ASEAN Interconnection Masterplan Study (AIMS) III Report

Phase 1: Capacity Expansion Planning

Phase 2: Grid Performance Analysis

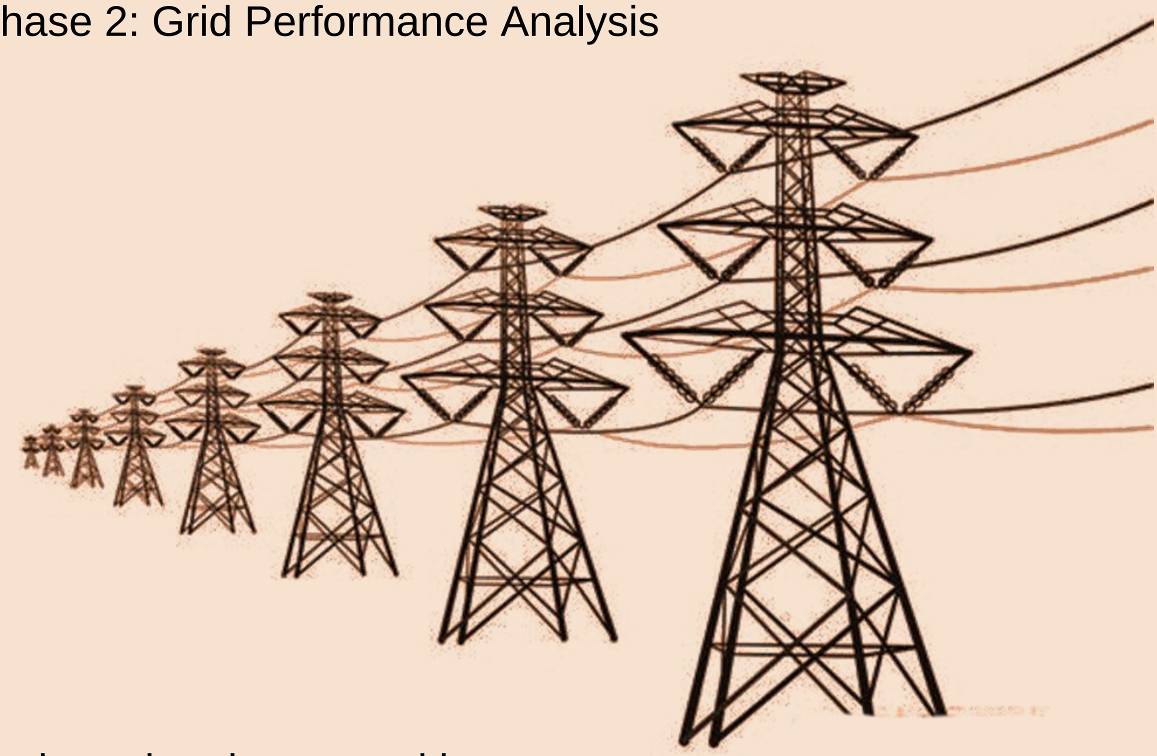

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Table of Contents

Table of Contents iv
List of Figures vi
List of Tables viii
Executive Summary ix
History of the AIMS III ix
The Objectives of AIMS III x
The Study Scenarios in the AIMS III x
Methodology of the Study xi
Regional Key Findings xi
1. Renewable Energy Potentials in ASEAN xii
2. Potential Avoided Fuel Consumption xii
3. Impacts on Total System Costs xiii
4. Grid Performance Analysis xiv
Summary of the AIMS III Interconnections xv
Concluding Remarks xvi
1 Introduction 1
1.1 Overview of the ASEAN Power Grid (APG) 1
1.2 History of the AIMS III 2
1.3 Objectives and Working Mechanism of the AIMS III 3
1.3.1 Objectives 3
1.3.2 Working Mechanism 3
2 Methodology of the Study 7
2.1 Scenario Philosophy 7
2.2 Scenarios Setting 9
2.3 Phases of the AIMS III Report 10
2.3.1 Phase 1 – Capacity Expansion Planning 11
2.3.2 Phase 2 – Grid Performance Analysis 15
2.4 Modelling Approach to APG Expansion Planning 17
2.4.1 Modelling of the APG As Three Subregions 17
2.4.2 Generation Capacity Modelling 19
2.4.3 Interconnection Capacity Modelling 20
2.5 Grid Modelling Approach for Grid Analysis 20
2.5.1 Approach I – Reduced Transmission Equivalent Model 20
2.5.2 Approach II – Nodal Equivalent Model 21

2.5.3 Approach III –Multiple-Area/Multiple Region Equivalent Model 21
2.6 Modelling Limitation 21
3 Study Results 22
3.1 Results for the Base Scenario 22
3.1.1 Future Capacity Expansion 22
3.1.2 Jobs Created by VRE 26
3.1.3 Avoided Emissions 27
3.2 Results from the Optimum RE Scenario 28
3.2.1 Future Capacity Expansion 28
3.2.2 Jobs Created by VRE 31
3.2.3 Avoided Emissions 32
3.3 Results from the ASEAN RE Target Scenario 33
3.3.1 Future Capacity Expansion 34
3.3.2 Jobs Created by VRE 37
3.3.3 Avoided Emissions 38
3.4 Results from the High RE Target Scenario 39
3.4.1 Future Capacity Expansion 40
3.4.2 Jobs Created by VRE 42
3.4.3 Avoided Emissions 43
3.5 Comparative Illustration from All Scenarios 44
3.5.1 Capacity Expansion 45
3.5.2 Production Costs & Operations 46
3.5.3 Share of VRE in the Capacity Mix 47
3.5.4 Potential Avoided Emissions 48
3.5.5 Total System Costs – Net-Present-Value (NPV) over the Study Horizon 51
3.6 Grid Performance Analysis Result Over the Study Horizon 57
3.6.1 A Brief Observation of Countries' Power Grid 58
3.6.2 2025 – Stability Analysis 61
3.6.3 2040 – Stability Analysis 66
3.6.4 Observation and Recommendations 69
3.7 AIMS III Proposed Interconnection Summary 72
4 Conclusion, Recommendations and Way Forward 75
4.1 Conclusion 75
4.2 Recommendations 76
4.3 Way Forward 77

List of Figures

Figure 1-1: The ASEAN Power Grid Today 1
Figure 1-2: AIMS III Organisation 4
Figure 2-1: Phase 1 – Task Flow & Correlations 11
Figure 2-2: Capacity Expansion Planning Scenarios 12
Figure 2-3: Objectives, Activities and Deliverables of Production Cost Simulation............... 13
Figure 2-4: Approach for Economic Analysis 13
Figure 2-5: Approach for estimating avoided CO_2 and N_2O emissions............................... 14
Figure 2-6: Approach for estimating VRE jobs creation 14
Figure 2-7: Approach to power flow analysis 15
Figure 2-8: Flow of contingency analysis.. 16
Figure 2-9: Approach for Short Circuit Analysis 17
Figure 2-10: The three ASEAN Power Grid (APG) sub-regions 18
Figure 2-11: Sub-Regions as a reflection of the APG shape and their respective constituent AMS 19
Figure 3-1: Projection of installed capacity (GW) under the Base Scenario at the ASEAN regional level 23
Figure 3-2: Progress line on the establishment of the APG to date 24
Figure 3-3: Proportion of ASEAN installed capacity in GW under the Base Scenario by Sub-regions 25
Figure 3-4: Proportion of VRE installed capacity under the Base Scenario categorised by Sub-regions 26
Figure 3-5: VRE Jobs created in the Base Scenario - ASEAN Region................................ 27
Figure 3-6: Avoided Fuel Consumption in 2040 for Base Scenario - ASEAN Region 28
Figure 3-7: Aggregated installed capacity (GW) under the Optimum RE Scenario at the ASEAN level 29
Figure 3-8: Proportion of ASEAN installed capacity under the Optimum RE Scenario......... 30
Figure 3-9: Proportion of VRE installed capacity under the Optimum RE Scenario categorised by the Sub-regions 31
Figure 3-10: Jobs created by VRE in 2040 under the Optimum RE Scenario - ASEAN Region 32
Figure 3-11: Avoided Fuel Consumption in 2040 under the Optimum RE Scenario - ASEAN Region... 33
Figure 3-12: Projection of optimum capacity expansion for the ASEAN RE Target Scenario – ASEAN Region 35
Figure 3-13: Proportion of ASEAN installed capacity under the ASEAN RE Target Scenario categorised by the Sub-Regions 36
Figure 3-14: Proportion of VRE installed capacity under the ASEAN RE Target Scenario categorised by the Sub-Regions 37
Figure 3-15: VRE Job Creation in 2040 for the ASEAN RE Target Scenario - ASEAN Region 38
Figure 3-16: Avoided Fuel Consumption in 2040 for the ASEAN RE Target Scenario - ASEAN Region... 39
Figure 3-17: Projection of capacity expansion (GW) under the the High RE Target Scenario – ASEAN Region 40
Figure 3-18: Proportion of capacity for the High RE Target Scenarioin ASEAN by sub-region 41
Figure 3-19: Proportion of VRE capacity in ASEAN for the High RE Target Scenario by sub-region 42

Figure 3-20: Job Creation by VRE in 2040 under the High RE Target Scenario - ASEAN Region 43
Figure 3-21: Avoided Fuel Consumption in 2040 under the High RE Target Scenario - ASEAN Region 44
Figure 3-22: Installation Mix Comparison (%) – ASEAN Region 45
Figure 3-23: Coal & Gas Capacity Additions - All Scenarios 46
Figure 3-24: Comparison of Share of VRE Capacity in 2025 and 2040 for All Scenarios – ASEAN Region 48
Figure 3-25: Avoided Coal, Oil and Natural Gas Consumption in ASEAN under 4 Scenarios 49
Figure 3-26: Overall Total CO_2 Emission Avoided in 2040 51
Figure 3-27: Overall Total N_2O Emissions Avoided in 2040 51
Figure 3-28: Cumulative Build Costs (in real $) – ASEAN 53
Figure 3-29: Production Costs per MWh for All Scenarios – ASEAN 54
Figure 3-30: Generator Build Costs up to 2025 (NPV) 56
Figure 3-31: Generator Build Costs up to 2040 (NPV) 57
Figure 3-32 Plots of Dynamic Simulation Results for tripping of Lao PDR to Thailand line on 3-Phase fault of 100 msec duration – 2025, Base Scenario, Peak Load 62
Figure 3-33 Plots of Dynamic Simulation Results for tripping of Lao PDR to Thailand line on 3-Phase fault of 100 msec duration – 2025, Base Scenario and Peak Load (cont'd) 63
Figure 3-34 Plots of Dynamic simulation results for tripping of Lao PDR to Vietnam line on 3-Phase fault of 100 msec duration – 2025, ASEAN RE Target Scenario, North Peak 64
Figure 3-35 Plots of Dynamic simulation results for tripping of Lao PDR to Vietnam line on 3-Phase fault of 100 msec duration – 2025, ASEAN RE Target Scenario, North Peak (cont'd) 65
Figure 3-36 Plots of Dynamic Simulation Results for tripping of 1 Pole of Sumatra to Java HVDC line – 2040, Base Scenario, Peak Load 67
Figure 3-37 Plots of Dynamic Simulation Results for tripping of Cambodia to Vietnam line – 2040, ASEAN RE Target Scenario, Northern Sub-region, Peak Load 68
Figure 3-38 Illustration of 500 kV Transmission Strengthening in the Lao PDR National Grid 71

List of Tables

Table 2-1: Increase in Energy and Electricity Demand in the AMS between 2019 and 2025. 8
Table 3-1: Projection of installed capacity in ASEAN by Technology under the Base Scenario 24
Table 3-2: Avoided Emissions in 2040 for Base Scenario - ASEAN Region 28
Table 3-3: Projection of capacity in ASEAN by technology under the Optimum RE Scenario 29
Table 3-4: Avoided Emissions in 2040 under the Optimum RE Scenario - ASEAN Region. 33
Table 3-5: Official Renewable Energy Targets of the 10 ASEAN Member States 34
Table 3-6: Share of capacity by technology in ASEAN under the ASEAN RE Target Scenario (in GW) 35
Table 3-7: Avoided Emissions in 2040 for the ASEAN RE Target Scenario – ASEAN Region 39
Table 3-8: Share of capacity by technology in ASEAN under the High RE Target Scenario (in GW) 40
Table 3-9: Avoided Emissions in 2040 for the High RE Target Scenario - ASEAN Region.. 44
Table 3-10: Annual production costs for the ASEAN Region 47
Table 3-11: NPV of Build Costs for All Scenarios – ASEAN (billion USD) 52
Table 3-12: NPV of Production Costs for All Scenarios – ASEAN (billion USD) 53
Table 3-13: NPV of Total System Costs for All Scenarios – ASEAN (billion USD) 54
Table 3-14: Proposed 500 kV Transmission Strengthening in the Lao PDR National Grid .. 70
Table 3-15: Proposed 500 kV Transmission Strengthening in the Sumatra Grid 71
Table 3-16: Official Status of ASEAN Interconnection Projects and the AIMS III Proposed Interconnection Summary (MW) 73

Executive Summary

The ASEAN Interconnection Masterplan Study (AIMS) III embodies the ASEAN Ministers on Energy Meeting's (AMEM's) directive to explore the viability of multilateral electricity trading in the ASEAN region. The purpose of this study is to enhance grid resilience and modernisation so as to provide affordable and resilient electricity supply and accommodate higher shares of renewable energy (RE) into the grid.

The AIMS III is an ASEAN flagship study geared to developing a comprehensive update of the former AIMS II completed by HAPUA (Heads of Power Utilities/Authorities) in 2010 on the planning of ASEAN's cross-border interconnection system to establish the ASEAN Power Grid (APG). The APG consists of several cross-border transmission projects that are grouped into the northern, southern and eastern development corridors named sub-regions, allowing for electricity among the AMS. The APG has been established gradually to connect the AMS and enable resource-sharing and utilisation among the ten countries, to meet increasing demand more efficiently and to secure energy supply.

The AIMS III is comprised of three phases. The first two phases of the AIMS III are presented in this report. Phases 1 and 2 plan the cross-border power transmission infrastructure needed to support multilateral power trade among the ASEAN Member States (AMS) and RE integration in the APG. Phase 1 is focused on identifying potential RE resources and cross-border interconnections to access these resources and enhance bilateral and multilateral power trade opportunities. The steps include an RE resource assessment, a generation capacity expansion plan which simultaneously co-optimises the interconnection capacity, production cost modelling to investigate the amount of variable renewable energy (VRE) that the APG can absorb and a socio-economic-environmental impact analysis. Phase 2 is focused on assessing the technical performance of the APG as designed in Phase 1. Phase 3 will further develop minimum requirements for multilateral market development, the regulatory framework, and grid code and technical standards.

History of the AIMS III

ASEAN has long pursued the realisation of the APG, promoting power interconnection and trade and increasing the transmission capacity of interconnections among and between the AMS. The initiative has been cemented since the signing of the 1986 agreement on ASEAN Energy Cooperation (AEC). The ASEAN leaders acknowledged that energy connectivity through the establishment of the APG had been an important issue that ASEAN must address, especially given the growing demand for energy in the region. Aside from the APG, they also expressed their support for the Trans-ASEAN Gas Pipeline (TAGP) regional energy connectivity project. They mandated continuous research into the APG and TAGP to unlock full harmonisation of regulatory frameworks and standards to facilitate energy connectivity in ASEAN.

The AIMS was in the masterplan of the APG's development planning. AIMS I was first initiated at the 17th AMEM in July 1999, held in Bangkok, Thailand. HAPUA established APG with AIMS as the foundation of its development. Soon after, the AIMS Working Group was established at the 16th Meeting of HAPUA in April 2000, held in Chiang Rai, Thailand. The APG development roadmap and the AIMS were fully enacted and approved by the 20th Senior Officials Meeting on Energy-ASEAN Ministers on Energy Meeting (SOME-AMEM) in July 2002, held in Bali, Indonesia. Then the AIMS I was completed by the Working Group, and the 21st AMEM endorsed its final report in July 2003 in Langkawi, Malaysia. AIMS I pioneered the APG's electrical power transmission network.

In 2010, to develop the APG more efficiently, a newly formed structure of the HAPUA bodies – the HAPUA Working Group No. 2, which focuses on the APG – was assigned to continue the AIMS I into AIMS II. AIMS II was primarily made to plan the APG through interconnections among the AMS and to promote more efficient, economical and secure power systems through the harmonious development of national electricity networks across the region.

As per the ministers' directive at the 35th AMEM in 2017, the HAPUA Council's commitment to the need to update AIMS II was noted. In addition, the success of the AIMS II brought the introduction of the AIMS III into being to focus on increasing inter-country cooperation among the AMS in the power sector and to increase RE integration (as part of the ASEAN's target for having 23% share of RE in ASEAN's energy mix by 2025) through greater interconnections. The AIMS III also explores the opportunities and benefits of having VRE pilot projects to promote multilateral power trading with high utilisation of RE.

The Objectives of AIMS III

First, to provide a new and updated master plan of the APG as the reference for the AMS in pursuing regional cooperation in the power and VRE sector.

Second, to evaluate the techno-economic viability of the potential cross-border interconnections and optimal generation capacity and VRE expansion that could be used as a reference for implementing VRE pilot projects to promote multilateral power trading with a high utilisation of RE.

Third, to enhance energy connectivity and market integration in ASEAN to achieve energy security, accessibility, affordability and sustainability for all.

An interconnected power system could further enhance the integration of VRE to help meet the ASEAN target of a 23% share of RE in the primary energy mix by 2025 and to decarbonise the energy sector through a low-carbon economy.

The Study Scenarios in the AIMS III

AIMS III explores four scenarios: the Base Scenario, Optimum RE Scenario, ASEAN RE Target Scenario and High RE Target Scenario. They are key in helping us understand the consequences of different generation mixes, RE shares and APG interconnections on overall investment costs and avoided emissions.

Base Scenario	• This scenario is created to understand the consequences if the AMS maintain their power development as per PDP in meeting the growing demand based on Business-as-Usual conditions, with non-committed thermal projects being re-optimised.
Optimum RE Scenario	• Explores the consequences if AMS explored an alternative scenario by optimising not only thermal, but also VRE and interconnections projections.
ASEAN RE Target Scenario	• Serves as the main objective of the study. To understand the consequences if AMS could achieve at least the projections under APAEC* Target and how this might impact ASEAN's energy systems even beyond 2025.
High RE Target Scenario	• Investigates the possibility for AMS considering higher aspiration level of RE penetration in the ASEAN Region (25%-30% in the generation mix by 2040)**

*The APAEC (ASEAN Plan of Action for Energy Cooperation) Target is a series of guiding policy documents that aims to promote multilateral energy cooperation and integration to attain the goals of the ASEAN Economic Community (AEC).[1]

**under the high RE Target Scenario, the coal, gas and interconnection capacities are optimised.

Methodology of the Study

The AIMS III was constructed in several steps. The first step was to collect the strings of technical and policy data sets through a series of consultation meetings with the AMS. RE Resource Assessment was done to support the need to model VRE generation profiles.[2] Through the collected data and the analysis findings from the RE Resource Assessment, capacity expansion planning was conducted for evaluating the optimum additions of generation and interconnection capacities in the APG. Production cost simulation was then used to assess the operating performance of the APG resulting from capacity expansion planning. Lastly, grid analysis was carried out to identify potential limitations of system operational feasibility and reliability for some operating conditions. Assessing the proposed interconnections that form the APG was the core of the analysis, providing the total MW required to establish the APG in all of the study scenarios.

Regional Key Findings

The establishment of the APG in the AIMS III was aimed at supporting better utilisation of RE resources, especially VRE, and advancing clean energy and climate protection goals in ASEAN. Power system connectivity increases power system flexibility through effective utilisation and resource sharing across geographical locations for common regional benefit. Power system connectivity can also provide economic benefits by allowing cost-effective generating units within the interconnected area to be dispatched, thereby enabling power trade between the systems. This is vital as power system connectivity among the AMS will smooth

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[1] ASEAN Centre for Energy (ACE). (2015). **ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021 – 2025**. ACE. https://aseanenergy.org/asean-plan-of-action-and-energy-cooperation-apaec-phase-ii-2021-2025/

[2] USAID, National Renewable Energy Laboratory (NREL) & ASEAN Centre for Energy (ACE). (2020, June). **EXPLORING RENEWABLE ENERGY OPPORTUNITIES IN SELECT SOUTHEAST ASIAN COUNTRIES: A Geospatial Analysis of the Levelized Cost of Energy of Utility-Scale Wind and Solar Photovoltaics**. NREL, https://www.nrel.gov/docs/fy19osti/71814.pdf
or https://aseanenergy.org/spatial-estimate-of-levelised-costs-of-electricity-lcoe-in-asean/

the variability and reduce the unwanted impacts resulting from the uncertainty of wind and solar generation.

1. Renewable Energy Potentials in ASEAN

The ASEAN region is rich with VRE (solar and wind) potential. As part of the AIMS III study, the VRE resource assessment estimated the technical potential of 8,119 GW of solar and 342 GW of gross wind capacity per year, generating about 12,004 TWh/year and 766 TWh/year, respectively. The total installed capacity of solar power in 2020 was around 22.8 GW, while for wind it was around 2.5 GW.[3]

> *"The ASEAN region is rich with VRE (solar and wind) potential; the technical potential of 8,119 GW of solar and 342 GW of gross wind capacity per year is generating about 12,004 TWh/year and 766 TWh/year, respectively"*

The wind and solar increments towards 2025 and 2040 are as follows for the different scenarios:

Base Scenario – 19.2 GW in 2025 and 61.4 GW by 2040 (solar); 6.5 GW in 2025 and 17.9 GW by 2040 (wind).

Optimum RE Scenario – 13 GW in 2025 and 109 GW by 2040 (solar); and 2 GW in 2025 and 14.2 GW by 2040 (wind).

ASEAN RE Target Scenario – 83 GW in 2025 and 109 GW by 2040 (solar); and 12.3 GW in 2025 and 17 GW by 2040 (wind).

High RE Target Scenario – 83 GW in 2025 and 438 GW by 2040 (solar); and 12.3 GW in 2025 and 66 GW by 2040 (wind).

2. Potential Avoided Fuel Consumption

Establishing the APG will develop multilateral power trade and help the AMS to achieve a clean energy transition that optimises mutual benefit among them and assists them in reaching their Nationally Determined Contributions (NDCs).

The AIMS III has analysed the AMS' climate pledges under the Paris Agreement as stated in their Nationally Determined Contributions (NDCs). In the **Base scenarios**, the NDCs have not kept up with the recent rapid growth in renewables. However, the **APAEC Target** articulated in **the ASEAN RE Target scenario** and **the High RE Target scenario** could help the AMS come closer to reaching the target for greenhouse gas emissions avoided each year due to RE deployment. This will be achieved through the potential avoided fuel consumption in the power sector where VRE is pivotal in replacing fossil fuel use in thermal power generation.

> *"VRE is pivotal in replacing fossil fuel use in thermal power generation and avoided significant fuel consumption in power sector."*

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[3] ASEAN Centre for Energy (ACE). (2021, September). **ASEAN Power Updates 2021**. https://aseanenergy.org/asean-power-updates-2021/

The potential avoided emissions by 2040 for each scenario are as follows:

Base Scenario – 30.1 million tons of coal, 1.4 million tons of oil and 17,524 million m^3 of natural gas consumption can be avoided cumulatively in 2040.

Optimum RE Scenario – 53.1 million tons of coal, 4.1 million tons of oil and 22,960 million m^3 of natural gas consumption can be avoided cumulatively in 2040.

ASEAN RE Target Scenario – 48.8 million tons of coal, 2.1 million tons of oil and 13,607 million m^3 of natural gas consumption can be avoided cumulatively in 2040.

High RE Target Scenario – 255.9 million tons of coal, 11.2 million tons of oil and 76,628 million m^3 of natural gas consumption can be avoided cumulatively in 2040.

3. Impacts on Total System Costs

Given the generation capacity expansion planning in the AIMS III, comprising expansion of coal power plants, gas power plants, conventional RE and VRE, including interconnection capacity new builds, a high-level economic analysis was undertaken to serve as the foundation of the analysis. The Net-Present-Value (NPV) of the total system costs consists of build costs and production costs derived from capacity expansion planning (i.e. build costs) and production simulation analysis (i.e. production costs).

"The potential avoided fuel consumption is an important finding since it will affect the overall cost for the AMS' generation and interconnection expansion capacity in meeting the regional demand growth."

At the ASEAN level, a comparison between the NPV of the total system costs for each of the four scenarios is summarised in the table below.

Table ES 1. Component Costs under AIMS III Scenarios

Component	Base	Optimum RE	ASEAN RE Target	High RE
Thermal Generator Build Cost	89.34	88.18	86.36	69.87
Firm Units Build Cost (except VRE)	77.83	77.83	77.83	77.83
Interconnection Build Cost	0.67	2.41	2.98	16.23
Solar Build cost	10.86	13.92	34.65	58.94
Wind Build cost	5.94	3.41	10.11	24.77
Total Build costs	184.64	185.76	211.93	247.63
Variable O&M Cost	26.73	25.42	25.72	22.02
Fuel Cost	484.40	479.00	458.68	421.83
Fixed O&M Cost	75.19	74.87	74.61	72.47
Cumulative Production Costs	586.32	579.29	559.02	516.32
Total Cost (Build + Production Costs)	770.97	765.05	770.95	763.95

All Figures in Billion US Dollars.

AIMS III shows that having higher RE shares in the generation mix will generally increase the costs of interconnections and VRE capacity builds. However, it is understood that allowing foreign and private investment for wind and solar will ease the AMS' financial burdens and enable them to invest more in cross-border connectivity instead. With such a view, it is apparent that cross-border connectivity will become necessary in the future, should the AMS embrace more wind and solar.

The AIMS III study shows that even though the total build costs are highest in the **High RE Target Scenario**, its production costs are the lowest.[4] This is mainly due to the very high VRE penetration target, which increases the build costs while causing the fuel costs to fall. However, because of this trade-off between the build and production costs, the NPV of the total costs is also the lowest in the **High RE Target Scenario**, closely followed by the **Optimum RE Target Scenario.** However, given the level of VRE curtailment in some AMS, and the potential intra-country issues with interconnecting VRE in the **High RE Target Scenario**, this scenario is not likely implementable under current assumptions.

With the interplay between interconnection build cost and wind and solar investment, the NPV of the total system costs for APAEC's **ASEAN RE Target Scenario** is roughly the same as for the **Base Scenario** (even USD 20 million less). Allowing private and foreign investors to participate in solar and wind investments will help ease the total cost burden needed. By doing so, the **ASEAN RE Target Scenario** will be perceived as a better option for the AMS. The **ASEAN RE Target Scenario** could realise the cost savings needed by the AMS government assuming that the associated investment in wind and solar could be shared among private and foreign investors. To conclude, the **ASEAN RE Target Scenario** can be regarded as the one that involves the most compromising.

4. Grid Performance Analysis

According to the results from the AIMS III study, the region will require 17,767 MW of interconnection capacity. The proposed interconnections are technically viable and will be capable of accommodating the VRE capacity necessary to achieve the ASEAN RE Target.

"From a technical standpoint, all APG interconnections are viable and will be capable of accommodating the VRE capacity to achieve the ASEAN RE Target. However, at this point the governmental policy infrastructure requirements are need significant improvement."

Grid performance analysis was carried out to study the essential performance of the APG interconnections in each scenario and to propose ways to mitigate any impeding effects from the capacity expansion planning.

In this study, the generation capacity additions in the **ASEAN RE Target** and **High RE Target Scenarios** are identical up to the year 2025. However, from 2030 onwards, VRE capacity additions are very high in the **High RE Target Scenario** relative to the other three scenarios. In most AMS, the planned VRE is considerably higher than their peak demand leading to high-capacity interconnections reaching 10GW. Therefore, the interconnection for the **High RE Target Scenario** is excluded as per the AMS' directions.[5]

Grid strengthening is found to be the main solution in the **Base Scenario**, **ASEAN RE Target Scenario** and **Optimum RE Scenario** and is applicable in the Northern and Southern Sub-regions.

[4] In this study, the associated costs for solar and wind include grid connections and the complementary infrastructure.

[5] The decision was made because the High RE Target Scenario assumed that a hypothetical technology might be visible in the future. Thus, grid analysis under the High RE Target Scenario does not show compatibility with the current technology adopted in the simulation study.

From 2030 onwards, Lao PDR has the highest potential VRE shares in the Northern Sub-region, and most of the power is exported to the neighbouring AMS (Thailand, Myanmar, Cambodia and Vietnam). Any fault on the interconnecting lines in the northern regions leads to instability (unstable inter-area oscillations) due to the low system inertia found in countries such as Lao PDR, where VRE penetration relative to the grid strength is very high. At the moment, few 500kV transmission lines exist in Lao PDR, and the 500kV transmission line at the national level there needs to be strengthened to ensure that grid stability is well maintained.

In the Southern Sub-region, Sumatra (also spelled Sumatera) is generally a net exporter of power due to cheaper coal generation and high RE potential. The interconnections with Sumatra, which are subsea links with high voltage direct current (HVDC), will be utilised to the full extent. The results of the AIMS III show that Sumatra has excellent potential to be a VRE powerhouse. If the AIMS III findings are realised, there will be a significant need to strengthen the Sumatra grid by 2030.

Huge transmission expansion at the national level in Sumatra will be required to pool power from VRE pooling stations to the interconnection points, mainly to tap the potential of Sumatra-Singapore and Sumatera-Java interconnectivity. The AIMS III projects that Sumatra-Singapore interconnectivity would be crucial. It would enable Singapore to transfer power from import points (Sumatera region) to the individual load centres and also wheel some power to Peninsular Malaysia. As the northern part would be the APG's largest sub-region, strengthening the interconnection points at Singapore and Peninsular Malaysia region is essential.

It must be noted that the energy imports mean that Singapore must feed 70% of its load through imports from Sumatra. This may pose reliability issues for the Singapore grid. Also, minimum dispatch of Singapore local generation may pose stability issues for the Singapore grid due to low inertia and limited reactive power support during transient events, limiting the power transfer on the interconnection. Thus, the AIMS III recommends that Singapore undertake some grid strengthening in order to prevent reliability issues in the future.

As for the Eastern region, connecting the Philippines to the rest of the AMS is proven beneficial, considering its high geothermal potential. Nevertheless, the official interconnection plan for the APG sees challenges in realising interconnectivity between Sabah and the Philippines. The challenge is attributed mostly to the cost-benefit factor of the lines. However, AIMS III suggests that future technologies may be able to tackle this matter.

Summary of the AIMS III Interconnections

The AIMS III findings show that by 2040, the Northern Sub-region would be ASEAN's largest sub-region and would require 45%-50% of the total ASEAN capacity (Please see **Figure 1-1**: Overview of ASEAN Power Grid). The Southern Sub-region is expected to be the second largest having 34%-37% of the total ASEAN capacity. The Eastern Sub-region would have about 16% of the capacity.

Coal capacity at the ASEAN level was 84.1 GW in 2020, and by 2040 was expected to increase by about 250.4% (**Base Scenario**), 244.4% (**Optimum RE Scenario**), 248.1% (**ASEAN RE Target Scenario**) and 220.8% (**High RE Target Scenario**). The gas power plant capacity at the ASEAN level was 87 GW in 2020, and by 2040 was expected to increase by about 77% (**Base & Optimum RE Scenario**), 78% (**ASEAN RE Target Scenario**) and 39.8% (**High RE Target Scenario**). The total VRE capacity in 2020 was 12.402 GW, and by 2040 it was projected to be ~79.4 GW (**Base Scenario**), 124 GW (**Optimum RE Scenario**), 126 GW (**ASEAN RE Target Scenario**) and 504 GW (**High RE Target Scenario**).

The capacity addition of fossil-based generation, i.e. coal and gas would remain significantly high in 2040 for all scenarios, including the **ASEAN RE Target Scenario** and **High RE Target Scenario**. This is an indicator of the normal role that thermal units would have to play in the future, with coal units used to meet the base load requirements and gas units helping to provide the balancing support to manage VRE variability.

Nevertheless, at the ASEAN level, the share of VRE capacity for all scenarios in 2040 would be significant. Such a situation will greatly aid the AMS' efforts to achieve the energy transition by enabling high shares of RE.

The following table presents the AIMS III's most important findings: the Proposed Interconnection Summary for each scenario compared to the official status of the ASEAN Interconnection Projects (September 2020, updated September 2021).

Table ES 2. Proposed Interconnections under AIMS III Scenarios

Status of ASEAN Interconnection Projects (Sep 2020)		Proposed Interconnection (Base Case)		Proposed Interconnection (Optimum Case)		Proposed Interconnection (ASEAN RE Target Case)	
Status	**MW**	**Status**	**MW**	**Status**	**MW**	**Status**	**MW**
Existing	7,650	Existing	7,650	Existing	7,650	Existing	7,650
Ongoing (up to 2021)	555-625	Proposed Additional Connection by 2025	1,085	Proposed Additional Connection by 2025	7,576	Proposed Additional Connection by 2025	12,634
Future	23,369-26,769	Future	10,117	Future	25,591	Future	25,837
Grand Total	31,574-35,044	Grand Total (2040)	17,767	Grand Total (2040)	33,241	Grand Total (2040)	33,487

The AIMS III found that the total MW capacity of the cross-border interconnections in the ASEAN region required to establish the APG in all of the scenarios (**Base Scenario** – 10,117 MW, **Optimum RE Scenario** – 25,591 MW and **ASEAN RE Target Scenario** – 25,837 MW) was lower than that envisaged through the official status of the ASEAN Interconnection Projects (31,574 MW – 35,044 MW). All of the interconnection capacities in the AIMS III scenarios were optimised to seek the best minimum required interconnection capacity needed to establish the APG. This finding can serve as the official reference point for ASEAN Interconnection Projects.

Concluding Remarks

There is still a long way to go before the AMS can fully establish the proposed cross-border interconnections envisaged by the AIMS III study. The establishment of the APG will require prolonged efforts on the part of the AMS, with progress occurring in a series of stages of development and harmonisation among interconnected countries.

Phase 3 of the AIMS III will need to be further developed. It will focus on the minimum requirements of multilateral market development, regulatory frameworks, technical standards and grid codes. The implementation plan must be brought to the national level to realise the proposed interconnections. A feasibility study for each proposed interconnection project must be conducted to support the implementation. A further study based on the AIMS III findings would be the best way for the AMS to confirm their directions and help realise the APG. High-level commitments and solid political commitments must be established to support the integration of the APG. The political commitments include several matters such as intergovernmental agreements and specific issues such as an agreement on a common technical language. Finally, exploring further interconnectivity for the APG beyond the ASEAN region would also be an excellent way to move forward. By examining some of the emerging grid integration initiatives, the APG is at the core and will ensure that the benefits of multilateral power trade will reach all of the AMS.

1 Introduction

1.1 Overview of the ASEAN Power Grid (APG)

Cooperation on the ASEAN Power Grid (APG) was initiated in 1997 to establish cross-border electricity interconnections between the ten ASEAN Member States (AMS): Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam. The APG consists of several cross-border transmission projects or concepts divided into the Northern, Southern and Eastern development corridors, some of which have been in operation for some time, and others which are still in the planning or conceptual phase. The APG was established to connect the national grids of the AMS to allow for either unilateral power transfer, economic power exchange or emergency transfer. With the ever-increasing and serious effects of climate change and the global energy transition to low-carbon forms of energy, it is apparent that the ASEAN region would greatly benefit from an interconnected power system to enhance the development and integration of variable renewable energy (VRE). Figure 1-1 is a map of the transmission interconnections of the three APG corridors.

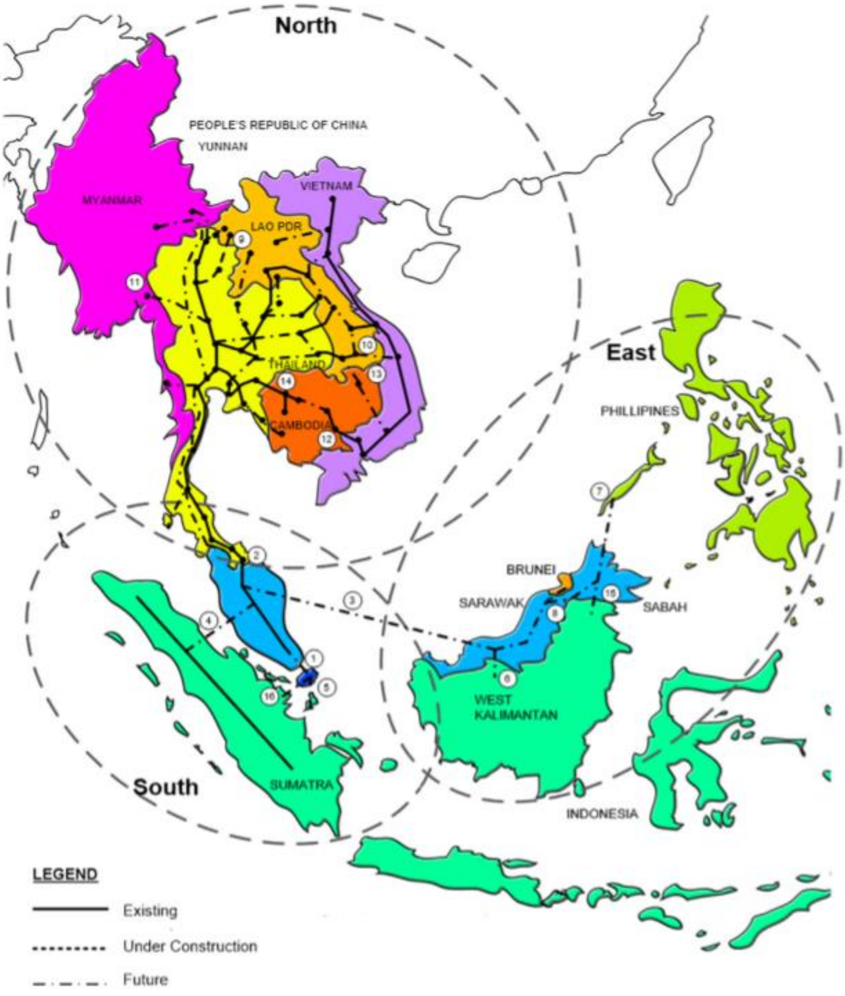


Figure 1-1: The ASEAN Power Grid Today

It is vital to have secure and reliable electricity infrastructure to support regional economic growth and integration. The electricity demand growth rate in the countries of Southeast Asia is expected to double from 993 TWh in 2018 to about 2,200 TWh in 2040, while the generation capacity is expected to double. The ultimate aim of the APG is to construct a regional power interconnection, beginning with cross-border bilateral terms and gradually expanding to sub-regional terms. Over time, a completely integrated Southeast Asia power grid system will be in place.

The APG is one of the physical energy infrastructure projects listed in the *Master Plan on ASEAN Connectivity 2025.*[6] As such, it would support the AMS in meeting the increasing electricity demand, improving access to energy services in the region and contributing to the region's environmental sustainability goals. The APG is also important for non-energy related reasons. To accelerate economic growth, social progress and cultural development in the region, joint endeavours in the spirit of equality and partnership are needed to strengthen the foundation for a prosperous and peaceful community of the Southeast Asian nations, and hence the significance of the APG. As the progress, there are already a number of bilateral interconnections in operation, such as between Singapore and Peninsula Malaysia, Thailand and Peninsula Malaysia, Thailand and Cambodia, Lao PDR and Vietnam, and Sarawak to West Kalimantan.

1.2 History of the AIMS III

The origin of this study lies in the pursuit of the realisation of the APG. The project was begun with the signing of the 1986 Agreement on ASEAN Energy Cooperation (AEC). The ASEAN Leaders expressed strong support for the strengthening of ASEAN energy connectivity, especially given the growing demand for energy in the region. They expressed their support for regional energy connectivity projects such as the APG and the TAGP (Trans-ASEAN Gas Pipeline) and instructed that the next level of planning be examined. They also called for harmonisation of the regulatory frameworks and standards to facilitate regional energy connectivity. They emphasised the critical role of the private sector participation in contributing to the capital needed to support the AEC.

As per the 17th ASEAN Ministers on Energy Meeting (AMEM) in July 1999 in Bangkok, Thailand, the Heads of ASEAN Power Utilities/Authorities (HAPUA) requested the establishment of the APG through AIMS, and the AIMS Working Group was established at the 16th Meeting of HAPUA in April 2000 in Chiang Rai, Thailand. In parallel with AIMS, the APG roadmap was drafted and approved by the 20th SOME-AMEM (Senior Officials Meeting on Energy-ASEAN Ministers on Energy Meeting) in July 2002, Bali, Indonesia. After the Working Group completed AIMS I, its final report was endorsed by the 21st AMEM in Langkawi, Malaysia, in July 2003. It pioneered a comprehensive study of the potential cross-border power interconnections among the AMS.

Although HAPUA realised that it was the vital player in pushing the APG project further, its former structure hindered its capabilities. Thus, a new structure was recommended and later adopted in 2004 to facilitate and develop more efficient ways to work on the APG. The AIMS-II was then assigned to Working Group No. 2 – Transmission, comprising three sub-working groups: The Power Interconnection Sub-Working Group (PI SWG), the Operation &

[6] The ASEAN Secretariat. **Master Plan on ASEAN Connectivity**. Jakarta. https://asean.org/wp-content/uploads/2018/01/47.-December-2017-MPAC2025-2nd-Reprint-.pdf

Maintenance Sub-Working Group (O&M SWG) and the Transmission Pricing Sub-Working Group (TP SWG). The TP SWG was subsequently cancelled, and the System Operations Sub-Working Group (SO SWG) was established at the 24th Meeting of the HAPUA Council held in Cebu, the Philippines, in June 2008. The AIMS II was completed in 2010. It updated AIMS I, but with the further investigation of generic cross-border links based on bilateral agreements.

As per the AMEM directive at the 35th AMEM (2017), the HAPUA Council's commitment to updating the AIMS II was noted. Therefore, in conjunction with this, the 36th AMEM (2018) indicated that HAPUA and APGCC (APG Consultative Committee) had started work on the AIMS III. The success of the AIMS II revealed that the AIMS III should focus on inter-country cooperation in the power sector to support greater renewable energy integration (including the 23% RE share in ASEAN's energy mix by 2025) in the future through cross-border power interconnections. They also requested that the AIMS III explore the opportunities and benefits of having higher VRE and follow the emergence of new and more sustainable technologies with lower costs, that could facilitate multilateral power trade.

1.3 Objectives and Working Mechanism of the AIMS III

1.3.1 Objectives

The ASEAN Interconnection Masterplan Study (AIMS) III is the third edition of the ASEAN Masterplan for the APG. The AIMS III continues the AIMS II study and evaluates some comprehensive plans for capacity expansion and transmission network expansion to support the realisation of ASEAN's comprehensive cross-border power interconnections and a much higher penetration VRE throughout the region. The AIMS III report also explains how ASEAN's target to have a 23% RE share in the regional energy mix by 2025 will be achieved.

The three main objectives of the AIMS III study are: (i) To provide a new and updated APG plan to be used as the main reference for the AMS in pursuing regional cooperation in the power and VRE sectors; (ii) To evaluate the potential cross-border interconnections' economic viability, optimal generation capacity and VRE expansion, as the basis to undertake a more comprehensive feasibility study, design and implementation of cross-border interconnection project to promote fully operable bilateral and multilateral power trading in the region; (iii) To enhance energy connectivity and market integration in ASEAN to achieve energy security, accessibility, affordability and sustainability for all.

1.3.2 Working Mechanism

The AIMS III Working Groups (AWG) held a series of consultation meetings with the energy ministry/regulatory bodies and power utility authorities of the AMS. At these meetings, the AMS provided technical guidelines to assist with the technical work. AMS also shared data necessary for simulation studies which were designed to reflect the landscapes of the ASEAN power sector.

The structure and organisation of the AIMS III Organisation are shown in Figure 1-2 The Organisation consists of a Project Advisory Committee (PAC), Technical Advisory Committee (TAC), Regional Advisory Committee (RAC) and Technical Reviewing Group (TRG). The PAC is led by the ACE, collaborating with the HAPUA Secretariat, HWG 2 – ASEAN Power Grid and USAID Clean Power Asia. The PAC received technical and regional advisories and directives for the study from the TAC and RAC. With that, the PAC led the AIMS III Working Group (AWG) under the guidance of the Utilities and Ministries/Regulatory Bodies from the ten AMS. The AWG strove to strengthen ASEAN energy cooperation through the adoption of the AIMS III findings for future direction inputs of the APG at the regional level.

In order to reinforce the quality of the study, the AIMS III report was peer-reviewed by a Technical Reviewing Group (TRG) which included several reputable energy research institutes/agencies: the National Renewable Energy Laboratory (NREL), Hawai'i Natural Energy Institute (HNEI), International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA). Amidst the compiling of the report, all of the analytical work for the proposed interconnections was based on scientific work that relied on a series of comprehensive inputs from the TRG.

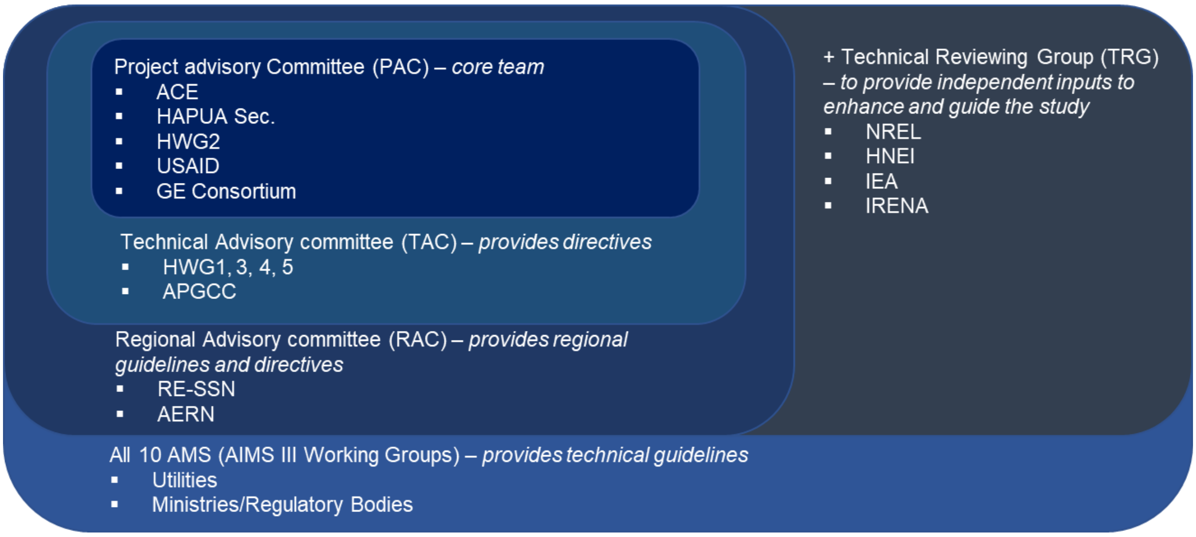


Figure 1-2: AIMS III Organisation

The work's first consultation meetings were the 26th Heads of ASEAN Power Utilities/Authorities (HAPUA) Working Committee Meeting held in November 2017 and the Special Senior Officials Meeting on Energy (SOME) held in January 2018. The purpose of these meetings was to ensure the endorsement of the ASEAN Centre for Energy (ACE) as the implementing agency for the development of the ASEAN Interconnection Masterplan Study III (AIMS III) in coordination with the HAPUA Secretariat and HAPUA Working Group (HWG) No. 2 Transmission/APG.

Several meetings thereafter continued the progress of the AIMS III to cement all stakeholders' commitment to ensuring the quality of the study. The meeting which officially launched work on the AIMS III was held in Bali, Indonesia, on 25 April 2019, and discussion with all of the HAPUA Working Members about the AIMS III methodology and plans took place at the Preliminary Meeting in Da Nang, Vietnam, on 22 May 2019. Approval of the methodology and plans brought focus to some of the technical aspects of the work. Verification of the methodology and initial assumptions and data collection from the AMS were dealt with at the Inception Meeting held in Bogor, Indonesia, on 24 July 2019.

Once a clear framework was established, discussions with the chairs of the APGCC and Renewable Energy Sub-Sector Network (RE-SSN) took place in Bangkok, Thailand and Putrajaya, Malaysia in August 2019. The primary purpose of these meetings was to further discuss higher VRE penetration, up to a 25-30% share, in the power generation mix

A series of meetings was held after these discussions to ensure that the AIMS III outreach was well endorsed, especially that pertaining to the study's objectives. These meetings were part of the 23rd Meeting of the ASEAN Power Grid Consultative Committee (APGCC), the 28th Meeting of the HAPUA Working Committee held 29-30 April 2019; the 24th Meeting of the ASEAN Power Grid Consultative Committee (APGCC); and the 29th Meeting of the HAPUA Working Committee and 35th HAPUA Council held 28-30 October 2019.

It was recognised that the progress of the AIMS III study had to be monitored effectively. Hence, technical and non-technical groups to oversee the AIMS III were institutionalised, including the Technical Review Group (TRG). Its objective was to review the selected tools, analysis and methodology; verify key assumptions and required data; review and verify simulation results and provide further inputs as external parties. A series of meetings was conducted to provide guidance on how the AIMS III should be developed.

The 1st Technical Review Group (TRG) was convened on 11 December 2019, in Bangkok, Thailand. At this meeting, the ACE invited international collaborators to provide inputs and feedback on the preliminary results and methodologies of the RE Resource Assessment and Capacity Expansion Planning. These particular collaborators were already well known: TRG members, including the IEA, IRENA, HNEI and NREL.

At the 2nd TRG meeting held 9-10 March 2020, in Jakarta, Indonesia, the TRG members provided inputs and feedback on the results and methodologies of the RE resource assessment. In addition, four study scenarios were agreed upon for capacity expansion planning, namely: 1) Base Scenario, 2) Optimum RE Scenario, 3) ASEAN RE Target Scenario and 4) High RE Target Scenario. More details about these scenarios are given in the Scenarios section.

The participants at these meetings all concurred that an urgent step at that point was to discuss the layout of the simulation study, including the assumptions and methodology used for, and results of, the capacity expansion planning, production cost simulation and socio-economic-environment analysis in the AIMS III study. Hence, between the 2nd TRG meeting and the 3rd virtual TRG, a virtual Interim Meeting was held 5-15 May 2020 at which the AIMS III project team and the AMS discussed and reviewed some of the key points and raised some other crucial aspects about the remaining the AIMS III processes. For example, it was agreed that the production cost simulations should be acceptable from the perspective of all of the AMS. Appropriate boundaries were presented, including a work plan, required consultation meeting on assumptions and data gaps, resources and data availability to guarantee the quality of the AIMS III report.

At the 3rd virtual TRG meeting held 28-30 July 2020, the TRG members provided inputs and feedback on the assumptions, methodology and expected grid performance analysis results of the AIMS III study. As a part of the progress monitoring apparatus, the ACE held its 1st preliminary meeting to discuss and review with each AMS. The discussion revolves around the preliminary results, methodology and assumptions used for the study. In turn, the AMS recorded some adoptions and approvals relating to the preliminary results. Endorsement by the AMS at this juncture was crucial to allowing work to continue on the AIMS III report.

Following the 1st Preliminary Results Meeting, the 38th Senior Officials Meeting on Energy (SOME) and Associated Meetings were hosted by the Ministry of Industry and Trade (MOIT) of Vietnam 24-27 August 2020. The SOME showcased some of the accomplishments of the AIMS III in aligning the output with the Implementation and Monitoring of The ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase 1: 2016-2020.

The successful presentation of the AIMS III to the SOME Meeting endorsed the continuation of the AIMS III at the Phase 1 Final Results Meeting held 5-6 October 2020. Representatives from all ten AMS attended this meeting which provided an update on RE resource assessment, capacity expansion planning, production cost simulation and socio-economic-environmental analysis.

Phase 2 activity for the grid performance analysis was initiated with the 2nd Preliminary Results Meeting held 12 November 2020. The successful completion of Phase 1 and finalisation of Phase 2 of the AIMS III, which recommended the transmission infrastructure for multilateral power trade and greater integration of VRE into the APG, was received favourably by the ASEAN Ministers during the 38th ASEAN Ministers on Energy Meeting (AMEM) held 17-20 November 2020 in Hanoi, Vietnam.

Completion of Phase 1 and Phase 2 was the body of the AIMS III report. It will be a *reference document* for the AMS to promote cross-border power exchange and development of the APG with greater utilisation of VRE, and to help determine the pathways for the ASEAN target to have a 23% RE share in the energy mix by 2025.

2 Methodology of the Study

Development of the APG is based on the existing pattern of cross-border electricity trade in the region, which has been predominantly bilateral. Cross-border electricity trade is complicated by political, social, economic and environmental factors. Even if profitable, it is considered a high-risk project due to the very high cost – billions of (US) dollars – to build. However, enabling cross-border electricity trade will unlock a higher share of low-cost, renewable energy generation and create cascading economic benefits. It can also provide system or grid flexibility which is needed for higher VRE penetrations and decreasing carbon emissions.

The expansion of RE in the ASEAN region may reduce the overall cost of the electricity system (e.g., investment in the transmission system, operation cost, etc.). However, wind, solar, hydro and other various other forms of renewable energy, may face geographical constraints. The value of cross-border transmission lines is that they may allow for RE consumption in places distant from the RE sources. Enabling cross-border trade will increase RE source mobility, reduce localised risks and spur inbound energy infrastructure and production investment.

At the outset of the AIMS III study, global opinion on the energy transition, i.e., moving away from fossil fuel energy systems towards non-emitting energy systems, was not as clear as it has become today. However, in the capacity expansion planning section of the AIMS III, the planning of new coal power plants has not been restricted by this new global trend.

2.1 Scenario Philosophy

By understanding the current situation and future policy direction and taking into account the possible use of new technologies a couple of decades ahead, it is possible to test the implications of different policy choices and technology adoptions to aid in envisioning the role of the APG in the future. The AIMS III report can help ASEAN energy planners and policymakers understand the challenges and benefits of different policy choices with respect to emerging energy trends. It not only explores the viability of generic cross-border links in need of increasing inter-country cooperation between the AMS, but also explores the opportunities and benefits of having higher VRE penetration and the potential emergence of new and more sustainable technologies with lower costs in the future.

ASEAN has set an ambitious aspirational target of a 23% RE (all sources of renewables, including hydro power of all sizes, but excluding traditional biomass) share in its Total Primary Energy Supply (TPES) by 2025, up from 13,9 % in 2019. This is in line with the global trend of targets set by many nations and regions to increase the share of RE in their respective energy mixes to ensure more sustainable development of the planet. It is also aligned with AMS's Nationally Determined Contributions (NDC) for reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC).

The efforts to attain this target constitute a good opportunity to promote energy cooperation among the AMS, as there are three technical considerations needed:

- To estimate the amount of RE power generation that each AMS can contribute towards this goal;

- To find ways to achieve synergy between the AMS' respective RE potentials vis-à-vis their demand and supply patterns so that the region can share the RE benefits; and
- To identify an efficient and effective mechanism that can kickstart and sustain the inter-country exchange/trade of power through the APG.

The power sector has been leading RE growth in almost every country in the world. The advantages that RE sources offer in the power sector (such as lowering harmful emissions from thermal projects) have led to their increased adoption in the electricity generation mix.

In the case of the AMS, the share of RE in power generation was around 26% in 2017[7], and this is expected to be around 35% by 2025 in terms of energy production if the RE target is to be achieved. The RE adoption will again be driven by the power generation sector, which could account for almost half of the planned RE capacity addition by 2025.

Like any developing region, ASEAN's 's energy demand is expected to soar in the coming years. For the ASEAN region as a whole, the energy demand in 2025 in the power sector alone is expected to increase by ~37% from the 2019 level.[8] The expected energy demand growth is comparable in nearly all of the AMS, as shown in Table 2-1.

Table 2-1: Increase in Energy[9] and Electricity Demand[10] in the AMS between 2019 and 2025

No.	ASEAN Member States	TFEC	Power Sector
1.	Brunei Darussalam	6%	8%
2.	Cambodia	46%	78%
3.	Indonesia	24%	47%
4.	Lao PDR	24%	77%
5.	Malaysia	19%	4%
6.	Myanmar	49%	85%
7.	Philippines	37%	33%
8.	Singapore	-23%	12%
9.	Thailand	-9%	23%
10.	Vietnam	45%	61%
	ASEAN Region	20%	37%

Note: TFEC (Total Final Energy Consumption)

To meet this huge increase in demand, it is imperative that the AMS concentrate on increasing their energy production capabilities with immediate effect.

Other factors in favour of increasing the RE share in ASEAN are:

- The AMS have expressed their strong commitment towards RE and energy efficiency (EE). These commitments are reflected in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016 – 2025, which aims to achieve an RE share in the ASEAN Total Primary Energy Supply (TPES) of 23% by 2025 and beyond.[11]

[7] ASEAN Centre for Energy (ACE). (2020). **The 6th ASEAN Energy Outlook.** ACE, Jakarta. https://aseanenergy.org/the-6th-asean-energy-outlook/
[8] Ibid.
[9] ACE. (2021). **ASEAN Energy Database System**, https://aeds.aseanenergy.org/
[10] ACE. (2019). **AIMS III Database (restricted).**
[11] ACE. (2015). **(2016-2025) ASEAN Plan of Action for Energy Cooperation (APAEC).**

- The ASEAN Centre for Energy (ACE) in the ASEAN 6th Energy Outlook 2017-2040 (2020, p. 19) projects that total final energy consumption (TFEC) in ASEAN could increase by 146% by 2040, rising from 375 Mtoe in 2017 to 922 Mtoe (Business-as-Usual Scenario - BAU) in 2040; other scenarios give figures for 2040 of 714 Mtoe (ASEAN Target Scenario - ATS), and 624 Mtoe (ASEAN Progressive Scenario - APS). The increase is driven by the industrial, transport and residential sectors. In the absence of enhanced RE, between 2015 and 2040, the total energy supply needed to account for industrial, transport and residential sectors will more than double.[12]
- In the Baseline Scenario of the ASEAN 6th Energy Outlook, TPES in 2040 is expected to be more than 2.5 times higher than in 2017, equivalent to 1,589 Mtoe compared with 625 Mtoe. In the ATS scenario, the TPES in 2040 is 1,298 Mtoe, twice as high as in 2017, and in the SDG Scenario, it is 1,290 Mtoe. In the APS scenario, it is 1,139 Mtoe, reflecting more ambitious EE efforts.[13]
- Hydro, solar PV and wind are expected to be the significant drivers of RE growth, with VRE (e.g., solar PV and wind) making contributions of 17.7% by 2025 and 22.1% by 2040 in the ATS scenario.[14] This means that achieving the 23% RE share by 2025 requires multiple layers of additional efforts to accelerate RE growth.

2.2 Scenarios Setting

As stated in the section on the Working Mechanism, the scenarios were designed on the basis of a series of consultative meetings with the AMS, particularly with the AIMS III Working Group. These meetings were vital in that they guided how the AIMS III would explore the policy choices and technical aspects that needed to be considered in one set of scenarios (section 2.1). By understanding the foundation of the chosen scenarios as explained in section 2.1, the scenario set was made to streamline the influence of the policy choices and technology adoptions to the Power Development Plan (PDP), and its connectivity with the APAEC target of a 23% RE share by 2025. As such, the scenarios impact the modelling under the Capacity Expansion Planning tasks. In the AIMS III, four scenarios were explored to signify the expression of the Scenarios Philosophy needed for the study.

(i) **Base Scenario –** the building blocks for this scenario, which forms the baseline for the subsequent scenarios, are the current installed capacity, the firm (committed) capacity additions for Generation and Transmission Interconnection assets as per the Power Development Plans (PDPs) for each AMS and any planned retirements. Some key points to be highlighted include:

  - While the committed projects are fully treated as fixed plans, the non-committed thermal power plants in the PDP will be re-optimised.
  - VRE (wind and solar) will be as per the country-level PDP; beyond the PDP, VRE will be increased according to the country's direction.
  - No new interconnections will be added to the existing ones.

[12] ACE. (2020). **The 6th ASEAN Energy Outlook**, page 19.
[13] ACE. (2020). **The 6th ASEAN Energy Outlook**, page 52.
[14] ACE. (2020). **The 6th ASEAN Energy Outlook**, page 58.

(ii) **Optimum RE Scenario** – the aim of this scenario is to develop optimised thermal, VRE and transmission interconnections. For this purpose, all capacity beyond the PDP is re-optimised, except hydro power. The non-committed thermal plants under the PDP, namely those for which construction has not commenced or where the Power Purchase Agreement (PPA) has not been signed, are also re-optimised under this scenario. This was done to make the outputs of this scenario reflect purely economic optimisation, which also co-optimises generation and interconnection requirements.

(iii) **ASEAN RE Target Scenario** – under this scenario, the main point of difference relative to the Optimum RE Scenario is that the VRE capacity additions are provided. These were determined in line with the RE target in the Progressive Scenario (APS) of the 6th ASEAN Energy Outlook.[15] In contrast, the thermal and transmission interconnection capacity expansions were optimised. A simultaneous process was undertaken to enhance the RE target under the ASEAN 6th Energy Outlook to 2025, which is then projected to 2040. To ensure consistency between the numbers resulting from the simulation, it was decided that the targets under this scenario would also regard the AEO6 as a reference.

(iv) **High RE Target Scenario** – much higher VRE capacity additions are entered into the future generation mix to understand the impacts of very high VRE penetrations on the grids at the national levels and on cross-border interconnections. The high RE target was determined by the consultative meetings with the AMS by considering a higher aspiration level of VRE penetration in the ASEAN region (25%-30% in the generation mix by 2040 instead of 23%). Also in this scenario, the capacity expansion of thermal generation and transmission interconnection was optimised.

2.3 Phases of the AIMS III Report

Phase 1 focused on identifying potential RE generation sites and transmission lines to enhance bilateral and multilateral power trade opportunities. The steps included an RE resource assessment, capacity expansion planning and production cost modelling. The later step assessed the performance of grid operations with thermal and VRE capacity additions produced by the capacity expansion planning. In Phase 1, a socio-economic-environmental impact analysis was also made.

Phase 2 focused on assessing the grid technical performance as designed in Phase 1, using power system analysis. The new power systems created in each study scenario were evaluated to uncover potential technical issues, for example, to understand how power system stability can be improved.

[15] The ASEAN Progressive Scenario is one of the scenarios in the ASEAN Energy Outlook 6. It implies the acceleration of RE by taking the APAEC's aspirational 23% RE share target into account.

2.3.1 Phase 1 – Capacity Expansion Planning

An overview of the process and data flow between various tasks under Phase 1 of the AIMS III is shown in Figure 2-1. The figure shows that capacity expansion planning is the heart of Phase 1 activity.

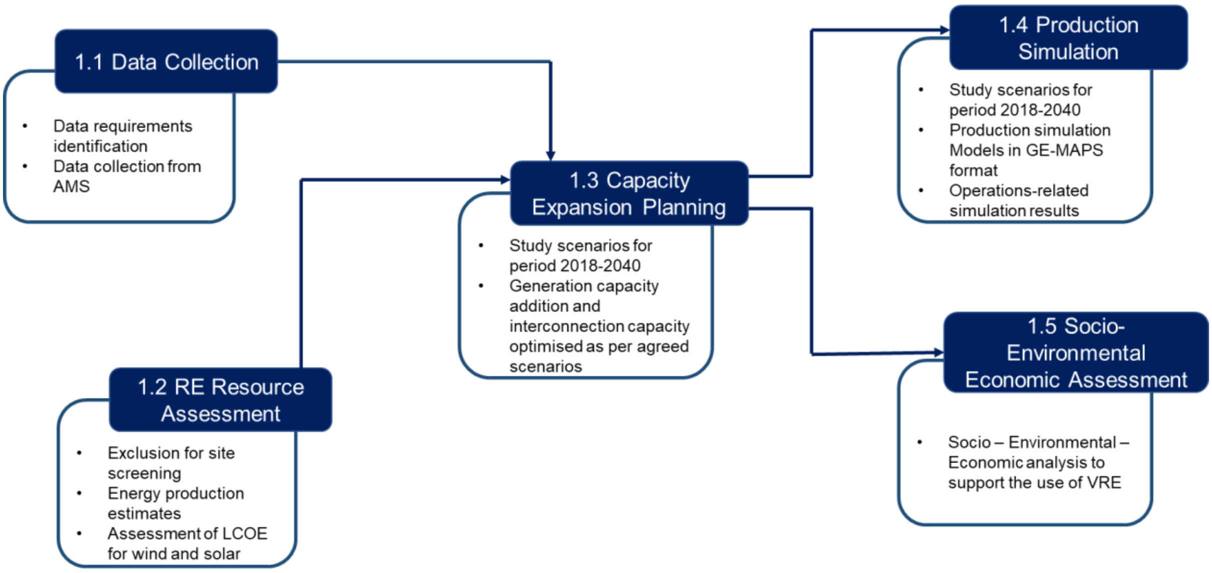


Figure 2-1: Phase 1 – Task Flow & Correlations

2.3.1.1 Data Collection

A comprehensive list of required data sets was prepared and conceptualised, then circulated to each AMS, based on the methodology of the AIMS III study and considering specific requirements of the selected software tools.

2.3.1.2 RE Resource Assessment

This aimed to support the efforts to model wind and solar and to identify sites to be developed in the subsequent study task. It aimed to identify possible VRE sites in the ASEAN region and provide hourly wind and solar energy production profiles for each site.

2.3.1.3 Capacity Expansion Planning

This is used to evaluate the optimal addition of generation and interconnection capacities to meet future demand that yields the lowest total system costs while maintaining reliability. As the core process of Phase 1, the key objective in expansion planning is to ensure that such capacity additions will result in the most economically optimised capacity expansion, in which the total operational cost and the capital cost required for the new additions are at the minimum while ensuring that the future demand will be met with acceptable reliability levels.

The capacity expansion planning task was made with PLEXOS using Energy Exemplar as the simulation tool. The scenarios definitions differ due to their specific considerations. The process details are presented in Figure 2.2.

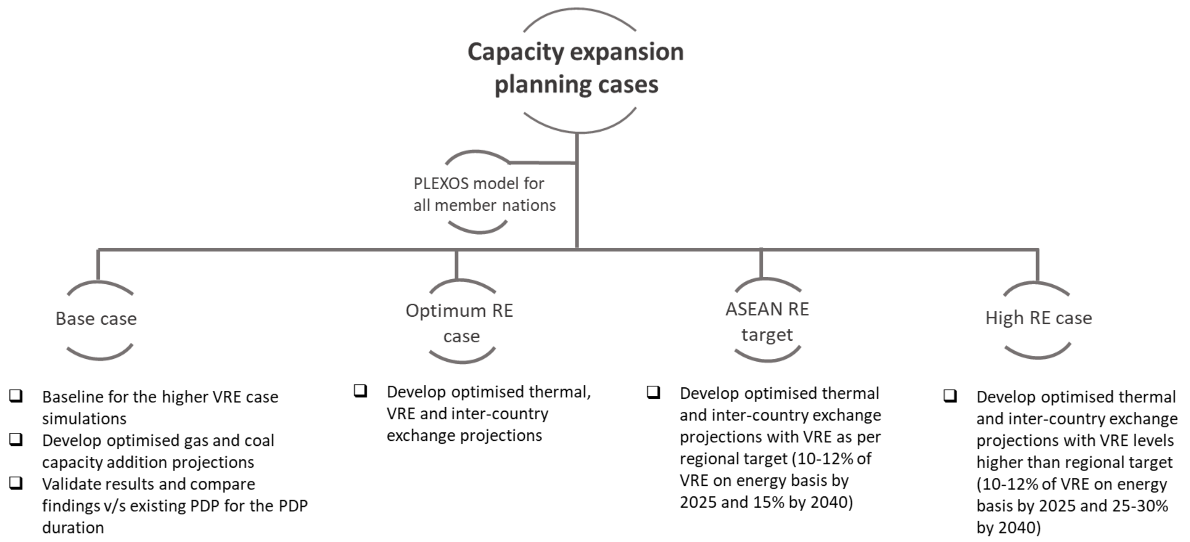


Figure 2-2: Capacity Expansion Planning Scenarios

2.3.1.4 Production Cost Simulations

The purpose of production cost simulations is to validate the results of capacity expansion planning by assessing the operating performance of the future power systems in the ASEAN region. They cover some aspects such as energy production, supply adequacy, reliability and system generation costs, using security-constrained economic dispatch. In the simulations, the hourly operations of thermal, hydro and VRE generating units and the energy interchange through the interconnections among the AMS are simulated chronologically, then evaluated.

Under this task, the analysis highlighting the maximum utilisation of VRE potential in the regional power system is undertaken, with the intent to quantify the economic benefits that the regional co-operation among the AMS is likely to produce, and to maximise VRE integration.

The first step under this task is to identify the study parameters essential for modelling fidelity. This includes the study horizon, study scenarios, load growth and load profile changes expected, the parameters associated with the thermal units' part-load operations, minimum stable loading, and so on. The impact of regional cooperation on the production costs of operating the interconnected systems and emissions is the primary focus. In terms of the analytical granularity, while the simulation is undertaken on an annual basis, production simulation analysis is done on an hourly basis for all the years along the study horizon. This simulation can also help assess the grid flexibility and VRE curtailment issues for a very high VRE penetration scenario.

Production simulation analysis also aims to evaluate the economic benefits of regional cooperation towards maximising VRE integration within the ASEAN power grid. For this purpose, detailed production simulation models for all of the AMS have been made to evaluate the impact of higher RE penetration on system operation. The analysis tool used in this task is the GE Multi-Area Production Simulation (GE-MAPS).

The objectives, activities and deliverables of production cost simulation are indicated in Figure 2-3.

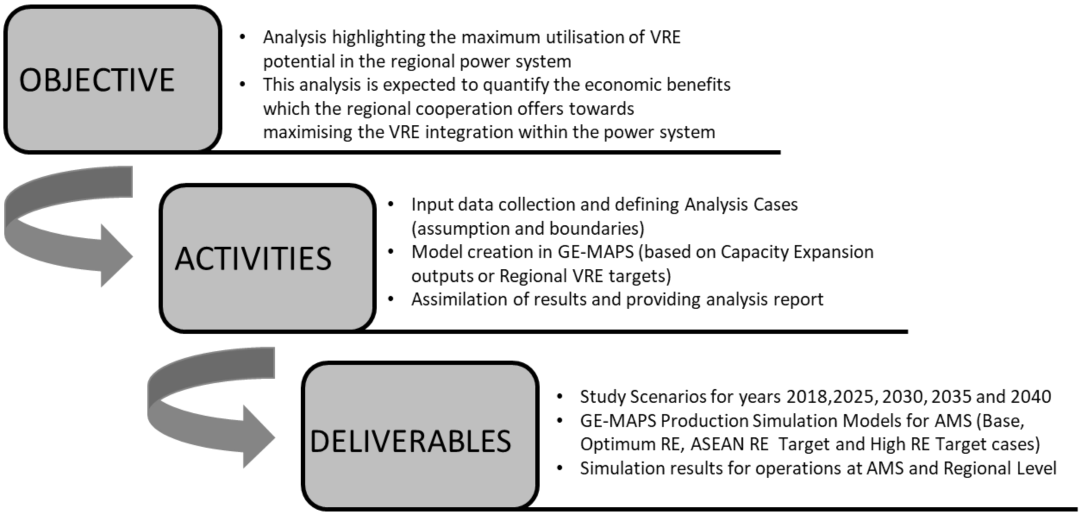


Figure 2-3: Objectives, Activities and Deliverables of Production Cost Simulation

2.3.1.5 Socio-economic and Environmental Assessment

Significant VRE capacity additions have been estimated in the study, ranging from 61.4 GW to 437.5 GW of solar capacity by 2040 under the “Base Scenario” and “High RE Target Scenario”, respectively. Similarly, wind power capacity additions are estimated at 17.9 GW to 66.7 GW under the “Base Scenario” and “High RE Target Scenario”. Deployment of such large-scale solar and wind power capacities is likely to have socio-economic and environmental impacts. In the AIMS III, the estimated VRE jobs created and the estimated CO_2 and N_2O emissions avoided due to the deployment of solar and wind power projects under the four scenarios are presented.

The economic benefits arising from the increased VRE penetration in the ASEAN system are quantifiable in terms of the investment cost of capacity additions and operation costs as illustrated in Figure 2-4.

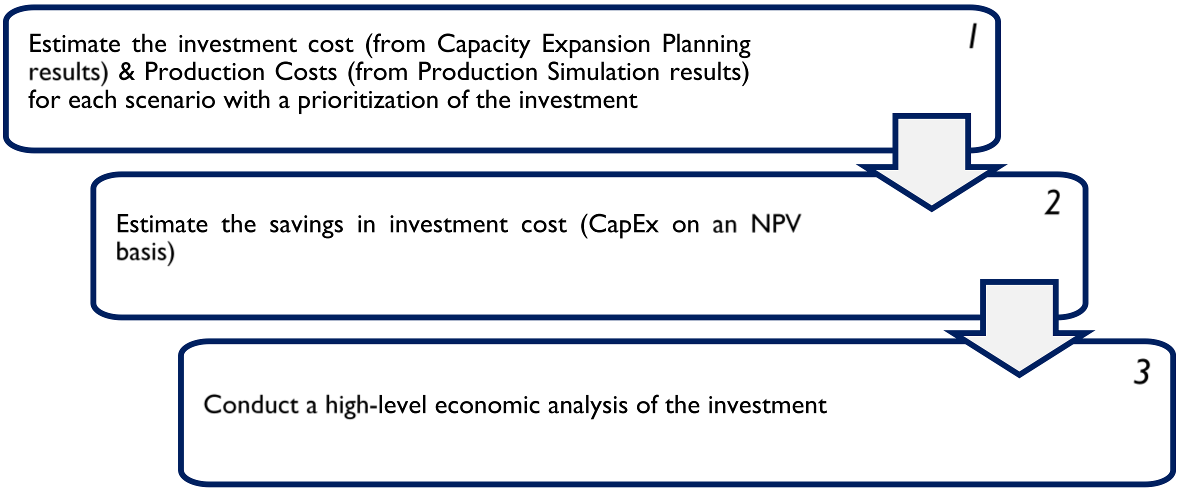


Figure 2-4: Approach for Economic Analysis

In AIMS III, the amounts of CO_2 and N_2O emissions avoided due to the deployment of VRE in each study scenario are also estimated. The approach adopted for calculating the avoided CO_2 and N_2O emissions is shown in Figure 2-5.

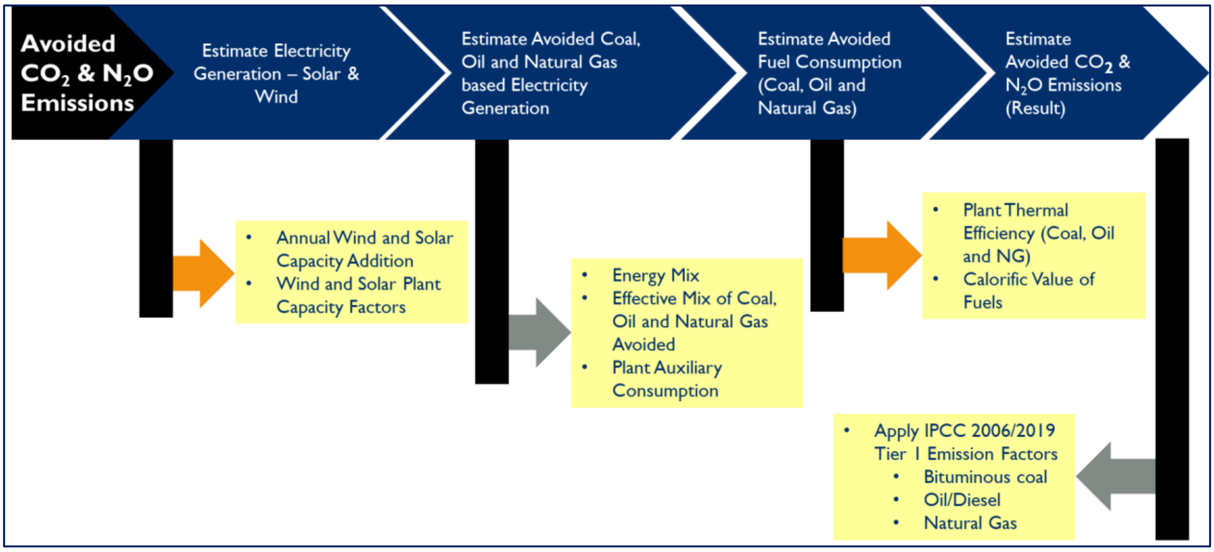


Figure 2-5: Approach for estimating avoided CO_2 and N_2O emissions

The two-pronged approach for estimating the jobs created by solar and wind power projects in each AMS is illustrated in Figure 2-6.

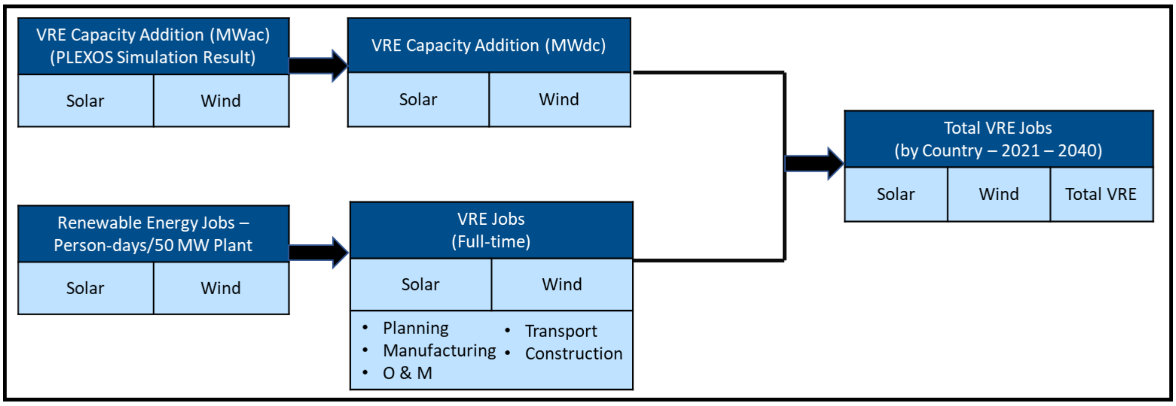


Figure 2-6: Approach for estimating VRE jobs creation

Firstly, the annual future solar and wind power capacity additions in each AMS were extracted from the PLEXOS simulation output. Secondly, the RE jobs estimation approach developed by the International Renewable Energy Agency (IRENA, 2017) were adopted and applied.

In the IRENA approach (2017), VRE jobs creation were categorised for different process streams, including one-time and lifetime jobs. One-time jobs referred to project planning, manufacturing and procurement, installation and grid-connection and decommissioning. Life-time jobs included the operation and maintenance workstreams. There was also categorisation for direct jobs and indirect jobs. Indirect employment referred to the process streams involving manufacturing and transport, while direct jobs meant building the other VRE power plants.

2.3.2 Phase 2 – Grid Performance Analysis

The objective of Phase 2 of the AIMS III study was to evaluate the technical feasibility of the candidate interconnections and VRE capacities as identified in the capacity expansion planning study of Phase 1. This was done through grid analysis comprising power flow analysis, contingency analysis, short circuit analysis and stability analysis. The grid analysis is a kind of snapshot taken at a particular instant or a particular operating condition. Phase 2 revolves around identifying the worst-case operating conditions to evaluate the system constraints and operating boundaries. The production cost simulation performed as part of Phase 1 provided hourly economic generation dispatch and cross-border power transfer for a year (8,760 hours), taking into account the hourly variation of the VRE and load profiles. This hourly dispatch data was scanned to select the hours or operating conditions that caused maximum stress to the transmission system, like peak load, maximum VRE generation, etc. These operating conditions, i.e., scheduled generation for each generator and load, were then transferred to the grid model for each study year.

The Phase 2 work comprised four tasks as described below.

2.3.2.1 Power Flow Analysis

Power flow analysis aims to identify the limitations of system operational feasibility under different operating conditions. A power flow study was performed to evaluate the proposed ASEAN Power Grid network in 2020, 2025, 2030, 2035 and 2040, for some selective operating conditions, which could cause maximum stress to the transmission system in each study year and for each scenario, i.e. Base Case, Optimum RE and ASEAN RE. This helped identify the constraints and set up the limits (boundary conditions) for the operation of the inter-connections between the member states and the national transmission within the member states, which directly impact the power exchange between member states.

The High RE Target scenario was omitted from the grid analysis in Phase 2 because this scenario assumes extremely high penetrations of VRE that the AMS all agreed were challenging from a practical implementation perspective. Figure 2-7 shows the approach of the power flow analysis.

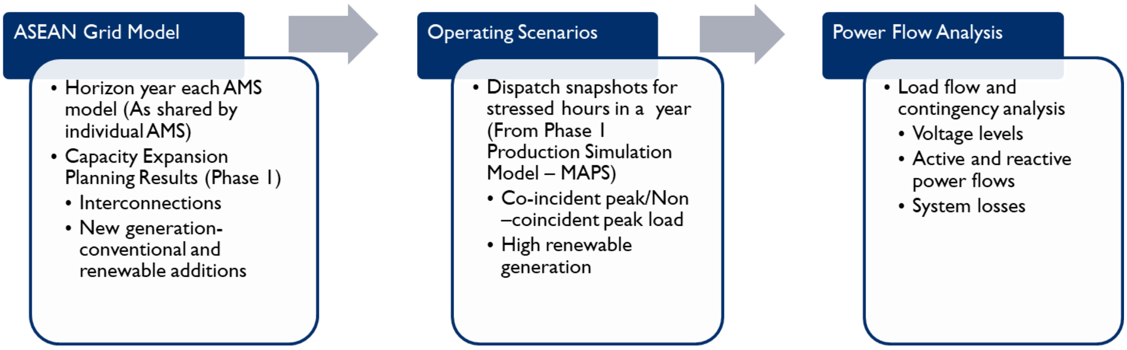


Figure 2-7: Approach to power flow analysis

Power flow analysis selected the generation dispatch from the production cost simulation results for each respective study year. In power flow analysis, active and reactive power flows on interconnecting transmission lines between member states, and line losses and violations, if any, for different network operating conditions, can be observed. It will also suggest network upgrades for improving the overall APG if required.

2.3.2.2 Contingency Analysis

A transmission system should be planned to survive a (N-1) contingency of critical network elements to ensure the grid's reliability. The term N-1 refers to the contingency loss of one element among all the N elements of the grid. This can be evaluated by carrying out a contingency analysis for each power flow scenario's outage of critical interconnections, as shown in Figure 2-8.

The contingency analysis included the assessment of the following:

- Thermal Assessment

This assesses transmission line overloads for both pre- and post-contingency conditions. Thermal criteria require line loadings to be less than applicable normal ratings for pre-contingency, and emergency ratings for post-contingency conditions.

- Voltage Assessment

This assesses violations of voltage criteria for both pre- and post-contingency conditions. The AMS must specify the high and low bus voltage limits. These may differ from one country to another.

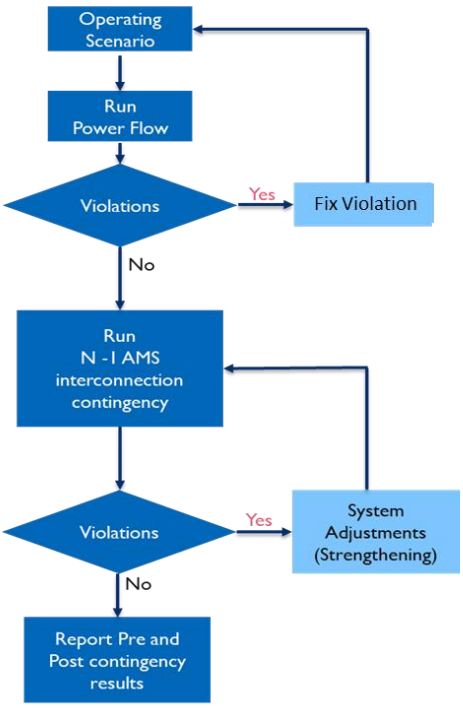


Figure 2-8: Flow of contingency analysis

2.3.2.3 Short Circuit Analysis

Short circuit analysis aims to evaluate the 3-phase short circuit current at the interconnection substations and identify any violation of short circuit levels there. The short circuit study was performed to estimate the maximum fault currents for the proposed APG network in 2020, 2025, 2030, 2035 and 2040 for operating conditions defined in power flow analysis. This short circuit analysis focuses on evaluating the contributions of short circuit currents at interconnections between the AMS for each study year for the selected peak load/generation conditions. Any violations in short circuit levels will be identified from the simulation results of three-phase faults at all of the interconnection points. Figure 2-9 shows the approach of the analysis.

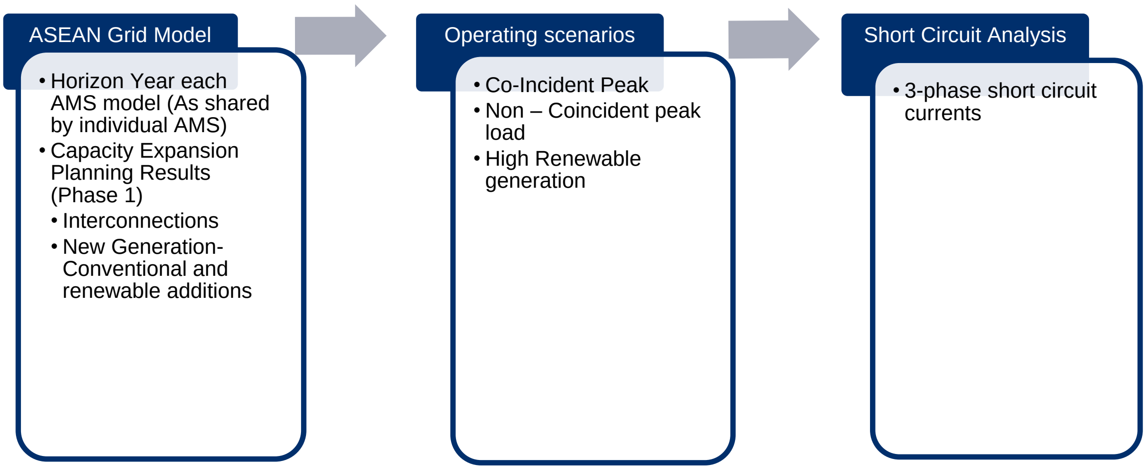


Figure 2-9: Approach for Short Circuit Analysis

2.3.2.4 Stability Analysis

The objective of the stability analysis was to identify the constraints in power exchange among the AMS in the APG, especially during system contingencies and worst operating conditions. Dynamic simulations were carried out for particular operating conditions and contingencies in order to identify the constraints in the interconnected APG and provide recommendations to improve system stability. The chosen operating conditions and contingencies represented the maximum possible stress on the grid system.

Using Siemens PTI *PSS/E software,* the dynamic stability study was performed for 2020, 2025, 2030, 2035 and 2040. The stability of the system configurations in three scenarios (Base, ASEAN RE and Optimum RE) were investigated.

2.4 Modelling Approach to APG Expansion Planning

At the price of appreciable design effort, it was necessary to reduce the size of the grid model in order to attain the proper level of sophistication.

2.4.1 Modelling of the APG As Three Subregions

The APG is divided into three subregions, the North, South and East, as shown in Figure 2.10. They were determined on the basis of the current categorisation used by ASEAN in consultation with the AIMS III Working Group. A total of 14 nodes representing the 10 AMS were defined in the interconnected model for analysis in the AIMS III. The North region (APG North) includes five AMS: Cambodia, Lao PDR, Myanmar, Thailand and Vietnam. The South Region (APG South) includes one whole country (Singapore) and two sub-regions Peninsular

Malaysia and Sumatera Indonesia. The East region (APG East) includes all of the Philippines, Brunei Darussalam, the eastern states of Malaysia (Sarawak and Sabah) and the West Kalimantan province of Indonesia.

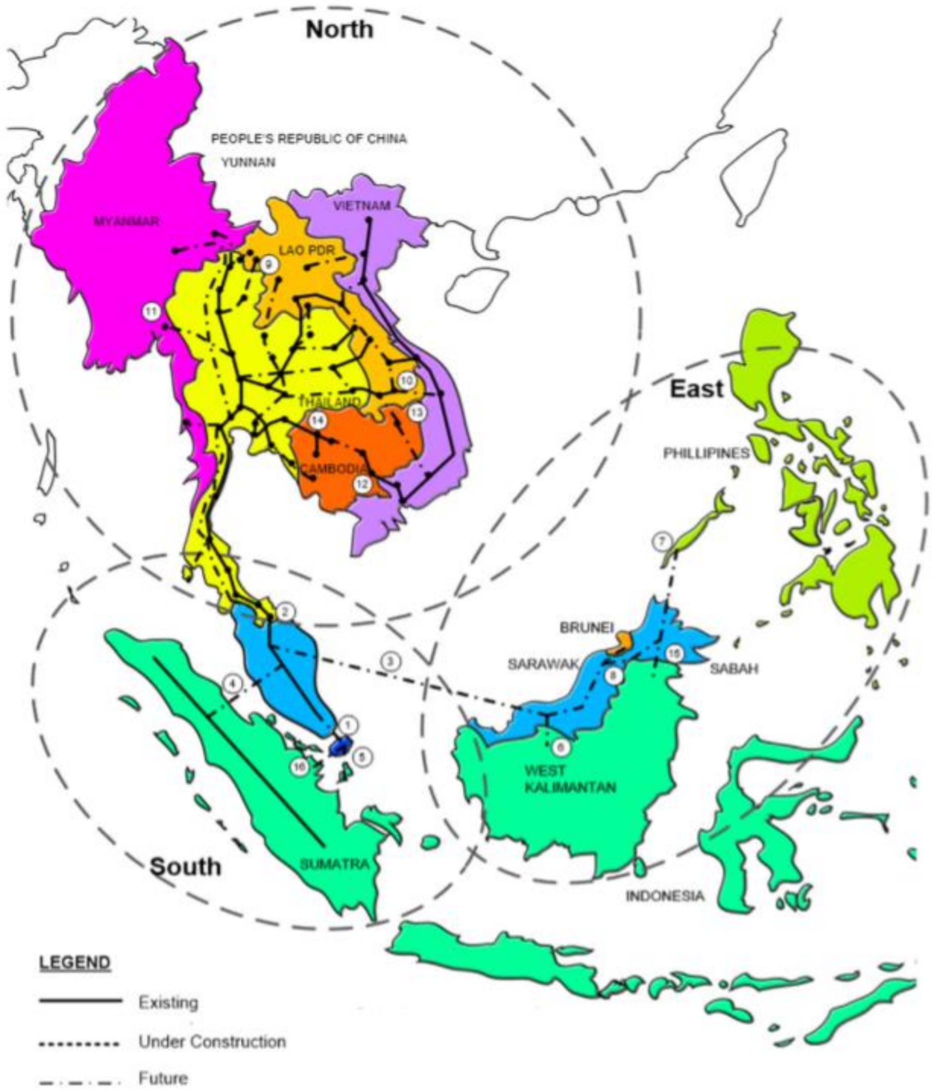


Figure 2-10: The three ASEAN Power Grid (APG) sub-regions

While the design principle in the modelling approach was network reduction, it had to reflect or preserve the shape of the three ASEAN Power Grid (APG) regions, as shown in Figure 2-10In the same manner, its design philosophy had to accommodate country-level characteristics. Stemming from the work done in the AIMS II, each AMS was modelled as a single node, except Indonesia (Java, Sumatera and Kalimantan) and Malaysia (Peninsular, Sabah and Sarawak), in which three nodes for each were modelled due to the islanded electrical systems of those grids. This nodal model was a reduced network approach which effectively assumed no intra-country transmission constraints. Thus, a combined total of fourteen nodes for the ten AMS were defined in the interconnected models for analysis in the AIMS III.

The overall interconnected model of the AMS grids is shown in Figure 2-11.

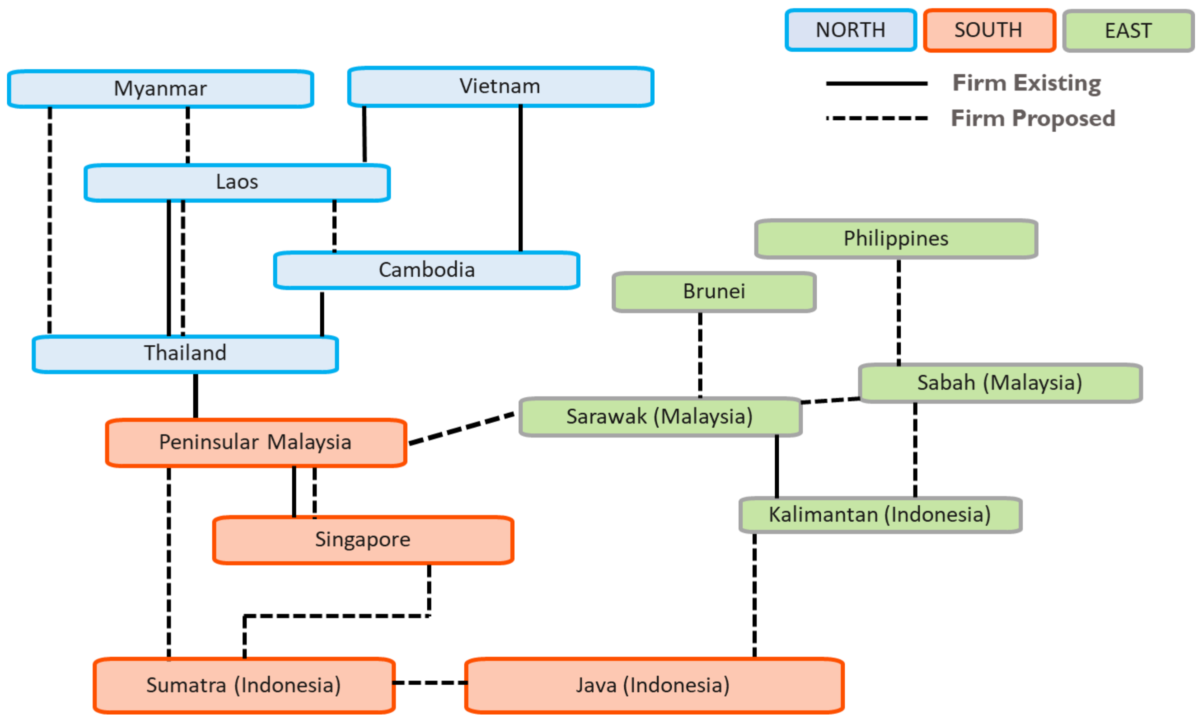


Figure 2-11: Sub-Regions as a reflection of the APG shape and their respective constituent AMS

2.4.2 Generation Capacity Modelling

When designing generation capacity modelling, common assumptions about the generating units and technologies had to be made in sufficient detail to ensure reliable output. In parallel, the modelling had to be able to accommodate minimum data input from the AMS.

In the AIMS III, several considerations were made with respect to the generation capacity expansion modelling. First, current and planned generation capacity (only firm or committed plans) in each of the AMS was respected. It was based on the planned year of commissioning as indicated in the PDP of the respective AMS or provided separately by the AMS.

Second, through the consultation meetings, a consensus was achieved that units with < 100 MW capacity were to be lumped together and segregated on the basis of node and technology.

Third, the commercial-operation-date (COD), technical life and retirement schedule for the existing units were based on the existing country's PDP and input from the AMS.

The techno-economic parameters of generating units, such as thermal capacity (net or gross), heat rate, maintenance rates, cost parameters, such as fixed, variable O&M costs, minimum up and downtime, start-up costs, ramp rates, build costs and fuel costs, were included in the model.

Apart from the above considerations, a key point relating to future generation capacity was that the optimisation of capacity expansion was made on an "economic" basis. In the AIMS

III, the narrative for promoting the clean energy transition was favoured, yet build decisions were made on the basis of economic expansion produced by the simulation tool (PLEXOS). By doing so, the simulation was able to determine that no particular thermal technology was favoured. The benefit of this approach was that the AMS received simulation results that were based purely on economics. This helped them formulate plans for future capacity additions while at the same time opening pathways to utilise cheaper energy from renewables.

2.4.3 Interconnection Capacity Modelling

The design of interconnection capacity modelling, as shown in the connecting line of each node in Figure 2-11, is usually made on the basis of several underlying considerations. In the AIMS III study, two common considerations were used. First, the existing, under construction and candidate transmission interconnections and their costing parameters for candidate transmission build (both HVAC over-land and HVDC under-sea) were included in the capacity expansion planning study. The capacity of the candidate transmissions was co-optimised together with generation capacity expansion.

Secondly, the interconnections in the AIMS III were planned without any “capacity sharing” consideration. This means that the interconnections were built only for unilateral power transfer or export/import of generation (based on economics) and not for any capacity-sharing to the support reserve margin within either interconnected node.

These two common considerations are typical in the integrated or interconnected models related to interconnection capacities. They are included to reflect the real-world decision-making.

2.5 Grid Modelling Approach for Grid Analysis

Besides the use of reduced network models to conduct generation capacity expansion and interconnection optimisation, as described in the previous section, a modelling approach for the APG was necessary to conduct grid analysis to ensure that the needed modelling had adequate detail to represent the country-level grid network in each AMS, while tackling data inadequacies and data restrictions. In the AIMS III, the design of the APG was made primarily on the basis of national grid data availability, geographical structure and grid size.

2.5.1 Approach I – Reduced Transmission Equivalent Model

Under the approval of the AMS, the APG system modelling was made using PSS/E software.[16] This approach was applied to Peninsular Malaysia, Lao PDR, Myanmar, Java and Sumatra. Either a PSS/E or equivalent software network model was reduced to an equivalent model retaining the transmission networks with the highest and second highest voltage. The downstream network was represented as equivalent. Generation and load connected to an Extra High Voltage (EHV) network were connected at their actual bus location. However, load and generation connected at lower voltages were lumped to the nearest EHV bus. For a few

[16] Siemens. **PSS/E software.** https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/pss-software.html

countries, including Myanmar, Peninsular Malaysia and Lao PDR, where the voltage level was being upgraded to a higher voltage, the model represented two voltage levels.

2.5.2 Approach II – Nodal Equivalent Model

The nodal equivalent model approach was adopted to model geographically compact countries with little shareable grid models data. The generation and load data were taken from Phase 1 capacity expansion planning studies, but information about the future transmission lines was limited. This was applied to the entire AMS or regions therein such as Sarawak and Sabah. The nodal equivalent model approach was also applied for small regions, such as the Kalimantan subsystem, in terms of installed base/load.

In this approach, depending on the structure of the grid in an AMS, a single or multiple node(s) equivalent model was developed by lumping the equivalent load and generation at each node. The equivalent generation was segregated by fuel type. The technology-wise segregation was made to ensure that appropriate dynamic models could be represented for generator controls.

2.5.3 Approach III –Multiple-Area/Multiple Region Equivalent Model

This approach was applied for large AMS like Thailand and Vietnam, that have national grids which are geographically divided into multiple sub-areas/sub-regions such as northern, central and southern. Hence, for these two AMS, the grid modelling at the national level was represented by one or two buses of the highest voltage level for each area in the country. The total generation and load in these areas were lumped together at an area node. The equivalent generation at each node was segregated by fuel type. The inter-area transmission at the national level was modelled on the basis of information provided by the AMS. When information on future transmission plans was not available, the existing inter-area transmission corridors were upgraded with additional circuits, ensuring the transmission corridors could secure the load growth and generation additions.

2.6 Modelling Limitation

The APG grid modelling in the AIMS III study was designed at the detail level which it could explore and investigate cross-border transmission level analysis, where from that point, it can capture what needed the directions from the AMS regarding their future policy view and the technologies adoption. It should be understood that the modelling and the analysis were initiated on the standpoint of what the AMS could share in terms of the materials for the study. Meaning, the simulation task depended on data availability, the AMS' acceptance regarding the study outcome and the agreed level of detail. Throughout the series of consolidation among the AMS, the AIMS III study was exercised at high-transmission level observation. The resulting grid performance analyses were bound under several limitations. The study did not account for the specific situation such as low operating reserve, high ramp periods and minimum netload – understandably these conditions occurred at microscale, a distributional level phenomenon that could capture little effect at the interconnection level. Sections 2.5.1 to 2.5.3, which briefly describe the modelling approach adopted in the AIMS III, are presented to consolidate the above point of view (the limitation) and the limited data that could be shared by the AMS, and how we had to address the study in a way such that the AIMS III output could still showcase acceptable results.

3 Study Results

The findings of the AIMS III focus essentially on updating the cross-border interconnections among the AMS, taking into account various aspects relevant to the specific scenarios discussed in turn. Although the primary driver of these aspects has always been attributed to the electricity demand tracks, to some extent, driving forces are the region's overall economic transformation, major industrial activity, rising per capita income and novel technology applications in the industrial, agriculture and transportation sectors. These are all country specific and therefore vary from country to country.

However, as shown in this chapter, even though the distribution of the economic benefits resulting from the interconnections is likely to be uneven among the AMS, depending on the situation of their national power growth, location and position with respect to its RE potential, the total economic benefits of the power grid interconnections are clear. Each APG interconnection is technically viable and will be capable of accommodating higher VRE capacity to achieve the AMS' NDC initiatives as well as the regional target of a 23% RE share by 2025.

In this chapter, the results of each scenario – Base Scenario (Section 3.1), Optimum RE Scenario (Section 3.2), ASEAN RE Target Scenario (Section 3.3) and High RE Target Scenario (Section 3.4) -– are presented. Section 3.5 offers a comparative illustration of all of the scenarios in terms of system installed capacity, production and operations costs, VRE installation mix, total system cost and grid performance analysis results.

3.1 Results for the Base Scenario

The ASEAN region's projected growth in electricity demand corresponds to the region's overall economic development. All of the AMS and end-use sectors have seen rapid growth in energy demand in recent years, particularly since 2005.[17] Despite the presence of the Covid-19 pandemic, this trend is expected to continue until 2040 in conjunction with growth in the region's GDP and population.

The Base Scenario adopted the AMS' existing Power Development Plan (PDP)[18] with uncommitted gas and coal-based thermal power plant projects that are re-optimised. It requires a direct continuation of the ongoing PDP without aggressive adoption of RE policies and technologies. This will affect the future of installed capacity additions, total system costs, potential avoided emissions and eventually the landscape of cross-border interconnections.

3.1.1 Future Capacity Expansion

3.1.1.1 Regional Projection

In 2025 under the Base Scenario, the ASEAN region falls far short of the RE target, with RE accounting for only 13.6% of the TPES.[19] In the power sector, this translates to an RE installed

[17] ACE (2020). **The 6th ASEAN Energy Outlook.**
[18] The "existing" PDP released before October 2020. The draft of Vietnam's PDP 8 will be included in Phase 3 of the AIMS III.
[19] ACE (2020). **The 6th ASEAN Energy Outlook.**

capacity attainment of only 32%: solar (6% - 19.3 GW), wind (2% - 6.5 GW), hydro (20% - 62.5 GW), bioenergy (1% - 3.5 GW) and geothermal (3% - 8 GW). Assuming there will be no further improvement in policy and technology adoption up to 2040, the shape of the installed capacity mix will be as shown in Figure 3-1.

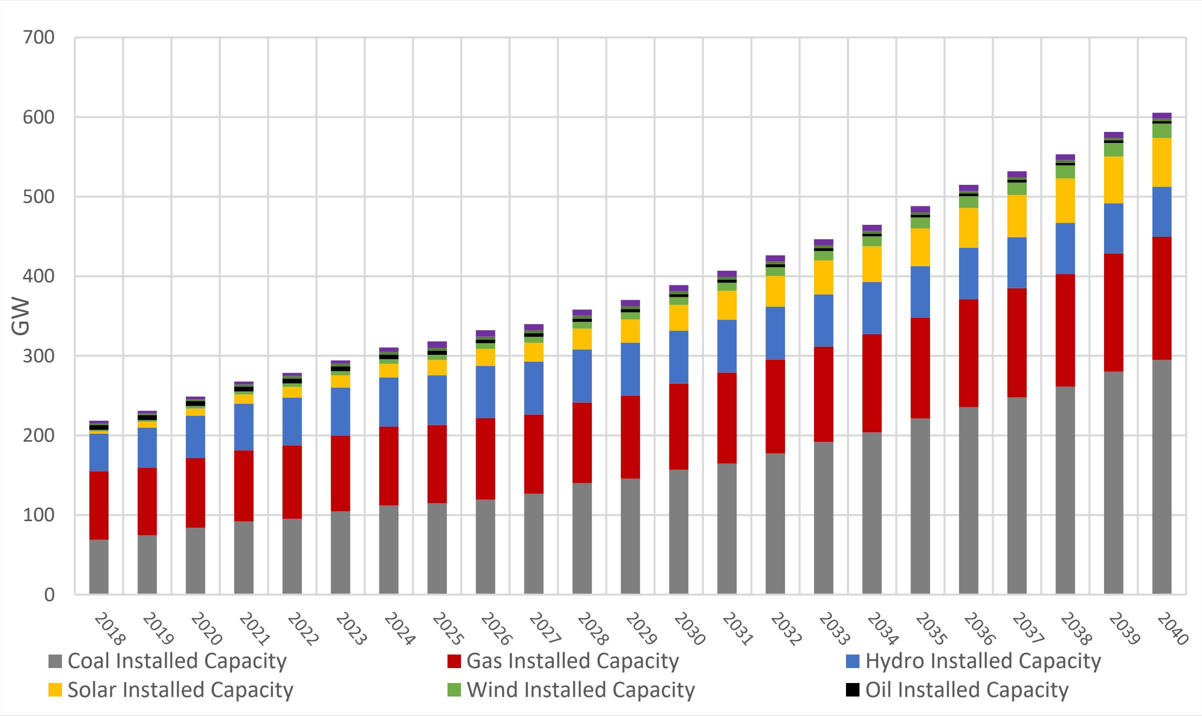


Figure 3-1: Projection of installed capacity (GW) under the Base Scenario at the ASEAN regional level

Table 3-1 shows the projection of installed capacity mix in the highlighted years of 2025 and 2040 for each type of technology under the Base Scenario at the ASEAN regional level. Generation is largely dominated by coal and gas-based generation, with a total VRE capacity of ~81 GW by 2040.

The peak demand in 2040 is forecasted to be about 412 GW. Under the current technology landscape, the total required installed capacity in 2040 reaches 606.7 GW. As mentioned earlier, the Base Scenario adopts the existing PDP of each AMS with non-committed gas. Coal-based thermal power plants are re-optimised. The study found that coal capacity will increase from 84 GW in 2018 to 295 GW in 2040. Gas capacity increases from 87.3 GW in 2020 to 155 GW in 2040. Hydro, natural gas and coal will dominate power-generation mixes in the region, with some notable countries disproportionately reliant on coal.

The AIMS III found that the total VRE installed capacity in 2018 was 4.5 GW, with solar at 2.5 GW and wind at 2 GW. By 2040 it is projected to reach ~79.4 GW, with solar at 19.2 GW in 2025 and 62.4 GW by 2040, and wind at 6.5 GW in 2025 and 17.9 GW by 2040. If the use of coal and gas in the power sector expands, there is still a clear possibility for the AMS to incorporate some use of wind and solar. Note that the total VRE installed capacity figures were received from the AMS.

Table 3-1: Projection of installed capacity in ASEAN by Technology under the Base Scenario

Technology	2018 GW	2025 GW	2040 GW
Coal	68.9	114.8	294.8
Gas	86.0	98.4	154.7
Hydro	47.5	62.5	62.9
Solar	2.5	19.3	62.4
Wind	2.0	6.5	18.0
Oil	5.8	5.3	3.3
Bioenergy	2.1	3.7	3.1
Geothermal	3.5	8.1	7.5
Grand Total	**218.5**	**318.4**	**606.7**

Although the progress towards using more VRE in the region seems promising, it raises questions about the national-level strategies to achieve sustainability and carbon neutrality and how the AMS will source their energy. There is the serious concern that if large imports of thermal energy continue without more aggressive use of RE, the AMS' national energy security will be compromised. Moreover, with major cities across the region experiencing rapidly deteriorating air quality, the AMS should devote more time to managing the growing energy demand and emissions from highly polluting power plants. The potentially avoided emissions at the ASEAN level under the Base Scenario are shown in section 3.1.3.

3.1.1.2 Regional Distribution

The North, South and East Sub-regions of the APG are shown in Figure 2-10. Power trading cannot occur without sufficient supportive infrastructure.[20] However, the APG efforts to date have focused primarily on infrastructure development, with market arrangements being organised only on a bilateral basis.[21]

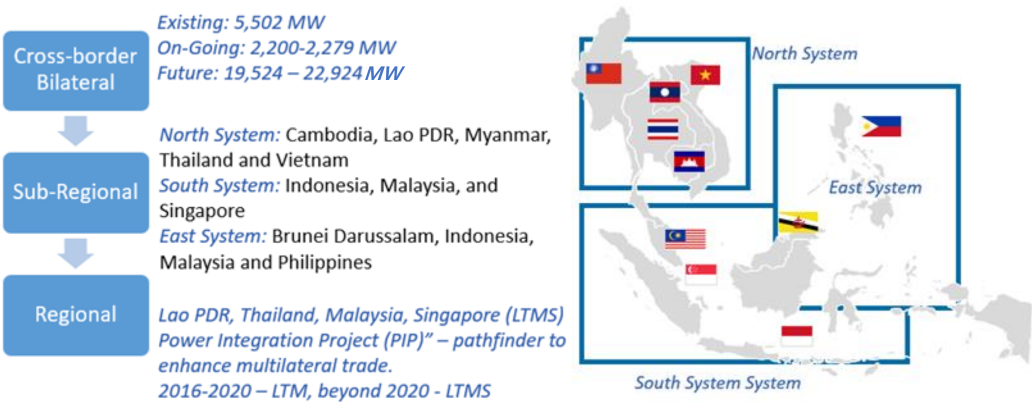


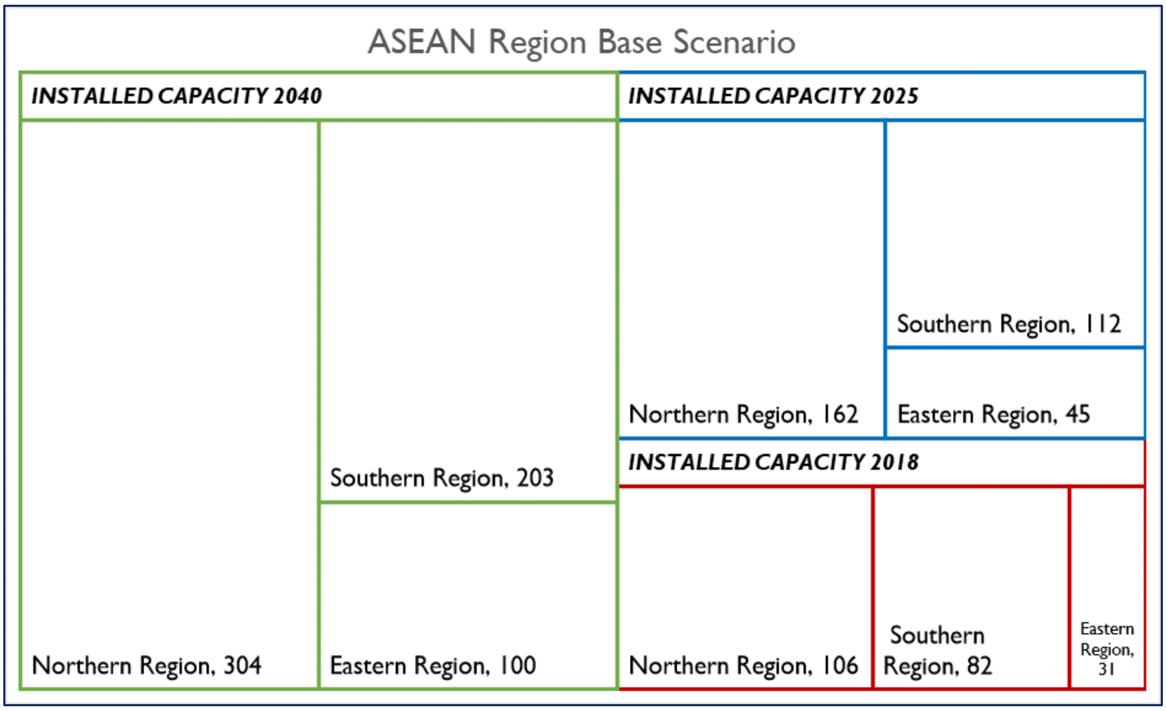
Figure 3-2: Progress line on the establishment of the APG to date

[20] ACE. (2020). **ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021 - 2025.**
[21] IEA. (2019). **Establishing multilateral power trade in ASEAN**.

Nevertheless, there is strong evidence that it will be possible to realise the full scale of the APG and fully functioning multilateral power trading. A simplified illustration regarding the progress of the establishment of the APG is shown in Figure 3-2.

By depicting the readiness of each sub-region to embrace multilateral power trade, Figure 3-2 shows that the design of the APG must be viewed initially at the sub-regional level. The distribution of the future capacity can be seen and reveals the potential scale of each sub-region before being merged into a single region.[22]

Figure 3-3 shows that of the three sub-regions under the Base Scenario, the Northern Region was the largest in 2018, and is projected to remain so in 2025 and continue so until 2040. In 2018 it had 48-50% of the total ASEAN installed capacity. The Southern part was the next largest sub-region with about 34-37% of the total ASEAN installed capacity. In the projections to 2040, the proportion of installed capacity in each of the sub-regions is not expected to change significantly.



Note: The numbers in each box are the installed capacity (GW).

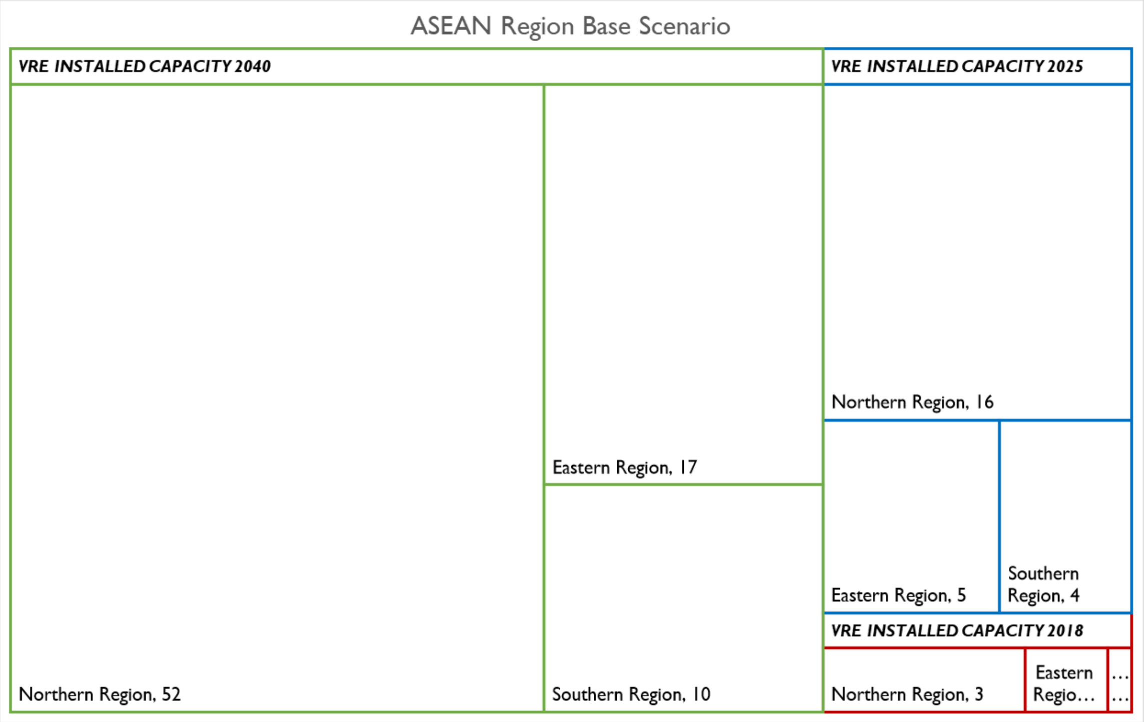
Figure 3-3: Proportion of ASEAN installed capacity in GW under the Base Scenario by Sub-regions

The proportion of VRE installed capacity in each sub-region under the Base Case Scenario is illustrated in Figure 3-4. It shows that by 2040, the northern region will be the VRE powerhouse in ASEAN. The South Sub-region is the next largest, while the Eastern Sub-region has the least VRE installed capacity.

It is clear from Figures 3-3 and 3-4 that the Northern Sub-region will play an essential role in the success of the APG. Owing to its huge potential VRE capacity, it could serve a suitable

[22] A. M. Rose. (2017). **Improving the performance of regional electricity markets in developing countries: the case of the Southern African Power**. Massachusetts Institute of Technology.

place to pioneer the identification and resolution of issues that could affect cross-border electricity trading in the ASEAN region as a whole. Moreover, by looking at the APG progress-line illustrated in Figure 3-2, exemplified by the progress of the Lao PDR-Thailand-Malaysia Power Integration Project (LTM-PIP), it is evident that construction of the APG is already on the right path. Indeed, the LTM-PIP could catalyse the existing efforts towards realising the full APG and the ASEAN Economic Community (AEC) by creating opportunities for electricity trading with ASEAN's neighbouring countries.

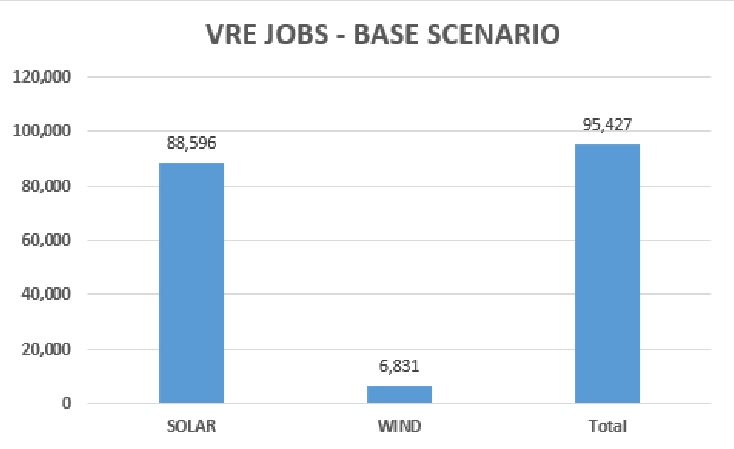


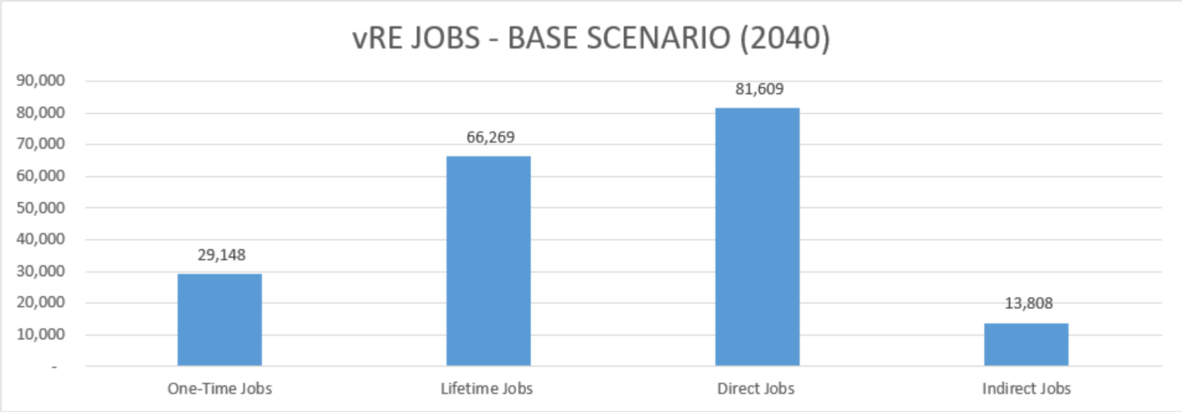
Note: The numbers in each box are the installed capacity (GW). The total VRE Installed Capacity in 2018 for the Northern Sub-region is 3 GW, 315 MW in the Southern Sub-region and 1.2 GW in the Eastern Sub-region.

Figure 3-4: Proportion of VRE installed capacity under the Base Scenario categorised by Sub-regions

3.1.2 Jobs Created by VRE

The AIMS III Report also looked at the macro-economic effects of the APG, namely VRE job creation through capacity expansion. In the Base Scenario, a significant amount of VRE capacity will be added between now and 2040: 61.4 GW solar and 17.9 GW wind power.





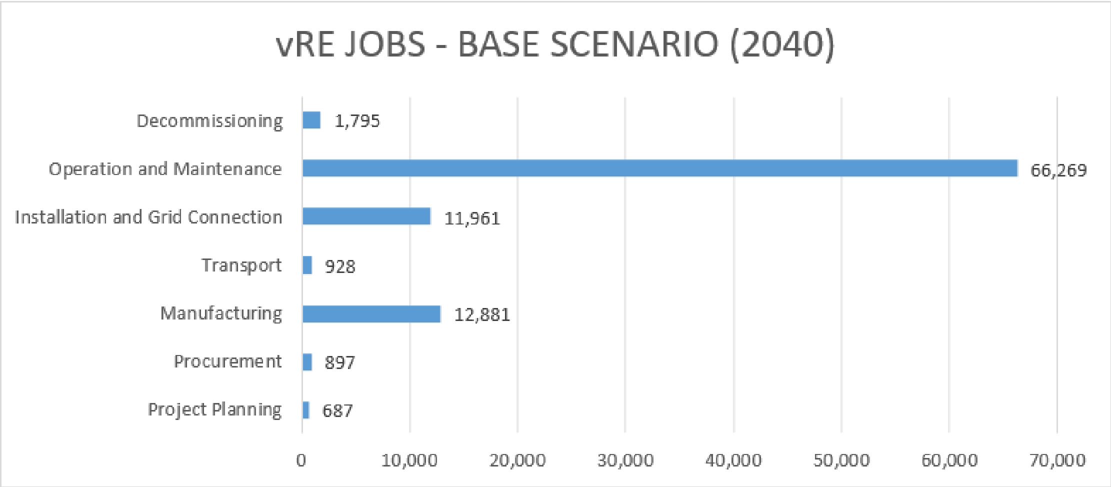


Figure 3-5: VRE Jobs created in the Base Scenario - ASEAN Region

Under the Base Scenario, 88,596 solar jobs and 6,831 wind jobs will be created by 2040, of which 30.5% of the total are categorised as one-time jobs and 69.5% are lifetime jobs. It is also estimated that 85.5% of the total solar and wind jobs will come from direct jobs and 14.5% from indirect jobs. As shown in Figure 3.5, the largest portion of job creation comes from operation and maintenance (O&M). The Base Scenario estimated 66,269 O&M jobs will be created.

3.1.3 Avoided Emissions

The AIMS III study also provides an environmental assessment, notably in terms of avoided emissions. As each scenario has a different degree of VRE projected deployment, the avoided fuel consumption and corresponding avoided CO_2 and N_2O emissions for each scenario can be assessed. This assessment follows the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National GHG Inventories Tier I emission factors for bituminous coal, diesel oil and natural gas.

Under the Base Scenario, which reflects the current PDP of the AMS, it is estimated that 30.1 Mt of coal, 1.4 Mt of oil and 17,524 million m^3 of natural gas consumption will be avoided through VRE projected generation by 2040. Consequently, 67,582 Mt of CO_2 and 36 thousand tons of N_2O emissions will be avoided by 2040.

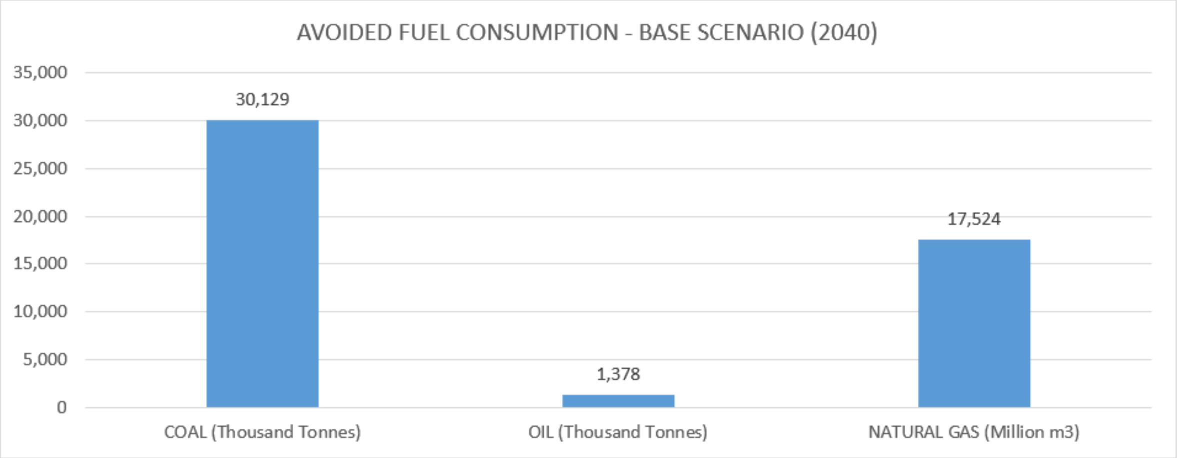


Figure 3-6: Avoided Fuel Consumption in 2040 for Base Scenario - ASEAN Region

Table 3-2: Avoided Emissions in 2040 for Base Scenario - ASEAN Region

Technology	CO_2	N_2O (in CO_2 eq.)
	Million Tons	Thousand Tons
Coal	43,353	34
Oil	2,460	1
Natural Gas	21,769	1

3.2 Results from the Optimum RE Scenario

The Optimum Scenario explores a possibility that the AMS respect their committed power projects in the current PDP, but the non-committed thermal power projects, VRE and APG interconnections are re-optimised on the least-cost economic optimisation principle.[23] The Optimum Scenario investigates the consequences if the AMS explore an alternative scenario in which new thermal capacity, VRE and interconnections are optimised in future expansion.

3.2.1 Future Capacity Expansion

3.2.1.1 Regional Projection

Under the Optimum RE Scenario, generation capacity expansion analysis produces optimised additions of coal, gas and VRE (wind and solar) capacity to maintain system reliability and optimised interconnection capacity. All other technology additions (such as hydro, bioenergy and geothermal) are treated as firm additions or fixed plans. The committed power projects (those which already have a PPA and are under construction) are also respected and treated as fixed plans. The target for this scenario is to develop optimised thermal, VRE and inter/intra-country exchange projections.

Figure 3-7 provides the projection of generation capacity by technology at the ASEAN level, resulting from the Optimum RE Scenario.

[23] “Optimisation which seeks to aim for least cost of OPEX and CAPEX of power plant expansion and retirements”, PLEXOS Energy Exemplar.

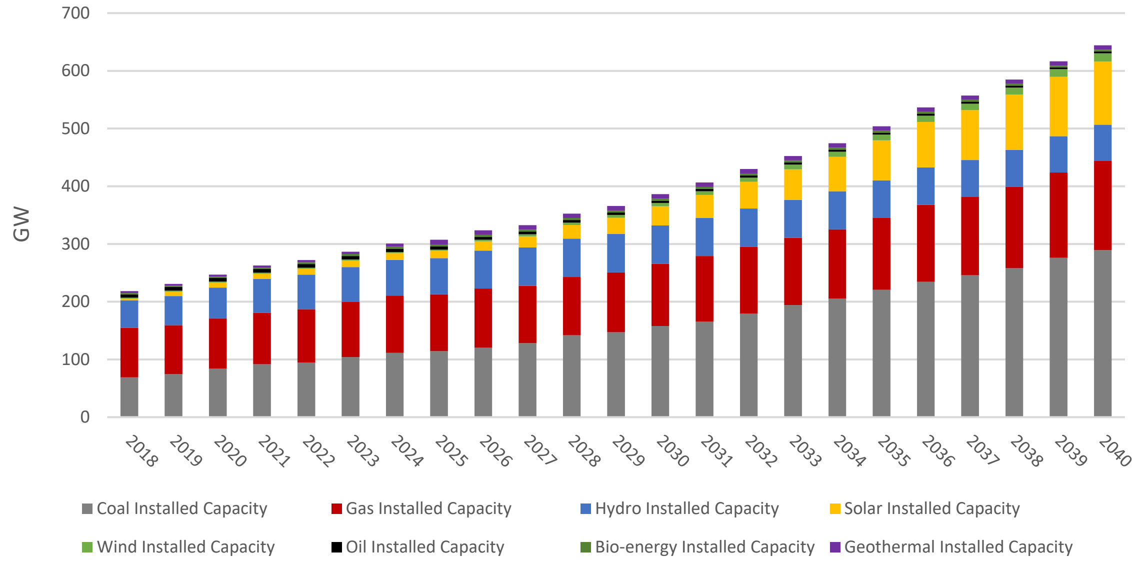


Figure 3-7: Aggregated installed capacity (GW) under the Optimum RE Scenario at the ASEAN level

Table 3-3 gives the capacity mix projection from the Optimum RE Scenario at the ASEAN regional level. It is dominated by coal- and gas-based generation, with a total VRE capacity of ~124 GW by 2040.

Table 3-3: Projection of capacity in ASEAN by technology under the Optimum RE Scenario

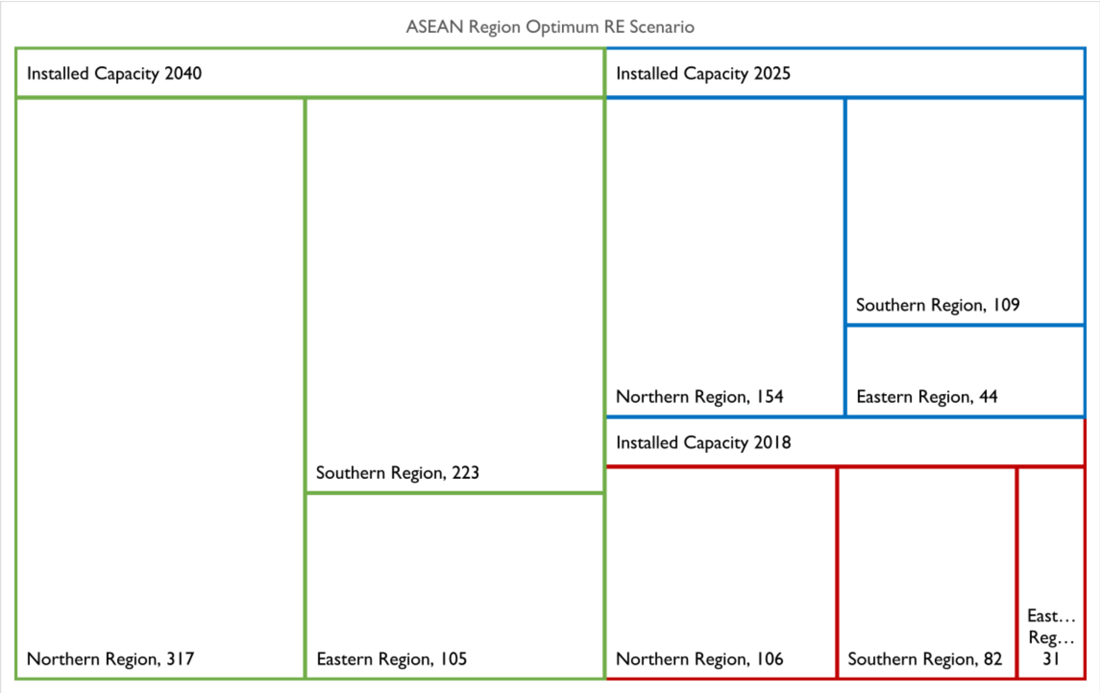
Technology	2018 GW	2025 GW	2040 GW
Coal	69	114	289
Gas	86	99	155
Hydro	47	62	63
Solar	3	13	109
Wind	2	2	14
Oil	6	5	3
Bioenergy	2	4	3
Geothermal	4	8	8
Grand Total	**218**	**307**	**644**

To meet the ASEAN peak demand of 412 GW in 2040, the total capacity required will be 644.2 GW. Under this scenario, it is found that the coal capacity increases from 69 GW in 2018 to 289 GW in 2040, while the gas capacity rises from 86 GW in 2018 to 155 GW by 2040. Coal and gas power plants dominate the power-generation mix in the region, but hydro and solar plants will contribute a significant portion.

Under the Optimum RE Scenario, as much as 123.6 GW of VRE can be economically integrated into the grid in 2040, comprising 109.4 GW solar and 14.2 GW wind. The estimation is much higher than the capacity addition planned in the Base Scenario.

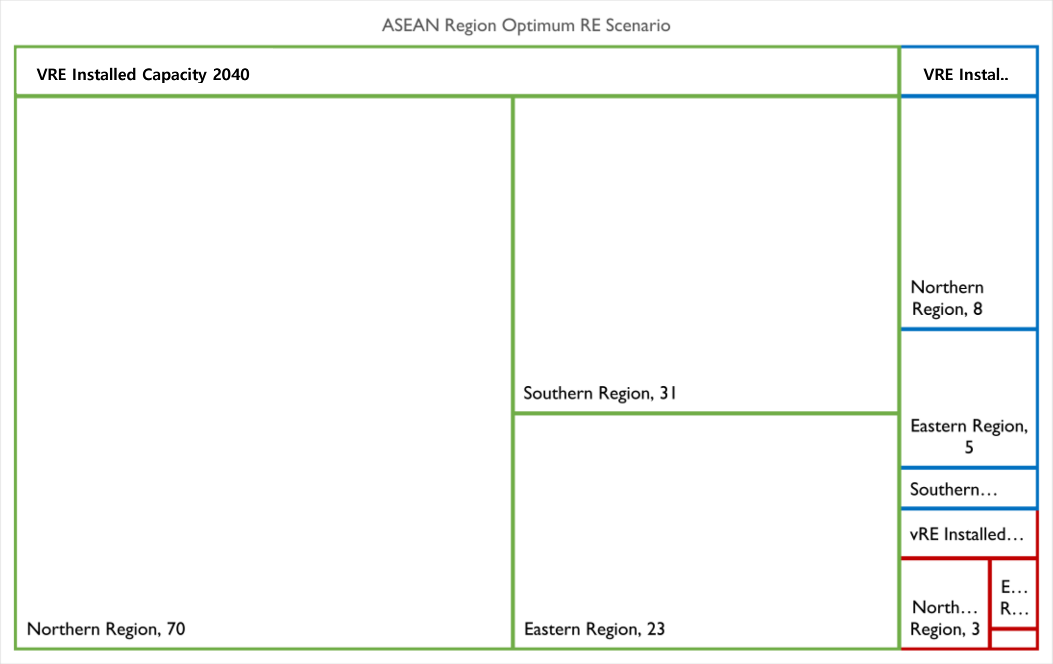
3.2.1.2 Regional Distribution

Figure 3-8 shows the division of capacity among the three sub-regions in the Optimum RE Scenario. The Northern Sub-region is the largest sub-region and has an installed capacity base of 48%-50% of the total ASEAN capacity. The South Sub-region is the next largest with 35%-37% of the total ASEAN installed capacity. The Eastern Sub-region has a 14%-16% share over the study horizon. The proportion of installed capacity in the various sub-regions will not change significantly up to 2040.



Note: The numbers in each box are the installed capacity (GW). The total VRE Installed Capacity in 2018 for the Northern Sub-region is 106 GW, 82 MW in the Southern Sub-region and 31 GW in the Eastern Sub-region

Figure 3-8: Proportion of ASEAN installed capacity under the Optimum RE Scenario

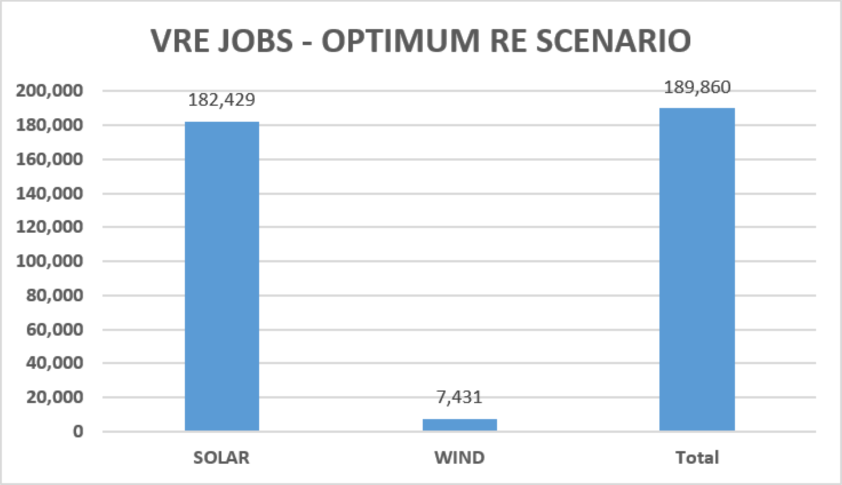


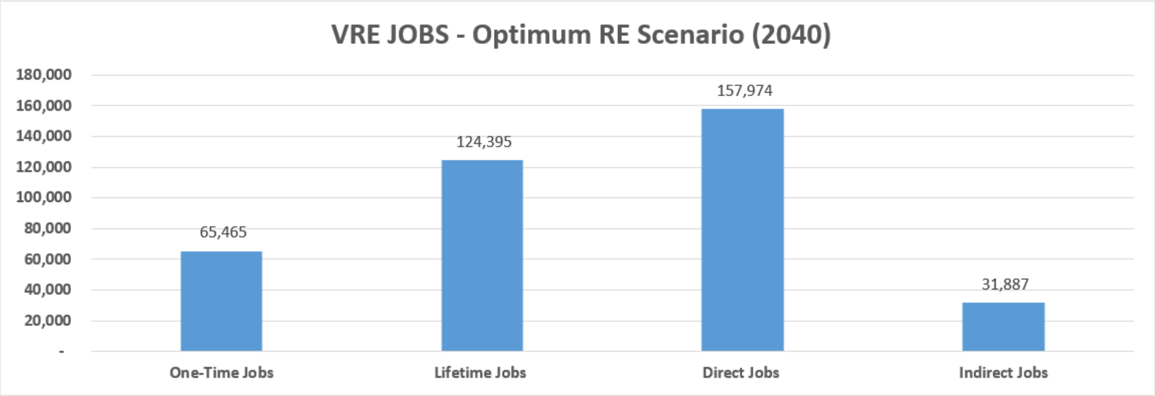
Note: The numbers in each box are the installed capacity (GW). The total VRE Installed Capacity in 2018 for the Northern Sub-region is 3 GW, 315MW in the Southern Sub-region and 1.2 GW in the Eastern Sub-region.

Figure 3-9: Proportion of VRE installed capacity under the Optimum RE Scenario categorised by the Sub-regions

3.2.2 Jobs Created by VRE

A significant amount of VRE capacity addition was estimated under the Optimum RE Scenario with a total of 109.4 GW solar and 14.2 GW wind power capacity in 2040.





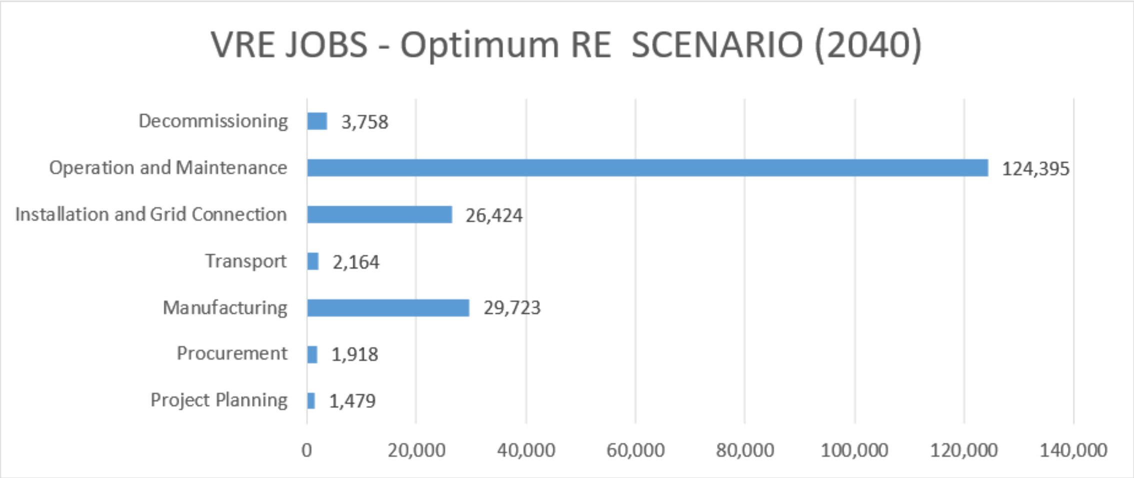


Figure 3-10: Jobs created by VRE in 2040 under the Optimum RE Scenario - ASEAN Region

Under the Optimum RE Scenario, it is estimated that 182,429 solar jobs and 7,431 wind jobs will be created by 2040. Of the solar jobs, there will be 60,534 one-time jobs and 124,395-lifetime jobs. An estimated 157,974 direct jobs and 31,887 indirect jobs will be created. As shown in Figure 3-10, the largest portion of job creation is in operation and maintenance (O&M), with a total of 124,395 jobs.

3.2.3 Avoided Emissions

Under the Optimum RE Scenario, where thermal capacity and VRE generation are optimised, it is estimated that 53.1 Mt of coal, 4,1 Mt of oil and 22,960 million m^3 of natural gas consumption will be avoided due to the higher VRE generation by 2040. Consequently, 112,267 Mt of CO_2 and 64 thousand tons of N_2O emissions will be avoided by 2040.

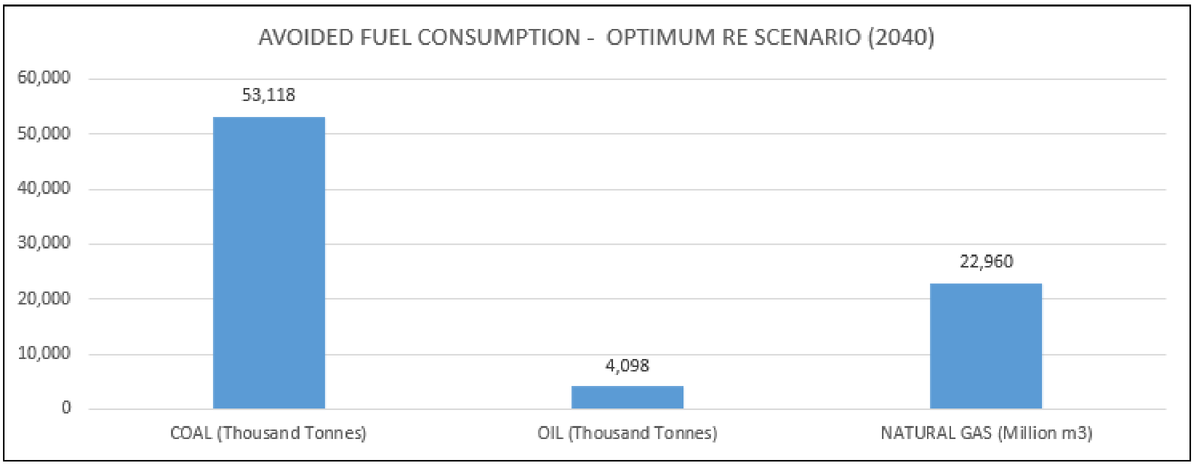


Figure 3-11: Avoided Fuel Consumption in 2040 under the Optimum RE Scenario - ASEAN Region

Table 3-4: Avoided Emissions in 2040 under the Optimum RE Scenario - ASEAN Region

AVOIDED EMISSIONS - OPTIMUM RE SCENARIO		
Technology	CO_2 (Million Tons)	N_2O (in CO_2-eq)
	Million Tons	Thousand Tons
Coal	76,432	60
Oil	7,314	2
Natural Gas	28,521	2

3.3 Results from the ASEAN RE Target Scenario

The purpose of this scenario is primarily to understand the consequences of the AMS achieving at least a 23% RE share in the TPES by 2025 as stipulated in APAEC Targets and how this might transform ASEAN's energy systems. It reflects at least a 35% RE share in installed capacity by deploying large-scale RE systems in the APG, increasing RE investments, and exploring new and emerging energy technologies such as hydrogen and fuel cells.[24]

In ensuring the RE target of at least a 23% share in the TPES by 2025, the AMS proposed specific RE targets. Table 3-5 summarises the ASEAN national targets of individual AMS.

[24] ACE. (2020). **ASEAN Plan of Action and Energy Cooperation (APAEC) Phase II: 2021- 2025**.

Table 3-5: Official Renewable Energy Targets of the 10 ASEAN Member States[25]

AMS	Official Targets
Brunei Darussalam	10% renewable energy share in installed power generation capacity by 2035
Cambodia	3% of residential electricity demand met by rooftop solar PV by 2035
Indonesia	23% RE in primary energy supply by 2025
	Biodiesel blending ratio target 30% by 2020 and maintaining that level through 2025 and to 2050
	20% bioethanol blending ratio target by 2025; 50% by 2050
Lao PDR	30% RE share of total energy consumption by 2025, including 20% of electricity from RE that is not large-scale hydro, and 10% biofuel share (blending ratio 5–10%)
Malaysia	20% RE in the power capacity mix by 2025 (excluding large-scale hydro)
Myanmar	12% share of RE in the national power generation mix by 2030 (excluding large-scale hydro)
Philippines	Triple RE installed capacity by 2030 from 2010 level to 15.3 GW from 5.4 GW
	Biofuel blending ratio around 2% for biodiesel and 10% of bioethanol
Singapore	350 MWp of solar capacity by 2020 and at least 2 GWp by 2030
Thailand	30% RE share in total final energy consumption (TFEC) by 2036, including15–20% renewable electricity in total generation; 30–35% of consumed heat from renewables; and a 20–25% biofuel share in TFEC
Vietnam	15 – 20 % RE share in TPES by 2030, 25-30% by 2050
	32% RE share in installed capacity by 2030 and 43% by 2050

As Table 3-5 shows, these ASEAN national targets (and consequently the VRE capacity additions) should be commensurate with the target of achieving at least a 35% RE share of installed capacity by 2025. To achieve this target, under the ASEAN RE Target Scenario, the AIMS III Working Group suggested that coal, gas and interconnection capacities (except the existing and committed) will be optimised, while the VRE capacities are provided as firm inputs in the capacity expansion planning to reflect the official RE targets of the ten AMS.

3.3.1 Future Capacity Expansion

3.3.1.1 Regional Projection

The ASEAN RE Target Scenario is expected to reflect the most optimum expansion related to the capacity additions for thermal generation and interconnections, assuming that the VRE (both wind and solar) levels are fixed as per the targets. Figure 3-12 provides the capacity expansion projection by types of generation or technology at the ASEAN Regional level for the ASEAN RE Target Scenario.

[25] ACE (2020). **The 6th ASEAN Energy Outlook.**

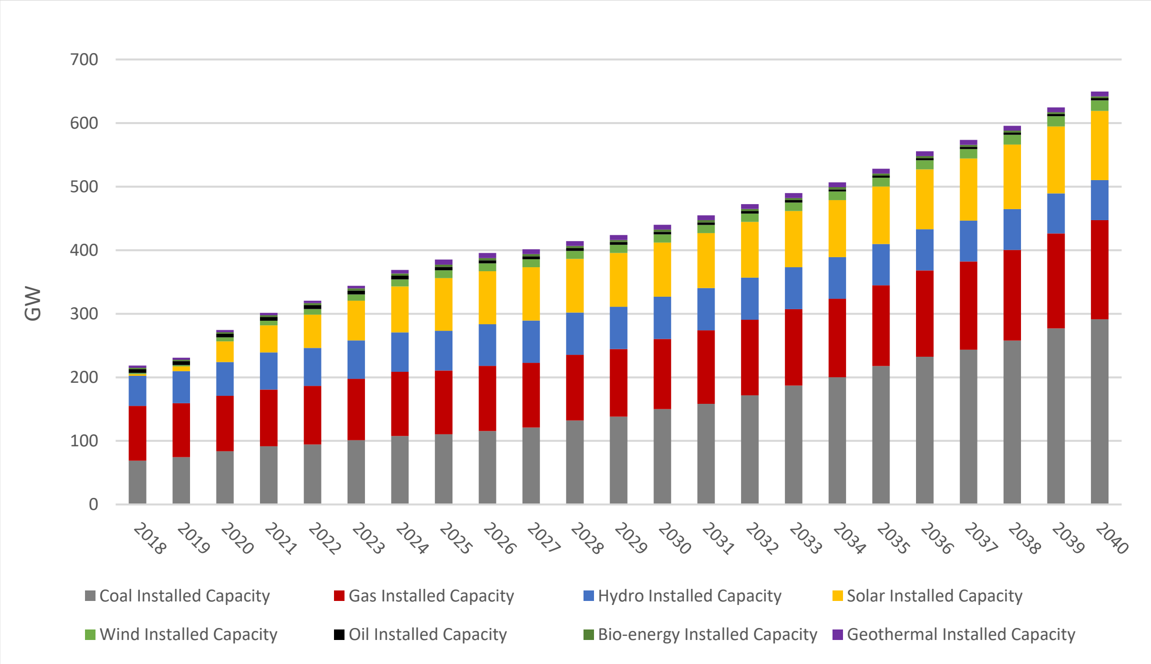


Figure 3-12: Projection of optimum capacity expansion for the ASEAN RE Target Scenario – ASEAN Region

Table 3-6 lists the installed capacity mix for all major generator technology types under the ASEAN RE Target Scenario at the ASEAN regional level. The capacity is primarily dominated by coal- and gas-based. Total VRE capacity is ~126 GW by 2040.

Table 3-6: Share of capacity by technology in ASEAN under the ASEAN RE Target Scenario (in GW)

Technology	2018	2025	2040
Coal	69	110	291
Gas	86	100	156
Hydro	47	62	63
Solar	3	83	109
Wind	2	12	17
Oil	6	5	3
Bioenergy	2	4	3
Geothermal	4	8	8
Grand Total	**218**	**386**	**650**

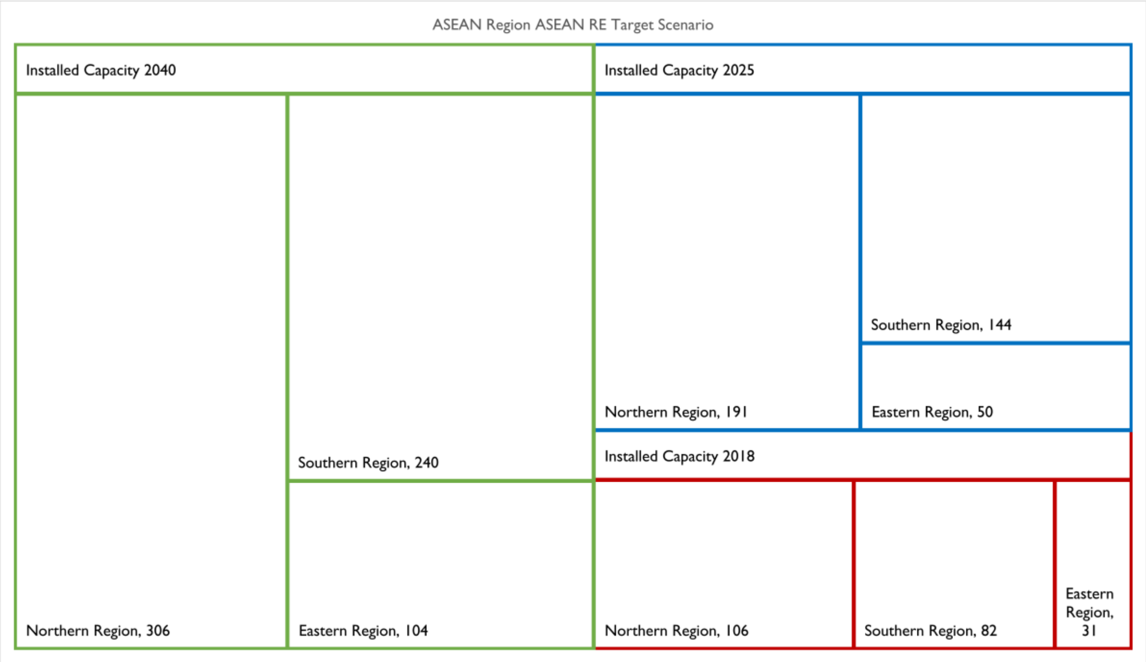
The study estimates that the region's total capacity in 2040 will be 649.5 GW to meet the demand. The required capacity is higher than in the Base and Optimum RE Scenarios. Higher thermal capacity additions would be required to meet the planning criteria of higher VRE integration from some notable countries. As mentioned earlier, the ASEAN RE Target scenario was adopted to achieve the regional RE target in the energy mix, in which the VRE capacity additions were those which had already been set in the countries' PDP. Under this scenario, it was found that the coal capacity increased from 69 GW in 2018 to 291.4 GW by 2040, whereas gas-based capacity rose from 86 GW in 2018 to 156 GW by 2040. Coal and gas plants were projected to dominate the power- installed capacity mixes in the region, and solar plants were to contribute a significant portion.

Under the ASEAN RE Target Scenario, the study found that the total installed capacity for VRE was projected to be 126 GW in 2040 with about 109 GW of solar and 17 GW of wind. The estimation is much higher than the capacity addition planned under the Base and Optimum RE Scenarios because more VRE installed capacity is added.

3.3.1.2 Regional Distribution

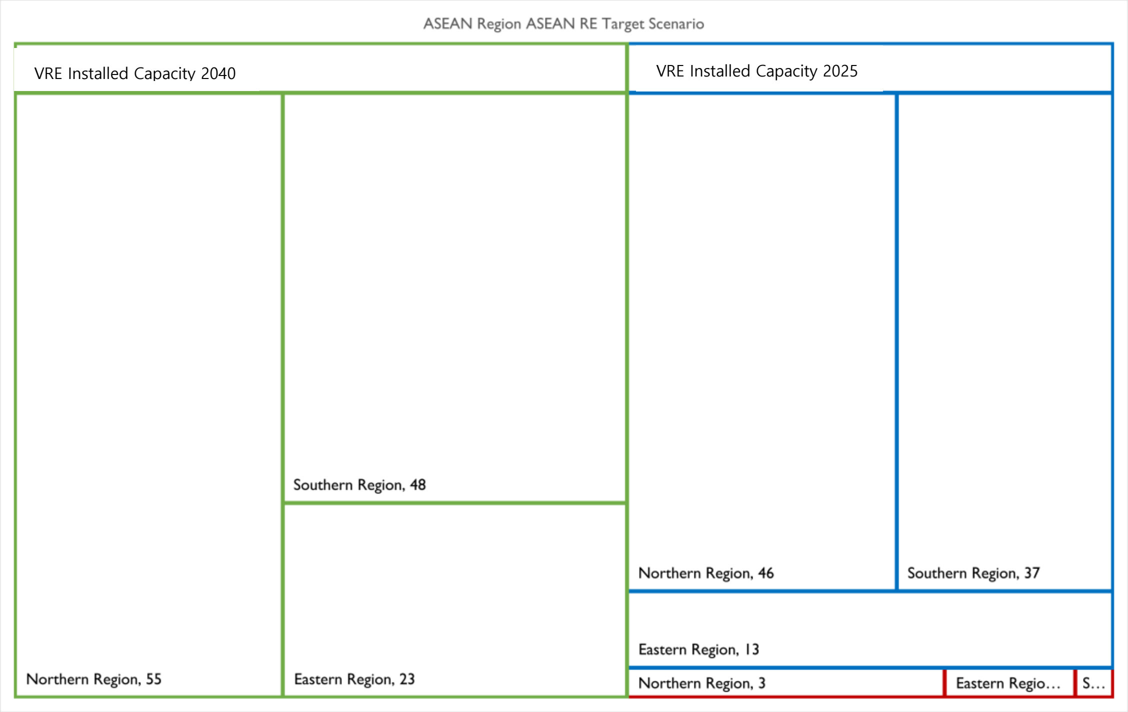
Figure 3-13 portrays the distribution of installed capacity among the three regions under the ASEAN RE Target Scenario. The Northern Sub-region, which is the largest, has an installed capacity base of 47%-50% of the total ASEAN capacity. The Southern Sub-region is the next largest and consistently has about a 37% share, followed by the Eastern Sub-region, which has a 13%-16% share over the study horizon. The proportions of installed capacity among the various sub-regions does not change significantly over the projections to 2040.

The proportion of VRE installed capacity in each sub-region under the ASEAN RE Target Scenario is also presented in Figure 3-14. As the Northern Sub-region is the largest in ASEAN, care must be taken due to its load concentration. This is discussed further in section 3-5.



Note: The numbers in each box are the installed capacity (GW).

Figure 3-13: Proportion of ASEAN installed capacity under the ASEAN RE Target Scenario categorised by the Sub-Regions

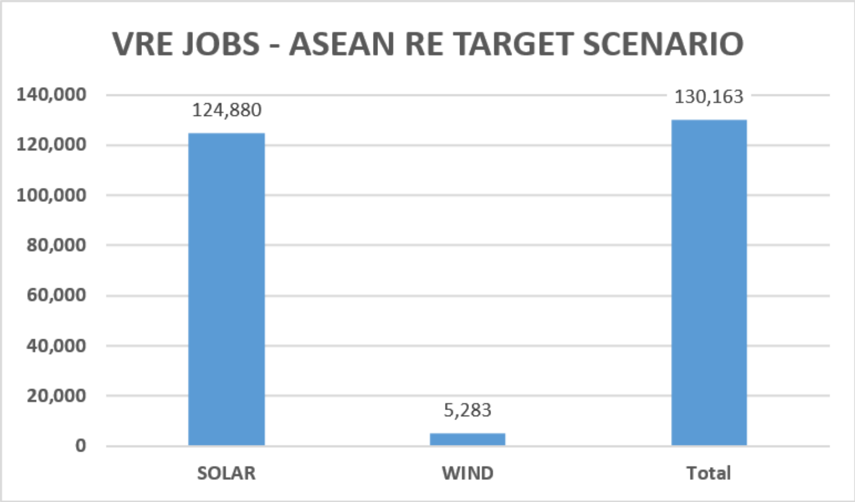


Note: The numbers in each box are the installed capacity (GW). The total VRE Installed Capacity in 2018 for Northern Sub-region is 3 GW, 315 MW in Southern Sub-region and 1.2 GW in Eastern Sub-region.

Figure 3-14: Proportion of VRE installed capacity under the ASEAN RE Target Scenario categorised by the Sub-Regions

3.3.2 Jobs Created by VRE

A significant amount of VRE capacity addition is projected under the ASEAN RE Scenario with a total of 109 GW of solar and 17 GW of wind power in 2040. Such large-scale deployment of solar and wind power capacities is likely to have socio- economic effects.



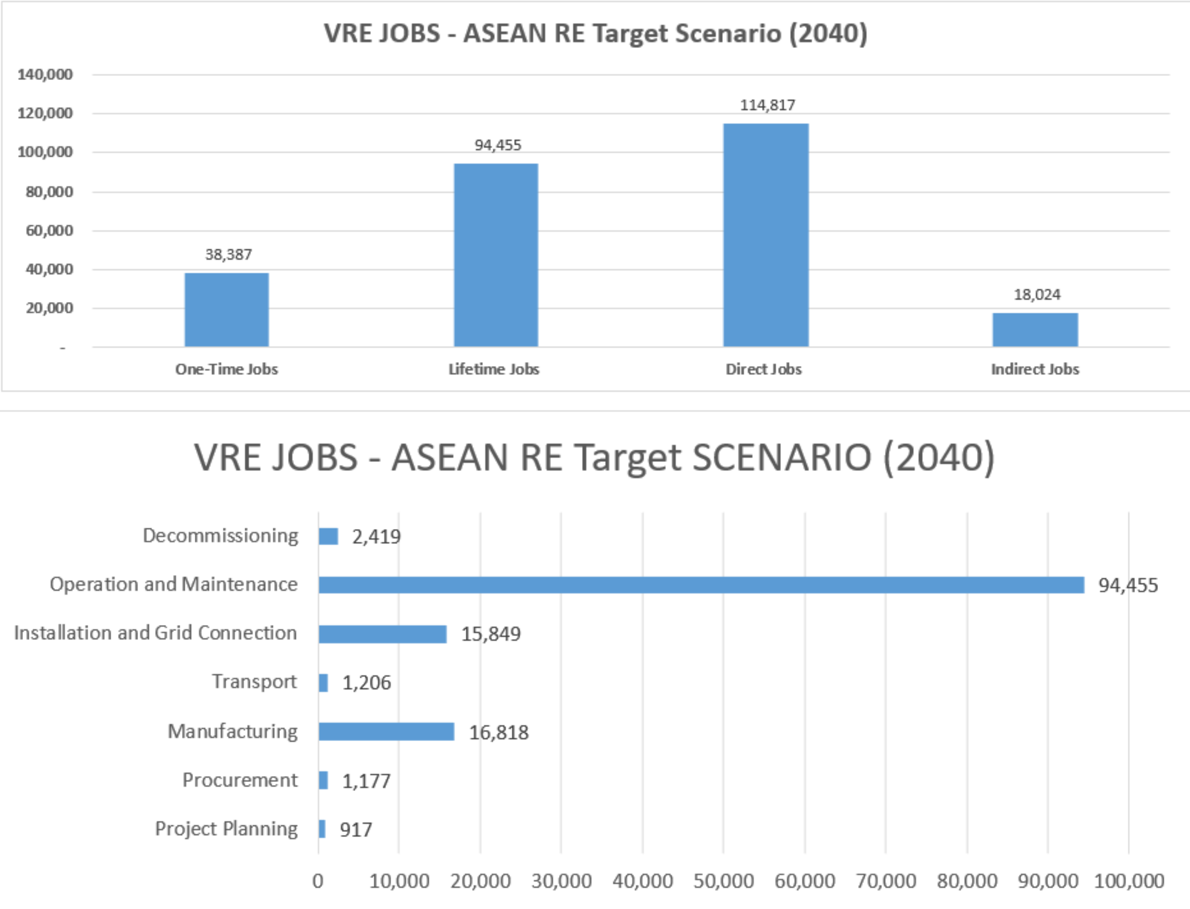


Figure 3-15: VRE Job Creation in 2040 for the ASEAN RE Target Scenario - ASEAN Region

The study estimated 124,880 solar jobs and 5,283 wind jobs will be created by 2040. It was also estimated that 35,709 one-time jobs and 94,455-lifetime jobs will be created from the total solar power expansion. There were also an estimated 112,883 direct jobs and 17,280 indirect jobs created. As shown in Figure 3-15, the most significant portion of job creation is in operation and maintenance (O&M). Under the Scenario, an estimated 94,455 O&M jobs will be created.

3.3.3 Avoided Emissions

Under the ASEAN RE Scenario, where the VRE generation is set to achieve the regional RE target, it is estimated that 48.8 Mt of coal, 2.1 Mt of oil and 13,607 million m^3 of gas consumption are avoided due to VRE projected generation by 2040. Subsequently, the ASEAN region could avoid 90,852 Mt of CO_2, and 57 thousand tons of N_2O emissions by 2040.

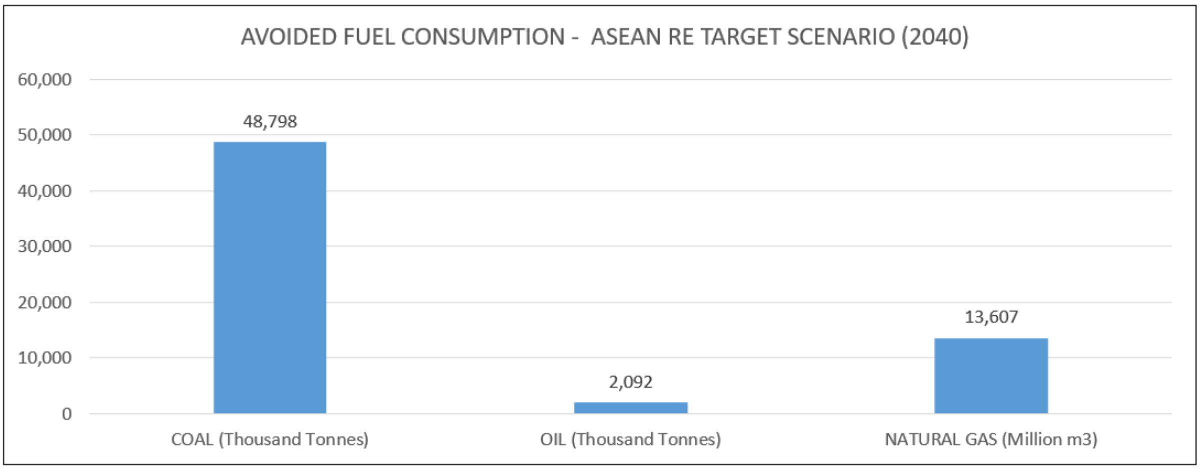


Figure 3-16: Avoided Fuel Consumption in 2040 for the ASEAN RE Target Scenario - ASEAN Region

Table 3-7: Avoided Emissions in 2040 for the ASEAN RE Target Scenario – ASEAN Region

AVOIDED EMISSIONS - ASEAN RE TARGET SCENARIO		
	CO_2	N_2O (in CO_2 eq)
	Million Tons	Thousand Tons
Coal	70,216	55
Oil	3,734	1
Natural Gas	16,902	1

3.4 Results from the High RE Target Scenario

The purpose of the High RE Target scenario in the AIMS III was to explore and understand the implications of ASEAN's setting of a much higher RE target. It differs from earlier scenarios in that some VRE capacity targets are fixed in capacity expansion planning, which is much higher than the targets specified in the ASEAN RE Target Scenario.

The VRE targets (and consequently the VRE capacity additions) are commensurate with the target of having 10%-12% of VRE in terms of energy by 2025, but for 2040 a much higher target than the ASEAN RE Target scenario is fixed at 25%-30%. In this scenario, coal, gas and interconnection capacities (except the existing and committed) are optimised, and VRE capacities are fixed as firm inputs.

The High RE Target Scenario yields optimum capacity expansion for thermal generation and interconnections, whilst the levels of VRE are fixed within the system as per the targets. In this scenario, the shares of VRE are much higher than the official regional targets and ambitious aspiration levels. However, it should be noted that in this High RE Target scenario, VRE is susceptible to curtailment, especially in the smaller countries with high VRE potential. It also needs higher interconnection capacity and would need more detailed analysis.

3.4.1 Future Capacity Expansion

3.4.1.1 Regional Projection

Figure 3-17 shows the projection of capacity expansion at the ASEAN level for the High RE Target Scenario.

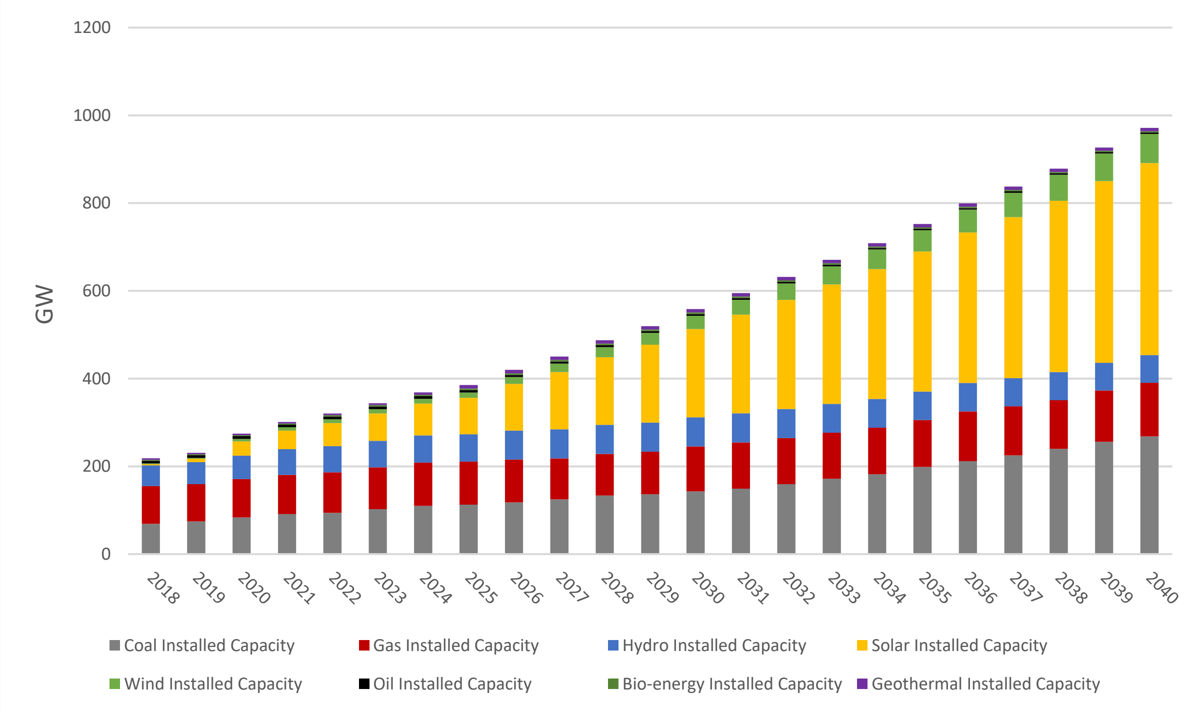


Figure 3-17: Projection of capacity expansion (GW) under the the High RE Target Scenario – ASEAN Region

Table 3-8 gives the capacity mix by technology for the High RE Target Scenario at the ASEAN level. The generation mix is dominated by VRE (largely solar), with a total VRE installed capacity of ~504 GW by 2040.

Table 3-8: Share of capacity by technology in ASEAN under the High RE Target Scenario (in GW)

Technology	2018	2025	2040
Coal	69	113	269
Gas	86	98	122
Hydro	47	62	63
Solar	3	83	438
Wind	2	12	66
Oil	6	5	3
Bioenergy	2	4	3
Geothermal	4	8	8
Grand Total	**218**	**386**	**972**

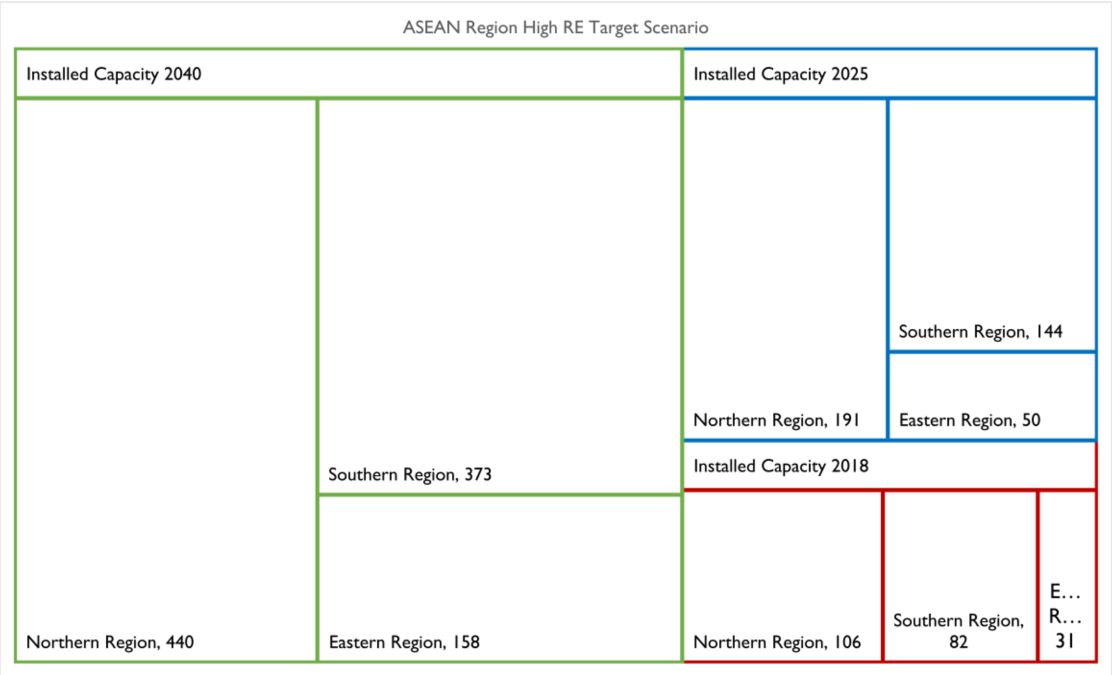
This High RE Target Scenario estimates that the region's total capacity in 2040 will reach 971.4 GW. The capacity of coal is projected to be 268.5 GW by 2040, an increase from 69 GW in 2018, whereas gas-based generation increases from 86 GW in 2018 to 122 GW by 2040.

As previously mentioned, the High RE Target Scenario has a higher aspiration level for VRE penetration at around 25%-30% in the power generation mix by 2040. In this scenario, the installed capacity is no longer dominated by coal and gas plants. Instead, the total generation for VRE is projected to be ~504 GW with about 438 GW of solar and 66.4 GW of wind. This VRE capacity is much higher than the capacity addition planned under the Optimum and ASEAN RE Target Scenarios.

Having an ambitious level of VRE will be useful for the AMS in setting its RE targets at much higher penetrations in their future generation capacity plans.

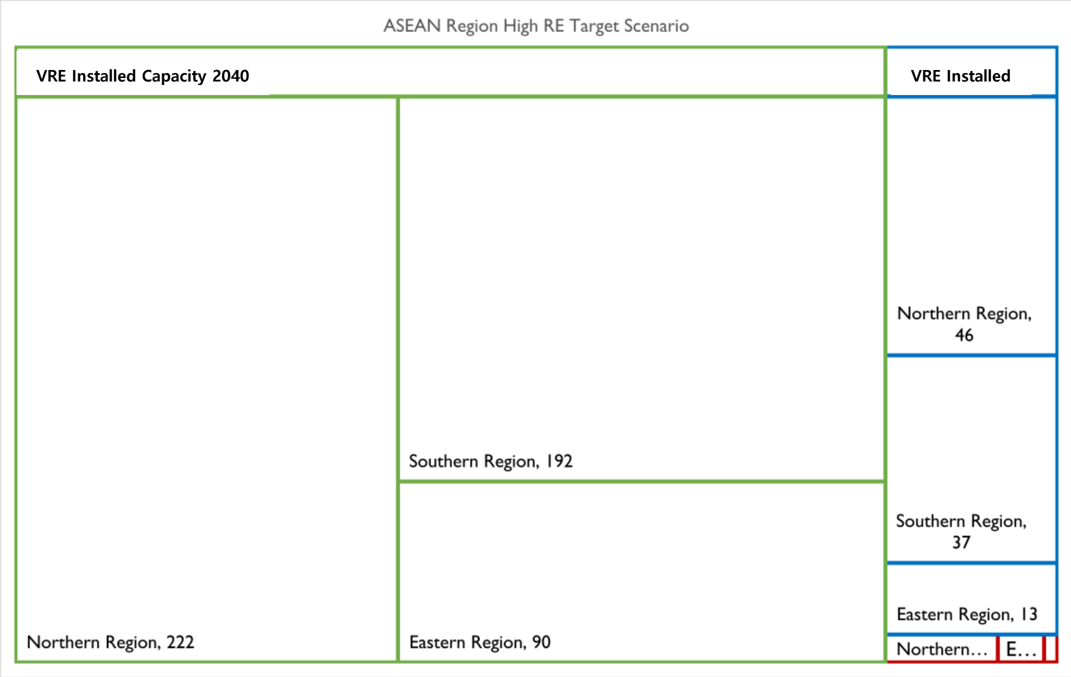
3.4.1.2 Regional Distribution

Figure 3-18 portrays the distribution of capacity among the three sub-regions under the High RE Target Scenario. The Northern Sub-region, which is the largest, has an installed capacity base of 45%-50% of the total ASEAN capacity. The South Sub-region is the next largest and consistently has about a 37%-38% share of the total ASEAN installed capacity. The Eastern Sub-region has a 13%-16% share over the study horizon. The proportion of VRE capacity under the High RE Target Scenario in each of sub-region is shown in Figure 3-19.



Note: The numbers in each box are the installed capacity (GW).The total VRE Installed Capacity in 2018 for Northern Sub-region is 106 GW, 82 MW in Southern Sub-region and 31 GW in Eastern Sub-region.

Figure 3-18: Proportion of capacity for the High RE Target Scenarioin ASEAN by sub-region



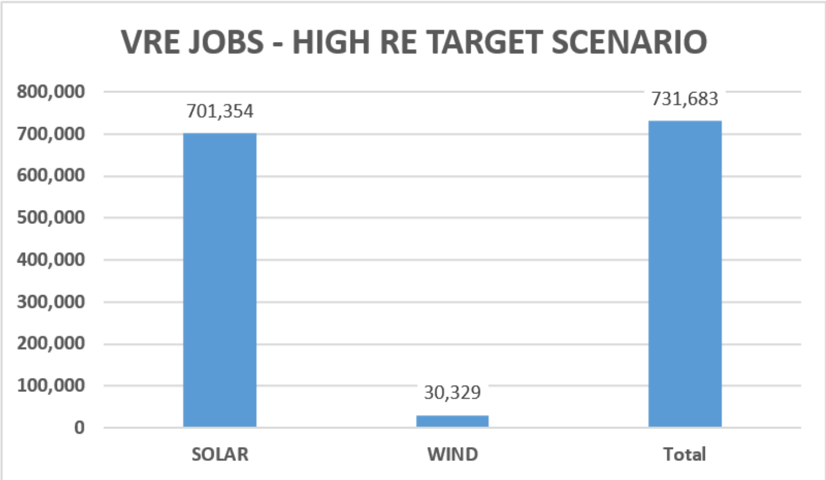
Note: The numbers in each box are the installed capacity (GW). The total VRE Installed Capacity in 2018 for Northern Sub-region is 3 GW, 315 MW in Southern Sub-region and 1.2 GW in Eastern Sub-region.

Figure 3-19: Proportion of VRE capacity in ASEAN for the High RE Target Scenario by sub-region

3.4.2 Jobs Created by VRE

An extremely high amount of VRE capacity was added in the High RE Target Scenario with a total of 438 GW of solar and 66.4 GW of wind power by 2040. Such extremely high deployment of solar and wind power is likely to have socio-economic effects.

The study estimates 701,354 solar jobs and 30,329 wind jobs will be created by 2040. It is also estimated that 227,865 one-time jobs and 502,067 life-time jobs will be created from the total solar and job creation. There are also an estimated 619,258 direct jobs and 110,674 indirect jobs created.



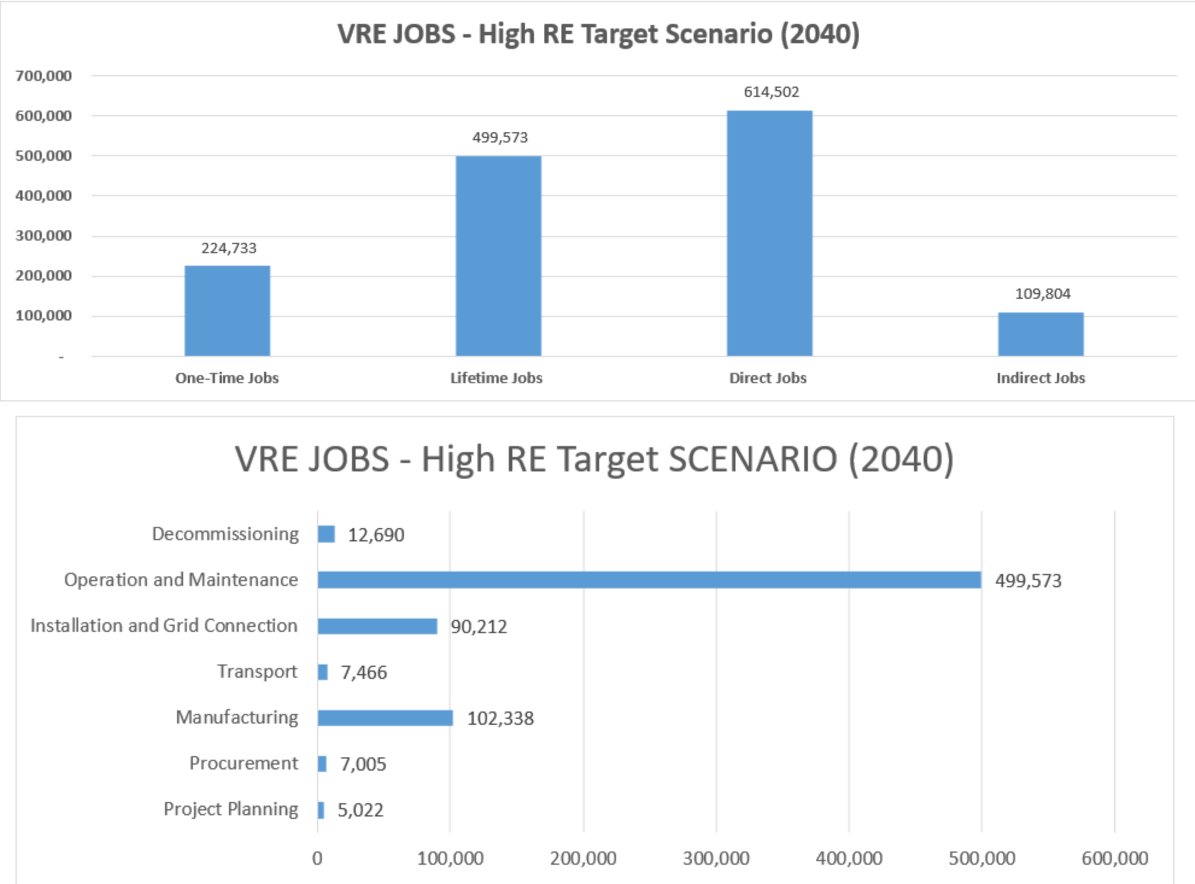


Figure 3-20: Job Creation by VRE in 2040 under the High RE Target Scenario - ASEAN Region

3.4.3 Avoided Emissions

Under the High RE Target Scenario where VRE generation has been set to a much higher aspiration level at 25%-30% in the generation mix by 2040, it is estimated that 255.9 Mt of coal, 11.2 Mt of oil and 76,628 million m^3 of gas consumption can be avoided. Under this very ambitious scenario, the ASEAN region could significantly reduce emissions. At least 483,408 Mt of CO_2 and 301 thousand tons of N_2O emissions could be avoided by 2040 in this scenario.

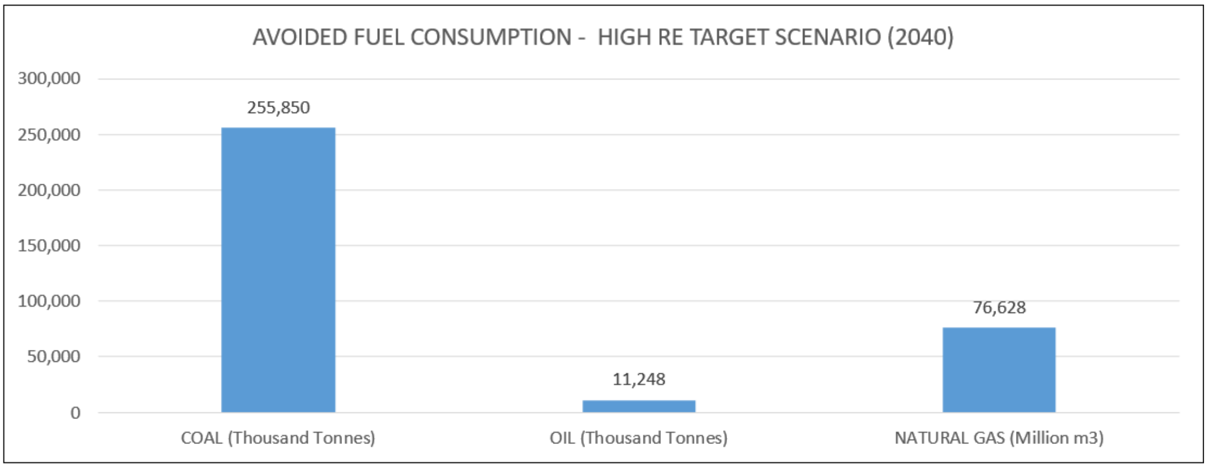


Figure 3-21: Avoided Fuel Consumption in 2040 under the High RE Target Scenario - ASEAN Region

Table 3-9: Avoided Emissions in 2040 for the High RE Target Scenario - ASEAN Region

	CO_2 (Million Tons)	N_2O (in CO2 eq)
	Million Tons	Thousand Tons
Coal	368148	290
Oil	20073	5
Natural Gas	95187	6

3.5 Comparative Illustration from All Scenarios

The underlying motivation behind establishing the APG is to enhance cross-border electricity trade by interconnecting the national power grids effectively and reliably. This motivation was clearly expressed in the AIMS II. However, when designing this AIMS III study, the emergence of lower-cost VRE exposed a need to reconsider the design of the APG to take into account the emerging new power resource technologies, which are wind and solar. The ongoing declining costs of wind and solar globally has led many policymakers and the energy industry to look into using VRE to gradually replace the already existing and planned thermal power plants.

Reshaping the purpose of the APG, the goal of the AIMS III report now is to advocate regional energy security through the redesigned APG by unlocking more RE growth, including solar energy, wind energy, hydropower, geothermal and biomass, for the economic and environmental benefit of the ASEAN region.

The four scenarios as reported in sections 3.1, 3.2, 3.3 and 3.4 offer future projections of four different policy and technology options The following section compares the key results of the four scenarios, mainly in terms of capacity expansion and interconnection capacity in the years 2025, 2030, 2035 and 2040.

3.5.1 Capacity Expansion

Figure 3-22 compares the four scenarios' capacity mix for the representative years. The amount of thermal capacity varies, with increased VRE (solar and wind) capacity additions. Under the Base Scenario, the target VRE proportion for 2025 is 10% and is aligned with the existing PDP, while the VRE proportion is optimised in the Optimum Scenario. Under the ASEAN RE Target Scenario, the VRE share is set at 10-12% by 2025 and 15% by 2040 to reflect the official RE Target from the AMS. Under the High RE Target Scenario, a higher VRE target of 25%-30% by 2040 is set.

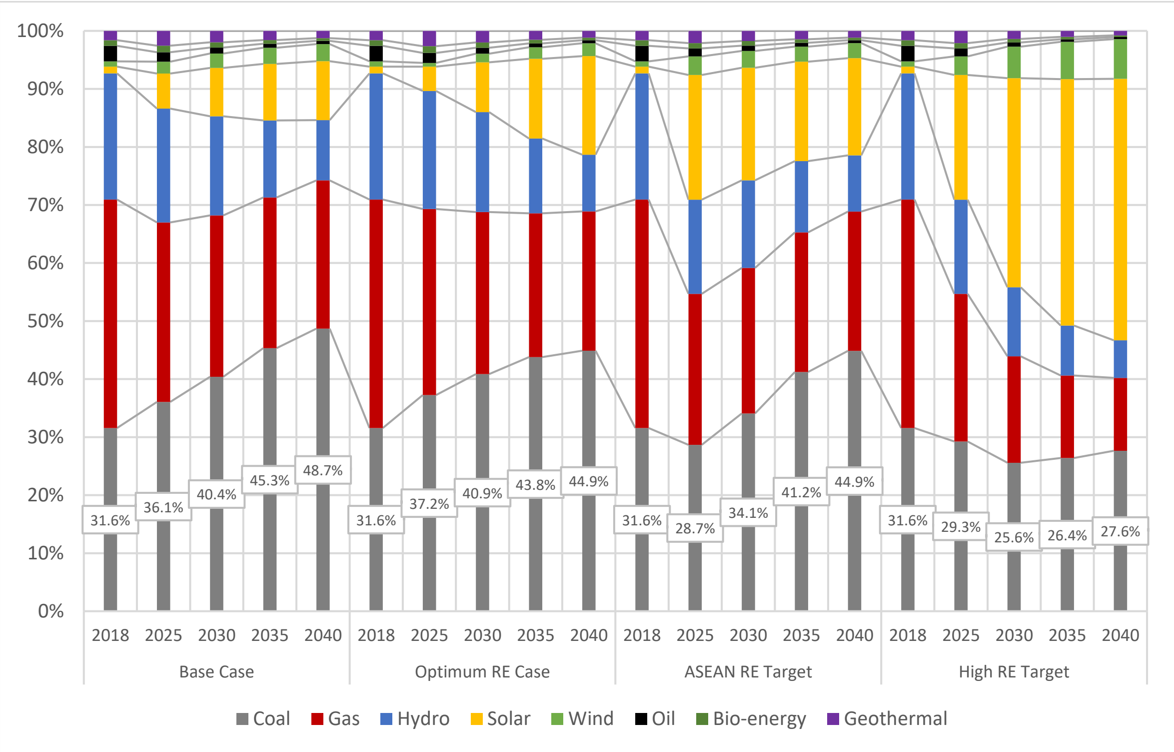


Figure 3-22: Installation Mix Comparison (%) – ASEAN Region

Figure 3-22 shows the values in percentage shares. Therefore, if a given value of a particular technology declines between the years in a given scenario, this does not mean that the actual capacity is reduced, but merely that the rate of increase in cumulative capacity is higher than the rate of increase in the capacity of that particular technology.

From Figure 3-22 it can be seen that the share of coal capacity in the study years was consistently the highest for any given year post-2025 in the Base Scenario, before which the largest coal capacity is seen in the Optimum RE Scenario (up to and including 2025). It can be inferred from this observation that generation capacity expansion planning, in the remaining Scenarios, is adding marginally lesser coal capacity when optimising the coal candidate units (especially post-2025).

Another viewpoint is that coal capacity has by far the lowest share under the High RE Target Scenario, especially post-2025. A similar trend can be observed for gas units, though their share is identical in all scenarios except in the High RE Target Scenario. This is also apparent from Figure 3-23, which shows coal and gas capacity expansion for all scenarios.

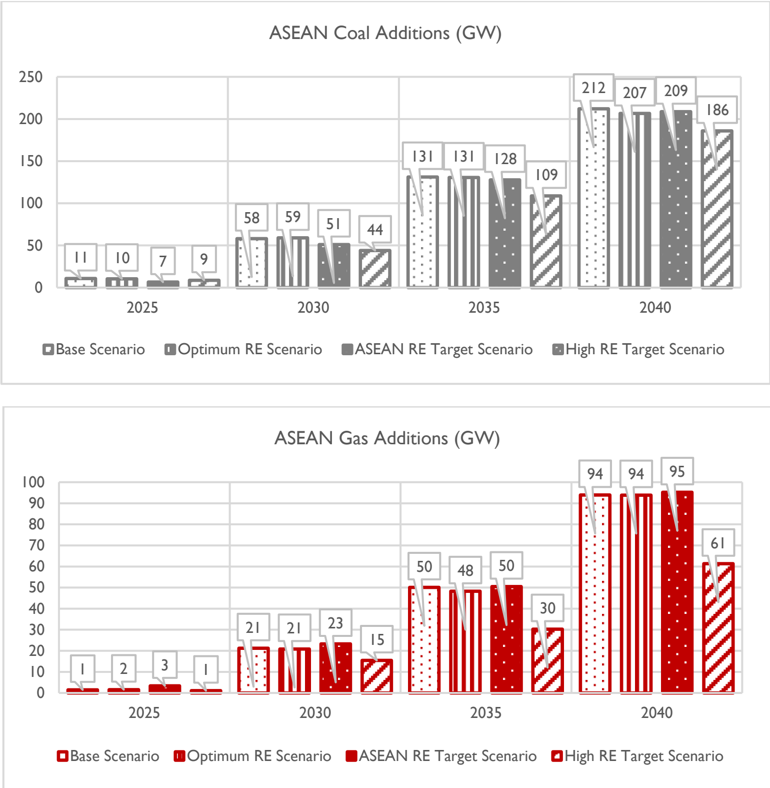


Figure 3-23: Coal & Gas Capacity Additions - All Scenarios

Lower thermal capacity additions in the later study years under the High RE Target Scenario could be attributed to the increase in solar capacity, which is the highest in the years post-2025 by a very large margin. Since hydro and geothermal are not optimised for all scenarios, only coal and gas capacities are left in the system which can be added not at all or very sporadically given the high VRE penetration over the study horizon (significantly later years).

Another point to consider is the high disparity between coal and gas price projections. Coal capacity additions are dominant and are about twice the gas additions. Moreover, as observed in the High VRE Scenario, there is a reduction (compared to other scenarios) in the capacity additions for both coal and gas due to the high VRE penetration. The reduction in coal and gas capacity additions are ~23 GW and ~34 GW, respectively, between the ASEAN RE Target and High RE Target Scenarios.

3.5.2 Production Costs & Operations

The following section compares the key results of the four scenarios in terms of annual production costs, avoided emissions, total system costs, average capacity factors and the number of starts per generating station.

Table 3-10 gives the annual production costs for the four scenarios in 2020, 2025, 2030, 2035 and 2040.

Table 3-10: Annual production costs for the ASEAN Region

Year	BASE CASE		OPTIMUM RE		ASEAN RE Target		High RE Target	
	Billion USD	$/kWh	Billion USD	$/kWh	Billion USD	$/kWh	Billion USD	$/kWh
2020	52	0.047	53	0.048	50	0.045	50	0.045
2025	60	0.041	59	0.041	53	0.037	50	0.035
2030	75	0.040	74	0.040	72	0.039	62	0.033
2035	97	0.042	94	0.041	93	0.041	79	0.035
2040	130	0.046	125	0.044	127	0.045	106	0.038

The key observations are as summarised below:

- The High RE Target Scenario yields the lowest production costs by large margins due to high VRE (wind + solar) contribution.
- The Optimum RE Scenario yields the second lowest production costs (for the year 2040), with the Base Scenario having the highest production costs.
- The production costs seem to follow an inverse trend with the VRE capacity additions.

3.5.3 Share of VRE in the Capacity Mix

Figure 3-24 shows the share of VRE (wind and solar) capacity in 2025 and 2040. The capacity is shown for these two years alone due to the targets defined in the 6th ASEAN Energy Outlook (AEO6), from which the values are taken as they are and the projections are for the period 2026 to 2040.

From Figure 3-24 it can be seen that solar capacity in the ASEAN Region is targeted to be around 22% by 2025, while wind capacity is only about 3%. This capacity will remain the same in both the ASEAN RE Target and High RE Target Scenarios in 2025. However, the projections of these two scenarios beyond 2025 up to 2040 will be very different. The solar capacity of 17% in the ASEAN RE Target Scenario will become about 45% in the High RE Target Scenario in 2040. Wind capacity also increases from about 3% in the ASEAN RE Target Scenario in 2040 to about 7% in the High RE Target Scenario.

Figure 3-24: Comparison of Share of VRE Capacity in 2025 and 2040 for All Scenarios – ASEAN Region

3.5.4 Potential Avoided Emissions

As expected, the AIMS III found that increasing the use of RE will mean avoiding some emissions attributed to avoided fossil fuel consumption. The avoided consumption will reduce a country's dependency, especially for countries with high fuel imports. At the ASEAN level, the demand for coal is also expected to surpass local production around 2035, while some countries like Indonesia and Malaysia may also stop LNG exports altogether after 2035 if no new offshore or nonconventional production projects are pursued.[26] Figure 3-25 shows the potential avoided coal, oil and natural gas consumption under the four scenarios.

[26] The Oxford Institute for Energy Studies. (2020). **The dilemma of gas importing and exporting countries.**

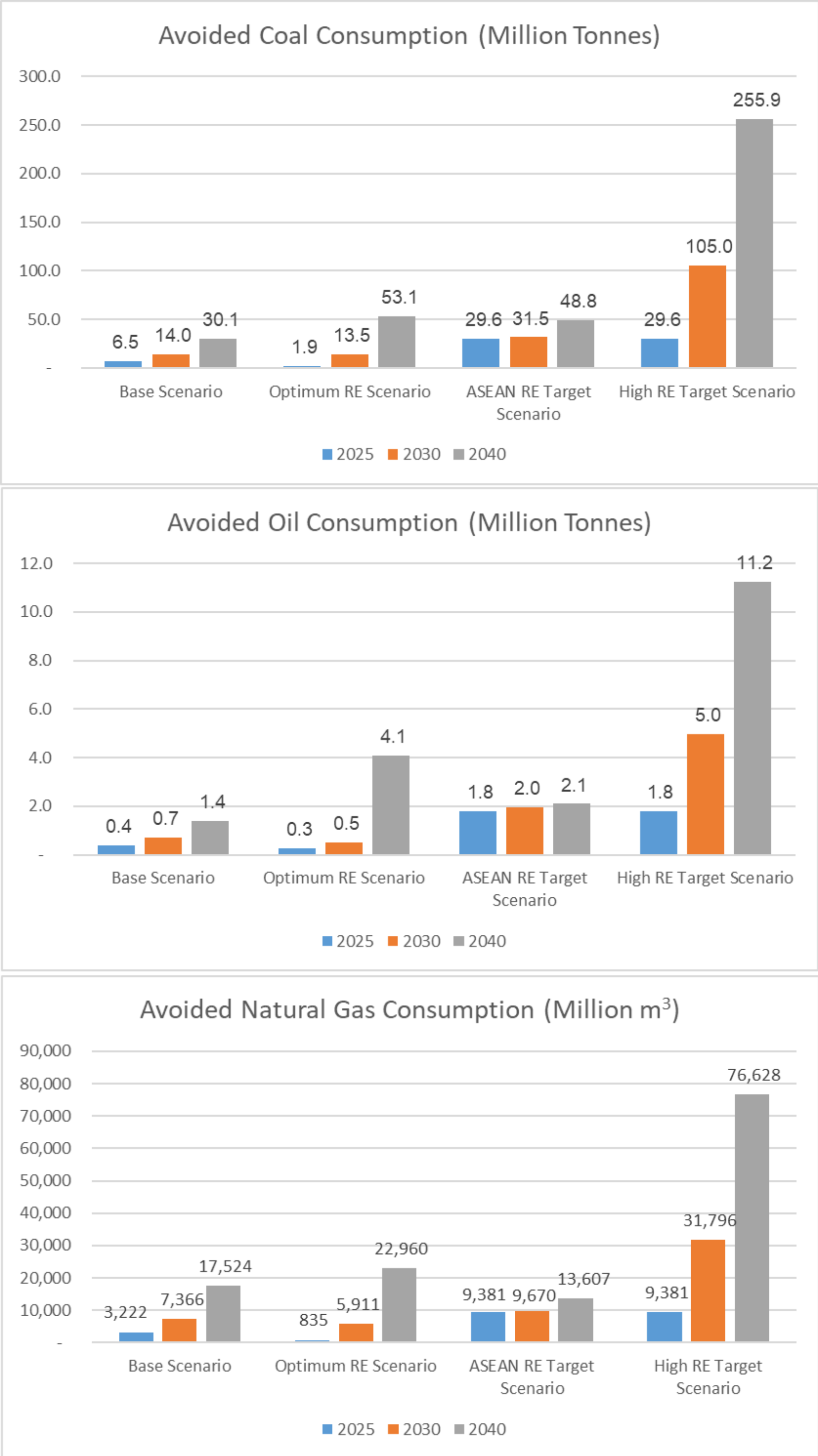


Figure 3-25: Avoided Coal, Oil and Natural Gas Consumption in ASEAN under 4 Scenarios

Figure 3-25 shows the gradual increase in avoided fossil fuel consumption for 2025, 2030 and 2040 in the three scenarios due to the rise in the shares of solar and wind energy in the energy mix. By 2040, under the Base Scenario, 30.1 Mt of coal, 1.4 Mt of oil and 17,524 million m^3 of natural gas consumption can be avoided due to VRE generation. This decrease in fossil fuel consumption will bring a significant emissions reduction of 67,582 Mt of CO_2 and 36 thousand tons of N_2O, cumulatively to 2040.

At the ASEAN level, the results show that the increase of VRE generation by 2040 in the ASEAN RE target Scenario and Optimum RE Scenario can almost double emissions reductions in the region, compared to the Base Scenario. It can cut the region's emissions up to 112,267 Mt of CO_2 and 64 thousand N_2O. This achievement originates from the various degrees of commitment to RE from each of the AMS.

Indonesia, Vietnam and the Philippines appear to have the highest potential for avoided reduction through the VRE utilisation (up to 20,757 Mt of CO_2 and 16,347 thousand tons of N_2O emissions reduction by 2040). This is mainly attributed to their natural resources and geography. However, on the contrary, the reality is different when it comes to the current commitment and plan of the countries in developing RE. From observing the current installed capacity and the firm (committed) capacity additions as per the PDPs for each AMS, it seems that Thailand appears to have a much higher VRE commitment and target than other AMS resulting from the capacity expansion simulation for the ASEAN RE Target Scenario and Optimum RE scenario.[27]

Some other AMS also have plans to increase the share of RE in their PDP that is higher than in their ASEAN RE Target Scenario. Singapore is one which shows a significant difference, followed by the Philippines and Vietnam, while Malaysia and Brunei have plans closer to their ASEAN RE Target Scenarios.

This observation indicates a potential progressive challenge for countries to reduce their emissions by 2040. Those AMS with high RE commitments in the current PDP/ base scenario may reach a higher target in the future to integrate VRE into the APG and contribute more to emissions reduction in the region.

As Indonesia has abundant RE resources, it needs to improve its RE target significantly. Its current target is less than a quarter of that in the ASEAN RE Target Scenario. This may make it even more challenging for Indonesia to achieve its optimum RE utilisation, and may reduce the maximum potential for emissions reduction in the region.

For other countries like Lao PDR and Cambodia, improving the RE plan in their Baseline and Optimum Scenarios would benefit the countries, contributing more to their regional emissions reduction.

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[27] Please note that our findings were made on basis of the situation at the time the AIMS III was being initiated. All data collection took place from 2018 to early 2020. Hence there will be different interpretations of the generation mixes to the current landscapes.

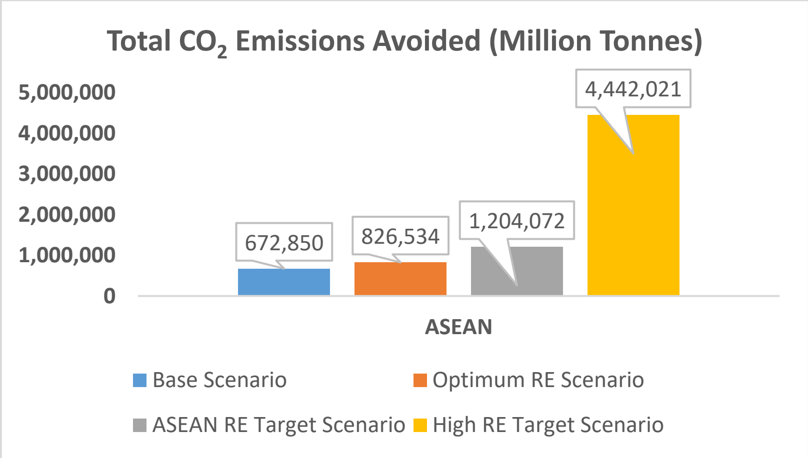


Figure 3-26: Overall Total CO_2 Emission Avoided in 2040

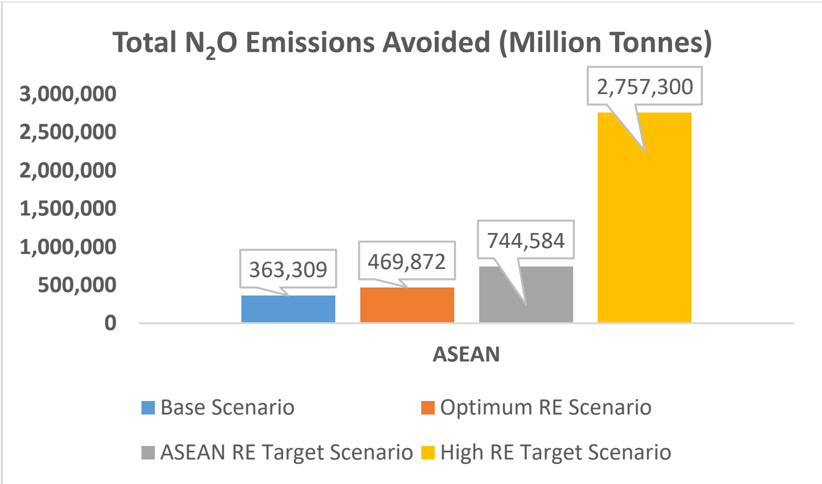


Figure 3-27: Overall Total N_2O Emissions Avoided in 2040

In the ASEAN RE Target Scenario, it is estimated that the emissions reduction will increase. Avoided fuel consumption is projected to be 48.8 Mt of coal, 2.1 Mt of oil and 13,607 million m^3 of gas. This will reduce emissions by some 90,852 Mt of CO_2 and 57 thousand tons of N_2O by 2040. In the optimum RE Scenario, emissions reduction is even higher. Avoided fuel consumption is estimated at around 53.1 Mt of coal, 4.1 Mt of oil and 22,960 million m^3 of gas. This will lead to 112,267 Mt of CO_2 and 64 thousand tons of N_2O emissions reductions by 2040.

3.5.5 Total System Costs – Net-Present-Value (NPV) over the Study Horizon

This section compares the NPV to the total system costs in the four scenarios. This comparison aims to provide a clear pattern of the indicative costs needed in each scenario and provide the necessary details for the respective AMS in order to aid them in selecting the most suited scenario.

3.5.5.1 Comparison of Total Build Costs - ASEAN

Table 3-11 presents the total build costs at the ASEAN level.

Table 3-11: NPV of Build Costs for All Scenarios – ASEAN (billion USD)

Output/Parameters	Base	Optimum RE	ASEAN RE Target	High RE Target
Thermal Generator Build Cost	89.34	88.18	86.36	69.87
Firm Units Build Cost (except VRE)	77.83	77.83	77.83	77.83
Interconnection Build Cost	0.67	2.41	2.98	16.23
Solar Build cost	10.86	13.92	34.65	58.94
Wind Build cost	5.94	3.41	10.11	24.77
Total Build costs	184.64	185.76	211.93	247.63

Notes:

The colour code uses green to indicate the scenario with the lowest value for that parameter among all the scenarios. Conversely, red signifies the scenario with the highest values for that particular parameter amongst the scenarios. Yellow (and orange) values signify the values at the intermediate level between the least and the highest.

The values shown in Table 3-11 indicate the costs on a "Net Present Value" basis for the planning period over the study horizon (i.e. between 2018 and 2040).

It should be noted that firm or committed units (except VRE), solar and wind build costs are not colour-coded since the VRE capacity (and thus the VRE unit build costs) are given as targets, and are therefore not being optimised under the Base, ASEAN RE Target and High RE Target Scenarios. Another point to note here is that the VRE build costs consider the declining price for a specific technology in the future.

Some key observations from Table 3-11 are summarised as follows:

- The thermal build costs are lowest in the High RE Target Scenario owing to the very high VRE capacity targets displacing some thermal generation capacity new builds. It may be noted here that these costs indicate the build costs for the new thermal units only and not the new VRE capacity, which is provided separately.
- The "firm" ("committed") units' build costs remain constant throughout since these costs correspond to the firm or committed units as per the PDPs, which will remain consistent between all scenarios in the modelling. It should be noted that these costs exclude VRE units build charges too.
- The interconnection build costs also increase in proportion to the increasing levels of interconnectivity among the AMS, which is the lowest in the Base Scenario and the highest in the High RE Target Scenario. This is why the magnitude of the interconnection costs in the High VRE Target Scenario are about five times more than in the ASEAN RE Target Scenario – indicating one factor impeding the AMS from going with the High RE Target Scenario.

Table 3-11 shows the NPV of the various components of build costs over the study horizon. The division can be illustrated in the following figure (3-28), which shows the cumulative investment cost. For clarity, the values shown in Table 3-11 and Figure 3-28 are different since the values shown in the table are the NPV over the study horizon, whilst the values shown in Figure 3-28 are cumulative (without discounting).

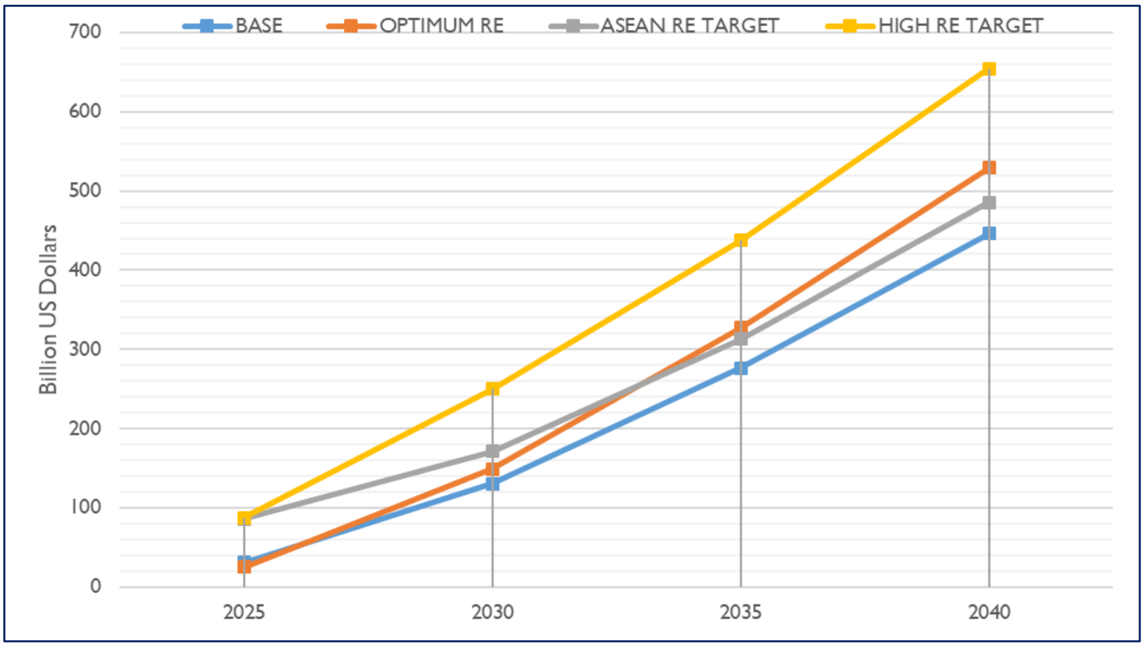


Figure 3-28: Cumulative Build Costs (in real $) – ASEAN

It can be observed from Figure 3-28 that the CAPEX trend in the High RE Target Scenario is the highest among all the scenarios. This is commensurate with the fact that the capacity additions (both generation and interconnection) are highest in the High RE Target Scenario. Further, an important point to note is that the dollar values in Figure 3-28 are "real" dollar values of investments over the study horizon (not NPV) and are intended only to illustrate the trend.

3.5.5.2 Comparison of Total Production Costs – ASEAN

Table 3-12 presents the total production costs as seen at the ASEAN level.

The values in Table 3-12 indicate the costs on a "net present value" basis for the period over the study horizon (i.e. between 2018 and 2040).

Table 3-12: NPV of Production Costs for All Scenarios – ASEAN (billion USD)

Output/Parameters	Base	Optimum RE	ASEAN RE Target	High RE Target
VO&M Cost	26.73	25.42	25.72	22.02
Fuel Cost	484.40	479.00	458.68	421.83
FO&M Cost	75.19	74.87	74.61	72.47
Cumulative Production Costs	586.32	579.29	559.02	516.32

Some key observations from Table 3-12 are summarised as follows:

- This difference in the production costs among the four scenarios is primarily due to the interplay between VRE capacity and interconnection additions, which accounts for the fuel costs.
- Since the thermal capacity in the High RE Target Scenario is the lowest among all of the scenarios, the fuel cost in the High RE Target Scenario is obviously the lowest. It can be noted here that the fuel cost forms the most significant chunk of production costs.

For further comparison, Figure 3-29 shows the trend in production costs (annually) for all of the scenarios. These values were obtained by dividing the total production costs for a year by the total in-house generation. It can be observed from Figure 3-29 that the trend of per unit production costs in the High RE Target Scenario was the lowest. This is commensurate with the fact that the fuel cost component (the most significant part of the production costs) was the lowest in the High RE Target Scenario.

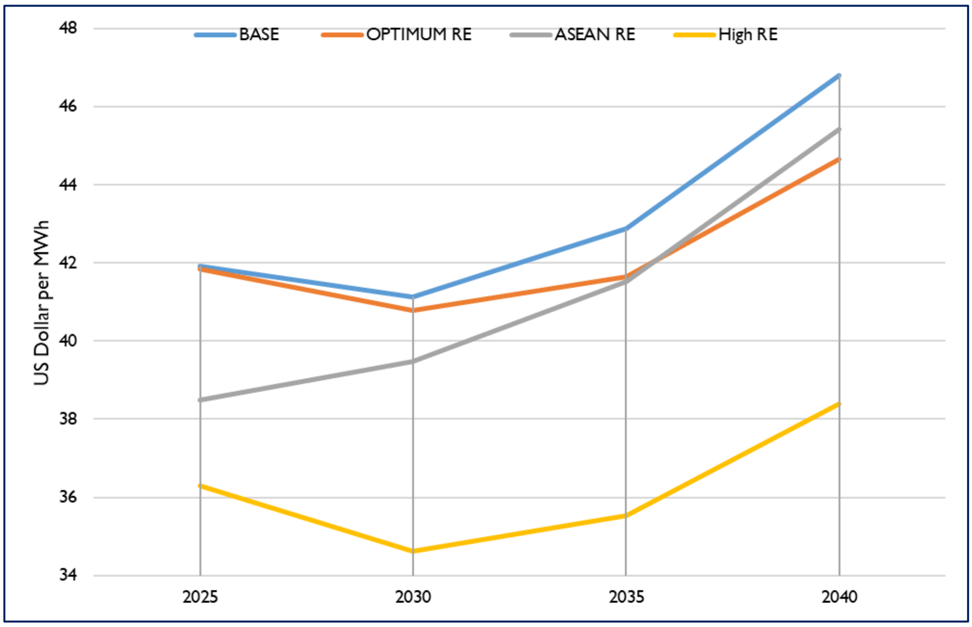


Figure 3-29: Production Costs per MWh for All Scenarios – ASEAN

3.5.5.3 Total System Costs – ASEAN

Moving from the total build costs and total production costs, the NPV of the total system costs for ASEAN was derived as an arithmetic sum of the above and is illustrated in Table 3-13.

Table 3-13: NPV of Total System Costs for All Scenarios – ASEAN (billion USD)

Particulars	Base	Optimum RE	ASEAN RE Target	High RE Target
Total Build costs	184.64	185.76	211.93	247.63
Cumulative Production Costs	586.32	579.29	559.02	516.32
Total Cost (Build + Production Costs)	771	765	771	764

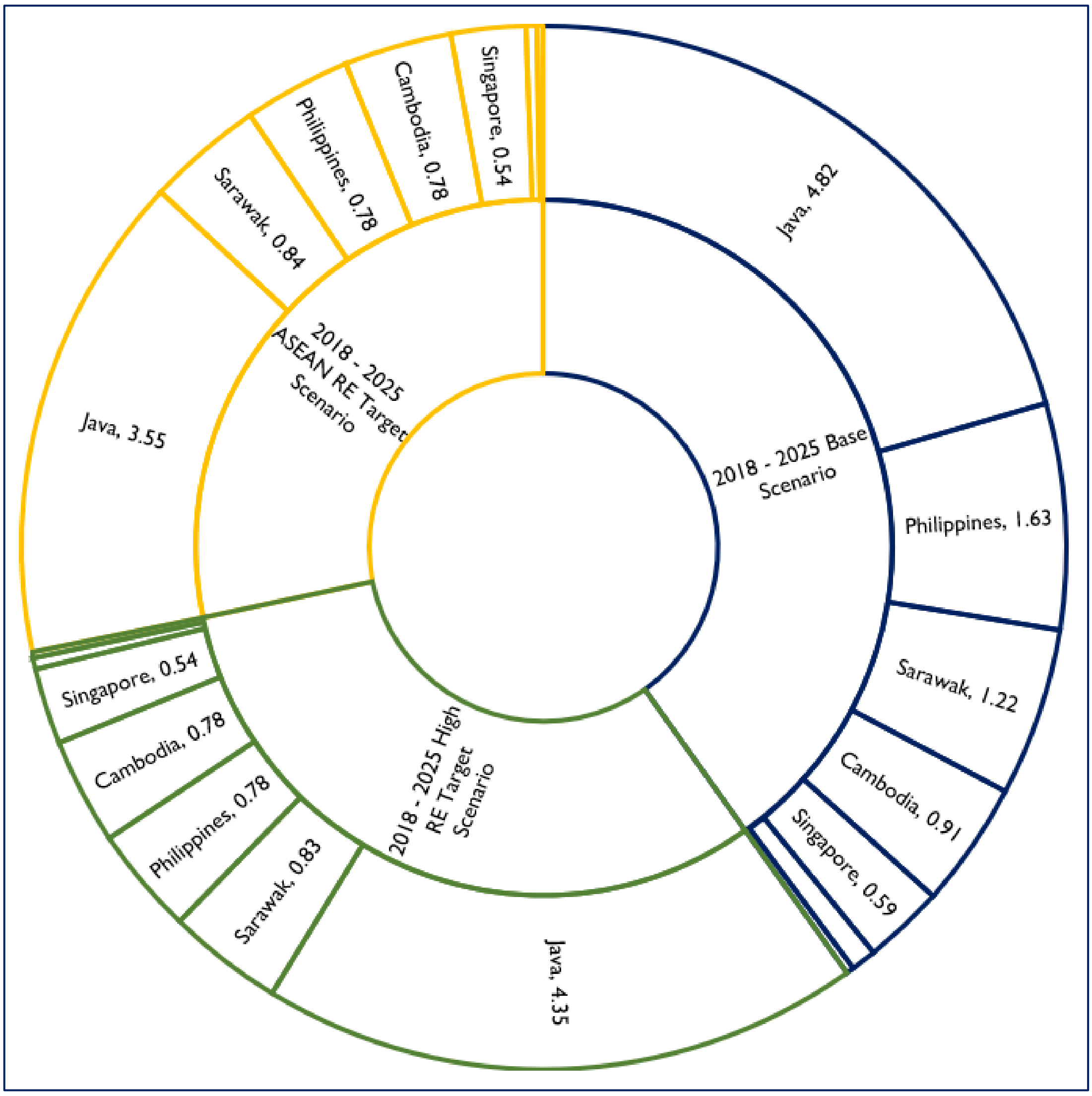
It can be observed from Table 3-13 that while the total build costs were highest in the High RE Target Scenario, the production costs were lowest. This is due mainly to the very high RE penetration target, which increases the build costs while resulting in the lowest fuel costs. However, because of this interplay between the build and production costs, the total system NPV was also the lowest in the High RE Target Scenario, closely followed by the Optimum RE Target Scenario. However, it may also be noted that the High RE Target Scenario was susceptible to VRE curtailment, especially in the smaller countries and also involved higher interconnection capacity and would need more detailed analysis.

This conforms with the initial assumption (at least at the ASEAN regional level) that a higher VRE along with enhanced interconnection capacities among the AMS is likely to provide quantifiable benefits to the participants.

3.5.5.4 Net Present Value (NPV) of Thermal Generator Build Costs by Node

This section explains the level of investments required to build new thermal generators in each of the fourteen nodes, in which one node represents a country or part of a country. For this purpose, the process adopted is to calculate the NPV of the investments for new thermal generator builds between the 2018 and 2025 and between 2018 and 2040. Figures 3-30 and 3-31 show the values for major nodes over these periods, respectively.

In this section we identify the nodes where the maximum number of new thermal units are built in different scenarios, which reflects the impact of increased VRE penetration and enhanced interconnection capacity between these nodes and, consequently, across the AMS. This is expected to provide a high-level insight enabling the AMS to decide on the priority order for undertaking a more detailed and focused analysis of their respective investment plans.



Note: The numbers in the figure represent the NPV in billion USD of Thermal Generator Build Costs by node as a consequence attributed by the impact of increased VRE penetration and enhanced interconnection capacity across AMS. This note also applies to Figure 3-31..

Figure 3-30: Generator Build Costs up to 2025 (NPV)

It can be noted from Figure 3-30 that for the period 2018 to 2025, Java is likely to see the largest number of thermal capacity builds among all of the scenarios. Sarawak follows Java in the ASEAN RE Target and High RE Target Scenarios However, in the Base Scenario, the Philippines sees the second most units built after Java.

Besides these nodes, Cambodia takes up the remainder, with similar levels of thermal capacity additions in all of the scenarios. For the other nodes, there are none or negligible thermal builds during this period.

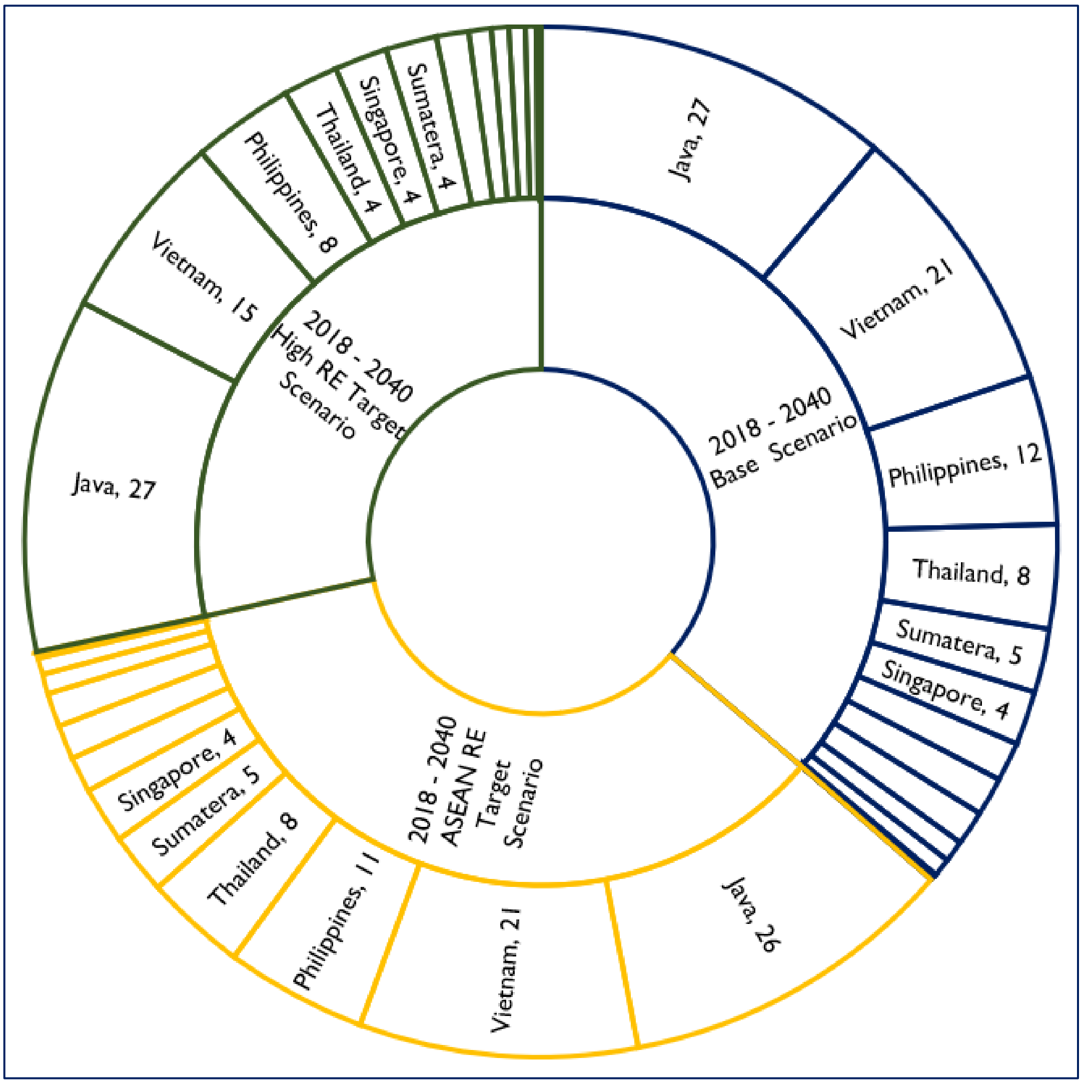


Figure 3-31: Generator Build Costs up to 2040 (NPV)

It can be seen from Figure 3-31 that for from 2018 to 2040, Java is still likely to see the most thermal capacity builds in all of the scenarios, Vietnam will see the second highest additions in all of the scenarios and the Philippines has the third most units built. Sumatra and Singapore will also have larger capacity additions relative to the other AMS from 2018 to 2040.

3.6 Grid Performance Analysis Result Over the Study Horizon

The overall objective of Phase 2 was to evaluate the technical feasibility of the interconnections and VRE capacities as identified by the capacity expansion planning study. The technical feasibility was carried out through stability analysis.

Throughout the grid performance analysis, several observations were found under two subsets. The first was the country level observation which serves to help us understand the geographical and grid situation better. It is important for the reader to understand the analysis outcome at the regional level. Note that due to ASEAN's very large grid size, the stability analysis under critical grid conditions, in order to reflect the worst possible scenario, was done to examine the grid's strength visibility with the proposed interconnection, listed in Table 3-16. The proposed interconnections, as given in this table are the AIMS III critical findings. Validating these interconnections through the grid performance analysis is therefore very important. Due to page limitations, this report highlights only some of the simulation results as a sample case. This sample is illustrated in Section 3.6.2 pertaining to stability analysis in 2025 and Section 3.6.3 pertaining to stability analysis in 2040. The full observations are given in Section 3.6.4.[28]

3.6.1 A Brief Observation of Countries' Power Grid

3.6.1.1 Thailand

Thailand has an installed generation capacity of 50 GW and peak load of ~ 33 GW. Gas-based generation makes up the largest percentage of the capacity, followed by hydro, coal and VRE It also has a small percentage of bio-based generation. The Electricity Generating Authority of Thailand (EGAT) is the state-owned power utility that owns and operates a high voltage transmission network. It is also a major power producer. The highest transmission voltage in the existing Thailand grid is 500 kV. Thailand is currently connected to Lao PDR, Cambodia and Peninsular Malaysia. However, as a part of the APG, it plans to connect to Myanmar.

3.6.1.2 Vietnam

Vietnam has the largest installed generation capacity of 58GW and approximately 41GW of the northern AMS. Hydro and coal-based generation predominate in Vietnam relative to gas-based generation. It is also a renewable-rich country in terms of solar and wind resources. There is also some bio-based generation. The transmission system is operated by Vietnam Electricity Corporation (EVN) and the highest transmission voltage is 500 kV. Currently, Vietnam is connected to Cambodia and Lao PDR via a 220 kV HVAC transmission lines.

3.6.1.3 Myanmar

Myanmar is a rapidly developing nation with a currently installed generation capacity of approximately 5.2 GW and a peak load of 4.5 GW. Geographically, Myanmar is divided into five regions: northern, central, eastern, western and southern. The northern and eastern parts of the country are very rich in hydro resources. Hence, the major share of the generation is hydro-based. Yangon has the main seaport and industrial zones, making it the largest load centre of Myanmar. The Mandalay, Naypyidaw and Ayeyarwady regions also have a high population density with increasing power demand.

The existing Myanmar grid is not connected to any of the ASEAN Member States. However, as a part of the APG, Myanmar plans to connect to Thailand and Lao PDR. For interconnection with Lao PDR, a nearby substation, Kengton located in the eastern part of Myanmar has been identified. Hutgyi substation, situated in the southern part of Myanmar, has been identified as the most suitable connection point for interconnection with Thailand given that a large hydropower plant is being planned in the vicinity.

[28] Please note that in Section 3.6.1, the country level illustration is given on the basis of the grid complexity.

3.6.1.4 Lao PDR

Lao People's Democratic Republic (Lao PDR) is a rapidly developing nation with an installed generation capacity of approximately 5.5 GW and a current peak load of around 1.6 GW. There are three generating entities, including Éllectricité du Laos (EDL), IPP(D) for domestic and IPP(E) for export. The EDL and IPP(D) units are connected to the Lao PDR transmission network and generate power primarily to meet the Lao PDR demand. Surplus power is exported to neighbouring countries. The IPP(E) units are utilised mainly to export energy, and they have a dedicated transmission system connected to a neighbouring system. A few IPP(E) units also meet the demand of the Lao PDR system load on an as-need basis. Most of the installed generation in Lao PDR is hydro-based with a small percentage of coal, VRE and biobased generation. Geographically, the Lao PDR system is comprised of four regions, i.e., North, Central1, Central2 and South. The generation is located mainly in the North region, and the major load centres are in the Central Region. Vientiane, the capital city, is the major load centre of Lao PDR located in the Central 1 Region. The power transmission is mainly at 230 kV and 115 kV and operated by Électricité du Laos (EDL). Currently, power from IPP(E) in Lao PDR is exported to Thailand and the northern region of Vietnam.

3.6.1.5 Cambodia

Cambodia is a rapidly developing nation with an installed generation capacity of approximately 2.2 GW and a peak load of 1.5 GW. The primary generation resource in Cambodia is hydro. There are two coal-based plants and two diesel/HFO based plants. Phnom Penh, its capital city, is the major load centre accounting for as much as 60% of the total load demand. The power transmission is mainly at 230 kV and 115 kV. Électricité du Cambodge (EDC) is the grid operator.

Cambodia is currently connected to Vietnam at Chau Doc substation through a 220 kV double circuit line (Chau Doc to Takeo) and Thailand at Aranyaprathet through a 115 kV single circuit line (Aranyaprathet to GS-IE). It is also connected to a dedicated plant, i.e., Don Sahong generating station in Lao PDR by 500kV D/C line from Stung Treng to Banhat substation, which is currently charged to 230kV. However, there is a plan to connect Cambodia directly to the Lao Grid through this transmission corridor in 2025.

Geographically speaking, Cambodia is comparatively compact. However, considering the load-generation locations and transmission system, it is represented as three regional equivalent models (North, South and West). The North area is dominated by hydro generation with potential to connect to Lao PDR, whereas the West has primarily thermal generation and a few hydro plants. South Cambodia is the primary load centre with limited Oil/HFO based generation. Each area is represented by a 230 kV node with equivalent generation (segregated fuel/technology-wise) and loads lumped at the 230 kV node.

3.6.1.6 Indonesia

Indonesia is the largest country in terms of installed generation capacity and geographical spread. It is composed of thousands of islands. Three of the largest islands are Java, Sumatra and Kalimantan, which together form the main Indonesian grid system. Perusahaan Listrik Negara (PLN) is Indonesia's national power company, which owns and operates generation and transmission systems in the three islands or sub-systems. Java and Sumatra are part of the Southern Sub-region within the APG framework, while Kalimantan is part of the Eastern Sub-region.

Java has the largest grid in Indonesia with an installed base of 66 GW, with predominantly coal-based generation and a sizeable proportion of gas, hydro and small VRE, bio and geothermal. The highest transmission voltage is 500 kV.

Sumatra is another major grid in Indonesia with an installed base of 12 GW and a peak load of 7.5 GW. Generation is dominated by coal with some gas, hydro, very small VRE and bio-based generation. Sumatra has a considerable amount of geothermal generation. The highest transmission voltage is 500 kV. The island is very rich in VRE resources and is expected to have a high percentage of VRE generation in the future.

Currently, Java and Sumatra are not connected. Also, they are not connected to any other AMS. However, as part of the APG, Java and Sumatra will be connected via an HVDC link in the future. Also, Sumatra will be connected to Peninsular Malaysia and Singapore via HVDC.

Kalimantan has a comparatively smaller grid. It consists of three sub-systems, which are Barito, Khatulistiwa and Mahakam. Collectively, Kalimantan’s installed capacity is 4.8 GW and the peak load is 2.2 GW. The highest transmission voltage is 150kV. Internally, the Barito and Mahakan grids are interconnected. The Khatulistiwa grid is currently connected to Sarawak. As a part of the APG, in future, Mahakam is planned to connect with Sabah.

3.6.1.7 Malaysia

The Malaysian power transmission system consists of three subsystems: Peninsular Malaysia, Sabah and Sarawak, operated by three companies: Tenaga Nasional Berhad (TNB) in Peninsular Malaysia, Sabah Electricity Sdn, Bhd (SESB) in Sabah region and Sarawak Energy Berhad (SEB) in the Sarawak region. Under the framework of the APG, Peninsular Malaysia is part of the Southern Sub-region, and Sabah and Sarawak are part of the Eastern Sub-region. These three subsystems are not interconnected.

Peninsular Malaysia forms the main part of the Malaysian power grid with the existing installed generation capacity of 26GW, with predominantly gas and coal-based generation with a small proportion of hydro and VRE generation. The peak load is 18.8 GW, while the highest transmission voltage is 500kV. Currently, it is connected to Singapore via a 230 kV subsea cable and to Thailand via an HVDC connection.

Sarawak is a comparatively smaller grid with an installed base of 7.4 GW and a peak load of 5.5 GW. Generation is mainly hydro and coal, with a small percentage of gas generation. The highest transmission voltage is 275kV. Currently, Sarawak is connected to the West Kalimantan or Khatulistiwa grid. In future, there is a possibility that Sarawak will be connected to Brunei and Sabah.

Sabah has an installed capacity of 1.4 GW, and the peak load is 1.0 GW. The generation is predominantly gas-based with a small percentage of diesel, hydro, VRE and bio-based. The highest transmission voltage is 275kV. Currently, Sabah is not connected to any of the AMS. However, Sabah plans to be connected to Sarawak and Kalimantan as a part of the APG.

As for Sarawak, the transmission will be upgraded to a 500kV corridor between them in future scenarios. West Sarawak is the major load centre with dominant thermal generation and is connected to the Kalimantan-Khatulistiwa grid through 275kV lines. Central Sarawak contains a hydro potential, and East Sarawak will be connected to Brunei and Sabah in 2025.

3.6.1.8 Philippines

The National Grid Corporation of the Philippines (NGCP) is the concessionaire granted a franchise to operate, manage, maintain and operate transmission networks in three islands/areas (Luzon, Visayas and Mindanao) owned by the National Government. Luzon's network consists of a 500 kV transmission line and is a major load centre in the Philippines, whereas the Visayas network has 230kV as the highest voltage. Luzon and Visayas are connected with a $\pm$ 350 kV HVDC link with a maximum transmission capacity of 440MW and provision to upgrade to 880MW in the future. Mindanao has 138kV as the highest voltage level and operates in island mode without any interconnection to the other two island networks.

3.6.1.9 Brunei Darussalam

Brunei is a compact country both geographically and in terms of grid size. It has an installed base of 0.9 GW and a peak demand of 0.6 GW. The generation is predominantly gas-based. The highest transmission voltage is 66kV which will be upgraded to 275kV in the near future. It consists of two areas, DES and BPS, which are connected with a 66kV transmission network through the Gadong substation. Brunei is currently not connected to any other AMS. However, in future, it is expected to be connected to Sarawak as a part of the APG.

3.6.1.10 Singapore

Singapore is a major country in the southern region of the APG. The Energy Market Authority (EMA) is the market and system operator in Singapore responsible for reliable electricity supply. The current installed generation capacity of Singapore is 11 GW, and the peak demand is 7.6GW. The generation is prominently gas-based with a small percentage of VRE and biomass. The highest transmission voltage is 400 kV. Although the grid size of Singapore is moderate, it is quite a compact system.

3.6.2 2025 – Stability Analysis

3.6.2.1 2025 – Base Scenario, Northern Sub-region, Peak Load

In this Operating Scenario, the ASEAN peak load is around 206GW. The dispatch is predominantly from conventional generators. Following selective cross-border interconnection line tripping, contingencies are simulated to evaluate any constraint in transferring the pre-fault power without compromising system stability.

Only the Northern Sub-region is reported here. Lao PDR-Thailand is interconnected through two double circuit 500 kV lines. One line carries 383 MW per circuit, and the other line carries 170 MW per circuit. Figures 3-32 and 3-33 show the dynamic simulation plots for tripping one circuit of the Lao PDR to the Thailand double circuit line (383 MW Loss) following a 3-phase fault of 100 msec duration. It is observed from the plots that the pre-fault power that gets transferred to the other circuit is within the thermal loading capability of the transmission circuit, and the system is transiently stable. Please note that Figure 3-32 and 3-33 show all interconnections which surround the faulted transmission line.

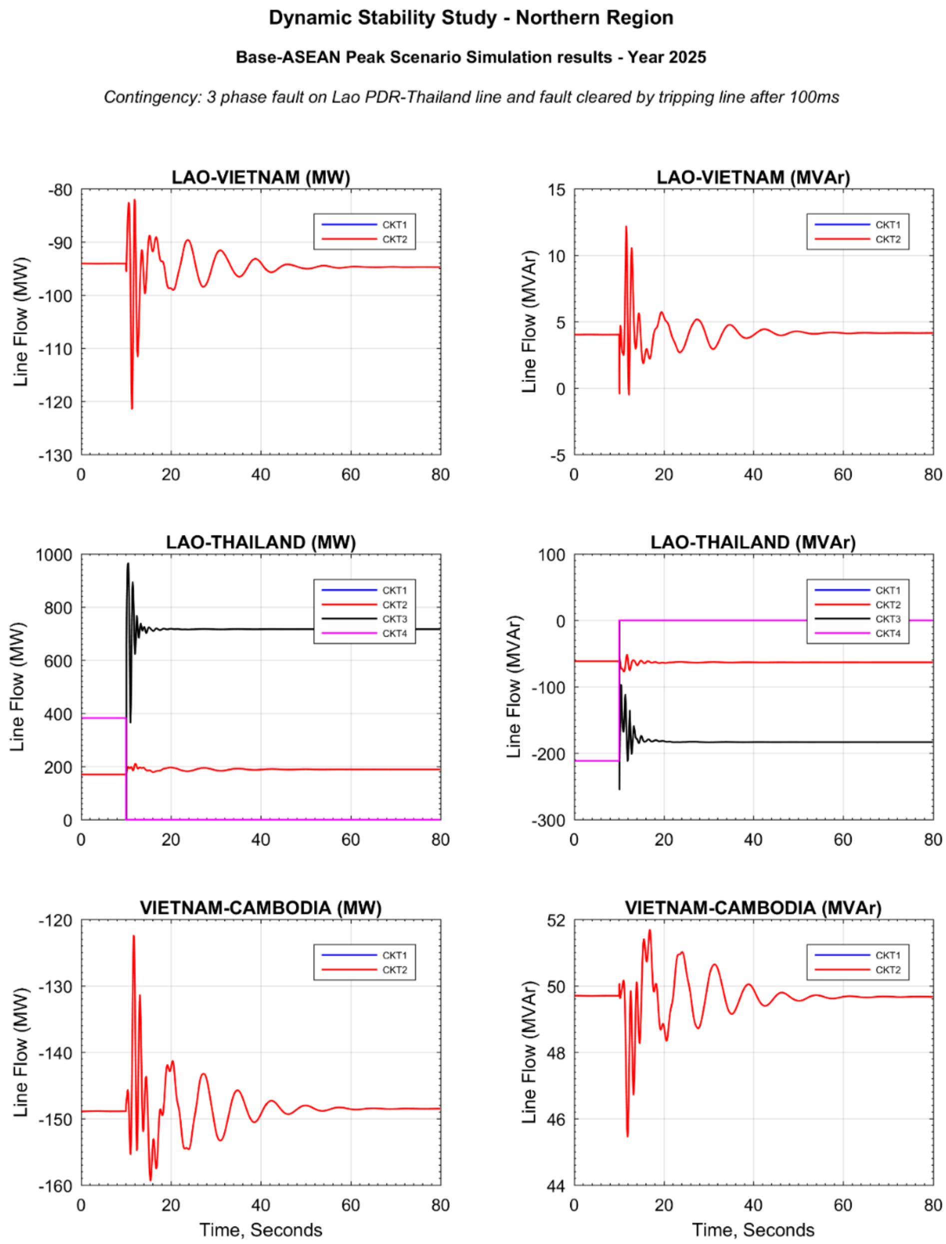


Figure 3-32 Plots of Dynamic Simulation Results for tripping of Lao PDR to Thailand line on 3-Phase fault of 100 msec duration – 2025, Base Scenario, Peak Load[29]

[29] CTK refers to the transmission line in the grid analysis study.

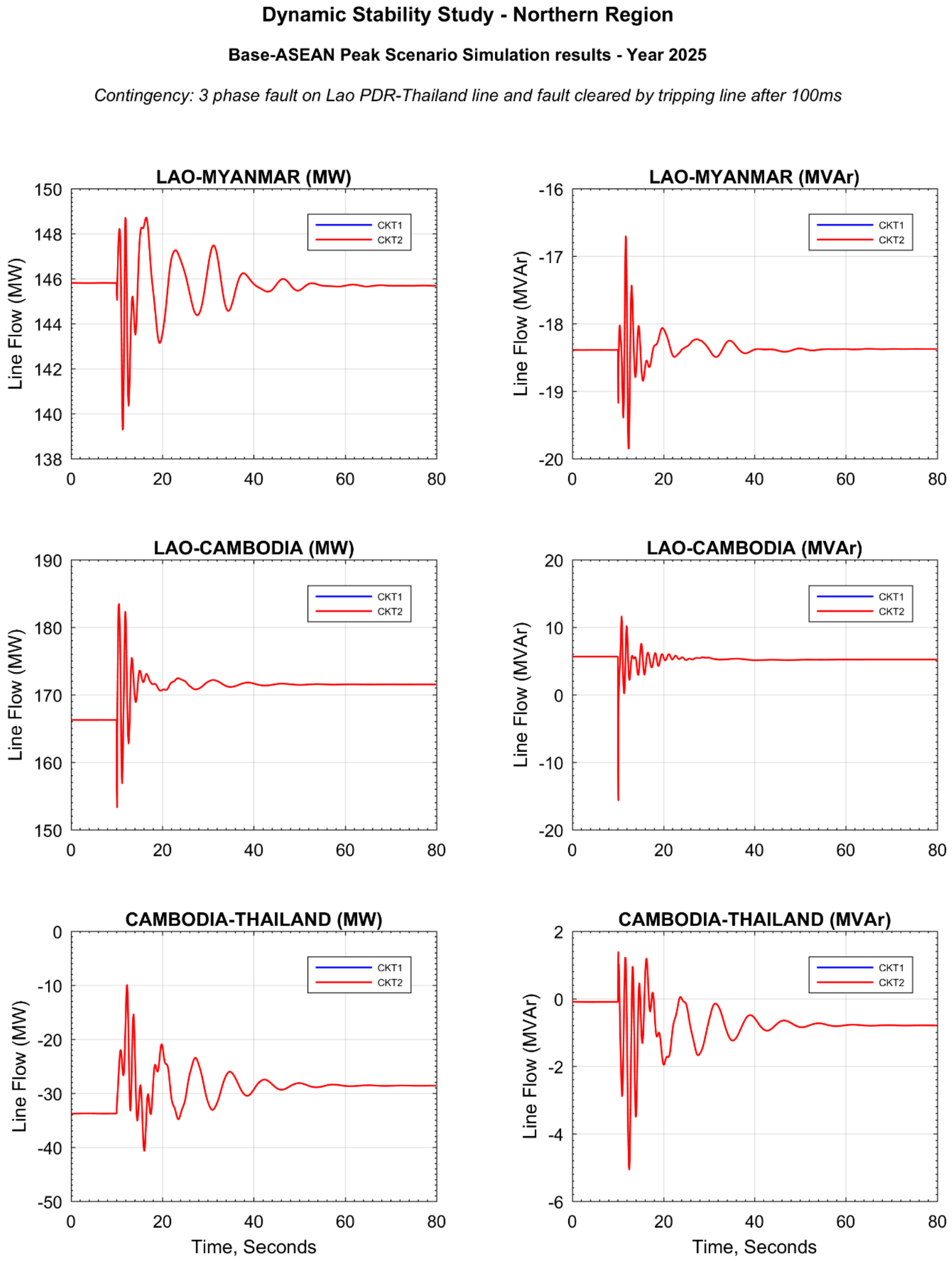


Figure 3-33 Plots of Dynamic Simulation Results for tripping of Lao PDR to Thailand line on 3-Phase fault of 100 msec duration – 2025, Base Scenario and Peak Load (cont'd)

3.6.2.2 2025 - ASEAN RE Target Scenario, Northern Sub-region, Peak Load

The total peak load is around 203 GW and has a maximum dispatch from conventional generators in this operating scenario. Following selective cross-border interconnection line tripping, contingencies are simulated to evaluate any constraint on maximum export possible without compromising system stability.

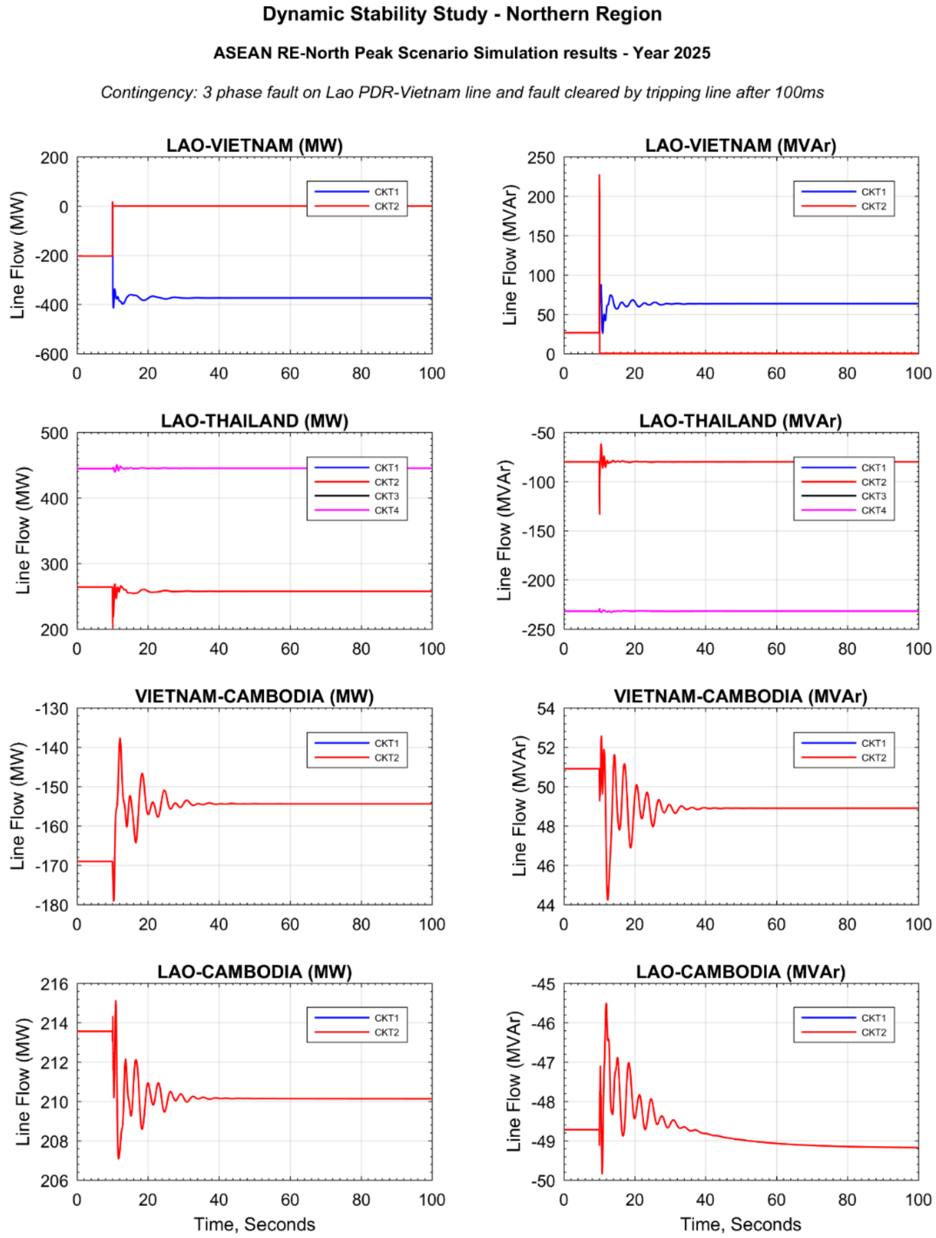


Figure 3-34 Plots of Dynamic simulation results for tripping of Lao PDR to Vietnam line on 3-Phase fault of 100 msec duration – 2025, ASEAN RE Target Scenario, North Peak

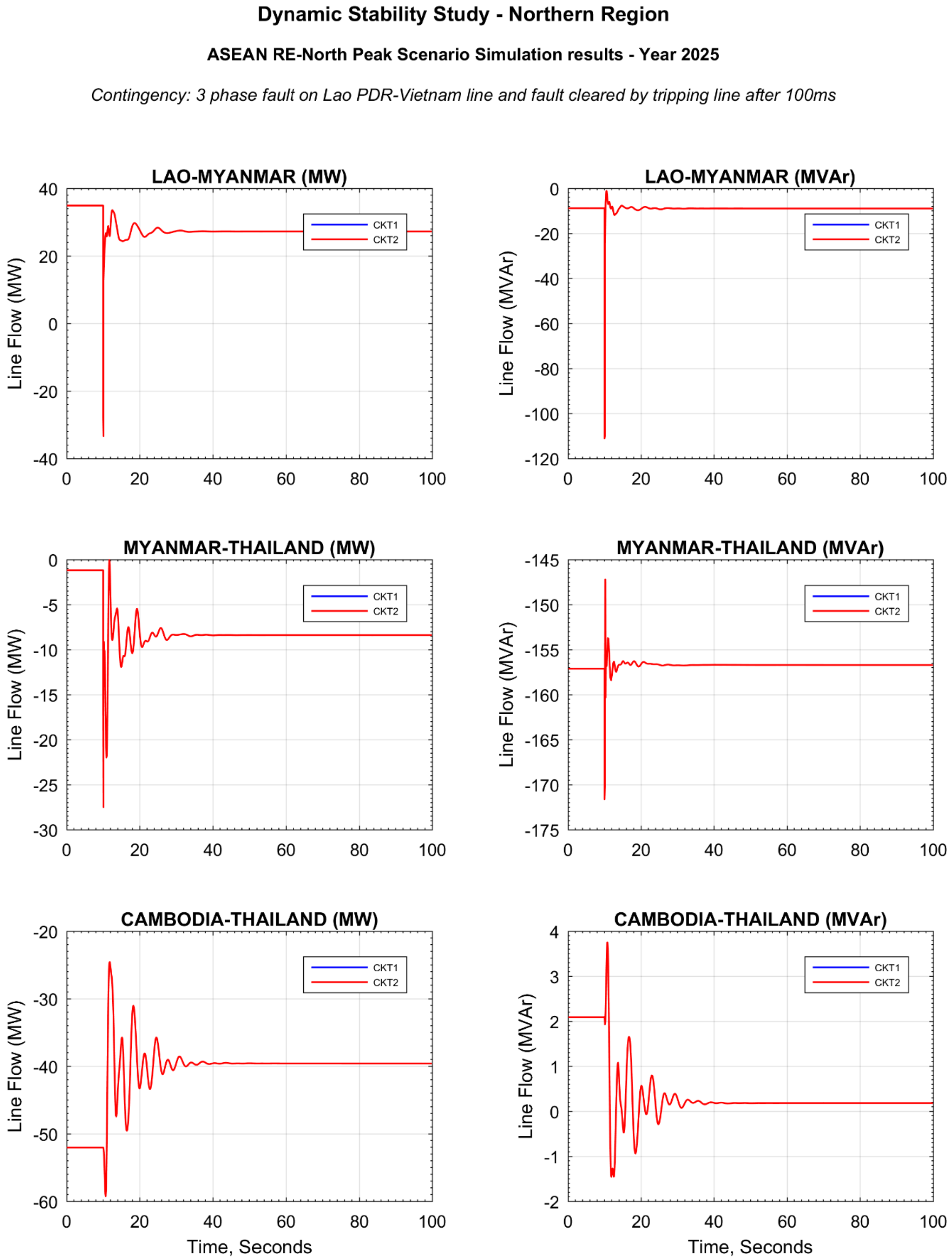


Figure 3-35 Plots of Dynamic simulation results for tripping of Lao PDR to Vietnam line on 3-Phase fault of 100 msec duration – 2025, ASEAN RE Target Scenario, North Peak (cont'd)

3.6.3 2040 – Stability Analysis

3.6.3.1 2040 – Base Scenario, Southern Sub-region, Peak Load

In this operating scenario, the total peak load is around 411 GW, and the dispatch is predominantly from conventional generators. Following selective cross-border interconnection line tripping, contingencies are simulated to evaluate maximum power transfer constraints without compromising system stability. One example presented here is a contingency when one pole of the HVDC link between Sumatra and Java is suddenly lost.

Figure 3-36 shows part of the dynamic simulation results for the tripping of one pole of the HVDC link between Sumatra and Java. The power flow from Sumatra to Java will diminish by about 1569 MW. This leads to under frequency on the Java side and over frequency on the Sumatra side. A reserve margin of 1,000 MW is maintained in the Java system. Under frequency load shedding (UFLS), the scheme will operate along with the primary frequency response to restore the frequency within the acceptable range. It has been assumed in the simulation that the setting of the first stage of UFLS is at 49 Hz with a 200 msec delay in order to shed some 600 MW of load.

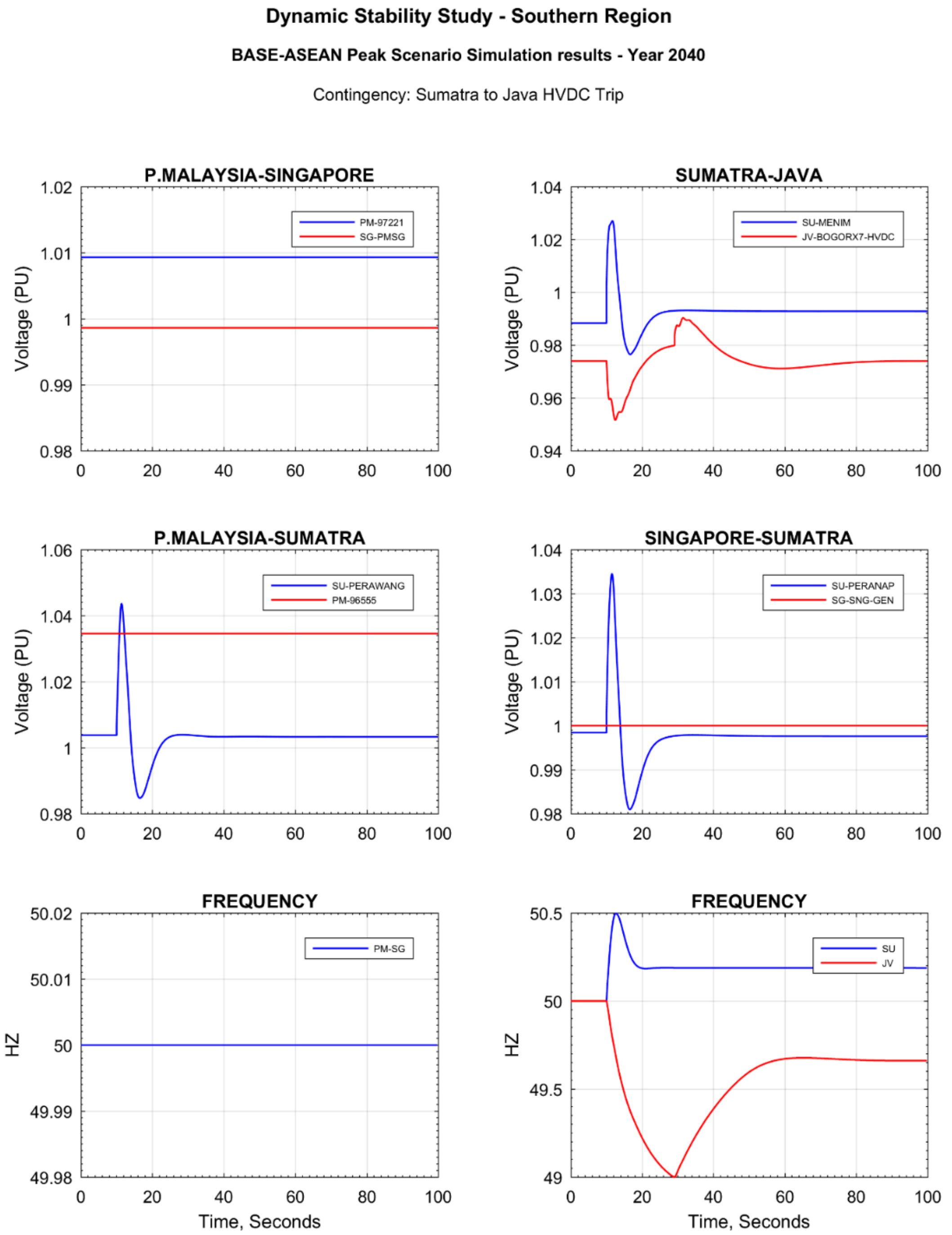


Figure 3-36 Plots of Dynamic Simulation Results for tripping of 1 Pole of Sumatra to Java HVDC line – 2040, Base Scenario, Peak Load

3.6.3.2 2040 ASEAN RE Scenario, Northern Sub-region, Peak Load

The total north peak load is around 411 GW. Following selective interconnection, line tripping contingencies are simulated to evaluate any limit on maximum transfer planned without compromising system stability.

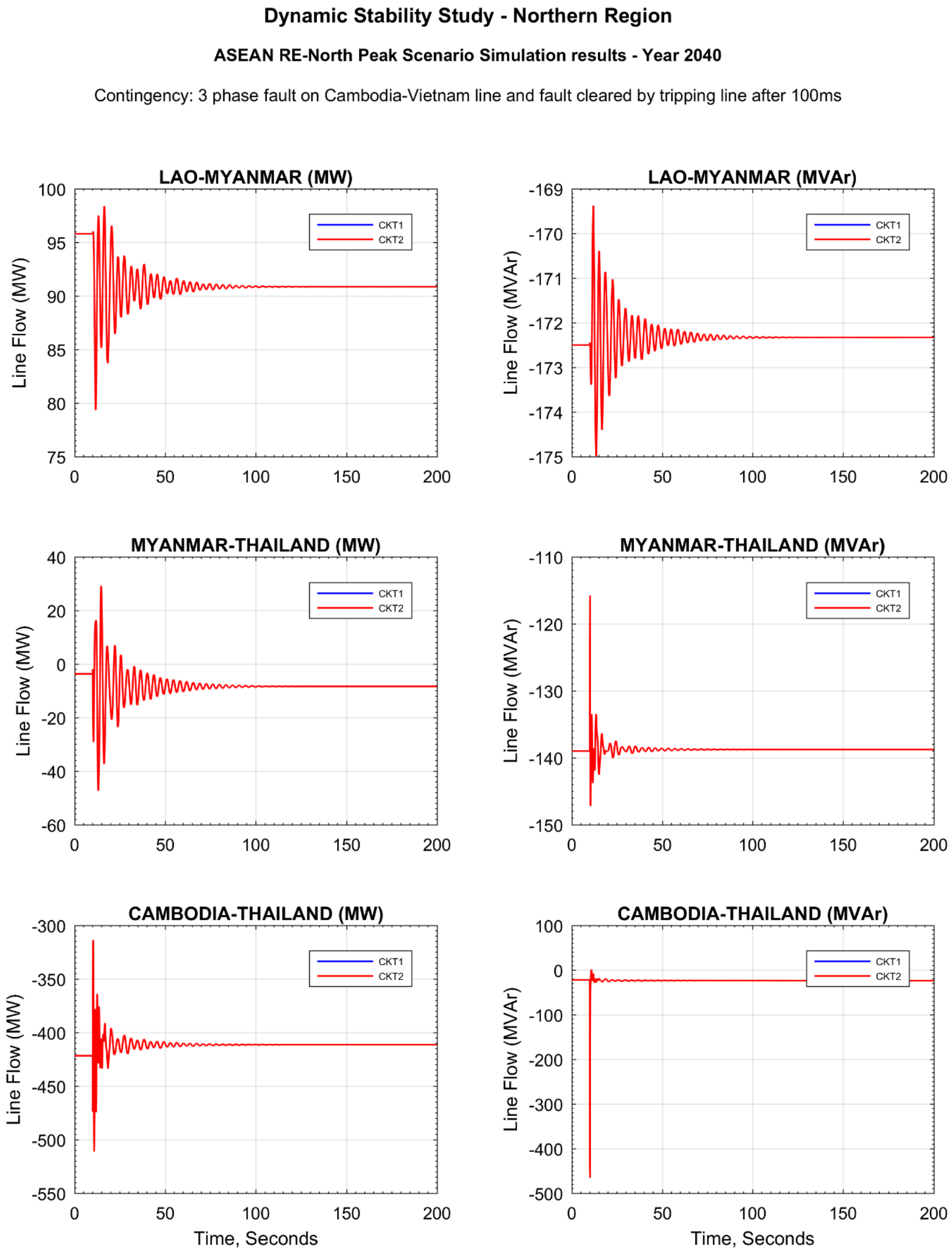


Figure 3-37 Plots of Dynamic Simulation Results for tripping of Cambodia to Vietnam line – 2040, ASEAN RE Target Scenario, Northern Sub-region, Peak Load

Figure 3-37 shows the dynamic simulation plots for tripping one circuit of the Cambodia to Vietnam double circuit following a 3-Phase fault of 100 msec duration. It is observed from the plots that the power gets transferred to the other circuit that is within its thermal loading capability, and the system is stable.

3.6.4 Observation and Recommendations

The grid performance analysis has been conducted to test the technical viability of the proposed interconnection in keeping up with the ASEAN capacity expansion planning reflected in the three study scenarios: Base, ASEAN RE Target and Optimum RE Scenarios.

In grid performance analysis, power flow, (N-1) contingency, and short circuit analyses have been performed to evaluate the steady-state performance of the APG for the existing system (2020) and four future study years (2025, 2030, 2035 and 2040). Three cases have been investigated for each study year, including Base, ASEAN RE Target and Optimum RE Scenarios. Five operating scenarios per study year have been studied.

The technology options (HVDC, HVAC) and high-level conductor configurations are suggested for all the cross-border interconnections proposed as part of the capacity expansion planning study. On this basis, interconnection models are developed. To facilitate the proposed cross-border power transfer for optimum utilisation of resources within the APG, national-level grid strengthening within the AMS on both sides of the interconnection will be required, especially in the case of very high interconnection capacities.

Based on power flow analysis, it is observed that the proposed interconnections are feasible with adequate AMS-level grid strengthening schemes for each of the study years.

Based on (N-1) contingency analysis, it is observed that all the interconnections are compliant with the (N-1) contingency philosophy, except the Peninsular Malaysia to Singapore connection.

Based on stability analysis, in the Southern Sub-region, a loss of one circuit in Peninsular Malaysia to Singapore’s two circuit lines will cause loading on the other circuit to 1,056MW. This leads to an overload of 200% as the rating of the subsea cable is 525 MW on each circuit. To make it compliant, one more circuit needs to be added for this interconnection to facilitate a 1,050 MW power transfer under N-1 contingency conditions.

Overall, from the steady-state analysis, it can be concluded that with adequate grid strengthening at the national grid level of individual AMS, the proposed cross-border interconnections can be feasible for three scenarios (the Base case, ASEAN RE Target and Optimum RE Scenarios). The High RE Target scenario looks challenging from a practical implementation perspective. The detailed pre-feasibility analysis may result in the technical non-viability of these interconnections for this scenario. Hence, grid analysis for the High RE Target Scenario is not conducted in the AIMS III study.

In the stability analysis, the major constraint is to be found under low-frequency oscillations following clearance of faults during contingencies. Even a small contingency lead to growing fluctuations and the system becoming unstable. For different contingencies and system configurations, oscillations in the range of 0.15 to 0.2 Hz have been observed. Hence all stability simulations in this report have been performed with Power System Stabilisers (PSS) installed on generating units above 100 MVA. Even under assumed common PSS parameters, the responses are still oscillatory. The adequately tuned PSS parameters based on a tuning study will provide clean responses. Implementing PSS on all generating units larger than 100 MW is recommended to dampen the oscillations effectively. PSS tuning parameters should be derived based on a detailed PSS tuning study for individual units. PSS should be robust to system operating conditions and should cover a range of frequencies covering inter-area modes (0.1-0.8Hz) and local modes (0.8 to 3 Hz). PSS performance should be tested on site before putting PSS into service.

An interconnection of around 3 to 10 GW of HVDC is proposed between Java and Sumatra for different scenarios to export power from Sumatra to Java. This is achieved through 500 kV multiple poles of 1500 MW per pole. The contingency of tripping of one pole between Java and Sumatra is simulated, and it is observed that Sumatra would see over frequency and Java would see under frequency because of a sudden loss of 1,500 MW. The spinning reserve of 1000 MW (equivalent to the largest unit size in Java) is maintained in Java. It is found that primary frequency response will not be sufficient to bring the frequency back within the acceptable range. Hence for the loss of HVDC pole (1500 MW), it is recommended to have either a special protection scheme to shed the load of around ~600 MW or implement the UFLS with first stage 49 Hz with 200 msec delay and a minimum load shed of 600 MW to bring back the frequency in the Java system to an acceptable range.

Beyond 2030, in the ASEAN RE Target Scenario, in a situation with maximum VRE and peak-load, any contingency on the Lao-PDR interconnection leads to unstable inter-area oscillations reflected in all of the AMS in the Northern Sub-region as Laos is highly interconnected. This limits the power transfer on the interconnections. Hence, strengthening the 500 kV national transmission network within Lao PDR is recommended as given in Table 3-14 and shown in Figure 3-38.

Table 3-14: Proposed 500 kV Transmission Strengthening in the Lao PDR National Grid

From Substation	To Substation	Circuits Added	Voltage
MHA	KM25	1	500 kV
MHA	KM25	2	500 kV
MHA	NBO	1	500 kV
MHA	NBO	2	500 kV
NAMO2	NBO	1	500 kV
NAMO2	NBO	2	500 kV
NORTH-CENTRAL Vietnam	NAMO2	S1	500 kV
NORTH-CENTRAL Vietnam	NAMO2	S2	500 kV

Figure 3-38 Illustration of 500 kV Transmission Strengthening in the Lao PDR National Grid

Beyond 2030, many VRE (>10 GW) plants in Sumatra are planned, mostly in southern Sumatra. The planned infrastructure will not be sufficient to transfer such large amounts of power to export points. The deficit of reactive power can also lead to system collapse. Hence it is recommended that the transmission network in southern Sumatra be strengthened, as suggested in Table 3-15.

Table 3-15: Proposed 500 kV Transmission Strengthening in the Sumatra Grid

From Substation	To Substation	Voltage Level (kV)	Additional Circuits proposed
SUMSEL-6	PLTUJAMBI1	500	1
SUMSEL-6	PLTUJAMBI1	500	2
NEWADURI	PLTUJAMBI1	500	1
NEWADURI	PLTUJAMBI1	500	2
NEWADURI	MENIM	500	1
NEWADURI	MENIM	500	2
GUMAWANG	LAMPUNG-1	275	1
GUMAWANG	LAMPUNG-1	275	2

In the Eastern Sub-region, Sabah, Sarawak and Kalimantan are connected through 275 kV HVAC transmission. Sabah acts as a transit point, wheeling power between Sarawak and Kalimantan (Mahakam). In the peak load scenario, beyond 2035, the loss of one circuit in the Sarawak-Kalimantan (Khatulistiwa grid in West Kalimantan) 275 kV double circuit line leads to the other circuit becoming highly loaded. Sustained inter-area oscillations are observed between Kalimantan (Mahakam grid) and the rest of the AMS in the Eastern Sub-region. To mitigate this issue, the national grid network of Sabah (East to West) needs to be strengthened to interconnection points to Sarawak and Kalimantan (Mahakam).

Assuming the recommendations above are taken into account, all proposed interconnections and the system will be found stable.

3.7 AIMS III Proposed Interconnection Summary

A snapshot of the interconnection ratings in the Base, Optimum RE and the ASEAN RE Target Scenarios for representative years (2025 and 2040) was proposed in the capacity expansion planning and tested in the grid performance analysis.

The high interconnection capacities required in the High RE Target Scenario seem challenging from a practical implementation perspective. A detailed pre-feasibility analysis may result in the technical non-viability of these interconnections. Hence, the High RE Target Scenario has not been included in the AIMS III Proposed Interconnection Summary.

Although generation capacity addition in ASEAN RE Target and High RE Target Scenarios are identical up to 2025, from 2030 onwards, VRE capacity additions are very high in the High RE Target Scenario compared to the other three scenarios (Base, Optimum RE and ASEAN RE Target). In the majority of the AMS, the planned VRE is considerably higher than peak demand leading to high-capacity interconnections, of the order of 10 GW, as a part of capacity expansion planning. Moreover, beyond 2030, the planning data availability at the national grid level of most of the AMS is very limited, as are the plans of the individual AMS irrespective of the large quantum of VRE additions.

Under the AMS' directive, the High RE Target Scenario is considered an "absolute upper limit" and was hence established as a reference point and is not included in the AIMS III Proposed Interconnections.

Table 3-16 shows the official status of the ASEAN Interconnection Projects as of September 2020, and the AIMS III Proposed Interconnection Summary. Note that under the main left column, the status of the ASEAN Interconnection Projects (as per August 2020) was given as a comparison with the proposed interconnection, which is placed under the main right column "Proposed ASEAN Interconnection Projects by the Year".

Table 3-16 also shows the Proposed ASEAN Interconnection Projects by the Year for each scenario, compared to the official status of the ASEAN Interconnection Projects (as of September 2020). In the Proposed APG interconnection Projects produced by the AIMS III study, the summed-up interconnection projects are compared to the official status of the ASEAN Interconnection projects. These alterations are based on consultation with the AMS' updated interconnection priorities. The updates include Java-Kalimantan, Sumatra-Java and Lao PDR-Myanmar as additional proposed interconnection projects in the AIMS III study, where the interconnection project between Batam and Singapore is incorporated with the Sumatra-Singapore Interconnection.[30]

[30] Direction from Singapore AIMS III Working Group (AWG) from the 1st Preliminary Consultative Meeting, 2020.

Table 3-16: Official Status of ASEAN Interconnection Projects and the AIMS III Proposed Interconnection Summary (MW)

Official Status of ASEAN Interconnection Projects (Sep 2020)						Proposed ASEAN Interconnection Projects from the AIMS III study (by the Year)					
No	Connection	Current APG list				Base Case (Existing PDP)		Optimum Case		ASEAN RE Target Case	
		2020	Ongoing (up to 2021)	Future	Total	2025	2040	2025	2040	2025	2040
1	P. Malaysia - Singapore	525	525		1,050	1,050	1,050	1,050	1,050	1,050	1,050
2	Thailand - P. Malaysia	300		400	700	380	380	380	1,155	380	1,043
3	P. Malaysia - Sarawak			1,600	1,600	0	0	79	727	64	695
4	P. Malaysia - Sumatra			600	600	0	600	1,103	2,124	1,067	2,130
5	Batam - Singapore										
6	Sarawak - Kalimantan	230			230	230	230	230	641	230	777
7	Philippines - Sabah			500	500	0	0	144	179	147	196
	Sarawak - Sabah - Brunei										
8	Sarawak - Brunei		30-100	50-300	80-400	30	100	63	71	62	71
	Sabah - Sarawak			0	0	50	50	156	177	156	177
9	Thailand - Lao PDR	5,427		1,310	6,737	5,427	5,427	5,427	5,427	5,427	5,427
10	Lao PDR – Vietnam**	538		5,000	5,538	538	5,000	538	5,000	538	5,000
11	Thailand - Myanmar			11,709-14,859	11,709-14,859	0	300	791	1,104	919	1,262
12	Vietnam - Cambodia	200			200	200	200	329	1,312	328	1,353
13	Lao PDR - Cambodia	200			200	300	300	300	579	306	625
14	Thailand – Cambodia**	230		2,200	2,430	230	230	351	1,370	351	1,315
15	Sabah - Kalimantan				0	0	0	158	159	158	174
16	Sumatra - Singapore				0	0	600	843	1,133	843	1,133
17	Lao PDR - Myanmar (New)				0	300	300	306	609	306	624
	Internal Indonesia										
18	Java - Kalimantan (New)				0	0	0	88	424	9	435
	Sumatra - Java (New)				0	0	3,000	2,890	10,000	7,943	10,000
Existing total		7,650			7,650	8,735	17,767	15,226	33,241	20,284	33,487
Total Additional Connection Required			555-625	23,369-26,769	31,574-35,044	1,085	10,117	7,576	25,591	12,634	25,837

** last update from the AIMS III Working Group Member of Vietnam by 22 August 2021, with a total of 5,000 MW of electricity from Lao PDR by 2030, and 120 MW to 230 MW for Thailand – Cambodia.

The total Additional Connection Required shown in the bottom row of Table 3-16 indicates the AMS' needed effort in adding interconnections. A detailed step needed for each interconnection is also illustrated, such as how many MW are needed per year for a scenario.

The AIMS III found that the total MW of interconnection capacity required in 2040 to establish the APG in all scenarios (Base Scenario– 10,117 MW, Optimum Scenario - 25,591 MW and

ASEAN RE Target Scenario - 25,837 MW) was lower than the official status of the ASEAN Interconnection Projects (31,574 MW - 35,044 MW). In the AIMS III, the interconnection capacity in the Optimum RE and ASEAN RE Target Scenarios was optimised. For the Base Scenario, the AIMS III followed the country's PDP with the coal and gas power plants, and the interconnections were optimised to seek the optimum and most efficient requirements for the AMS to pursue APG.

Compared to both the Optimum RE Scenario and ASEAN RE Target Scenario, the required interconnection size in MW proposed in the AIMS III was about the same, with a difference of only around 200 MW. However, the Proposed ASEAN Interconnection Projects in the Optimum RE Scenario can be an alternative option.

The same situation was found in the ASEAN RE Target Scenario, in which the 2025 target is reflected in the APAEC Target, namely, a 23% share of RE in the TPES. The required interconnection size in MW proposed in the AIMS III by the year 2040 is slightly lower (33,487 MW against 31,574 MW-35,044 MW). Moreover, under the Base Scenario, aiming for higher interconnectivity requires interconnection build cost and room for wind and solar investment. However, with interplay between interconnection build cost and wind and solar investment, the total costs NPV for the ASEAN RE Target Scenario were about the same under the Base Scenario (even USD 20 million cheaper). Therefore, pumping more private sector investment into solar build cost and wind build cost will add to the interconnection build cost. Nevertheless, the combination of interconnection build cost, solar build cost and wind build cost under the APAEC Target Scenario saved variable operation and maintenance (VO&M) Cost, Fuel Cost, FO&M Cost, and eventually cumulative production costs.

These scenarios seem to be convincing and promising for the further adoption of official ASEAN Interconnection Projects. The findings of the AIMS III revealed many benefits for the AMS and will unlock power generation diversification with cleaner energy resources as a possible option. Eventually, the AIMS III findings will open more potential private sector initiatives that could create more robust ASEAN energy connectivity.

4 Conclusion, Recommendations and Way Forward

4.1 Conclusion

The AIMS III sought to strengthen the consideration to build a robust and reliable ASEAN Power Grid (APG) for the benefit of the ASEAN Member States (AMS). With some of the already growing interconnections in and surrounding the ASEAN region, an effort to conceptualise the APG in the context of the recent policy trends towards the energy transition, and trends in technology adoption are imperative for the AMS to look forward to the goals of the ASEAN Economic Community (AEC) as it serves as a platform for the AMS in the moves towards energy security, accessibility affordability, and sustainability within the framework the AEC.

Within ASEAN, progress has so far been focused on bilateral interconnections, but the first phase of a new strategy titled the *ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025* targeted the development of the first multilateral connection and the provision of multilateral electricity trade in at least one subregion.[31] Thus, AIMS III exists as the pathway to move forward the APAEC target and beyond.

The APG will be designed to ensure that the benefits of multilateral power trade will reach all of the AMS. In this light, the AIMS III is the focal point of the APG programme. The AIMS III proposes the need to update the official status of the ASEAN Interconnection Projects. Under three scenarios, the AIMS III provides several interconnections as an option for the new APG policy adoption. The proposed interconnections, based on the AIMS III findings, present a more reliable opportunity since all show less capacity needed than the official ASEAN Interconnection Projects for achieving the same purpose of establishing the APG. Under careful investigation, all of the proposed interconnections in the scenarios in the AIMS III are found to be possible and thus possibly made for ASEAN-level policy adoption and directive for further arrangements of future official ASEAN Interconnection Projects.

The AIMS III suggests that the total MW of interconnection capacity required to establish the APG in all scenarios is lower than the official status of ASEAN Interconnection Projects. The interconnection capacity has been validated by optimising all of the AMS' capacity expansion planning by taking into account country-level directives based on the whole series of consultative meetings with the AIMS III Working Groups. For example, under the Base scenario, the PDP projection for all countries was used, even though coal and gas power plants and the interconnection capacity have been re-optimised to seek the optimum requirements and most efficient ways for the AMS to pursue the APG.

In comparing the Optimum Scenario with the ASEAN RE Target Scenario, the required interconnection size in MW proposed in the AIMS III is about the same, with a difference of only around 200 MW. The Proposed ASEAN Interconnection Projects in the Optimum RE Scenario offer the optimum capital needed among all of the scenarios, with a potential saving of the required capital cost up to USD 5.9 billion. This can be made possible when the AIMS III is fully adopted for further direction and policy choices for all of the AMS.

[31] Mid-Term Review of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016 – 2025 Phase I: 2016-2020.

4.2 Recommendations

At present, the existing electricity trade within the APG occurs on cross-border bilateral terms. The existing Lao PDR-Thailand-Malaysia Power Integration Project (LTM-PIP) had a total interconnection capacity of 1,000 MW in 2018, with around 700 MW coming from RE generation.[32] However, more integrated regional connectivity could further increase RE integration to support the ASEAN RE aspirational target in the power mix by 2025.

The growing demand for electricity in the region is an important issue that ASEAN must address. In parallel, the AMS should reduce their greenhouse gases as required under the United Nations Framework Convention on Climate Change. Indeed, the AMS have submitted their Nationally Determined Contributions (NDCs) and are committed to them. However, for the commitments to become reality by 2025 and beyond, continued momentum needs to be provided in terms of RE deployment in the power sector.

The AIMS III study provides recommendations for the power sector in the region to move towards the establishment of regional power market integration with energy transition as the centrepiece. The study demonstrates the essential findings and benefits in technical, socio-economic and environmental terms to increase the inter-country cooperation between the AMS through power system interconnections to integrate significant RE. As one of the physical energy infrastructure projects in the Master Plan of the ASEAN connectivity, the APG would enable the AMS to meet rising electricity demand, enhance electricity security and system reliability, improve access to energy services in the region and contribute to the region's sustainability goals.

This effort aligns with the unique challenges of the ASEAN power sector, particularly the unmatched demand and supply of RE generation. ASEAN is rich in RE, which collectively refers to hydro, geothermal, wind, solar and bioenergy. The estimated technical potential of the VRE alone is 8,119 GW of solar and 342 GW of wind gross capacity.[33] Around 12,004 TWh/year and 766 TWh/year of gross annual generation can be generated from the estimated technical potential of solar and wind generation in the ASEAN region, respectively. However, connecting these abundant RE resources to the fast-growing electricity market is still the main challenge in addition to the necessity of reducing the variability of VRE generation.

The integration of the power market could connect the abundance of RE resources with the fast-growing electricity demand, particularly in the urban areas. The proposed power market integration will integrate more VRE through resource-sharing across a large geographical area to achieve the ASEAN RE target. Moreover, the proposed cross-border interconnections will be one of the main flexibility resources that can accommodate the flexibility needed due to variability associated with a large share of VRE generation.

Under the ASEAN RE target Scenario, it was estimated that the AMS could reach the additional VRE capacity target of around 83 GW of solar and 12.3 GW of wind capacity, with a total of 5% additional RE share. In achieving the ASEAN RE Target in 2025, it was estimated that ASEAN will require 20,284 MW of interconnection capacity to provide system flexibility while also evacuating these power generations to the electricity markets. Exploring the

[32] Lao PDR supplied 700 MW of hydropower capacity to Thailand in 2018.
[33] RE resource assessment, as part of the AIMS III Phase I study.

opportunity and benefits of having higher VRE and the potential emergence of new and more sustainable technologies with a lower cost in the different time horizons (up to 2040) for advancing multilateral power trade is also being studied.

A significant amount of additional VRE capacity has been estimated throughout the study horizon. Such large-scale deployment of solar and wind power capacities is likely to have socio, economic and environmental impacts. The macroeconomic effects, for instance, are estimated at 100-200k RE jobs in 2040 under the ASEAN RE Target scenario. Under the High RE Target scenario around 700,000 RE jobs (one-time, lifetime direct and indirect) could be generated. As for the environment, it is estimated that the potential for avoided fuel is approximately 259 Mt of coal, 11.2 Mt of oil and 77 million m^3 of natural gas in 2040, reducing the region's dependency on import fuels and increasing security.

The establishment of the APG will occur step-wise, initially on cross-border bilateral terms then gradually expanding to the sub-regional level and finally to an integrated Southeast Asia power grid system. The ASEAN leaders' support for advancing ASEAN energy connectivity in the APG is crucial, particularly to harmonise regulatory frameworks and standards to facilitate regional energy connectivity. The AIMS III covers the region's dynamics and energy landscape development to adopt the economic, social and environmental paradigm changes with the long-term goal of being better prepared for this challenging energy transition.

The geographical situation of the region and the great distances involved would require the use of the latest technologies to realise the Master Plan of the ASEAN power connectivity. The existing infrastructure conditions would not be able to cope if highly volatile, inertia-less power sources of wind and solar were introduced. This should not be seen as a significant drawback. National-level grid strengthening within the AMS on both sides of the interconnection transmission line will be required, especially in the case of very high interconnection capacities. In the future, the loads in the APG are expected to scale up with the projected growth. Upgrades need to be considered to make the future transmission systems adequate for accommodating the additional generation and load growth in the APG system and for anticipation of the variability of wind and solar.

For smooth cross-border power transfer in the future, harmonisation of the grid codes is required to maintain the grid performance at the APG level. Each AMS has different grid codes and may be able follow the different operation, connection, and scheduling codes. Grid modernisation could also be applied by introducing sophisticated technology in Wide Area Monitoring Systems (WAMS), which help monitor and detect abnormal conditions in the APG grid system. They improve the viability of the system and facilitate proactive measures, thereby improving system stability and reliability.

4.3 Way Forward

Phases 1 and 2 of the AIMS III have assessed the current power infrastructures and revealed the potential of increasing VRE in the region. As a way forward, several steps need to be implemented to develop Phase 3 of the study.

The operationalisation of Phase 3 will need to be further developed, which will focus on minimum requirements for multilateral market development, regulatory frameworks and technical standards and grid code.

The implementation plan needs to be brought to the national level to realise the proposed interconnections further, and a feasibility study must be conducted to support the implementation. A further study based on the AIMS III findings would provide a better way for the ASEAN countries to firm up their positions and realise full operationalisation of the APG.

High-level and solid political commitments will be needed to support the integration of the APG. The political requirements include intergovernmental agreements and an agreement on a common technical language. Recommendations related to particular intergovernmental contracts should be the central theme of this study. Agreements may be needed to establish and/or designate specific authorities to relevant regional institutions. The political will to support integration is the most crucial matter, as it is one of the elements that differentiates cross-border integration from power system development within a single jurisdiction

Exploring the APG for further interconnectivity beyond the ASEAN region would also be an excellent way to move forward. Progress has been focused on bilateral interconnections within ASEAN through the pilot *Lao PDR, Thailand, Malaysia Power Integration Project* (LTM-PIP). In the northern border of the ASEAN northern sub-region, there is also an interconnection which has been under development. It is connected to China under the Greater Mekong Subregion (GMS) power framework. In 2017, ASEAN exchanged about 51.7 TWh with Yunnan and Guangxi Provinces in China via seven 500 kV cross-border transmission lines (one line between Yunnan-China and Myanmar, six lines in between Lao PDR and Thailand). Further efforts on grid integration of countries in South Asia were shown to enhance cooperation—with energy as a priority—with the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC). Within the centre of the region, there has been particular interest in tapping the hydropower potential in Cambodia, Lao PDR and Myanmar for domestic use and cross-border interconnections to supply the growing demand in Thailand, Malaysia, Singapore and Vietnam, as a means of facilitating trade and underpinning the development of a regional power market.

By looking at some of the emerging grid integration initiatives, the APG offers a centrepiece to ensure that multilateral power trade benefits could reasonably reach all AMS. Therefore, the AIMS III is the focal point of the APG programme. The AIMS III proposes the need to update the official status of ASEAN Interconnection Projects. In three scenarios, the AIMS III provides several interconnections as an option for the new APG policy adoption. In general, the proposed interconnection based on the AIMS III findings presents a more reliable opportunity since all show lower capacity requirements than the official ASEAN Interconnection Projects for achieving the same purpose of establishing the full APG. Under careful investigation, all of the proposed interconnections under the scenarios are acceptable, and are thus possibly made for ASEAN-level policy adoption and directive for further arrangements of future official ASEAN Interconnection Projects.

HEADS OF ASEAN POWER UTILITIES/AUTHORITIES (HAPUA)

Heads of ASEAN Power Utilities/Authorities (HAPUA) is the official ASEAN Specialised Energy Body to implement the ASEAN Power Grid (APG) under the ASEAN Plan of Action for Energy Cooperation (APAEC). Its member includes the Department of Electrical Services of Brunei Darussalam, Electricité du Cambodge of Cambodia, PT PLN (Persero) of Indonesia, Electricité du Laos of Lao PDR, Tenaga Nasional Berhad of Malaysia, Department of Electric Power of Myanmar, National Power Corporation of Philippines, Singapore Power Limited of Singapore, Electricity Generating Authority of Thailand, and Electricity of Vietnam.

Its objective is to promote cooperation among its members to strengthen regional energy security through interconnection development, enhancing private sector participation, encouraging the standardization of equipment, promoting joint project development, cooperation in human resources, research & development, and enhancing quality & reliability of electricity supply system.

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ASEAN CENTRE FOR ENERGY (ACE)

Established on 1 January 1999, the ASEAN Centre for Energy (ACE) is an intergovernmental organisation within the Association of Southeast Asian Nations' (ASEAN) structure that represents the 10 ASEAN Member States' (AMS) interests in the energy sector. The Centre accelerates the integration of energy strategies within ASEAN by providing relevant information and expertise to ensure the necessary energy policies and programmes are in harmony with the economic growth and the environmental sustainability of the region. It is guided by a Governing Council composed of Senior Officials on Energy from each AMS and a representative from the ASEAN Secretariat as an ex-officio member. Hosted by the Ministry of Energy and Mineral Resources of Indonesia, ACE's office is located in Jakarta.

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