An Overview Of Renewable Energy In Southeast Asia: Current Status And Future Target

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Abstract: In the latest years, nations in Southeast Asia such as Singapore, Malaysia, Thailand, the Philippines and Indonesia have experienced significant economic growth. The tropical climate in the region enables the potential for using renewable and sustainable energies. This discussion provides an overview of the Southeast Asian region's renewable energy resources like solar energy, wind power, geothermal, hydropower, biomass, by considering their national resource potential. This study also discusses the present and future energy demands, renewable energy targets and economic perspectives. However, the energy potency cannot be managed optimally, because it is hampered by several challenges to fulfil the nations' renewable energy's target. The present reorganization of traditional energy utilities to introduce renewable energy systems will have a tremendous effect on the region's social, political and environmental circumstances.

Index Terms: Renewable energy, Potency, Target, Southeast Asia, Energy situation, Current status.

1 INTRODUCTION

COUNTRIES in Southeast Asia still depend on large hydro and fossil fuels as their primary source of energy. It is important to know that the Southeast Asian region has a large enough scale of energy variation. The situation of renewable energy and its usage patterns as shown in Table 1. Energy for the economic and building sectors had begun to extend by accounting for roughly half of the total final consumption in 2011, followed by the twenty-fifth transportation sector as shown in Fig. 1. Within the building sector, the use of traditional biomass remains a significant supply of energy, though its percentage declines as a result of rising living standards and urbanization which leads to the transition to contemporary energy sources.

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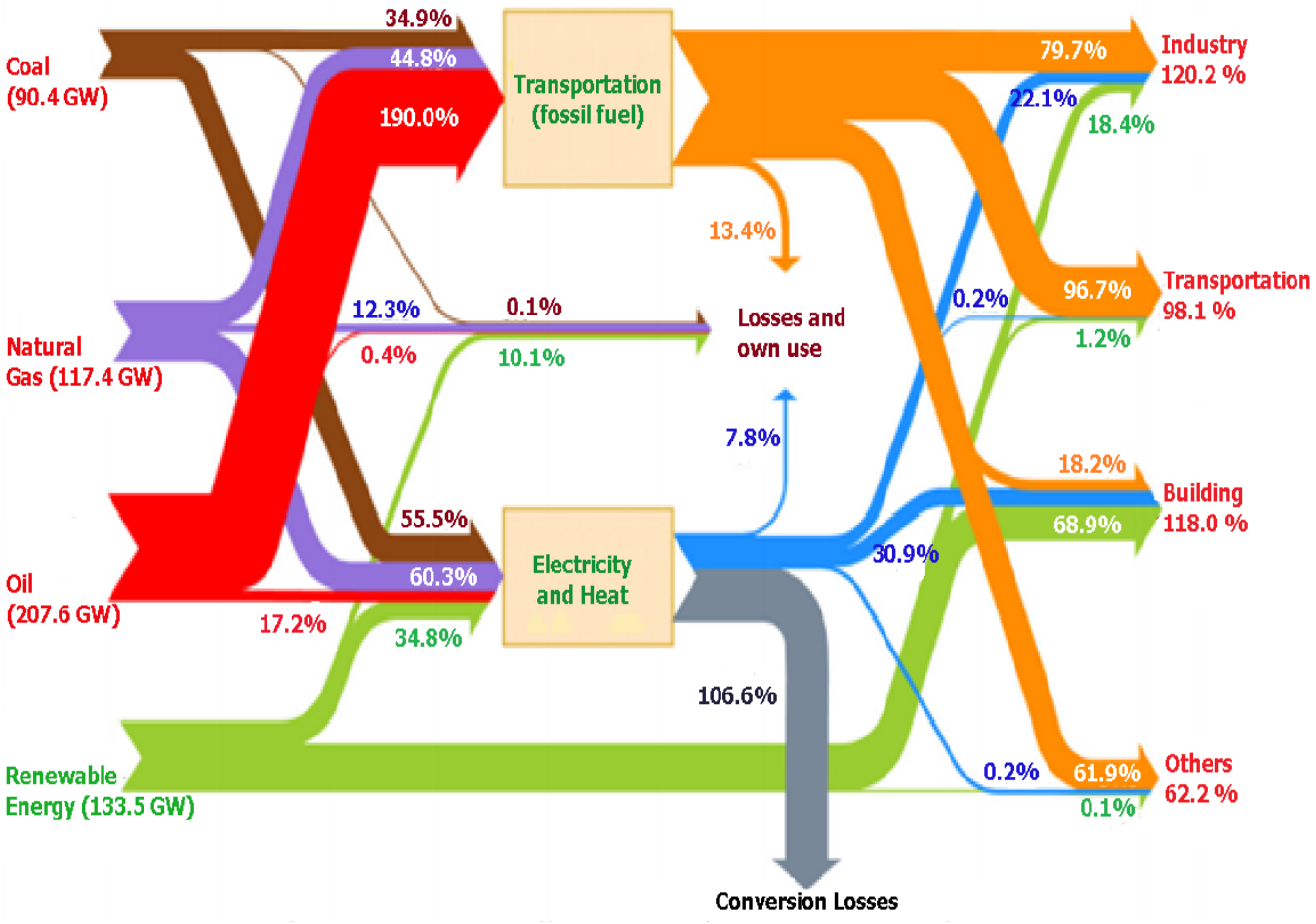
Based on the data collected from Southeast Asian nations the use of energy from fossils and hydro still plays a significant role in energy generation except for Laos and Singapore which no longer use fossil and hydro as shown in Fig. 2. Present oil production in Brunei is around 372.000 barrels per day equal to the special BOEPD for oil and gas [1,2]. High dependency of Gas based power plants for power generation exist in Malaysia and Singapore [3]. The amount of energy supplied from natural gas reached 35.740 Ktoe in Malaysia [4,5]. Indonesia is the most essential energy user in the geographic region. Their annual energy consumption is sixty-six time more than another Asian country (second largest user), and it is fifty times more than Negara Brunei Darussalam (which has all-time low consumption). Another significant indicator, access to electricity, varies tremendously within the Asian nation like Brunei, Singapore, Thailand and to below 50% in Myanmar and Cambodia. It is calculated that more than 134 million individuals in this the region, or 22% of the population, doesn't have access to electricity. About 280 million individuals within the region still rely on the use of ancient biomass for cookery [6]. The ascent of business on energy consumption is online with the step towards a lot of energy-intensive producing activities at the expense of agriculture [7,8]. The use of renewable energy in Southeast Asian countries is expected to increase by 4% each year and by 2025 by 595 Mtoe [9,10]. Increased demand for energy comes from the power generation sector, as power generation has so far only relied on fossil fuels that are running low. For all economic sectors both small and large are very interested in electricity for their day-to-day activities. It is estimated that by 2025, 63% of the energy which is produced by the power plants is going to be utilised by the industries. Fig. 3 outlines the increasing demand for all countries in Southeast Asia. Energy growth also occurs in the transport sector. However, the total energy requirement is expected to remain unchanged and always identical to the industry as predicted by 2025. Southeast Asia is well known for its vast resources of fossil fuels such as oil, natural gas, and coal, but, as seen through the energy landscape, it has a lot of diversity as seen in Table 3. The huge oil reserves are widely owned by several states such as Malaysia, Indonesia, and Brunei Darussalam [11]

while other countries whose energy reserves are relatively less are dependent on the imports. The combination of insufficient energy sources and the pace of economic growth in the region has forced to create policies to develop sustainable energy resources. Each country has different targets, preference, ability to use renewable energy. The progress and development of renewable energy in Southeast Asia as a whole are very different. Renewable energy sources account for only 9.5% in 2014 of the total primary energy supplies. By 2014, APEC has set new targets of 23% renewable energy share by 2025 in Southeast Asia. Indonesia, Thailand and Cambodia, are heavily dependent on fuel oil. While in Indonesia oil is still the most important energy source followed by coal, but they have plans to invest in hydro energy shortly. The increase in interest is also due to global electricity demand, which is estimated to double in the next 20 years and also due to excessive emissions, various countries have committed to reducing CO_2 emissions at the same time. This study is based on various publications which had been published by several researchers on renewable energy from each of the countries in Southeast Asia. Previous research data available in the literature, books, websites related to renewable energy in Southeast Asia are collected and look at the present situation for the final reporting baseline. The objective of the study is as follows:

- ✓ To analyses the current energy scenario and future target in Southeast Asia.
- ✓ To review the realistic potency of renewable energy sources such as solar energy, wind energy, geothermal, hydropower, biomass and other renewable energy resources in Southeast Asia.
- ✓ To study the current status and future targets of renewable energy in Southeast Asia.

The novelty of the study is reflected by the comprehensive analysis of multi-interaction issues between the potency, use, current status and future target of renewable energy which is bundled with policy implications and regulations among the Southeast Asia countries that have quite different characteristics and behaviors.



Based on Fig. 2, Indonesia is the highest in the use of fossil oil compared to other ASEAN member countries. However, in recent years the use of fossil fuels has been reduced by the use of hydropower and coal energy. Also, the Government of Indonesia has targeted the use of renewable energy in 2025 by 23% [14]. The second-largest use of fossil fuels in Southeast Asia is Malaysia. However, the Malaysian Government has implemented the use of biodiesel to reduce the use of fossil fuels. The availability of biodiesel fuel in Malaysia is predicted to reduce dependence on the use of fossil fuels [15–17]. While Thailand is the third-largest country in Southeast Asia in the use of biodiesel fuel sourced from palm oil [18,19]. While the Philippines in recent years has turned its attention to the use of fuels sourced from biomass,

sun, hydro, and ocean [20–22]. This is done by the Philippine government to reduce dependence on fossil fuels. The main energy used by the state of Singapore is wind energy and solar PV by targeting in 2030 at 80% [23,24]. While Laos only relies on energy sourced from hydropower and other renewable energy for national energy security [10]. However, it is different from Brunei Darussalam compared to other countries in Southeast Asia. The main energy possessed by Brunei Darussalam is Gas which reaches 99%. While Cambodia only depends on fossil fuels for national energy security. Another case with Vietnam, the main energy used is the same as Laos, namely hydropower energy. However, besides Vietnam's hydropower, it also has energy sourced from coal, natural gas, oil and other renewable energy. [21,25].

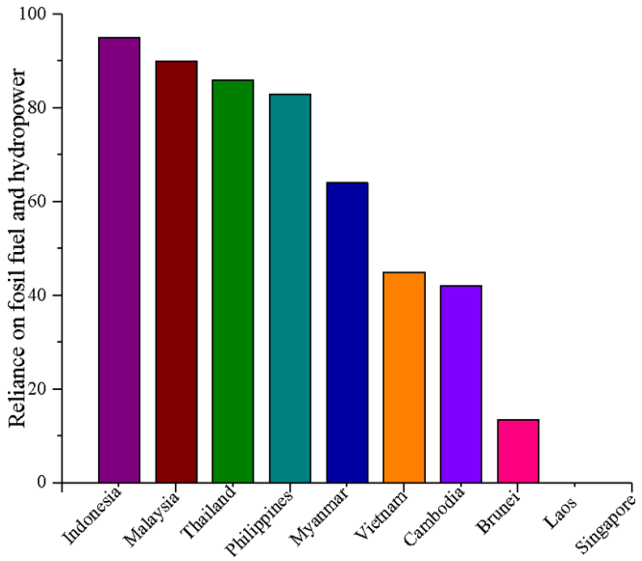


Fig.2*. Countries in Southeast Asia which depends on fossil fuel and hydropower*

2 Overview of Renewable Energy in Southeast Asia

Southeast Asia has embarked on a quest to develop a clean, eco-friendly,environment-conscious and socially acceptable power generation [29–31]. Power generation from various renewable energies such as geothermal energy, solar and wind energy is well suited to be utilised because in addition to its abundant wealth in the region it's also less expensive and eco-friendly. Some countries have taken different steps to improve the quality and market share of renewable energy including feed-in-tariffs (FITs) [32–36]. A wide range of renewable sources like solar thermal energy, wind energy, hydro energy, biomass, etc., be used for energy production [37–40]. Renewable energy such as solar, wind, geothermal, biomass and hydropower can be utilised for power generation, transportation, industry, building, and for another domestic commercial purpose [41–43]. The use of renewable energy, in general, can be directed for electricity generation, industry, transportation, total primary energy consumption (TPEC), total final energy consumption (TFEC), and buildings including household, domestic and commercial housing as shown in Fig. 4.

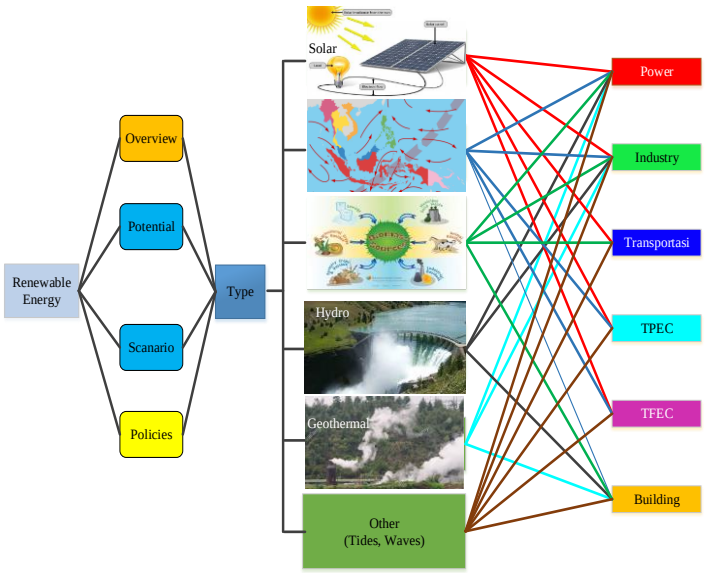


Fig. 4. *Type of renewable and application*

The enormous potential of solar, wind, geothermal, aquatic and biomass energy in Southeast Asia can be used to produce electricity on a massive scale to replace the current dependence on petroleum within few years [44–46]. The abundant renewable energy in the region can be utilised with latest technologies at this time, so that energy sources can provide new hope, especially for power plants that experience weakness in the electricity sector [47–49]. Biomass energy is now becoming one of the most potent renewable energies among other renewable energies, abundant agricultural products such as palm, wheat, maize, and urban waste products, and abundant animal waste can be processed into biomass energy [50–52]. Biomass energy does not cost that much and also the market price is very affordable [47,48]. The temperature gradient between the hot surfaces of the earth when processed can produce energy for a power plant; its use can be utilised through the thermal energy converting process[50–52]. In the last few decades, Southeast Asia has begun to focus on the development and installation of renewable energy for power generation and industry [53]. However, as the regions of Europe and the Asia Pacific have already used and rejoicing in their renewable energy; it's new in the run-in Southeast Asian countries today [54–56]. Although in recent times the utilization of renewable energy can provide a motive for future advancement, the government is now beginning to give funds and support for development in the field of renewable energy to be able to achieve targets set by each country against renewable energy and security potential for exports contained in the previous framework [57–59]. Provision of funding by the government primarily for the development of power plant energies for remote areas not yet accessed by electricity 100%, electric power generation is preferred using geothermal, solar and water energy, while biomass is more intended for household needs [60–62]. Rapid economic growth in Southeast Asia with the increasing demand for energy and rising imports for fossil fuels have had an impact on the environment, electrification for the village is very low and added to the reliance on fossil fuels and also very high biomass. It is proven as mentioned by the International Energy Agency (IEA) recently [63,64], so with the existence of the renewable energy that is utilised very give an advantage, especially for the state. Although the countries in

Southeast Asia have very varied energy sources, however, most renewable energy sources cannot yet be utilised in the region, since there are still many problems that cannot be overcome to be able to use renewable energy nationally [65–67]. Some of the most potential renewable energies in Southeast Asia are geothermal energy, solar energy, wind energy and hydropower [59,68,69]. The rich and diverse sources of energy in Southeast Asia are the momentum for future progress. This abundant energy source has become a concern for Southeast Asian countries to use renewable energy to replace fossil fuel reserves that are dwindling and environmental concerns due to climate change caused by fossil fuels. Renewable energy sources in Southeast Asia as shown in Fig. 5. The utilisation and use of renewable energy with various technologies also reach promising stages. There has been a lot of sophisticated technology today to be able to do renewable energy processing such as solar, geothermal, wind, water, biomass, and other energy energies, especially in Europe which are the major suppliers of renewable technologies almost all over the world have used the technology. However, as the current technological developments are increasingly varied and also the price is soaring high [54,70]. Solar energy has been widely used in major countries such as France, the United States, Italy, Japan, China, Germany, and Europe. France has used the solar energy of 5,678 MW, 18.317 MW of United States, 18.622 MW of Italy, 23.409 MW of Japan, 28.330 MW of China and 38.250 MW of Germany. While Indonesia currently only installed 1.197 MW and also in other countries in Southeast Asia has not been much use of solar energy [53,56]. Conversion devices for solar and geothermal energy use ocean thermal energy conversion (OTEC) with the help of several experts in the field. Solar and geothermal energy has a reasonably high conversion estimated between from 20% to 40%. The technology for heat conversion has been very well designed and can be used by various energy fields related to renewable energy. However, cost estimates do not have the exact certainty because the material world of technology is now uncertain, so it has been contemplating for the foreseeable future [41,58,59]. The technology used today is only a small scale, to utilise renewable energy experiencing congestion. The developers themselves are still reluctant to invest in renewable energy developers because of the lack of support from the government, regarding power generated from renewable energy sources can replace oil [53,58,59]. Problems regarding the various technologies used in the utilisation of renewable energy sources have also been previously discussed by [71–73].

TABLE 2

The type of RE and application to sustainable benefits and their negative impacts [74–76]

Type of renewable energy	To Application	Adaptation benefits	Mitigation benefits	Benefits for the social and economic development of the community.	Negative impacts of renewable energy
Solar	Cooking, water heating, lighting, and cooling.	To access information technology, communication and education in rural areas.	The improved local air quality, fuelwood consumption, batteries and kerosene.	Improved health, social, quality of life and water through improved street lighting sanitation.	✓ Requires a very large land. ✓ The production process should be handled appropriately because otherwise, it will be harmful to the environment
Wind	Power generation, irrigation, water pumping, and crop processing	Reduce water scarcity, agriculture selection through irrigation is increasing.	They reduce CO_2 emissions, biogas and dependence on wood.	Improved quality of life, the risk of vector-borne diseases can be reduced, increased water supply and food security, increased incomes, reduced migration and increased attendance at school (especially girls).	✓ Changed the migration path of bird flight. ✓ Electromagnetic interference for radio and television signals. ✓ The sound of a rotating propeller disturbs the consequences.
Biomass	Heating, evaporation and electricity generation	Deforestation and desertification are very likely to be reduced.	Reduced pressure on natural resources and the use of charcoal and firewood.	The creation of employment and livelihood opportunities, reducing tedious work, respiratory infections and reducing fatal incidents due to indoor air pollution.	✓ Due to the uncertain fuel source so land for waste production is needed. ✓ Requires an enormous amount of land and water facilities. ✓ The surrounding biodiversity is highly affected. ✓ The emission of GHG such as deadly methane and CO_2.
Hydro	Agricultural processing, lighting	To improved social resilience	Protection of land and reduce greenhouse gases	Increased agricultural yields.	✓ Indigenous migration ✓ Danger of avalanches ✓ Farmland will be reduced. ✓ Disturbance to the ecosystem increases. ✓ Reduced springs.
Geothermal	Hydro Power Plant (PLTA) or Steam Power Plant (PLTU).	The anticipated problems of electricity and development support.	The reduced risk-prone areas such as landslides, floods, earthquakes and Tsunami.	Reducing carbon emissions, reducing costs, can be used continuously, overcoming the scarcity of electricity especially in rural areas and the prospect of having long-term time.	✓ Damage to agricultural land. ✓ Revenue on agricultural products has decreased. ✓ The roof of the house's zinc roof is damaged (porous). ✓ Increases ARI and skin disease experienced by the community.
Biogas	Energy thermal; used to production of sludge for fertilizer	Soil erosion, aridity, and environmental degradation are likely to be reduced.	The reduced the use of pesticides, fertilizers, firewood, charcoal, and liquefied petroleum gas.	Reduce incidents related to IAP, respiratory infections and reduce the burden of many workloads; better agricultural productivity prospects and increased revenues and revenues.	✓ Due to the uncertain fuel source, so land for waste production is needed. ✓ Requires an enormous amount of land and water facilities. ✓ The surrounding biodiversity is highly affected. ✓ The emission of GHG such as deadly

methane and CO_2.

Several studies are being conducted as well as those already reported on renewable energy in the Southeast Asian region, the utilisation of renewable energy in the region has enormous potential [77–79]. Renewable energy in Southeast Asian countries is still limited to wishful thinking because the abundant amount of renewable and abundant renewable energy sources cannot be utilised. To be able to use this renewable energy need some policy and support from the government. For that reason, the governments of several countries have made several strategies through the law on renewable energy [80,81]. The policy regulated in the law aims to accelerate the utilisation of renewable energy at the national level. In this study, in addition to explaining the policy and security of renewable energy, it also discusses the general picture of renewable energy, their potential, current & future scenario and the safety of renewable energy created in the State legislation. Further, the utilisation and use of renewable energy for power generation, industry, transportation, Total primary energy consumption (TPEC), Total final energy consumption (TFEC), and buildings including housing for households, domestic and commercial. This container will also cover the amount of electricity usage and target within several years of punctuality such as the target of screening for 2020, 2025, 2030, 2035, 2050, and also for the next 50 years. This data is based on collected information on renewable energy from various literature [82,83].

***Fig. 5**. The renewable energy sources in Southeast Asian countries [84,85]*

The centre of gravity of the worldwide energy system has shifted to the Asian region. Together with China and India, this incorporates the ten nations of the affiliation of Southeast Asian Countries: Malaysia, Indonesia, Brunei, Singapore, Myanmar, Thailand, Philippines, Cambodia, Vietnam, and Laos. This economic revival lets to the urbanisation and industrial enterprise that has driven the ascent in Southeast Asian energy use since the 1997-1998 Asian monetary Crisis, that diode to a pointy decline in energy consumption. The growth in energy demand continues even through the recent international depression. The demand for Southeast Asia's primary energy in 2011 was about 550 million tons of oil equivalent (Mtoe), 4.2% of the global market [21,28]. The probability of this share can increase: Southeast Asia's energy use on a per capita basis is low, regarding 0.5 the worldwide average, and its home to just about 600 million individuals over a fifth lacks access to electricity.

3 RENEWABLE ENERGY POTENTIAL IN SOUTHEAST ASIA

Southeast Asia has large renewable energy reserves. This abundant energy can meet the energy needs for decades to hundreds of years to come. However, until now it has not been utilized. This is also due to the limited human resources so that abundant energy cannot be utilized. The governments of Southeast Asian countries must be more proactive to investors to develop and invest in renewable energy. In addition, the policies adopted are more in favor of the developers. Thus, abundant energy can be utilized so that fossil energy which is increasingly depleting in the next few years can be resolved as quickly as possible. However, renewable energy in Southeast Asia has yet to be maximally utilized. This can be influenced by several factors such as costs, human resources and government policies. Renewable energy found in Southeast Asia including biofuels 57.4%, hydropower 27.8%, solar 9.7%, wind power 1.64%, solid fuel 1.32%, geothermal 1.32% and other renewable energy 0.82% shown in Fig. 6.

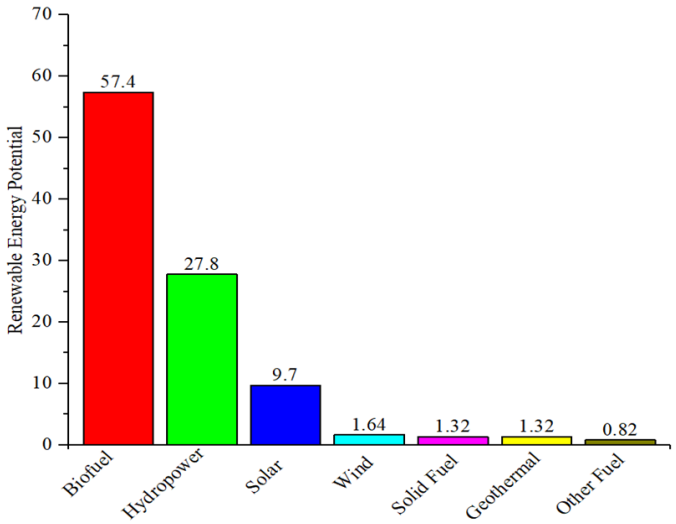


***Fig. 6**. Renewable Energy potential in Southeast Asia*

3.1 RENEWABLE ENERGY POTENCY IN MALAYSIA

Malaysia is one among Southeast Asia's fastest-growing economy. Malaysia comprises of two regions, West Malaysia and East Malaysia, separated by the South China Sea. It spreads over an area of approximately 330.000 km^2 and distinguished by a humid tropical climate, long coastline, high rainfall and numerous rivers. About 28.3 million people reside in Malaysia as of 2011 census with the majority of the population in the peninsula Malaysia or West Malaysia [86–88]. According to official records from the Department of Statistics, Mining, Manufacturing, Malaysia 2015 and Electricity, electricity consumption increases by 4% during the year 2010to 2014. Due to rapid population growth, industrialisation and urbanisation, the energy demand is expected to increase more than 150.000 GWh or half of the demand in 2010, within ten years [86,89,90]. Since Malaysia is highly dependent on polluting fossil fuels, the government is

very interested in the use of renewable energy. In this regard, Malaysia had launched a Small Renewable Energy Program (SREP) in 2001 which in turn encouraged the government's first step towards strengthening the utilisation of renewable energy for electricity generation. Renewable energy sources such as photovoltaic solar, biomass, solid waste, biogas, and mini-hydro are being used in Malaysia [88,91,92]. The contribution of renewable energy source was 1% of power generation as per record in 2011 but is expected to increase in coming years, and by 2030 the total electricity generation from renewable energy will rise to 16.5 GWh or by 13% [93]. Malaysia has a strategic geographical position in the South China Sea with a high annual rainfall of about 250 cm so that it is rich in hydroelectric power potential, which is also regarded as renewable energy. It is estimated that the hydroelectric power generation in Malaysia can contribute up to 29 GW [86]. Also, Malaysia has several areas, such as Sabah and Sarawak that have not been electrified. These untapped renewable sources, especially hydropower provide a sustainable way to electrify these areas. In addition to that, Malaysian oceans have tremendous energy potential because of the highly variable wave current velocities with an average of 0.56 to 1 m/s and inwardness of about 15-30 m [86]. Due to the presence of some international restrictions contained in the South China Sea, it is necessary to make modifications in the policy which will allow tapping of energy that can be given to power in remote areas. Available and highly profitable renewable energy resources are being capitalized in Malaysia by the rich lobby. The Malaysian government has come up with an important policy which ensures a balance in improvement and development of the energy devices used in the hydro-kinetic energy which in turns throw light to a sustainable future.

3.2 Renewable Energy Potency in Indonesia

It has to be noted that Indonesia's dependence on fossil fuels reached 1.358 million BOE or about 96% of the total primary energy consumption in 2014. The significant energy sources in Indonesia are oil, contributing about 48%, followed by coal and gas. With an annual coal energy growth of about 1.9%, the dependence on oil has decreased. The reliance on fossil fuels in the electricity sector reached 288 kWh in 2014 [67,94,95]. Though Indonesia is rich in renewable energy sources, it is not effectively utilised due to a wide range of socio-economic problems. Indonesia has launched a Fast Track Electrical (FTE) program to aid in meeting its 100% power generation target by 2020. In this view, the government has accelerated the construction of a new power plant with a cumulative capacity of 20 GW. These power plants are operated by using energy from coal as well as the use of renewable energy [94,96]. After completion of the program of the construction of power plants, it is expected that the share of coal in electricity generation will increase which in turn reduces the dependence on crude oil. In 2014, Indonesia collectively allocated more than 5 billion USD for energy subsidies to the local community and electricity rate was subsidised by 26%. This huge subsidy provided by the government has been hindering the development of renewable energy for long years. Major available renewable energy sources in Indonesia are hydropower, wind, biomass, solar, and geothermal. It is not possible to replace dependence on fossil fuels in the near term, considering the technical or economic constraints such as maximum capacity utilisation [97,98]. Though the total potential for renewable energy is estimated to be more than 273 GW, excluding the thermal potential of marine energy, only 4% of this potential is used. The hydropower potential, one of the significant renewable energy potentials has a capacity of around 75 GW. Only 11% of this potential, about 8.1GW, is utilised. Similarly, Biomass can contribute up to 32 GW, however, only about 5% is being used for power generation. Due to Indonesia's geographical position on the equator, it is blessed with renewable energy sources like geothermal and solar. The estimated amount of geothermal energy potential is about 28 GW, making it the largest one of its kind in the world [94]. Despite the geographic advantage that Indonesia possesses, the utilisation of solar energy is negligible. By 2015, the total installed solar power was only 71 MW. Wind energy lags when compared to solar energy. The Government of Indonesia has committed to reducing greenhouse gas emissions by 2020 up to 26% along with international support. Emissions reductions of up to 23% are estimated by 2025 and up to 50% by 2035 [94,99,100]. This target can be realized with the support and policy of the government. The Government of Indonesia will also seek the use of renewable energy that helps in producing electricity sustainably.

3.3 Renewable Energy in Brunei

Brunei has many fossil fuels reserves in Southeast Asia. Unfortunately, oil and gas reserves are estimated to be exhausted within the next 17 and 30 years at the current exploitation rate. According to World Bank data, Brunei is the largest CO_2 emitter in Southeast Asia. This amount of emission is due to the wide use of fossil fuels. According to some researches, greenhouse gases (GHG) in this area mostly results from the burning of fossil fuels. The power plant sector in Brunei is a significant contributor to CO_2 emissions and followed by the transport sector. At the same time, the electricity consumption in Brunei is the highest in Southeast Asia, along with the government subsidy for electricity tariffs, especially for households. By 2030, Brunei is estimated to experience a rise in energy demand of 3.9% every year [101–103]. Based on increased energy consumption, CO_2 emissions also continues to rise. This is mainly due to the government that does not support and contribute to the use of renewable energy. Brunei Darussalam has signed an agreement in Paris to reducing CO_2 emissions by divesting from fossil fuels to sustainable renewable energy sources. By 2035 Brunei has been planning for renewable energy development in a long-term. This lead to a reduction in fossil energy uses up to 45% starting from the year 2005. Renewable energy sources are sought after by many countries to meet increasing energy demands [102,104,105].

3.4 Renewable Energy Potency in Singapore

Singapore's power generation from fossil fuels is high at the cumulative capacity of 12.5 GW. Out of the total consumption of energy, households account for 15%, commercial and services about 37%. By 2020, Singapore has committed to cut-down their emissions by 7%-11%. Decentralised and distributed energy sources such as wind and solar installations need special attention to achieve this target. The maximum photovoltaic energy production of Singapore in 2030 as too be around 5 GW using 80% of the area of house roof [106–108]. But the areas of wind energy potential is not appropriately analysed in the past years. Some agencies have established

cooperation with governments such as Institutes of Higher Learning and local SMEs to achieve Singapore's renewable energy goal. The feasibly of Wind energy potential in Singapore is done by the Energy analysis Institute at Nanyang Technological University with the collaboration of the Singapore government. Singapore has also tried to conduct wind measurements using Sonic Detection and Ranging (SODAR) technology [109–111]. The average temperature in Singapore varies from 26°C to 28°C every month. Singapore has four different seasons, namely the December Sea of Season, the Southwest Season between June and September, the other two seasons are relatively short. Singapore receives an enormous amount of rain, with an average monthly rainfall of about 150 mm to 275 mm. Based on these data, Singapore has the potential of renewable energy with excellent scope for wind and hydro energy. However, until now it wasn't appropriately utilised. In addition to that, the lack of support from the government in the financial and technical sector is a concern. The community is not aware of the energy generated from wind and solar power, thus making the task of the government more critical for a sustainable future.

3.5 Renewable Energy Potency in Myanmar

The enormously rich source of solar energy in Myanmar is the region's largest renewable energy resource potential. Solar power helps in rural electrification, because of its very affordable nature, even for low-income communities. Until now Myanmar is still experiencing various barriers to the development of solar PV systems. The Government of Myanmar did not support the development of solar PV along with a very complicated bureaucracy and imported solar equipment [112–114]. Nationally in 2011, the installed power generation capacity is 76% from hydropower, 21% gas power plant and 3% from coal. According to data analysis, the average solar radiation in Myanmar is more than 4.7 kWh/m^2 per day [37,112,115]. In 2010, 750 MWh of energy was generated from solar power. Due to this project and the development of solar, 235 families, primary schools and health clinics in rural Myanmar have benefited. The potential of solar energy is used in the health centre, while it still needs to improve the social economy in remote locations. Use of solar power for battery charging and irrigation is important [53,112,116]. Myanmar recently installed a solar power plant of 176 kW capacity. It made the solar PV systems as the fourth largest energy used in Myanmar after candles, power lines, and batteries as of 2014. In 2014, Thailand made the world's first solar energy source for rural households 900.000 or 12% for conventional homes [112]. Some developers of the solar industry in Myanmar provide equipment from foreign countries such as China, Japan, Singapore, and Thailand. While the Myanmar government only produces thin-film PV panels which are very small when compared to the production of other countries. Still, the state has six SHS installers in rural areas of Myanmar.

3.6 Renewable Energy Potency in Thailand

Thailand is a pioneer in utilising renewable energy sources like biomass and biogas. In 2013, renewable energy growth was at a phase of 2.4% per year in Thailand, and then it rose to 8.274% in 2014, each of which contributes 2.35% biomass, 1.73% MSW, and 0.03% biogas. By the end of 2014, the total capacity reached 34.770 MW in natural gas, 23.919 MW in biogas, 4.776 MW in coal, 3.444 MW in hydropower, 2.405 MW is by import power and RE 317 MW. However, the main energy in Thailand is from fossils, around 68.69% while 13.7% are coal and natural gas. Total production of energy accounts for 192.189 GWh including from VSPP. The use of renewable energy sources has so far increased by about 10.4% compared to the previous year. Fossil fuels are still the primary energy used in Thailand, especially natural gas and coal [117–119]. Thailand has now proposed the policy for the use of renewable energy sources such as wind energy, biomass, solar, hydropower, MSW, and biogas for electricity production. In 2015, Thailand installed a 6.000 MW of solar power plant as compared to 1.299 MW in 2014. Thailand is also working to promote solar power and hybrid solar thermal power plant, as the average solar radiation in Thailand is about 18.2 MJ/m^2/day. Wind energy sources in Thailand is also important as the average speed is 5.3 - 6.4 meters per second. In 2007 wind resources potential were around 1.5 MW. Thailand has fixed a target to install windmills of 3.002 MW capacity within 2036. These targets can be achieved through the use of newer efficient turbines in which the wind power can be well controlled, and the risk of interconnection can be reduced [119–121]. Thailand is one of the largest producers of agricultural products in Southeast Asia such as palm oil, rice, and sugarcane. In a rice cultivation processing, about 220 kilograms of husk from the grinding can be used in a power plant to generate about 90-125 kWh. The waste of sugarcane of about 290 kilograms can generate electricity around 100 kWh. Recently Thailand has used biomass residues to produce biogas which can be used as a fuel for vehicles.

3.7 Renewable Energy potency in Philippines

The primary source of energy in the Philippines is fossil fuels. In 2008, the Philippine government enacted a law on renewable energy (RE). By this law, it has been motivating industry into renewable energy which helps to meet the demands of consumers diverting through renewable energy. With the development of renewable energy, the dependence on fossil fuels can be reduced. However, the use of fossil fuels is still very dominant compared to the use of renewable energy sources, even after the RE Act. The Philippines is currently seeking to promote renewable energy sources and has a target to install renewable energy sources of more than 60 GW capacity by 2030 [80,122,123]. In 2010, the Philippines installed 16 GW of renewable energy power plants which are based on biomass, sun, hydro, and ocean, which pave the way to reduce dependence on fossil fuels gradually. Based on research by Mindanao State University, Philippines has the renewable energy potential of about 170.000 MW. Majority of this potential of renewable energy comes from tidal. The source of renewable energy in the Philippines coming from the waves is very significant to replace the dependence on fossil fuels. But this can be realised only if there is full support from the government which develops the industry by creating long-term projects regularly [122–124]. Based on the research in several institutes, the potential of renewable energy in the Philippines derived from tidal power is about 200 GW and practically between 40 to 60 GW. It highlights that the possibility of wave energy is very reliable in this region.

3.8 Renewable Energy Potency in Cambodia

The government has not officially done any investigation into Cambodia's renewable energy sources or to develop

sustainable energy. In 2014, few renewable energy plants were installed. Renewable energy sources in Cambodia is not well known due to the lack of technological development. Recent study report that the estimated renewable energy potential in Cambodia is about 67.388 GWh per year. This amount of energy is more than triple times the overall requirement. Hydropower is the most significant energy out of renewable energy sources [125–127] and all rural areas can be electrified by it. The development of power plants through government support can accelerate economic growth. The hydropower plant built in the Mekong Subregions (800 MW) and the one with the Asian Development Bank of 8.600 MW are not sufficient to meet current energy demand. So, it was expanded for an additional 300MW and about 10.000 MW for a larger plant. Cambodia plans to develop a hydroelectric power of 15.000 MW using the Mekong River water (40%), remaining from the Mekong River branch on the southwest coast. In 2000 hydropower resources could only generate 145 MW whereas the potential hydro energy in Cambodia is much more [126,128,129]. In addition to Cambodia's hydel power, energy can also be derived from biomass and agricultural products such as animal waste, municipal waste, fuel-wood and fuel. In 2007, the generation for electricity from firewood increased from 73.637 TJ and to 35.522 TJ in 2030. At the same time, the animal manure usage varies considerably from 683 TJ to 1068 TJ in the same period. Cambodia also has tapped energy from solar PV, with solar energy used for radio, television, and telecommunications in 1997. This region receives average solar irradiation about 5.10 kWh/m^2 per day. Solar potential is estimated to reach up to 49.3 GWh per day. In 2011, the Cambodian government installed 12.000 MW of solar energy systems in seven provinces. But awareness, acceleration, and empowerment are the main obstacles facing Cambodia is [130–132]. As per wind energy report in Southeast Asia which includes Cambodia, Vietnam, and Thailand, wind power amount to 1380 MW [133–135]. However, some areas in Cambodia especially those located on the south coast have very favorable conditions for wind energy with an average wind speed of 5-7 m/sec. Wind power plant installation in this area can provide 400 MW electricity for households in rural areas, with an annual capacity of about 39 GWh.

3.9 Renewable Energy Potency in Vietnam

Based on a World Bank study conducted in Southeast Asian countries including Cambodia, Laos, Thailand, and Vietnam in 2000, the development of wind resources in this region is important for economic growth. The potential for wind energy in Vietnam is very suitable for transformation into a renewable energy source. Vietnam has an estimated wind energy source of approximately 513.36 GW mostly at a land surface of about 65 m. With an average wind speed of more than 6 m/s, wind energy is available in over 39% of the total area of Vietnam, making it suitable in the region for energy generation. This is based on the wind energy assessment in Vietnam, conducted by the Electricity Department of Vietnam (EDV) in 2007 [136,137]. This study claimed that Vietnam has wind energy potential of about 1.785 MW. Of the three areas studied, the most suitable location for windmills is on the central coast and the south-central coast. The wind in Vietnam has an average speed between 6.5-7.0 and 6.0-6.5 m/s in the central-western region, 5.0-6.0 m/s for the southern coastal region. Apart from this area, wind speeds in other parts of Vietnam are relatively low, ranging from 3.0 to 5.0 m/s. In 2011, the average wind speed in Vietnam for that year was about 6 m/s at 80 m AGL covering an area of about 2.676 km^2 or about 0.82% of the total land area of Vietnam, equivalent to the wind power capacity of 26.763 MW. The potential for wind energy in Vietnam is more significant than other countries in Southeast Asia [138–140].

4. Renewable Energy Target in Southeast Asia

The region of Southeast Asia is rich in renewable energy sources as per the literature survey [141–143]. In this regard, every south-east Asian country can realize the energy security, development and economic growth of their people through clean and environmentally friendly energy sources. Currently, fossil fuel dominates the energy mix in these countries, up to 74% and the rest comes from renewable energy sources. Out of this, renewable energy from waste and biomass contribute to 22%, geothermal and hydro are 3% and 1% respectively [141,142]. Biomass mainly firewood and charcoal is the second-largest energy in Southeast Asia's region apart from fossil fuel energy. However, wood and charcoal are used in traditional ways which are inefficient and unsustainable [144,145] Recently, Indonesia has come up with several steps towards the use of renewable energy by involving the community and those engaged in industries in the area of Solar Photovoltaic (PV), biomass, wind, geothermal and solar thermal [142,144,145]. In the Philippines, oil is the most significant fuel component of the energy mix. However, the Philippines is almost the same as Indonesia which is trying to make the most of renewable energy into the national energy mix shortly. Since 2011, the combined renewable energy installation in the Philippines is about 41% of the total, with more focus on biomass, wind, geothermal and solar [146]. Meanwhile, in Thailand, the primary energy demand is met from fossil fuels, oil, and natural gas, which in turn makes it the second-largest oil importer after Singapore in Southeast Asia region [147–149]. Primary energy sources in other Southeast Asian countries such as Laos, Vietnam and Myanmar are mainly from biomass. Nearly one-third of Vietnam's energy supply comes from biomass. Meanwhile, in Laos, the energy is derived from biomass which contributes about 61.4% of the total. Of all the countries in Southeast Asia, Myanmar is not depended on oil and gas resources [150–152]. The primary energy requirement in Myanmar is mostly met from biomass resources especially agricultural waste, firewood, and charcoal (69.9%). The share of fossil fuels is natural gas (18.2%), followed by oil (8.5%) and contributions of the coal and hydel power is respectively 0.9% and 2.4% [153–155]. Although the primary dependence of traditional energy sources such as oil and gas in Southeast Asian countries, development for renewable energy is potentially more enormous and energy-efficient [1,38,41]. The member countries in Southeast Asia are rich in geothermal, solar and wind energy. The entire Southeast Asian region is surrounded by seawater. Hence alternative energy derived from the sea is currently being studied and assessed for its sustainable use. In addition to having a highly strategic geographical location, the countries also have several private companies that have shown interest in renewable energy development so that climate change and greenhouse gas emissions can be reduced [1,41,54]. The various support policies that have been implemented in Southeast Asia can advance the development of renewable energy. Several other factors have to be

considered for the development of renewable energy in the region so that full potential can be utilised [37,59].

TABLE 3
Renewable energy in Southeast Asia: Current status and target

Region / Country	Renewable Energy Installed (MW)	Ref	Progress to target	Most Renewable Technology Preference	Renewable Energy Target	Overview of Energy Resources
Malaysia 	6.286	[5,88]	29%	Solar Energy (18.700 MW)	21.370 MW (2050)	Oil and gas are the principal energy sources and the primary providers of the government's revenue; hydro, solar, and biofuels are amongst the leading renewable energy potential
Indonesia 	6.680	[94,156]	16%	Hydropower (21.300 MW)	46.307 MW (2025)	The most populated country and therefore the largest energy buyer in ASEAN; world's major LNG exporter and largest coal exporter; one of the countries with the highest geothermal potential globally
Brunei 	1.67	[1,101]	0.20%	Solar Energy (954 GWh)	954 GWh (2025)	Significant producer and exporter of oil and gas; energy policy is mainly focused on the oil and gas sector, and their conservation; most preferable renewable energy technology is solar energy
Singapore 	5.898	[107]	38%	Hydropower (8.937 MW)	15.306 MW (2030)	Almost entirely reliant on energy imports, and the core energy supply is petroleum products; the government aims to become a regional leader in renewable energy research and development; most preferable renewable energy is solar energy
Myanmar 	3.204	[113]	N/A	Small hydro (472 MW)	472 MW (2020)	Priority to advance domestic energy supply due to low levels of energy access; foremost source of energy is waste and biofuels as traditional biomass; increasing domestic oil and gas production
Thailand 	7.901	[54]	40%	Solar Energy (6.000 MW), Biomass (5.570 MW)	19.684 MW (2036)	The primary objective in the energy sector is efficiency; the leading energy supply is fossil fuels; energy supply is progressively imported; solar, bioenergy, and hydropower are amongst the most probable renewable energy
Philippines 	33.1	[1,157]	9%	Solar Energy (350 MWp)	350 MWp (2020)	The importance is to enhance energy security as it is much dependent on imports; the world's second-largest geothermal power producer; geothermal and hydro are the main renewable sources in energy supply
Cambodia 	952	[126]	42%	Hydropower (2.241 MW)	2.241 MW (2020)	Small levels of energy access and renewable energy use is encouraged for rural electrification; biomass and oil are the principal sources of energy supply; it has potential in hydropower, biomass and biofuel
Vietnam 	17.140	[1,136]	37%	Hydropower (27.800 MW)	45.800 MW (2030)	Growing energy demand has a diode to increasing imports despite the local production of fossil fuels; traditional biomass from waste and biofuels is generally used in rural areas; it has potential in solar energy and hydropower
Laos 	3.348	[1]	5%	Small hydro (543 MW)	951 MW (2025)	Hydro and traditional biomass dominate energy supplies; significant hydropower potential with aims to export to neighbouring countries; most desirable renewable energy technology is small hydro

5. Policy Implications and Regulations of Different Countries in Southeast Asia

The following main consequences for policy are drawn. It is anticipated that EMI in Southeast Asia will considerably encourage the use of renewable energy. Together with EMI, FIT appears to be more cost-effective than RPS and is suggested for the Southeast Asia region, although it may be a practical problem to administer execution expenses. Furthermore, the findings indicate that if by 2030 30% RPS of electricity from renewable sources is regarded by many policymakers to be an area-reasonable alternative. This research demonstrates that the policy appears to be the "low-hanging fruit" and would attain mild improvements in the reduction of carbon emissions and the growth of renewable energy while leading to negligible rises in total electricity costs. Indonesia, Malaysia, the Philippines, and Thailand have specific policy targets related to the development of the use of biofuels. In 2030, Malaysia aims to replace 5% diesel in road transportation, while the Philippines aims to replace 15% diesel and 20% gasoline with biofuels. Meanwhile in 2021 Thailand aims to save 44% of oil by biofuels [158,159]. Each country has its policy targets to balance energy security and environmental benefits with other potential implications, especially in food security, deforestation, biodiversity and

handling social problems that might arise. Indonesia is currently leading the way in the use of biodiesel in terms of issuing policies on the application of biodiesel blends from 5% to 20%.Regulations in the new and renewable energy sector (RE) are considered unfriendly to Small and Medium Enterprises (SMEs) because it makes it difficult for entrepreneurs to enter the power generation (RE) business with a capacity of less than 10 MW. This unfriendly regulation has hampered the construction of renewable energy power plants because of funding problems. Moreover, the utilization of renewable energy sources, the scheme of building, owning, operating, and transferring (build, own, operate, and transfer/BOOT) is considered burdensome to the private sector. The governments of each Southeast Asia member country have targeted the portion of renewable energy in the energy mix (such as Indonesia 23% 2025, Malaysia 4 GW 2030, Brunei Darussalam 10% 2035, Singapore 350 MW 2020, Myanmar 15-20% 2030, Thailand 30% 2036, Philippines 15 GW 2030, Laos 30% 2025, Vietnam 27 GW 2030 and Cambodia 2 GW 2020 [21,160,161]. While in Indonesia itself, based on data from the Ministry of Energy and Mineral Resources, the portion of the energy mix in the electricity sector has only reached 12.4%. Renewable energy is also expected to be a major contributor to achieving the target of reducing greenhouse gas emissions by 29% by 2030. The government should issue regulations that can encourage renewable energy investment. However, the opposite happened, the regulations issued became the main factors that inhibit investment in renewable energy.

6 Conclusions

This study examines the renewable energy potential of Southeast Asia. The following are the key conclusions drawn from the study.

- Generally, countries in Southeast Asia are still dependent on fossil fuels, except Singapore and Laos.
- The primary renewable energy source in Southeast Asia includes solar, geothermal, wind, hydropower, biomass, and other energy.
- The current share of renewable energy installations in south-east Asia stands at an average of 10%.
- The government of south-east Asian countries has set a target to increase the share for renewable energy usage by 2025 to support the growth of renewable energy nationally.
- Various policies, law and framework are established within the country for the development of renewable energy.

The optimal utilisation of renewable energy can improve the economy of the south-east Asian countries and support industrial and commercial growth.

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Conflict of Interest

All authors declare that they have no known competing for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Nomenclature

RE	Renewable energy	SMEs	Small and Medium Enterprises
FIT	Feed-in Tariff	MW	Megawatt
EMI	Energy Management Indonesia	GWh	Giga Watt-hour
PV	Solar Photovoltaic	EDV	Electricity Department of Vietnam
GHG	Greenhouse Gases	FTE	Fast Track Electrical
CO_2	Carbon Dioxide	TPEC	Total Primary Energy Consumption
TFEC	Total Final Energy Consumption	OTEC	Ocean Thermal Energy Conversion
APEC	Asia-Pacific Economic Cooperation	BOEPD	Barrel Oil Equivalent Per Day

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