Chapter 15

Energy Security in the ASEAN Economic Community Beyond 2025

Youngho Chang

This chapter should be cited as
Chang, Y. (2025), 'Energy Security in the ASEAN Economic Community Beyond 2025', in Rillo, A.D and B. Shepherd (eds.), *Where Next? Priorities for the ASEAN Economic Community Post-2025*. Jakarta, Indonesia: Economic Research Institute for ASEAN and East Asia, pp. 368-382.

15.

Energy Security in the ASEAN Economic Community Beyond 2025

Youngho Chang

1. Introduction

Energy, alongside capital and labour, is a key input for production and hence a critical factor of economic growth, contributing to improved well-being across the economy. Consumed in various forms – chemical and electrical, for example – energy is essential not only for daily life but also for the proper functioning of an economy. Securing energy is, therefore, crucial for both the survival and affluence of people. Traditionally, energy security has been defined as ensuring the supply or availability of physical energy resources for an economy or country. A more detailed definition described it as 'an adequate and reliable supply of energy at a reasonable price' (Yao and Chang, 2014; Taghizadeh-Hesary et al, 2019). The ASEAN Economic Community (AEC) Blueprint 2025 identifies key issues and sets forth new approaches, insights, and recommendations for energy cooperation, positioning energy security as a priority. The blueprint addresses this directly and indirectly discussed under B.8 Sustainable Economic Development and C.4 Energy, envisioning 'enhancing energy connectivity and market integration in ASEAN to achieve energy security, accessibility, affordability and sustainability for all' (ASEAN Secretariat, 2015). Whilst ASEAN member countries are working on enhancing energy connectivity and market integration, progress has been slow. Although the mid-term review of the AEC Blueprint 2025 does not explicitly discuss energy security, it notes progress in energy connectivity, such as the ASEAN Power Grid and the Trans-ASEAN Gas Pipeline (ASEAN Secretariat, 2021). Cooperation amongst ASEAN member countries on energy security is progressing, but more concerted action should be taken. Experiences from the European Union (EU) and West African countries could provide valuable lessons for ASEAN.

Focusing solely on the assurance of energy supply or physical availability may overlook key factors that could prevent energy resources from reaching end-users, thereby undermining energy security. To reach end-users, energy must pass through four stages: physical availability, technological applicability, societal acceptability, and affordability. Failing at any stage disrupts delivery to end-users.

The multi-stage approach suggests a more comprehensive framework for evaluating energy security in any country or region. For an energy resource to be accessible to end-users, a country must first have sufficient physical energy resources within its borders or be able to import them, defining the availability stage that addresses the scientific aspects of energy security.

Next, the resources must be extracted, processed, and delivered using appropriate technologies. For example, vast oil reserves remained untapped until advancements such as horizontal drilling enabled extraction, defining the applicability stage that addresses the technical aspects of energy security. Beyond technical feasibility, societal acceptance is essential. Even with applicable technologies, an energy resource must be accepted by end-users to reach them. The acceptability stage is illustrated by coal, which, despite significant reserves, is being phased out in many countries, especially in Europe. Nuclear energy, too, though technically mature, is limited or being scaled down in countries such as Germany and Japan.

Finally, accepted energy resources must be affordable. Renewable resources such as solar and wind are increasingly available and supported by applicable technologies and societal acceptance. However, their relatively high prices compared with conventional resources often prevent full adoption.

The four-dimensional model, known as the 4A framework of energy security, has been applied in countries such as China, India, Pakistan, and Bangladesh, and in regions such as ASEAN (Yao and Chang, 2014; Sarangi et al., 2019; Malik et al., 2020; Amin et al., 2022; Tongsopit et al., 2016). This analytical framework reveals how energy security evolves within a country or region and identifies key factors driving the changes.

The study applies the 4A framework to assess energy security in ASEAN, examining the availability, applicability, acceptability, and affordability of energy resources. By exploring the four dimensions, the review aims to critically discuss ASEAN's energy security, identify current challenges and gaps, and offer recommendations for addressing them. Following an analysis of ASEAN's current energy security status, challenges and issues, the chapter suggests new initiatives to bridge the gaps and enhance the region's energy cooperation framework.

2. Energy Security in ASEAN: Status, Challenges, and Issues

ASEAN has undertaken collective efforts to secure energy resources, focusing mainly on the physical supply and regional cooperation to increase energy availability. The ASEAN Petroleum Security Agreement, signed on 24 June 1986, established the ASEAN Emergency Petroleum Sharing Scheme for crude oil and petroleum products. In 1990, the Program of Action for the Enhancement of ASEAN Cooperation on Energy was approved by the Ministers on Energy Cooperation. Since its establishment in 1999, the ASEAN Center for Energy (ACE) has developed a series of the ASEAN Plans of Action for Energy Cooperation, guiding regional initiatives to enhance energy security. The ACE has facilitated the formation of special bodies to support energy security through cooperative efforts, such as the Heads of ASEAN Power Utilities and Authorities (HAPUA), the ASEAN Council on Petroleum, and the ASEAN Forum on Coal. ASEAN has launched programmes such as the ASEAN Power Grid and the Trans-ASEAN Gas Pipeline to strengthen energy security by connecting power grids and establishing transport networks

for natural gas across the region. The mid-term review of the ASEAN Economic Community Blueprint 2025 acknowledged some progress in enhancing energy security (ASEAN Secretariat, 2021). However, a comprehensive analysis of ASEAN's energy security remains limited. A recent study used the 4A framework to assess energy security in ASEAN (Tongsopit et al., 2016), highlighting critical issues.

This study discusses the efforts of ASEAN member countries to enhance energy security through the four pillars of the 4A framework: availability, applicability, acceptability, and affordability. By evaluating ASEAN's performance across these dimensions, it identifies challenges and gaps, recommending ways to strengthen energy security across the region.

2.1. Availability

A few ASEAN countries have limited fossil fuel reserves (Table 15.1).

Table 15.1. Fossil Fuel Reserves in ASEAN Countries (as of December 2020)

Country	Oil (million tonnes)	Natural Gas (trillion cubic feet)	Coal (million tonnes)
Brunei	149.86 (27.3)	7.85 (17.6)	
Indonesia	337.48 (9.0)	44.22 (19.8)	34,869 (62)
Malaysia	357.57 (12.5)	32.07 (12.4)	
Myanmar		15.26 (24.4)	
Thailand	30.46 (1.7)	5.05 (4.4)	1,063 (80)
Viet Nam	594.59 (58.1)	22.81 (74.1)	3,360 (69)

ASEAN = Association of Southeast Asian Nations.

Source: BP Statistical Review of World Energy 2021 (British Petroleum, 2021).

Note: Numbers in the parentheses indicate reserve/production (R/P) ratio.

Table 15.2, Table 15. 3, and Table 15. 4 show the production and consumption levels of oil, natural gas, and coal in ASEAN, respectively. Despite being oil producers, Indonesia, Malaysia, Thailand, and Viet Nam still import oil.

Table 15.2. Oil Production and Consumption in Selected ASEAN Countries (Unit: Thousand barrels per day)

Country	Production	Consumption	Import Dependency (%)
Indonesia	644	1,768	63.6
Malaysia	567	921	38.4
Philippines		469	100.0
Singapore		1,199	100.0
Thailand	331	1,325	75.0
Viet Nam	194	515	62.3

ASEAN = Association of Southeast Asian Nations.

Source: Statistical Review of World Energy 2023 (Energy Institute, 2023).

Whilst natural gas-producing countries such as Indonesia and Malaysia are net exporters of natural gas, as shown in Table 15. 3, four ASEAN member countries are importing natural gas.

Table15.3. Natural Gas Production and Consumption in Selected ASEAN Countries (billion cubic metres)

Country	Production	Consumption	Import Dependency (%)
Indonesia	57.7	37	–55.9
Malaysia	82.4	49.4	–66.8
Philippines		3.1	100.0
Singapore		18.1	100.0
Thailand	25.6	44.3	42.2
Viet Nam	7.8	7.8	0

ASEAN = Association of Southeast Asian Nations.

Source: Statistical Review of World Energy 2023 (Energy Institute, 2023).

Except for Indonesia, five ASEAN countries import coal (Table 15.4).

Table 15.4. Coal Production and Consumption in Selected ASEAN Countries (exajoules)

Country	Production	Consumption	Import Dependency (%)
Indonesia	13.95	4.38	–218.5
Malaysia		0.94	100.0
Philippines		0.84	100.0
Singapore		0.017	100.0
Thailand	0.14	0.71	80.3
Viet Nam	1.17	2.05	42.9

ASEAN = Association of Southeast Asian Nations.

Source: Statistical Review of World Energy 2023 (Energy Institute, 2023).

Whilst fossil fuel endowments are modest, ASEAN countries possess abundant renewable energy potential, especially in hydro, wind, and solar energy resources (Table 15.5).

Table 15.5. Potential Renewable Energy Sources in ASEAN Countries (GW)

Country	Biomass	Hydro	Geothermal	Wind	Solar PV
Brunei	-	0.07	-	0.02	16
Cambodia	-	10.00	-	69.00	3,198
Indonesia	32.60	75.00	29.50	50.00	1,052
Lao PDR	1.20	26.00	0.05	13.00	1,278
Malaysia	0.60	29.00	-	2.00	1,965
Myanmar	0.99	40.40	-	482.00	7,717
Philippines	0.24	10.50	4.00	217.00	1,910
Singapore	-	-	-	0.02	2
Thailand	2.50	15.00	-	239.00	10,538
Viet Nam	0.56	35.00	0.34	311.00	2,847
Total	**38.69**	**240.97**	**33.89**	**1,383.04**	**30,523**

ASEAN = Association of Southeast Asian Nations, GW = gigawatt, Lao PDR = Lao People's Democratic Republic, solar PV = solar photovoltaic.

Source: Handayani et al. (2022).

To meet the region's fast-growing energy demand, ASEAN must develop domestically available energy resources, mainly renewable energy sources, and/or increase imports. Whilst ASEAN's fossil fuel reserves are limited, its substantial renewable energy potential offers a critical opportunity to enhance energy security. This raises the question of how best to utilise renewable energy resources to meet ASEAN's energy needs.

2.2. Applicability

A study on ASEAN's pathways to net-zero emissions by 2050 presents 16 electricity generation technologies, covering both currently used ones and new technologies, such as nuclear and carbon capture and storage (CCS). The technologies considered include ultra-supercritical coal, combined-cycle and open-cycle natural gas, diesel, geothermal, hydro, mini-hydro, biomass, wind, solar photovoltaic (PV), nuclear, coal with CCS, natural gas combined cycle with CCS, bioenergy with CCS, lithium-ion (Li-ion) batteries, and hydro pumped storage (Handayani et al., 2022). ASEAN has the potential to deploy available and highly advanced electricity generation technologies.

Another study on the possibility of decarbonisation potential in ASEAN shows eight electricity generation technologies ready for deployment. The technologies include hydro, biomass, geothermal, wind, solar PV, coal with CCS, gas with CCS, and nuclear (Lau, 2023). Notably, renewable energy storage solutions, such as batteries, are not considered due to their limited readiness or maturity. Whilst this study presents a narrower range of applicable technologies, advanced power generation technologies are likely to become available with adequate investment and technology transfer.

In terms of applicability or the technological dimension, there appears to be no significant barrier to utilising available energy resources within ASEAN. The region can collectively develop energy technologies and foster electricity market integration through power grid interconnections. An integrated electricity market would, for example, enable the Lao People's Democratic Republic (Lao PDR) to export hydropower-generated electricity to Singapore, supporting Singapore in meeting its growing electricity demand.

2.3. Acceptability

The societal acceptance of energy resources, especially fossil fuels, is commonly measured by carbon dioxide emissions per capita, used here as a proxy indicator. Generally, a higher level of carbon dioxide emissions per capita suggests a lower level of societal acceptance of fossil fuels. Table 15. 6 presents carbon dioxide emissions per capita for selected countries in ASEAN and northeast Asia. Notably, in most ASEAN member countries, carbon dioxide emissions per capita remain below 4 tonnes, with exceptions in Malaysia and Singapore.

Table 15.6. Carbon Dioxide Emissions Per Capita in Selected Countries (tonnes)

Country	CO_2 Emissions per Capita
Indonesia	2.07
Malaysia	7.38
Philippines	1.19
Singapore	7.69
Thailand	3.71
Viet Nam	3.68
China	7.75
Japan	8.03
Korea	10.99

CO2 = carbon dioxide.

Source: Our World in Data (World Bank, 2024).

In terms of energy acceptability, ASEAN countries show a relatively moderate acceptance of fossil fuels, as indicated by comparatively low carbon emissions per capita. This contrasts with developed countries such as Japan, the Republic of Korea, and China, the largest carbon-emitting country in the world.

2.4. Affordability

The affordability of energy resources is measured by the primary energy consumption per capita, amongst other factors. Table 15. 7 presents the levels of primary energy consumption per person in selected ASEAN countries.

Table 15.7. Primary Energy Consumption in Selected ASEAN Countries (gigajoules per capita)

Country	Consumption
Indonesia	35.5
Malaysia	142.5
Philippines	18.2
Singapore	529.5
Thailand	70.6
Viet Nam	46.7
Asia-Pacific (average)	64.4
North America (average)	235.6
Europe (average)	118.0
World (average)	75.7

ASEAN = Association of Southeast Asian Nations.

Source: Statistical Review of World Energy 2023 (Energy Institute, 2023).

Countries such as Indonesia, the Philippines, and Viet Nam show lower primary energy consumption per capita than the global average (75.7 gigajoules [GJ]), with all but Thailand falling below the Asia-Pacific average of 64.4 GJ. Singapore's consumption exceeds even the North American average (235.6 GJ), and Malaysia's surpasses the Euro7pean average (118.0 GJ).

Regarding energy affordability, there remains room for improvement across the ASEAN region. ASEAN could consider establishing funds to provide fair and better energy access for low-income households within the region.

3. Energy Security in ASEAN: A Way Forward

This study recommends ways to enhance energy security in ASEAN member countries, based on an analysis of the 4A framework. The recommendations are structured around four key areas: increasing the availability of energy resources, enhancing the technological applicability of energy harnessing, ensuring societal acceptability, and guaranteeing affordability. The overarching theme is that energy security must be pursued through a fair and equitable energy transition.

To improve the availability of energy resources, the study suggests developing fossil fuels only with carbon capture and storage (CCS) or carbon capture, usage, and storage (CCUS) technologies, expanding renewable energy and green hydrogen, integrating regional electricity markets, and establishing a consortium to harness civilian nuclear energy use, such as small-scale nuclear reactors. To enhance the applicability of energy resources, it recommends establishing ASEAN-wide technology centres focused on research on CCUS, nuclear technology, and renewables. In terms of acceptability, the study suggests studying ways to alleviate public fears around civilian nuclear energy and to build consensus amongst ASEAN populations on its safe use. To ensure affordability, the study recommends establishing ASEAN-wide funds to support low-income households, guaranteeing fair and better access to energy, and furthering the integration of electricity markets across ASEAN.

3.1. Increasing the Availability of Energy Resources

ASEAN has reserves of fossil fuels, which could strengthen its energy availability (Table 1). However, it is recommended that these reserves be developed only if supported by CCS or CCUS technologies. ASEAN has huge potential in renewable energy resources, including hydropower, wind, and solar PV (Table 5). These resources should be harnessed to produce green hydrogen, with development potentially accelerated through an integrated electricity market across ASEAN.

Integrating individual electricity markets can significantly increase the availability of energy resources within a region, as shown by the European common electricity market (Jamasb and Pollitt, 2005), Western African countries (Oseni and Pollitt, 2016), Northeast Asia's power grid interconnection (Otsuki et al., 2016), bilateral cooperation in electricity trade in South Asia (Singh et al., 2018), and the integrated electricity market in ASEAN (Chang and Li, 2015; Chang et al., 2016; Chang, 2021).

In ASEAN, regional power market integration has advanced institutional and policy frameworks for energy cooperation (Yu, 2003; Yu et al., 2005; Watcharejyothin and Shrestha, 2009; Economic Consulting Associates, 2010). Linking energy-rich and energy-poor countries within ASEAN could reduce the overall cost of meeting growing electricity demand (Chang and Li, 2013).

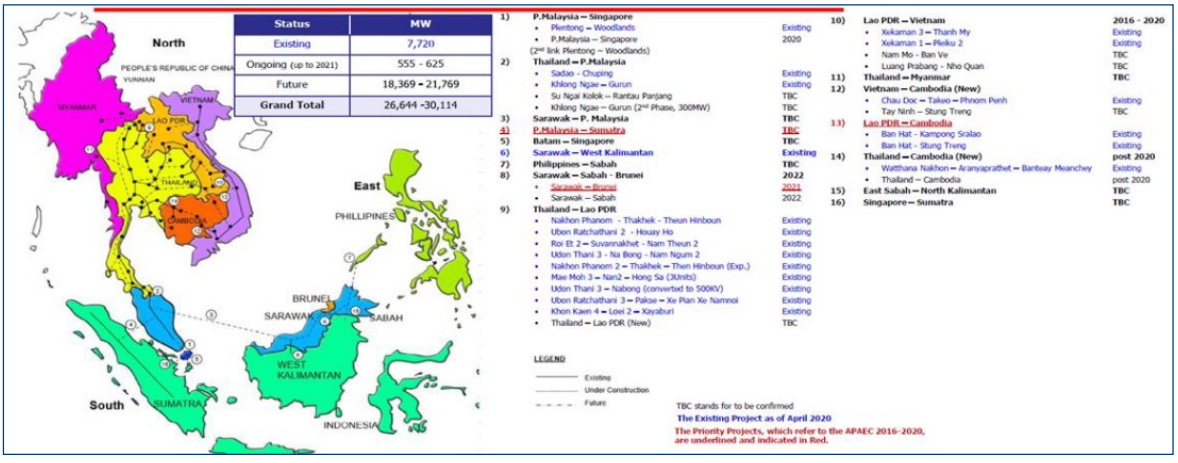
Hydropower is expected to promote cross-border power trade between the United States (US) and Canada, supporting the US transition to a low-carbon economy (Yuan et al, 2021), although, in North America, such trade may also increase reliance on natural gas (Siddiqui et al, 2020). In ASEAN, cross-border power trade is expected to accelerate wind energy development (Chang and Phoumin, 2021). Excess renewable electricity, such as wind power, could be tapped to produce hydrogen to replace fossil fuels in generating electricity (Chang and Phoumin, 2022).

Transmission grids are essential to facilitate cross-border power trade, but constructing an integrated electricity market requires substantial upfront investments. These costs, however, could be offset by the benefits of cross-border power trade, bringing net positive gains despite relatively small absolute returns (Li and Chang, 2015). Cross-border energy trade infrastructures within the Central Asia Regional Economic Cooperation Energy Corridor have reduced carbon emissions per gross domestic product (GDP), increased GDP per energy use, and accelerated renewable energy generation in the region (Qadir and Dosmagambet, 2020). The evidence suggests that promoting power trade through interconnected transmission grids in an integrated electricity market would bring net benefits for participating countries.

The Great Mekong Subregion (GMS) countries possess abundant hydropower capacity. Cross-border power trade appears to stimulate hydropower development in the GMS (Chang, 2024a). The study shows that the utilisation rate of hydropower capacity in the GMS increases with the maximum allowed electricity imports. If an importing country is allowed to import electricity up to 50% of its domestic demand, the utilisation rate could exceed 80%, compared to just over 50% if no imports are allowed. However, utilisation rates differ across countries: Cambodia, Lao PDR, and Myanmar experience increases, whilst Malaysia, the Philippines, and Viet Nam show no change, and Indonesia and Thailand see decreases (Chang, 2024a). These findings suggest that the GMS countries should work to remove cross-border trade barriers and address hydropower underutilisation to increase energy resource availability through enhanced hydropower development and trade.

ASEAN has established a master plan to connect transmission networks across the region. According to the ASEAN Centre for Energy (2023) (Figure 15.1), the cross-border interconnection capacity within ASEAN stood at 7,720 megawatts (MW) as of April 2020. Additional capacity, from 555 MW to 625 MW, was planned by 2021, with future capacity expected to increase from 18,369 MW to 21,769 MW by 2025.

Figure 15.1. ASEAN Power Grid Interconnection Project Status



ASEAN = Association of Southeast Asian Nations.

Source: ASEAN Centre for Energy (2023).

Once these interconnections are complete, energy availability in ASEAN will increase, and the cost of meeting electricity demand will be lower than in a scenario without interconnections or cross-border trade (Chang, 2024b).

A cross-border power trade model explores how to minimise total electricity generation costs in ASEAN by considering capital expenditure, operational expenditure, carbon emissions and their costs, transmission costs, and losses under various trade conditions (Chang, 2024b). The model simulates two scenarios: a baseline scenario, replicating current networks with no cross-border trade, and an alternative scenario that assumes the full operation of planned ASEAN Power Grid interconnections, factoring in transmission costs over distances. The study explores how energy availability could increase under a net-zero transition by 2050 in ASEAN, along with economic and environmental implications.

Following the two cases, the study constructs four scenarios: the business-as-usual (BAU) case, no cross-border power trade with emissions capped at 2030 levels (NT2030), cross-border power trade up to 50% of domestic electricity demand (T50), and cross-border power trade up to 50% of domestic electricity demand with emissions capped at 2030 levels (T50-2030). The study presents four key findings. First, NT2030 incurs the highest total system cost, whilst T50 incurs the lowest. Second, completing the planned cross-border interconnections in ASEAN would be advantageous. Third, accelerating the integration of hydropower into ASEAN's power system would be beneficial, although it is essential to address possible environmental repercussions of hydropower development. Fourth, it is imperative to develop transparent, fair, and efficient frameworks for cross-border power trade in ASEAN.

Grid interconnections are anticipated to foster cooperation and peaceful relations (Stegen, 2023). The above simulation studies support the premise that cooperation amongst ASEAN member countries will ensure energy security by increasing the availability of energy resources in the region.

Long-distance interconnections are economically viable when the combined cost of renewable energy production costs in favourable locations, plus transmission costs and losses to less favourable areas, is lower than the cost of lower production in the less favourable area (Financial Times, 2023a). The interconnection of power grids and cross-border power trade is expected to increase the availability of energy resources in ASEAN, emphasising the need for expedited interconnection.

Small-scale nuclear reactors could further enhance the availability dimension of energy security in ASEAN. ASEAN should consider incorporating civilian nuclear energy into its fuel mix by forming a nuclear task force to study how ASEAN can best harness civilian nuclear energy, such as by establishing regulatory frameworks, advancing research collaboration, and nurturing a skilled nuclear workforce.

3.2. Enhance the Technological Applicability of Harnessing Energy Resources

Electricity generation in ASEAN member countries typically relies on nine technologies: coal, oil, gas, hydro, geothermal, solar PV, wind, biomass, and waste. Coal holds the largest share at about 43%, followed by gas at 33% and hydro at 14% (Lau, 2023). ASEAN countries have substantial renewable energy potential, especially in solar PV, wind, and hydro. Power generation technologies, both existing and emerging, include ultra-supercritical coal, combined-cycle and open-cycle natural gas, diesel, geothermal, hydro, mini-hydro, biomass, wind, solar PV, nuclear, coal with CCS, natural gas combined-cycle with CCS, bioenergy with CCS, lithium-ion batteries, and hydro pumped storage (Handayani et al, 2022).

New power generation technologies, especially renewables, incur high capital costs exceeding $2,000/MW. Similarly, carbon removal technologies such as CCS face high capital costs, ranging from $1,840 for natural gas CCS to over $3,000 for coal CCS and $5,000 for biomass CCS (Handayani et al., 2022). These substantial upfront capital costs are the main barrier to enhancing the technological applicability of harnessing energy resources. CCUS is another promising area for strengthening energy security.

Renewable energy resources, being capital-intensive, can be particularly vulnerable to 'working capital crunch' risks, especially with high interest rates increasing the borrowing costs. Green and transition finance can help ease the burden of these high capital costs. A green and transition finance taxonomy tailored to ASEAN – similar to the EU's Green New Deal and Japan's Green Growth Strategy – is expected

to draw private capital for sustainable technology investments. A working group under the ASEAN Secretariat, or a consortium of central banks in ASEAN, can work together to develop the finance taxonomy. It is critical to remain vigilant against 'transition-wash' to ensure that green and transition finance are used genuinely and effectively.

Civilian nuclear energy, as discussed in the availability dimension of energy security, also holds potential in the applicability dimension. ASEAN would benefit from a collective effort to develop a road map for harnessing civilian nuclear energy across ASEAN.

3.3. Ensuring the Societal Acceptability of Energy Resources

ASEAN member countries' carbon emissions from energy remain lower than those of other Asian countries such as China, Japan, and Korea (Section 2.3). However, this does not imply that ASEAN member countries have free rein to emit unlimited carbon dioxide. ASEAN member countries are advised to commit to reducing carbon dioxide emissions, improving energy efficiency, and targeting a net-zero transition by 2050.

The phase-down of fossil fuels was a key issue at the COP28 in the United Arab Emirates (Financial Times, 2023b), and a global shift away from fossil fuels is becoming imperative. ASEAN member countries would benefit from setting clear timelines to eliminate fossil fuels from their energy mix. Collaboration with financial institutions is essential to redirect capital towards a net-zero transition supported by clean energy technologies.

Civilian nuclear energy, as noted in the availability and applicability dimensions of energy security, presents a viable option to bolster energy security in ASEAN. Small-scale nuclear reactors may be appropriate for ASEAN's needs. Exploring how best to incorporate civilian nuclear energy into ASEAN's energy landscape is advisable. In addition to establishing a consortium to assess the feasibility of nuclear energy, forming a neutral body with representatives from both the private and public sectors is crucial to addressing public concerns and eliminating fears surrounding civilian nuclear energy use.

3.4. Guaranteeing the Affordability of Energy Resources

The per capita levels of primary energy consumption in ASEAN member countries remain lower than those of other countries (Section 2.4). Ensuring energy access and eliminating energy poverty amongst low-income households in ASEAN member countries must be prioritised. Establishing ASEAN-wide funds to promote the integration of electricity markets and the development of standalone renewable energy solutions can be considered. Such measures would enable fairer and improved energy access for low-income households, enhancing their overall well-being.

Developing strategies to guarantee the affordability of energy resources for people in ASEAN member countries requires an adaptable whole-of-government approach as well as ASEAN-wide schemes. One effective measure to support low-income households could be lowering energy bills and providing direct financial assistance, as has been suggested for the Roma community in Europe (Jovanovic, 2023). Collecting more comprehensive data on the status of energy access for those vulnerable to the net-zero transition is advised. Such data would facilitate the development and implementation of more viable policies.

4. Conclusion

Energy security is generally understood as the assurance of the physical availability of energy resources. However, this interpretation often tends to miss other key factors that are equally essential in securing energy supply. The mere physical availability of energy resources does not guarantee their delivery to end-users, as extraction, processing, and transport require applicable energy technologies. If a society does not accept a particular energy resource, as seen with coal or nuclear energy, it will remain unused. If energy prices are prohibitively high, resources become unaffordable, as is often the case with renewable energy sources, which, despite their potential, are still more expensive than fossil fuels.

Applying the 4A framework to ASEAN member countries, the study examines energy security across four key dimensions: the availability of physical energy resources, the technological applicability of energy resources, the societal acceptability of energy resources, and the affordability of energy resources. ASEAN shows limited availability of fossil fuels but huge potential for renewable energy development. The region has the capacity to deploy existing power generation technologies and could adopt advanced technologies with proper investment and technology transfer. Relatively low carbon dioxide emissions from energy use imply that ASEAN may not object to the use of fossil fuels, whilst low per capita primary energy consumption suggests that there is room for improvement in energy affordability.

Based on the evaluation of energy security across the four dimensions, the following four recommendations are proposed:

1. **Increase energy availability.** Develop fossil fuel reserves only with CCS or CCUS, invest in renewable energy and green hydrogen, accelerate the interconnection of power grids across ASEAN, and establish a consortium to study the use of civilian nuclear energy in the region.
2. **Enhance technological capabilities.** Establish ASEAN-wide technology centres to research and develop energy technologies such as CCS, CCUS, and civilian nuclear energy. Develop a workable taxonomy for green and transition finance to support environmentally friendly power generation and avoid 'transition-wash' when developing this taxonomy.
3. **Increase social acceptance.** Form a private–public body to study and address the concerns associated with civilian nuclear energy. Establish a timeline to reduce reliance on fossil fuels and gradually phase them out.
4. **Ensure affordability and fair energy transition.** Implement an adoptable, whole-of-government approach to enhance the affordability of energy resources, with fairness and equity as guiding principles. Create ASEAN-wide funds to support low-income households, ensuring that they have better access to energy and a better quality of life.

References

Amin, S.B., Y. Chang, F. Khan, and F. Taghizadeh-Hesary (2022), 'Energy security and sustainable energy policy in Bangladesh: From the lens of 4As framework', *Energy Policy*, 161, Article 112719.

ASEAN Centre for Energy (2023), Status of Southeast Asia Interconnectivity under ASEAN Power Grid, presented at Asia Pacific Energy Forum in Bangkok, 16 October 2023. https://tinyurl.com/yfnp59xp

ASEAN Secretariat (2015), *ASEAN Economic Community Blueprint 2025.* Jakarta: The ASEAN Secretariat.

ASEAN Secretariat (2021), *Mid-Term Review: ASEAN Economic Community Blueprint 2025*. Jakarta: The ASEAN Secretariat.

British Petroleum (2021), *BP Statistical Review of World Energy 2021*. British Petroleum.

Chang, Y. (2021), 'Integrated regional energy markets: Principles and prospects', in S.C. Park, C.J. Kim, F. Taghizadeh-Hesary, and P. Sirivunnabood (eds.), *Economic Integration in Asia and Europe: Lessons and Policies.* Tokyo: Asia Development Bank Institute, pp.621–37.

Chang, Y. (2024a), 'Power trade and hydroelectricity development in the Greater Mekong Sub-region: Perspectives on economic and environmental implications', in H. Phoumin, R. Nepal, F. Kimura, and F. Taghizadeh-Hesary (eds.), *Economic Analysis of Large-Scale Development of Solar PV with Battery Storage in ASEAN*. Jakarta: Springer and Economic Research Institute for ASEAN and East Asia, pp.55–77.

Chang, Y. (2024b), 'Net-zero transition and the power sector in ASEAN: Perspectives from an integrated electricity market, in F. Kimura, R. Shi, and H. Phoumin (eds.), N*avigating the Complexities of Energy Transitions in ASEAN and East Asia Region*. Jakarta: Economic Research Institute for ASEAN and East Asia (forthcoming).

Chang, Y. and Y. Li (2013), 'Power generation and cross-border grid planning for the integrated ASEAN electricity market: A dynamic linear programming model', *Energy Strategy Reviews*, 2(2), pp.153–60.

Chang, Y. and Y. Li (2015), 'Renewable energy and policy options in an integrated ASEAN electricity market: Quantitative assessments and policy implications', *Energy Policy*, 85, pp.39–49.

Chang, Y. and H. Phoumin (2021), 'Harnessing wind energy potential in ASEAN: Modelling and policy implications', *Sustainability*, 13, 4279.

Chang Y. and H. Phoumin (2022), 'Curtailed electricity and hydrogen in Association of Southeast Asian Nations and East Asia Summit: Perspectives from an economic and environmental analysis', *International Journal of Hydrogen Energy*, 47, pp.24548–57.

Chang, Y., Z. Fang, and Y. Li (2016), 'Renewable energy policies in promoting financing and investment among the East Asia Summit countries: Quantitative assessment and policy implications', *Energy Policy*, 95, pp.427–36.

Economic Consulting Associates (2010), *Greater Mekong Subregion (GMS) Transmission & Trading Case Study*. London: Economic Consulting Associates Limited.

Energy Institute (2023), *Statistical Review of World Energy 2023*. London: Energy Institute.

Financial Times (2023a), 'Interconnectors: why long-distance electricity makes sense', *Financial Times*, 23 October. https://tinyurl.com/48rnunzp (accessed 24 October 2023).

Financial Times (2023b), 'Ikea and BT among 130 companies to push COP28 for a timeline to ditch fossil fuels', *Financial Times*. https://tinyurl.com/4kvj9rvn (accessed 24 October 2023).

Handayani, K., P. Anugrah, F. Goembira, I. Overland, B. Suryadi, and A. Swandaru (2022), 'Moving beyond NDCs: ASEAN pathways to a net-zero emissions power sector 2050', *Applied Energy*, 311, Article 118580.

Jamasb, T. and M. Pollitt (2005), *Electricity Market Reform in the European Union: Review of Progress toward Liberalization and Integration.* Cambridge: Center for Energy and Environmental Policy Research.

Jovanovic, Z. (2023), 'Roma energy security', *Nature Energy,* 8, pp.1049–50.

Lau, H. C. (2023), 'Decarbonization of ASEAN's power sector: A holistic approach', *Energy Reports*, 9, pp.676–702.

Li, Y. and Y. Chang (2015), 'Infrastructure investments for power trade and transmission in ASEAN+2: Costs, benefits, long-term contracts and prioritized developments', *Energy Economics*, 51, pp.484–92.

Malik, S., M. Qasim, H. Saeed, Y. Chang, and F. Taghizadeh-Hesary (2020), 'Energy Security in Pakistan: Perspectives and Policy Implications from a Quantitative Analysis', *Energy Policy,* 144, Article 111552.

Oseni, M O. and M.G. Pollitt (2016), 'The promotion of regional integration of electricity markets: lessons for developing countries', *Energy Policy*, 88, pp.628–38.

Otsuki, T., A.B.M. Isa, and R.D. Samuelson (2016), 'Electric power grid interconnections in Northeast Asia: A quantitative analysis of opportunities and challenges', *Energy Policy*, 80, pp.311–29.

Qadir, S. and Y. Dosmagambet (2020), 'CAREC energy corridor: Opportunities, challenges, and IMPACT of regional energy trade integration on carbon emissions and energy access', *Energy Policy*, 147, Article 111427.

Sarangi, G.K., A. Mishra, F. Taghizadeh-Hesary, and Y. Chang (2019), 'Indian electricity sector, energy security and sustainability: An empirical assessment', *Energy Policy*, 135, Article 110964.

Siddiqui, S., K. Vailancourt, O. Bahn, N. Victor, C. Nichols, C. Avraam, and M. Brown (2020), 'Integrated North American energy markets under different futures of cross-border energy infrastructure', *Energy Policy*, 144, Article 111658.

Stegen, K.S. (2023), 'International relations theory on grid communities and international politics in a green world', *Nature Energy*, 8, pp.1073–77.

Taghizadeh-Hesary, F., N. Yoshino, Y. Chang, and A. Rillo (eds.), (2019), *Energy Security in Asia: Diversification, Integration and Policy Implications.* World Scientific.

Tongsopit, S.N.K., Y. Chang, A. Aksornkij, and W. Wangjiraniran (2016), 'Energy security in ASEAN: A quantitative approach for sustainable energy', *Energy Policy*, 90, pp.60–72.

Watcharejyothin, M. and R.M. Shrestha (2009), 'Effects of cross-border power trade between Laos and Thailand: Energy security and environmental implications', *Energy Policy*, 37, pp. 1782–92.

Word Bank (2024), *World in Data*. https://ourworldindata.org/co2-and-greenhouse-gas-emissions (accessed 3 February 2024).

Yao, L. and Y. Chang (2014), 'Energy security in China: A quantitative analysis and policy implications', *Energy Policy*, 67, pp.595–604.

Yu, X. (2003), 'Regional Cooperation and Energy Development in the Greater Mekong Sub-region', *Energy Policy,* 31, pp.1221–34.

Yu, Z., B.H. Bowen, F.T. Sparrow, V. Siriariyaporn, and L. Yu (2005), 'Integrated Energy Resources Planning for the ASEAN Countries and Southern China', *Oil, Gas & Energy Law Intelligence*, 3(4), pp.1–12.

Yuan, M., K. Tapia-Ahumada, and J. Reilly (2021), 'The role of cross-border electricity trade in transition to a low-carbon economy in the Northeastern U.S.', *Energy Policy*, 154, Article 112261.