Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The potential contribution of projected ASEAN Power Grid to emission reduction

Ibnu Budiman (ibnu.budiman@wur.nl)
Wageningen University & Research https://orcid.org/0000-0002-9128-0866
Akbar Swandaru
ASEAN Center for Energy
Beni Suryadi
ASEAN Center for Energy

Research Article

Keywords: ASEAN Power Grid, renewable energy, solar energy, wind energy, emission reduction potential

Posted Date: December 9th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1141749/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Abstract

This paper analyzed the potential contribution of the projected ASEAN Power Grid (APG) with increased contribution of renewable energy (RE) in the power system, toward emission reduction in South East Asia, both in region and country level, in three different scenarios (Baseline, ASEAN Target, and Optimum RE). Data collection was done with a series of (co-creation) consultation meetings with countries in the region and international energy institutes. Estimation of emission reduction from CO2 and N2O was calculated based on projected solar and wind capacity addition to replace fossil fuel consumption in the APG. We found that the potential contribution of the projected APG toward emission reduction in South East Asia is up to 112,267 million tons of CO2 and 64 thousand tons of N2O by 2040, under the optimum RE scenario. The source of that contribution is varying at the country level. Countries with potential significant contributions are Thailand, the Philippines, Vietnam, Malaysia, and Indonesia. Countries like Singapore and Brunei that have a relatively small contribution to the region, also having progressive trends to meet the RE target and its emission reduction. This trend shows a potential progressive improvement for those countries to reduce their emission from the energy sector by 2040. With their current high base scenario, they may reach a higher target in the future to integrate variable RE to the APG and contributing to emission reduction in the region.

Highlights

- ASEAN is planning to expand the Interconnected Power Grid with increased contribution of renewable energy (RE) in the power system
- We assessed projected emission reduction from the new ASEAN interconnected power plan.
- We compared projected emission reductions in ten ASEAN countries based on three scenarios.
- The projected emission reduction is up to 112,267 million tons of CO2 and 64 thousand tons of N2O by 2040, under optimum RE scenario
- Countries with potential significant contributions are Thailand, the Philippines, Vietnam, Malaysia, and Indonesia.

Introduction

As the fast economic growth[1] arises in South East Asia, the energy demand increases substantially, as in comparison to other regions of Asia (Erdiwansyah et al., 2019; *The 5th ASEAN Energy Outlook (AEO5)*, 2017). Sustained population and economic growth will considerably increase the Total Final Energy Consumption (TFEC) by 1.6 times in 2015–2040 (Kimura & Phoumin, 2019). Meaning, the total primary energy supply (TPES) in the southeast region is forecasted to rise at a slightly slower pace of 1.5% per year (Kimura & Phoumin, 2019). As such the southeast region is expected to increase from 7,488 Mtoe (as recorded per 2015) to 10,943 Mtoe in 2040. Coal will remain the largest share of the TPES[2] (Kimura & Phoumin, 2019).

To accelerate the energy transition and meeting climate targets, the ASEAN power grid (APG) was endorsed by countries in South East Asia, under the ASEAN plan of action for energy cooperation (APAEC) 2016-2025 (*ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025*, 2015, pp. 2016–2025). The Association of Southeast Asian Nations (ASEAN) represents 10-member countries: Brunei, Cambodia, Indonesia, Malaysia, Myanmar, Lao PDR, Philippines, Singapore, Thailand, and Vietnam.

The primary aim of APG is to advocate regional energy security by promoting effective utilization and unlocking better growth of renewable resources for the benefit of the ASEAN region (Utama et al., 2012). The aims are also extended to enhance cross-border electricity trade by interconnecting the national power grid effectively and reliably for the best economic purpose; through the participation sharing of surplus power export for securing the demand-supply (Ahmed, Mekhilef, Shah, Mithulananthan, et al., 2017). APG is expected to be contributing to the establishment of the plan for future energy transactions and, in the long term, could be made for mutually implementing the renewable energy resources within ASEAN and therefore seamlessly reduce the dependency on the fuel-based power source and reducing GHGs emission (Ahmed, Mekhilef, Shah, & Mithulananthan, 2017).

APG has the potential to promote knowledge enhancement, and even possible, technology transfer between ASEAN and other countries (Brinkerink et al., 2019; Gielen et al., 2019). It is important to note that addressing the analysis of the technical, economic, environmental, and socio-political matters related to the integration of (mostly) remotely located renewable generation into APG is necessary (Pranadi et al., 2018). Moreover, the need of delivering assessments of the major barriers and limitations for the establishment of APG is essential for pushing the establishment of APG in the Southeast Asian region. APG is expected to help, ASEAN to achieve its goal of increasing renewable energy resource share in its energy investment planning from approximately 23% by 2025 (*ACE 20th Anniversary Book*, 2018; Huang et al., 2019).

By the end of 2014, 11 power grid interconnections between 6 pairs of countries were in commercial operation (Andrews-Speed, 2016). The Lao PDR, Thailand, and Myanmar are the starting point of the APG (Kimura & Phoumin, 2019). Currently, ASEAN is planning to build more interconnections until 2030. Efforts to achieve this target will encourage the development of renewable energy and has the potential to contribute to sustainability by meeting Intended National Determined Contribution from countries in ASEAN to Paris Agreement, for their climate mitigation from the energy sector (Aris & Jørgensen, 2020; Chang & Li, 2013; Matsuo et al., 2015).

Available renewable energy technologies such as solar energy, wind energy, hydropower, geothermal, and biomass will have to be explored in APG to establish a low emission power system (Overland et al., 2021). Attention and priority should be focused on technologies to tap energy sources from hydropower, geothermal, and biomass because it is vastly available at the cheapest cost. This is crucial as climate action because many ASEAN countries such as Indonesia, Thailand, the Philippines, Vietnam, and Myanmar are highly exposed to climate change based on the Global Climate Risk Index (Veng et al., 2020).

Many previous studies have modelled how the increase of renewable energy shares will certainly contribute to emission reduction and maintaining regional energy security through the reduction of imported fossil fuel consumption and increasing the use of domestic energy (Anbumozhi et al., 2018; Kimura &

Phoumin, 2019). Yet, those studies have not identified emission reduction from long-term APG plan in different scenarios and different year targets (Aris & Jørgensen, 2020; Chang & Li, 2013; Matsuo et al., 2015).

This paper aims to analyze the potential contribution of the projected APG (especially the projected increased contribution of renewable energy in the energy mix in the power system) toward emission reduction in the ASEAN Member States (AMS). We investigate how significant is the potential contribution of emission reduction from variable renewable energy (vRE) in the projected APG in three different scenarios.

[1] The increase of GDP per capita (PPP) of countries in South East Asia has been more than doubled over a seventeen-year period, from constant PPP USD of 4,470 in 2000 to constant PPP USD of 12,361 by 2017 (*SME Policy Index: ASEAN 2018 - BOOSTING COMPETITIVENESS AND INCLUSIVE GROWTH*, 2018). Further the Asian Development Bank (ADB) forecasting report has been shown that Southeast Asia are able to maintain its 2017 growth rate of 5.2% in 2018 and 2019 (*Asian Development Outlook 2018*, 2018). In addition, the increasing rate of ASEAN countries GDP would be expected reaches up to 4.6% until by the year of 2040 and could attribute to the global GDP increment from 5.9–7.7% within this period (*The 5th ASEAN Energy Outlook (AEO5)*, 2017).
[2] However, its growth is expected to be slower, and it is observed to be increasing at only 1.3% per year. Consequently, the share of coal in the TPES is forecasted to decline from 41.4% in 2015 to 38.9% in 2040.

Methods

Data collection and analysis in this study were done under the ASEAN Interconnection Master Study (AIMS) III Project that contributes to the APG plan, organized by HAPUA and ASEAN Center for Energy.

2.1 Modelling and co-creation

Data collection went underway during March-April 2019, along with the series of (co-creation) consultation meetings with AMS and international energy institutes such as NREL, HNEI, IEA, and IRENA. The initial step under this task was to prepare the Data Requisition templates which were to be perused by the respective AMS.

Under the AIMS-III project, an assessment has been made for power capacity addition in the ASEAN region by 2040 including variable renewable energy (vRE) through solar and wind power systems. The study has been conducted under three scenarios:

1. Base Scenario – this case was to form the baseline for the subsequent analysis Scenarios. The building blocks for this scenario were 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.
2. ASEAN RE Target Scenario – under this scenario, the main point of difference with Optimum RE Scenario was that the vRE capacity additions were provided as a firm input in PLEXOS, determined in line with the projections under Progressive Scenario (APS) as laid out in the ASEAN Energy Outlook 5 (AEO5) for key study years of 2025, 2030, and 2040. These targets were set to achieve the regional RE target in the energy mix as per ASEAN Energy Outlook 5 (10-12% of vRE by 2025 and 15% by 2040). However, as the study progressed, there was a simultaneous process being undertaken of enhancing these RE targets under ASEAN Energy Outlook 6 (AEO6) up to 2025, which were then projected up to 2040. To ensure consistency between the numbers reported in these simultaneous studies, it was decided that the targets under this scenario shall also be considering the AEO6 as a reference.
3. Optimum RE Scenario – under this scenario, the aim was to develop optimized thermal, vRE, and transmission interconnections projections. For this purpose, all capacity beyond the PDP was re-optimized (except hydro). The non-committed thermal plants under PDP namely the ones where construction has not commenced or where the PPA has not been signed were also re-optimized under this scenario. This was done to make this case outputs purely taken on an economic basis (with minimal 'hard inputs') by PLEXOS which also co-optimizes generation and interconnection requirements. We are referring to this as free economic optimization.

In this study, we estimated the amount of CO_2 and N_2O emissions avoided due to the deployment of vRE especially solar and wind power projects in the projected APG under the three scenarios planned in the AIMS III.

2.1.1 Estimating emissions reduction

Avoided CO_2 and N_2O emissions that are achievable from vRE deployment based on the AIMS-III project are estimated for each of the scenarios. The approach adopted for estimating the avoided CO_2 and N_2O emissions is shown in the Figure below.

Key steps adopted and the accompanying data input used are explained in the following subsections[1].

2.1.2 Estimating solar and wind capacity additions and electricity generation

First, we estimated electricity generation from projected solar and wind power plants integration in the APG. Annual solar and wind capacity additions (in MW) in each ASEAN member state (AMS) obtained from the PLEXOS simulation are converted into electricity generation (in MWh) by applying the capacity utilization factor for wind and solar power plants for each AMS. The capacity utilization factors for wind and solar power plants are taken from the estimates

developed by UL (AWS Truepower) analysis. We found that the plant capacity factors for solar power plants in AMS range from 18.3 % to 20.9 % and from 24.2% to 32.8% for wind[2] power plants.

2.1.3 Estimating avoiding fossil fuel consumption

Second, we estimate avoiding fossil fuel consumption due to the solar and wind integration. To estimate it, we combine calculations from the plant capacity factors with the energy mix in each AMS.

It is assumed that if the vRE generation estimated under the AIMS-III project were not available, the same amount of electricity would be supplied from coal, oil, and natural gas power sources.[3] For each AMS, the fuel mix is different based on the coal, oil, or natural gas-based generation. Table 2 shows the energy mix for AMS.

Table 1: Energy mix in ASEAN in 2018[4]

Energy Mix	Coal	Gas	Hydro	Solar	Wind	Oil	Others
Brunei Darussalam	0%	100%	0%	0%	0%	0%	0%
Myanmar	4%	46%	50%	0%	0%	0%	0%
Cambodia	13%	13%	13%	13%	13%	13%	25%
Indonesia	50%	0%	49%	0%	0%	1%	0%
Lao PDR	4%	0%	95%	1%	0%	0%	0%
Malaysia	13%	13%	13%	13%	13%	13%	25%
Philippines	60%	12%	9%	2%	1%	0%	16%
Singapore	0%	97%	0%	1%	0%	0%	2%
Thailand	23%	67%	7%	1%	1%	0%	2%
Viet Nam	41%	23%	35%	0%	0%	0%	0%

The table above shows that some countries do not consider certain power-based generation, thus affecting their equivalent fossil fuel-based energy mix. For example, in the case of Singapore and Brunei, no coal-based generation has been considered. From the above table, an equivalent energy mix of coal, oil, and natural gas-based power is developed for vRE power generated in each AMS as shown in Table 3.

Table 2: Equivalent mix for coal, oil, and natural gas-based electricity

Equivalent Fossil Fuel Based Energy Mix	Coal	Gas	Oil
Brunei Darussalam	0.0%	100.0%	0.0%
Myanmar	7.8%	92.2%	0.0%
Cambodia	33.3%	33.3%	33.3%
Indonesia	98.9%	0.0%	1.1%
Lao PDR	100.0%	0.0%	0.0%
Malaysia	33.3%	33.3%	33.3%
Philippines	82.9%	17.1%	0.0%
Singapore	0.0%	100.0%	0.0%
Thailand	25.4%	74.6%	0.0%
Viet Nam	63.8%	36.2%	0.0%

Third, we combined the equivalent coal, oil, and natural gas-based electricity with plant heat rate and calorific value of fuels, to estimate the amount of avoided fuel (coal, oil, and natural gas) consumption.

2.1.4 Calculating average plant heat rate and calorific value of fuels

The weighted average plant heat rate for each AMS is calculated based on the proportion of power plants installed capacity based on (a) sub-critical coal, (b) super-critical coal, (c) diesel, (d) fuel oil, (e) gas turbine, and (f) combined cycle co-generation. The efficiency and the installed capacity of fossil fuel power plants considered for the study for each AMS are used for the calculation. The average efficiency is ranged from 32.42% to 39.45%[5].

For the calorific value, we derived it from the AIMS III simulation. The table below shows the calorific value for coal, oil, and natural gas.

Table 3: Calorific value of fuel

Calorific Value	kCal/kg
Coal	6,000
Oil	9,500
Natural Gas	8,750

2.1.5 Estimating avoided emission

Next, we used the amount of avoided fuel (coal, oil, and natural gas) consumption to estimate emission reduction from that consumption.

The IPCC 2006 Tier 1 emission factors for bituminous coal, diesel oil, and natural gas are applied to estimate the avoided CO_2 and N_2O emissions from the projected vRE deployment under different scenarios.[6] The N_2O emission factor is adjusted with a GWP[7] factor of 298 to obtain emission estimates in CO_2-equivalent.

Table 4: IPCC 2006 Tier 1 Emission factors[8]

Fuel Type	CO_2 Emission Factor (IPCC 2006 - Tier 1) - Kg/TJ			N_2O Emission Factor (IPCC 2006 - Tier 1) - Kg/TJ		
	Lower	Default	Lower	Default	Lower	Default
Other Bituminous Coal	89,500	94,600	99,700	0.5	1.5	5
Gas/Diesel	72 600	74,100	74 800	0.2	0.6	2
Natural Gas	54 300	56,000	58 300	0.03	0.1	0.3

[1] An Excel spreadsheet model has been developed to estimate the avoided CO_2 and N_2O emissions for each AMS.
[2] * For wind power, the average of capacity utilization factors of other AMS has been used for Brunei, Indonesia, Malaysia, and Singapore.
[3] The generation mix input to the model is based on the AIMS III.

[4] *Data source: AIMS III simulation*
[5] Data source: AIMS III simulation
[6]Chapter 2: Stationary Combustion. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

[7] Global Warming Potential

[8] There are no refinements to the IPCC 2006 emission factors for CO_2 and N_2O in the IPCC 2019 version. Also, the default emission factors are used in the present analysis.

Results

3.1 Future interconnections and their vRE

Further extensions of the ASEAN Power Grid to neighbouring countries are under development or active consideration. The subregion is also 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 between China and Myanmar, six between Lao PDR and Thailand). Australia is actively investigating the potential of exporting solar electricity via a submarine HVDC cable to Singapore, and countries in South Asia are seeking to enhance cooperation—with energy as a priority—through the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC).

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 to initiate multilateral electricity trade in at least one subregion by 2018 (*Mid-Term Review of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016 – 2025 Phase I: 2016-2020*, 2018, pp. 2016–2020). The pilot *Lao PDR, Thailand, Malaysia, Singapore Power Integration Project* (LTMS-PIP) will enable Malaysia to purchase up to 100 MW electricity power from Lao PDR using Thailand's existing transmission grid. It is a stepping-stone for multilateral electricity trade towards realizing the APG beyond neighboring borders (*Partner Country Series - Development Prospects of the ASEAN Power Sector*, 2015). For the pilot multilateral electricity trading, Lao PDR-Thailand-Malaysia signed a cross-border power and transmission agreement in September 2017 (Wu, 2016). Since 1 January 2018, Lao PDR has begun its electricity trading to Malaysia through the LTM contract, while Thailand is a power wheeler.

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 growing demand in Thailand, Malaysia, Singapore, and Vietnam, as a means of facilitating trade and underpinning the development of a regional power market.

3.2 Projected emission reduction in South East Asia

The figure below shows the gradual increase of avoided fossil fuel consumption from 2025, 2030, to 2040 in three scenarios, due to the increase in solar and wind energy shares in the energy mix. By 2040, under the base scenario, 30,129 thousand tons of coal, 1,378 thousand tons of oil, and 17,524 million m3 of natural gas consumption are estimated to be avoided due to vRE generation. This decrease in fossil fuel consumption will bring significant emission reduction up to 67,582 million tons of CO_2 and 36 thousand tons of N_2O.

In ASEAN RE Target Scenario, estimation of emission reduction increases. Avoided fuel consumption is projected up to 48798 thousand tons of coal, 2092 thousand tons of oil, and 13607 million m3 of gas. This will reduce 90,852 million tons of CO_2 and 57 thousand tons of N_2O emissions by 2040.

In the optimum RE Scenario, emission reduction is even higher. Avoided fuel consumption is estimated at around 53,118 thousand tons of coal, 4,098 thousand tons of oil, and 22960 million m3 of gas. This will lead to 112,267 million tons of CO_2 and 64 thousand tons of N_2O emissions reductions by 2040.

Table 5 Avoided Emissions in 2040 All Scenarios - ASEAN Region

	Base scenario		Optimum RE		ASEAN RE TARGET	
	CO_2	N_2O (in CO_2 eq.)	CO2 (Million Tons)	N2O (in CO2 eq)	CO2 (Million Tons)	N2O (in CO2 eq)
Technology	Million Tons	Thousand Tons	Million Tons	Thousand Tons	Million Tons	Thousand Tons
COAL	43,353	34	76,432	60	70,216	55
OIL	2,460	1	7314	2	3734	1
NATURAL GAS	21,769	1	28,521	2	16,902	1
Total	67,582	36	112,267	64	90,852	57

Emission reduction per country

Subsections below explain the trend on avoided fossil fuel consumption and emission reduction per country in South East Asia, due to projected vRE integration into APG by 2040.

Brunei Darussalam

Under the base scenario, Brunei expects to avoid 244 thousand m3 of natural gas consumption due to vRE generation by 2040. This projection is estimated to reduce emissions by 303 million tons of CO_2 and 18 thousand tons of N_2O emissions.

The result of the base scenario of Brunei is closed to the ASEAN RE Target Scenario where avoided fuel consumption due to vRE generation is estimated at around 295 thousand m3 of natural gas. This change will increase emission reduction up to 366 million tons of CO_2 and 22 thousand tons of N_2O by 2040.

While in Optimum RE Scenario, avoided fuel consumption is higher, up to 326 thousand m3 of natural gas consumption is estimated to be avoided due to more vRE generation. This is expected to reduce emissions by 404 million tons of CO_2 and 25 thousand tons by 2040.

Cambodia

Under the base scenario, Cambodia is not planned to reduce any fossil fuel consumption. Thus, no emission reduction is expected to happen by 2040. Yet, ASEAN encourages Cambodia to adopt or adapt ASEAN RE Target Scenario where avoided fuel consumption is expected up to 356 thousand tons of coal and 388 thousand tons of oil to be avoided due to vRE generation. This target can help the country to reduce their emission by 1205 million tons of CO_2 and 579 thousand tons of N_2O emissions by 2040.

With international supports, Cambodia may be able to follow the Optimum RE Scenario where their vRE generation will reduce fossil fuel consumption by 847 thousand tons of coal and 925 thousand tons of oil by 2040. This projection will reduce the country's emissions up to 2869 million tons of CO_2 and 1379 thousand tons of N_2O by 2040.

Indonesia

Under the Base scenario, Indonesia is planning to reduce 476 thousand tons of coal consumption due to vRE generation by 2040. This change will reduce the country's emissions up to 685 million tons of CO_2 and 540 thousand tons of N_2O emissions by 2040.

The base scenario of Indonesia is way below the ASEAN RE Target Scenario where 22,339 thousand tons of coal consumption is expected to be avoided due to vRE generation by 2040. This target can help the country to cut their emission up to 32,508 million tons of CO_2 and 25,407 thousand tons of N_2O emissions by 2040.

In contrast with other countries, Optimum RE Scenario in Indonesia is lower than the ASEAN RE target for the country. Under the optimum RE scenario, Indonesia is expected to reduce 14,425 thousand tons of coal consumption due to vRE generation. This will lead to 20,757 million tons of CO_2 and 16,347

thousand tons of N_2O emissions reduction by 2040.

Lao PDR

Under the Base scenario and Optimum RE Scenario, Lao does not plan to reduce any fossil fuel consumption. Thus, it will not help the country to reduce their emission until 2040.

However, under ASEAN RE Target Scenario, Lao is expected to reduce 2,204 thousand tons of coal consumption due to vRE generation by 2040. This will help to reduce the country's emissions up to 3,172 million tons of CO_2 and 2498 thousand tons of N_2O emissions by 2040.

Malaysia

Under the Base scenario, Malaysia is planning to reduce 1,285 thousand tons of coal, 1374 thousand tons of oil, and 928 thousand m3 of gas consumption due to vRE generation by 2040. This target will reduce the country's emissions up to 5453 million tons of CO_2 and 2149 thousand tons of N_2O emissions by 2040.

Same as Brunei, Malaysia's baseline is closed to their ASEAN RE target, where the country is expected to reduce 1402 thousand tons of coal, 1500 thousand tons of oil, and 1012 thousand m3 of gas consumption due to vRE generation by 2040. This will help the country to reduce their emission by 5951 million tons of CO_2 and 2345 thousand tons of N_2O emissions in 2040.

Under the Optimum RE scenario, Malaysia is expected to double the reduction of its fossil fuel use. Avoided fuel consumption is expected around 2844 thousand tons of coal, 3042 thousand tons of oil, and 2053 thousand m3 of gas due to vRE generation by 2040. This will reduce 12,071 million tons of CO_2 and 4756 thousand tons of N_2O emissions in 2040.

Myanmar

Under the Base scenario, Myanmar is planning to reduce 701 thousand m3 of natural gas consumption due to vRE generation by 2040. This change will help to reduce the country's emissions up to 952 million tons of CO_2 and 117 thousand tons of N_2O emissions in 2040.

Under the ASEAN RE target scenario, Myanmar is expected to triple its fossil fuel reduction. Avoided fuel consumption is expected around 2268 thousand m3 of natural gas consumption due to vRE generation by 2040. This will boost emission reduction in the country up to 3080 million tons of CO_2 and 378 thousand tons of N_2O emissions in 2040.

In the Optimum RE scenario, the reduction of fossil fuel use is higher. Avoided fuel consumption is estimated up to 3341 thousand m3 of natural gas due to vRE generation by 2040. This will increase emission reduction to 4539 million tons of CO_2 and 757 thousand tons of N_2O in 2040.

Philippines

Under the Base scenario, the Philippines is planning to reduce 10,994 thousand tons of coal consumption due to vRE generation by 2040. This change will reduce the country's emissions up to 18,150 million tons of CO_2 and 12,600 thousand tons of N_2O in 2040.

In contrast to other countries, the ASEAN RE target scenario for the Philippines is lower than the country base scenario. Avoided fuel consumption due to vRE generation by 2040 is estimated at around 10,171 thousand tons of coal consumption. This target will help the country to reduce its emission of about 16,792 million tons of CO_2 and 11,657 thousand tons of N_2O in 2040.

Under the Optimum RE scenario, the Philippines is expected to increase its emission reduction. Avoided fuel consumption is projected around 15,279 thousand tons of coal consumption. This projection will lead to 17,530 million tons of CO_2 and 12,170 thousand tons of N_2O emissions reduction by 2040.

Singapore

Under the Base scenario, Singapore is planning to reduce 1432 thousand m3 of natural gas consumption due to vRE generation by 2040. This will reduce the country's emissions to 1779 million tons of CO_2 and 108 thousand tons of N_2O emissions in 2040.

Besides the Philippines, Singapore is another country with a higher base target compared to the ASEAN RE target scenario. The difference is significant, more than threefold. Under the ASEAN RE target scenario, Singapore is only expected to reduce 444 thousand m3 of natural gas consumption by 2040. This will only lead to 552 million tons of CO_2 and 34 thousand tons of N_2O emissions reduction by 2040.

Under Optimum RE Scenario, Singapore is expected to raise its base scenario. Avoided fuel consumption is expected to reach 2,077 thousand m3 of natural gas consumption to be replaced by vRE generation by 2040. This will cut the country's emissions by around 2,580 million tons of CO_2 and 157 thousand tons of N_2O in 2040.

Thailand

Under the Base scenario, Thailand is planning to reduce 3,674 thousand tons of coal and 7,783 thousand m3 of natural gas consumption to be replaced with vRE generation by 2040. This will reduce the country's emissions up to 14,955 million tons of CO_2 and 4751 thousand tons of N_2O in 2040. Almost the same as Singapore, the base scenario of Thailand is higher than their ASEAN RE Target scenario.

Under ASEAN RE Target Scenario, Thailand is only expected to replace 2,126 thousand tons of coal and 4,505 thousand m3 of natural gas consumption with vRE generation by 2040. This will cut the country's emissions by around 8,655 million tons of CO_2 and 2,750 thousand tons of N_2O in 2040.

In contrast to other countries, the base scenario of Thailand is also higher than their Optimum RE Scenario. Under Optimum RE Scenario, Thailand is expected to replace 2,966 thousand tons of coal and 6,284 thousand m3 of natural gas consumption with vRE generation by 2040. This will lead to 12,073 million tons of CO_2 and 3,836 thousand tons of N_2O emissions reduction in 2040.

Vietnam

Under the Base scenario, Vietnam is planning to replace 13,644 thousand tons of coal and 4,559 thousand m3 of natural gas consumption with vRE generation by 2040. This will reduce the country's emissions up to 25,296 million tons of CO_2 and 15,806 thousand tons of N_2O emissions in 2040. Same as the Philippines, this baseline of Vietnam is higher than their ASEAN RE Target Scenario.

Under the ASEAN RE Target scenario, Vietnam is only expected to replace 10,016 thousand tons of coal and 3,347 thousand m3 of natural gas consumption with vRE generation by 2040. This will only reduce the country's emissions up to 18,571 million tons of CO_2 and 11,603 thousand tons of N_2O in 2040.

In Optimum RE Scenario, Vietnam is expected to raise its target, to replace 21,148 thousand tons of coal and 7,067 thousand m3 of natural gas consumption with vRE generation by 2040. This will help the country to reduce their emission by 39,209 million tons of CO_2 and 24,499 thousand tons of N_2O in 2040.

Table 6 Avoided fossil fuel consumption and emission reduction per country.

Countries	Scenarios	BASE SCENARIO			OPTIMUM RE			ASEAN RE TARGET		
		AVOIDED FUEL CONSUMPTION	AVOIDED EMISSIONS		AVOIDED FUEL CONSUMPTION	Avoided emissions		Avoided fuel consumption	Avoided emissions	
	Energy sources	Coal and oil (Thousand Tonnes); Natural gas (Thousand m^3)	CO2 (Million Tons)	N2O (in CO2 eq) Thousand Tons	Coal and oil (Thousand Tonnes); Natural gas (Thousand m^3)	CO2 (Million Tons)	N2O (in CO2 eq) Thousand Tons	Coal and oil (Thousand Tonnes); Natural gas (Thousand m^3)	CO2 (Million Tons)	N2O (in CO2 eq) Thousand Tons
Brunei	COAL	0	0	0	0	0	0	0	0	0
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS	244	303	18	326	404	25	295	366	22
	Total									
Cambodia	COAL	0	0	0	847	1219	960	356	512	403
	OIL	0	0	0	925	1650	419	388	693	176
	NATURAL GAS	0	0	0	0	0	0	0	0	0
	Total									
Indonesia	COAL	476	685	540	14425	20757	16347	22339	32144	25314
	OIL	4	8	2	132	235	60	204	364	93
	Total									
Lao	COAL	0	0	0	0			2204	3172	2498
	OIL	0	0	0	0	0	0	0		
	NATURAL GAS	0	0	0	0	0	0	0	0	0
	Total					0	0			
Malaysia	COAL	1285	1848	1456	2844	4092	3222		2017	1589
	OIL	1374	2452	623	3042	5428	1379		2676	680
	NATURAL GAS Total	928	1152	70	2053	2551	155		1258	76
Myanmar	COAL	57	81	64	269	388	305	183	263	207
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS Total	701	871	53	3341	4151	252	2268	2817	171
Philippines	COAL	10994	15819	12458	10619	15279	12033	10171	14635	11526
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS Total	1877	2331	142	1812	2251	137	1736	2157	131
Singapore	COAL	0	0	0	0	0	0	0	0	0
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS Total	1432	1779	108	2077	2580	157	444	552	34
Thailand	COAL	3674	5286	4163	2,966	4268	3361	2126	3059	2409
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS Total	7783	9669	588	6,284	7805	475	4505	5596	340
Vietnam	COAL	13644	19633	15461	21148	30431	23965	10016	14413	11350
	OIL	0	0	0	0	0	0	0	0	0
	NATURAL GAS Total	4559	5664	344	7067	8778	534	3347	4158	253

Comparing emission reduction scenarios among countries

At the ASEAN level, the results show that the increase of vRE generation in the APG by 2040 under the ASEAN RE target scenario and optimum RE scenario can increase the achievement of emission reduction in the region by almost double, compared to the base scenario. It can cut the region's emissions up to 112,267 million tons of CO_2 and 64 thousand tons of N_2O. This projected achievement is originated from the various degree of commitment to RE from each country in the region.

Although countries such as Indonesia, Vietnam, and the Philippines appear as the majority contributor (up to 20,757 million tons of CO_2 and 16,347 thousand tons of N_2O emissions reduction by 2040) due to their natural resources and geography, the result is different when it comes to the current commitment and plan of the country. In comparison to the base scenario that shows the current installed capacity and the firm (committed) capacity additions for Generation and Transmission Interconnection assets as per the Power Development Plans (PDPs) for each AMS, Thailand appears as the country that has base scenario much higher than their result for ASEAN RE target scenario and optimum RE scenario.

Some other countries also have a base scenario that is higher than their ASEAN RE target scenario. Singapore appears to be the one with a significant difference and followed by the Philippines and Vietnam. While Malaysia and Brunei have base scenarios closer to their ASEAN RE target scenario.

That trend shows a potential progressive improvement for those countries to reduce their emission from the energy sector by 2040. With their current high base scenario, they may reach a higher target in the future to integrate vRE to the APG and contributing to emission reduction in the region.

In contrast to the above-mentioned countries, despite its abundant renewable resources, Indonesia seems to have a low base target, compared to their ASEAN RE target. It is more than four times lower. This makes Indonesia may even more difficult to achieve its optimum RE utilization and may lower the maximum potential for emission reduction in the region. Also, the ASEAN RE target for Indonesia is found higher than their Optimum RE scenario, why?

While for other smaller countries such as Laos and Cambodia, these countries have no RE plan in their baseline and optimum scenario. Thus, they may contribute less to regional emission reduction.

Discussion

Findings from this study are important information to be informed to policymakers, industries, practitioners, and other related stakeholders, to explain projected milestones and potential achievement of increased RE in 2025, 2030, 2040 in South East Asia. This will help stakeholders in the region for preparing a more detailed implementation plan such as detailed pre-feasibility studies to build future APG and achieve their emission reduction targets. This study contributes to show potential regional climate targets from ASEAN from the energy sector. This will help the AMS to achieve their INDCs (Intended National Determined Contribution) on Climate Change Mitigation from the energy sector.

This study provided different scenarios that can be chosen by ASEAN member states (AMS) depend on their national context. AMS can choose/decide it considering different budgets/investments needed for each scenario and other factors that affect implementation possibility. Thus, more detailed pre-feasibility studies for each projected power grid interconnection are needed to come to that decision.

The result of the feasibility studies can help further shed light on the strategy of how the developed countries can bolster investments in renewable energy sources to developing countries in South East Asia, to integrate the geographically dispersed distributed renewable power generation.

Besides technical feasibility studies to build the interconnection, further research is also required on the scheme for multilateral energy trade and carbon market in ASEAN. The idea for integrating the ASEAN energy market needs to promote cross-border trade and free movement of green electricity within the region. Cross-border trade in the integrated energy market can boost the electricity trade of the AMS with rich renewable energy sources to countries with less potential renewable sources.

The projected APG will help AMS for helping each other in terms of one need RE but lacks the technology and human capital and can be compromised by another one who can trade RE at a reasonable price.

Regarding the carbon market, the future (policy) gap will be on the method to count or verify emission reduction from each APG that connects several AMSs. Further study is then required to count emission reduction per grid code/sub-region, per APG. It is important to look at a small group of interconnections. The group could be categorized according to the existing barriers (like the grid code) then the focus can be on a small group with the same grid code, e.g., how RE can avoid these problems by using the "microgrid grid" concept.

Renewable Energy Resource, which has often been attributed by the nature of intermittencies (often termed as variable Energy Resource – vRE (Lee et al., 2019)), imposes challenges to the grid operations due to its unpredictable behavior and thus its continuity of supplying the grid demand. Grid flexibility, the electric grid's capability in handling rapidly changing demands and supply (*ACE Annual Report 2018*, 2018), now presents a vital resource in tackling these uncertainties. The grid flexibility is primarily supported by a power source that could immediately change its supply capacity seamlessly to cope with rapid load changing or vRE intermittency. Such power sources are usually in a form of gas-, or oil-based power plants. With the utilization of such a power plant, we could improve the generation mix with the vRE while at the same time, securing the grid stability effectively. Member nations need to increase grid flexibility capacity to adequately prepare for higher penetrations of renewable electricity and lower overall system costs. Therefore, as ASEAN pursues renewable energy targets, regional cooperation presents the essential matter to address identified challenges. This requires an integrated policy, distribution of power (Budiman & Smits, 2020), and intensive coordination among stakeholders across countries.

These future studies may help to define and divide emission reduction from each APG to per country involved.

Conclusion And Policy Implications

This study found that the potential contribution of the projected APG (especially projected increased contribution of solar and wind power plants to the power system) toward emission reduction in South East Asia is up to 112,267 million tons of CO_2 and 64 thousand tons of N_2O by 2040, under optimum RE scenario. This figure is higher than the annual emission in the US. The projection is almost two times higher, compared to the base scenario.

The source of that contribution is varying at the country level. Countries with potential significant contributions are Thailand, the Philippines, Vietnam, Malaysia, and Indonesia. But not all these countries are currently having progressive trends in their efforts to achieve the target. For example, Indonesia is currently having a base scenario way below their ASEAN RE target and Optimum RE scenario.

Meanwhile, countries like Singapore and Brunei that have a relatively small contribution to the region, are having a progressive trend to meet the RE target and its emission reduction. Singapore has a base scenario that is higher than their ASEAN RE target scenario and Brunei has a base scenario closer to their ASEAN

RE target scenario. This trend shows a potential progressive improvement for those countries to reduce their emission from the energy sector by 2040. With their current high base scenario, they may reach a higher achievement in the future to integrate vRE to the APG and contributing to emission reduction in the region.

Emission reduction in South East Asia is important to reduce climate change exposure in forms of disaster risk to ASEAN countries, especially the most vulnerable ones such as Indonesia, Thailand, the Philippines, Vietnam, and Myanmar.

Future study is required on how significant the emission reduction from APG can contribute to regional and national climate targets of ASEAN and AMS. This will link to the AMS' INDCs (Intended National Determined Contribution) on Climate Change Mitigation from the energy sector. Currently, NDC is still a lot dependent on individual country and APG can be a catalyst. Future study needs to investigate how the group of APG and its trading can help the countries in implementing NDCs, e.g. calculating how many percent emission reduction from APG contribute to NDC target from (energy sector).

To have a more comprehensive calculation, the future study also needs to consider the fugitive and life cycle emissions of the power plants.

This study shows that the ASEAN RE target may affect a base country target that may link to the degree of ambition of their NDC. Countries with the highest NDC plan may have a higher base scenario and may contribute more to emission reduction. A previous study by ACCEPT identified the degree of NDC in each AMS, but not all of them clearly define the detailed target for contribution from their energy sector. Thus, further study is required, to measure the significance of potential APG emission reduction to their NDC.

Declarations

Acknowledgments

Thanks to HAPUA, AIMS III Working Group Members, and Hoyyen Chan for supporting this study.

This work was supported by the USAID Clean Power Asia.

Authors declare that we have no competing interests to declare.

References

ACE 20th Anniversary Book. (2018). ASEAN Centre for Energy (ACE). http://www.aseanenergy.org/resources/publications/ace-20th-anniversary-book/

ACE Annual Report 2018. (2018). ASEAN Centre for Energy (ACE). http://www.aseanenergy.org/resources/ace-annual-report-2018/

Ahmed, T., Mekhilef, S., Shah, R., & Mithulananthan, N. (2017). Investigation into transmission options for cross-border power trading in ASEAN power grid. *Energy Policy*, *108*, 91–101.

Ahmed, T., Mekhilef, S., Shah, R., Mithulananthan, N., Seyedmahmoudian, M., & Horan, B. (2017). ASEAN power grid: A secure transmission infrastructure for clean and sustainable energy for South-East Asia. *Renewable and Sustainable Energy Reviews*, *67*, 1420–1435.

Anbumozhi, V., Lutfiana, D., & LoCastro, M. (2018). Challenges and Opportunity for a Green ASEAN Grid System. *2018 International Conference and Utility Exhibition on Green Energy for Sustainable Development (ICUE)*, 1–9.

Andrews-Speed, P. (2016). Connecting ASEAN through the Power Grid: Next Steps. *Energy Studies Institute Policy Brief*, *11*, 2016.

Aris, H., & Jørgensen, B. N. (2020). ASEAN power grid 20 years after: An overview of its progress and achievements. *IOP Conference Series: Earth and Environmental Science*, *463*(1), 012055.

ASEAN plan of action for energy cooperation (APAEC) 2016-2025. (2015). ASEAN Centre for Energy (ACE).

Asian Development Outlook 2018. (2018).

Brinkerink, M., Gallachóir, B. Ó., & Deane, P. (2019). A comprehensive review on the benefits and challenges of global power grids and intercontinental interconnectors. *Renewable and Sustainable Energy Reviews*, *107*, 274–287. https://doi.org/10.1016/j.rser.2019.03.003

Budiman, I., & Smits, M. (2020). How Do Configuration Shifts in Fragmented Energy Governance Affect Policy Output? A Case Study of Changing Biogas Regimes in Indonesia. *Sustainability*, *12*(4), 1358. https://doi.org/10.3390/su12041358

Chang, Y., & Li, Y. (2013). Power generation and cross-border grid planning for the integrated ASEAN electricity market: A dynamic linear programming model. *Energy Strategy Reviews*, *2*(2), 153–160.

Erdiwansyah, Mahidin, Mamat, R., Sani, M. S. M., Khoerunnisa, F., & Kadarohman, A. (2019). Target and demand for renewable energy across 10 ASEAN countries by 2040. *The Electricity Journal*, *32*(10), 106670. https://doi.org/10.1016/j.tej.2019.106670

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Huang, Y. W., Kittner, N., & Kammen, D. M. (2019). ASEAN grid flexibility: Preparedness for grid integration of renewable energy. *Energy Policy*, *128*, 711–726.

Kimura, S., & Phoumin, H. (2019). *Energy Outlook and Energy Saving Potential in East Asia 2019*. ERIA. https://aseanenergy.sharepoint.com/PRA/ACCEPT/Thematic%20papers/%2314%20Energy%20Efficiency%20White%20Certificate%20Scheme/Literature%20L

Lee, N., Flores-Espino, F., Cardoso de Oliveira, R. P., Roberts, B. J., Brown, T., & Katz, J. R. (2019). *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/TP-7A40-71814, 1527336; p. NREL/TP-7A40-71814, 1527336). https://doi.org/10.2172/1527336

Matsuo, Y., Fukasawa, K., Nagatomi, Y., Fujisaki, W., Kutani, I., Seki, N., & Kubota, Y. (2015). Quantitative analysis of effects of international power grid interconnection in ASEAN region. *The Institute of Energy Economics, Japan*, *35*.

Overland, I., Sagbakken, H. F., Chan, H.-Y., Merdekawati, M., Suryadi, B., Utama, N. A., & Vakulchuk, R. (2021). The ASEAN climate and energy paradox. *Energy and Climate Change*, *2*, 100019. https://doi.org/10.1016/j.egycc.2020.100019

Pranadi, A. D., Suryadi, B., & Yosiyana, B. (2018). Status on Renewable Energy Policy and Development in ASEAN. In H.-Y. Chan & K. Sopian (Eds.), *Renewable Energy in Developing Countries: Local Development and Techno-Economic Aspects* (pp. 3–24). Springer International Publishing. https://doi.org/10.1007/978-3-319-89809-4_1

SME Policy Index: ASEAN 2018—BOOSTING COMPETITIVENESS AND INCLUSIVE GROWTH. (2018). ASEAN, ERIA, OECD. https://asean.org/storage/2018/09/ASPI-2018-Brochure_FINAL.pdf

The 5th ASEAN Energy Outlook (AEO5). (2017). ASEAN Centre for Energy (ACE). https://aseanenergy.sharepoint.com/PRA/ACCEPT/Thematic%20papers/%2314%20Energy%20Efficiency%20White%20Certificate%20Scheme/Literature%20L

Utama, N. A., Ishihara, K. N., & Tezuka, T. (2012). Power generation optimization in ASEAN by 2030. *Energy and Power Engineering*, *4*(04), 226.

Veng, V., Suryadi, B., Pranadi, A. D., & Shani, N. (2020). A review of renewable energy development and its policy under nationally determined contributions in ASEAN. *Int. J. Smart Grid Clean Energy*, *9*(1), 149–161.

Figures

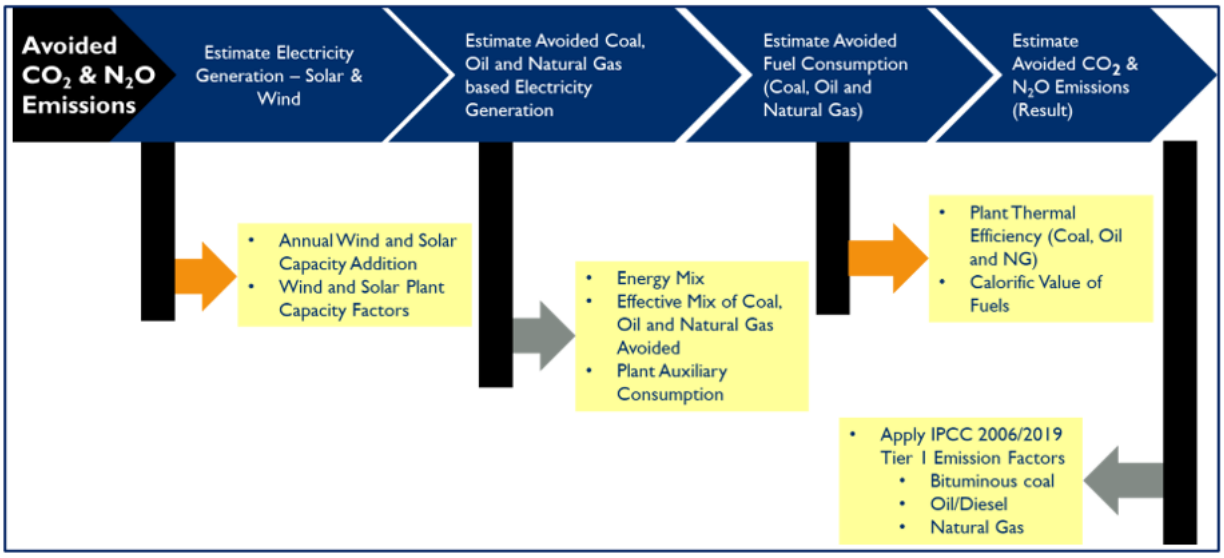

Figure 1

Approach for estimating avoided CO2 and N2O emissions

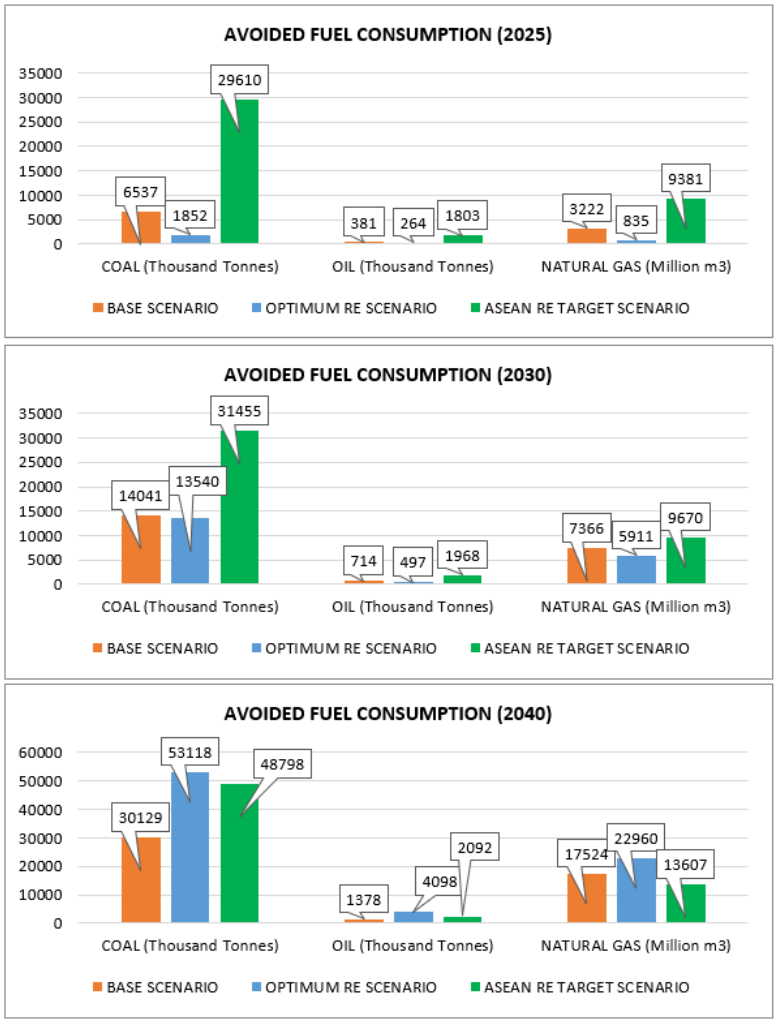

Figure 2

Avoided Fuel Consumption from 2025, 2030, and 2040 in ASEAN.

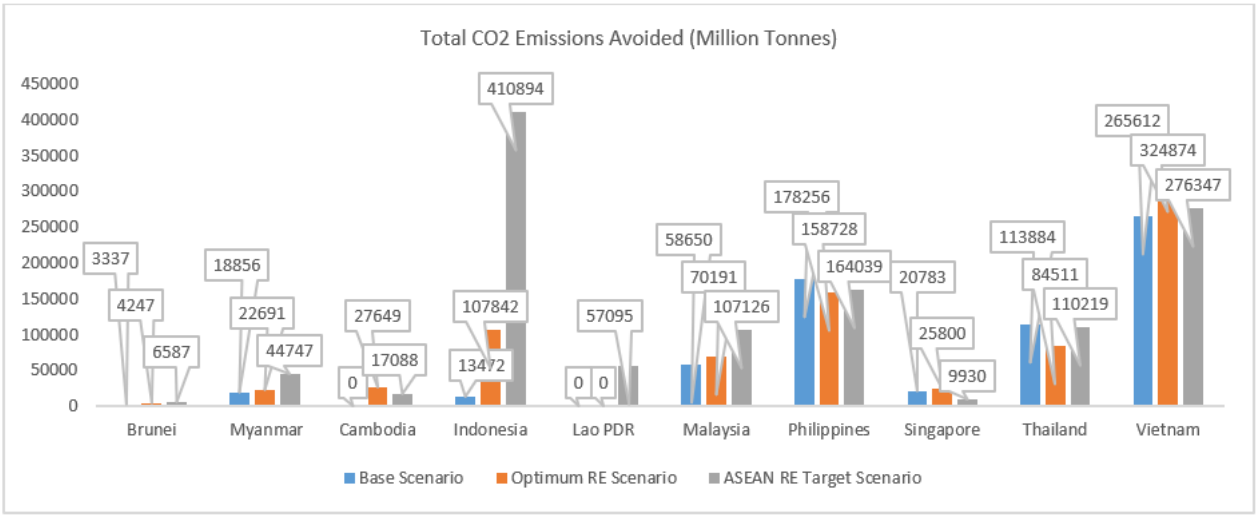

Figure 3

Total CO2 Emission Avoided in 2040 – the ASEAN Member States

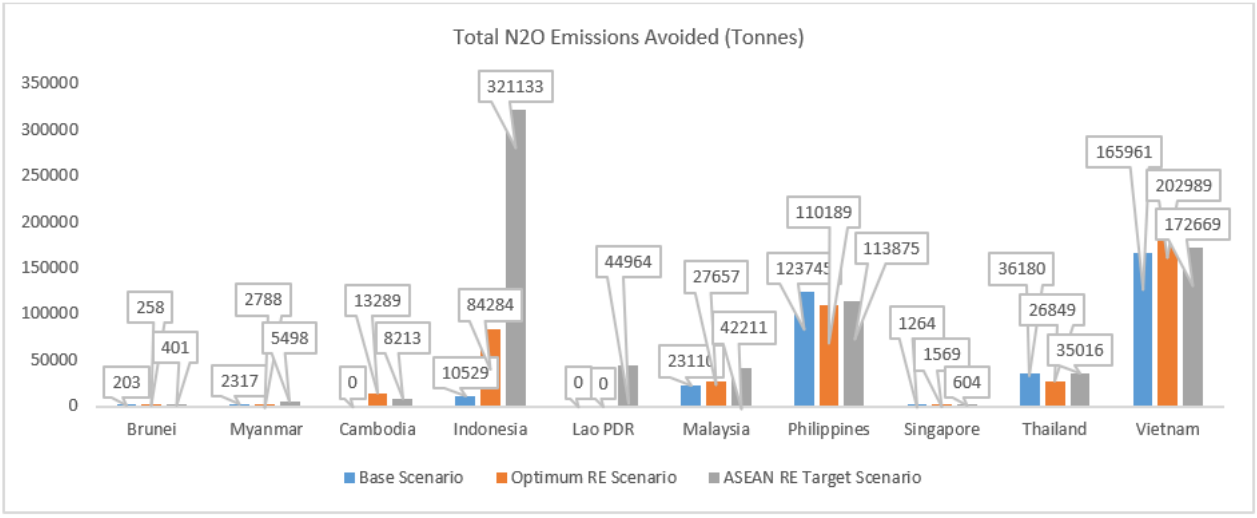

Figure 4

Total N2O Emission Avoided in 2040 – the ASEAN Member States