

# Quantifying Impacts of Renewable Electricity Deployment on Air Quality and Human Health in Southeast Asia Based on AIMS III Scenarios

## Study Overview

### Why Study Air Quality Impacts of Power Generation in Southeast Asia?

Exposure to outdoor air pollution is the largest environmental risk factor for death and disease worldwide, associated with millions of cases of excess deaths each year (GBD 2016). Although many pollutants in the air affect our health, the most important class of pollutants is fine particulate matter, PM<sub>2.5</sub>, which is airborne particles of a diameter  $\leq 2.5$  micrometers. These particles are small enough to deposit deep in the respiratory system where they can then enter the bloodstream, traveling and causing damage to other bodily systems. Exposure to outdoor (ambient) PM<sub>2.5</sub> has been found to be the most important environmental risk factor for mortality in Southeast Asia, associated with 130,000–320,000 excess deaths in the ten Association of Southeast Asian Nations (ASEAN) member countries in 2019 (McDuffie et al. 2019). Southeast Asia, especially in its mega-cities, has some of the worst air quality in the world.

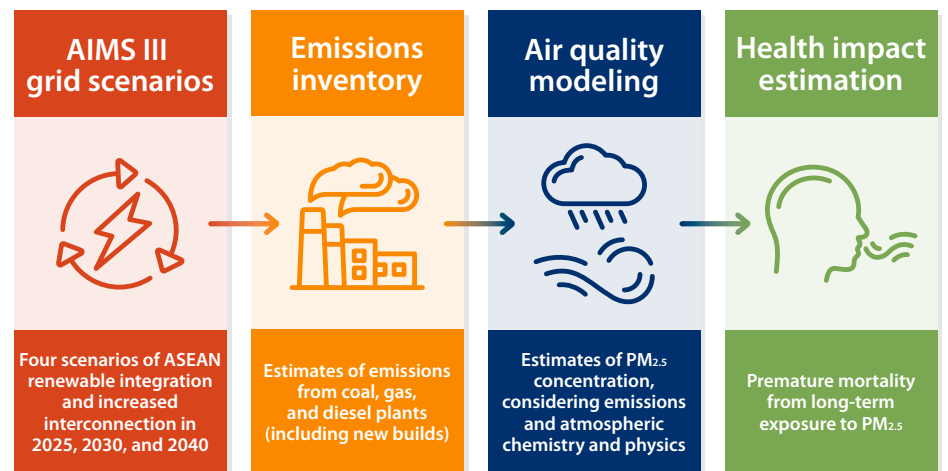
Almost all human activity emits air pollutants. Fine particulate matter is both directly emitted and formed in the atmosphere through chemical reactions, the latter of which requires mathematical modeling to predict. Electric power generation is one of the major sources of air pollutants that lead to elevated concentrations of fine particulate matter, including in Southeast Asia. Fossil fuel combustion, especially coal but also diesel, is the main source of air pollutant emissions from power generation.

While natural gas burns cleaner than coal or diesel, in the quantities combusted for power generation in Southeast Asia, it is also a significant emitter.

### Analysis Overview

The ASEAN Interconnection Masterplan Study (AIMS) III provides a plan for a regional transmission network that links the power systems of ASEAN countries and maximizes the utilization of renewable energy resources. This study augments AIMS III by quantifying changes to air quality and human health that result from its renewable integration and transmission expansion scenarios. Performing this analysis requires translation of the changes in projected generation from different power sector fuel sources in the AIMS III scenarios to changes in air pollutant emissions, developing what is known as an emissions inventory for each scenario and year evaluated. An emissions inventory represents who emits air pollutants, from where the

pollutants are emitted, when, and how much of which air pollutants are emitted. With the collaboration of the ASEAN Centre for Energy and leveraging the best available in-region public data sources, the National Renewable Energy Laboratory (NREL) team compiled a detailed inventory of power plants in the ASEAN region, including a mapping of their PM<sub>2.5</sub>, sulfur oxides (SO<sub>x</sub>), and nitrogen oxides (NO<sub>x</sub>) emissions. A new, first-of-its-kind, and user-friendly global air quality model from the University of Minnesota, Global InMAP (Thakrar et al. 2022), is then used to (a) transform the inventory of changes in emissions to changes in concentration of fine particulate matter, and (b) map the location of human populations in ASEAN countries to calculate humans' exposure to PM<sub>2.5</sub>. Altogether, this analysis estimates excess PM<sub>2.5</sub>-caused mortality attributable to fossil thermal generation sources, as modeled in the AIMS III scenarios. **Figure 1** displays these methodological steps.



**Figure 1.** Schematic of the methodological steps of this study

# Generation, Emissions, and Air Quality Based on AIMS III Scenarios

## The Four AIMS III Scenarios

The AIMS III study developed four scenarios (see **Box 1**) which were analyzed in this air quality study for 2025, 2030, and 2040 at the country level. The scenarios were developed using a capacity expansion model, which designs a resource mix to meet future projected power demand in a least-cost manner. The primary difference across these scenarios is their assumptions on renewable generation (specifically wind and solar) and which parameters additional to cost were co-optimized.

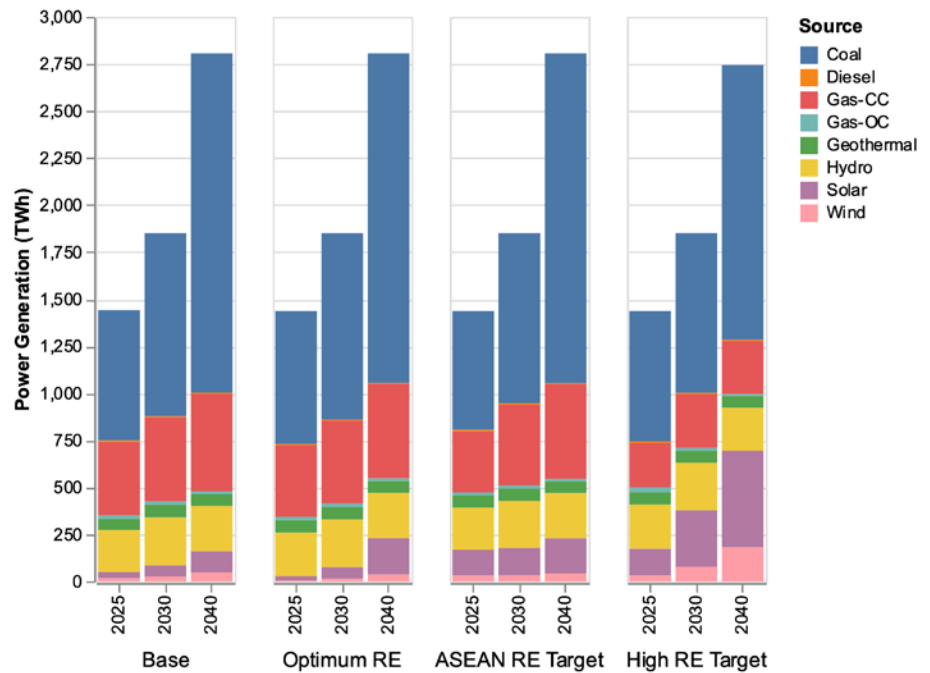
**Figure 2** displays generation by fuel type for the AIMS III scenarios.

AIMS III scenarios were developed in 2018–2019. Many countries have since updated their power development plans, and these updates are not included in the air quality study. Study results could be updated to reflect more recent power development plans in future work. Note also that biomass-based power sources were not included in the AIMS III study. For certain countries like Thailand, biomass combustion could potentially be

### Box 1. The Four AIMS III Scenarios

Descriptions of the four AIMS III scenarios analyzed in the air quality study for 2025, 2030, and 2040 at the country level:

- The **Base Scenario** is a baseline formed from power development plans of each ASEAN country from 2018-2019, with adjustments.
- The goal of the **Optimum Renewable Energy (RE) Scenario** was to develop optimized thermal, solar, wind, and transmission investments.
- The goal of the **ASEAN RE Target Scenario** was to reflect solar and wind capacity additions based on country-level RE targets in the progressive scenario of the 6th ASEAN Energy Outlook, with enhancements (ASEAN 2020).
- The **High RE Target Scenario** was developed to understand the impacts of higher solar and wind penetration and on cross-border interconnections.



**Figure 2.** Power generation in terawatt-hours (TWh) by different sources, including renewable (geothermal, hydropower, solar, and wind) and fossil (coal, natural gas, and diesel), shown for the four AIMS III scenarios and three modeling years. Capacity for gas plants is shown separately for open cycle (OC) and closed cycle (CC) units

non-trivial additional sources of directly emitted PM<sub>2.5</sub>, and could be considered in future work.

### Key Points

Key points from the AIMS III capacity expansion modeling relevant to air pollutant emissions, air quality, and health impacts include:

- 1 Generation is estimated to nearly double from 2025 to 2040 in all four AIMS III scenarios.
- 2 Most of the projected increase in generation is met by coal in all four AIMS III scenarios.
- 3 While generation from renewables increases in all four AIMS III scenarios, the fraction of total generation (its share) is generally estimated to decrease because of the much greater increase in non-renewable sources, mostly coal. Only in the High RE Target scenario do renewables represent a higher share in 2040 than in 2025, though even here it is at the expense of natural gas rather than coal.

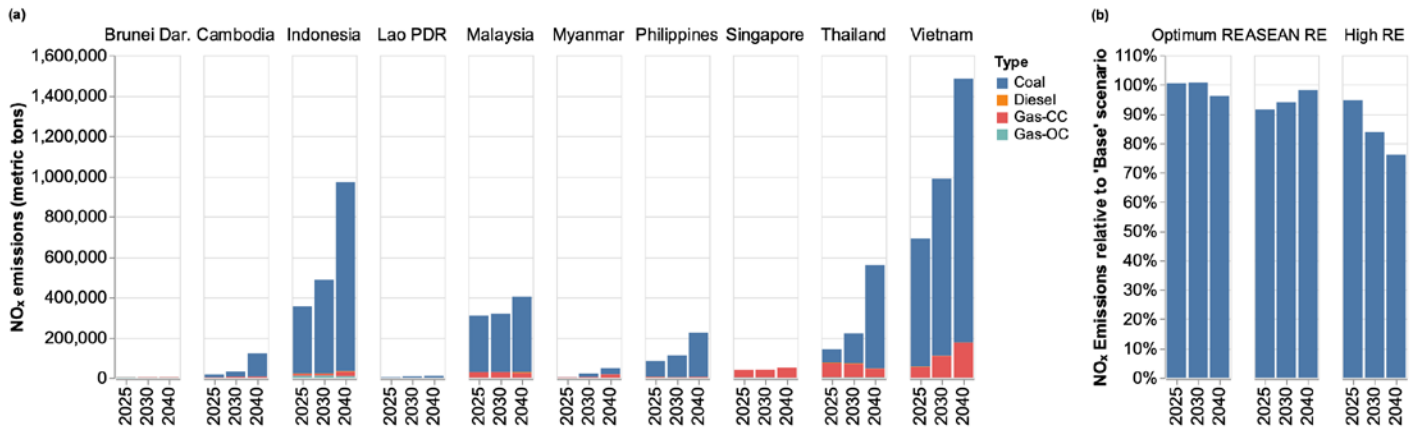
From these results alone, one can expect emissions to increase from 2025 to 2040 in all AIMS III scenarios, as well as lead to an increase in PM<sub>2.5</sub> concentration and

resultant health effects. **Figure 3** shows that the results of our emissions inventory calculations reflect these expectations. (While the figure displays only NO<sub>x</sub>, it is also true for the other pollutants that were analyzed.)

### Air Quality Modeling Results and Insights

Because emissions are estimated to increase in 2040 compared to 2025 for all four AIMS III scenarios, PM<sub>2.5</sub> concentrations are estimated to increase as well. Even for the High RE Target scenario compared to the Base scenario in 2025, PM<sub>2.5</sub> concentrations are estimated to be higher in 2040. Additional insight can be gained by comparing each AIMS III alternative scenario to the Base scenario in the same year. In this regard, the Optimum RE and ASEAN RE Target scenarios are not estimated to differ much from the Base in terms of PM<sub>2.5</sub> concentration. The High RE Target scenario, on the other hand, is estimated to yield noticeably lower PM<sub>2.5</sub> concentration.

For all three alternative AIMS III scenarios, air quality attributable to the power sector emissions modeled in comparison to the Base scenario is projected to improve for most ASEAN countries.



**Figure 3.** Estimated emissions of NOx by country and unit types in the three AIMS III modeling years for the Base Scenario (Frame a) and for the ASEAN region as a whole (relative to the Base scenario) for the three AIMS III scenarios (Frame b)

## Human Health Results: Annual Premature Mortality From AIMS III Scenarios

Following from the generation and air quality modeling results, the incidence of premature mortality increases, as can be seen in **Figure 4**, frame a. The distribution of increases in excess mortality reflects the spatial distribution of growth in emissions across ASEAN countries, with the greatest increases projected in countries such as Thailand, Vietnam, Indonesia, and the

Philippines. Compared to the Base scenario in 2040 (**Figure 4**, frame b), each of the alternative AIMS III scenarios is estimated to result in net reductions in power-sector air quality-related premature mortality in the ASEAN region. However, there are a few countries for which the Optimum RE and ASEAN RE Target are estimated to result in increases in PM<sub>2.5</sub>-related excess mortality (Thailand and Vietnam for the ASEAN RE Target scenario and Thailand for the Optimum RE scenario).

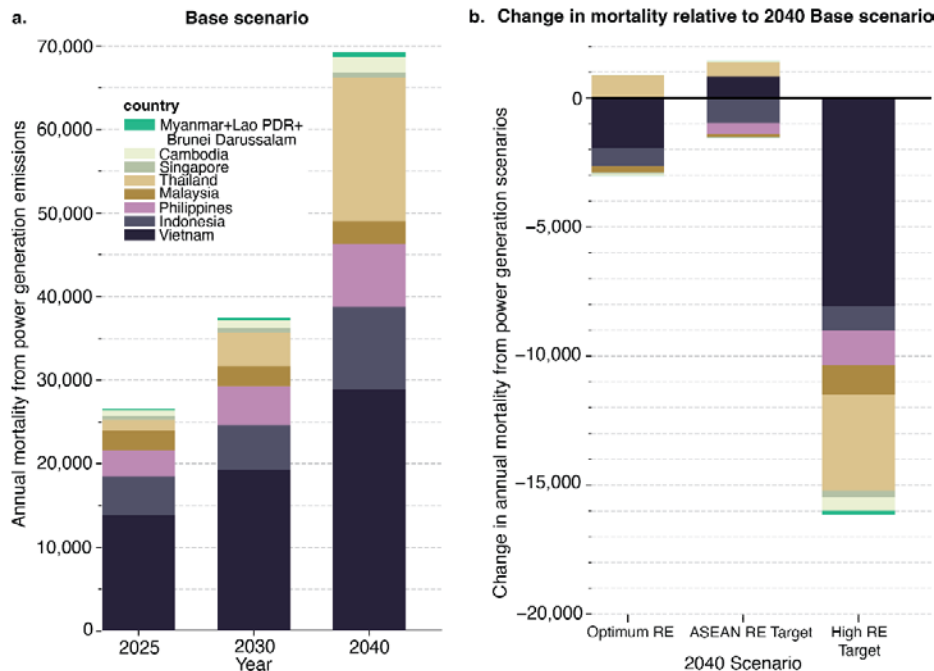
By contrast, the High RE Target scenario

is estimated to yield a greater magnitude of benefits, and for all ASEAN countries, in terms of reductions in premature mortality compared to the Base scenario. This is mainly because there is less coal-powered generation in 2040 in the High RE Target scenario than in the Base scenario.

## Key Limitations

The goal of this study is to estimate the potential future emissions, air quality, and health effects from power generation in the ASEAN region under the AIMS III scenarios. The best available information and assumptions were used, supported by local partners like the ASEAN Centre for Energy and their members. However, not only is the future unknown, but all elements that make up the emissions inventory have uncertainties, such as locations of future power plants. Additional uncertainties and limitations include:

- 1 Power sector capacity expansion modeling was performed at the country level (with two countries having more than one node represented). Therefore, the highest geographic resolution for interpretation of results of this study is at the country-level.
- 2 Biomass-based fuels were not considered in the AIMS III and likewise not in this air quality analysis. While this study does not provide a complete consideration of the power sector, biomass-based power is only a significant contributor in select ASEAN countries.



**Figure 4.** (a) Annual excess mortality attributable to total projected power generation emissions in the Base scenario, broken down by ASEAN member country in which mortality occurs. (b) Change in excess mortality in 2040 (relative to the Base scenario) for the ASEAN RE Target, High RE Target, and Optimum RE scenarios, broken down by ASEAN member country in which mortality occurs



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3 Other economic sectors also contribute to air pollution in Southeast Asia, notably transportation and household fuel consumption. These sectors too could see significant changes in their fuel mixes in the future. An accounting of other air pollution sources could be considered in future research, including in combination with the power sector (e.g., electrification of motor vehicles).

## Conclusions and Recommendations

Air quality-related health effects from power generation are substantial in the ASEAN region, representing an opportunity to improve the health of citizens of ASEAN countries. The results of this study indicate that premature mortality is estimated to increase from 2025–2040 if ASEAN nations follow the power sector transition based on any of the four AIMS III scenarios, especially because of increased coal utilization. Yet increasing generation from renewable sources like wind and solar can mitigate the worsening of air quality and health effects. Even if remaining reliant on coal, switching to more efficient emission control technologies can reduce

health impacts from coal combustion emissions.

Of all the AIMS III scenarios considered, the High RE Target scenario is estimated to save the most lives (relative to the Base scenario) by reducing exposure to outdoor air pollution. In particular, the High RE Target scenario avoids over 16,000 deaths each year by 2040, with every ASEAN country receiving a portion of this benefit.

Reducing mortality will only become a more pressing challenge by 2040, where the choice of an AIMS III scenario can greatly determine this trajectory. The High RE Target scenario indicates that collaborative efforts to reduce dependency on fossil fuels could have benefits for the whole ASEAN region, and strategic power sector investments could reduce the public health burden.

## References

- ASEAN Centre for Energy. (2020). 6th ASEAN Energy Outlook. <https://aseanenergy.org/the-6th-asean-energy-outlook>.
- GGBD 2016 Risk Factors Collaborators. (2017). "Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016." *Lancet* 390, no. 10100 (2017): 1345. [https://doi.org/10.1016/S0140-6736\(17\)32366-8](https://doi.org/10.1016/S0140-6736(17)32366-8).
- Kopplitz, S. N., Jacob, D. J., Sulprizio, M. P., Myllyvirta, L., and Reid, C. (2017). "Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia." *Environmental Science & Technology* 51(3), 1467–1476. <https://doi.org/10.1021/acs.est.6b03731>.
- McDuffie, E. E., Martin, R. V., Spadaro, J. V., Burnett, R., Smith, S. J., O'Rourke, P., Hammer, M. S., van Donkelaar, A., Bindle, L., Shah, V., Jaeglé, L., Luo, G., Yu, F., Adeniran, J. A., Lin, J., and Brauer, M. (2021). "Source sector and fuel contributions to ambient PM<sub>2.5</sub> and attributable mortality across multiple spatial scales." *Nature Communications*, 12(1), 3594. <https://doi.org/10.1038/s41467-021-23853-y>.
- Thakrar, Sumil K., Christopher W. Tessum, Joshua S. Apte, Srinidhi Balasubramanian, Dylan B. Millet, Spyros N. Pandis, Julian D. Marshall, and Jason D. Hill. (2022). "Global, high-resolution, reduced-complexity air quality modeling for PM<sub>2.5</sub> using InMAP (Intervention Model for Air Pollution)." *Plos One* 17, no. 5: e0268714. <https://doi.org/10.1371/journal.pone.0268714>.

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