Renewables development for energy transition in ASEAN: Status quo, gaps and the prospect

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Key messages:

- Focusing on four major ASEAN member states, including Indonesia, Viet Nam, Thailand and the Philippines, this paper reviews the current status, and identifies the gaps and prospects for achieving a high penetration of renewables for energy transition in ASEAN.
- These four countries have been leading renewable policies in this region, and have established some key measures such as guaranteed purchase of renewable power at set tariffs, economic incentives for project development, financing schemes to support investments, and permitting mechanisms to facilitate grid connection. However, the development of renewables is still at an early stage in ASEAN, especially for solar PV and wind power.
- Most scenario studies suggest a high share of and even 100% renewables for energy transition in ASEAN. Solar PV is key due to its abundance across the region. Variable renewables and energy storage also play a central role. Meanwhile, there are some studies proposing a moderate share of renewables in the future electricity mix of the region, as well as addressing the role of CCS, and hydrogen and ammonia-fired power generation.
- The basic barrier hindering renewables development is the economic order. Renewables are still more expensive than coal power in ASEAN. Another critical obstacle is the bureaucracy in the region's power sector. Major non-economic obstacles include grid problems, infrastructure, regulation and administrative deficiency. A lack of policies to regulate proper land use and the accompanying environmental impact is a growing concern for large-scale renewable projects. Geographical and technical conditions may bring challenges for renewables development, i.e., fragmented power grids in Indonesia and the Philippines as archipelagic countries. Lack of exploration techniques, extended permission time and lack of public acceptance are barriers for geothermal in ASEAN.
- Nevertheless, many opportunities remain for ASEAN to expand renewables by establishing a level playing field. A short-term affordability perspective in energy planning should be avoided. Energy transition should be recognised as a business chance with a focus on leapfrogging by building renewables infrastructure. Phasing out fossil fuel power should be also promoted.

1. Introduction

The Association of Southeast Asian Nations (ASEAN) was established in 1967 and consists of 10 countries. Overall, ASEAN has a population of around 667 million and an area of 4.5 million km^2. The region's gross domestic product (GDP) reached 3.66 trillion USD in 2022, indicating significant growth from previous years (Statista, 2023). Energy demand and carbon emissions are bound to increase significantly in the region which has become a growth engine for the global economy. According to IEA (2022), energy demand in ASEAN countries has been increasing by around 3% per year on average over the last two decades, and this trend is likely to continue to 2030 under current policy settings.

Around three-quarters of the increased energy demand in ASEAN has been supplied by fossil fuels, especially coal. The high reliance on coal can be attributed to the region's coal abundance and its lower cost relative to other energy sources. According to Global Energy Monitor et al. (2023), the operating coal-fired power generation capacity reached 40.6 GW in Indonesia in 2022, an increase of 3% from the previous year. Indonesia also has 18.8 GW of coal-fired power generation categorised as under construction as of the end of 2022. This number exceeds all other countries globally except China and India. The existing capacity of coal-fired power generation in Viet Nam has more than doubled in last decade, consisting of over 70 units in 25 power plants. Five new coal-fired power plants, equivalent to 6 GW of capacity, are under construction as of January 2023. The capacity of operating coal-fired power generation in the Philippines has also doubled over the last decade despite its annual capacity addition leveling out. The Philippines ranked sixth in the world for its increase in new coal-fired power generation capacity in 2022, equivalent to 1.3 GW (Global Energy Monitor et al., 2023).

Accordingly, ASEAN emitted a total of 1.76 billion tons of CO_2 emissions from energy use in 2019, with Indonesia, Viet Nam, Thailand, Malaysia and the Philippines being the highest emitting countries (IRENA, 2022). As so far, nearly all 10 ASEAN member states have declared to become carbon neutral by around mid-century except the Philippines. This requires the region to accelerate its energy transition by upgrading energy policies and regulatory frameworks, and promoting much higher levels of investment for the expansion of renewable energy to replace fossil fuels (IEA, 2022). With a focus on Indonesia, the Philippines, Thailand and Viet Nam, which contribute to around 75% of overall emissions in the ASEAN region, this paper reviews the current status of the development of renewable energy in these countries, and identifies the gaps and prospects for them to achieve a sufficiently high penetration of renewables toward energy transition.

2. Research method

This study was carried out mainly through an overview of literature with high relevance, and a comprehensive and systematic analysis of information gathered from various sources. Taking an overview of policies relevant to renewable energy development is particularly useful to gain a better understand of the regulatory environment and future strategies of the target countries in ASEAN. An

analysis of the available statistical data identifies which renewable energy source has a relatively high share in the current electricity mix, and shows the gap in diffusion of renewable energy with a significant potential. In addition, the barriers widely presented in the literature are identified and structured to create a classification of barriers for further survey studies (Juszczyk et al., 2022).

3. Overall energy landscape in ASEAN

Referring to the data published by the International Renewable Energy Agency (IRENA), around 20% of total primary energy supply (TPES) in ASEAN came from renewable energy in 2018, and the remainder (around 80%) consisted of fossil fuels. Most of the energy was used by the four target countries of this paper, as well as Malaysia. Although Thailand and Malaysia indicate a slightly increasing trend in terms of renewable energy percentage in total final energy consumption (TFEC), this share decreased between 2000 and 2015 across ASEAN as a whole (Lau, 2022). The decreasing trend has to be reversed if the region wants to achieve the recently declared net-zero target.

Overall, the development of renewable energy is still at an early stage in ASEAN, especially for variable renewable energy, including solar PV and wind power. In 2020, power generation from fossil fuels had a 78% share of the ASEAN electricity mix, hydropower accounted for 16%, and the share of other renewable energy was only 6% (Handayani et al., 2022). So far, the most important types of renewable energy capacity in the region include hydropower, solar PV, bioenergy and geothermal, with hydropower dominating over all the other types of renewable energy. Furthermore, the share of renewable electricity in total power generation has stayed relatively flat, confirming that renewable energy has still not gained much ground over fossil fuel electricity in the ASEAN power sector. In fact, ASEAN currently is facing a dilemma in terms of development of renewable energy. If the major projects planned for hydropower were to be slowed down due to the concern of environmental impacts, it would be hard for the share of renewable electricity in the total power generation to grow significantly in the next decade. Solar PV may not be enough to bridge the gap due to its low rate of capacity utilization. Geothermal energy is mainly located in the Philippines and Indonesia, but these two countries are not planning any large increase in the use of geothermal power (Lau, 2022).

4. Status quo of renewable energy in the target ASEAN countries

Fig.1 shows the installed power generation capacity by energy type and the share of renewable energy in the four target ASEAN countries between 2000 and 2022 (IRENA, 2023).

The installed capacity of power generation of Indonesia was 37.3 GW in total in 2000. This amount fell to 27.3 GW in 2005 mainly due to the significant decrease of oil-fired power generation capacity. Along with the large increase in the installed capacity of coal-fired power generation, the total amount increased to 77.4 GW by the end of 2022. Out of this, hydropower capacity was around 5.7 GW, and geothermal was the second largest renewable energy with a capacity of around 2.7 GW. On the other hand, the installed capacity of solar PV and onshore wind power was very marginal at 221 MW and 154 MW, respectively. Overall, the share of renewable energy was only 15.4% of installed capacity in 2022.

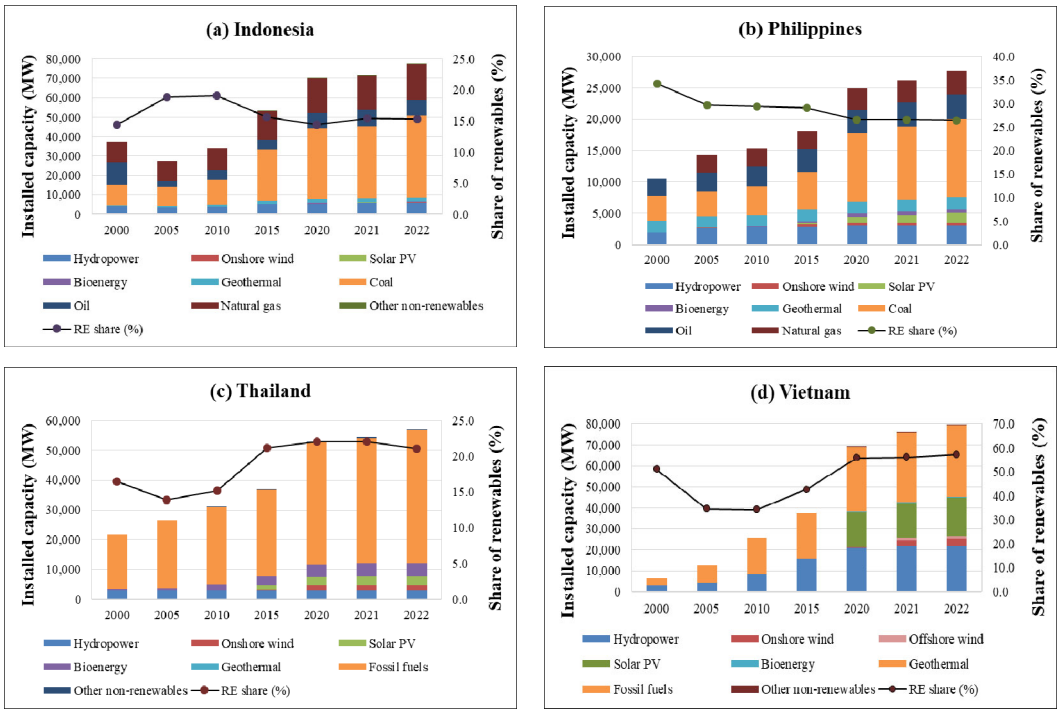

Fig.1: Installed power capacity and the share of renewable energy in target countries (2000-2022).

In order to satisfy an increasing demand for electricity, the installed capacity of power generation in the Philippines increased year by year from around 10.6 GW in 2000 to around 27.7 GW in 2022. In particular, coal-fired power generation contributed to a large portion of this increase, and accounted for nearly 45% of the total capacity in 2022. The share of renewable power generation capacity was 26.4% in the same year — 3.0 GW for hydropower, around 1.9 GW for geothermal, around 1.6 GW for solar PV and less than 0.5 GW for onshore wind power.

For the case of Thailand, the installed capacity of power generation using fossil fuels increased from around 18.1 GW in 2000 to around 44.9 GW in 2022, indicating that the amount more than doubled since the start of this century. Accordingly, the total power generation capacity increased from 21.7 GW to 57.1 GW during the same period. For renewable energy, the installed capacity was individually 4.2, 3.1, 3.1 and 1.5 GW for bioenergy, hydropower, solar PV and onshore wind power in 2022, resulting in a 21% share of renewable energy in the total installed capacity in Thailand.

The installed capacity of power generation in Viet Nam was around 6.5 GW in 2000, with a combination of hydropower and fossil fuel power generation accounting for almost half of the total at that time. This amount increased significantly to 79.2 GW in 2022, mainly due to an increase in hydropower to 21.8 GW, fossil fuel power generation to 34.0 GW and solar PV to 18.5 GW. In addition, capacity of around 3.5 GW and 1.1 GW was developed respectively for onshore and offshore wind power. Accordingly, the share of renewable energy in installed capacity was around 57.2% in 2022. This confirms the relatively faster expansion of renewable energy in Viet Nam, especially for hydropower between 2005 and 2020, and for solar PV and wind power in more recent years (after 2015).

Fig.2 lists the amount of power generated by energy type and the share of renewable energy in the four target ASEAN countries between 2000 and 2020 (IRENA, 2023).

The total power generation amount in Indonesia increased from around 98 TWh in 2000 to 290.9 TWh in 2020, almost tripling within two decades. In 2020, most of the power generation was from coal-fired power units, accounting for 62.1%, with natural gas being another important source which contributed 17.4% of the total. Around 18.1% of the total power generation came from renewable energy in 2020 — 46.5% from hydropower, 29.6% from geothermal and 23.6% from bioenergy. While Indonesia is planning to add a further 6 GW of hydropower between 2021 and 2030, it is unlikely that electricity from renewable energy will exceed 20% of the country's total power generation by 2030 (IEA, 2021a).

In the case of the Philippines, where the growth rate is not as large as Indonesia, the total power generation increased from 44.9 TWh in 2000 to 101.5 TWh in 2020, more than doubling in 20 years. In 2020, 57.3% of the electricity was supplied by coal-fired power generators, and 20.6% came from renewable energy, with nearly 50% coming from geothermal, 33% from hydropower, 6% from solar PV, 6% from bioenergy and 5% from wind power. Therefore, solar PV and wind power only accounted for 2.4% of the total power generation in the Philippines in 2020. Despite a plan for a slight increase of geothermal and small hydropower projects, it also seems unlikely that renewable electricity would exceed 25% of the total power generation by 2030 in the Philippines (Lau, 2022).

The total power generation amount in Thailand also increased rapidly from 96.3 TWh in 2000 to 195.6 TWh in 2020, slightly more than doubling in 20 years. Unlike Indonesia and the Philippines, gas-fired power generation was the largest electricity supplier in Thailand and contributed to 58.2% of the total in 2020. Together with a share of 18.8% of coal-fired power generation, thermal power accounted for around 77% in the total power supply in the same year. In 2020, 22.3% of the total power generation was from renewable energy — nearly 70% from bioenergy, 11% from hydropower, 11% from solar PV and 8% from wind power. This resulted in a share of 4.3% for solar PV and wind power in total electricity generation. Even if power production using bioenergy doubled by 2030, electricity generated using renewable energy would not reach 33% of the total power generation in Thailand (IEA, 2021a).

As described earlier, the dominant renewable energy in Viet Nam is hydropower, which is mainly generated by establishing dams along the Mekong River and its tributaries. The total power generation in Viet Nam in 2000 was 27.0 TWh — around half (51%) from hydropower, and the other half from fossil fuel power generators. By 2020, total power generation saw a rapid increase to 232.4 TWh, more than eight times the level of 2000. In 2020, nearly 40% (39.7%) of the total power generation came from renewable energy — nearly 80% from hydropower, 18% from solar PV, and 2% from wind power. This confirms the quick expansion of solar PV in recent years in Viet Nam. There is a plan to further increase capacity by 4 GW for hydropower between 2021 and 2030. Even if this was realised, renewable energy electricity would not exceed 45% of the total power generation in 2030 (IEA, 2021a).

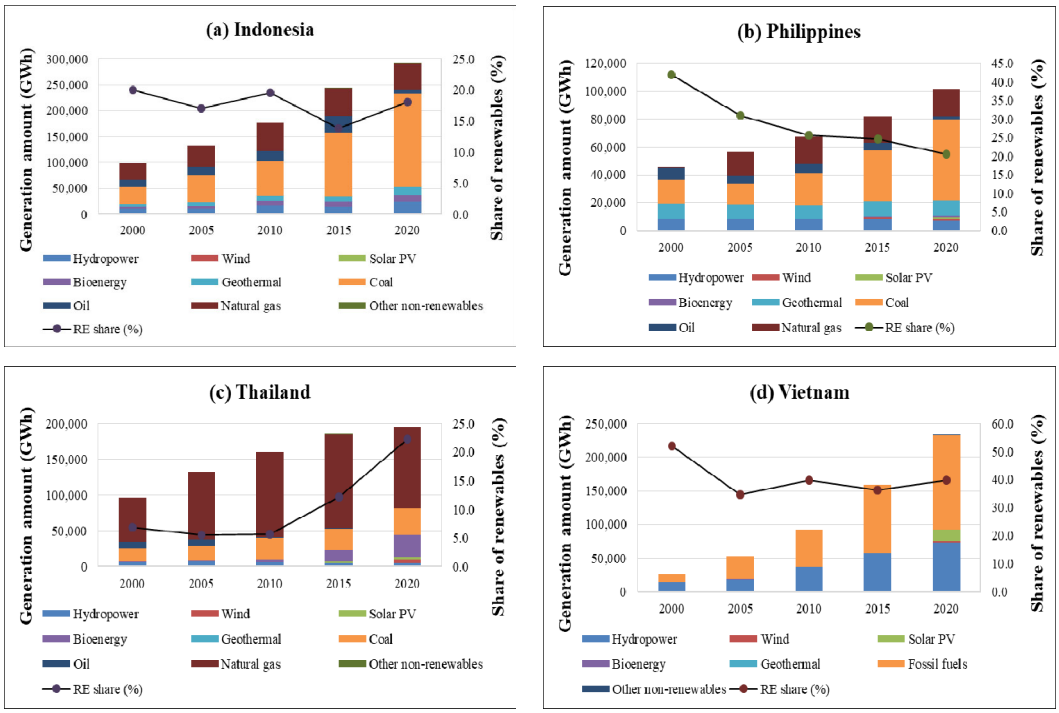

Fig.2: Power generation amount and the share of renewable energy in target countries (2000-2020).

5. Renewable energy potential in the target ASEAN countries

Solar irradiance across ASEAN is strong, with an average of 1,500 to 2,000 kWh per square meter per year, which is equal to a capacity utilisation factor of over 20%. Comparatively, wind resource is not so favourable in ASEAN. In a few countries like the Philippines, Viet Nam and Thailand, there exist areas along the coasts and inland allowing for a capacity factor higher than 30%. Land areas suitable for solar PV and wind power vary by country. Among the four target ASEAN countries, Thailand has the most suitable land areas in the region for solar PV, and Viet Nam has the most suitable land areas for wind power. The Philippines is another country with large land areas appropriate for both types of renewable energy. Suitable land areas are more constrained in Indonesia, in particular for wind power. Indonesia and the Philippines have significant potential for geothermal energy, and there is good potential for bioenergy all over the region (Lee et al., 2020).

Vidinopoulos et al. (2020) provided an estimation of the technical potential of selected categories for renewable energy across ASEAN. Their results confirmed the technical possibility for ASEAN to achieve a decarbonised energy system by 2050. It is certainly necessary to refine the estimation for the technical potential of renewable energy resources and to further analyse their commercial feasibility based on practical technology applications.

Table 1 lists the estimation results of the technical potential for selected renewable energy resources in terms of the amount of potential annual electricity generation in the four target countries and ASEAN as a whole. A comparison of the overall technical potential and the TPES forecast in 2040 under the ASEAN target scenario indicated in the 5th ASEAN Energy Outlook 2015-2040 implies that it would be possible,

at least technically, to supply an equivalent of TPES solely by the selected renewable energy types in most of the four target ASEAN countries. Rural solar PV is the source with the highest potential among the selected renewable categories. This relies heavily on land availability and land allocation for various use purposes, i.e., forest, agriculture, urban and expansion of land transportation (Vidinopoulos et al., 2020).

Table 1: Technical potential of selected renewable energy in ASEAN (Vidinopoulos et al., 2020).

Country/ region	Solar (TWh)		Wind (TWh)		Hydro (TWh)	Geothermal (TWh)	Total (TWh)	Total/2040 TPES
	Urban	Rural	Onshore	Offshore				
Indonesia	1,042	24,398	20	169	402	203	26,225	4.7
Philippines	299	NA	164	1,547	24	32	2,066	1.6
Thailand	281	9,023	900	79	55	NA	10,338	4.0
Viet Nam	287	NA	64	291	96	NA	738	0.3
ASEAN	2,431	51,700	2,495	2,134	1,130	235	60,125	4.1
Note: Technical potential refers to the achievable energy generation from specific technologies given system operation efficiency, topographic constraints, and environmental and land use limitations.								

Based on geographic information system (GIS) data, the Institute of Energy Economics, Japan (IEEJ) estimated the potential of solar PV, onshore wind and offshore wind power capacity to be individually 3,513, 313 and 1,241 GW for the whole of the ASEAN region (Kimura et al., 2022).

6. Renewable energy targets of the target ASEAN countries

The mitigation target for greenhouse gas (GHG) emissions by 2030 in the latest nationally determined contributions (NDCs) and the long-term goal for the decarbonisation of the four target ASEAN countries are listed in Table 2.

Table 2: Mitigation and decarbonisation goals of the target ASEAN countries (UN, 2023).

Country	GHG emission reduction from BAU level by 2030		Long-term decarbonisation goal
	Unconditional	Conditional	
Indonesia	31.89%	43.20%	To achieve net-zero emissions by 2060 or sooner
Thailand	30%	40%	To achieve carbon neutrality (net-zero CO_2 emissions) by 2050 and net-zero GHG emission by 2065
Viet Nam	15.8%	43.5%	To peak carbon emissions in 2035 and achieve net-zero emissions by 2050
Philippines	2.71%	72.29%	None
Note: The latest NDCs update date was September 23, 2022 for Indonesia; November 2, 2022 for Thailand; November 8, 2022 for Viet Nam; and, April 15, 2021 for the Philippines.			

Overall, these four countries announced unconditional and conditional reduction rates for GHG emissions from the levels of business as usual (BAU) by 2030. In more detail, Indonesia, Thailand and

Viet Nam updated and further enhanced their NDCs before or during COP27 held in November 2022. These three countries also declared a long-term goal for achieving net-zero emissions by around mid-century (UN, 2023). Specifically, Indonesia announced that it would achieve net-zero emissions by 2060 or sooner. Thailand has declared that it aims to realise net-zero CO_2 emissions and net-zero GHG emissions in 2050 and 2065, respectively. Viet Nam declared the country's carbon emissions would peak in 2035 and that it would subsequently achieve net-zero emissions by 2050. The Philippines does not have a clear goal yet for decarbonisation in the long term.

Based on various sources, the latest targets for development of renewable energy in ASEAN as a whole and the four target countries are summarised in Table 3. Each of the countries have a significantly different level of ambition for the development of renewable energy. In general, the targets do not seem to be so ambitious and further efforts remain to be made (REI, 2019).

The ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II: 2021-2025 sets out that ASEAN seeks to raise the proportion of renewable energy in the region's energy supply to 23% by 2025. In 2021, ASEAN had a share of 14.3% for renewable energy in the region's primary energy supply, and this figure has remained almost unchanged for half a decade (ACE, 2022a). This implies that increasing the share of renewables in the primary energy supply will be a challenge (ACE, 2022a). Therefore, ASEAN needs to seize any available funding opportunity to be able to meet the regional target for renewable energy development (APAEC Drafting Committee, 2020).

Table 3: Renewable energy development targets of ASEAN and the four target countries.

Country/region	Published targets	References
ASEAN	• To increase the share of renewable energy in TPES to 23% by 2025 (excluding traditional biomass).	(APAEC Drafting Committee, 2020)
Indonesia	• To increase the share of new and renewable energy in TPES to reach at least 23% by 2025 and at least 31% by 2050.	(Indonesia, 2022)
Philippines	• To aim for renewable energy to comprise 35% of total power generation by 2030 and 50% by 2040.	(DOE, 2022)
Thailand	• To increase the share of renewables to 30% in TFEC by 2037. • To increase the share of renewable energy power to 35% in capacity and 29% in generation by 2037.	(MOE, 2020); (IEA, 2021b)
Viet Nam	• To develop a capacity of 21.88 GW onshore wind power and 6 GW offshore wind power by 2030, and further increase offshore wind power to a range of 70 to 91.5 GW by 2050. • To develop a capacity of around 12.8 GW for solar PV by 2030 and a range of 168.6 to 189.3 GW by 2050. • In 2030, wind power, solar PV, hydropower and biomass will provide 48% of the installed capacity, this share will rise to a range of 66.8% to 72.3% in 2050.	(Barnes, 2023)

In Indonesia's enhanced NDC for COP27, the country pledged to increase the use of new and renewable energy to at least 23% of the total primary energy supply by 2025 and to at least 31% by 2050. This effort has been supported by the implementation of regulations set out in the 'Electricity Supply Business Plan' that prioritises the development of new and renewable energy (Indonesia, 2022).

According to the National Renewable Energy Program (NREP) 2020-2040, the Philippines aims for renewable energy to make up 35% of the total power generation by 2030 and 50% by 2040. To this end, new-build renewable energy capacity of over 52 GW needs to be added by 2040, comprising of more than 27 GW of solar PV and 16 GW of wind power, followed by more than 6 GW of hydropower and 2.5 GW of geothermal energy (DOE, 2022).

Thailand's Alternative Energy Development Plan 2018-2037 (AEDP 2018-2037) was approved by the Thai cabinet in October 2020. The overall goal of the AEDP 2018-2037 is to increase the share of renewable energy to 30% of TFEC by 2037. Accordingly, renewable energy will expand to nearly 30 GW (around 15.6 GW for solar PV, 5.8 GW for biomass, 3 GW for hydropower and 3 GW for wind power), accounting for 35% of installed capacity and 29% of the amount generated in the same year (MOE, 2020; IEA, 2021b).

In May 2023, the government of Viet Nam approved the National Electricity Development Plan for 2021-2030 with a Vision to 2050, known as the Power Development Plan 8 (PDP8). Electricity consumption is expected to reach around 505.2 TWh by 2030 and further increase to between 1,224 and 1,378 TWh by 2050. According to the PDP8, Viet Nam aims to develop a capacity of 21.88 GW for onshore wind power and 6 GW for offshore wind power by 2030, as well as further increase offshore wind power to a range of 70 to 91.5 GW by 2050 within technology capability and economic feasibility. Solar PV has been playing an increasing role in Viet Nam's electricity mix and the country is estimated to have potential solar power of up to 963 GW. According to the PDP8, Viet Nam expects to develop capacity with a range of 168.6 to 189.3 GW by 2050. In 2030, wind power, solar PV, hydropower and biomass will contribute to 48% of the total installed power generation capacity, and this share will rise to between 66.8% and 72.3% in 2050 (Barnes, 2023).

In addition to the target setting, the four target countries have established several key policy measures for renewable energy development. All of them have implemented a feed-in tariff (FIT) policy. Thanks to this policy, solar PV has been expanding in Thailand. The first solar PV FIT in Viet Nam, starting from mid2017, has led to a quick expansion of solar PV capacity in recent years. This policy also triggered moderate expansion of solar PV in the Philippines, but the effect was very marginal in Indonesia. In comparison with solar PV, FIT incentives for wind power are generally not attractive in this region. Some of the target ASEAN countries began holding bidding for the development of renewable energy projects, i.e., solar PV and wind power in the Philippines and bioenergy in Thailand. Additional policy measures include economic incentives for project owners and investors, financing mechanisms to support renewable energy projects, and permitting and licensing regulations and technical criteria to facilitate integration with the power grid (REI, 2019).

7. Levels of renewable energy necessary for energy transition in ASEAN

Many model studies were carried out to depict scenarios for long-term decarbonisation of either ASEAN as a whole or some specific countries. Most of these analyses suggested a sufficiently high share and even 100% of renewable energy for energy transition in ASEAN. Several other studies proposed a moderate share of renewable energy in the future electricity mix. The results of these two categories of literature are summarised in section 7.1 and 7.2, respectively.

7.1 Pathways for energy transition with very high penetration of renewable energy

IRENA and ACE (2022) presented two ways for the transition of the ASEAN power system consistent with IRENA's global 1.5°C scenario as referred to in the World Energy Transitions Outlook. One is a 100% renewable energy system and the other reaches 90% renewable energy with a very small portion of fossil fuel power generation, mostly from natural gas. Electricity demand in ASEAN as a whole per year is currently around 1,100 TWh. This amount would increase fivefold under the 1.5°C scenario. In practice, closing the 10% gap in the share of renewable energy needs significant power storage capacity and expansion of transmission lines. Solar PV is viewed as a key option due to its abundance across the ASEAN region. The 100% renewable energy scenario requires solar PV on a reasonably large scale, up to 2,400 GW, and a compatible increase in battery storage. Batteries will play an essential role from the 2030s but might have some application within this decade. Thus, under the 1.5°C scenario, GHG emissions in ASEAN will be reduced to half of the current levels by mid-century (IRENA and ACE, 2022).

Handayani et al. (2022) evaluated the ASEAN power sector in terms of pathways to net-zero emissions by 2050 by applying the Low Emissions Analysis Platform (LEAP). This study developed three scenarios — a reference scenario, a renewable energy scenario and a net-zero emissions scenario. The reference scenario suggests a continuation of current power generation technology portfolio until 2050. The renewable energy scenario is consistent with renewable energy targets, NDCs and power development plans published by the member states of ASEAN. The net-zero emissions scenario assumes that the ASEAN power sector will evolve beyond the current NDCs with a target of net-zero emissions by 2050. As a result, the electricity demand of ASEAN as a whole is assumed to reach 3,323 TWh by 2050, around three times the 2020 level, with a share of 58% for Indonesia and Viet Nam. The simulations confirm that ASEAN needs to quickly explore the underdeveloped potential of renewable energy if the region is to achieve net-zero emissions by 2050. The technology portfolio would change substantially and variable renewable energy and energy storage would play a critical role. Under the net-zero emissions scenario, power generation capacity will increase to 2,092 GW by 2050, with 81% composed of variable renewable energy. To balance the huge amount of variable renewable energy, a total of 156 GW energy storage capacity will be added and most of this will be deployed in Indonesia, Viet Nam, the Philippines, Malaysia and Thailand. Due to the limited potential of pumped hydro storage in ASEAN, battery storage would play a critical role and the cost reduction of battery become a key for energy transition. Power generation from fossil fuels would be completely phased out by 2050, with renewable energy accounting

for 99.5% of the power generated, and the remaining 0.5% possibly supplied by nuclear power. In particular, solar energy has the largest potential across ASEAN and would therefore dominate the power sector with a share of 61% in the electricity mix, followed by wind power, with a share of 17%. From the view of cost, renewable energy and energy storage are confirmed to be more competitive than carbon capture and storage (CCS). In comparison with the reference scenario, the increased abatement cost on average under the net-zero emissions scenario would be 12 USD/t-CO_2, which is lower than that of the renewable policy scenario at 16 USD/t-CO_2. These figures may be referred to when considering carbon price levels in ASEAN (Handayani et al., 2022).

With individual countries in ASEAN as study targets, Reyseliani and Purwanto (2021) assessed if the power system transition of Indonesia was to reach 100% renewable energy by 2050. This study was conducted using the TIMES (The Integrated MARKAL-EFOM System) model developed under the IEA's ETSAP (Energy Technology Systems Analysis Program), and covers 27 power generation and three energy storage technologies. Two main scenarios were analysed. One is BAU and the other is a 100% renewable energy scenario by 2050, in which power generation is limited to renewables and nuclear power. Three more scenarios were evaluated to review the impact of changing economic growth, the renewable energy portfolio according to the current policy, and the exclusion of nuclear power. Under the 100% renewable energy scenario, solar PV, biomass and nuclear power would play a central role. The capacity of solar PV would continue to increase to 211 GW until 2050, making up 18% of the total power supply. Biomass energy would experience an increase of capacity up to 33 GW. The expansion of nuclear power would be large (26 GW in 2040 and 121 GW by 2050) due to its cost competitiveness in comparison with solar PV combined with energy storage. If nuclear is excluded from the power supply, the installed capacity of solar PV and batteries would need to increase significantly, which would require much more land and a rise in the cost of the power supply (Reyseliani and Purwanto, 2021).

Gulagi et al. (2021) simulated a transition pathway with 100% renewable energy by 2050 for the Philippines using the LUT Energy System Transition model and data with high temporal and spatial resolution. Apart from gas-fired power generation, this study assumed no newly commissioned fossil fuel power generation capacities after 2015 and the replacement of decommissioned fossil fuel capacities only by renewable energy and storage technologies. Increasing the carbon tax was considered and certain limits were also set, i.e., for the maximum growth rate of the share of renewable energy in total power generation capacity. In line with the growth of its economy and population, primary energy demand in the Philippines is forecast to almost double by 2050 compared to 2015, with a share of 88% for electricity due to mass electrification of all energy sectors. As a result of the transition to a renewable energy system, the total installed capacity would be around 455 GW, dominated by solar PV with a share of 68%. Among various storage technologies, battery storage is the preferred option to balance the large scale of solar PV in power system. Solar PV together with battery would form the backbone for the country's power system transition. The total cost of energy system would increase due to the phaseout of fossil fuel power generation and new investment in renewable energy and storage facilities. Meanwhile, the transition would cause a decrease in the imports of fossil fuel, thereby enhancing energy security.

Moreover, the levelised cost of electricity (LCOE) is likely to decrease by nearly 23% in 2050 compared to 2015. In summary, abundant solar resources together with the decreasing cost of solar PV and battery storage may enable the transition toward a 100% renewable energy system in the Philippines (Gulagi et al., 2021).

Thailand developed its long-term low greenhouse gas emission development strategy using the multi-sector AIM/Computable General Equilibrium (AIM/CGE) model to evaluate the macroeconomic impacts of net-zero pathways. The model estimated that the share of renewable energy electricity would be 68% of the total by 2040 and 74% by 2050. Furthermore, bioenergy with CCS technologies (BECCS) would also be needed to achieve Thailand's 2050 net-zero CO_2 emission target. New technology and systems, i.e., solar PV with battery storage, fossil fuel power generation coupled with CCS, hydrogen co-firing and 100% green hydrogen power generation, may be considered as technology options for long-term achievement of the country's net-zero GHG emission target by 2065 (MONRE, 2022).

7.2 Scenarios with modest renewable energy expansion for energy transition

Several other studies proposed a modest share of renewable energy in the future electricity mix of ASEAN by giving more consideration to the role of CCS and hydrogen. One such study by Kimura et al. (2022) involved an analysis of scenarios for carbon neutrality in the ASEAN region by applying an optimum technology selection model, covering energy conversion and end-use sectors and incorporating more than 350 technologies. Among the five scenarios analysed in this study, CN2050/2060 reflects the nationally-declared carbon-neutral targets and considers carbon sinks in some major ASEAN countries. Under this scenario, the primary energy supply in 2060 would substantially increase to about 3.2 times that of the 2017 level. In the electricity mix, renewable energy would become a major source, accounting for 56% of the total in 2060. The share of solar PV would be 53% of the electricity supplied by renewable energy, with H_2 and NH_3-fired power generation accounting for 26%. During the period up to 2030, high-efficiency gas-fired power generation is expected to help reduce CO_2 emissions from power generation. In the medium to long term, co-firing with H_2 or NH_3, and fossil fuel power generation with CCS is like to make a significant contribution to the decarbonisation of the region's power sector (Kimura et al., 2022).

The energy sector as well as forest and other land uses (FOLU) have been confirmed as the two major emission sources in Indonesia. The country's energy system needs to significantly reduce emissions to achieve its near-zero target in the long-run. The Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 presents a set of models, including AIM-EndUse and the AIM-ExSS (Extended Snapshot) and the Asia Pacific Integrated Model/Computable General Equilibrium (AIM/CGE), and these were applied to develop emission pathways for the energy sector and analyse the economic impact of mitigation. Three pathways were developed, including a current policy scenario (CPOS), a transition scenario (TRNS) and a low-carbon scenario compatible with Paris Agreement targets (LCCP). Under the most ambitious LCCP, emissions would decrease quickly after 2030 to 540 million t-CO_2 in 2050, equivalent to around 1.61 t-CO_2 per capita. Renewable energy would account for around 43% in the

electricity mix by 2050, with electricity from coal, natural gas and BECCS having shares of 38%, 10% and 8%, respectively. Around 76% of coal-fired power generation is likely to be equipped with CCS (Indonesia, 2021).

8. Barriers for renewable energy development in the target ASEAN countries

As described above, Indonesia, the Philippines, Thailand and Viet Nam are taking the lead in terms of renewable energy policy practices in ASEAN (REI, 2019). Nevertheless, a review of the literature confirms that there are various barriers for more successful development of renewable energy in these target ASEAN countries. Table 4 lists the categories and examples of barriers for renewable energy development in ASEAN.

Table 4: Categories and examples of barriers for renewable energy development in ASEAN

Category	Examples	References
Economic and market	▪ High initial installation cost ▪ High operation and maintenance cost ▪ Lack of financing sources and support ▪ Lack of expertise for investment risk assessment	(REI, 2019); (The ASEAN Post Team, 2019); (Sachs et al., 2019); (Lee et al., 2020)
Policy and regulatory	▪ Ineffective and unstable policies, i.e., FIT ▪ Lack of policies for regulating proper land-use and environmental impact ▪ Complex bureaucracy of power sector ▪ Difficulty in getting power purchase agreements ▪ Excessive and complex procedures, i.e., for geothermal	(The ASEAN Post Team, 2019); (REI, 2019); (Do et al., 2021); (ACE, 2022b)
Technical	▪ Limited and fragmented power grids due to geographical limitation, i.e., in Indonesia and the Philippines ▪ Lack of exploration techniques for geothermal energy	(The ASEAN Post Team, 2019); (ACE, 2022b)
Societal	▪ Lack of awareness on the benefit of renewable energy ▪ Lack of social acceptance, i.e., for hydropower and geothermal energy	(The ASEAN Post Team, 2019); (REI, 2019); (ACE, 2022b)

From the literature review and discussions presented earlier, investment in renewable energy still falls far short of the levels needed for achieving energy transition consistent with net-zero emissions pathways in ASEAN. The fundamental barrier hindering renewable energy development is the economic order. Renewable energy is generally more expensive than coal-fired power generation in ASEAN on a benchmark basis. Solar PV is now approaching the range of LCOE of coal-fired power generation, and is most cost competitive in Thailand, a little higher in Viet Nam but relatively expensive in Indonesia. Onshore wind power in Viet Nam has been demonstrated as a feasible alternative to coal-fired power generation. However, LCOE of onshore wind power projects in Indonesia and Thailand are much higher than the levels in Viet Nam (REI, 2019). Lee et al. (2020) provided high-quality data and spatial analysis regarding the cost of utility-scale wind power and solar PV in select ASEAN countries. The results

confirm that there is great potential for the development of utility-scale, land-based wind power and solar PV in ASEAN with a range of power generation costs. High initial installation costs for solar PV and wind power are identified as a potential barrier for Indonesia and the Philippines. Installation costs for wind power are high in Thailand, while Viet Nam has high operation and maintenance costs for wind power and solar PV (Lee et al., 2020).

Financial access has thus become the most essential factor for renewable energy development in ASEAN due to its capital-intensive nature. Solar PV and wind power are still at extremely low levels of market penetration in the target ASEAN countries. The finance gap may explain this low level of diffusion (Sachs et al., 2019). The lack of financial sources and support, i.e., the low availability of public funding, makes renewable energy relatively unattractive for investors. Currently, there is a lack of experience and expertise in ASEAN countries, including Indonesia and Viet Nam, making it difficult to conduct appropriate risk assessment of renewable energy investment (The ASEAN Post Team, 2019).

Do et al. (2021) carried out semi-structured interviews with experts in Viet Nam from January to March 2021, in order to identify the factors driving the rapid expansion of solar PV and wind power in recent years. The generous FIT was confirmed to have been an important driver. The exemption of income tax and land lease payment were also useful. On the other hand, uncertainty surrounding some policies, i.e. FIT, appears to be a key barrier more recently. The case of Viet Nam indicates that a strong price signal and enabling policy conditions for investment can pave the way for rapid expansion of solar PV and wind power. Early preparation of the transmission system is also necessary to maximise the development of renewable energy (Do et al., 2021). A lack of policies to regulate proper land use and environmental impacts has become a growing concern for the development of large-scale renewable energy projects in ASEAN (ACE, 2022b).

One more regulatory and policy obstacle is the complex bureaucracy of the power sector in ASEAN. This inhibits the interest of potential investors for renewable energy development (The ASEAN Post Team, 2019). Overall, the reform of the power sector is moving very slowly, and is far from being complete in ASEAN. Competition for power generation is limited and varies among ASEAN countries. In the Philippines and Thailand, independent power producers (IPPs) have become important players. In Indonesia and Viet Nam, IPPs also play a certain role but the national utilities like PLN in Indonesia, and Viet Nam Electricity (EVN) still dominate. Power transmission and distribution, and electricity supply businesses are highly regulated, and are dominated by national or regional public monopolies in general. Among the four target countries, only the Philippines has introduced a wholesale electricity market where electricity can be traded through competitive processes (REI, 2019). Some other policy barriers, such as difficulty in getting power purchase agreements and extended permission times that can be from 7 to 10 years, also hinder the development of geothermal energy in ASEAN (ACE, 2022b).

Technical and geographical conditions are some of the challenges for renewable energy development in ASEAN. For example, limited infrastructure for electricity transmission hinders the deployment of renewable energy in Indonesia and the Philippines. Both countries are archipelagic and their power grids

are more fragmented (The ASEAN Post Team, 2019). Technical barriers, including a lack of exploration techniques, are hindering the exploration of geothermal energy in these two countries (ACE, 2022b).

A lack of awareness and public support contributes to the challenges faced by ASEAN countries for renewable energy development. It is evident that land and building owners as well as industries are still not sufficiently motivated to use renewable energy. This may be due to a lack of awareness on the potential benefits of renewable energy (The ASEAN Post Team, 2019). ASEAN countries, such as Indonesia, have some of the best untapped hydropower potential in the world. The technical potential of hydropower may be constrained by economic viability and some other critical factors like social acceptance and environmental impact. There is already opposition to hydropower projects in some ASEAN countries like Viet Nam (REI, 2019). Social barriers, such as lack of public awareness and acceptance, are also specified as impediments to developing geothermal energy in ASEAN (ACE, 2022b).

9. Summary and future research direction

This paper clarifies the current status, gaps and barriers for renewable energy development in several selected ASEAN countries. ASEAN is one of the few regions in the world where coal-fired power generation is forecast to increase up to 2040. Most ASEAN countries are facing a choice whether to use more coal and natural gas for power generation, or expand their use of renewable energy. When looking at energy transition in ASEAN, it is important to avoid focusing on short-term affordability. Energy transition should be recognised as a business opportunity, whereby the development of renewable energy infrastructure can ensure countries “leapfrog” to a smooth transition. Meanwhile, phasing out fossil fuel power generation should be promoted. The development of local micro-grid and off-grid facilities, and the acceleration of power connectivity in a wider scope enable renewable energy development in ASEAN (Overland et al., 2021).

In fact, many opportunities remain for ASEAN to expand renewable energy in the region by establishing a fair playing field. Further cost reduction, more ambitious target setting supported by effective policies, market conditions favouring competition and customer choice, as well as more robust power grid infrastructure would greatly benefit renewable energy expansion in ASEAN (REI, 2019). In particular, electricity market liberalisation should be promoted in ASEAN. It is important for governments to develop a regulatory and policy framework beneficial for all parties involved in renewable energy development (Erdiwansyah et al., 2019).

As the transition to a variable renewable energy system progresses, including more solar PV and wind power, the flexibility and stability of power system will become more obvious. The development of a modern power grid network needs massive investment which in turn, requires advanced planning and implementation. Sector coupling may reduce the need for additional capacity to meet peak load or reduce grid congestion, and will also facilitate further integration of variable renewable energy. Smart electrification can also reduce the cost of electricity generation and consumption by shifting the load. Energy storage should be developed to address the intermittency of variable renewable energy. As one

alternative, the ASEAN region has enormous potential for pumped storage hydropower (ACE, 2022b).

Power grids for transmission and distribution should be expanded and reinforced to satisfy the increasing electricity demand and ensure the reliability of power system operation. Consistent with the 1.5°C target, the capacity of cross-country transmission lines needs to reach nearly 200 GW by 2050 for deep integration of the power grid in ASEAN (IRENA and ACE, 2022). Electricity market coupling across borders would allow for higher penetration of renewable energy due to the electricity portfolio and geographical diversification. Although the region's power grid is becoming more and more integrated, energy imports and exports represent around 3% of the overall electricity supply currently (PwC, 2022). ASEAN Power Grid (APG) interconnection was initially driven by bilateral agreements and is expected to evolve to reach the sub-regional and regional levels in the future. There are also proposals for integration across Asia as a whole using an Asian Super Grid.

Future research should look for countermeasures to overcome the existing barriers, analyse the effects of optional policies, and then propose effective financing mechanisms driving renewable energy development for energy transition in ASEAN.

Acknowledgements

This study was conducted thanks to the Environment Research and Technology Development Fund (JPMEERF20221C06) of the Environmental Restoration and Conservation Agency provided by the Ministry of the Environment, Japan. The author wishes to express sincere thanks for this financial support.

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