Solar Renewable Energy Potential and Development in Malaysia, Indonesia, Vietnam and Japan

Mohamad Yuszaimie Abdul Hamid, Ku Nur Afrina Ku Azman Shah, Nor Akmal Fadil, Jafri Mohd Rohani, Mohd Zamri Mohd Yusop
School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
Johor, Malaysia
mohamadyuszaimie@gmail.com, kuafrina@gmail.com, norakmal@utm.my, jafrimr@utm.my, zamriyusop@utm.my

Nguyen Duc Tuyen
School of Electrical Engineering
Hanoi University of Science and Technology
Hanoi, Vietnam
tuyen.nguyenduc@hust.edu.vn

Budi Hartono
Mechanical and Industrial Engineering Department
Gadjah Mada University
Yogyakarta, Indonesia
boed@ugm.ac.id

Abstract

To reduce the dependencies on depleted fossil fuel sources, ASEAN countries adopted renewable energy policies to ensure future energy security. Due to the regions' ideal geographic positions and climatic condition, the solar power generation has been increasing prominence among the sources of renewable energy. Therefore, the study aims to highlight the difference in the potential of solar renewable energy and its development in the respective countries of Malaysia, Indonesia, Vietnam and Japan. This paper reviews the solar energy availability, targets, and initiatives for their growth in the respective countries based on the review of published papers, country reports as well as from analysis using an open source tool. Analysis on the potential specific photovoltaic power output using the Global Solar Atlas v2.6 by Solargis found that all four countries have about the same amount of median specific photovoltaic power output with the highest is Malaysia (3.71 kWh/kWp) while Japan is the lowest (3.39 kWh/kWp). In the last decade, the ASEAN countries have started to harness their solar power through solar photovoltaics with steady growth in Malaysia, a late but impressive sudden development in Vietnam and relatively slower implementation in Indonesia. In Japan, solar energy development has grown considerably throughout the decade. From the findings, solar energy has great potentials in these ASEAN countries, and with proper implementation, ASEAN countries will have significant growth in the solar generation for the next decade, as witnessed in Japan.

Keywords
ASEAN, Solar, Photovoltaics, Renewable Energy, Energy generation

1. Introduction

Southeast Asian developing countries are expected to experience substantial economic and population expansion. The region's socioeconomic development will result the energy consumption of the ASEAN countries to have significant growth (Shi, 2016). Based on the report from the International Energy Agency (IEA), accompanied by the regional economic development, the demand for energy in ASEAN has grown to two and a half times since 1990 and the energy demand will increase by 80 percent for 2040 (International Energy Agency, 2019). The increased demand for energy comes from the power generation sector as the result of increasing access to electricity. As the power generation has so far heavily relied on fossil fuels which are producing excessive carbon dioxide emissions, the countries have undertaken a number of initiatives to make use the renewable energy technologies as the alternative to minimize the fossil fuel's reliance and overcome global warming. In addition, due to their geographical advantage, the source of renewable energy, which includes biomass, solar energy, wind energy, and hydropower are abundant in the ASEAN countries (Karki, Mann, & Salehfar, 2005).

Hence, the ASEAN countries have agreed to make renewable energy a target of 23% of total primary energy supply and 35% renewable energy for power capacity installed by 2025 in order to develop renewable energy capability (Lee et al., 2019). By 2025, this would necessitate the capacity addition of 35GW to 40GW of renewable energy (Sharma, 2021) Presently, renewable energy installations account for only 10% of all installations in Southeast Asia, but their use is predicted to grow by 4% every year as concluded by Erdiwansyah et al., (2020). Meanwhile, as mentioned by Vaka et al. (2020), the renewable energy total primary energy supply is expecting to reach 17% by 2025. It is still six percent short of the 23-percent target. Thus, each country's contribution to renewable energy is critical in closing the gap. Therefore, the government of Southeast Asian countries has established targets for promoting their use to support the growth of renewable energy nationally in order to achieve the energy efficiency goals in the future (Erdiwansyah et al., 2019). Various policies, laws and frameworks are established within the country to expand the renewable energy development.

At the same time, the technology to harness from the renewable sources has gone through a significant transformation and development all around the world as well as considered to reach the promising stages. There has been a lot of sophisticated technology today to be able to do renewable energy processing. Solar energy technologies, in particular, are one of the world's fastest developing energy technologies since they make use of the most abundant resource, the sun. It is deemed to be one of the most reliable source of renewable energy because of its benefits. This energy is clean, eco-friendly and environment-conscious, as it can generate electricity without polluting the environment with the greenhouse and harmful gases. One of the remarkable benefits in solar technology is it can operate on a building's rooftops, making it a great option for producing clean electricity in rural areas (Kumar, 2020).

Furthermore, advances in solar PV technology have experienced a significant cost reduction in between 2010 and 2020. It has gone from an expensive niche to a head-to-head competition with fossil fuels for new capacity due to the combination of targeted policy assistance and industry drive as described by Wang et al.(2021). In the process, it has become clear that the renewables will become the backbone of the electricity system and help decarbonized electricity generation with a lower cost in the future. Based on the International Renewable Energy Agency (IRENA) (2020), for a newly commissioned utility-scale solar photovoltaics (PV) projects, the global average levelized cost of energy (LCOE) dropped by 85% between 2010 and 2020, which is from 0.381 to 0.057 USD per kWh, as total installed costs fell from 4,731 to 883 USD per kW. This has made solar PV increasingly less expensive than fossil-fuel capacity, which will eventually undercut the operational expenses of current fossil-fuel power plants. As a result, solar PV has become the most cost-effective new energy source and produced a boosting demand for energy generation.

Currently, solar energy has been widely used in major countries such as France, the United States, Italy, Japan, China, and Germany (Erdiwansyah et al., 2020). Geographically, most of these country is located in the temperate climate region on the globe. Meanwhile, ASEAN countries are located at the equator and having tropical and humid climate conditions in general. This make the ASEAN countries to have greater potential for solar power. Most of the countries in the ASEAN region are receiving high levels of solar radiation when compared to the countries that have successfully harness significant solar power in a much lower amount of solar radiation. For example, although the countries in Europe receive a lower average of sun hours per day and throughout the year than the countries near the equator, yet some of them generates significant energy through solar power (British Business Energy, 2016). The region's solar power real achievable cost cannot be determined until the countries create a favourable environment for investment and production of renewable energy as well as establish a long-term and large-scale auction, which have resulted in huge reductions in costs for other regions of the world (Overland et al., 2021). Therefore, the effort from the power holders in ASEAN countries is important in achieving clean energy targets through their programs and regulations.

Throughout the emerging markets of developing country in the ASEAN region, the governments are trying to encourage more solar growth in solar PV technology through different alternatives such as the rooftop solar, floating solar and ground-mounted solar PV. Different support and incentive schemes are deployed as the mechanisms to mobilize the solar energy growth which includes solar Feed-in Tariff (FIT), Net Energy Metering (NEM), and Large-

Scale Solar tenders (LSS) (Vaka et al., 2020). Implementation of these mechanism aids in the financing of infrastructure and arrangements to boost the solar PV industry and product consumption, hence increasing solar generation capacity in ASEAN countries. In addition, the effort raises consumer awareness of its technology, economics, and proper application. Thus, it is significant to explore the potency, use, current status and the future target of solar renewable energy which is bundled with policy implications and regulations among the Southeast Asia countries that have quite different characteristics and behaviors.

This project is a collaboration between four countries namely Japan, Vietnam, Indonesia and Malaysia. The objective of this project is to observe the relationship between government policies and its impact on the renewable energy implementation specifically on the solar PV for each country. The comparison is made between the similar Southeast Asian country with benchmarking to the developed country which is Japan. Japan has an established policy and implementation for renewable energy, including solar PV. Up until now, there is no comparison study has been conducted to compare the solar renewable energy implementation between these four countries. The comparison between the countries potential and development is made to analyze the influence of the government's implementation and approaches in reaching the country's own target and their contribution to the regional aims of the renewable energy mix in the future.

2. Methods

The study was conducted by reviewing various publications in order to observe the different technical potential of solar energy for selected ASEAN countries of Malaysia, Indonesia, and Vietnam with Japan in term of received solar radiation and sunny hours. The country's targets towards the renewable energy mix were reflected, especially in the utilization of the solar energy resources among various renewable energy. Then, the potential of solar energy installed capacity performance in each country was studied by relating the solar energy installed capacity in 2020 with the country land size and the median specific photovoltaic power output measured using Global Solar Atlas v2.6 by Solargis. The analysis for the potential specific photovoltaic power output conducted was based on the solar resource database that Solargis develop and maintains. The measured parameters included in the analysis were the solar irradiance and the air temperature data as inputs for the calculations of the photovoltaic power production.

On the other hand, the development of solar energy was studied based on descriptive statistics and graphical analysis comparing their solar renewable energy generation. The study using secondary data generated from the primary data that were collected from each country's government reports from 2010 to 2020 as well as data from the intergovernmental organization which aids countries in their change to a more energy-efficient future. The output data represent the total solar photovoltaics installed capacity, which represent solar energy and the total installed capacity of renewable energy for each country from 2010 to 2020. The trend was then analyzed regarding the solar energy percentage from the total renewable energy installed capacity of the countries. The data for total renewable energy installed capacity was included the hydropower energy to be one of the renewable energy sources even though some consider that it is a non-renewable energy due to its huge negative impact on the ecological system (International Rivers Network, 2003). However, the data was included in this study to benchmark solar PV performance in battling the reduce of energy dependency to hydropower source especially from the large scale dam. From this output, the growth of solar renewable energy within these countries throughout the years was studied based on the factors which influenced the performance of solar renewable energy implementation specifically for solar PV. The policies, incentives and schemes that have been established within the countries which act as driving instruments by their respective governments in order to promote more solar energy installation, especially solar photovoltaics were discussed to look at the present situation and its implication to the solar photovoltaics' installation in the countries.

3. Results and Discussion

The potential and development of solar energy in each country is discussed to see the progress of harnessing this particular renewable energy in the region.

3.1 Malaysia Solar Renewable Energy Scenario

Due to its proximity to the equator, Malaysia has a high potential for harvesting energy through solar power plants. This is because the country receives much solar radiation all year, with 4.7 to 6.5 kWh/m^2 of daily average solar radiation in most regions (Petinrin & Shaaban, 2015). The average daily amount of sunshine reported in the country is between 4 and 8 hours according to Sabo et al. (2016). Presently, natural gas and coal make up the majority of Malaysia's energy mix for electricity generation. Therefore, Malaysia's government is putting an ambitious aim of boosting renewable energy's contribution to the country's overall energy mix. Currently, only 8% of its' energy comes from renewable sources at the moment, although they have committed to achieving a 20% renewable energy capacity mix by 2025 (Vaka et al., 2020). One option for helping to that effort is solar energy power generation through the solar PV. The government's methods and mechanisms which help to keep the costs down have resulted in a continuous increase in solar PV installation in the country year after year. As illustrated in Figure 1, Malaysia's solar PV breakthrough has installed capacity approaching almost one-fifth of total renewable energy capacity in 2020, up from less than 1% in 2013. The total capacity of renewable energy installed in the country includes the renewable hydropower, solar energy, biomass and biogas. It was a steady growing trend of PV installation in the country throughout the decade which is implicated from different instruments implemented to administer the solar power growth.

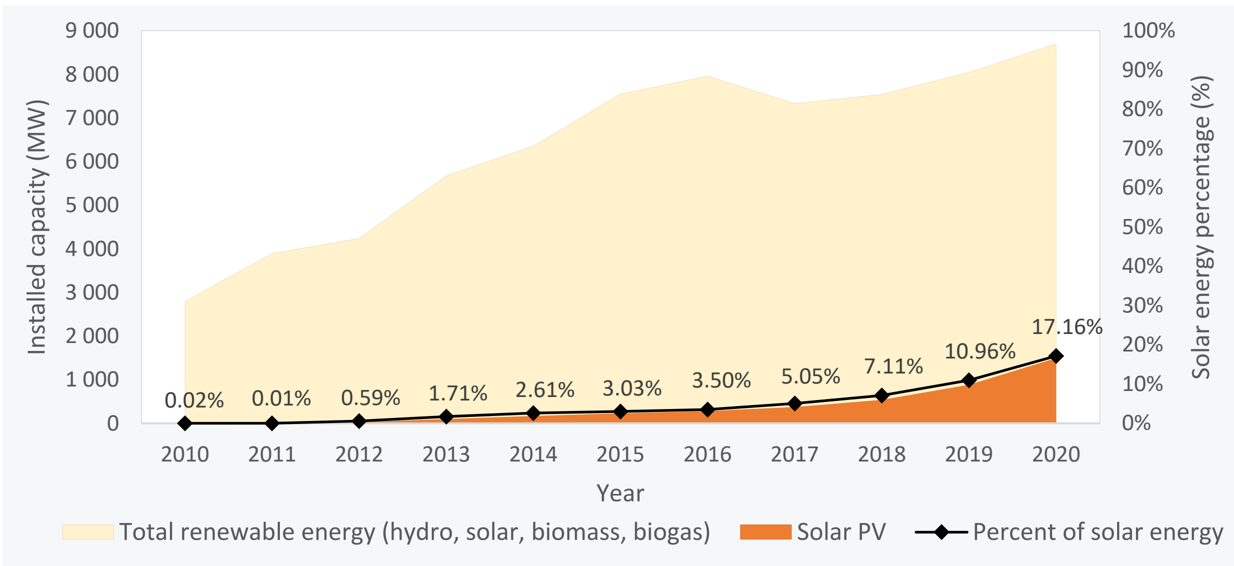

Figure 1: Malaysia installed capacity for renewable energy and solar energy from 2010 to 2020 (Energy Commission, 2020b; International Renewable Energy Agency, 2020, 2021)

The country's solar renewable energy share is driven by the supportive initiatives and policies introduced by the government. Malaysia introduced the feed-in tariff (FIT) as early as 2004, but the biggest impact on the renewable energy market was when FIT scheme was introduced back in 2011 as reported by Abdullah et al.(2019). In Malaysia's FIT, any individual or company can sell their generated solar PV energy to the distribution licensees which are the Tenaga Nasional Berhad (TNB) and Sabah Electricity (SESB) with contracts set for 21 years from the commencement date. The FIT rates differ based on the capacity solar PV system installed, where it is categorized to capacity up to 4kWh, 24kWh, 72 kWh, 1MW, or more. In 2020, the FIT rate is 0.075 and 0.13 USD per kWh for large and small solar system, respectively (Sustainable Energy Development Authority, 2021a). The cumulative installed capacity of solar PV commissioned is 381.53MW under FIT scheme. To encourage more renewable energy uptake and attract the installation of rooftop solar PV, the Malaysian government established the first NEM scheme in 2016, NEM 2.0 in 2019 and NEM3.0 in 2021 with quota allocation of 500 MW for each of the schemes (Sustainable Energy Development Authority, 2021b). In NEM2.0, true net energy metering is adopted allowing a "one-on-one" offset basis for excess generated energy. This has result to the capacity allowed in NEM applications increased dramatically from 27.80MW to 103.22MW in 2018 to 2019 and increased higher to 295.85MW in 2020, according to data from Malaysia's Sustainable Energy Development Authority (SEDA) (The Edge Property, 2020). This program which was initially implemented in Peninsular Malaysia has now been expanded to Sabah in 2020 with 50MW approved quota (Energy Commission, 2020a). At the end of 2020, the 500MW capacity under NEM 2.0 had been completely filled. Apart from NEM, through the Energy Commission (EC), Malaysia implemented the large scale solar (LSS) scheme to reduce the LCOE of large-scale solar PV plant development. In this scheme, the successful bidder can develop, operate and maintain solar facility to generate power for the utilities in Peninsular Malaysia and Sabah. The levelized tariff ranges from 0.096 to 0.11 USD per kWh. (Timo, 2020). The first LSS in 2016 offers a total of 250MW meanwhile, the second LSS in 2017 tender 460 MW, both in Peninsular Malaysia and Sabah. The 50MW Sepang

LSS, Malaysia's first solar project, was built after winning the first round of LSS. The third LSS tender offers 500 MW in 2019 meanwhile, the fourth LSS recently open tender for 1 GW in 2021. To date, a solar power capacity of roughly 1.39 GW has been installed with the projects of the third LSS round (Sticher, 2021). Malaysia is expected to witness substantial growth as these upcoming LSS power projects in the country is expected to dominate the solar energy market in Malaysia.

3.2 Indonesia Solar Renewable Energy Scenario

Indonesia is the biggest country in the ASEAN and it is the only one that stretches along the equator. Thus, it has the most potential for the renewable energy generation through solar power. Its location greatly favors for solar energy generation as the majority of Indonesia's region receives sufficient sun radiation, with an average daily exposure of roughly 4 kWh/m^2 (NA, 2012). The country receives an average of sunshine for 5 to 6 hours per day as reported by Soonmin et al.(2019). The Indonesian government has pledged to construct more power plants using renewable energy, with a target of 23% renewable energy mix by 2025, as the country's population grows (Setyawati, 2020). Various kinds of renewable resource are utilized in the country, which are the renewable hydropower, solar, wind, biomass, biogas and geothermal energy. Figure 2 shows the installed capacity for solar PV in Indonesia as compared to the total renewable energy capacity from the 2010 to 2020. Although the country has a significant amount of total renewable energy installed each year which is around 6GW to 11GW, however, the solar energy generation and development have been relatively slow than the other renewable resources with less than 2% from its total renewable up until 2020. Currently, only around 307 MW of solar energy capacity has been installed, lagging behind its renewable energy target and the country vast potential for solar energy (Sticher, 2021). However, by 2025, the country has set a goal of producing 6.4 GW from solar power generation. The market will be expected to increase until 2030 to produce a capacity of 9.3 GW, with 2.1 GW coming from off-grid solar PV and another 7.2 GW from grid-tied solar PV (Soonmin et al., 2019).

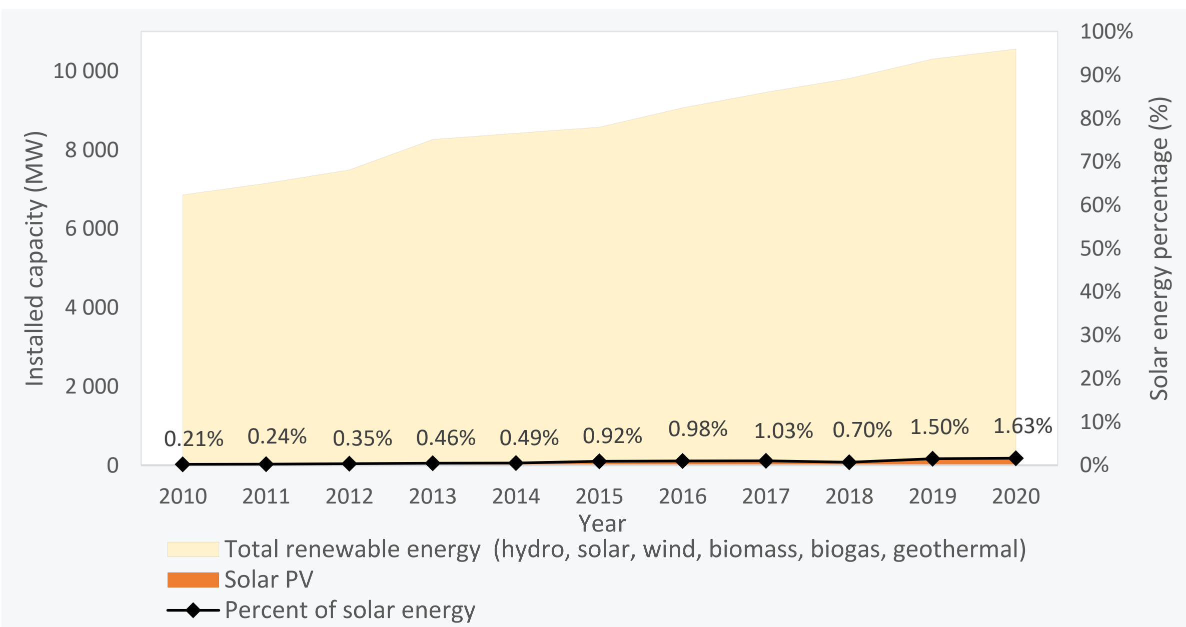

Figure 2: Indonesia installed capacity for renewable energy and solar energy from 2010 to 2020 (International Renewable Energy Agency, 2020, 2021; Secretariat General of the National Energy Council, 2019)

In 2013, the Indonesian government's Perusahaan Listrik Negara (PLN) issued a policy allowing distributed photovoltaics (DPV) users to earn a full kilowatt-hour credit for all electricity pumped into the grid. In 2014 and 2018, more regulations were enacted, resulting in a minimum monthly cost for DPV system capacity, lower average remuneration for DPV, and encouragement of self-consumption. This resulted in the interconnection of 1,435 DPV units with a capacity of 3.6 MW into the PLN network, with the majority of systems around 83% being installed on the Java island, 15% on Bali, and the remainder on other islands according to Gokhale-Welch et al.(2020). Then, Indonesia set a solar PV FIT rate ranging from 0.145 to 0.25 USD per kWh in 2016, with a small national quota of

250 MW in the first phase (Dang, 2017). Later in 2018, a NEM program for solar arrays was introduced, which was later revised in 2019. Under NEM, the PV system worth of 18.2 MW have been delivered to the country, with 7.7 MW originating from industrial power users, 5.1 MW from residential power consumers, 1.8 MW from small enterprises, and the rest from public bodies (Bellini, 2020). On the other hand, as an extensive archipelago, Indonesia has huge floating solar potential. In 2020, Indonesia began the construction of 145 MW solar floating project in West Java, which will be Southeast Asia's largest floating power plant. The rate for the plant's electricity is 0.058 USD per kilowatt-hour and it is estimated to be able to power 50,000 houses upon its operation (Rahman, 2020). According to Indonesia's National Energy Plan, solar power facilities have a potential capacity of 207,898 MW (Setyawati, 2020).

3.3 Vietnam Solar Renewable Energy Scenario

Vietnam has abundant solar resources that might be exploited to grow the country's solar energy industry. In general, the south of Vietnam receives more solar radiation than the north, with an average of 5.9 kWh/m^2 of daily solar radiation intensity in the south compared to 3.69 kWh/m^2 in the north as mentioned by Polo et al. (2015). In the north, the average amount of sunshine hours is from 1,500 to 1,700 hours per year, while in the central and southern regions are ranged from 2,000 to 2,600 hours per year (EVN Central Power Corporation, 2019). This means that the country is receiving 4 to 7 hours of sunshine each day. Based on the National Power Development Plan in 2016, Vietnam targets to grow its solar power capacity to 850 MW by 2020, 4,000 MW by 2025, and 12,000 MW by 2030 (The Socialist Republic Of Vietnam, 2016). Vietnam has been extremely effective in achieving these goals. Aside from massive amounts of renewable energy generation from hydropower, biomass, wind, and solar energy in the country from 2010 to 2020, Figure 3 also illustrates that the total capacity of solar PV installation in Vietnam has shown a substantial trend toward the end of the decade. Earlier up until 2017, Vietnam was moving slowly in the adoption of solar PV. In 2017, the country's total installed capacity was only about 8 MW, which is quite low when compared to the region's solar power potential (International Renewable Energy Agency, 2017). This is because the government had no policy at the time to stimulate the growth of solar power, unlike Malaysia's FIT and NEM policies. However, solar PV development and installation capacity have risen dramatically in a short amount of time once the government enacted the policy of assistance. All the targets for 2020, 2025, 2030 were surpassed in a span of two years. There was about 86 MW of solar PV were installed in the end of 2018, and this has climbed to 4,898MW in 2019 and up to 16.9 GW in 2020.

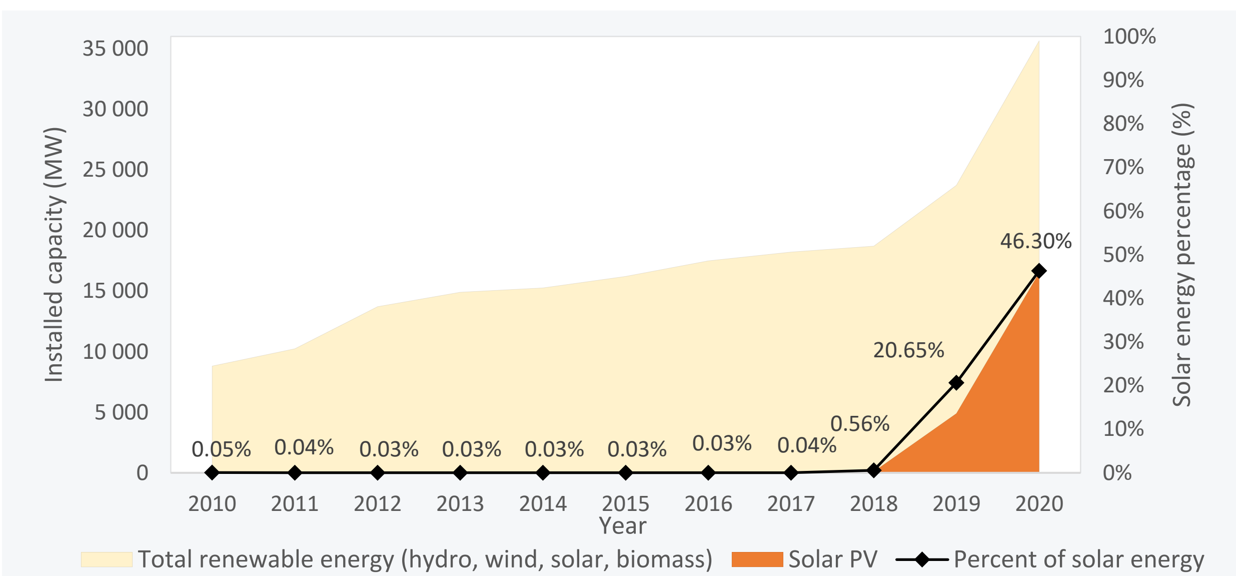

Figure 3: Vietnam installed capacity for renewable energy and solar energy from 2010 to 2020 (Do & Burke, 2020; International Renewable Energy Agency, 2020, 2021; Vietnam Initiative for Energy Transition, 2020)

In 2017, Vietnam introduced FIT rates for solar at 0.0935 USD per kilowatt-hour, which were for facilities that would be operational by June 2019 (Do & Burke, 2020). By the end of 2018, the Ministry of Industry and Trade (MOIT) reported that only two projects with a combined capacity of roughly 86 MW had come into operation, despite the fact that around 10,000 MW had been registered. Later in the first half of 2019, around 82 solar power plants were approved and commissioned which significantly boost the total capacity to 4,464 MW as reported by Phap et al.(2020). The time leading up to the initial solar FIT's expiration is the main drive to this dramatic increment of solar PV installation. Up until 8.28% of installed capacity for electricity system in Vietnam at the time is coming from solar power. By the end of 2019, another 630 MW of total capacity is added from 13 new solar power plants, resulted to 95 plants in the whole system in which increased the overall capacity to almost 5 GW (Riva et al., 2020). During this time, Vietnam has moved well past Thailand and became the country with the most solar power producing capacity deployed in the ASEAN region. However, the country, on the other hand, experiences a more remarkable boom as a result of the second FIT. Vietnam witness rooftop solar installations to skyrocket in 2020 prior to a hard installation deadline for FIT2 which is on 31st December 2020. Rooftop solar has been deployed in the country in excess of 9GWp under FIT2 policy which paying 0.0838 USD per kWh for 20 years period (Gunther, 2021). According to MOIT, in the end of 2020, around 16.5 GW of solar generation capacity has been installed in the country (Thang & Paul, 2021). In this huge number, ground-mounted and floating solar installations account for 1.549 GW under FIT2 with the rate of 0.0709 and 0.0769 USD per kWh, respectively. This tremendous increment has made the solar PV capacity become almost half of the total renewable capacity in 2020 as shown in Figure 3 and this also accounts for almost a fourth of Vietnam's installed power capacity. Besides that, this capacity substantially exceeds the 850 MW target for PV power development in 2020 (Phap et al., 2020). Beyond FIT2, idle new PV installations happen nationwide, waiting for FIT3, which is expected to release soon because of the consistent commitment of Vietnam for encouraging renewables.

3.4 Japan Solar Renewable Energy Scenario

Being one of the most developed countries in the world, Japan leads the country in Asia Pacific region in many ways. However, following the Fukushima nuclear disaster in 2011, Japan modified its policies to promote more renewable energy, with the solar power generation becoming a top priority. This is also part of Japan's endeavour to reach its decarbonization targets. Solar irradiation in the country ranges from 4.3 to 4.8 kWh/m^2 per day. The renewable energy goal is set to 22 to 24% in the country's 2030 energy mix following their new greenhouse gas emission reduction target (Hasegawa, 2021). Thus, the government of Japan has established different measures to promote renewable energy. Initially, they set their solar PV power installation targets to 28 GW by 2020 and 53 GW by 2030 (Yamamoto, 2011). However, as can be seen in Figure 4, in 2014, the 2020 target was surpassed, and in 2018, the 2030 target was also reached. After then, the capacity of solar energy has already surpassed 50% of the country's total renewable energy capacity. In 2020, for 67GW of solar energy installed capacity, Japan is third in the world behind China and the United States of America.

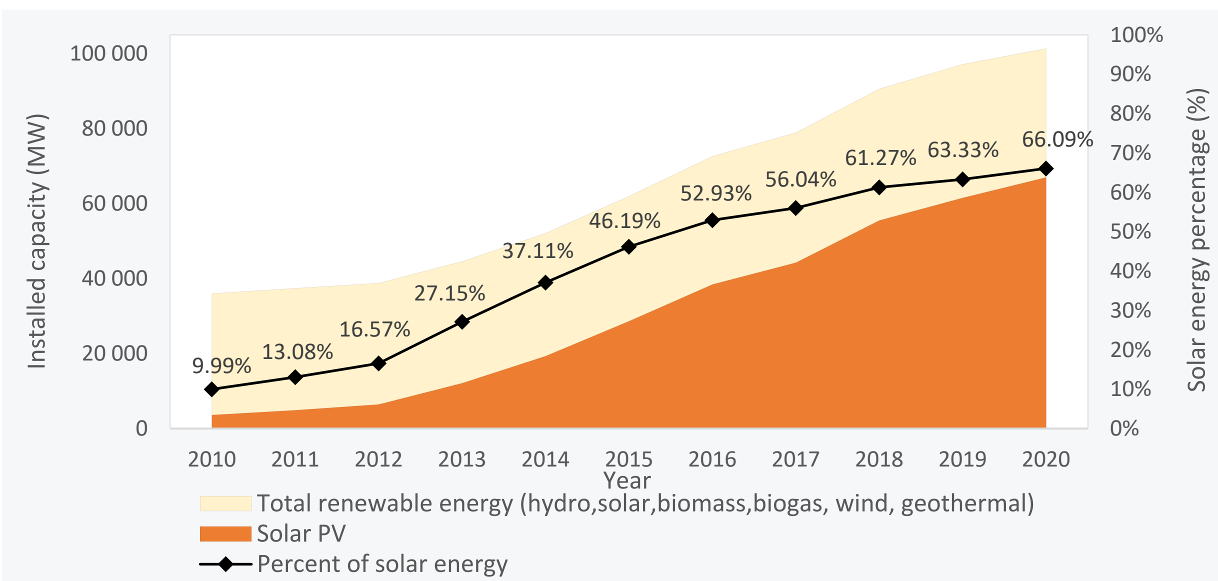

Figure 4: Japan installed capacity for renewable energy and solar energy from 2010 to 2020 (International Renewable Energy Agency, 2020, 2021; Japan Electric Power Information Center, 2020; Yamazaki, 2020)

In 2009, the Japanese government launched the first solar FIT scheme and reinstated the residential solar PV system subsidies. The solar PV purchasing rates were 48 yen per kWh for a 10-year period for residential users and 24 yen per kWh for non-residential users (Li, Xu, & Shiroyama, 2019). The impact of these new policies on residential solar PV increasing demand was immediate. This high demand persisted until 2012, when a new FIT was implemented. The new FIT will cover surplus generation for the first 10 years for systems under 10 kW and 20 years for systems exceeding 10 kW. In 2012, the pricing was 42 yen per kWh, but it dropped to 37.8 yen per kWh in 2013 and 32 yen per kWh in 2014 (Watanabe, 2014). This FIT has resulted in a massive surge in solar PV deployment in Japan, which peaked in 2015 with the installation for over 10.8GW of solar PV capacity. Later, a new feed-in tariff was adopted in 2016, cutting the rate of electricity generation from photovoltaic power plants which have a capacity of more than 10 kW to 24 yen per kWh and those with a capacity of less than 10 kW to 31-33 yen per kWh. This time, however, Japan amended the Renewable Energy Law to address the enormous backlog of incomplete solar PV projects that had accumulated as a result of the previous feed-in tariff's absence of commission deadlines (Li et al., 2019). Later, Japan runs additional solar PV auctions starting in 2017 for utility-scale projects. The country also announced plans to shift to a more market-orientated approach in subsidizing renewables in 2022. Overall, the solar PV development in Japan has been the main driver of new renewable deployment where it is contributing to 75% of the growth in renewables since 2010.

3.5 Solar Energy Potential and Development

Based on the analysis of the potential specific photovoltaic power output conducted using the Global Solar Atlas v2.6 by Solargis, the results found that all four countries have about the same amount of median specific photovoltaic power output with Malaysia as the highest (3.71 kWh/kWp) while Japan as the lowest (3.39 kWh/kWp). However, Japan was committed to install their solar PV at considerably high capacity with the total solar energy installed in 2020 was 66,999 MW (Figure 5). Vietnam and Malaysia have potential to achieve Japan's solar PV performance because both ASEAN countries have similar land area to Japan and their median specific photovoltaic power output are higher than Japan, while Indonesia could even achieve more due to its land area is five times larger than Japan.

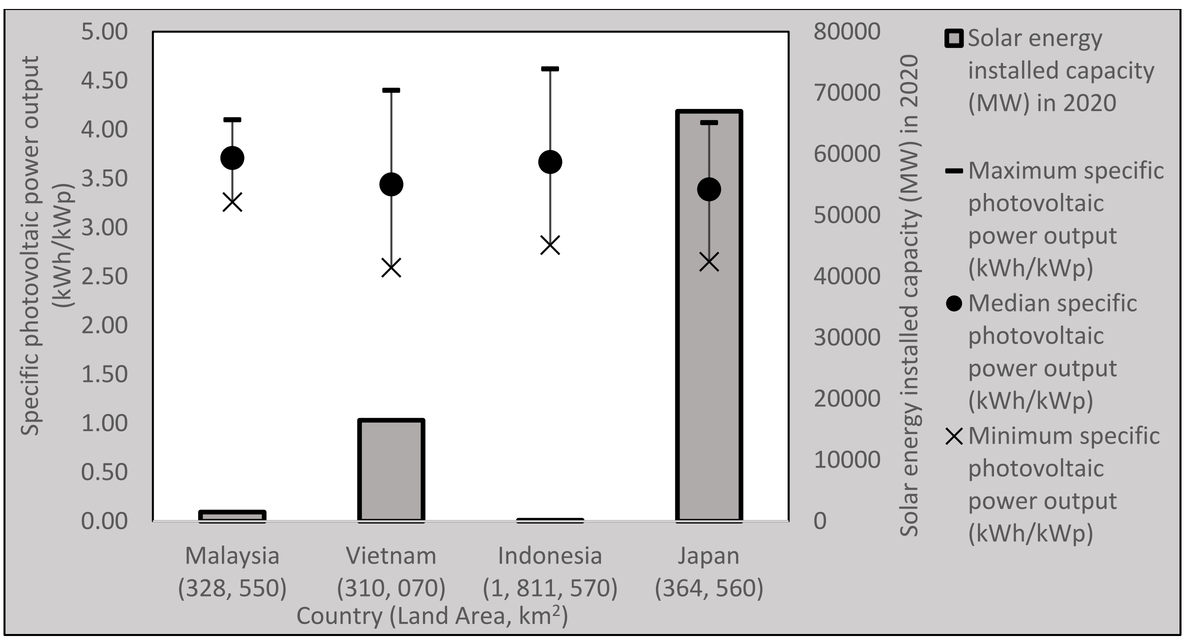

Figure 5: Specific photovoltaic power output and solar energy installed capacity in 2020 for each country (International Renewable Energy Agency, 2021)

Meanwhile, Figure 6 compares the percentage of solar photovoltaics installation capacity over the total renewable energy installed capacity for each country from 2010 until 2020 to depict the development progress of solar renewable energy sources throughout the decades. It can be seen that around this time frame, each of the ASEAN country started to embark on their quest to develop solar renewable energy as the clean, eco-friendly environment and the socially acceptable power generation. Although all of the three countries have a high potential for the solar energy generation technically, a different trend of growth can clearly be seen among the ASEAN countries due to different policies and regulations put into place in the different year as well as due to the business climate and solar market potential in the country itself. Through FIT alone, Vietnam recorded a massive growth of solar PV installation although the country implements the scheme the latest among the ASEAN countries. Besides that, Malaysia is having a firm increment in the solar PV capacity installation as the country increased the solar energy generation continuously each year through different initiatives. Meanwhile, Indonesia has relatively stagnant solar energy capacity development over the years. On the other hand, as the benchmarked country in this study, the solar PV capacity depicts a significant growth in Japan and currently dominate the share of the renewable energy generation in the country.

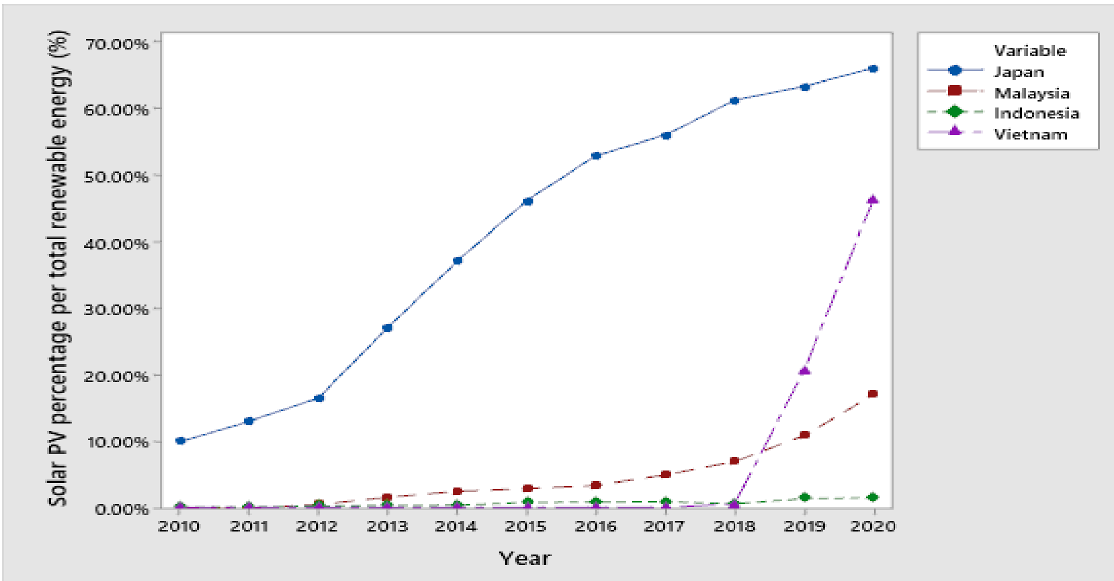

Figure 6: Solar PV percentage per total renewable energy in Malaysia, Indonesia, Vietnam and Japan from 2010 to 2020

4. Conclusion

This study examines the solar renewable energy of Malaysia, Indonesia, Vietnam and Japan. The solar energy potential of the countries is vast, and it is able to meet the growing energy demands if proper implementation is done. From the study, the potential specific photovoltaic power output for all four countries have about the same amount with the median value of all the ASEAN countries are higher than Japan. With that, the ASEAN countries have equal potential to achieve Japan impressive solar PV performance. Currently, the solar energy generation in the ASEAN region is still in its preliminary phases, and further development is required in the next decade to ensure energy security at both global and national levels. According to the findings, solar renewable energy development has been different in each country. In between 2010 to 2020, there is steady growth in Malaysia solar renewable energy development from the application of FIT, NEM and LSS schemes over the years. In Indonesia, through the implementation of solar FIT and NEM, the trend of solar energy is relatively low compared to other renewable energy capacity. Meanwhile, in Vietnam, the adoption of its FIT programs has resulted to an impressive surge in the development of solar renewable energy in a short span of time. In Japan, solar energy is largely dominating renewable energy generation as significant growth of solar renewable energy is achieved every year through the FIT program. It can be seen that the targets, policies and initiatives set in the countries have successfully kick-starting and mobilise the solar renewable energy generation in the ASEAN countries in the last decade. Significant development in ASEAN solar renewable energy is expected to expand in the next decade as witnessed in Japan.

Acknowledgements

The work reported on this paper is part of AUN/SEED-Net Collaborative Education Program Research Grant (UTM CEP 2103). The authors wish to acknowledge the support given by Universiti Teknologi Malaysia, the Malaysia Japan International Institute of Technology, Gadjah Mada University, Hanoi University of Science and Technology, Nagoya Institute of Technology and MyBamboo Sdn. Bhd. This grant registered in Universiti Teknologi Malaysia under the project (R.J130000.7351.4B673).

References

Abdullah, W. S. W., Osman, M., Ab Kadir, M. Z. A., & Verayiah, R. (2019). The potential and status of renewable energy development in Malaysia. *Energies, 12*(12), 2437.

Bellini, E. (2020). Indonesia has 18.2 MW of solar under net metering. *PV Magazine.*

British Business Energy. (2016). World Solar PV Energy Potential Maps.

Dang, M.-Q. (2017). *Potential of Solar Energy in Indonesia*.

Do, T. N., & Burke, P. J. (2020). Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. *Energy Policy, 144*, 111561. doi:https://doi.org/10.1016/j.enpol.2020.111561

Energy Commission. (2020a). *Energy Malaysia, Volume 20, 2020*. Retrieved from Suruhanjaya Tenaga (Energy Commission):

Energy Commission. (2020b). *Malaysia Energy Statistics Handbook 2020*. Retrieved from

Erdiwansyah, A. Taleb, M., Mamat, R., Sani, S., Umar, H., & Sudhakar, J. (2020). An Overview Of Renewable Energy In Southeast Asia: Current Status And Future Target. *International Journal of Scientific & Technology Research, 9*, 294-309.

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

EVN Central Power Corporation. (2019). Central and Southern regions have a lot of rooftop solar power potential. *TuoiTre.*

Gokhale-Welch, C., Darghouth, D. N., McCall, J. D., Keyser, D. J., & Aznar, A. Y. (2020). *Distributed Photovoltaic Economic Impact Analysis in Indonesia*. Retrieved from

Gunther, E. A. (2021). Vietnam rooftop solar records major boom as more than 9GW installed in 2020. *PVTECH.*

Hasegawa, M. (2021). Japan on track to achieve 2030 renewable power goal. *Argus.*

International Energy Agency. (2019). *Southeast Asia Energy Outlook 2019*. Retrieved from International Energy Agency (IEA), Paris:

International Renewable Energy Agency. (2017). *Renewable Capacity Statistics 2017*. Retrieved from International Renewable Energy Agency (IRENA), :

International Renewable Energy Agency. (2020). *Renewable Energy Statistics 2020*. Retrieved from The International Renewable Energy Agency (IRENA):

International Renewable Energy Agency. (2021). *Renewable Capacity Statistics 2021*. Retrieved from The International Renewable Energy Agency (IRENA):

International Rivers Network (Producer). (2003). Twelve Reasons to Exclude Large Hydro from Renewables Initiatives.

Japan Electric Power Information Center. (2020). *The Electric Power Industry in Japan 2020*. Retrieved from Japan Electric Power Information Center. Inc, Japan:

Karki, S. K., Mann, M. D., & Salehfar, H. (2005). Energy and environment in the ASEAN: challenges and opportunities. *Energy Policy, 33*(4), 499-509. doi:https://doi.org/10.1016/j.enpol.2003.08.014

Kumar, M. (2020). Social, economic, and environmental impacts of renewable energy resources. *Wind Solar Hybrid Renewable Energy System*.

Lee, N., Cardoso de Oliveira, R., Roberts, B., Katz, J., Brown, T., & Flores-Espino, F. (2019). *Exploring Renewable Energy Opportunities in Select Southeast Asian Countries: A Geospatial Analysis of the Levelized Cost of Energy of Utility-Scale Wind and Solar Photovoltaics* (NREL/TP-7A40-71814; Other: MainId:20963;UUID:b55d4e78-c474-e811-9c14-ac162d87dfe5;MainAdminID:9439 United States https://dx.doi.org/10.2172/1527336 Other: MainId:20963;UUID:b55d4e78-c474-e811-9c14-ac162d87dfe5;MainAdminID:9439 NREL English). Retrieved from https://www.osti.gov/servlets/purl/1527336

Li, A., Xu, Y., & Shiroyama, H. (2019). Solar lobby and energy transition in Japan. *Energy Policy, 134*, 110950. doi:https://doi.org/10.1016/j.enpol.2019.110950

NA, H. (2012). Potency of solar energy applications in Indonesia. *International Journal of Renewable Energy Development, 1*(2), 33-38.

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

Petinrin, J. O., & Shaaban, M. (2015). Renewable energy for continuous energy sustainability in Malaysia. *Renewable and Sustainable Energy Reviews, 50*, 967-981. doi:https://doi.org/10.1016/j.rser.2015.04.146

Phap, V. M., Thu Huong, N. T., Hanh, P. T., Van Duy, P., & Van Binh, D. (2020). Assessment of rooftop solar power technical potential in Hanoi city, Vietnam. *Journal of Building Engineering, 32*, 101528. doi:https://doi.org/10.1016/j.jobe.2020.101528

Polo, J., Gastón, M., Vindel, J. M., & Pagola, I. (2015). Spatial variability and clustering of global solar irradiation in Vietnam from sunshine duration measurements. *Renewable and Sustainable Energy Reviews, 42*, 1326-1334. doi:https://doi.org/10.1016/j.rser.2014.11.014

Rahman, R. (2020). Indonesia begins construction of 145MW Cirata floating solar project. *Institute For Energy Economics And Financial Analysis (IEEFA), .*

Riva, S. E., Le Thi Thuy, H., Pham, M.-H., Di Silvestre, M. L., Nguyen Quang, N., & Favuzza, S. (2020). Review of Potential and Actual Penetration of Solar Power in Vietnam. *Energies, 13*(10), 2529.

Sabo, M. L., Mariun, N., Hizam, H., Mohd Radzi, M. A., & Zakaria, A. (2016). Spatial energy predictions from large-scale photovoltaic power plants located in optimal sites and connected to a smart grid in Peninsular Malaysia. *Renewable and Sustainable Energy Reviews, 66*, 79-94. doi:https://doi.org/10.1016/j.rser.2016.07.045

Secretariat General of the National Energy Council. (2019). *Indonesia Energy Outlook (IEO) 2019*. Retrieved from

Setyawati, D. (2020). Analysis of perceptions towards the rooftop photovoltaic solar system policy in Indonesia. *Energy Policy, 144*, 111569. doi:https://doi.org/10.1016/j.enpol.2020.111569

Sharma, P. (2021). ASEAN Ideas in Progress Series.

Shi, X. (2016). The future of ASEAN energy mix: A SWOT analysis. *Renewable and Sustainable Energy Reviews, 53*, 672-680. doi:https://doi.org/10.1016/j.rser.2015.09.010

Soonmin, H., Abraham, L., Okoroigwe, E., & Urrego, L. R. (2019). Investigation of Solar Energy: The Case Study in Malaysia, Indonesia, Colombia and Nigeria. *International Journal of Renewable Energy Research, 9*, 86-95.

Sticher, M. (2021). Solar power in ASEAN: A snapshot and outlook of the solar power markets and growing M&A scene. *Apricum.*

Sustainable Energy Development Authority. (2021a). Feed-In Tariff (FIT)

Sustainable Energy Development Authority. (2021b). Net Energy Metering (NEM) 3.0.

Thang, N. D., & Paul, B. (2021). Vietnam's Solar Power Boom: Policy Implications for Other ASEAN Member States. *The Institute of Southeast Asian Studies (ISEAS).*

The Edge Property. (2020). Successful NEM2.0 Is A Testimony to Malaysia's Renewable Energy Drive.

The Socialist Republic Of Vietnam. (2016). *Approval of the Revised National Power Development Master Plan for the 2011-2020 Period with the Vision to 2030* Hanoi, Vietnam.

Timo. (2020). From 2% to 20% – Accelerating Renewable Energy Development in Malaysia. *The Energy Bit.*

Vaka, M., Walvekar, R., Rasheed, A. K., & Khalid, M. (2020). A review on Malaysia's solar energy pathway towards carbon-neutral Malaysia beyond Covid'19 pandemic. *Journal of Cleaner Production, 273*, 122834. doi:https://doi.org/10.1016/j.jclepro.2020.122834

Vietnam Initiative for Energy Transition. (2020). Ability to release capacity for wind power and solar power in 2022. from Vietnam Initiative for Energy Transition, Vietnam

Wang, H., Yang, X., Lou, Q., & Xu, X. (2021). Achieving a Sustainable Development Process by Deployment of Solar PV Power in ASEAN: A SWOT Analysis. *Processes, 9*(4), 630.

Watanabe, C. (2014). Japan Cuts Subsidy for Solar Power, Boosts Offshore Wind. *Bloomberg.*

Yamamoto, M. (2011). *National Survey Report of PV Power Applications in Japan 2010*. Retrieved from International Energy Agency (IEA:

Yamazaki, M. (2020). *National Survey Report of PV Power Applications in JAPAN 2019*. Retrieved from International Energy Agency (IEA):

Biographies

Mohamad Yuszaimie Abdul Hamid is a Master of Science (Mechanical Engineering) student at Universiti Teknologi Malaysia, Johor, Malaysia. He earned Bachelor in Engineering (Mechanical) from Universiti Teknologi Malaysia, Johor, Malaysia

Ku Nur Afrina Ku Azman Shah is a Master of Science (Industrial Engineering) student at Universiti Teknologi Malaysia, Johor, Malaysia. She earned Diploma in Manufacturing Engineering Technology from Kolej Kemahiran Tinggi Mara Balik Pulau, Penang, Malaysia and B.Eng. in Mechanical Engineering from Universiti Tenaga Nasional, Kajang, Malaysia.

Nor Akmal Fadil is a Senior Lecturer at the Department of Materials, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia. Received her Bachelor Degree in Mechanical (Engineering-Material) from Universiti Teknologi Malaysia, Master Degree in Material Science & Engineering from the Shibaura Institute of Technology, Tokyo, Japan and PhD in Regional Environment Systems from the Shibaura Institute of Technology, Tokyo, Japan.

Jafri Mohd Rohani is a Senior Quality and Statistical Engineering Lecturer. He is also Head of the Industrial Engineering Programme at the Department of Materials, Industrial and Manufacturing Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor. Currently, he is the President of Johor Cost and Quality Engineers Society. He is a member of the American Society for Quality (ASQ) and Human Factor Society of Malaysia.

Mohd Zamri Mohd Yusop received his Bachelor of Degree, Master and PhD degree from the Nagoya Institute of Technology (NITech), Nagoya, Japan in 2013. Before return to Universiti Teknologi Malaysia (UTM) in 2015, he finished two years post-doctoral in “Basic Research and Development of Graphene, R&D of Single Crystal Graphene by Camphor” under New Energy and Industrial Technology Development Organization (NEDO) Japan Fellowship at NITech, Japan.

Nguyen Duc Tuyen
Dr. Nguyen Duc Tuyen received the Undergraduate Degree at Hanoi University of Science and Technology in 2006, Master Degree in 2009 and Ph.D. in 2012 at the Shibaura Institute of Technology, Tokyo, Japan. From 2012 to 2015, he was also a researcher at the Shibaura Institute of Technology, Tokyo, Japan and part-time lecturer at Chiba University and Tokyo Wildlife College, Japan. From 2015 to 2017, he worked at Tokyo University of Science, Japan. From 2017 to 2018, he conducted the research at the National Institute of Advanced Industrial Science and Technology, Japan. Since 2018, Dr. Nguyen Duc Tuyen is a lecturer of the Department of Power System, Electrical Engineering School, Hanoi University of Science and Technology. He is now also with the Shibaura Institute of Technology as the Adjunct Associate Professor.

Budi Hartono
Dr. Budi Hartono is an associate professor and the head of the Mechanical & Industrial Engineering Department, Faculty of Engineering, Universitas Gadjah Mada (UGM). He received his Ph.D. from the Industrial & Systems Engineering Department, National University of Singapore (NUS), with the NUS and the AUN-SEED joint scholarship program. Dr. Budi Hartono is the Chair of the Gadjah Mada Project Management Research Group (Gama-Pro) and a former director of Project Management Institute Indonesia, Yogyakarta Branch. Dr. Hartono's research interests include project management, risk and complexity analysis, cognitive ergonomics, and systems approach.