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Review

Solar Energy Utilization Techniques, Policies, Potentials, Progresses, Challenges and Recommendations in ASEAN Countries

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Abstract: Sustainable development goals not only contributes towards a clean environment but also towards better climatic conditions. Within Asia next to China and India, the Association of Southeast Asian Nations (ASEAN) are the actively developing countries in terms of economy and technologies. On the verge of achieving development, the ASEAN countries highly depend on fossil fuels for their energy needs. The ASEAN countries have taken visionary steps towards increasing the renewable energy mix with the conventional grid without hampering the ongoing development; this study presents the solar energy utilization policies, potential, progresses, and challenges adopted in ASEAN countries; furthermore, in these nations there is a huge potential of solar energy being located near the equator, therefore, they should focus on both solar to electrical and solar to thermal energy applications; however, in order to meet the peak demand and ensure the reliability of renewable energy like solar power, the development of advanced energy storage systems could be the key areas, and concrete efforts are required. Therefore, this article is a spotlight on government policies and goals focusing on energy potential, major progress in terms of energy storage and challenges in implementation of renewable energy systems in ASEAN countries; furthermore the recommended highlights on policies to accelerate the exploitation of renewable energy usage among the people are also discussed in detail, besides, the insights on reduction of carbon footprints over the next decade through incorporation of advanced energy storage systems. The issues discussed in this article will be helpful for exploring the desired energy storage systems and energy policies to be followed, which will eventually attract the stakeholders for small and medium-scale entrepreneurs for the development of renewable energy business in the region, if implemented on the ground.

Keywords: ASEAN; energy storage; renewable energy policies; carbon footprint; solar radiation

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1. Introduction

The human desire to reduce the global temperature by 1.5 °C and to achieve sustainable development goals (SDG) by 2050 is highly feasible with strong enforcement of renewable energy sources [1]. A foremost influence factor for the progress of economic development of any nation is energy affordability and consumption [2]. As energy plays a significant role in transportation, commerce, agriculture, producing job opportunities and economic improvement. In addition, energy is also a key parameter for sustainable development, production and abolishing poverty [3]. As per the developing era of energy-dependent economies, the attraction of poor and rich nations are highly dependent on renewable energy sources; it is observed that the pace of energy demand in ASEAN is twice that of China. Analysis and survey reports indicate the growth in energy demand by about two-thirds, which is around 12% of global energy demand. ASEAN has a principal source of fossil energy resources, specifically coal, which highly influences the economic development in the region. As per the statistics from World Bank, renewable energy like biomass, biofuels, hydroelectric, solar, tidal and geothermal sources contribute to about 16% of the total electric power generation in ASEAN countries [4]; these countries are very likely to be the hub for the global renewable energy (RE) market in the near future, owing to the availability of natural sources in abundance in each nation [5]. In spite of the abundance of natural sources, the share of RE among the total primary energy supply in these countries has been very small in the energy mix [6]; however, the share of biomass within the energy consumption has reduced due to the energy policies particularly, for cooking and heating energy requirements.

Energy is one of the major components in progressing the economic pursuit of the ASEAN community as they self-motivate regional integration towards 2025. The economic development of ASEAN countries has been paused by the COVID-19 pandemic and caused exceptional setbacks, and shocked the various sectors, including industries [7]; however, energy has the potential to help the reconstruction and recovery of the global economy. Solar energy is the leading renewable source of energy, and highly influences all other RE sources such as wind, hydro, tidal and bioenergy directly or indirectly. Therefore, the exploitation of this vast and abundant energy resource for meeting the daily energy needs of humans would lessen the electricity generation by conventional (fossil) fuels. Solar power is extremely popular since it is completely carbon-neutral, freely available and renewable but it has certain challenges such as being intermittent in nature and available only during the day time, therefore, economical energy storage is required [8].

The energy storage (ES) technique is considered as a potential solution to bridge the gap between energy availability and demand; it plays a vital role in (a) providing flexibility to energy systems (b) improving the potential to accommodate variable renewable energy generation and (c) progressing in energy network management [9]. The energy storage system is very much essential due to its multifaceted functionality such as rising exploitation of renewable incorporation, dipping peak demands, and improving electric grid dependability. The electrical energy can be stored using batteries and capacitors but there are still many challenges for their reliability and performance. Similarly, thermal energy can also be stored in thermal energy storage materials, which may be either sensible or latent heat storage systems [10]. For effective and affordable utility of solar energy in the ASEAN region, the gap between demand and supply has to be narrowed down at par with conventional energy; however, the supply could be regulated only when effective and economical energy storage is available in the vicinity of solar energy plants to handle the intermittent and diluted nature. Thus solar energy is preferable to an effective energy storage system, the latter has numerous advantages including bridging seasonal, daily and monthly differences and imbalances, thereby, optimizing the daily load cycle, peak saving of power and enhanced power quality, grid stability, and reliability of supply; however the inclusion of energy storage technologies in solar PV and solar thermal systems will increase the overall cost of energy significantly and hence, the economic feasibility and affordability analysis is required before incorporating any energy storage in solar energy utilization systems.

As per the ASEAN plan of Action for Energy Cooperation (APAEC), it is expected to intensify the substantial use of RE to around 25% by 2025 [7]. A sudden shift over to renewable sources of energy is possible only with proper continuous supply of energy. Hydro and wind energy are seasonally dependent and are discontinuous, whereas solar energy is available throughout the year with intermittent nature; however, the major hurdle for the integration of RE to such a high level is the lack of a reliable energy storage facility. Solar energy is a high source of renewable power, with the potential to meet global energy demand, a proper technique to completely utilize solar power is possible with energy storage. TES using phase change material is widely researched and commercialized in every part of the ASEAN countries; this particular research article is about consolidating such solar energy potentials and the technique adopted to store solar power.

A number of articles published previously with a focus on ASEAN countries have been related to (a) impacts of micro-plastic pollutants, (b) waterborne parasite (c) electricity import and export scenarios (d) effect of drought on power generation (e) SWOT analysis of hybrid energy source (f) energy policies related to solar PV and (g) energy policies and consumption of biofuels, as summarized in Table 1.

However, articles on energy storage policies, post-COVID energy potentials, progress and challenges to be overcome for an effective contribution towards SDGs were found to be missing. Therefore, this article is dedicated towards energy storage potential and energy policies followed in ASEAN countries for electrical and thermal energy storage. Indeed the present article with new policies and energy storage trends followed in ASEAN countries would be an insight for the researchers working to contribute towards a green environment, especially for future scientists and researchers for a remarkable contribution towards achieving sustainable development goals of clean, green and affordable energy solutions for the ASEAN region. Current review article also provides an analysis on environmental benefits of storing energy for consumption; this particular energy policy review article is specifically intended for scientists and researchers belonging to South East Asia to make a remarkable contribution towards achieving the sustainable development goal of clean and affordable energy. The energy storage potential of the South East Asian countries would attract numerous industries for commercializing electrical and thermal batteries for human comfort; this review article also aims to analyze the potential evolution of ASEAN nations in the energy field and how they share best practices and promote a joint dialogue among themselves to improve long-standing renewable energy collaboration.

The review manuscript is divided into seven sections. Geographical location along with the need and benefits of solar energy are elaborated in introduction, this section also highlights the novelty of the review article. Detailed analysis on the solar energy potential and the energy policies in terms of incentives for harnessing solar power are consolidated in Sections 2 and 3, respectively. The core part of the review article is elaborated in Section 4. ASEAN countries comprises 10 nations and this section reviews the current progress and energy storage policies of all the members of ASEAN countries. Section 5 provides an analysis of the environmental benefits of storing energy for further consumption. Important challenges on electric and TES in the ASEAN nations are listed in Section 6. Section 7 provides a summary and insights of the review article; in addition, future research scope and recommendations for researchers are highlighted.

Table 1. Overview of Previously Published Review Articles.

Year of Publication	Literature Work	Outlooks	Limitations	Ref.
2021	A comprehensive review on energy potential, energy consumption, energy position and the hurdles to overcome for exploitation of renewable energy like solar, wind, bio-energy and geothermal at the central part of Asia is concisely carried out.	Discusses the potential of all renewable energy sources with information on the installed capacity.	Focus on recent renewable energy technologies and their evaluation, performance was not discussed.	[11]
2021	A state of review on the adverse impacts of micro plastic pollutants on the shores and marine ecosystems of ASEAN countries is reviewed. A focus on the cause of micro plastic pollutants and the necessary mitigations protocols were elaborated.	Focuses on a statistical review in regard to ASEAN countries.	However the article specifically deals with marine ecosystems and their pollutants.	[12]
2017	Technical review on hybrid PV/diesel system in specific to Thailand	Focuses on the cost of electricity generation for Thailand.	Specific for hybrid PV/diesel systems and for a single nation.	[13]
2017	A critical review on the electric power import-export scenario, renewable energy-based electric power transmission practice, barriers for establishing the ASEAN grid and extensive review on energy sources, present consumption with future projection are provided.	Extensively focuses on both fossil fuel and renewable energy sources of ASEAN countries. Discusses on import and export trends of electric power.	Lack of simulation models to identify future interconnecting zones for utilizing renewable resources.	[14]
2016	Insights on the effects of drought in the generation of electricity among the ASEAN countries are provided. The article also provides implications for energy policies and planning.	Provides sufficient information on availability and reliability of renewable energy sources based on global climatic changes.	Specifically focused on drought in regard to energy security issues.	[15]
2016	This particular review article provides a detailed SWOT analysis specific to the future ASEAN hybrid energy source. The review article also discusses the actions from stakeholders, political leaders and national government to achieve an effective greener energy mix.	Provides an outlook on the energy mix (fossil fuel and renewable energy) in the ASEAN countries.	Individual national energy security strategies for each of the ASEAN countries were not discussed.	[16]
2015	Overview on development of solar photovoltaic (PV) in ASEAN countries with a focus on RE policies for the growth of PV panel-related research activities and installation techniques are reviewed.	Summarizes the PV panel potential in ASEAN countries based on the research policies and actions by the government.	Lack of information in regard to other renewable energy sources.	[17]
2015	This review article compiled the global energy scenario of biofuel along with the biofuel policy followed in ASEAN countries. Energy policy on usage of biofuel blended diesel engines and the emission characteristics are highlighted.	Consolidates information on the worldwide scenario of a few ASEAN countries in terms of biofuel potential and policies in comparison to global networks.	Major focus was on biofuels; however, the impacts and percentage of NO_x and SO_x emission were omitted.	[18]

2. Solar Energy Potential in ASEAN Countries

Solar energy is the primary energy source for all renewable energy, as (a) Flow of wind from the equator to the north pole and the south pole are influenced by the solar radiation, as they cause the density difference for wind movement (b) In hydro power, sun influences the occurrence of rain (c) In ocean thermal energy conversion, the top layer of water is heating by the solar radiation, (d) In tidal energy, neap tide and spring tides are influenced by sun in addition to the major contribution from lunar and (e) In bioenergy solar radiation contribute towards photosynthesis for trees and plants. Overall, the solar energy dominates all other renewable energy sources, conversely in regard to energy generation using solar thermal system and solar PV panels, the amount of irradiation are of a significant factor. The higher the irradiation, the higher is the input power for the solar thermal system as well higher the packets of photons for solar PV panels, thus it's vital to have an understanding on the potential of solar energy and irradiation for effective energy utilization. Indonesia and Vietnam are leading among the ASEAN countries in terms of the solar energy potential as per 2020 statistics; however, all the ASEAN countries also have a wide reserve for oil making them more reliable on the conventional oil fields rather than the renewable solar potentials. Due to the high availability of conventional fossil fuels, renewable sources of energies are almost used in at least fraction. Hydropower, wind, biomass, geothermal, biofuel, and solar energy are some of the renewable energies available in ASEAN countries [19]. As per the UN goals to attain sustainable development, it is vital to make a transition from conventional energy to renewable energy to contribute worldwide to global warming and rise in temperature issues. Currently with the intention to achieve UN SDG goals, researchers and scientists, as well as government agencies are carrying out a wide research investigation to develop new technologies for effective utilization of renewable sources coupled with energy storage techniques. Even though energy conservation and management, including developments in energy performance in all sectors such as industrial, residential, transportation and commercial are essential for a sustainable energy future, sustainable and renewable energy is observed as essential for achieving this goal [17]. Aside from that, renewable energy minimizes their leasing of greenhouse gas (GHG) emissions to the environment, which improves the quality of the environment while also aiding in the fight against climate change. Furthermore, renewable energy sources are abundant, long-lasting, and completely free to use, even when accounting for the expenses of the processes and equipment required to collect them [20]. Table 2 shows various renewable energy resources available in ASEAN countries. The geothermal potential of Indonesia is 29 GW, or 40% of the world's total; however, until 2015 the utilization remained extremely low, with just roughly 1438.5 MW being utilized; this is less-than-optimal consumption prompted by the Indonesian government to embark on a series of initiatives to catch up, with the goal of being able to utilize from geothermal power plants to up to 7239 MW by 2025, according to the country's geothermal development program; this is an extraordinarily valuable prospect for Indonesia to trade in global energy in order to participate in the improvement of energy security in the entire ASEAN countries [21–25].

As aforementioned, renewable energy has significant advantages in general; it has the inherent limitation of being intermittent; it is critical to decide the most appropriate form of RE for a given country or location in order to achieve the best possible results. Many elements must be considered in this regard, including expenses associated with energy generation, performance of the selected system, water and land needs, and economic impact associated with their applications [27]. As a RE source, solar energy is regarded to be virtually limitless, sustainable, and almost limitless. Solar thermal and solar PV are the two most common energy harvesting technologies on the market today. In overall, solar PV panels harvest the sun's energy through the use of PV cells, which are a type of semi-conductive diode which induce irradiation into direct current (DC) that may be used for various purposes. For most types of buildings, solar photovoltaic is employed in grid-connected systems to power household applications, business equipment, and lights.

The usage of standalone devices and batteries makes it particularly suited for distant areas where there is no other electrical power source available to power the system. PV systems can either be put on the ground or positioned on the roofs of buildings. The majority of the time, photovoltaic modules fixed on building roofs may generate as much electricity as the structure needs [17]. Solar thermal energy, on the other hand, refers to the process of capturing solar energy to generate heat and power from it. Abundance of solar energy potential available in all ASEAN countries are listed in Table 3; it is clearly displayed that Thailand and Cambodia have the highest irradiation than other ASEAN countries, which also coincides with Table 3.

Table 2. Renewable Energy Sources in ASEAN Country [26].

Renewable Energy / Countries	Geothermal Energy (GW)	Wind Energy (m/s)	Solar Energy ($kWh/m^2/day$)	Bio Energy (GW)	Hydro Energy (GW)	Ocean Energy (kW)
Brunei	-	5	-		0.07	335
Cambodia	-	>5	5	-	10	-
Indonesia	28.9	3–6	4.8	32.6	75	49
Laos	0.05	3–6	3.6–5.3	1.2	26	-
Malaysia	-	1.2–4.1	4.5	0.6	29	0.5–4.6
Myanmar	-	4	5	14.7	40.4	-
Philippines	1.2	7–6	5	0.24	10.5	170
Thailand	-	5.3–6.4	5–5.55	2.5	15	-
Vietnam	0.34	7	4–5	0.56	35	0.1–0.2

Table 3. Global horizontal solar radiation and photovoltaic power potential as per 2020 statistics.

ASEAN	Global Horizontal Irradiation (kWh/m^2)—Yearly		Photovoltaic Power Potential (kWh/kWp)—Yearly	
	Minimum	Maximum	Minimum	Maximum
Brunei	1497	1935	1205	1497
Cambodia	1607	1972	1241	1570
Indonesia	1314	2191	1095	1680
Laos	1314	1899	1095	1534
Malaysia	1534	1899	1168	1534
Myanmar	1168	1899	1095	1680
Philippines	1387	1972	1095	1680
Thailand	1607	1972	1314	1534
Vietnam	1168	2045	949	1680

Brunei is also known as Brunei Darussalam. Brunei obtains a higher daily average irradiation of 5.43 kWh/m^2, with an annual average of approximately 1982 kWh/m^2; however, the contribution of solar energy to the country's energy supply is extremely minimal. The natural gas and crude oil companies have long held a monopoly on the world's principal energy supply [28]. Brunei doesn't have a dedicated policy background for environmental protection. As an alternative, they have focused on energy policy on natural gas and oil production. The oil production policy was established in 1981 with the goal of extending the life oil reserves of the country. Later, in the year 2000, the Brunei Natural Gas Policy (Production and Utilization) was implemented with the goal of opening up new areas for development and exploration, as well as promoting further investigation by both existing and new operators [29]. In this strategy, emphasis was given to the use of natural gas in the home, particularly for the creation of electric power. The National Development Plans, which are five-year economic development plans, are implemented in Brunei. The ninth National development plan (2007–2012) was the most recent plan to be put into effect in Cambodia. Brunei's vision is to develop a long-term plan to double the energy production capacity by 2035. By 2035, they hope to have at least 10% of the total energy capacity derived from renewable sources, which translates to installed 50 MW in total [30].

Cambodia receives an average irradiation of around 1825 kWh/m^2 per year, with an annual average irradiation of 5 kWh/m^2 per day with sunshine ranging in duration from 6 to 9 h. The weather is governed by the yearly monsoon time, specifically the dry season and wet season. During the dry season, the temperature reaches its maximum levels in March and April, with temperatures ranging between 30 and 40 °C. Nearly two million families have no access to power from the public grid, which accounts for around 55% of the people living in rural areas [31]. As a result, 55% of the houses rely on rechargeable car batteries, 35% rely on dry cells, and the remaining 10% people have no access to electricity. As part of the Rural Electrification Strategy (RES) intends to increase the rural communities' access to grid and off-grid power services while also raising living standards, alleviating poverty, and fostering economic growth [32].

Based on data from Singapore's Energy Market Authority (EMA), the most promising renewable energy source in the country is solar energy, which receives an average annual isolation of roughly 1635 kWh/m^2 per year [33,34]. Because of the country's limited natural resources and land, Singapore is reliant on foreign energy supplies, particularly natural gas, which is primarily sourced from Malaysia and Indonesia. The most important source of energy is oil, accounting for 87% of total supply, with natural gas accounting for the remaining 13% [35,36]. Indigenous resources, such as solar energy and solid waste, make up only a small portion of the total (less than 1%). Because of the higher solar isolation and robust semiconductor production and invention base in the nation, the government is dedicated to growing the country's green energy sector, and in particular its solar power resources.

Malaysia's major energy sources include natural gas and oil, which are the most widely used. In 2012, According to the Energy Informative Administration, Malaysia is the second largest natural gas producer in South East Asia and the world's second largest exporter of liquefied natural gas. When it comes to the power sector, fossil fuels account for the vast majority of Malaysia's electrical generation capacity, with significant contributions from natural gas (53% of total capacity) and coal (40% of total capacity) [37]. The majority of the electricity generated by renewable energy sources comes from hydropower (5%). Malaysia has an abundance of solar isolation, with annual solar insolation ranges from 1400 to 1900 kWh/m^2 and an average of 1643 kWh/m^2 annually [17]; this shows that Malaysia has the potential to develop solar PV technology in the future. The government hopes to have 7000 MW of installed capacity of renewable energy by 2030 [34]. Photovoltaic system performs a prominent role to reach this goal, as it is estimated to provide approximately 60% of the total renewable energy supply over the long term; furthermore, the government has invested large resources in energy-related research and development initiatives in order to expedite the adoption of solar PV [38].

Vietnam receives a significant amount of solar energy, with the southern part receiving approximately 1825 kWh/m^2, whereas the northern portion receives approximately 1460 kWh/m^2. During the summer, these regions receive between 2000 and 2600 h of sunlight per year, while the other receives between 1800 and 2100 h [38].

Philippine solar energy applications have the ability to be both on-grid and off-grid depending on their location. The average annual sun insolation varies from 1643 to 2008 kWh/m^2. Fossil fuels are the predominant energy source in the Philippines, accounting for 80% of total energy production [39]. Despite this, the sharing of renewable energy is still very high (41%), owing to the significant contributions from biomass and geothermal energy resources, among other factors. In contrast, renewable energy sources like wind, solar, and biofuel make up barely 1% of total energy use. After the United States, the world's second-largest production of geothermal energy is in the Philippines [40].

Myanmar receives yearly solar insolation varies from 4.5 to 5.5 kWh/m^2 per day, which is sufficient for electricity generation [19,39]. In its current form, Myanmar intends to maintain its energy independence and expand the use of RE sources, while also making energy conversion more efficient and getting alternative fuels into the home. By 2020, Myanmar hopes to achieve a renewable energy proportion of 15–20% of its overall energy production.

Thailand has a significant amount of solar energy is available. The annual insolation varies between 1825 and 1935 kWh/m^2, with an average of 1875 kWh/m^2. Higher isolation rates are seen in particular during the months of April and May, with solar insolation varying from 5.6 to 6.7 kWh/m^2 per day. The northern and northeastern parts collect approximately 6–8 sunlight hours per day [41].

3. Energy Policies and Incentives for Solar Energy Harnessing in ASEAN Countries

Southeast Asian countries' booming economy has significantly increased energy usage. The consumption of energy is expected to increase by 2.6 times between 2005 and 2030, and demand is likely to increase by over two-thirds in 2040, accounting for one-tenth of the increase in global demand [19,42]. Meanwhile, environmental pollution caused by energy-related GHG emissions will continue to rise globally and regionally. Due to the environmental effects, ASEAN countries, particularly Indonesia, Thailand, Philippines, and Vietnam, Philippines must accelerate their investment in renewable energy sources. Southeast Asia is rapidly emerging as an attractive market for biomass energy development, with biomass energy capable of providing 26% of primary supply of energy, or 87% of renewable energy supply. Numerous ASEAN countries produce agricultural commodities like sugar cane, rubber, rice, palm oil, coconut, and other wastes include wood residue, rice husk, oil palm residue, and sugarcane bagasse. The annual average energy consumption in ASEAN countries is predicted to be around 3.9%, while the average carbon output has climbed by more than 5% as a result of the region's rapid growth in economy [43]. Rise in purchasing power parity increases per capita electricity consumption, which results in an increase in per capita carbon dioxide (CO_2) emissions. Although CO_2 is the main source of GHG emissions globally, which are largely attributed to the energy sector, this is not the case for several ASEAN countries, where emissions are primarily attributed to forests and agriculture [44]. Singapore, Brunei Darussalam, Thailand and Malaysia already had achieved 100% electrical access as shown in Figure 1. Likewise, remaining countries are also expected to achieve 100% power availability by 2030 [45].

Hydropower is about 80% of renewable energy, is the backbone of ASEAN's energy portfolio, and the emergence of solar and wind energy, as well as bioenergy and biofuel, is expected to bring promising development. Additionally, progress of hydrogen carbon technology has the potential to significantly alter ASEAN's energy landscape [46]. In recent decades, ASEAN countries have become popular in industrial and export hubs. Achieving sustainable and renewable energy targets has been a challenge for them. According to consultancy Wood Mackenzie, ASEAN's cumulative PV capacity might nearly triple to 35.8 GW by 2024, up from an anticipated 12.6 GW this year. By the year's end, the region should have built 5.5 GW of solar generating capacity, or 44% of its total capacity [19].

It has been observed that the current installed capacity of PV modules has dramatically increased. In 2018–2019 the increased installation of PV module production is 5527 MW and in between 2019 to 2020 the improvement of energy production is 12,473 MW respectively; moreover, the lower capacity of PV module installation ASEAN countries Brunei, Lao, Myanmar, Indonesia and Cambodia were 1.4 MW, 21.63 MW, 84.5 MW, 171.8 MW and 208.5 MW in the year 2020. The average installation of PV modules in Vietnam, Thailand, Malaysia, Philippines and Singapore were 16,504 MW, 2983 MW, 1493 MW, 1048 MW and 329.3 MW respectively in the year of 2020; it was observed that the highest and lowest solar energy production ASEAN countries are Vietnam and Brunei in the year of 2020 [47]. Table 4 displays the various ASEAN countries' solar and renewable energy targets and their primary resources.

The aim of energy policy in the Philippines to minimize the countries dependence on fossil fuels, adopt socio-economic development in rural areas of the Philippines, minimize the country's exposure to price variations. Improve the utilization of RE by offering fiscal and non-fiscal incentives. The Philippines implemented some mandatory policy mechanisms like biofuel mandate, Renewable energy Portfolio Standard (RPS) and Feed in Tariff (FIT). In the Philippines, a FIT scheme is available solely for four types of RE sources: solar PV, wind, hydropower, and biomass. The FIT has a specified period of 20 years, with no degradation rate thus far; however, after three years of implementation, the Energy Regulatory Commission (ERC) will conduct an assessment and readjustment. The Asian Development Bank (ADB) offered a £64.5 million credit facility in 2012 for solar energy projects and development in the Philippines [51,52].

Thailand's Ministry of Energy's Department of Alternative Energy Development and Efficiency (DEDE) has announced a £120 million budget for RE development, of which £9 million would be used for solar energy development; these solar R&D efforts will focus on the investigation and development of low-cost solar hot water and cooling systems on a modest scale, building-integrated photovoltaic systems, and the recycling of photovoltaic modules. Local and international investors have also been attracted by the Thailand government's support in terms of policy and R&D funding. In 2013, the National Energy Policy Commission (NEPC) approved for a 25-year term FiT prices for 200 MW of rooftop solar and 800 MW of community-owned ground mount solar [53,54].

In Malaysian rules and regulations, various policies have been implemented to aid in the acceleration of the use of solar energy technologies in Malaysia. Since 1999, Malaysia has implemented a number of significant projects in this area, including the Malaysia Industrial Energy Efficiency Improvement Project (MIEEIP), the Small Renewable Energy Power Programme (SREPP), Building Energy Efficiency Programme (BEEP), and Malaysia Building Integrated Photovoltaic (MBIPV). FiT which began in November 2011, was Malaysia's most recent taxation scheme; this programme places a premium on solar photovoltaic (PV) energy. There is a payback term of 21 years for the FiT, and an annual regression rate of 8% for the entire period, and it's a self-financing system [55]; this was accomplished by raising the energy tariff by 1.6% and allocating the additional revenue to the FiT fund; this fund will remain available until it has a cumulative value of MYR18.9 billion in 2030 (£3.4 billion). With a depression rate in place, it is projected that the cost of solar electricity will approach grid parity by that year, pushed by environmental concerns and Malaysia's energy security [56]. The FiT programme is expected to accelerate the adoption of grid-connected PV systems in Malaysia [17,51].

In June 2013, the Indonesian Minister of Energy and Mineral Resources (MEMR) authorized the sale of solar energy generated back to the grid by issuing Ministerial Decree No.17/2013; this new legislation has resulted in an increase in the number of solar photovoltaic installations in Indonesia. Despite beginning with just 14 MW of installed solar energy capacity in 2011, Indonesia had a big increase in 2013, with total capacity rising to 59 MW.

Singapore aspires to be a regional leader in RE research and development. In 2007, they launched the Clean Energy Program, allocating a fund of Singapore Dollars (SGD) 700 million (£329 million) for 5 areas: research and development, human capital development, smartening up Singapore-based enterprises, international promotion of Singapore's industry, and intensifying a dynamic industry ecosystem. Solar energy strategy was adopted by the Inter-Ministerial Committee for Sustainable Development in 2009, authorizing the Housing Development Board (HDB) to develop solar technology capabilities and inventions. HDB, Singapore's public housing authority, established the Solar Capability Building Program (SCBP) in 2009 with a budget of SGD31 million to investigate the viability of large-scale solar PV on both new and old HDB estates [33,36,57].

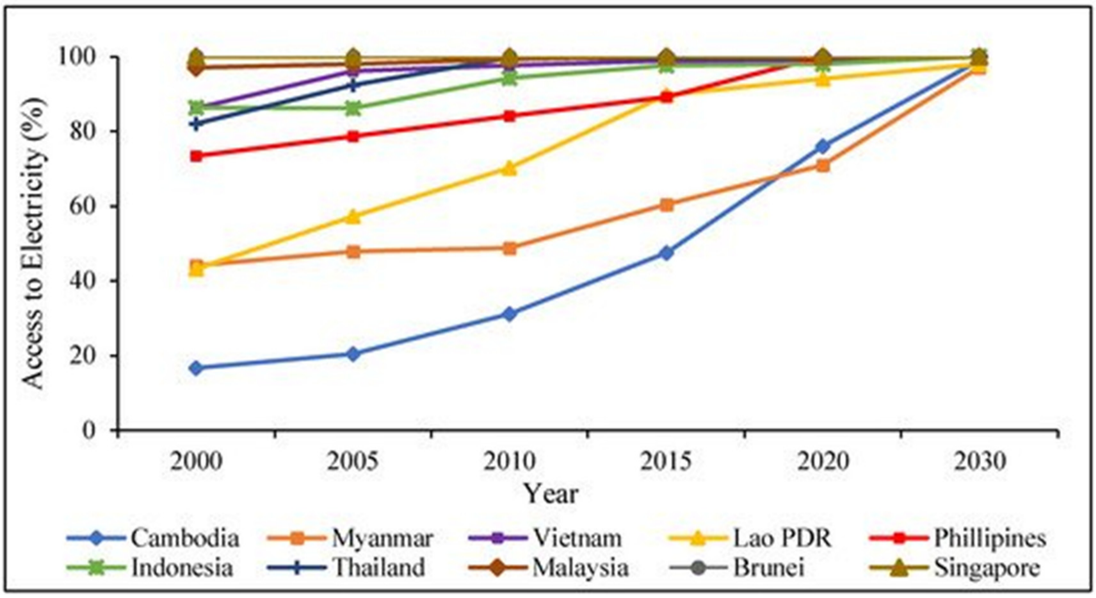

Figure 1. Electricity access in ASEAN countries [45].

Table 4. Summary of solar photovoltaic and renewable energy targets in ASEAN countries.

Country	Average Solar Insolation (kWh/m^2 Year) / Average Solar Insolation (kWh/m^2 Day)	Solar PV Installed Capacity by 2020 (MW)	Target Renewable Energy by Year (MW)	Target Solar PV by Year (MW)	Primary Renewable Energy	Ref.
Brunei	1982 / 5.43	298	10% by 2035	-		[45]
Cambodia	1825 / 5	208.5	10% by 2030	-	Hydropower and biomass	-
Indonesia	1752 / 4.8	171.8	23% by 2025	6.5 GW by 2025	Geothermal, hydro, biomass and solar	[17,45]
Laos	- / 3.6–5.5	21.63	30% by 2025	106 MW by 2025	Hydropower, biogas, solar	[48]
Malaysia	1643 / 4.5	1493	7000 MW by 2030	4200 MW by 2030	Solar biomass	[49]
Myanmar	1825 / 5	84.5	1.2% by 2030	2.3 GW by 2030 (Solar + Wind)	Hydro, biomass	[48]
Philippines	1862 / 4.5–5.5	1048	15,304 MW by 2030		Geothermal, hydro, wind	[19]
Singapore	1635 / 4.5	329.3	540 MW by 2030	2 GW by 2030	Solar, solid waste	[49]
Thailand	1875 / 5–5.3	2983	500 MW by 2037	15,574 MW by 2037	Hydropower, biomass, solar wind	[47]
Vietnam	1460 (Northern) 1825 (southern) / -	16,504	27 GW by 2030	12 GW by 2030	Hydro, biomass	[50]

Myanmar has significant renewable energy resources, particularly biomass and hydropower, in addition to the potential for wind, solar, and other renewable energy sources. Hydropower is the country's largest renewable energy resource, with a projected capacity of more than 1 GW. Hydropower generated 13,267 GWh of electricity in 2012 [58]. The remaining RE resources are still being researched and developed. While hydropower continues to account for the majority of RE sources in Myanmar, the country has entered into agreements with neighboring Asian countries such as Singapore, Thailand, Japan and China to boost its solar potential, particularly through the import of solar panels. Green Earth Power Co., Ltd., Bangkok, a Thai business, signed a memorandum of understanding (MoU) with the Myanmar Government's Ministry of Energy (MOE) in 2013 to build a 210 MW solar power plant in the Magway region for around £178 million; this solar power station is the world's third-largest station. The power station is built in three stages of 50 MW, 70 MW, and 90 MW, with 70% of the cost covered by debt and the remainder by equity [51,59].

Brunei and Mitsubishi Corporation (Japan) collaborated on a joint project dubbed the Large-Scale Photovoltaic Power Generation Demonstration Project Tenaga Suria Brunei in August 2008. (TSB Project) [60]. The power plant installed and evaluated six different types of advanced photovoltaic modules, including single-crystalline silicon, polycrystalline silicon, amorphous silicon, CIS (copper-indium-selenium), and two amorphous/microcrystalline silicon hybrid modules. The aim is to find the best solar technology and gather information for policy-making purposes, the project sought to determine the most appropriate and high-performance technology for the local weather circumstances. The solar power plant is projected to produce 1.344 MWh of electricity per year and will minimize the emission of 340,000 L of crude oil and 960 tons of carbon monoxide, the equivalent of 260 hectares of forest [28]. The solar power installation is connected to the Department of Electrical Services' (DES) power grid and serves electricity to approximately 200 households. The production capacity on a sunny day is around 5000–6000 kWh, however, it is limited to 3000–4000 kWh on a cloudy day [61].

Vietnam has lofty goals for the advancement of renewable energy. The 2011–2020 National Master Plan for Power Development was established with the goal of increasing the share of RE in total energy production in Vietnam. Although there has been a Feed-in-Tariff mechanism in place since 2011, it does not apply to solar projects. Solar energy's contribution to Vietnam's total RE energy system is still negligible. In terms of solar PV advancement, several ASEAN regions have executed FiTs, such as Indonesia, Malaysia and Thailand, supported by the investment of several investors and solar firms, who have taken part in large-scale solar projects. Whereas in Vietnam, because solar project investors are not subject to government FiT, they can benefit from power purchase agreements made with users of electricity, especially in places without access to the main grid, such as regions with power shortages [38,52].

Solar floating photovoltaic may be gaining popularity in Asian countries. Capacity is currently limited: by 2019, the two largest participants, Japan and China, have deployed 1.3 GW of floating photovoltaic (FPV) capacity combined; however, ASEAN countries, which had virtually no electricity prior to 2019, now have over 51 MW and are planning to add another 858 MW. IEEFA discussed FPV appears to be more cost-effective and efficient in balancing peaks and troughs than coal-fired power plants. Developing new transmission infrastructure is expensive. Land shortage is also a factor. FPVs, on the other hand, can be built on water (rivers, lakes, and reservoirs) adjacent to existing hydropower facilities, eliminating land use and piggybacking on existing transmission lines [62]. Vietnam has installed a capacity of 47 MW of FPV, and National Thermal Power Corporation (NTPC), India's largest power generation firm has started developing 200 MW of FPV over four locations, making it one of the world's leading developers [63].

In ASEAN countries the floating PV was installed less than 1 MW up to 2019. After 2019, six ASEAN (Vietnam, Malaysia, Indonesia, Philippines, Thailand and Singapore) countries planned to the install FPV. In Singapore Clean tech solar was announced and planned for completion of a 9.8 MW FPV by February 2019 and this mixed roof top solar PV and FPV (2.8 MW) on water reservoir power Cambodian cement factory. In July 2019, the Public Utilities Board (PUB), Singapore bought 50 MW FPV for Tengeh reservoir and it is expected to operate 2021. Additionally, PUB is constructing two 1.5 MW FPV systems on Seletar and Bedok reservoirs.

4. Current Progress and Energy Storage in ASEAN Countries

4.1. Progress in Energy Storage and Utilization Techniques for Brunei Darussalam

Brunei being the second smallest country among the ASEAN countries, they cover about 5766 square kilometers of area. Brunei Darussalam is an oil-rich country and completely depends on natural gas and petroleum fuels for power generation. The major Gross Domestic Product (GDP) of the country is due to export of oil products, and the economic activities are mainly operated using fuel-powered systems due to abundance available [64]; however, the Brunei government is working towards the vision of using renewable energy by 2025. New policies and regulations are framed to ensure use of renewable energy among the people by 10% around 2035 and also for renewable energy mix with the conventional fuel [65]. Many non-government organizations like Brunei Energy Association (BENA) and Energy Efficiency conservation committee are actively involved in carrying out numerous advanced types of research for energy storage and advanced application of renewable energies [66]. In regard to energy storage techniques in Brunei, the country needs to improve their renewable energy mix in a large quantum, as among ASEAN nations Brunei is the country that is least dependent on renewable energy sources. And the major constraint with erecting new solar PV farms is the availability of land.

The dense population of Brunei Darussalam makes it very competitive for installation of solar-based PV and thermal systems as the majority of the land is allocated for the livelihood of people. Government rules and regulations with enforced to install PV-based lighting system for unit with pave easy route for contributing towards SDG. Due to the above issues, the country is expected to install PV panels at remote or individual rooftop housing and connect the power with the grid. Electrical batteries can be used for electric power storage to use lighting in the absence of solar radiation. Meanwhile Pacudan [67] carried out a futuristic study by comparing the feed-in tariff and incentive subsidy for the installation of 10 kW PV panels for power generation in about 5000 houses of Brunei within a period of 5 years. The economic analysis shows that the proposed solar PV installation plans to generate lots of environmental and overall economic benefits with reduction in GHG emission. The target of generating 10% of electric power using renewable energy sources is possible only with proper incentives which would encourage the people to set up PV panel units on rooftop.

4.2. Progress in Energy Storage and Utilization Techniques for Cambodia

Rural population of Cambodia is about 85% and they have a high potential of renewable energy reserves, however the installed capacity of renewable energy sources is very less [32]. The government of Cambodia has developed a green growth energy plan by 2030 which was created in 2013 to provide electric supply to 70% of households through a proper grid [68,69]. Energy efficiencies and conservation policies in Cambodia have ended up with implementing certain projects for shifting towards renewable energy. The projects are

(a) Efficient lighting system for rural houses on decentralized basis: this is highly feasible with solar PV panels supported by energy storage batteries.
(b) Ways to improve energy efficiency in buildings: application of PCM into buildings reduces the energy consumption and makes the building more efficient in terms of energy.
(c) Improved energy efficiency techniques in collaboration with the ministry of energy and United Nation Industrial Development.

Since Cambodia has good petroleum and natural gas reserves, the country proposes a high renewable energy mix for future power supply, in which solar and wind energy sources are fastest growing with average annual growth of 18.7%. In regard to Cambodia, the country is enhancing their renewable energy mix, using solar and wind power. And in regard to wind power, the electricity generated is directly coupled to the grid and they are not in need of any energy storage system. On the contrary, in regard to solar power, the country is yet to make huge investment on PV farms with battery powered storage units, and solar thermal units with TES storage systems are yet to be explored for enhancing commercialization.

4.3. Progress in Energy Storage and Utilization Techniques for Indonesia

Indonesia is well endowed with natural resources like coal, oil and gas reserves; they hold a potential of about 39.9 billion tons of coal and exports coal globally, as well the oil and gas reserves are about 3.15 billion barrels and 2.7 trillion cubic meters respectively. The natural reserves however continue to deplete and the country explores its foot in renewable energy sources. Indonesia also holds 442 GW of renewable energy power plants among which only 9 GW of power is utilized due to the high production rate. Owing to the equatorial location of Indonesia, it possesses about 207.8 GW of power generation using solar power. Even then the contribution of solar power to the total energy supply of the country is only 3% [70]. National energy policy (KEN) of Indonesia targets to reduce consumption of oil by renewable energy mix, electric vehicles and by using efficient boilers in power plants. Among the renewable energy mix, contribution of solar PV is predominant, due to their electric power storage capacity using electric batteries. Power generation using PV panels are classified into two systems as On-Grid and Off-Grid. In an on-grid system the surplus power generated using a PV panel is directly supplied to the grid, whereas in an Off-Grid system the electric power generated is stored using an electric battery and consumed within the household appliances. To boost the usage of solar energy developments in household applications, the Indonesian government has introduced two policies namely (a) Net metering and (b) Net billing which aims to reduce GHG emission and contribute towards SDG [71]. The above policies are well adapted using solar PV panels, with electric battery backup systems, and also by supplying the excess to the grid. With the aim to increase the solar energy mix up to 23% with conventional energy by 2025, Rooftop PV solar systems (RPVSS) policy was introduced by the Indonesian government [72]. The policy ensured customers to generate electric power using solar PV panels and supply the surplus electric power generated to the grid. Figure 2A shows the on-grid based Solar PV system followed as per RPVSS and Figure 2B indicates the opinions of people for installing PV panels. Among the ASEAN countries Indonesia actively participates in achieving the SDG goals designed by the UN. The government provided enough subsidiaries and tariffs to the people to ensure installation of PV panels. And excess energy generated is stored in battery banks, though the people are in need of more training and knowledge to maintain the battery for a long number of cycles. Indonesia majorly adopts an off-grid based PV system to generate the power required in office and household needs. Off-grid systems are very advantageous in remote locations where the government finds it difficult to extend grid lines [73]. Contribution of electric power using solar power in Indonesia is projected to reach about 3.1 GW by 2030 depending on the renewable energy policy. Electric power storage using electric batteries also indents to optimize the power generation using generators. The major concerns regarding utilization of batteries are its cost, number of cycles and the disposal policies.

The ministry of energy and renewable resources in connection with the state electricity board offer tenders for establishing off-grid electricity in the eastern parts of Indonesia as the country lacks interconnectivity as per the geographical location [74]. Thus, major villages operate on solar-diesel hybrid power sources; meanwhile the usage of diesel mix can be eradicated with a well-established battery backup system. Study by Reyseliani and Purwanto [75] assesses the potential of Indonesia to function on 100% renewable energy by 2050. The analysis was carried out by comparing 3 energy storage techniques and 27 power plants. Results ensure that about 70% of the power requirement in 2050 can be fulfilled by solar PV systems and about 16% power requirement can be fulfilled by nuclear power. The total invested cost is calculated to be about 3 times higher compared to electric power generation by usual techniques; however the emission is expected to be lowered by one-sixth of present.

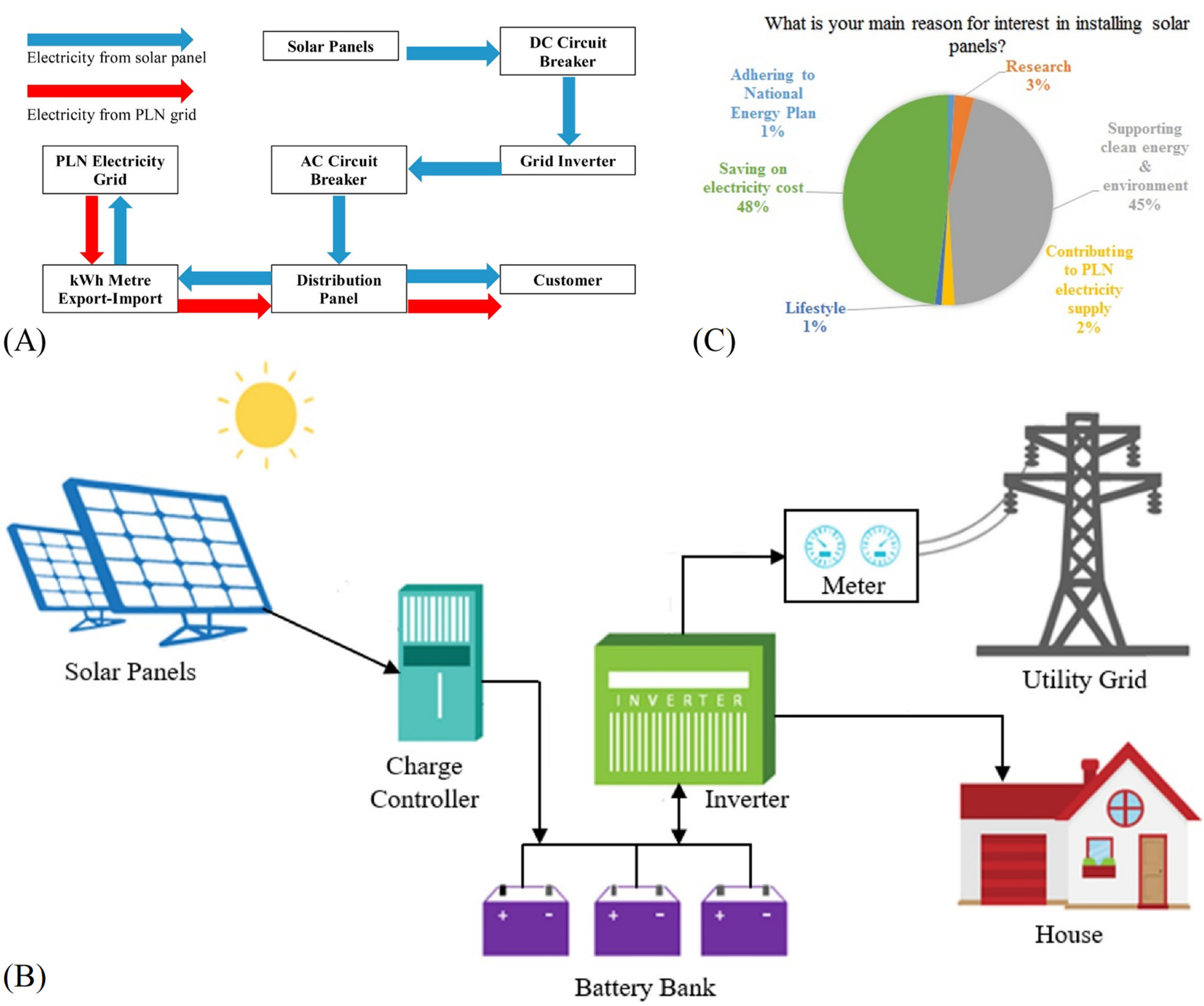

Figure 2. PV connected to Grid (**A**) Without Energy Storage system [72] (**C**) With Energy Storage system [73] (**B**) Peoples opinion on PV [72].

4.4. Progress in Energy Storage and Utilization Techniques for Lao PDR

The only landlocked country in the ASEAN group is the Lao People's Democratic Republic (Lao PDR). The country has an enriched potential of renewable energy, among which the predominant are hydropower and biomass. Lao PDR also exports energy generated from hydropower to the neighboring country after meeting the whole country's requirement, and generates currencies of money every year. Next to electric power, biomass is consumed in large scale by the residential peoples rather than industrial and commercial sectors; however, liquefied petroleum gas (LPG) has significantly replaced biomass in the rural areas. Meanwhile research work is focused on introducing solar cookers with energy storage facilities to replace LPG, in order to ensure complete usage of green energy. The government of Lao PDR also focuses on (a) improving the electricity distribution facility (b) promote renewable energy usage in transportation (c) developing energy conservation plans by 2030 (d) expand electric power to 98% of the rural areas. The Laotian government has introduced a village electrification project to extend electric power needs for isolated and remote parts of the country using solar PV [76]; however the generation of renewable energy using solar power is very minimal, as they have a rich source of other easily accessible renewable energy. Since the country is highly enriched with hydropower, their reliability over solar power is very minimal, and the country has just started to make some awareness and impacts among the peoples to use solar power, and at this early stage, their need over solar energy storage systems are not that needy.

4.5. Progress in Energy Storage and Utilization Techniques for Malaysia

Contribution from every individual nation is highly appreciable for achieving SDG. Sustainable development scenarios need to ensure access to electric power to all people by 2030, mitigate emission of air pollutants and to assure global climatic conditions. The entire above scenario is feasible with effective utilization and on dependency of RE like wind and solar power. Based on the number of research and review articles published every year after year, it is very clear that Malaysian University and Malaysian Research Institute highly focus on developing a high efficient renewable energy system and developing material that has the potential to store thermal energy effectively. As an economic relief benefit for the people, Malaysia has announced about US USD 2.9 billion for a new grid line, rooftop Solar PV panel, and LED street lights installation for low carbon emission; it is also noted that as per the report from IRENA, the HVAC system in Malaysia depends on conventional energy sources for about 90%. Numerous research with PCM based solar power energy storage systems for HVAC are studied on laboratory scale, as well thermal energy storage within buildings using nano-additive PCM are opted as a suitable solution to reduce power consumption for building heating and cooling [77].

In order to overcome the peak demand charge of electricity for the utilization of industries and customers, energy storage systems on a small scale have been introduced. Research analysis by Chua et al. [78] identified the economic benefits and cost of electricity generation for the users on adopting small scale energy storage systems. In the current work, four different batteries were evaluated for effective energy storage, among them lead acid batteries were determined to be cost effective with a payback period of 2.8 years. Results show that the electricity prices for devices with lead acid batteries are less than those of items without ES technology. Islam et al. [79] performed a techno economic analysis to determine suitable concentrating solar power (CSP) system for successful electric power generation. Analysis shows that parabolic trough collector (PTC) assured better efficiency on installation at the eastern part of Malaysia and contributed towards cost effective electricity generation. The PTC system was hybridized with wind and biomass technologies and were supported by financial government policies like subsidiary and laws to commercialize PTC. The Malaysian government also adopts the FiT scheme which was established in 2011 [80]. As per FiT scheme the government encourages use of renewable energy like solar power in homes as well they could sell the excess generated electric power to the grid; this contributed towards reduction of reliability on fossil fuel and a step towards alleviation of climate change. Real time case studies were conducted by Lim et al. [81] to provide sufficient reliable information on technical, financial and environmental benefits of integrating grid with energy storage system (ESS). Maximum demand of electric power is ASEAN countries is expected to be reduced by integrating the grid with ESS with the support of entrepreneurs by establishing power businesses. Analysis results also ensure annual saving of electricity bills and reduction in tons of CO_2 emission thereby providing opportunities for development of small and medium entrepreneurs in the field of energy. Major research centers and institutes of Malaysia highly focus on storing solar heat energy using PCM. Many new working models are established and are in the initial stage of active commercialization. Solar energy stored using PCM is used for building heating during winter season, solar thermal systems equipped with PCM are capable of operating during the off-sunshine hour, and improves the efficiency and reliability. Solar desalination units and coupled with PCM, which stores excess solar energy during daytime and supports freshwater generation during late hours; however, there are numerous research works being performed to improve the solar energy storage using PCM.

4.6. Progress in Energy Storage and Utilization Techniques for Myanmar

Energy saving can help alleviate energy shortages and environmental difficulties. Han and Cudjoe examined the factors that influence urban inhabitant's energy storage activities in Myanmar [82]. Multiple regression is used to observe this study empirically using survey data acquired from urban dwellers in Myanmar (n = 200). The findings indicate that energy-saving behaviors are favorably and significantly influenced by understanding of energy issues, apparent energy-saving control, and degree of concern and sense of responsibility. Among the four determinants, concern had the greatest effect on urban inhabitants' energy saving practices. As the first empirical study to examine the factors that influence urban residents' energy-saving habits in Myanmar, this study presents sound recommendations to Myanmar policymakers for developing and executing energy-saving and environmental protection laws. Vietnam has a plethora of sites suitable for pumped-hydro energy storage [83]. Additionally, batteries have grown in popularity as grid control tools. Vietnam also has a chance to attract additional investment in the battery production industry due to its huge reserves of bauxite and titanium and good production capabilities [84]. With increasing population rate, and electricity demand, the country is in extreme need to generate electric power on a large scale. Though the government erect any thermal power plants, their accessibility by the people would be very tedious as only 30% of the country has access to grid connection. In such a situation, electric power generation using PV panels is the most reliable technique, however, the people need to equip themselves with basic knowledge to access batteries for their long life. Similarly solar cookers and solar water heaters with PCM offering TES can reduce many people's problems, in terms of giving high benefits for preparing foods, even during off-sunshine hours. The photovoltaic system with thermal energy storage system for rural areas of Vietnam was analyzed by using HOMER software [85]. Sensitivity approach reveals that this will be reinforced further as energy consumption grows. With a twofold rise in power consumption, PV systems and ESS alone have the maximum capability, signifying economies of scale. As rural areas in developing countries expand economically and access to electrical appliances becomes more affordable, developing countries are urged to take substantial measures to deploy renewable energy and ESS technology. A 3DOM is a Japan based smart energy solution planned to increase/develop the solar rooftop energy system with battery energy storage system (BESS) in Myanmar. The MOU with Ayeyarwaddy Development Public Co. Ltd. (ADPCL) (Yangon, Myanmar) is a significant step forward in 3DOM's expansion in Southeast Asia, a region with a population of approximately 670 million people and where electricity demand is expected to nearly triple from 47 GW in 2020 to 130 GW in 2030, with a significant portion of that demand coming from renewable sources. The region's electricity demand has been among the highest in the globe, yet networks in many countries remain unreliable, creating an opportunity for 3DOM's safer, more dependable, and more sustainable BESS solutions [86].

4.7. Progress in Energy Storage and Utilization Techniques for Philippines

BESS is emerging as the strongest solution for increasing grid flexibility and dependability, with the global energy storage system market anticipated to reach USD 17.9 billion by 2021. Countries worldwide are gradually converting to BESS in order to increase grid dependability and promote the deployment of renewable energy sources, and high growth rates of 31.4% CAGR by 2027 have been forecast. Batteries are particularly well suited for regions afflicted by grid instability, like the Philippines. ABB was awarded the contract in 2019 to support two 20 MW plants and a 40 MW plant scheduled for commissioning in 2021. The remaining locations are scheduled to open in 2022 [87]. Policymakers and decision makers can contribute to SDG07 (Affordable and Clean Energy) by establishing certain incentives that may push the renewable energy share above 50%. To begin, 24 h supply should be prioritized because it has relatively lower overall costs and significantly improves the living standards of affected consumers. Second, 24 h supply is required for economically viable hybridization, as opposed to evening and night service hours.

Additionally, initial costs or weighted average capital cost (WACC) can be minimized through special loans or tax incentives, making long-term investments in solar photovoltaic and battery capacity more appealing; this increases the share of renewable energy in the economy, reduces fuel consumption and costs, and pushes the Philippines closer to achieve SDG07 [88]. According to the Energy department, 13 power projects in Luzon have received financing and are being backed by BESS, totaling 320 MW. According to the Institute for Energy Economics and Financial Analysis, coal's part in the power mix may be reduced to 16% from 41.50% currently, while solar and wind contribute to 42.80%, from 5.40% [63,87]. The Philippine leads among the ASEAN countries in terms of energy storage using batteries, they also work on the major issue of battery thermal management using PCM, as high heat is generated in batteries during the charging process; however the country needs to initiate a lot in terms of enhancing the thermal energy storage for off sunshine hours.

4.8. Progress in Energy Storage and Utilization Techniques for Singapore

Solar energy is the most viable and sustainable energy source for Singapore. With an energy storage system, the intermittency difficulties of solar energy owing to cloud cover and rain in our tropical region can be managed. Energy storage systems enable the storing of solar energy for subsequent use. The fast reaction feature of an energy storage system will also aid in maintain a stable source of power supply when solar systems are disrupted by weather changes. Sumba Island, Singapore has made great progress toward its objective of 100% RE over the last three years. With the assistance of external organizations like Asian Development Bank, new generation facilities have been constructed, including a 660 kW wind farm, multiple photovoltaic (PV), and several micro-hydro power plants (less than 50 kW). Studies of the island's renewable energy potential have shown huge resources, involving up to 150 MW of wind energy at three easily reachable locations. Additionally, 6.5 MW of solar photovoltaic energy and 800 kW of hydropower are being developed. The new generation of resources is clearly up to the task of meeting the rising demand for electricity on the island. Even if it's complicated because of the current state of the infrastructure, integrating and optimizing this new variable creation will be a challenge. The island had 400 kW flow BESS installed to help integrate new renewable energy sources and to stabilize and improve the grid's power quality. The battery was delivered by Chinese company Prudent Energy, and ABB provided power electronics, controls, and system integration services. The ESS's major function will be to improve power quality and stability by providing frequency regulation and voltage support, which is critical when incorporating a significant proportion of variable generation. Additionally, this system can supply additional generation capacity when renewable energy sources are unavailable. Government support was critical to the project's finance and progress. The flow battery system was principally funded by the Indonesian Agency for Technology Assessment and Application (BPPT); this agency is a non-ministerial government entity that reports to the Ministry of Research and Technology of the Republic of Indonesia and is charged with carrying out government functions related to technology appraisal and application. BPPT developed this ESS in collaboration with Indonesia's state utility and Sumba's local electrical cooperative [89]. Wartsila has completed the first utility-scale battery storage project in Singapore and has secured an order for an additional 90 MWh of battery storage from a customer in ASEAN country. In addition to or in conjunction with that solar PV target, Singapore aims to deploy 200 MW of ES beyond 2025 with the announcement of lithium ion battery project in 2017, EMA said it would try other technologies, including flow batteries [90].

4.9. Progress in Energy Storage and Utilization Techniques for Thailand

The energy storage techniques of office buildings in Thailand is examined [91] with a focus on (a) rooftop PV system, (b) PV system with lithium ion battery storage system (c) PV with an ice storage system. The life cycle assessment of the above systems were compared to that of conventional grid-dependent building. PV systems with Li-ion-battery and PV with storage systems gave 16% of the electricity generated by the photovoltaic system as surplus over weekends when the building was empty. The outcomes indicate that while scenarios PV installed in rooftop, PV system with Li-ion-battery and PV with storage system reduced operational grid usage by 33%, 37.8%, and 37.9%, respectively, they raised the potential for metal depletion by 23.9%, 34.4%, and 29.0%. Ice storage resulted in the largest reduction of environmental impacts over time. Efficient production and use of renewable energy in buildings is critical for reducing reliance on nonrenewable fuels; nevertheless, metal depletion must be minimized during the adoption of such technologies. The economic and energy saving depends on net present values (NPV), battery cost and size and levelized costs of electricity (LCOE) and retail rate design has a substantial effect on returns, whereas buyback incentives for excess power have a negligible effect. Peerapong and Limmeechokchai conducted a comparative analysis of PV systems with lead acid battery and diesel based hybrid systems to determine the influence on electricity generation costs and harmful emission from fossil fuels in Thailand; this research evaluated the optimal hybrid system using the net present cost (NPC) estimate approach. The findings indicate that the hybrid system equipped with a lead-acid battery significantly reduces NPC and cost of electricity (COE). Additionally, the hybrid system can help rural islands achieve sustainable energy by reducing all air pollutants. COE reduces from 0.36 €/kWh to 0.32 €/kWh as compared to the present diesel-powered system, resulting in a reduction of 796.61 tons of CO_2 and 21.47 tons of other gasses per year. Additionally, the hybrid PV/battery/diesel system saves diesel fuel usage by 302,510 L per year as a result of the system's optimal PV resource share of 41% [13].

Thailand has abundant solar resources; PV farms with a combined capacity of 989.7 MW have already been erected (in 2015). Thailand authorities have pushed small-scale solar photovoltaic (PV) systems, such as solar rooftops on residential and commercial structures. In terms of hybrid photovoltaic/diesel systems, or photovoltaic/wind/diesel systems, Thailand has previously had success installing hybrid systems on several islands. The hybrid photovoltaic/diesel system on Thailand's Koh-jig island was researched and the system was built on the island; this island is located in the province of Chantaburi on Thailand's eastern coast; this hybrid photovoltaic/diesel system has 7.5 kW photovoltaic arrays, a 60 kW diesel generator, and 60 units of 2100 Ah battery storage; this storage system is lower cost than a standalone diesel generator (costs vary with a cost of USD 0.315–USD 0.526 per kWh), and significantly lower emissions and noise issues associated with diesel generators [92]. From the above case studies it is quite evident that for any developing country, at the initial stage, hybrid energy systems coupling conventional and unconventional energy sources are more economical and attractive.

4.10. Progress in Energy Storage and Utilization Techniques for Vietnam

The South East Asia Clean Energy Facility (SEACEF), a collaboration of worldwide foundations dedicated to accelerating Southeast Asia's low-carbon transition, has invested in the development phase of a floating solar and storage project in Vietnam. Blue leaf Energy is developing the project, which will include a floating solar and storage with a projected capacity of 500 MW and a BESS with a capacity of up to 200 MWh [93]. A BESS in a photovoltaic system in Vietnam was analyzed by simulation study [94]. The goal of this simulation is by utilizing BESS to store curtailed energy, solar PV projects can sell the stored (but curtailed) energy via time shifting, benefiting the grid and perhaps improving the project's economics. From the simulation results reported that in Ninh Thuan a Binh Thuan places BESS are utilized to avoid system congestion rather than to reduce the output of photovoltaic (PV) plants. Excess solar energy is used to charge the BESS rather than being curtailed. To preserve the BESS's life, the state of charge (SOC) is set to between 20% and 80%; it is expected that the stored energy in BESS is discharged during the times when BESS is not charged. Vietnam's Power Development Plan for 2021 to 2030 may include significant thermal power capacity to solve an imminent power deficit as economic expansion drives electrical demand; it was believed that sophisticated technologies such as solar and storage peaking plants can aid in the cost-effective and sustainable resolution of Vietnam's power shortfall challenges [95].

5. Environmental Impacts of Adopting Energy Storage Techniques

Research analysis by Hak et al. proposes five important strategies for improving the climatic condition by reducing emission of carbon dioxide [96]. The strategies proposed are (a) Green energy usage, (b) Investment in Green Technologies, (c) Green buildings, (d) Establishing Green Transport system and (e) Low carbon infrastructures. Green energy uses solar power and lays a foundation for a greener environment, as they are renewable, non-polluting, abundant and free of cost. Any investment made in green technologies in terms of new solar thermal systems, or commercializing products attract a huge market from the government and world organization, as the major concern is on preventing earth from pollution. Another interesting technique is the construction of green buildings, which are designed in a way to produce power using greener sources within the building, without any support from the grid; these kinds of buildings are supported with subsidies and tariffs from the government. Keen focus is made on the design of the building, in a way that the building is completely equipped with solar light energy instead of electric lamps, and the flow of air is considered in a way to provide natural ventilation. The major polluting resource after buildings is the transportation sector, and thus comes the innovation of the green transport system, operating on batteries, the batteries are charged using electric power generated from solar energy and are of greater impact. Numerous automotive industries and research teams are working on to improving the effective charging of batteries without any accident. Meanwhile, with international support Cambodia proposes a GHG mitigation technique by adopting a solar energy-based system with the aim to reduce about 3100 gigagrams of CO_2 by 2030. CO_2 emission can be reduced drastically by replacement of coal with renewable energy compared to replacement of oil and gas. In the majority of ASEAN countries coal is used in power plants for energy generation, which can be significantly replaced with established solar power plants with energy storage facilities; it has been noted that low emission pathways adopted by the ASEAN countries contribute wisely towards limiting the global temperature rise. Depending on the country's resources and policies, mitigation techniques depend on solar power, carbon capture and carbon storage and use of advanced biofuel in industries. National policy improves the reliability of countries' pathway towards global temperature reduction goal [97]. In a research analysis, Indonesia is projected to utilize 100% renewable energy for the operation which accounts for a drop in CO_2 emission by about 215 million tons; this shows that on achieving the target of 100% renewable energy the country would ambitiously contribute towards the Paris Agreement target to reduce global temperature. Lao PDR also focuses on energy efficiency and renewable energy generation until 2050 to reduce the consumption of conventional energy sources and to reduce CO_2 emissions.

6. Challenges in Incorporating Energy Storage

In spite of the availability and potential of renewable energy resources in ASEAN countries, there are certain challenges and problems associated with incorporating RE systems powered with energy storage technologies. Here the authors have consolidated major tasks and up hills to overcome.

- Due to the advanced-developed of PV panels in terms of commercialization and ease of energy generation with semi-skilled laborers, the government highly focuses on energy generation using PV systems; however storage of electric power depends on the number of PV panels erected, whereas for countries like Singapore, Brunei, Philippines and Vietnam are the smallest country among Asia as well as among ASEAN countries, the available land is significantly used for the livelihood of people and are in need of rooftops, water areas with floating PV technology. Though enough potential of electric energy is generated, storage of electric power within batteries requires huge investment as well area.

- Another attractive research hotspot is the storage of heat energy from solar power as thermal energy using PCM; these technologies are not well matured and developed among the ASEAN countries, and the major research works on the specific area is and carried out by Malaysia. On the contrary, energy stored within PCM is low-grade energy and energy stored with batteries is high grade energy.
- The major risk factors and challenges faced by the Malaysian government for the installation of Renewable Energy based power units includes (a) Lack of financial security for Project Funding (b) Environmental taxes (c) Market Failure and (d) Risk towards Green Investment.
- Additionally incorporating any new technologies among the people by overcoming their mental barricades are a major challenge for any country. The technologies must be convincing and easily executable by the government, political leaders, investors, industrialists and the people who are at the receiving end.
- Energy storage either using electrical batteries or using thermal batteries (PCM) requires semi-skilled labor. For example, people fail to follow the acid levels in the case of lead acid batteries, which would degrade its performance and reduce the number of operating cycles. Similarly for PCM, the operating temperature range must be monitored for performance and thermal stability.
- In spite of enormous solar energy potential, in Indonesia to their equatorial location, large scale grid-connected solar PV power plants require huge investment which is difficult for a developing nation. Thus distributed solar PV systems in every household with a net-metering system and net billing can be adopted with continuous assessment systems.

7. Recommendation and Further Scope

As all ASEAN countries are located under the same geographical area having similar tropical hot and humid climatic conditions. Though most of nations are under the developing process in terms of economy and technology, they highly depend on energy for themselves to attain the status of a developed nation. The potential of these countries in terms of solar energy are similar to each other and are considered to improve their energy mix with solar power. In this regard the ASEAN nations are highly recommended to develop energy policies that are predictable and reliable in the context of the country's overall energy strategy. There should be a clear goal and roadmap for the long-term energy mix, including a renewable energy goal or strategy, or simply the use of renewable energy. Reduce non-economic constraints, such as regulatory impediments, grid access issues, ability, and lack of awareness. Other than economic grants and renewable energy subsidies, continued expansion of the ASEAN Power Grid will contribute significantly to ASEAN unity. Policymakers must also examine electricity's non-consumptive applications (such as home lighting and cooking) as well as its productive ones. Regulative units provide incentives for renewable energy capital investment through the application of energy regulations, which may include feed-in costs, feed-in charges, internet metering, auctions, and quotas; furthermore, exempting the income, import and native tax, export obligations, accelerated depreciation, and VAT will lower the initial financial outlay. Renewable energy subsidies and FiTs are emphasized in order to increase the share of renewable energy in the energy generation mix. Government support for renewable energy projects, particularly for solar PV is encouraged, but policies should be clear; it is expected that project developers will feel more comfortable when they know that their investment will go through grid access priority and a transmission discount policy if electricity is generated from renewable energy. Finance uses currency hedging, a specific budget, qualified finance, and assurances to minimize the risk to investors. Additional investigation should be undertaken on the challenges and loopholes encountered during the implementation of renewable energy policies, as well as the country having specific policies beyond 2030 for each country.

Currently, the role of technologies allows the selection of environmental implications. In the future, technology must be enabled for better performance to have sustainable resource use. Reducing consumption is the only choice left to conserve resources. The results presented here indicate that a lifecycle perspective is needed for renewable energy systems sustainability, not just considering an energy source and generation strategy. In addition, along with the latest technologies, innovation in research and development, technology transfer from developed countries and expanding energy markets around the world. As a result, renewable energy will be a key component in offering economic and environmental benefits to the energy sector in the future. Highly stable generation of solar energy is considered to drastically reduce the daytime consumption of fossil energy sources. A substantial focus on the grid management of RE is expected to initiate in the ASEAN countries. Renovation of the modern grid system, consideration of solar energy integration techniques will be more essential and beneficial for the countries with lower economy cost rather than completely focusing on pure solar energy-based urban areas.

8. Conclusions

The continuing growth of ASEAN's economy and social stability is resulting in increased energy demand. As a result, there is a gap between the supply of energy and demand. Most of the ASEAN countries depend on fossil fuels, other than Singapore and Lao PDR, and the regions contribute to climate change and environmental pollution. Although the other renewable energy sources in ASEAN countries include wind, solar, hydropower, geothermal, biomass, and other sources, hydropower is the primary source of renewable energy. Few insightful conclusions and outcomes of the current review are consolidated below

- In ASEAN countries, the ratio of renewable energy installations covers around 10%. The total installed capacity of ASEAN countries is 22,845 MW in the year 2020; furthermore, it was noted that the maximum installed capacity PV module is in Vietnam, around 16,504 MW, and the lowest installed PV capacity country was Brunei Dar, around 1.4 MW in 2020.
- Furthermore, ASEAN country government has set a target for the percentage/portion for the renewable energy mix such as Vietnam 27 GW by 2030, Malaysia 7000 MW by 2030, Indonesia 23% by 2025, Thailand 30% by 2036, Philippines 15 GW by 2030, Brunei 10% by 2035 and Laos 30% 2025; moreover, the planned capacity of floating PV modules of Vietnam, Malaysia, Indonesia, Philippines, Thailand, and Singapore are 330, 150, 145, 100, 80, and 54 MW. Currently, the installed floating PV capacity of Vietnam and Cambodia is 45 MW and 5 MW, respectively.
- In terms of energy storage, due to the well-developed technology and commercialized products, PV panel are very common globally, which stores solar energy in the form of electric power using batteries and supplies as per the demand; however, the major concern is the huge investment cost of batteries and the PV system.
- On the contrary is the storage of heat energy obtained from solar power. Numerous research investigations are being carried out in Malaysia, in regard to thermal energy storage using PCM. Though TES using PCM has been being under research for over two decades, the percentage of commercialization is comparatively lower to that of PV panels. TES storage using PCM is expected to sustainably reduce the consumption of fossil fuel for cooking, and to contribute towards low cost energy storage units.
- To assist the development of renewable energy in ASEAN countries, the government has to set a target to raise the percentage of renewable energy by 2025. To support renewable energy development, many regulations, policies, laws, and frameworks are implemented inside the country. By effectively using renewable energy, ASEAN countries can strengthen their economics and increase CO_2 mitigation and industrial and commercial growth.

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Abbreviations

APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of Southeast Asian Nations
ADPCL	Ayeyarwaddy Development Public Co. Ltd.
BESS	Battery Energy Storage System
BENA	Brunei Energy Association
BEEP	Building Energy Efficiency Programme
COE	Cost of Electricity
DES	Department of Electrical Services'
DEDE	Department of Alternative Energy Development and Efficiency
DC	Direct Current
EMA	Energy Market Authority
ERC	Energy Regulatory Commission
ESS	Energy Storage System
FIT	Feed in Tariff
FPV	Floating Photovoltaic
GHG	Green House Gas
GDP	Gross Domestic Product
HDB	Housing Development Board
IDR	Indonesian Rupiah
Lao PDR	Lao People's Democratic Republic
LCOE	Levelized Costs of Electricity
LPG	Liquefied Petroleum Gas
KEN	National Energy Policy
MEMR	Minister of Energy and Mineral Resources
MBIPV	Malaysia Building Integrated Photovoltaic
MIEEIP	Malaysia Industrial Energy Efficiency Improvement Project
NEPC	National Energy Policy Commission
NPC	Net Present Cost
NTPC	National Thermal Power Corporation
NPV	Net Present Values
PCM	Phase Change Material
PV	Photovoltaic
RPS	Renewable Energy Portfolio Standard
RPVSS	Rooftop PV Solar Systems
RES	Rural Electrification Strategy
SREPP	Small Renewable Energy Power Programme
SDG	Sustainable Development Goal
SGD	Singapore Dollars

SCBP	Solar Capability Building Programme
SEACEF	South East Asia Clean Energy Facility
WACC	Weighted Average Capital Cost
ES	Energy storage
RE	Renewable energy

References

1. Masson-Delmotte, V.; Zhai, P.; Pörtner, H.; Roberts, D.; Skea, J.; Shukla, P.; Pirani, A.; Moufouma-Okia, W.; Péan, C.; Pidcock, R. IPCC, 2018: Summary for Policymakers. In *Global Warming of 1.5 C*; An IPCC Special Report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global; World Meteorological Organization: Geneva, Switzerland, 2018.
2. Poumanyvong, P.; Kaneko, S.; Dhakal, S. Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries. *Energy Policy* **2012**, *46*, 268–277. [CrossRef]
3. Karekezi, S.; McDade, S.; Boardman, B.; Kimani, J. Energy, poverty, and development. In *Global Energy Assessment—Toward a Sustainable Future*; Johansson, T.B., Nakicenovic, N., Patwardhan, A., Gomez-Echeverri, L., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA; International Institute for Applied Systems Analysis: Laxenburg, Austria, 2012; pp. 151–190.
4. Barbier, E.B.; Burgess, J.C. Sustainable development goal indicators: Analyzing trade-offs and complementarities. *World Dev.* **2019**, *122*, 295–305. [CrossRef]
5. Hayes, M.; Parker, V. *New Drivers of the Renewable Energy Transition*; KPMG Renew. Point View; KPMG: Amstelveen, The Netherlands, 2018.
6. Malahayati, M. Achieving renewable energies utilization target in South-East Asia: Progress, challenges, and recommendations. *Electr. J.* **2020**, *33*, 106736. [CrossRef]
7. Zamora, C.G. *Asean Plan of Action for Energy Cooperation (APAEC) 2016–2025*; ASEAN Centre for Energy: Jakarta, Indonesia, 2015; pp. 1–51.
8. Wu, X.; Li, C.; Shao, L.; Meng, J.; Zhang, L.; Chen, G. Is solar power renewable and carbon-neutral: Evidence from a pilot solar tower plant in China under a systems view. *Renew. Sustain. Energy Rev.* **2021**, *138*, 110655. [CrossRef]
9. Siraganyan, K.; Mauree, D.; Perera, A.; Scartezzini, J.-L. Evaluating the need for energy storage to enhance autonomy of neighborhoods. *Energy Procedia* **2017**, *122*, 253–258. [CrossRef]
10. Kalidasan, B.; Pandey, A.; Shahabuddin, S.; Samykano, M.; Thirugnanasambandam, M.; Saidur, R. Phase change materials integrated solar thermal energy systems: Global trends and current practices in experimental approaches. *J. Energy Storage* **2020**, *27*, 101118.
11. Laldjebaev, M.; Isaev, R.; Saukhimov, A. Renewable energy in Central Asia: An overview of potentials, deployment, outlook, and barriers. *Energy Rep.* **2021**, *7*, 3125–3136. [CrossRef]
12. Curren, E.; Kuwahara, V.S.; Yoshida, T.; Leong, S.C.Y. Marine microplastics in the ASEAN region: A review of the current state of knowledge. *Environ. Pollut.* **2021**, *288*, 117776. [CrossRef]
13. Peerapong, P.; Limmeechokchai, B. Optimal electricity development by increasing solar resources in diesel-based micro grid of island society in Thailand. *Energy Rep.* **2017**, *3*, 1–13. [CrossRef]
14. Ahmed, T.; Mekhilef, S.; Shah, R.; Mithulananthan, N.; Seyedmahmoudian, M.; Horan, B. ASEAN power grid: A secure transmission infrastructure for clean and sustainable energy for South-East Asia. *Renew. Sustain. Energy Rev.* **2017**, *67*, 1420–1435. [CrossRef]
15. Shadman, F.; Sadeghipour, S.; Moghavvemi, M.; Saidur, R. Drought and energy security in key ASEAN countries. *Renew. Sustain. Energy Rev.* **2016**, *53*, 50–58. [CrossRef]
16. Shi, X. The future of ASEAN energy mix: A SWOT analysis. *Renew. Sustain. Energy Rev.* **2016**, *53*, 672–680. [CrossRef]
17. Ismail, A.M.; Ramirez-Iniguez, R.; Asif, M.; Munir, A.B.; Muhammad-Sukki, F. Progress of solar photovoltaic in ASEAN countries: A review. *Renew. Sustain. Energy Rev.* **2015**, *48*, 399–412. [CrossRef]
18. Mofijur, M.; Masjuki, H.H.; Kalam, M.; Rahman, S.A.; Mahmudul, H. Energy scenario and biofuel policies and targets in ASEAN countries. *Renew. Sustain. Energy Rev.* **2015**, *46*, 51–61. [CrossRef]
19. Erdiwansyah, M.; Mamat, R.; Zaki, M.; Sani, M.; Hamdani, M.; Sudhakar, K.; Alias, J.; Mat, N.; Sidik, N. An Overview Of Renewable Energy In Southeast Asia: Current Status And Future Target. *Int. J. Sci. Technol. Res.* **2020**, *9*, 294–309.
20. Zhou, W.; Lou, C.; Li, Z.; Lu, L.; Yang, H. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. *Appl. Energy* **2010**, *87*, 380–389.
21. Fraune, C.; Knodt, M. Sustainable energy transformations in an age of populism, post-truth politics, and local resistance. *Energy Res. Soc. Sci.* **2018**, *43*, 1–7. [CrossRef]
22. Hafez, A.; Soliman, A.; El-Metwally, K.; Ismail, I. Tilt and azimuth angles in solar energy applications—A review. *Renew. Sustain. Energy Rev.* **2017**, *77*, 147–168.
23. Mukherjee, I.; Sovacool, B.K. Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand. *Renew. Sustain. Energy Rev.* **2014**, *37*, 1–12. [CrossRef]
24. Panteli, C.; Kylili, A.; Stasiuliene, L.; Seduikyte, L.; Fokaides, P.A. A framework for building overhang design using Building Information Modeling and Life Cycle Assessment. *J. Build. Eng.* **2018**, *20*, 248–255. [CrossRef]

25. Shukla, A.K.; Sudhakar, K.; Baredar, P.; Mamat, R. BIPV based sustainable building in South Asian countries. *Sol. Energy* **2018**, *170*, 1162–1170. [CrossRef]
26. Veng, V.; Suryadi, B.; Pranadi, A.D.; Shani, N. A review of renewable energy development and its policy under nationally determined contributions in ASEAN. *Int. J. Smart Grid Clean Energy* **2020**, *9*, 149–161. [CrossRef]
27. Banos, R.; Manzano-Agugliaro, F.; Montoya, F.; Gil, C.; Alcayde, A.; Gómez, J. Optimization methods applied to renewable and sustainable energy: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1753–1766. [CrossRef]
28. Malik, A. Assessment of the potential of renewables for Brunei Darussalam. *Renew. Sustain. Energy Rev.* **2011**, *15*, 427–437. [CrossRef]
29. Ali, A.S.H.M. Brunei Darussalam country report. In *Analysis on Energy Saving Potential in Eastasia*; Economic Research Institute for ASEAN and East Asia: Jakarta, Indonesia, 2013; p. 83.
30. Mathew, S.; Ming, L.; Patrick, L. Sustainable electricity model for brunei darussalam. In Proceedings of the the 47th ANZSES Annual Conference, Townsville, Australia, 29 September–2 October 2009; pp. 1–9.
31. ADB. *Renewable Energy Developments and Potential in the Greater Mekong Subregion*; Asian Development Bank: Mandaluyong, Philippines, 2015; pp. 12–27.
32. Sarraf, M.; Rismanchi, B.; Saidur, R.; Ping, H.; Rahim, N. Renewable energy policies for sustainable development in Cambodia. *Renew. Sustain. Energy Rev.* **2013**, *22*, 223–229. [CrossRef]
33. Kannan, R.; Leong, K.; Osman, R.; Ho, H. Life cycle energy, emissions and cost inventory of power generation technologies in Singapore. *Renew. Sustain. Energy Rev.* **2007**, *11*, 702–715. [CrossRef]
34. IEA. *Southeast Asia Energy Outlook 2019*; IEA: Paris, France, 2019.
35. Wong, J.L.; Teh, P.; Wang, V.X.; Chia, L.M. Solar capability building programme for public housing. *Energy Procedia* **2013**, *33*, 288–301. [CrossRef]
36. Doshi, T.K.; Loi, A. Singapore Country Report. In *Analysis on Energy Saving Potential in East Asia*; ERIA Research Project Report; ERIA: Jakarta, Indonesia, 2012; Volume 19, pp. 277–296.
37. IRENA. *Malaysia Energy Profile*; IRENA: Abu Dhabi, United Arab Emirates, 2019.
38. Dung, T.Q. Photovoltaic technology and solar energy development in Viet Nam. *Renew. Energy Technol.* **2009**, 29–36. Available online: https://kipdf.com/photovoltaic-technology-and-solar-energy-development-in-viet-nam_5ab1ae541723dd349c80fcd5.html (accessed on 5 January 2022).
39. Balangue-Tarriela, M.; Mendoza, J.P. Updates on the geothermal energy development in the Philippines. In Proceedings of the World Geothermal Congress 2015, Melbourne, Australia, 19–24 April 2015.
40. Vivar, D.V. Philippines Country Report. In *Energy Outlook and Energy Saving Potential in East Asia 2019*; ERIA: Jakarta, Indonesia, 2019; p. 255.
41. Phdungsilp, A.; Wuttipornpun, T. Analyses of the decarbonizing Thailand's energy system toward low-carbon futures. *Renew. Sustain. Energy Rev.* **2013**, *24*, 187–197. [CrossRef]
42. Liu, Y.; Noor, R. *Energy Efficiency in ASEAN: Trends and Financing Schemes*; Asian Development Bank: Mandaluyong, Philippines, 2020.
43. Bakhtyar, B.; Sopian, K.; Sulaiman, M.; Ahmad, S.A. Renewable energy in five South East Asian countries: Review on electricity consumption and economic growth. *Renew. Sustain. Energy Rev.* **2013**, *26*, 506–514. [CrossRef]
44. Purwanto, A.J. *Energy Outlook and Energy Saving Potential in East Asia 2020*; ERIA: Jakarta, Indonesia, 2021; pp. 313–327.
45. Liu, H. *Regional Energy Trends Report 2020 Tracking SDG 7 in the ASEAN Region*; United Nation ESCAP: Bangkok, Thailand, 2020.
46. Phoumin, H.; Kimura, F.; Arima, J. Potential renewable hydrogen from curtailed electricity to decarbonize ASEAN's emissions: Policy implications. *Sustainability* **2020**, *12*, 10560. [CrossRef]
47. Sticher, M. Solar Power in ASEAN: A Snapshot and Outlook of the Solar Power Markets and Growing M&A Scene. Available online: https://apricum-group.com/solar-power-in-asean-a-snapshot-and-outlook-of-the-solar-power-markets-and-growing-ma-scene/?cn-reloaded=1 (accessed on 17 July 2022).
48. Heling, M. Solar policy, programs, and progress in Southeast Asia: Current status and future outlook. *Power Util.* **2018**. Available online: https://asian-power.com/power-utility/commentary/solar-policy-programs-and-progress-in-southeast-asia-current-status-and-fut (accessed on 17 July 2022).
49. Benoit, M.Z.A.N. Asia's renewable energy future. *Energy News*, 28 June 2021. Available online: https://www.openaccessgovernment.org/asias-renewable-energy-future/114063/(accessed on 5 January 2022).
50. IRENA. *Renewable Capacity Statistics 2020*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
51. Pocci, M. *Feed-In Tariff Handbook for Asian Renewable Energy Systems*; Winston & Strawn: Hong Kong, China, 2014.
52. Junlakarn, S.; Kittner, N.; Tongsopit, S.; Saelim, S. A cross-country comparison of compensation mechanisms for distributed photovoltaics in the Philippines, Thailand, and Vietnam. *Renew. Sustain. Energy Rev.* **2021**, *145*, 110820. [CrossRef]
53. Tongsopit, S.; Greacen, C. An assessment of Thailand's feed-in tariff program. *Renew. Energy* **2013**, *60*, 439–445. [CrossRef]
54. Malik, C.L. Indonesia Country Report. In *Energy Outlook and Energy Saving Potential in East Asia 2019*; ERIA: Jakarta, Indonesia, 2019; p. 128.
55. Haris, A. *Introduction and The Malaysian Feed-in Tariff Scenario (Presentation Material) Malakoff Community Partnerships*; Energy Expert Series; The Malakoff Community Partnerships: Kuala Lumpur, Malaysia, 2010.
56. Department, S.R. Solar Energy Capacity in Asia from 2010 to 2019. Available online: https://www.statista.com/statistics/873124/solar-energy-capacity-asia/ (accessed on 17 July 2022).

57. Quek, A.; Ee, A.; Ng, A.; Wah, T.Y. Challenges in Environmental Sustainability of renewable energy options in Singapore. *Energy Policy* **2018**, *122*, 388–394. [CrossRef]
58. Chadha, M. Off-Grid Solar Power Projects for Myanmar. Available online: https://cleantechnica.com/2013/01/13/off-grid-solar-power-projects-for-myanmar/ (accessed on 17 July 2022).
59. Hyun, S.; Taghizadeh-Hesary, F.; Shim, H.S. Modeling solar energy system demand using household-level data in Myanmar. *Econ. Anal. Policy* **2021**, *69*, 629–639. [CrossRef]
60. IRENA. *Renewable Capacity Statistics 2018*; International Renewable Energy Agency (IRENA): Abu Dhabi, United Arab Emirates, 2018.
61. Cheong, C. Bruneians receiving power from the sun. *The Brunei Times*, 13 September 2010.
62. Solomin, E.; Sirotkin, E.; Cuce, E.; Selvanathan, S.P.; Kumarasamy, S. Hybrid floating solar plant designs: A review. *Energies* **2021**, *14*, 2751. [CrossRef]
63. Adhiguna, E.H.A.P. IEEFA: Indonesia's State-Owned Utility PLN's 2060 Net Zero Ambition Not without Flaws and Gaps. 2021. Available online: https://ieefa.org/articles/ieefa-indonesias-state-owned-utility-plns-2060-net-zero-ambition-not-without-flaws-and (accessed on 17 July 2022). (In Bahasa).
64. Kimura, S.; Pacudan, R.; Phoumin, H. *Development of the Eco Town Model in the ASEAN Region through Adoption of Energy-Efficient Building Technologies, Sustainable Transport, and Smart Grids*; Economic Research Institute for ASEAN and East Asia: Jakarta, Indonesia, 2017.
65. Vidinopoulos, A.; Whale, J.; Hutfilter, U.F. Assessing the technical potential of ASEAN countries to achieve 100% renewable energy supply. *Sustain. Energy Technol. Assess.* **2020**, *42*, 100878. [CrossRef]
66. Mamat, R.; Sani, M.; Sudhakar, K. Renewable energy in Southeast Asia: Policies and recommendations. *Sci. Total Environ.* **2019**, *670*, 1095–1102.
67. Pacudan, R. Feed-in tariff vs incentivized self-consumption: Options for residential solar PV policy in Brunei Darussalam. *Renew. Energy* **2018**, *122*, 362–374. [CrossRef]
68. Mahapatra, M.; Upadhyaya, S.; Aviso, S.; Babu, A.; Hutchings, G.; Parida, S. Selection of vaccine strains for serotype O foot-and-mouth disease viruses (2007–2012) circulating in Southeast Asia, East Asia and Far East. *Vaccine* **2017**, *35*, 7147–7153. [CrossRef] [PubMed]
69. Matsuda, K. Comparative study of energy saving potential for heavy chemical complex by area-wide approach. *Energy* **2016**, *116*, 1397–1402. [CrossRef]
70. Hidayatno, A.; Setiawan, A.D.; Supartha, I.M.W.; Moeis, A.O.; Rahman, I.; Widiono, E. Investigating policies on improving household rooftop photovoltaics adoption in Indonesia. *Renew. Energy* **2020**, *156*, 731–742. [CrossRef]
71. Kurniawan, R.; Sugiawan, Y.; Managi, S. Cleaner energy conversion and household emission decomposition analysis in Indonesia. *J. Clean. Prod.* **2018**, *201*, 334–342. [CrossRef]
72. Setyawati, D. Analysis of perceptions towards the rooftop photovoltaic solar system policy in Indonesia. *Energy Policy* **2020**, *144*, 111569. [CrossRef]
73. Syahputra, R.; Soesanti, I. Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: A case study in Yogyakarta, Indonesia. *Energy Rep.* **2021**, *7*, 472–490. [CrossRef]
74. Burke, P.J.; Widnyana, J.; Anjum, Z.; Aisbett, E.; Resosudarmo, B.; Baldwin, K.G. Overcoming barriers to solar and wind energy adoption in two Asian giants: India and Indonesia. *Energy Policy* **2019**, *132*, 1216–1228. [CrossRef]
75. Reyseliani, N.; Purwanto, W.W. Pathway towards 100% renewable energy in Indonesia power system by 2050. *Renew. Energy* **2021**, *176*, 305–321. [CrossRef]
76. Riva, F.; Ahlborg, H.; Hartvigsson, E.; Pachauri, S.; Colombo, E. Electricity access and rural development: Review of complex socio-economic dynamics and causal diagrams for more appropriate energy modelling. *Energy Sustain. Dev.* **2018**, *43*, 203–223. [CrossRef]
77. Vaka, M.; Walvekar, R.; Rasheed, A.K.; Khalid, M. A review on Malaysia's solar energy pathway towards carbon-neutral Malaysia beyond Covid'19 pandemic. *J. Clean. Prod.* **2020**, *273*, 122834. [CrossRef]
78. Chua, K.H.; Lim, Y.S.; Morris, S. Cost-benefit assessment of energy storage for utility and customers: A case study in Malaysia. *Energy Convers. Manag.* **2015**, *106*, 1071–1081. [CrossRef]
79. Islam, M.T.; Huda, N.; Saidur, R. Current energy mix and techno-economic analysis of concentrating solar power (CSP) technologies in Malaysia. *Renew. Energy* **2019**, *140*, 789–806. [CrossRef]
80. Wong, S.; Ngadi, N.; Abdullah, T.A.T.; Inuwa, I. Recent advances of feed-in tariff in Malaysia. *Renew. Sustain. Energy Rev.* **2015**, *41*, 42–52. [CrossRef]
81. Lim, Y.S.; Koh, S.L.; Hau, L.C.; San Liew, S.M. Business opportunities for grid-integrated energy storage systems in Malaysia based on a real case study. *J. Energy Storage* **2019**, *26*, 101028. [CrossRef]
82. Han, M.S.; Cudjoe, D. Determinants of energy-saving behavior of urban residents: Evidence from Myanmar. *Energy Policy* **2020**, *140*, 111405. [CrossRef]
83. Blakers, A.; Stocks, M.; Stocks, R.; Lu, B.; Cheng, C. A global atlas of 616,000 pumped hydro energy storage sites. In Proceedings of the ISES Solar World Congress 2019/IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019, Santiago, Chile, 3–7 November 2019.

84. Do, T.N.; Burke, P.J.; Baldwin, K.G.; Nguyen, C.T. Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. *Energy Policy* **2020**, *144*, 111561. [CrossRef]
85. Kim, H.; Jung, T.Y. Independent solar photovoltaic with Energy Storage Systems (ESS) for rural electrification in Myanmar. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1187–1194. [CrossRef]
86. Newswire, P. *3DOM Signs MOU on Battery Energy Storage System for Pathein Industrial City Project in Myanmar*; Cision PR Newswire: Singapore, 2017.
87. Whitlock, R. ABB partners with SMC to install battery energy storage systems in the Philippines. *Renewable Energy Magazine*, 4 June 2021. Available online: https://en.prnasia.com/releases/apac/3dom-signs-mou-on-battery-energy-storage-system-for-pathein-industrial-city-project-in-myanmar-299055.shtml(accessed on 5 January 2022).
88. Bertheau, P.; Blechinger, P. Resilient solar energy island supply to support SDG7 on the Philippines: Techno-economic optimized electrification strategy for small islands. *Util. Policy* **2018**, *54*, 55–77. [CrossRef]
89. Li, Y.; Taghizadeh-Hesary, F. *Energy Storage for Renewable Energy Integration in ASEAN and East Asian Countries: Prospects of Hydrogen as a Energy Carrier vs. Other Alternatives*; ERIA Research Project Report; ERIA: Jakarta, Indonesia, 2020.
90. Colthorpe, A. Wärtsilä installs Singapore's first utility-scale ESS as Southeast Asia business ramps up. *Energy Storage News*, 28 October 2020.
91. Tevis, R.; Schuster, N.; Evans, F.; Himmler, R.; Gheewala, S.H. A multi-scenario life cycle impact comparison of operational energy supply techniques for an office building in Thailand. *Energy Build.* **2019**, *190*, 172–182. [CrossRef]
92. Phuangpornpitak, N.; Kumar, S. User acceptance of diesel/PV hybrid system in an island community. *Renew. Energy* **2011**, *36*, 125–131. [CrossRef]
93. Garanovic, A. SEACEF Invests in Vietnamese Floating Solar and Storage Project. Available online: https://www.offshore-energy.biz/seacef-invests-in-vietnamese-floating-solar-and-storage-project/ (accessed on 17 July 2022).
94. Chaitusaney, S. *Case Study of Battery Energy Storage System Analysis Conducted in Vietnam for Binh Thuan and Ninh Thuan Provinces*; USAID Clean Power Asia: Washington, DC, USA, 2019.
95. Renewable Energy World. *SEACEF Invests in 500mw Floating Solar + Storage in Vietnam*; Renewable Energy World: Hanoi, Vietnam, 2021.
96. Hak, M.; Matsuoka, Y.; Gomi, K. A qualitative and quantitative design of low-carbon development in Cambodia: Energy policy. *Energy Policy* **2017**, *100*, 237–251. [CrossRef]
97. Fragkos, P.; van Soest, H.L.; Schaeffer, R.; Reedman, L.; Köberle, A.C.; Macaluso, N.; Evangelopoulou, S.; De Vita, A.; Sha, F.; Qimin, C. Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. *Energy* **2021**, *216*, 119385. [CrossRef]