportation of biomass in the region, the efficiency of biomass delivery can be improved.

The establishment of a cooperative association is also beneficial. A cooperative association is exempt from taxation, while a corporation is not. In addition, activities conducted by such a cooperative association contribute to the local economy and create jobs. Furthermore, they will be regarded as corporate social responsibility activities of the operator.

In this connection, authorisation by the government of a plant for biomass co-combustion and capacity of the collection function is considered to expedite the realisation of the biomass utilisation project by public or private participators.

(4) Support by the regional government for jobs related to collection of biomass waste

Since the collection of agricultural waste is labour intensive, hiring enough workers to collect, transport, and pelletize it, if required, is very important. Initiatives by the regional government for securing employment are recommended. This has also the advantage of utilising manpower in the agricultural sector during off-season.

Several financial support schemes can be considered, such as subsidy for the number of employees, a discount interest rate for investment, etc. Support for the establishment of a cooperative association might be also effective to secure the required workers.

(5) Collaboration to realise biomass co-combustion projects

Technical collaboration, as bilateral/multilateral cooperation between ASEAN countries and a country which has the experience and applicable technologies, is recommended to materialise the biomass co-combustion project.

This kind of collaboration is effective especially for the introduction of applicable technologies such as CFB boiler for combustion of agricultural waste with coal. Public-based cooperation with technologies owned country is highly recommended.

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Appendices

Appendix I. Overview of the Power Sector in ASEAN

Current Situation of the Power Sector

- Corporate structure of the power business
  The power generation business of each country is shown in Table 1A. The Philippines and Malaysia are privatised. However, in Indonesia, Thailand, Viet Nam, and Myanmar, their respective state power companies conduct the countries' electricity business. The Lao PDR and Cambodia have mixed state-owned and private companies, but independent power producers (IPPs) account for most of them (Table 1A).

Table 1A. Corporate Form of the Electric Power Business

	Government Organisation	National Company	Private Company
Cambodia	Ministry Mine and Energy (MME)	Electricité du Cambodge (EDC)	Independent Power Producer (IPP) Rural Electricity Enterprise (REE) Provincial Electricity Company (PEC) Provincial Electricity Utility
Indonesia	Ministry of Energy and Mineral Resources (MEMR) Directorate General of Electricity (DGE)	Perusahaan Listrik Negara (PLN)	PT. Indonesia Power (IP) PT. Pembangkitan Jawa Bali (PJB)
Lao PDR	Ministry of Energy and Mines (MEM)	Electricité Du Laos (EDL)	IPP Domestic IPP International EDL Generation Public Company (EDL-Gen)
Malaysia	Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC)	Tenaga Nasional Berhad (TNB)) Sabah Electricity Sdn Bhd.(SESB) Sarawak Energy Bhd. (SEB)	IPP Small Power Producer (SPP)
Myanmar	Ministry of Electricity and Energy (MOEE)	Electric Power Generation Enterprise (EPGE) Department of Power Transmission and System Control (DPTSC)	Yangon Electricity Supply Cooperation (YESC) Mandalay Electricity Supply Cooperation (MESC) Electricity Supply Enterprise (ESE)
Philippines	Department of Energy (DOE) Electric Power Industry	National Power Corporation (NPC)	Manila Electric Company (MERALCO)

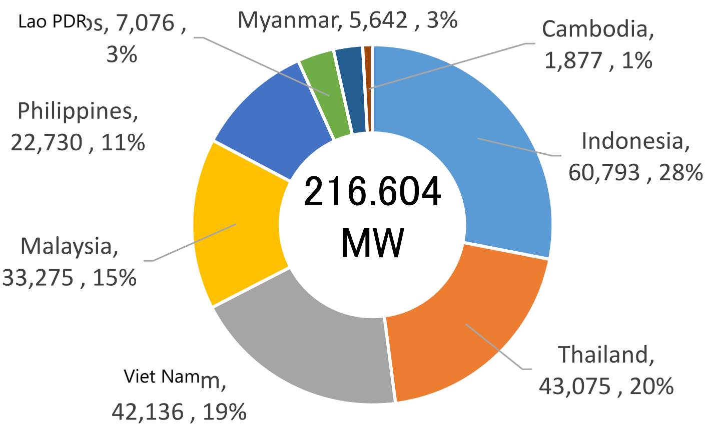
	Management Bureau Director of Energy Policy and Planning Bureau		Visayan Electric Company (VECO) Davao Light and Power Company, Inc. (DLPC)
Thailand	Ministry of Energy (MOE)	Electricity Generating Authority of Thailand (EGAT)	IPP SPP Very Small Producer (VSPP)
Viet Nam	Ministry of Industry and Trade (MOIT) Electricity and Renewable Energy Authority (EREA)	Electricity of Viet Nam (EVN)	IPP Vinacomin EVN

Source: Created by each government website.

- Power generation capacity in each country

  The total capacity of the power generation facilities of the eight countries in 2017 was 216,604 MW. The share of each country is 28% for Indonesia, 20% for Thailand, 19% for Viet Nam, 15% for Malaysia, 11% for the Philippines, 3% for the Lao PDR, 3% for Myanmar, and 1% for Cambodia (Figure 1A).

Figure 1A. Capacity of Power Generation in Each AMS (MW)

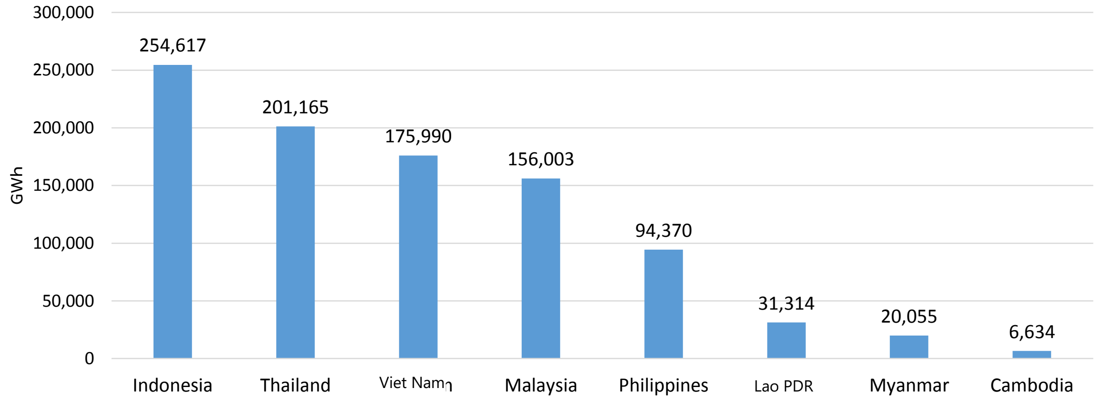


AMS = ASEAN member state.
Source： Created by Home Page in each country.

Figure 1B hows the amount of electricity generated in 2017[1] by country. Indonesia is the largest with 254,617 GWh. The smallest is 6.634 GWh by Cambodia. The Lao PDR uses only 4,697 GWh (15%) of the total 31.314 GWh for domestic consumption, and the remaining 85% of the electricity is exported to neighbouring countries. Thailand, Viet Nam, and Cambodia buy electricity from the Lao PDR.

[1] Thailand and Myanmar in 2018, Viet Nam and Malaysia in 2016.

Figure 1B. Power Generation in Each AMS (GWh)

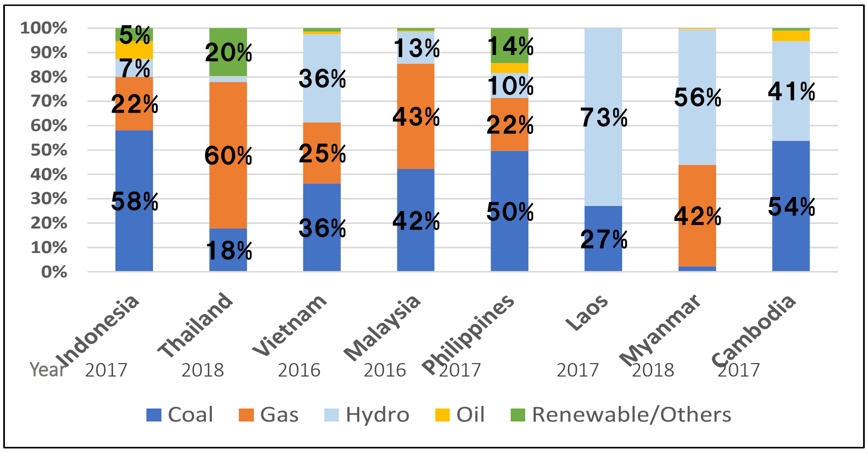


AMS = ASEAN Member State.
Source：Created by Home Page in each country.

Current situation of the coal-fired power plant

The following graph shows the ratio of electricity generation by source in each AMS in 2017. Indonesia (58%), Cambodia (54%), Philippines (50%), Malaysia (42%), Viet Nam (36%) are the countries with the highest ratio of coal. High ratio of gas is in Thailand and hydropower is in the Lao PDR, hydropower and gas are in Myanmar. In Thailand and the Philippines, the ratio of renewable energy is high. Especially in the Philippines, geothermal power generation is thriving.

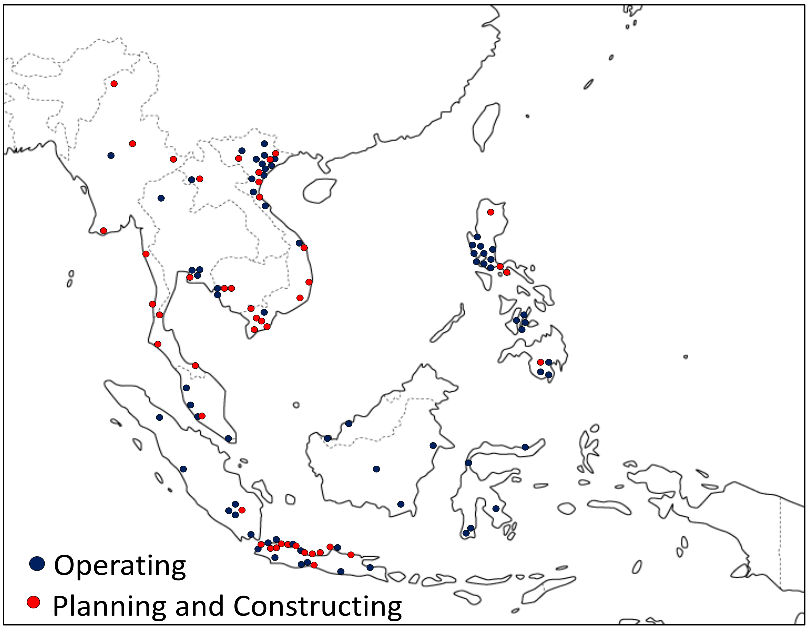
Figure 1C. Electricity Generation by Source, %



Note: The Government of Indonesia categorises hydropower as renewable energy. This graph separates hydro from renewable only for the sake of comparison.
Source: Created by Home Page in each country.

Figure 1D hows the location of coal-fired power plants currently in operation and being planned and under construction. Indonesia, Malaysia, Philippines, and Viet Nam are being installed by coal-fired power.

Figure 1D. Coal-fired Power Plants that Are Operating, Being Planned, and Under Construction



Source: Created by Home Page in each country.

Future power generation plan

In the power planning of the eight countries, coal plays a major role in the future as its consumption will steadily increase with the operation of new coal power plants. In Indonesia, coal consumption is predicted to be 192 Mt (electricity 163 Mt) in 2027. Viet Nam is expected to consume 157 Mt (electric power 131 Mt) in 2030. Coal consumption of Malaysia, Thailand, the Philippines, Lao PDR, and Cambodia is also predicted to increase to millions of tons. The current 264.23 Mt of coal consumption, including industries other than electric power, will further increase and is predicted to exceed 400 Mt tons after 10 years.

Cambodia

The transition of power generation from 2007 to 2017 in Cambodia increases at an annual rate of 17.3%. At this rate, power generation will be 23,774 GWh in 2025, 3.6 times of 6,634 GWh in 2017. The power plan is expected to add 720 MW of coal-fired power plants.

Indonesia

Indonesia's power generation will be 501,917 GWh in 2027, which is about 2.5 times compared to the current quantity. Coal generated is 293,902 GWh, accounting for 58% of the total generation. In addition, the total capacity of power generation facilities to be built between 2018 and 2027 is 56 GW, 27 GW of which is coal power, which is 48% of the total generation.

Lao PDR

The power plan of the Lao PDR is driven mainly by hydropower and coal. Hydropower generation will be 17,486 MW in 2030, increasing three times compared with 2017. The coal generation will be expanded to 3,378 MW in 2025 because of the expansion of the Hongsa Power Plant and two new coal power plants. Hydropower growth is overwhelming that of coal. The ratio of coal in the electricity mix will fall to 15% in 2035 from 27% in 2017.

Malaysia

The 11th Malaysia Plan (2016–2020) has been announced. Among the power plans, that of 2020 (191,937 GWh) will be 1.9 times more than the 2010 (101,727 GWh); the ratio of coal is planned to increase from 42% in 2010 to 53% in 2020. However, the actual for 2015 was 135,450 GWh, which is behind the planned 158,843 GWh.

Myanmar

According to Myanmar's electricity plan, electricity demand will increase to 8,121 MW by 2025. Myanmar's power generation capacity is large because power supply loss is as large as 30% due to the poor grid. The total electricity capacity in 2030 is planned to be 16,112 MW, 2.9 times that of 2017. Hydropower accounts for 55% of the overall installed capacity, followed by 16% coal, 15% gas, and 14% renewable energy. As of 2016, six coal-fired power plants were in the government's power development plan.

The Philippines

According to the Philippine power plan, power demand will be 16,325 MW in 2020; 28,185 MW in 2030; and 49,287 MW in 2040. It will increase 1.3 times, 2.3 times, 4.0 times, respectively, compared with 2015.

Thailand

The power plan of Thailand is to construct a new 57,460 MW power plant by 2036, when power generation will be about 320,000 GWh. The amount of power generated is 1.6 times of the current quantity. The composition rate of 2036 is 18% renewable energy, 2% (domestic) hydropower, 15% (imported) hydropower, 37% natural gas, 17% imported coal, 6% lignite coal, and 5% nuclear power. Coal, with indigenous lignite and imported all together, accounts for 23%.

Viet Nam

According to the power plan of Viet Nam, the amount of power generation is 572,000 GWh in 2030, 3.2 times of the current quantity. Coal accounts for 53%.

Appendix II. Working Group Members and the Meeting at ERIA Headquarters on 6 February 2019

(1) Working group members

No	Country	Name	Affiliation	Designation
1	Cambodia	Mr Chheang Bunthy	Generation, Transmission and Sub-Transmission Department, Electricity Authority of Cambodia (EAC)	Deputy Director
2	Cambodia	Mr Sok Chandareth	Ministry of Mines and Energy	Chief of Energy Statistic Office
3	Cambodia	Mr Han Vanra	Independent Power Producers Operation Office, Generation Department Electricite du Cambodge (EDC)	Deputy Chief
4	Indonesia	Ms Elis Heviati	Directorate of Bioenergy, Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources	Deputy Director for Investment and Cooperation of Bioenergy
5	Philippines	Mr Jensen M. Alvarez	Biomass Energy Management Division, Renewable Energy Management Bureau, Department of Energy	Senior Science Research Specialist
6	Philippines	Ms Litz M. Manuel-Santana	External Affairs, MERALCO PowerGen Corporation	Vice President & Head
7	Thailand	Mr Chawit Chongwilaiwan	Hydro Power Plant Planning and Feasibility Study Department, Power Plant Development Planning Division, Electricity Generating Authority of Thailand (EGAT)	Head of Hydro Power Project Feasibility Study Section
8	Thailand	Dr Yaowateera Achawangkul	Department of Alternative Energy Development and Efficiency, Ministry of Energy	Mechanical Engineer, Senior Professional Level

(2) Summary of the Meeting: Attendance List

No	Country	Name	Affiliation	Designation
1	Cambodia	Mr Chheang Bunthy	Generation, Transmission and Sub-Transmission Department, Electricity Authority of Cambodia (EAC)	Deputy Director
2	Cambodia	Mr Sok Chandareth	Ministry of Mines and Energy	Chief of Energy Statistics Office
3	Cambodia	Mr Han Vanra	Independent Power Producers Operation Office, Generation Department Electricite du Cambodge (EDC)	Deputy Chief
4	Indonesia	Ms Elis Heviati	Directorate of Bioenergy, Directorate General of New Energy, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources	Deputy Director for Investment and Cooperation of Bioenergy
5	Thailand	Mr Chawit Chongwilaiwan	Hydro Power Plant Planning and Feasibility Study Department, Power Plant Development Planning Division, Electricity Generating Authority of Thailand (EGAT)	Head of Hydro Power Project Feasibility Study Section
6	Thailand	Dr Yaowateera Achawangkul	Department of Alternative Energy Development and Efficiency, Ministry of Energy	Mechanical Engineer, Senior Professional Level
7	Japan	Dr Kazuyuki Murakami	Business Development Department, Japan Coal Energy Center	Principal Deputy Director
8	Japan	Ms Yamada Fumiko	Business Development Department, Japan Coal Energy Center	Assistant Director
9	Japan	Mr Yasuo Otaka	Business Development Department, Japan Coal Energy Center	Deputy Director
10	Japan	Mr Itsuki Watanabe	Jakarta Representative Office, Sumitomo Heavy Industries, Ltd	Chief Representative
11	Japan (Indonesia)	Mr Irul Khoiruddin	Jakarta Representative Office, Sumitomo Heavy Industries, Ltd	
12	Japan (Indonesia)	Mr Yoga Iriansyah Unthailawal	Jakarta Representative Office, Sumitomo Heavy Industries, Ltd	
13	ERIA	Dr Han Phoumin	ERIA	Energy Economist
14	ERIA	Mr Shigeki Kamiyama	ERIA	Director General for Research Administration

(3) Summary of the Meeting: Minutes

Date and time : 6 February 2019, 9:30–15:20

Location : Meeting Room 5-6, ERIA

Attendance : Dr Phoumin, Mr Kamiyama, six delegates from Cambodia, Indonesia, and Thailand, Dr Murakami, Mr Otaka, and Ms Yamada of JCOAL Study Team

Morning Session

Members of the JCOAL team expressed their appreciation to delegates who came all the way to Jakarta during their busiest time of the year. Two delegates from the Department of Energy (DOE) and MERALCO PowerGen of the Philippines could not be physically present but were willing to provide their inputs through electronic communication.

Mr Kamiyama of ERIA, in his brief welcome address, indicated that ERIA handles about 20 studies annually, some of which are requested by the AMSs and others are proposed by relevant organisations. In any case, the point is that the study concept and its objectives are in line with the East Asia Summit (EAS) Energy Study Roadmap. Four pillars constitute the roadmap and these are always on the agenda of the EAS Energy Ministers' Meeting. He closed his address by expressing his expectation of a fruitful discussion.

Dr Murakami of the JCOAL Study Team served as the chair. The self-introduction of participants was followed by a photo session.

Cambodia's delegates Mr Sok Chandreath of MME and Mr Han Vanra of EDC made the first presentation. They described the structure of the relevant institutions with the Ministry of Mines and Energy (MME) functioning as the policymaker, the Electricity Authority of Cambodia as the regulator, and the Electricité Du Cambodge (EDC) as the central utility/operator/retailer/single buyer from the independent power producer (IPP). Current renewable energy is contributing both to the national and the isolated grids. Comprising Cambodia's power strategy is the development of diversified energy sources, transmission lines – national/Greater Mekong Subregion/ASEAN – and rural grid as well as upgrading HV/MV/LV lines. It also includes the development of rural electrification through enhancement of supply from the national grid and stand-alone systems.

Looking at the overall situation, the annual electricity demand per capita increased from 416 kWh in 2017 to 490 kWh in 2018. The peak capacity supply increased from 1,100 MW in 2016 to 1,269 MW in 2017. At the same time, the peak demand in Phnom Penh was about 735 MW. In 2018, the national electrification rate increased to 81.58%, while the electrified households in urban areas were almost 100%, and those in rural areas about 70%. Cambodia has a good potential of hydropower of about 10,000 MW. At present, about 13% of its potential is constructed. In 2018, the total electricity supply increased to 7,954 GWh within the installed capacity of about 2,215 MW while imported electricity accounted for 17%.

As for the primary energy supply mix, coal accounted for 16% as of 2017, which means a massive increase from 0% in 2010, according to the country's strategy for energy diversification.

During the presentation, general specifications of coal-fired power plants were indicated. They used 6,210 GCV/kg of bituminous coal imported from Indonesia.

The environmental regulatory values for air quality control are SO_2 500, NOx 1,000, PM 400. Ash removal is done by the ESP. The SO_2 control system is part of the standard equipment for environmental control.

The installed capacity of biomass power generation reaches 51.27 MW with eight IPPs. Fuels vary from firewood to bagasse to paddy husk.

Dr Phoumin mentioned that coal and woodchip co-combustion has been demonstrated already in Thailand, which would be a good reference to the other AMS.

Indonesia, represented by the Ministry of Energy and Mineral Resources, was the second presenter in the working group meeting. Indonesia is highly dependent on fossil fuel; more than 90% of national energy consumption is derived from oil, gas, and coal. The government is shifting its energy policy priorities towards renewable energy in view of the limited remaining reserves of fossil fuel as well as the global and national environmental concerns.

However, the situation of current utilisation is that the total generation by renewable energy is 9.525 GW only against the potential 441.7 GW.

As of 2018, renewables accounted for 7.3% and coal accounted for 30.1%. Renewable energy will considerably increase up to 23% of the primary energy mix in 2025, while coal will be steady; it will remain at 30%.

During the last decade, Indonesia's national electrification ratio has impressively improved. By Q3 2018, it had reached 98.30%; in the same quarter in 2010, it was 67.2%.

Overviewing national policy priorities, the National Energy Plan emphasises the following: (i) maximising the use of renewable energy, (ii) minimising the use of petroleum, (iii) using coal as a reliable national energy supply, (iv) optimising the use of natural gas and new energy, and (v) using nuclear as a last resort.

The government also sets out bioenergy development goals consisting of six main pillars, including the commitment to reduce GHG emissions to 29% below the Business-As-Usual scenario by 2030.

A regulatory framework, including electricity tariff to facilitate renewable energy, is also in place.

Under government initiative, various programmes are progressing. Biomass potential for electricity is highest in Sumatra (15,588 MWe). National potential is as much as 32,654 MWe. As of today, the installed capacity of biomass power is 1,858.5 MW with on-grid at 214.6 MW and off-grid at 1,643.9 MW. The target capacity in 2025 is 5.5 GW.

The latter part of the presentation discussed coal resources, such as quality, reserves, production, price mechanism, and domestic market obligation.

Finally, challenges in bioenergy development and the government's efforts to overcome them were introduced.

The Department of Energy (DOE) and MERALCO PowerGen were not able to send delegates, so the third presenter was Thailand. The first part of the presentation was undertaken by the Department of Alternative Energy Development and Efficiency. As of now, Thailand is also dependent on fossil fuel, which accounts for 75.63% of the national energy consumption. The major fossil fuels used are oil and gas. Coal's share is relatively small in its energy mix. Renewable energy accounts for 15.28%. The installed capacity of biomass power accounts for 30%, 3,276.88 MW out of 10,797.50 MW.

Three main pillars constitute the fundamental energy policy of the Government of Thailand: (i) secure the country's energy supply, (ii) implement fair pricing for energy, and (iii) conserve energy. The government is committed to reduce GHG emissions by 20%–25% by 2030.

The government has embarked on the Alternative Energy Development Plan (AEDP) 2015–2036, which sets out an integrated and by-fuel strategy towards the target of 30% renewables in total energy consumption by 2036. Biomass use is no doubt an important part of the AEDP. The government has been continuously endeavouring to reform relevant strategies that support renewable energy development.

The potential type of biomass in Thailand varies, such as rice straw, sugar cane top and trash, corn trunk, cassava rhizome, cassava trunk, oil palm frond, para-wood root, etc.

Ongoing major activities consist of encouraging (i) biomass use, promotion, and support; and (ii) research and development (R&D). To increase the use of unutilised biomass and improve energy efficiency in agro-industry, the government is facilitating development of off-grid 300 MW biomass power plants mainly with residual para wood in three southern border provinces. The programme is to be implemented under a public–government partnership.

The government is also trying to promote and support biomass utilisation through updating and revising biomass potential and collection factors, providing financial support and knowledge sharing with the community. R&D activities are also enthusiastically pursued. Pelletization, torrefaction, biocoal, and innovative biomass energy monitoring are among the R&D themes.

The second part of Thailand presentation's was undertaken by the Electricity Generation Authority of Thailand (EGAT).

Firstly, the structure of Thailand's electricity sector was shown. The contracted capacity is 46,090 MW as of December 2017. The 2018 Power Development Plan forecasts that the overall installed capacity will reach 77,210 MW with capacity addition of 56,431 MW and capacity retirement of 25,310 MW. Renewable energy is envisaged to account for 32.5% (25,086 MW). Thermal power will account for 6.8% (5,213 MW). Biomass is anticipated to be 17% in the renewable electricity mix in 2037.

Thailand is well on its way towards biomass use in the power sector. As of 2017, 688 biomass projects submitted a request for power purchasing agreement (PPA). However, 58% (5,053 MW in 432 projects) were cancelled, while 33% (2,910 MW in 194 projects) had seen a commercial operation date and 9% (790 MW in 62 projects) had their PPAs done. While Thailand is endowed with a wide variety of biomass, the envisaged most potential agricultural biomass is bagasse (56%, equivalent to 2,053 MW), woodchip (22%, 800 MW), rice husk (11%, 407 MW), and palm (3%, 111 MW). These major biomass resources have been developed in connection with a particular industry sector and/or regions and are featured accordingly.

The latter part of EGAT's presentation was dedicated to a biomass and coal co-firing research at the EGAT Mae Moh Thermal Power Plant. The purpose of the research that continued on 40 tons/day biomass (total biomass mix: 1,000 tons) and pulverised coal is to pursue a possibility of co-combustion of biomass at the existing coal-fired power plant. The anticipated research outcomes in terms of emission reduction and technical effect on the existing equipment are to be evaluated in the research.

The envisaged solution is co-firing of (i) bio-coal pellets of 5,700 kcal/kg; (ii) biomass (woodchip) pellets of 3,700 kcal/kg and woodchips of 2,000 kcal/kg; and (iii) lignite coal of 2,790 kcal/kg.

The tentative outcomes of the research indicate two scenarios: (i) without modification of the power plant and (ii) with modification of the power plant. The former is advantageous only in terms of lowest initial cost; however, it is less flexible with the highest mixture ratio at 2%–3%. Also, poor mixing could risk a mill fire. In the meantime, the second scenario no doubt requires a higher investment cost in installation of new biomass mill and burner. That said, the second scenario will realise more flexibility with the highest ratio over 10% and high throughput.

Thailand has its own biomass tariff and it would be possible to earn the +5% premium tariff through biomass power generation. However, it is still at the experimental stage, and how the government will ensure that +5% is important.

Feed-in tariff for biomass power generation in Thailand was allocated by B4.00–5.50/kWh corresponding to its existing capacity. Furthermore, power plant project owners can obtain the premium rate if their project is located in the three southern border provinces throughout the power purchasing contract period.

At the end of the morning session, Dr Murakami mentioned that in case of Japan, 3% is deemed to be the mix limit. A wide range of biomass fuels is also used for co-combustion.

Dr Phoumin commented that coal itself is sustainable in terms of energy security, so it would be beneficial to pursue the optimal use of biomass through co-combustion with coal.

Afternoon Session

The representatives of JCOAL and Sumitomo Heavy Industries (SHI), both as part of the JCOAL study team, presented the overview of the study and technological considerations, respectively, based on their own experiences.

Q&A, Discussion

- The circulating fluidised bed (CFB) may provide the same level and scope of advantages in terms of CO_2 emission reduction and other environmental mitigation. Then how about the cost? I would also like to know required volume of biomass and levelized tariff.
- What is the optimal size of biomass?
- Demolition wood waste utilisation might have potential.
- CAPEX and OPEX are the most crucial.
  → In Thailand, stoker boilers are used for co-combustion, so the situation might be a little different. （SHI）
- Biomass–coal co-combustion is beneficial as it reduces CO_2 emissions and coal consumption. Also, possible emissions of methane from dumped agricultural waste will be prevented.
- As of now, Indonesia has not seen a policy framework for co-firing power plants (including the pricing policy) in place. This is partly because they are yet to find an effective way to monitor the use of the feedstocks. However, PT PLN (Persero), the national utility company, will soon conduct a co-firing trial in one of its power plants.
- In Thailand, public campaigns against coal caused coal-fired power plant plans to be cancelled. However, coal share is increasing in the latest PDP. Coal used is sub-bituminous or bituminous.
- To maximise biomass use, gasification is thought to be suitable for smaller power generation.
- JCOAL conducted a demonstration of biomass gasification in rural areas. That was on small scale, 2 MW, and efficiency is not as high as a large-scale USC. However, it is possible where a smaller scale plant is suitable. The JCOAL team will later provide details.
- Identification of a possible biomass–coal co-combustion and the desired composition is important. The most crucial is whether it is feasible in ASEAN.
- Talking about safety, what type of technology is required to ensure safety? In Thailand, where people are more concerned about environmental impacts and safety of power generation, it is to be much clearer.

- Indonesia's price policy is US ¢ 4–5/kWh for coal and US ¢ 10/kWh for biomass.
- As for plant scale, the biggest in Indonesia is 10 MW; that is in palm oil plantations.
- There are concerns about big differences in skills and economic feasibility.
- A unit of 50–100 MW is considered appropriate. Plant location is important for increasing feasibility with plantation, etc. （SHI）
- There are five important points: (i) feasibility, (ii) biomass potential, (iii) public acceptance, (iv) price policy, and (v) recommendations for policy support.
- People in Thailand have impressions that biomass does not require much labour and time.
- Policy barriers are to be identified and addressed. (SHI)
- In summary, the Mae Moh mine mouth power plant is running out of cheap coal.
- Power plants that use co-combustion of biomass with coal of any mix ratio may not be allowed to register under Republic Act No. 9513.
- A co-combustion power plant may be registered under Republic Act No. 9513 until such time that the plant is 100% fired by biomass.
- Considering the volume of biomass needed to replace coal in power plants of big capacity, it would be very difficult to identify the source of biomass feedstock, and the collection/consolidation and logistical requirement needed. A typical 12 MW biomass power plant requires 13 tons/hour or about 103,000 Mt of pure rice hull per year.

To conclude, the working group summarised the importance of biomass utilisation as follows: (i) use of domestic biomass resources, especially waste materials; (ii) GHG reduction; and (iii) mitigation of regional environmental impact for replacing coal.

For further materialisation and facilitation, policy recommendations for government support, such as tariff incentive, demonstration, and research and development, are the most important outcomes of the study.

Through the discussion, the scope and schedule of the biomass study were agreed on by working group members. JCOAL will provide the draft report by the middle of May for further feedback by the working group members.