Comparison of Ammonia Co-firing and Early Retirement of Coal-fired Power Plant

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1. Introduction

Actions to reduce CO_2 emissions to address climate change issues have gained further momentum globally in recent years. Among the efforts to reduce the emissions, adopting renewable energy sources such as wind and solar, are often given the highest priority to mitigate the adverse effects caused by the climate change. It is no doubt that these renewable energy sources must be adopted to the highest degree in any country in order to combat climate change. It is, however, also true that such renewable energy resources are not evenly distributed across the world and, depending on the resource endowment, are not always sufficient to fully substitute the existing fossil fuel consumption and eliminate the CO_2 emissions from the use of fossil fuels. This resource limitation is particularly acute in the developing world whose electricity demand is highly likely to grow fast in the coming decades.

What makes the emissions reduction actions in Southeast Asia more complicated is the existence of a relatively young fleet of coal-fired power generation. The number of coal power units has rapidly grown in the last decade and is expected to increase in the next few years because of the additional units currently under construction. These plants are still new and it takes years to fully recover the initial investment. In Southeast Asia, in addition to the installation of additional renewable power generation, decarbonization of the existing coal power units is a critical challenge for this region's energy and environmental policies.

As a solution to decarbonize the coal-fired power generation units in Southeast Asia, there are two approaches: earlier retirement including replacement with renewable power units, and co-firing of clean ammonia. Both approaches will require technical and financial support from the firms in the developed world and multilateral development financial institutions. This paper compares these two solutions with multiple scenarios, in terms of generation costs and CO_2 emissions. The paper first offers an overview of the current status of coal-fired power plants in five major Southeast Asian countries. It then explains the assumptions and analyzes the generation costs and CO_2 emissions of various scenarios. The paper concludes by summarizing the findings and raising future study agendas.

2. Coal-fired power plants in Southeast Asia

Coal-fired power generation is regarded as one of the primary energy generation sources in Southeast Asia, and a number of new units have been constructed in the last decade. As shown in Figure 1, the majority of the generation capacity is less than 10 years old with the average age of the total capacity at 8.16 years[1]. This is a stark difference from the status of the coal-fired power plants in the EU, most of which are more than 20 and even 30 years old.

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[1] The age of the units under construction is counted as negative.

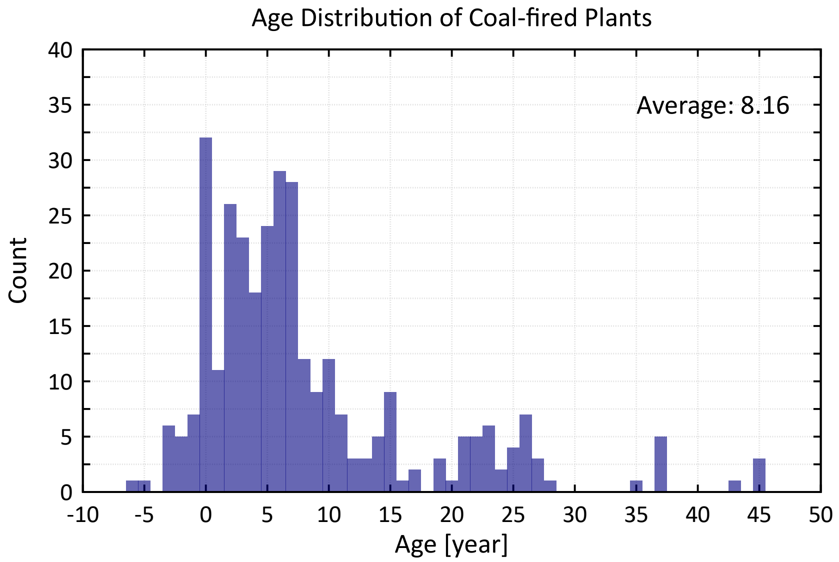

Figure 1 Age distribution of coal-fired plants in five countries*

*: Indonesia, the Philippines, Malaysia, Thailand, and Vietnam

Source: Enerdata Database

Because of this young age, the total capacity of coal-fired power plants is expected to remain high in Southeast Asia. Figure-2 shows the capacity of coal-fired plants of the five countries from 1976 to 2066 (the figures from 2021 are assumptions). The figure suggests that the peak of the total generation capacity has yet to come until around 2030 because of the on-streams of the under-construction units in the next several years. This is not only a surprise but also an inconvenient fact in terms of the urgency to reduce CO_2 emissions to tackle the climate change issues, necessitating a policy action to somehow mitigate the emissions from these units.

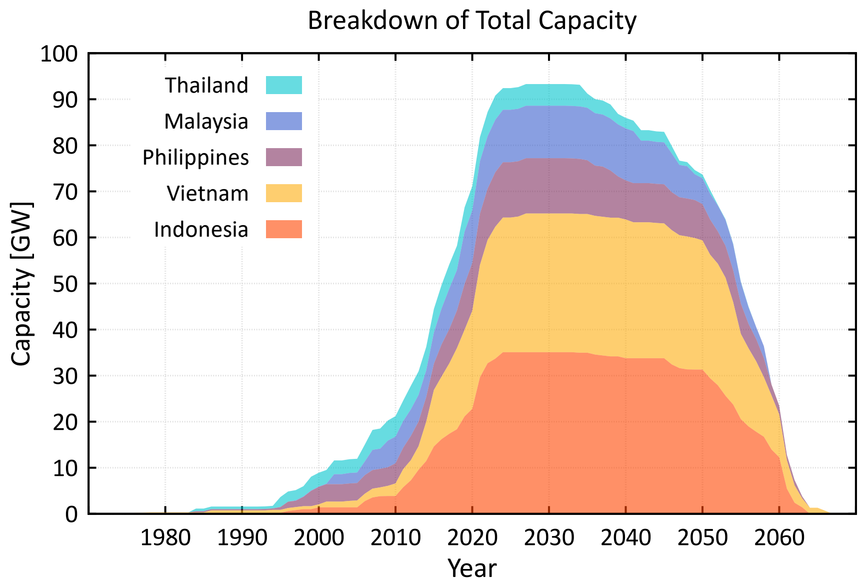

Figure 2 Total generation capacity of coal-fired power generation in five ASEAN countries

Source: Enerdata Database

3. Assumptions

(1) General assumptions

This paper assumes two emission reduction options for existing coal-fired power generation units in Southeast Asia, namely, 1) early retirement of coal unit and replacement with solar power and storage batteries, and 2) installation of clean ammonia co-firing facilities to the existing coal units. In order to analyze various possibilities of each emissions reduction option, this paper assumes six different scenarios depending on the timing of early retirement of coal power generation and the level of co-firing ratio for clean ammonia (Table 1). Three scenarios are based on the option 1) and the other three scenarios are based on the option 2). Except for the NH3-Newbuild scenario, all scenarios assume that the coal-fired power plant is 10 years old, and the construction cost of the coal-fired power plant is not considered when calculating the generation cost.

Table 1 Scenarios of the Study

Scenario	Generation patterns
ETM-Base	Coal 100% for 25 years [5 years early retirement] + Solar & Battery for 25 years
ETM-10	Coal 100% for 20 years [10 years early retirement] + Solar & Battery for 25 years
ETM-15	Coal 100% for 15 years [15 years early retirement] + Solar & Battery for 25 years
NH3-Base	Coal 100% for 5 years + NH3 20% for 5 years + NH3 50% for 20 years
NH3-50	Coal 100% for 5 years + NH3 50% for 25 years
NH3-Newbuild	Coal 100% for 5 years + NH3 20% for 5 years + NH3 50% for 30 years
BAU	Coal 100% for 30 years

Remarks: ETM stands for early transition mechanism, NH3 stands for ammonia based on its chemical composition. BAU stands for business as usual.

Source: IEEJ

The graphical representations of ETM-Base, ETM-10, NH3-Base, and NH3-50 scenarios are shown in the Figure 3. The figures show that NH3 co-firing scenarios (NH3-Base and NH3-50) can reduce CO_2 emissions at an earlier timing than ETM scenarios (ETM-Base and ETM-10).

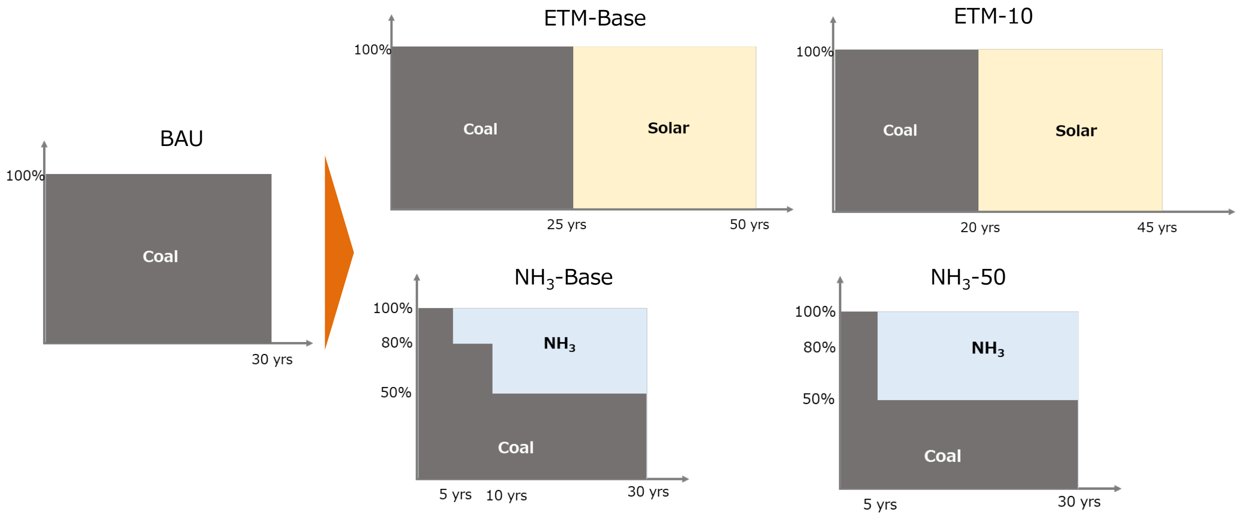

Figure 3 Graphical representation of generation patterns of selected scenarios

Source: IEEJ

(2) Assumptions for coal-fired power plant and ammonia co-firing

This paper aims to analyze the economics and the emissions of the above scenarios. The assumptions for coal-fired power generation are provided in Table 2. The generation capacity of a coal-fired power plant is assumed at 700 MW, and its capacity factor (utilization rate) is estimated at 70%, considering that most coal-fired power plants are used as base-load generation. The price of coal is set at $44/ton based on the IEA (2021), assuming the coal used is domestic.

Table 2 Assumptions for coal-fired power plant

Item	Assumptions
Generation capacity	700MW
Capacity factor	70%
Operational lifetime	40 years
Heat efficiency	45.7% (LHV)
Heat value of coal	24.8 MJ/kg (LHV)
Price of coal	44 $/ton
Internal use rate	5%
CO_2 intensity of coal	93.7 g-CO_2/MJ

Source: IEA (2021); Advisory Committee for Natural Resources and Energy (2022); Agency of Natural Resources and Energy (2020)

Assumptions for clean ammonia co-firing operation are shown in Table 3. Since ammonia co-firing has not been commercialized yet, the assumptions refer to relevant literature. The number of additional investments required for 20% and 50% co-firing are estimated with reference to the study by J-Power (2018). Both coal and fuel ammonia prices are assumed based on IEA (2021).

Table 3 Assumptions for coal-fired power plant

Item	Assumptions
Capital expenditures for co-firing facilities	US$ 224 million for 20% co-firing; US$ 337 million for additional 30% co-firing
Price of fuel ammonia	317.5 $/t-NH3
Heat value of ammonia	14.1 MJ-Nm3 (LHV)
CO_2 intensity of ammonia	0 g-CO_2/MJ

Source: J-Power (2018); International Energy Agency (2021)

(3) Assumptions for solar and battery

This paper assumes that solar power will be the alternative power source for the early retirement program of coal-fired power generation. This is because the generation cost of solar is more competitive, and most of the existing coal power plants are being operated on land where the replacement of solar power generation is more easily done. The capacity for the solar power is calculated based on the electricity generated by the replaced coal fired power generation plus the required power generation for battery transactions. Since coal-fired power generation is used as a baseload power source in Southeast Asia, it is assumed that coal-fired power generation will not be simply replaced by solar power generation units alone but will accompany storage batteries. While coal-fired power generation is capable to supply very stable power generation if sufficient fuel is available, solar power generation is inevitably intermittent by its nature, and it is necessary to install enough storage batteries to stabilize the intermittent power generation. Based on this approach, we assumed that the storage batteries would be used for 12 hours, half of the day, and that the combined efficiency of charge and discharge would be 81%. We assumed the construction cost of large storage batteries to be the one mentioned in the New Energy and Industrial Technology Development Organization (2013), as there is no commercialized case for large storage batteries combined with intermittent renewable power generation sources.

Table 4 Assumptions for solar and battery installation

Item	Assumptions
Capacity factor of solar	17.2%
Required capacity solar	3.0GW
CAPEX of solar	1,600 $/kW
Operational lifetime for solar	25 years
Compensation for battery	12 hours per day
Required battery capacity	36GWh
Battery cost	US$ 177/kWh (including PCS)
Efficiency of battery transactions	81%
Annual operating expenses of battery	2% of investment
Operational lifetime of battery	25 years
Land requirement for solar	0.86MW/ha (0.35MW/acre)

Source: New Energy and Industrial Technology Development Organization (2013);
International Energy Agency (2021); Bolinger and Bolinger (2022)

4. Results

(1) CO_2 emissions reduction

The volume of CO_2 emissions reduction of the NH3-Base case is more than twice as large as the one of the ETM-Base scenario. This is because, in the ETM-Base scenario, coal-fired power generation will continue to be used for the next 25 years until the switch to solar power generation. The emissions of ETM-Base case will inevitably be larger than those of NH3-Base scenario, where the switch to clean ammonia co-firing will be made gradually from the sixth year of the assumed period. In the NH3-50 scenario, the blending rate is increased to 50% from the sixth year, resulting in the larger emissions reduction than in NH3-Base case. Given the cumulative nature of CO_2 (Rhys 2011), if emissions reduction is the most prioritized goal, it is clearly preferable to start ammonia co-firing as early as possible rather than to support early retirement of coal-fired power plants at a later point in time.

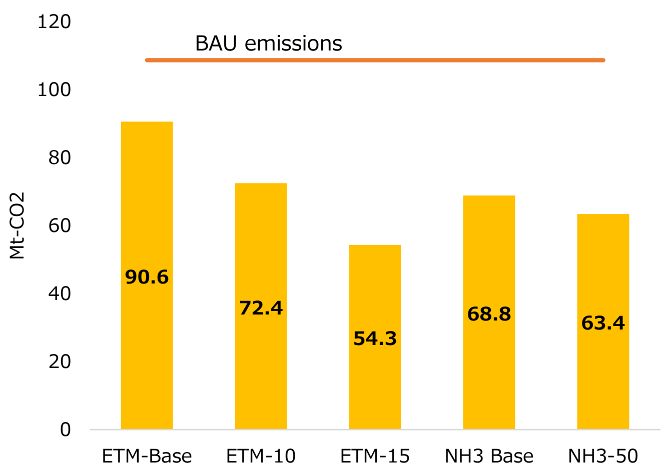

Figure 4 CO_2 emissions of each scenario

Source: IEEJ

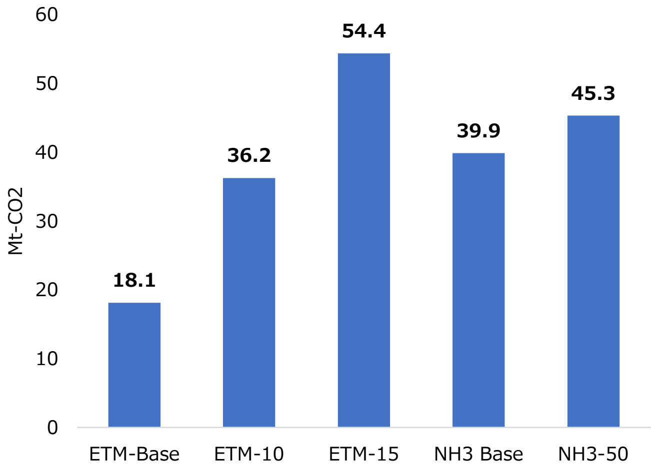

Figure 5 CO_2 emissions reduction of each scenario

Source: IEEJ

(2) Generation costs

In terms of generation costs, NH3-Base case provides slightly lower cost than ETM-Base case. This is because the overall capital cost of NH3 case is lower than the cost of ETM-Base although its fuel cost is much higher. In the comparison with ETM-10 and ETM-15 cases, which speed up the early retirement process, their generation costs tend to be higher than that of ETM-Base case because of the earlier timing of investments in solar and storage batteries.

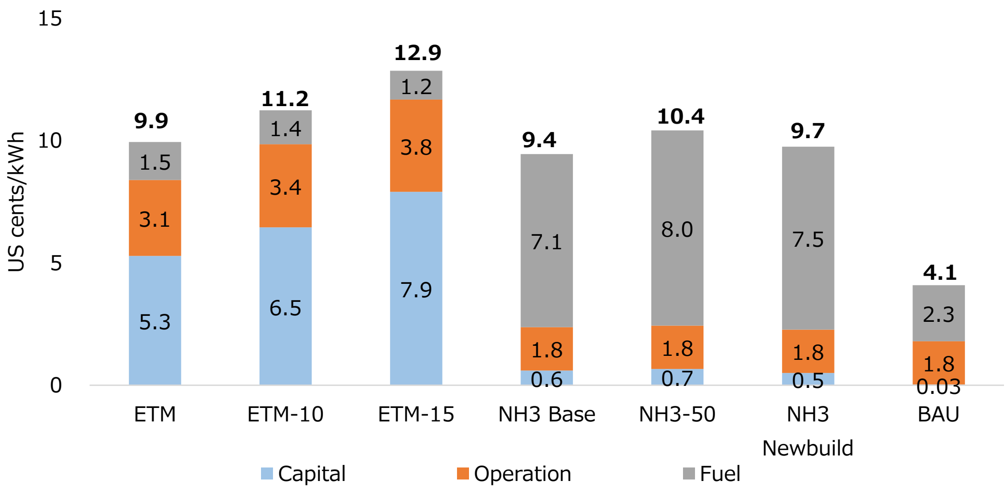

Figure 6 Generation cost of each scenario

Remarks: The initial investment for coal power plant is not included.

Source: IEEJ

(3) Land requirements

Replacing the 700 MW of coal-fired power plants that operate at 70% capacity factor with solar power panels requires a substantial area of land. Based on the analysis of Bolinger and Bolinger (2022) that reflects the latest efficiency improvements of solar PV power generation, the required land for the replacement of 700 MW coal-fired power plant is calculated as 3,478 hectares. It should be noted that not all of the coal-fired power plants have this size of substantial land nearby. If additional land needs to be procured for the replacement, additional acquisition costs (if required) must also be considered when converting from coal-fired to solar power.

5. Conclusions

It is clear that CO_2 emissions need to be reduced as much as possible at the earliest possible time to avoid the catastrophic effects of climate change. On the other hand, many coal-fired power plants in Southeast Asia are still new, and many more are still under construction. Because the electricity demand in Southeast Asia is certain to grow significantly in the future, early retirement of these relatively new coal-fired power plants in the near future is not a realistic option neither in terms of the requirement of power generation capacity to meet the growing demand, nor in regards to the recovery of the investment. To solve this dilemma, the study found that in addition to accelerating the adoption of renewable energy sources, co-firing of clean ammonia at existing coal-fired power generation units will be an effective option.

Because this paper is still a preliminary attempt to examine the validity of ammonia co-firing option, the study left several important issues for future research. First, it is necessary to update the investment amount for facilities that have not yet been fully commercialized, such as ammonia co-firing and large-scale storage batteries juxtaposed to solar power generation. Second, it is also needed to examine the impact of the global high prices of resources after 2022. While coal and natural gas prices have continued to soar as of August 2022, the price of mineral resources used for photovoltaic power generation have also risen in recent years. Such increase of resource prices may contribute with different implications to the comparison of ETM and NH3 cases depending on the relative impacts on each resource market. Third, the feasibility of the substitution of coal power plants with solar energy and batteries needs to be examined in regard to each specific coal power plant. This paper was conducted under the assumption that solar power can fully substitute coal-fired power generation if storage batteries are installed. Yet, in some locations that do not have sufficient land for such solar power plants, investment for additional power grid or land acquisition would be required, and such additional investment would have a negative impact on the feasibility and economics of the solar and batteries option. Hence, a detailed analysis should consider the specific conditions of each coal-fired power plant in each country.

This paper shows that ammonia co-firing for existing and under-construction coal-fired power plants can be an effective decarbonization option for the future, but its conclusions need to be further elaborated and refined in future studies, including the above-mentioned research agenda.

References

1) Agency for Natural Resources and Energy. 2020. "Standard heat value and CO_2 intensity of energy resources." [in Japanese] (https://www.enecho.meti.go.jp/statistics/total_energy/pdf/stte_028.pdf) Accessed on July 31, 2022.
2) Advisory Committee for Natural Resources and Energy. 2022. "Review sheet for generation cost calculation." [in Japanese](https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/pdf/cost_wg_20210908_03.xlsx) Accessed on July 31, 2022.
3) Bolinger, M., and G. Bolinger. 2022. "Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density." IEEE Journal of Photovoltaics, vol. 12, no. 2, pp. 589-594. March 2022.
4) J-Power. 2018. "Technical study on CO2 free ammonia as a fuel for thermal power generation." Final report for Strategic Innovation Program. [in Japanese] (https://www.jst.go.jp/sip/dl/k04/end/team3-19.pdf) Accessed on July 31, 2022.
5) International Energy Agency. 2021. The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector. October 2021. (https://iea.blob.core.windows.net/assets/01ca16c8-e493-475c-81c4-04ac5d3b9882/Theroleoflow-carbonfuelsinthecleanenergytransitionsofthepowersector.pdf) Accessed on July 31, 2022.
6) New Energy and Industrial Technology Development Organization. 2013. "NEDO Battery Roadmap 2013." August 2013. [in Japanese] (https://www.nedo.go.jp/content/100535728.pdf) Accessed on July 31, 2022.
7) Rhys, John. 2011. "Cumulative Carbon Emissions and Climate Change." The Oxford Institute of Energy Studies. July 2011. (https://a9w7k6q9.stackpathcdn.com/wpcms/wp-content/uploads/2011/07/EV-571.pdf) Accessed on August 15, 2022.

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