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Renewable Energy Progress and Utilization Gaps in ASEAN: A Comparative Analysis

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Abstract

This study investigates renewable energy development trends and utilization gaps across ASEAN countries between 2016 and 2020 through a comparative, data-driven analysis. The research highlights temporal differences in installed capacity and project realization, focusing on solar, biomass, hydropower, and geothermal energy sources. Vietnam experienced the most dramatic increase in installed capacity, from 0 MW in 2017–2018 to approximately 850 MW in 2019–2020. Cambodia followed with a jump from 0 MW to 370 MW during the same period, while Thailand more than doubled its capacity from 320 MW to 680 MW. In the solar sector, Thailand led with 950 MW added in 2016, though growth slowed afterwards. The Philippines maintained steady development, increasing from 600 MW in 2016 to 640 MW by 2018. A three-layer comparison reveals that solar energy had a technical potential of 4,800 MW, with only a 2,000 MW target by 2021, and biomass had a potential of 4,400 MW, with a 2021 target of 3,600 MW. This study's novelty lies in its multi-year comparative approach, project commitment data incorporation, and potential vs. realisation analysis. The dominance of fossil fuels, 91% of Indonesia's renewable mix in 2015, highlights the urgent need for diversification. The findings provide valuable insight for policymakers to align targets with investment and capacity-building strategies across the ASEAN region.

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1. Introduction

Southeast Asia, particularly the ASEAN region, is experiencing rapid economic growth, urbanization, and industrial expansion, significantly increasing energy demand. This growing demand, historically met by fossil fuels, has led to rising greenhouse gas emissions and heightened concerns over energy security, environmental sustainability, and long-term economic resilience. As countries within the ASEAN community seek to transition toward low-carbon development, renewable energy has become vital to national energy strategies.

Several studies have addressed the renewable energy landscape in ASEAN. ASEAN countries possess vast untapped renewable energy potential, including solar, biomass, hydro, and geothermal resources (ACE, 2022; Gani et al., 2023; Mufti et al., 2025; Pranoto et al., 2025). Malaysia and Thailand have been pioneers in solar PV development, while Indonesia has focused on geothermal due to its geological advantages (Erdiwansyah, Mamat et al., 2019; Kumar et al., 2015; Rosdi et al., 2025; Selvakumar et al., 2025). However, despite these efforts, the region still relies heavily on fossil fuels, and the pace of renewable energy integration remains uneven (Erdiwansyah, Mahidin, et al., 2019; Fitriyana et al., 2025; Muhibbuddin et al., 2025; Vadhanavisala, 2021). Earlier research has primarily focused on country-specific case studies or singular technologies, such as solar in the Philippines (Garcia & Tamayo, 2020) or biomass in Thailand (Gani et al., 2025; Khalisha et al., 2025; Muhtadin et al., 2025; Tun et al., 2019). While these works provide essential insights, they often lack a regional comparative perspective over time, especially one that incorporates technical potential and policy targets into a unified analysis framework.
Additionally, many previous studies present data from a single point in time, overlooking the dynamic changes and project implementation gaps between initial commitments and actual capacity realization. For instance, project announcements often do not result in operational facilities due to regulatory, financial, or technical delays (Bahagia et al., 2025; Iqbal et al., 2025; Jalaludin et al., 2025; Kuok et al., 2024). This underlines the need for more comprehensive and time-sensitive evaluations of renewable energy development trends in ASEAN. Another critical aspect is underutilising technical renewable energy potential in several ASEAN countries. For example, Indonesia's solar potential exceeds 4,800 MW, yet installed capacity remains far below expectations (Kurniawan et al., 2022; NOOR et al., 2025; Sumarno et al., 2025; Yana et al., 2025). Similarly, biomass and biogas potentials in Malaysia and Vietnam are only partially harnessed. These gaps emphasize the importance of assessing the alignment between resource availability, development targets, and actual deployment.
Furthermore, fossil fuels continue to dominate the energy mix across the region. In Indonesia, for example, renewable energy in 2015 was still overwhelmingly based on fusel fuel, accounting for 91% of the mix, with solar and geothermal making up only 1.5% each. This pattern demonstrates the urgent need for diversification and more strategic integration of sustainable technologies (Febrina & Anwar, 2025; Gould et al., 2024; Irhamni et al., 2025; Maghfirah et al., 2025). Given these challenges and opportunities, this study aims to conduct a comprehensive comparative analysis of renewable energy development in ASEAN from 2016 to 2020. It includes a detailed evaluation of installed capacity, project commitments, technical potentials, and national targets across different renewable energy sources. The study employs a multi-year, cross-country approach to offer updated and nuanced insights beyond static or isolated assessments.
This research aims to identify the gaps between renewable energy potential, planned targets, and capacity growth in ASEAN countries while highlighting policy implications and best practices that can accelerate the energy transition in the region. This study contributes a novel synthesis of temporal development patterns and offers strategic guidance for future energy planning.

2. Methodology

This study employs a comparative descriptive approach based on secondary data analysis to evaluate renewable energy development and utilization gaps across ASEAN countries from 2016 to 2020. Data were collected from reliable sources such as the International Renewable Energy Agency (IRENA), ASEAN Centre for Energy (ACE), national energy ministries, and international institutions including the Asian Development Bank (ADB), International Energy Agency (IEA), and the World Bank. The dataset includes installed renewable energy capacity by source (solar, biomass, hydropower, geothermal, wind, and waste-to-energy), technical potential of each source, new project commitments, and national energy development targets (e.g., 2021 targets).
Once collected, the data were categorized by country, type of renewable energy, and timeframe (2016, 2017–2018, and 2019–2020). A comparative analysis was conducted across countries to examine development trends, growth rates, and the success of implementation strategies. Additionally, the study

compared actual installed capacities with both technical potentials and targeted goals to identify utilization gaps. The results were visualized using bar charts, pie charts, and comparative diagrams for more precise interpretation. The findings were then critically interpreted to reveal patterns of fossil fuel dominance, evaluate the effectiveness of renewable energy transition policies, and identify opportunities to enhance the contribution of renewable energy across the ASEAN region.

Fig. 1 illustrates the research methodology flowchart employed in this study, which outlines a structured and systematic approach to analyzing renewable energy development in ASEAN countries. The process begins with defining the research objectives, specifically identifying gaps between technical potential, national targets, and installed capacities of renewable energy sources from 2016 to 2020. The methodology then collects secondary data from reputable sources such as IRENA, the ASEAN Centre for Energy (ACE), and national government reports. These data sets are then categorized based on country, type of renewable energy (e.g., solar, biomass, hydropower, geothermal), and timeframes, allowing for precise segmentation and comparability across different dimensions.

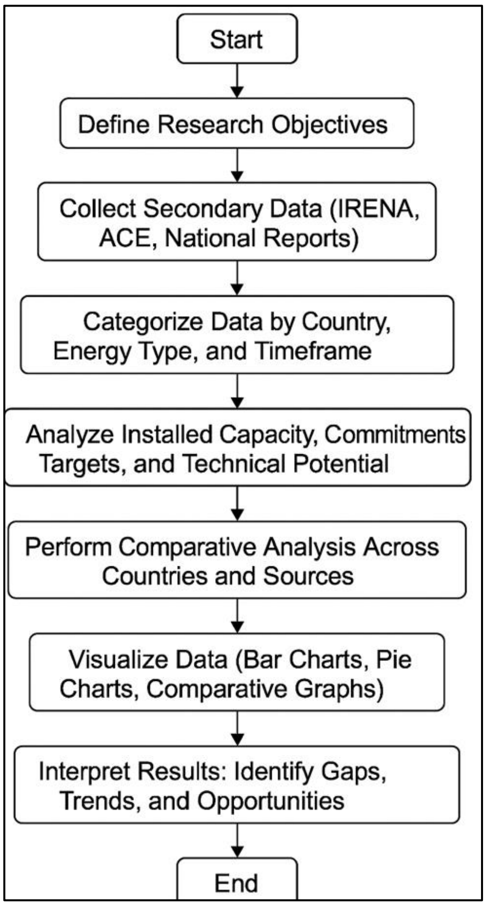

Fig. 1. Flowchart of Research Methodology for ASEAN Renewable Energy Study

Subsequently, the data are analyzed to examine installed capacities, project commitments, national development targets, and technical potential. This stage enables the identification of progress and underutilization in various energy sectors. The next step involves performing a comparative analysis across countries and energy sources to assess performance disparities, regional trends, and policy effectiveness. Visualization tools such as bar charts, pie charts, and comparative graphs are utilized to present the data in an interpretable and communicative manner. Finally, the results are interpreted to identify gaps, emerging trends, and strategic opportunities to improve renewable energy planning and policy. Overall, the flowchart provides a comprehensive framework that enhances the clarity and reproducibility of the research process.

3. Result & Discussion

Fig. 2 compares installed energy capacity across ASEAN countries during two distinct periods: 2017–2018 (black bars) and 2019–2020 (red bars). The data demonstrates significant growth in several countries, reflecting active investment and development in the region's renewable and conventional energy sectors. Vietnam and Indonesia exhibit the most notable increases in installed capacity between the two periods. Vietnam's installed capacity surged from 0 MW in 2017–2018 to approximately 850 MW in 2019–2020, indicating a dramatic development, likely driven by aggressive solar and wind energy deployment. Indonesia increased from around 120 MW to 200 MW, reflecting moderate but consistent growth.

Thailand also showed a substantial jump, increasing from about 320 MW to 680 MW, more than doubling its installed capacity, possibly due to increased solar PV adoption and energy policy support. On the other hand, Malaysia experienced a slight decline from approximately 570 MW in 2017–2018 to 540 MW in 2019–2020, suggesting a possible plateau or slowdown in project commissioning during the latter period. The Philippines showed a steady upward trend, with capacity growing from around 180 MW to 290 MW. Despite space limitations, Singapore expanded from 90 MW to 150 MW, reflecting its growing interest in sustainable energy.

In mainland Southeast Asia, Laos rose modestly from about 30 MW to 150 MW, while Myanmar saw a more minor increase from 50 MW to about 80 MW. Meanwhile, Cambodia experienced a significant jump, with installed capacity increasing from 0 MW in 2017–2018 to 370 MW in 2019–2020, signalling a major policy shift or new investments in energy infrastructure. Brunei, however, remained stagnant with negligible capacity addition across both periods, suggesting minimal progress in expanding energy infrastructure. The data indicates that while most ASEAN countries accelerate their energy development, the magnitude and pace vary significantly. The most dynamic expansions are observed in Vietnam, Thailand, and Cambodia, pointing to a successful implementation of energy strategies and foreign investment in these countries.

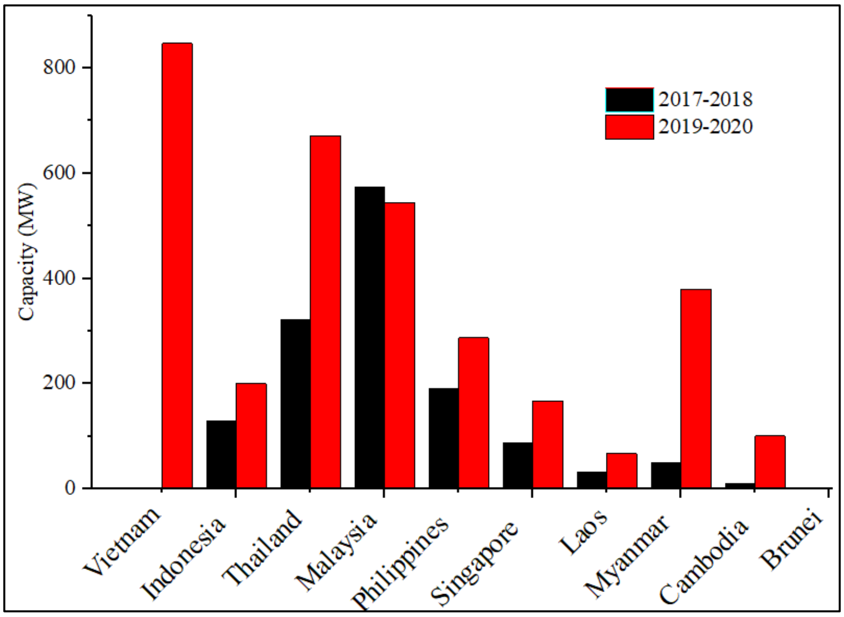

Fig. 2. Comparison of Installed Energy Capacity in ASEAN Countries for the Periods 2017–2018 and 2019–202

Fig. 3 presents the solar power capacity trends in ASEAN countries, highlighting four significant indicators: solar capacity additions in 2016 (black bars), new solar project commitments in 2016 (red bars), capacity additions in the first half of 2017 (blue bars), and total capacity additions during 2017–2018 (teal bars). This visualization provides a comprehensive understanding of how solar power deployment evolved in the region. Thailand led the area with the highest solar capacity additions in

2016, reaching nearly 950 MW, indicating early momentum in its solar energy initiatives. However, its new project commitments in 2016 were comparatively lower at around 300 MW, and subsequent additions in 2017 and 2018 showed a decline, with around 50 MW in early 2017 and about 140 MW in total for 2017–2018.

Malaysia follows a consistent and balanced solar development trend. In 2016, it saw about 300 MW of new project commitments; by the first half of 2017, it added around 70 MW. Total capacity growth in 2017–2018 reached approximately 320 MW, indicating steady progress in implementing solar infrastructure. The Philippines showed strong and continued solar deployment. While its solar capacity additions 2016 were about 600 MW, it also had significant new commitments in that year—around 520 MW. The first half of 2017 added about 60 MW, and its total capacity for 2017–2018 reached nearly 640 MW, reflecting robust follow-through on commitments.

Singapore, despite land constraints, demonstrated steady development. It registered about 180 MW of additions in 2017–2018, building on modest growth in earlier years. Laos also saw moderate additions in 2017–2018, nearing 120 MW, despite having no visible activity in 2016, suggesting recent uptake of solar energy initiatives. Myanmar and Cambodia showed relatively lower activity, though Myanmar had a notable project commitment of about 290 MW in 2016, which did not fully translate into realized capacity by 2018. Cambodia added around 50 MW in 2017–2018, indicating emerging solar development. Vietnam, Indonesia, and Brunei recorded minimal or no activity during this period, underscoring limited solar deployment or data availability during the assessed years.

Overall, the figure highlights Thailand and the Philippines as early and leading adopters of solar technology in ASEAN, with Malaysia demonstrating consistent growth. Countries like Laos and Cambodia show late but promising engagement, while others like Vietnam and Indonesia have yet to capitalize on solar potential significantly during the analysed timeframe.

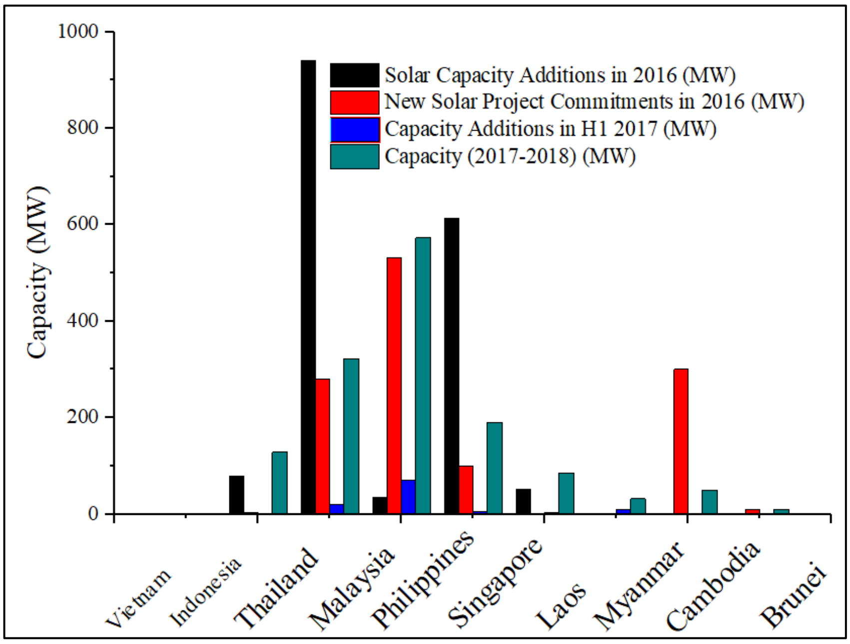

Fig. 3. Solar Power Capacity Trends in ASEAN: 2016 Additions, Project Commitments, and 2017–2018 Growth

Fig. 4 illustrates the renewable energy potential, installed capacity as of 2008, and 2021 development targets for various energy sources in megawatts (MW). The comparison helps assess the progress and ambition in renewable energy deployment relative to each source's technical potential. Solar energy exhibits the highest technical potential, estimated at around 4,800 MW. Despite this, the installed capacity in 2008 was negligible, close to 0 MW, highlighting a sizeable untapped opportunity. The 2021 target for solar reaches approximately 2,000 MW, reflecting a strong strategic push to harness this vast resource. Wind energy follows with a technical potential of about 2,000 MW, while the 2008 capacity remained minimal. By 2021, the target is around 1,600 MW, indicating a proactive move toward exploiting wind power, though still short of full potential.

Hydropower shows a technical potential near 1,300 MW, with 2008 capacity close to 600 MW. The 2021 target is around 1,200 MW, nearly reaching the full estimated potential, suggesting a mature and saturated renewable source. Biomass ranks high with a technical potential of approximately 4,400 MW. The 2008 installed capacity stood at around 1,600 MW, and the 2021 target aims for about 3,600 MW, indicating substantial planned expansion and confidence in its feasibility. Biogas shows a technical potential of around 800 MW, with minimal 2008 capacity but an ambitious 2021 target of nearly 400 MW, suggesting increased interest in waste-to-energy systems.

Waste-to-energy has a technical potential close to 500 MW, with minimal 2008 capacity and a 2021 target of around 300 MW. Similarly, geothermal shows a technical potential near 500 MW and a modest 2021 target of 100 MW. Although included, tidal wave energy shows zero across all bars, indicating very low feasibility or a lack of prioritization in current national planning. In conclusion, the chart shows significant gaps between technical potential and actual utilization as of 2008. However, the 2021 targets reveal a clear commitment to bridging this gap, especially in solar, biomass, and wind energy sectors. The trend reflects national efforts to diversify the energy mix and shift toward cleaner, renewable sources.

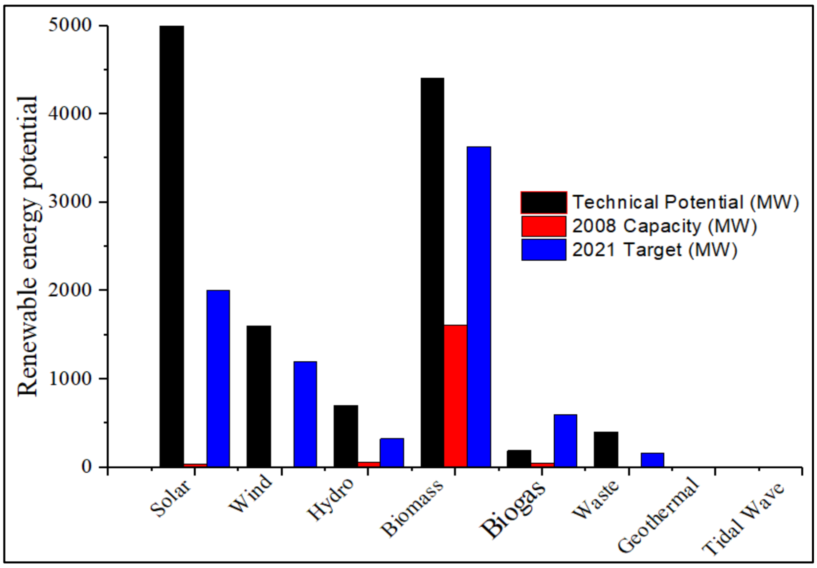

Fig. 4. Renewable Energy Potential and Development Targets by Source (MW)

Fig. 5 shows Indonesia's total installed renewable energy capacity for 2015, categorized by energy source. The chart highlights a significant imbalance in the contribution of different renewable energy types, with fusel fuel (biofuel derived from waste alcohol) overwhelmingly dominating the mix. Fusel fuel accounted for 91% of the total renewable energy capacity in 2015. This dominant share indicates a heavy reliance on bio-based liquid fuels rather than diversified renewable options, which may raise concerns about sustainability, fuel supply chains, and emissions. Hydropower contributed 5%, representing the most significant share among conventional renewables. Although hydropower is a mature and reliable source in Indonesia, its share appears underrepresented in the national energy portfolio compared to its potential.

Solar and geothermal energy accounted for only 1.5% of the total renewable capacity, signalling underdevelopment despite Indonesia's intense solar irradiation and geothermal resource base. The limited solar uptake could be attributed to higher installation costs and a lack of infrastructure or policy support. The chart suggests that Indonesia's renewable energy strategy 2015 was narrowly focused on a single fuel type, with minimal deployment of cleaner and more sustainable technologies like solar and geothermal. This highlights the need for diversification in the renewable energy sector to improve resilience, sustainability, and long-term energy security.

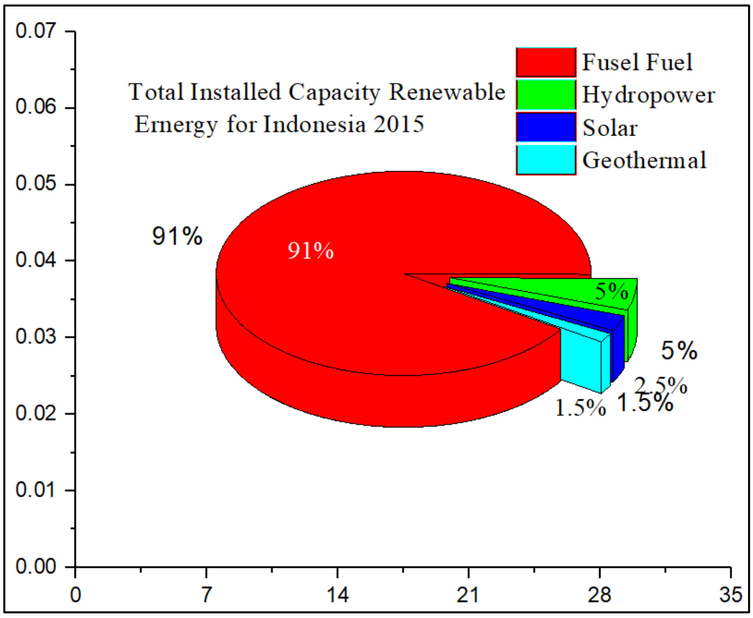

Fig. 5. Total Installed Renewable Energy Capacity in Indonesia (2015)

Fig. 6 illustrates the comparative reliance on various energy sources, particularly fossil fuels and key renewables, hydropower, solar, and geothermal. The bar chart visualizes how energy consumption or production is distributed among these sources across three categorical x-axis groups. Across all three groups, fossil fuel (represented in red) consistently shows the highest value of 10, highlighting a strong and continued dependence on non-renewable energy sources. This indicates that fossil fuels remain the dominant part of the energy mix, overshadowing the contribution of renewables. In the first group, hydropower stands at 5, while solar and geothermal are at 2.5 and 1.5, respectively. This suggests a moderate reliance on hydropower and minimal solar and geothermal energy utilisation.

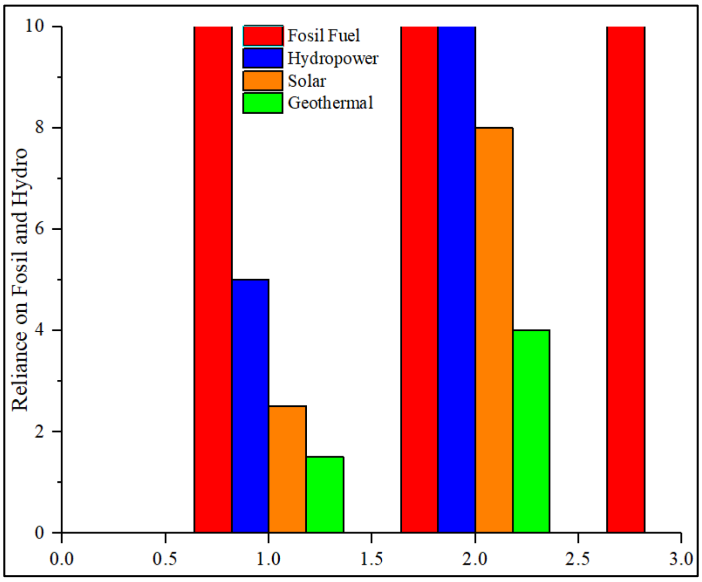

Fig. 6. Energy Source Dependence: Comparison of Fossil Fuel and Renewable Energy Utilization

The second group shows a more balanced distribution: fossil fuel and hydropower are at 10, indicating a possible dual reliance. Solar energy also rises significantly to 8, and geothermal energy increases to 4, showing greater adoption of diverse renewable energy sources in this segment. In contrast, the third group returns to exclusive reliance on fossil fuels at the maximum level of 10, with no visible contribution from renewables. This stark contrast implies variability in energy strategies or development levels among the grouped entities, potentially in different regions, sectors, or timeframes. Overall, the figure reveals that fossil fuel dependence remains a central challenge despite some efforts toward diversification, especially in the second group. Solar and geothermal energy expansion appears promising but insufficient to offset heavy fossil fuel usage in most categories.

This study presents significant novelty in analyzing renewable energy development in the ASEAN region through a comparative and data-driven approach across different timeframes. The key novelty lies in the temporal analysis that compares installed energy capacity during two distinct periods, 2017–2018 and 2019–2020 (**Fig. 2**), which is rarely explored in previous studies that often focus on single-year snapshots. The research also enhances understanding by tracking solar energy development in detail, starting from project commitments in 2016, capacity additions in the first half of 2017, to realized growth in 2017–2018 (**Fig. 3**). This multi-phase trend analysis reflects policy effectiveness and the actual implementation of investments more accurately. Furthermore, the three-layered approach in **Fig. 4** comparing technical potential, actual installed capacity in 2008, and the 2021 target visually and quantitatively highlights the underutilization of key renewable sources, particularly solar and biomass. The emphasis on the dominance of fossil fuels in Indonesia's 2015 energy mix (**Fig. 5** and **6**) also contributes new insights, underlining the urgency of accelerating energy diversification. Overall, this research offers a more comprehensive and up-to-date perspective on renewable energy development in Southeast Asia, providing both empirical evidence and strategic implications for future energy planning.

4. Conclusion

This study concludes that renewable energy development across ASEAN countries between 2016 and 2020 demonstrates promising progress and notable disparities. Vietnam showed the most significant increase in installed capacity, from 0 MW in 2017–2018 to approximately 850 MW in 2019–2020, while Cambodia jumped from 0 MW to around 370 MW in the same period. Thailand and Malaysia continued their steady growth, with Thailand increasing from 320 MW to 680 MW and Malaysia maintaining above 500 MW across both periods despite a slight decline. In contrast, Brunei and Indonesia exhibited minimal growth, with Indonesia increasing only from 120 MW to 200 MW. In terms of solar energy development, Thailand led the region with 950 MW of solar capacity additions in 2016, although its growth plateaued in subsequent years. The Philippines displayed a consistent and balanced trend, with 600 MW added in 2016 and 640 MW by 2018. Malaysia followed closely with a 2021 target of 320 MW, while Myanmar showed a significant project commitment of 290 MW in 2016 but limited actual realization.

A critical gap remains between technical potential and realized capacity. For instance, solar has a technical potential of 4,800 MW, yet the 2008 installed capacity was negligible, and the 2021 target was only 2,000 MW. Similarly, biomass has a potential of 4,400 MW, with a 2021 target of 3,600 MW from just 1,600 MW in 2008. These findings highlight the underutilization of abundant resources and the importance of accelerating infrastructure and investment to meet future energy goals. Indonesia's renewable energy mix 2015 further emphasized the imbalance, with 91% reliance on fusel fuel, while hydropower, solar, and geothermal contributed only 5%, 1.5%, and 1.5%, respectively. The strong dominance of fossil fuel usage across all segments (rated at the maximum scale of 10 in all categories) in Figure 6 underscores the urgent need for energy diversification and broader adoption of cleaner technologies. In summary, while several ASEAN nations have made measurable progress, the overall regional landscape reveals the need for improved policy alignment, enhanced investment strategies, and more substantial commitment toward unlocking the full potential of renewable energy resources.

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