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Review

Review on Greenhouse Gases Emission in the Association of Southeast Asian Nations (ASEAN) Countries

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Abstract: The Association of the Southeast Asian Nations (ASEAN) region is a critical contributor to global development from an environmental perspective. This study has reviewed carbon emissions from energy generation, influence factors from the population, economic growth and renewable energy, emission and energy intensity projection, spatial distribution characteristics, and decarbonization strategy. This work utilizes a comparison methodology between ASEAN countries in the emission intensity and energy intensity in the future projection of electricity conditions in 2030 or 2040, as well as opportunities for reducing greenhouse gas (GHG) emissions as determined by the national policies of each government. The results show that Indonesia, Vietnam, Thailand, and Malaysia produce 79.7% of the electricity in the ASEAN region. As a developing country, Indonesia has the largest population and gross domestic product (GDP) but has the highest predicted emission intensity, of 0.97 CO_2e/MWh, in 2030. Vietnam is predicted to have an emission intensity of about 3.56t-CO_2e/cap and 0.747t-CO_2e/GDP in 2030. Vietnam is expected to increase in energy intensity to 1241 MWh/GDP, while Brunei Darussalam has a high energy intensity of 11.35 MWh/cap. However, the capacity of solar power plants (more than 11 GW) and wind-power plants (2384 MW) have generally increased in ASEAN from 2015 to 2019, indicating the positive development of renewable energy source (RES) use. The national policies strongly influence the estimated GHG emission in ASEAN by aggressively replacing fossil fuels with RESs. Support, via government policies, can reduce the cost of electricity generation from RESs is needed to increase and enhance the installment of clean power generation systems. In future work, the research needs to consider the intermittent characteristics of variable RES in power system operation.

Keywords: ASEAN member states; electricity; emission; greenhouse gases

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1. Introduction

The Association of the Southeast Asian Nations (ASEAN) region is an essential contributor to global development from economic and environmental points of view. In terms of greenhouse gas (GHGs) emissions, the power sector offers significant opportunities to achieve emission reductions by leveraging technology and national policies [1,2]. The ASEAN member states (AMS) have made various efforts to be able to meet the emission reduction targets that have been previously set [3]. According to the Paris agreement, policies regarding carbon emission mitigation in AMS are inseparable from the understanding in the ASEAN plan of action for energy cooperation (APAEC) and nationally determined contributions (NDC).

The cooperation of AMS in the power sector for energy security, connectivity, and integration in the ASEAN region is stated in APAEC. Strategies and action plans that are closely related to electricity development are clean coal technology (CCT) and renewable energy sources (RES) [4–6]. The use of RES has significantly reduced CO_2 emissions [7–9].

Additionally, there are other strategies and action plans, such as building the ASEAN power grid (APG) and the trans-ASEAN gas pipeline (TAGP) [10,11]. The development of APG and TAGP would allow for the optimization of regional energy resources and the assurance of sustainable energy development through reducing GHGs [6].

The NDC document in the Paris agreement contains a country's climate commitments and actions communicated to the world through the United Nations framework convention on climate change (UNFCCC). In 2015, 196 countries, including the AMS, agreed to the Paris agreement to jointly hold the global temperature rise below 2 degrees Celsius and keep it closer to 1.5 degrees Celsius. Moreover, it increases the ability to adapt to the impacts of climate change and increases climate resilience and low-emission development while maintaining food production. AMS also agreed to align funding flows with low-emissions and climate-resilient development paths.

In addition to the policies of each AMS and NDC, population, gross domestic product (GDP), and electricity production based on energy sources also influence GHGs. Population number and population growth determine electricity demand and production. Population data can also be used to analyze energy intensity (GWh/cap) or GHG emission intensity (t-CO_2e/cap). These values may describe the adequacy of the energy supply, the need for energy efficiency, and the individual's contribution to GHG emissions. GDP is also a critical indicator to determine a country's economic conditions and GHG emissions for a certain period [12,13]. GDP is the added value of all business units or the total value of goods and services produced by all economic units in a particular country. Energy intensity (GWh/GDP) and emission intensity (t-CO_2e/GDP) can also describe the financial condition of the energy supply and the behavior of energy use in AMS.

Many previous studies have focused on GHG emissions from the electricity sector for different countries to quantify total CO_2 emissions, emission intensity values, and GHGs drivers, and only some of them focus on the ASEAN region. Some studies have investigated the relationship between electricity consumption, economic growth, and carbon emission for Nigeria between 1970 and 2008 [14], for Iran between 1971 and 2011 [15], and for seven selected Asia-Pacific and North American countries between 1990 and 2030 [16]. Saidi and Hammami have identified the amount of carbon emissions for three regional panels, including Europe and North Asia, Latin America and Caribbean and Sub-Saharan, North Africa and the Middle Eastern [17]. Other studies have analyzed the impact of renewable energy sources (RESs) on emission intensity in Turkey [18], Greece [19], and China [20]. Therefore, emission intensity, energy intensity, and RE contribution projections are explicitly conducted for the ASEAN region based on each AMS electricity development plan scenario in this study. Various factors' influence must be considered to identify future opportunities for GHG emission reductions. Regarding the causal relationship between economic growth, energy consumption, and CO_2 emissions, the literature studies indicate that empirical studies' results vary considerably. The nature and direction of causality may differ from country to country [21].

2. Methods

General information on AMS, such as economic level (in the form of GDP), electrification rate (proportion of the population with access to electricity energy sources), energy consumption, and composition of energy sources (between fossil fuels and RES) are needed to identify the electricity conditions in the ASEAN region. More detailed information is also required related to coal-fired power plants (CFPPs) in AMS in the form of projected generating capacity (MW), operating hours of the plant (OH), boiler technology used, amount of fossil fuel consumption (t/year), characteristics of the fuel used, as well as national policies of emission reduction targets. Baseline data from various sources can be used to calculate CO_2e emissions from power generation activities in AMS. Two primary data sources that are often used in various studies for the ASEAN region are the ASEAN center of energy (ACE) [22] and the International Energy Agency (IEA) [23].

Each AMS sets a specific target for reducing GHG, stated in the national electricity development plan, following the agreement pledged by NDC and APAEC. Scenarios are developed considering the availability of energy resources within the country, economic condition, and development of RES, as follows in Table 1.

Table 1. AMS's national strategy and commitment to carbon emission targets.

Country	Target	Reference
Brunei Darussalam	RE 30% by 2035	[24]
Philippines 1 (Reference Scenario)	RE 34.13%, coal 58.36%, oil 0.62%, gas 6.89% by 2030 RE 26.31%, coal 55.34%, oil 0.31%, gas 18.03% by 2040	[25]
Philippines 2 (Clean Energy Scenario)	RE 31.9%, coal 56.16%, oil 0.63%, gas 11.31% by 2030 RE 38.15%, coal 34.22%, oil 0.33%, gas 27.29% by 2040	[25]
Indonesia 1 (Business as Usual)	RE 8.21%, coal 78.71%, oil 0.41%, gas 12.67% by 2030	[26]
Indonesia 2 (Optimal Scenario)	RE 22.83%, coal 64.09%, oil 0.41%, gas 12.67% by 2030	[26]
Indonesia 3 (Low Carbon Scenario)	RE 24.78%, coal 59.37%, oil 0.4%, gas 15.44% by 2030	[26]
Cambodia 1 (Existing Scenario)	RE 32.8%, coal 52.2%, oil 15% by 2020 RE 26%, coal 64.8%, oil 9.2% by 2025 RE 25.4%, coal 67.5%, oil 7.2% by 2030	[27]
Cambodia 2 (Aggressive Scenario)	RE 35.8%, coal 56%, oil 8.1% by 2020 RE 53.3%, coal 46.4% by 2025 RE 65%, coal 35% by 2030	[27]
Laos	RE 70%, coal 30% by 2030	[28]
Malaysia	RE 31%, coal 31.38%, oil 0.55%, gas 37.07% by 2025 RE 40%, coal 22.38%, oil 0.55%, gas 37.07% by 2035	[29]
Myanmar	RE 74.1%, coal 3.4%, gas 22.4% by 2021 RE 64%, coal 23.3%, gas 12.7% by 2024 RE 67.7%, coal 24%, gas 8.3% by 2027 RE 62.3%, coal 29.5%, gas 8.2% by 2030	[30]
Singapore	RE 3% (2 GWp by solar) by 2030	[31]
Thailand	RE 36%, coal 11%, gas 53% by 2037	[32]
Vietnam 1 (Base Load Scenario)	RE 34.3%, coal 58.73%, gas 6.97% by 2025 RE 28.79%, coal 49.2%, gas 22.01% by 2030	[33]
Vietnam 2 (High Load Scenario)	RE 34.3%, coal 58.73%, gas 6.97% by 2025 RE 28.79%, coal 49.2%, gas 22.01% by 2030	[33]

Most of the power plants in the ASEAN region are CFPPs. Therefore, the CO_2e emissions calculation from CFPPS requires information regarding the type of boiler (subcritical, supercritical, ultra-supercritical, fluidized bed technology) and year of operation. Each AMS's total power generation capacity can be analyzed using the following equation [22].

$$P_{CFPP,AMS,t} = \sum_{i=1,2,\ldots} P_{SubC,i,t} + \sum_{i=1,2,\ldots} P_{SC,i,t} + \sum_{i=1,2,\ldots} P_{USC,i,t} + \sum_{i=1,2,\ldots} P_{FB,i,t} \quad (1)$$

where:

$P_{CFPP,AMS}$ = total installed power generation capacity in AMS.
$P_{SubC,i}$ = i-th subcritical.
$P_{SC,i}$ = i-th supercritical.
$P_{USC,i}$ = i-th ultra-supercritical.
$P_{FB,i}$ = i-th fluidized bed.
t = year of operation.

The principle of CO_2 emissions calculation is performed by applying an emission factor based on power plant operating time [34], as shown in Equation (2) or fuel consumption [35] in Equation (3).

$$\text{Emission} = EG_{m,y}\ EF_{m,y} \quad (2)$$

where:

$EG_{m,y}$ = the total electricity production by power plant m in year y (MWh).
$EF_{m,y}$ = CO_2 emission factor by power plant m in year y (t-CO_2/MWh).
m = power plant operating in year y.
y = year of operation.

$$\text{Emissions}_{\text{GHG,fuel}} = \text{Fuel Consumption}_{\text{fuel}}\ \text{EF}_{\text{GHG,fuel}} \tag{3}$$

where:

$\text{Emissions}_{\text{GHG,fuel}}$ = GHG emissions from a particular type of fuel (t-GHGs/year).
$\text{Fuel Consumption}_{\text{fuel}}$ = the amount of fuel used (TJ/year), in this case, the amount of fuel equivalent to the electricity production.
$EF_{\text{GHG,fuel}}$ = default emission factor of a GHG based on a specific fuel type (t-GHGs/TJ).

The projection of CO_2e emissions was performed using three alternative calculations, which depend on the available data from the national electricity development plan at each AMS. The first approach used population data, GDP, and annual electricity production per energy source (coal, oil, and gas). The calculation of CO_2 emissions from CFPPs was carried out by applying emission factors from ACE based on coal quality and the type of boiler technology. Meanwhile, the measure of CO_2 emissions from oil and gas power plants utilized emission factors from the intergovernmental panel on climate change (IPCC) [35]. To obtain CO_2e emissions from oil and gas power plants, calculated CH_4 and N_2O emissions were multiplied by global warming potential (GWP) from the IPCC fifth assessment report (AR5). After obtaining the total contribution of CO_2e emissions from each energy mix, the emission intensities (t-CO_2e/GWh, t-CO_2e/cap, and t-CO_2e/GDP) and energy intensity (MWh/cap and MWh/GDP) were generated.

The second approach applied population data, GDP, total electricity production every year, and the percentage of the energy mix in the baseline year and end of the projection year. Since the energy mix along the projection range was unknown, a constant increase in the energy mixes every year was estimated using Equation (4).

$$\text{Energy mix in the projection range}(\%) = \frac{\left(\text{EM}_{\text{py}} - \text{EM}_{\text{by}}\right)}{\text{Projection year} - \text{Baseline year}} \tag{4}$$

where:

EM_{py} = percentage of energy mix at the end of projection year (%).
EM_{by} = percentage of energy mix in baseline year (%).

After obtaining a constant energy mix in the projection range, the annual electricity production every year per energy source (GWh) was determined by using Equation (5) as:

$$\text{EG}_{\text{fuel,y}} = \text{EG EM} \tag{5}$$

where:

$EG_{\text{fuel,y}}$ = the total electricity production per energy source in year y (GWh).
EG = the total annual electricity production (GWh).
EM = percentage of energy mix (%).

Calculating CO_2e emissions, emission intensity, and energy intensity is performed similarly to the first approach using Equation (2).

The third approach used population data, GDP, electrification rate, electricity production in the baseline year, the energy mix in the baseline, and the end of the projection year. Because the electricity production in the projection year is unknown, the electricity production per capita (GWh/cap) derived from baseline data (Equation (6)) is generated and utilized in calculating the total electricity production year.

$$EG_{cap} = \frac{EG_{by}}{P_{by}} \quad (6)$$

where:

EG_{cap} = electricity production per capita (GWh/capita).
EG_{by} = the total electricity production in the baseline year (GWh).
P_{by} = the population number in the baseline year (capita).

The annual electricity production within the projection range is estimated based on the electricity production per capita, the number of populations in the projected year, and each country's electrification rate (%) using Equation (7). The CO_2e emissions and energy intensity were calculated similarly to the first and second approaches.

$$EG = EG_{cap}\ P\ ER \quad (7)$$

where:

EG = the total annual electricity production (GWh).
EG_{cap} = electricity production per capita (GWh/capita).
P = the population number (capita).
ER = electrification ratio (%).

3. Results and Discussion

3.1. Baseline Data of Carbon Emissions

Based on IEA baseline data [36], the electricity sector in AMS is heterogeneous, with significant variations between countries in terms of electricity production per capita and the intensity of carbon dioxide emissions from electricity production. Figure 1 shows four countries, i.e., Indonesia, Vietnam, Thailand, and Malaysia, which produce 79.7% of the electricity in the ASEAN region (2019). AMS uses fossil fuels (gas, oil, and coal) and other energy sources, such as biofuel, waste, hydro, geothermal, solar, and wind. Fossil fuels are the primary energy source in almost all AMS, except in Laos, where hydropower becomes the primary energy source.

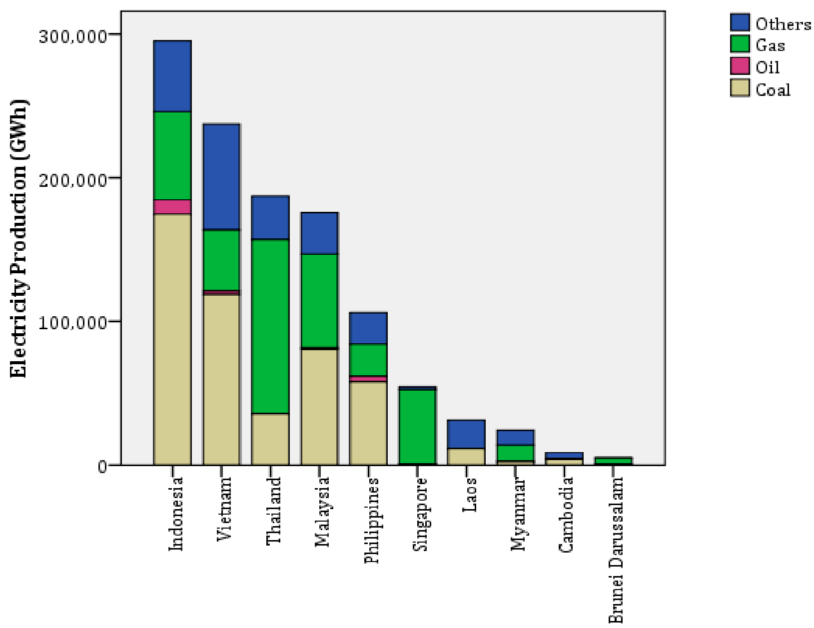

Figure 1. Electricity production (GWh) in AMS (2019) (reprinted from ref. [36]).

Electricity production in Indonesia and Philippines emits the highest carbon emission, although they have the lowest electricity production per capita compared to other AMS, as indicated in Figure 2.

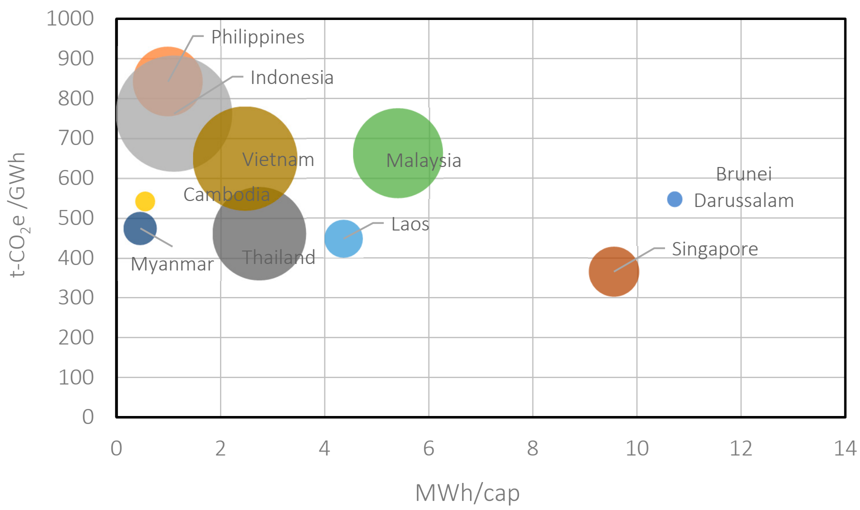

Figure 2. CO_2e emission intensity (t-CO_2e/GWh) and electricity production (MWh/cap) in AMS 2019 (reprinted from ref. [36]).

Indonesia and the Philippines utilize coal as the primary energy source, the main source of CO_2e emission. Based on [36], the world's electricity production in 2019 was 23.835 billion MWh with a population of 7.673 billion [37]; therefore, the global average of electricity production in the world was about 3.11 MWh/cap.

3.2. *Influencing Factors of Carbon Emissions Level*

The determinants of carbon emissions include population, economic growth (GDP), and the share of renewable energy.

3.2.1. Population and Economic Growth

Population and GDP growth play a critical role in increasing carbon emissions by impacting demand for higher electricity consumption [38]. Indonesia is a developing country in the ASEAN with the largest population and total area. As a member of the G20, Indonesia's GDP is the largest in the region. The country's burgeoning population is the largest in the AMS and the fourth largest globally. The information related to carbon emission targets in the AMS are shown in Table 2.

Table 2. The AMS's summary information regarding carbon emission targets [39,40].

Country	Electricity Used (TWh)	RE Share on Energy Mix (%)	Population (Thousand)	GDP (Billions USD)	Total Area (Sq. Km)
Brunei Darussalam	5.3	0.5	433.3	13.5	5765.0
Philippines	92	1.0	108,116.6	376.8	300,000.0
Indonesia	268.1	12.4	270,625.6	1120.0	1,913,578.7
Cambodia	11.5	3.5	16,486.5	26,7	181,035.0
Laos	7.7	71.6	7169.5	18.8	236,800.0
Malaysia	168.3	0.5	31,949.8	364.7	331,388.0
Myanmar	15.1	0.1	54,703.6	68.8	676,576.0
Singapore	52.9	0.3	5703.6	374.4	728.0
Thailand	193.4	19	69,625.6	544.1	513,139.0
Vietnam	226	6	96,462.1	329.5	331,317.0

3.2.2. Renewable Energy Contribution

Based on baseline data in 2019, the AMS are significantly reliant on fossil fuels for power generation [36]. Brunei Darussalam and Singapore rely almost entirely on natural gas. More than 60% of electricity generation in Thailand, Vietnam, Malaysia, Philippines, and Indonesia are dependent on a coal and natural gas energy mix.

With a significant margin, hydropower is the ASEAN region's largest non-fossil fuel contributor to electricity production (Figure 3). Hydropower is the primary energy source in Laos, Cambodia, and Myanmar. Cambodia, Indonesia, Laos, Malaysia, and the Philippines have plans to expand large-scale hydropower in the coming decades, especially for micro-hydro plants. However, constructing hydropower plants has significant environmental and social impacts, especially when built on a large scale. The effects on regional food security and the environmental impacts on biodiversity and natural flows of water and sediment are well documented in the Mekong region [41]. Rising costs of hydropower plant construction and an increasing understanding of how drought and climate change affect hydropower productivity could hinder plans to expand large-scale hydropower.

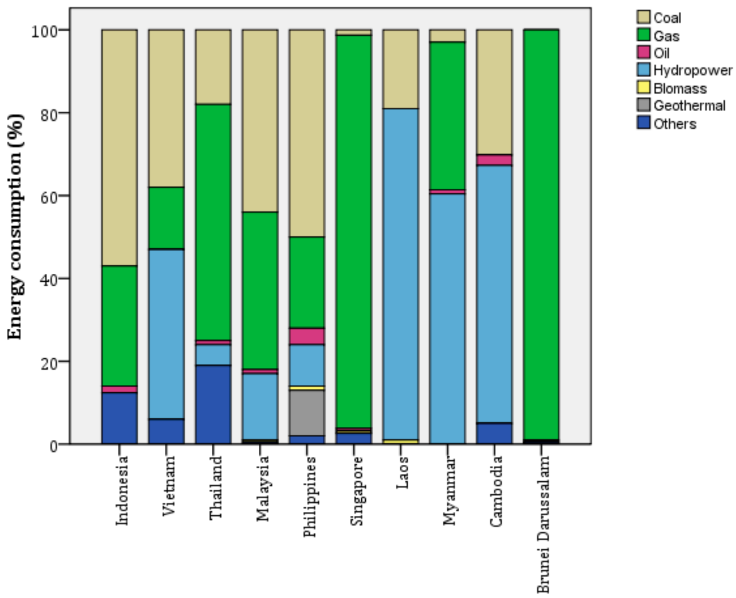

Figure 3. Percentage of energy consumption by country (reprinted from ref. [41]).

The trend in renewable electricity production by source (non-combustible) in AMS over the 1990–2020 period is shown in Figure 4.

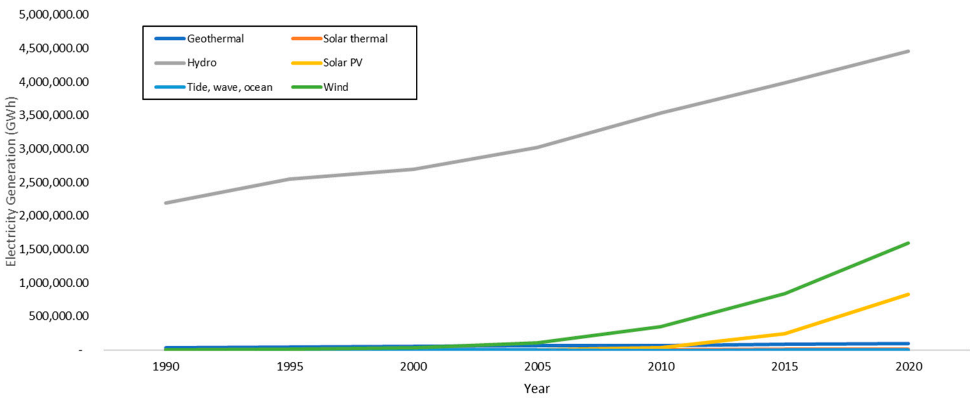

Figure 4. Renewable electricity generation by source (non-combustible) in AMS (1990–2020) (reprinted from ref. [39]).

The capacity of solar power plants (Figure 5) and wind-power plants (Figure 6) have generally increased in AMS, indicating positive RES use development. Based on Figures 5 and 6, within four years (2015 to 2019), Photovoltaic (PV) mini-grid capacity increased almost six times (from under 2 GW to more than 11 GW). The majority of increased RES use has occurred in Vietnam and Thailand, although other countries also have a sharp increase in RES utilization through the implementation of PV mini-grid capacity. Vietnam's success in developing solar and wind power is supported by the government's strong commitment to renewable energy development, carbon pricing policies, and reduced fossil fuel subsidies [42]. In 2019, solar power plants accounted for 10% of installed RES capacity in Vietnam and nearly 6% in Thailand. The use of wind-power plants has grown at a slower rate, with capacity tripling from 800 MW in 2015 to 2384 MW in 2019.

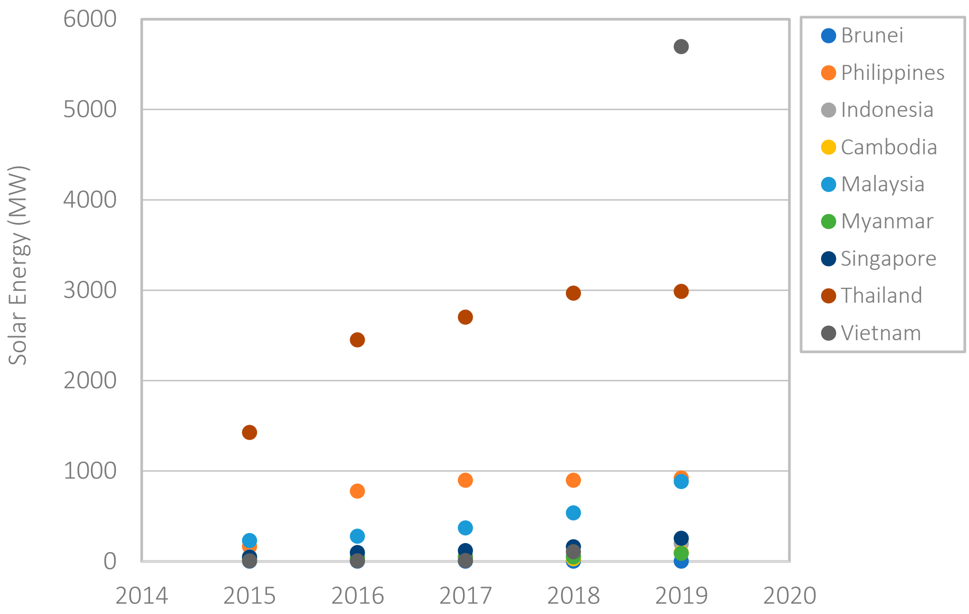

Figure 5. Solar PV development in the ASEAN.

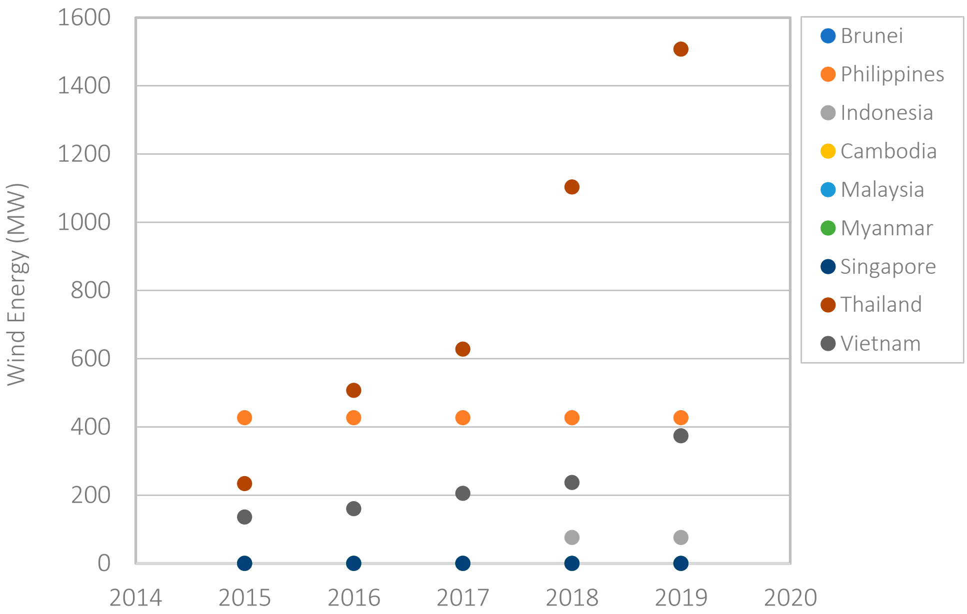

Figure 6. Wind-power plant development in the ASEAN.

Policymakers in many ASEAN countries face the challenge of simultaneously expanding power generation to meet growing demand, improve electricity access and grid reliability, and implement RES technologies. Based on the ASEAN RE target of 23% by 2025 [11], AMS is slowly transitioning towards modern renewable technologies. The widespread perception that RES is expensive and technically complicated has slowed the transition to using clean energy. However, these perceptions oppose the declining trend of RES installment prices. The rapid deployment of PV mini-grid in Vietnam and geothermal power development in the Philippines provide essential lessons for enhancing the RES transition elsewhere in the ASEAN region.

3.3. Projection of Carbon Emissions

The projected level of carbon emissions in the AMS is shown Figure 7. In contrast to other nations, Indonesia and Vietnam had greater increases in carbon emissions between 2020 and 2030.

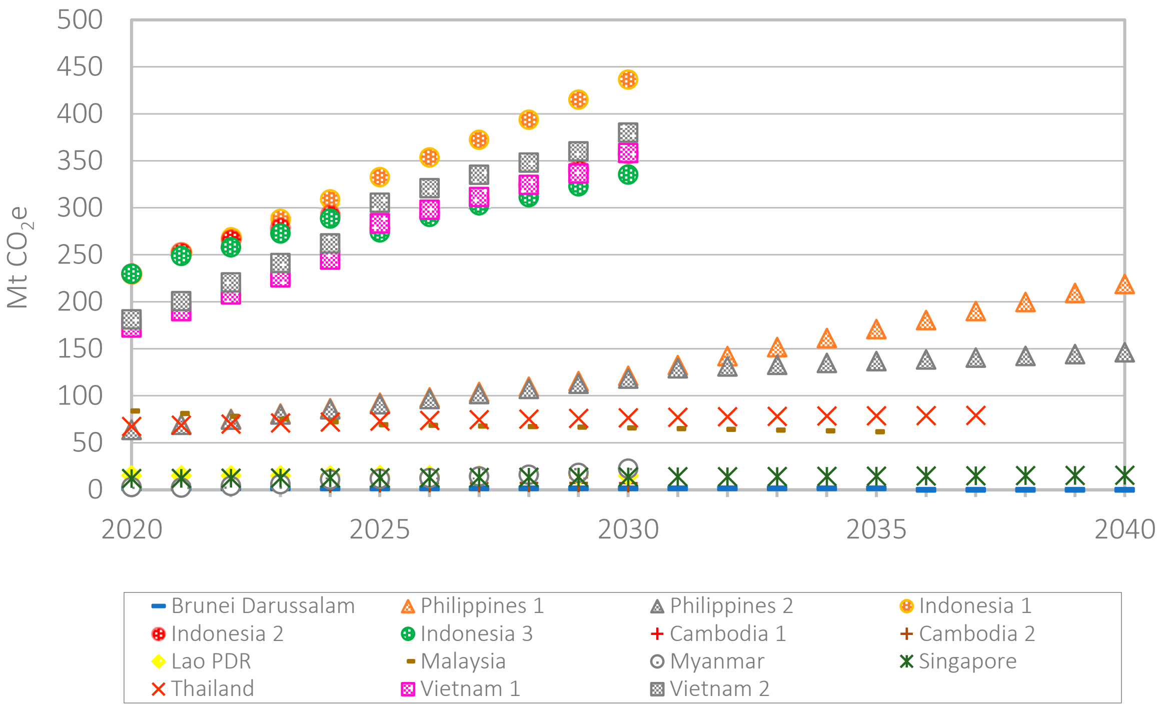

Figure 7. Projection of carbon emissions level in AMS.

Carbon emissions are divided into emission intensity and energy intensity categories.

3.3.1. Emission Intensity Projection

The results of emission intensity projections for various AMS scenarios are presented by identifying the influence of electricity production (Figure 8), demographic development (Figure 9), and economic condition (Figure 10). The projected emission intensities in t-CO_2e/MWh of each AMS from 2020 to 2040 are shown in Figure 8. Data show that, in 2020, Indonesia, Vietnam, and the Philippines had the highest CO_2e emission intensities with the value of 0.85, 0.65, and 0.59t-CO_2e/MWh, respectively. The relatively high emission intensities in these countries are directly related to using coal as the primary source of electricity generation. These countries are also ASEAN's leading fossil fuel producers, of which 88% is represented by Indonesia. The availability of abundant coal resources in these countries influences the choice of energy sources.

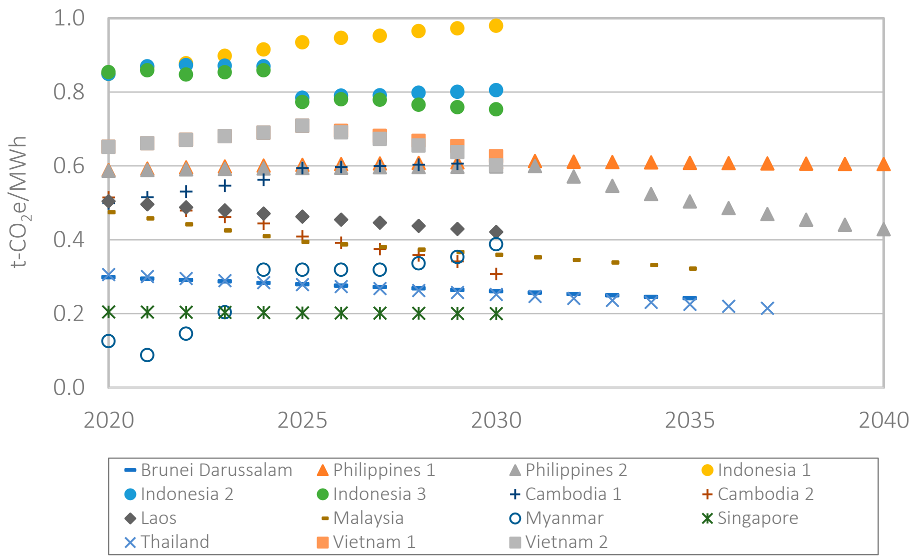

Figure 8. Projection of emission intensity (CO_2e/MWh) in AMS.

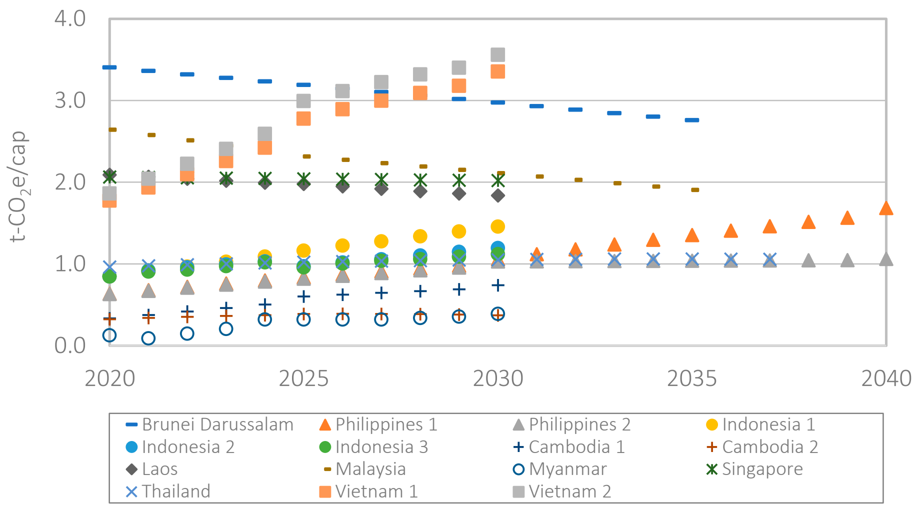

Figure 9. Projection of CO_2e per capita in AMS.

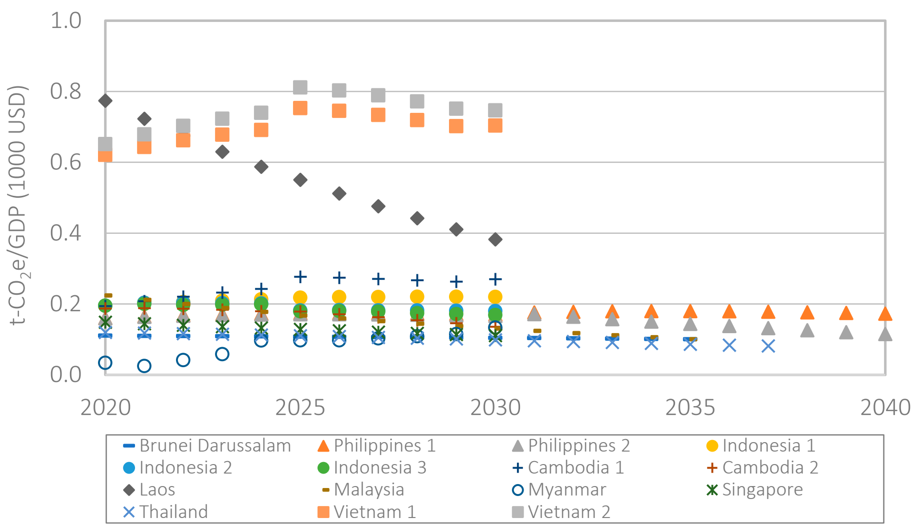

Figure 10. Projection of CO_2e per GDP in AMS.

Singapore and Myanmar had 0.205 and 0.112t-CO_2e/MWh emission intensities. Singapore has a relatively low emission intensity. Its energy sources come from fossil fuels with less intensive carbon, such as gas (93%). In comparison, Myanmar has the lowest emission intensity in the ASEAN region because 64.5% of its energy sources are renewable (mainly hydropower).

In 2030, Indonesia is predicted to still have the highest CO_2e emission intensity, followed by Vietnam. In 2030, electricity production (GWh) from coal in Vietnam is predicted to be greater than Indonesia 1 and Indonesia 2. However, Vietnam has a lower emission intensity because the total electricity production (GWh) in Vietnam is more significant (Vietnam 1 is 572,000 GWh, and Vietnam 2 is 632,000 GWh) than Indonesia (Indonesia 2 for 444,096 GWh, and Indonesia 3 for 445,096 GWh). In addition, the mix of energy sources from gas and RE in Vietnam is also higher than in Indonesia. The most significant factor affecting the value of emission intensity is the type of energy source used. The availability of resources determines the type of energy source utilized to generate electricity.

The projected emission intensities in a unit of t-CO_2e/cap for AMS from 2020 to 2040 are shown in Figure 9. In 2020, the emission intensities were 3.40, 2.58, 2.09, and 2.06t-CO_2e/cap for Brunei Darussalam, Malaysia, Laos, and Singapore, respectively. Brunei has the highest emission intensity in t-CO_2e/cap, which also means that every person in Brunei produces more CO_2e due to their increased electricity consumption activities than any country in the ASEAN region. Laos is also noted to have a high intensity of tons-CO_2e/cap emissions, but this is because Laos is the largest electricity exporter in the ASEAN region, to countries such as Thailand [43] and Malaysia [44], not because of high electricity consumption. In 2030, countries with the highest emission intensity in t-CO_2e/cap are predicted to shift to Vietnam 2 (3.56t-CO_2e/cap), Vietnam 1 (3.35t-CO_2e/cap), Brunei Darussalam (2.97t-CO_2e/cap), Malaysia (2.11t-CO_2e/cap), Singapore (2.02t-CO_2e/cap), and Laos (1.84t-CO_2e/cap), then the country with the lowest emission intensity will be Cambodia 2 (0.372t-CO_2e/cap). Vietnam in 2030 is predicted to have the ambition to increase electricity production by 2.2 times compared to 2020, with coal as the primary energy source. The projected emission intensities in t-CO_2e/GDP for AMS from 2020 to 2040 are shown in Figure 10.

Based on Figure 10, in 2020, Laos had the highest emission intensities (0.774t-CO_2e/GDP), while in 2030, Vietnam 2 is predicted to have the highest emission intensities (0.747t-CO_2e/GDP). Laos has set a very high target of RE proportion in the energy mix in 2030 (70% of RE). Therefore, it has the highest gradient reduction in emission intensities and is predicted to be able to set a CO_2e emission intensity of 0.38t-CO_2e/GDP in 2030. The emission intensity value in tons of CO_2e/GDP is influenced by electricity production from fossil fuels, especially coal, RE proportion in the energy mix, and the GDP of each country. Countries with a low GDP tend to have higher emission intensity per GDP.

3.3.2. Energy Intensity Projection

The energy intensity projections in units of electricity production per capita (MWh/cap) from 2020 to 2040 are shown in Figure 11. Brunei and Singapore had the highest energy intensity value in 2020 and are set to remain constant until 2030 (11.38 MWh/cap and 10.06 MWh/cap, respectively). Brunei and Singapore are producing more electricity for their citizens than other ASEAN countries. Energy intensity values indicate the amount of energy consumed by individuals in each country. Residents in Brunei and Singapore use a lot more energy than other countries, i.e., the average in ASEAN is 3.12 MWh/cap in 2020 and 3.88 MWh/cap in 2030.

The energy intensity projections in units of electricity production per GDP (MWh/GDP) from 2020 to 2040 are shown in Figure 12. In 2020, Laos (1.534 MWh/GDP) and Vietnam 2 (0.999 MWh/GDP) had the highest value of energy intensity, while in 2030, Vietnam 2 is predicted to be higher (1241 MWh/GDP) than Laos (0.907 MWh/GDP). The average energy intensity in the ASEAN region is 0.479 MWh/GDP in 2020 and 0.471 MWh/GDP in

2030. A high value of energy intensity in units of MWh/GDP indicates that the electricity production in a country such as Laos is relatively cheaper than other countries in the ASEAN region.

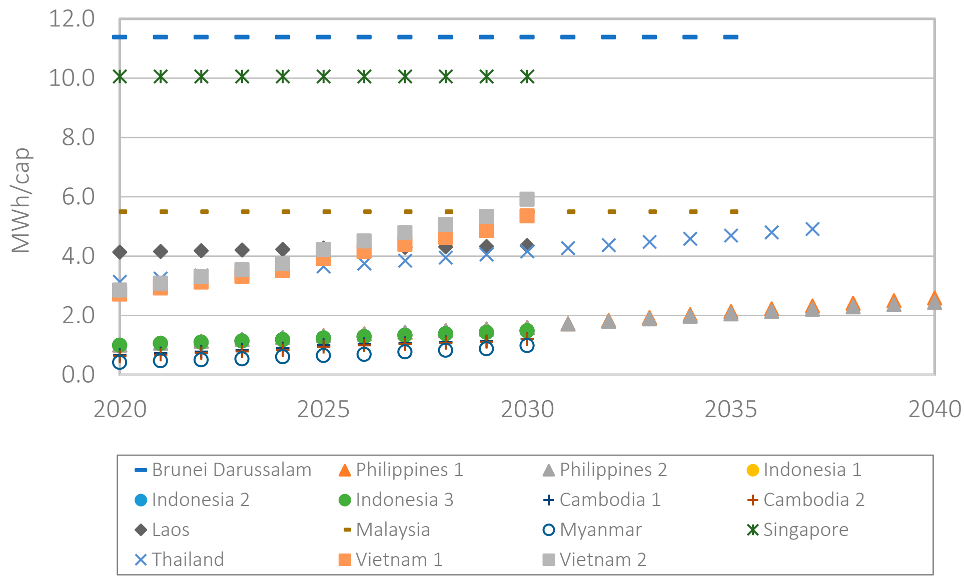

Figure 11. Projection of energy intensity (MWh/cap) in AMS.

Figures 13 and 14 represent variations in electricity production (proportional to the circle image), CO_2e emission intensity (t-CO_2e/GWh), and energy intensity (MWh/cap) in 2020 and 2030. Two figures denote the shifting in emission and energy intensity for each country as electricity production and population growth over time.

Figure 13 indicates that, in 2020, Indonesia had the highest emission intensity while Myanmar had the lowest. The value of energy intensity for the Philippines, Indonesia, Cambodia, and Myanmar was less than 2 MWh/cap. Vietnam and Thailand were between 2 and 4 MWh/cap. Laos and Malaysia were between 4 and 6 MWh/cap, while Brunei Darussalam and Singapore were the highest, with a value between 10 and 12 MWh/cap. For comparison, the average energy intensity in the ASEAN region in 2020 is around 3.1 MWh/cap.

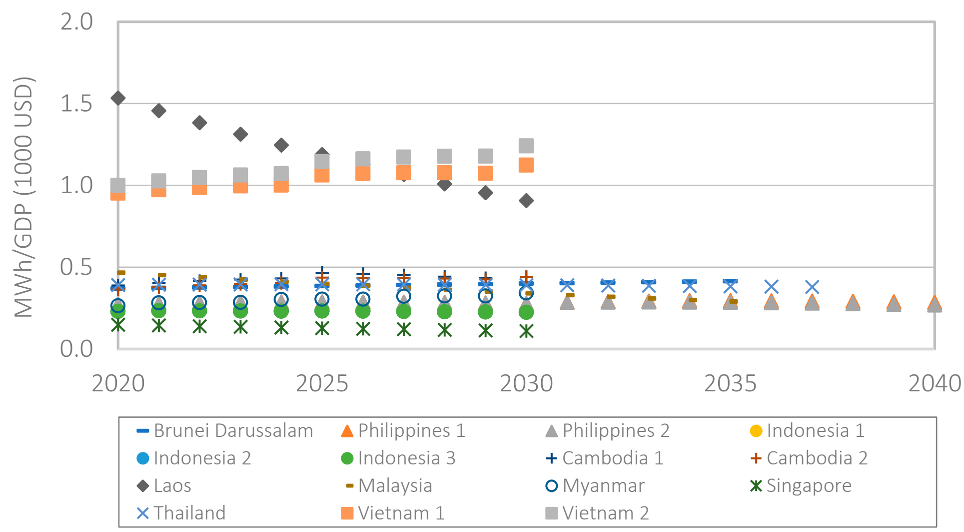

Figure 12. Projection of energy intensity (MWh/GDP) in AMS.

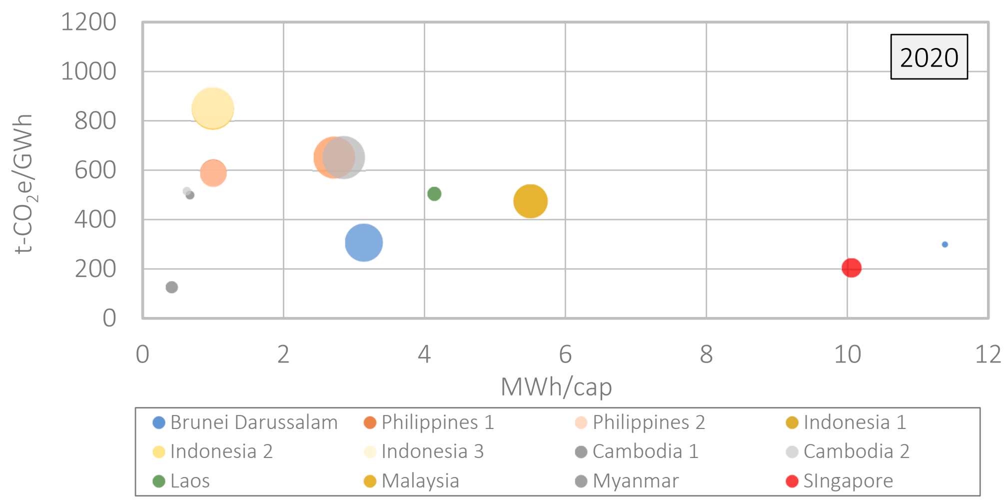

Figure 13. Relationship between electricity generation (GWh), emission intensity (CO_2e/GWh), and energy intensity (MWh/cap) in AMS (2020).

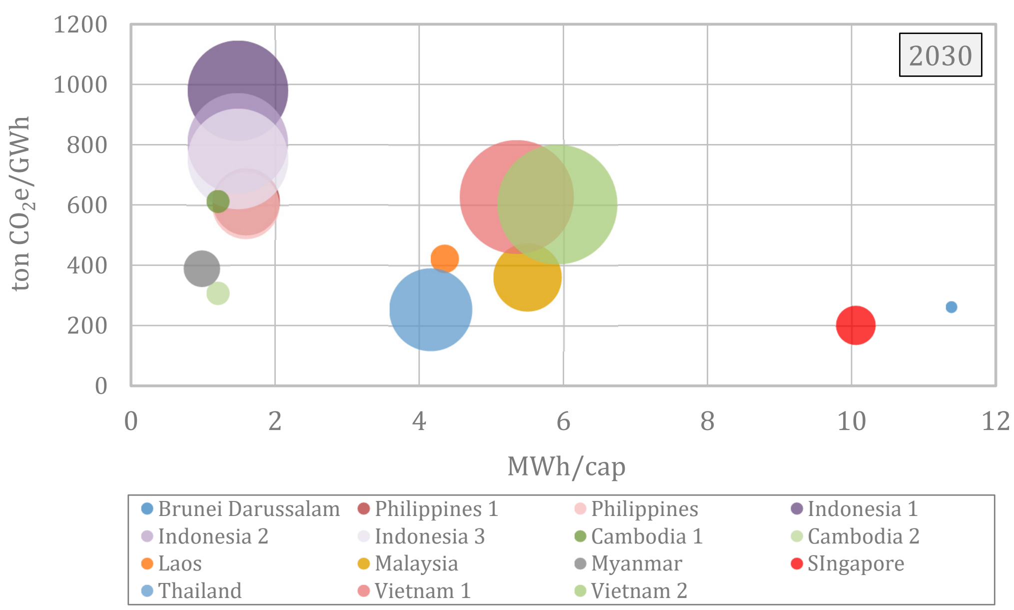

Figure 14. Relationship between electricity generation (GWh), emission intensity (CO_2e/GWh), and energy intensity (MWh/cap) in AMS (2030).

Figure 14 shows that, in 2030, Indonesia is predicted to have the highest emission intensity, while Singapore is predicted to have the lowest. Most countries increase their electricity production, which also leads to an increase in energy intensity. However, there is no increase in energy intensity for Brunei and Singapore. Countries that have already had high energy intensity, such as Brunei and Singapore, do not intend to increase their energy intensity, and they intend to focus on energy intensity reduction. The high energy intensity (MWh/cap) indicates the high level of electricity consumption per individual and a modern lifestyle where most of the equipment that supports daily life uses electricity.

Table 3 shows differences in electricity production (GWh), emission intensity (t-CO_2e/GWh), and energy intensity (MWh/cap) between 2030 and 2020.

Based on Table 3, Vietnam has the most aggressive plans to increase its electricity production, followed by Indonesia. The plan to increase electricity production is accompanied by a reasonably high energy mix from fossil fuel with relatively low CO_2 emissions factors, such as gas and RE, resulting in a reduction in emission intensity (50.4t-CO_2e/GWh for Vietnam 2 scenario and 25.4t-CO_2e/GWh for the Vietnam 1 scenario). Likewise, the

Indonesia 2 scenario (optimal scenario) resulted in an emission intensity reduction of 44t-CO_2e/GWh, and the Indonesia 3 scenario (low carbon scenario) resulted in an emission intensity reduction of 100.6t-CO_2e/GWh.

Table 3. Changes in electricity production (GWh), emission intensity (CO_2e/GWh), and electricity production per capita (MWh/Cap) in 2030 and 2020.

Country	Δ (2030–2020)		
	GWh	**t-CO_2e/GWh**	**MWh/cap**
Brunei Darussalam	572	−37.9	-
Philippines 1	98,721	20.4	0.65
Philippines 2	98,086	10.7	0.65
Indonesia 1	174,852	130.1	0.49
Indonesia 2	174,852	−44.0	0.49
Indonesia 3	175,852	−100.6	0.49
Cambodia 1	12,424	113.1	0.54
Cambodia 2	13,111	−206.9	0.58
Laos	6005	−83.3	0.22
Malaysia	27,635	−148.9	-
Myanmar	43,244	275.8	0.70
Singapore	9305	−4.3	-
Thailand	83,192	−53.6	1.02
Vietnam 1	307,000	−25.4	2.63
Vietnam 2	354,000	−50.4	3.06

3.4. Spatial Distribution Characteristics

The spatial distribution characteristics in the AMS are shown in Figure 15. In contrast to other nations, Indonesia and Vietnam had more significant increases in carbon emissions in 2030 with the value of 335.3 and 358.3Mt-CO_2e. In comparison, Brunei Darussalam has the lowest emission in the ASEAN region with 1.5 Mt-CO_2e because its energy sources are renewable, being mainly from hydropower.

3.5. Decarbonization Strategies

The RE installation can significantly impact CO_2e emission reduction if it replaces CFPPs. The AMS are targeting emission reduction of CO_2e emissions by increasing RE or using an energy source with less carbon emission in the energy mix to replace coal [45,46]. Until 2030, coal and other fossil fuels will still represent a significant proportion of the energy mix. In addition to coal being a tremendous natural resource in some ASEAN countries, RE power plants' Levelized Cost Of Electricity (LCoE) is still higher than CFPPs [47].

However, there is currently a global energy transition, including in the ASEAN countries, and this energy transition is occurring rapidly and will result in significant changes to human life. This trend will have far-reaching implications for businesses, governments, and individuals in the coming decades. The trends that shape the future of energy are driven by local trends, which will occur at varying speeds. The innovation of RE technology and its large-scale deployment has enabled the rapid reduction in energy costs for RE installation, led by solar and wind technologies. In just a decade (2010–2019), the prices of PV modules and wind turbines have fallen by 89% and 59%, respectively [48]. ASEAN countries could also strengthen their capacity by expanding cooperation with the United Nations Economic and Social Commission for Asia and the Pacific Repository (UN ESCAP) and joining the International Renewable Energy Agency (IRENA) [42].

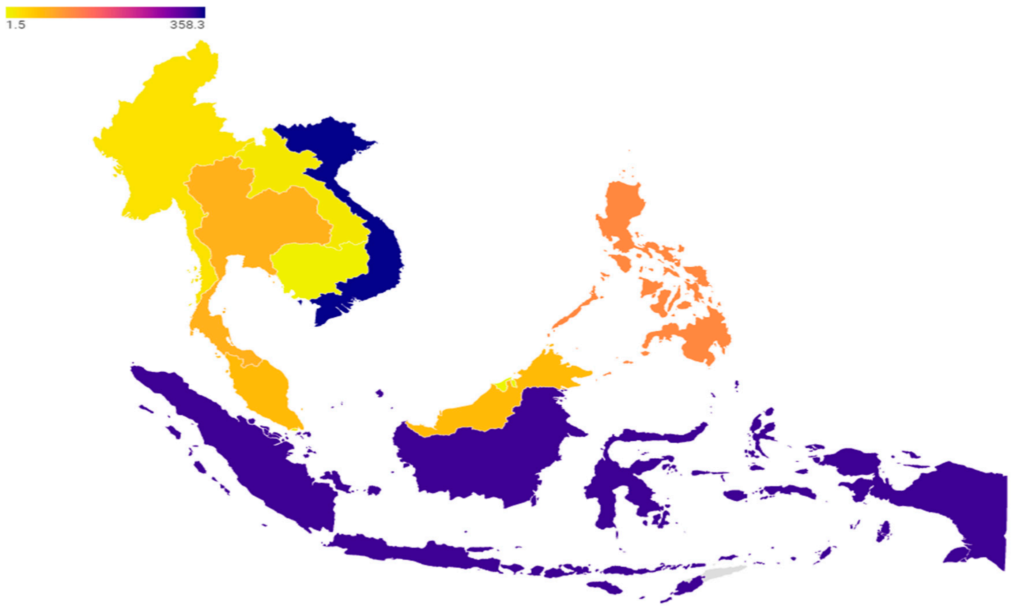

Figure 15. Projection of AMS carbon emissions level in 2030.

Wars have affected the economy, monetary system, international commerce and progress, nature, and energy. The energy impact of the war between Russia and Ukraine will play a key role in energy supply, particularly in terms of CO_2 emissions. Nuclear energy is one of the essential low-carbon alternative energy strategies required to reduce emissions [49]. This new energy contributes to reducing environmental degradation in the USA, France, Russia, South Korea, Canada, Ukraine, Germany, and Sweden; findings from [50] show that ammunition emissions are positively correlated with the aforementioned military parameters and global carbon emissions. There is a connection between global carbon emissions and the number of Ukrainian military personnel. The AMS's national policies of the electricity development plan relevant to the projected GHG emissions must consider the effect of war, especially in the 2030 to 2040 nuclear scenario.

4. Conclusions

The projection of CO_2e emissions and intensity from electricity generation activities in the ASEAN region has been carried out according to the national development plan of each AMS. The population and GDP growth significantly increase energy production and consumption in the AMS. The electricity supply needs to be improved to meet the growing demand. The GDP directly affects the individual income, thus influencing the lifestyle, which relies more on electricity consumption. Electricity generation is directly related to the CO_2e emission and intensity if fossil fuels are still utilized as the source of energy for the electricity sector.

The study's results indicate that, as a developing country, Indonesia has the largest population and gross domestic product (GDP) but is predicted to have the highest 0.97 CO_2e/MWh emission intensity in 2030. Vietnam is predicted to have an emission intensity of about 3.56t-CO_2e/cap and 0.747t-CO_2e/GDP in 2030. Vietnam is expected to increase its energy intensity to 1241 MWh/GDP, while Brunei Darussalam is expected to have a high energy intensity of 11.35 MWh/cap. However, the capacity of solar power plants (more than 11 GW) and wind-power plants (2384 MW) have generally increased in the ASEAN from 2015 to 2019, indicating positive renewable energy source (RES) use development. The national policies of the electricity development plan strongly influence the projected CO_2e emissions and intensity plan. Policies that address replacing coal with lower carbon energy sources, such as gas, will not have significant impacts if the proportion of coal in the energy mix is still high. Compared with other ASEAN countries, Indonesia and Vietnam need to develop a comprehensive strategy to significantly decarbonize the electricity sector to reduce carbon emissions. Aggressive policies in replacing CFPPs with RE power plants affect CO_2e emissions and intensity reduction. Feed-in tariffs, RE auctions, or corporate RE procurement should be bolstered as strong policy supports for mitigating investment risks and expanding RE technology deployment. Southeast Asia has a high potential for wind and solar availability throughout the year, which is a significant capital in the development of RE technology.

Despite its importance, this study has limitations. In the future, researchers can investigate the role of renewable energies in reducing carbon emissions from the electricity sector by considering the intermittent characteristics of renewable energy and the development trend of RE plants.

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