A Comparative Analysis of the Energy Security Index in the ASEAN Region

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Abstract. In this study, a comparative analysis of four ASEAN countries has been done to assess these countries' energy security (ES) levels. With an overall degradation in the climate change situation, it calls for improving the ES level for each country through proper policy implications and implementation. This study aims to provide evidence and a data-driven framework to assess these countries' overall energy security index (ESI) to ensure long-term ES can be achieved. With stakeholder engagement and data curation, normalization is the critical method to be followed in this study. The results suggested an overall improvement in each country's ESI level, with Thailand showing the highest margin of gain of 58.6% and Singapore with the lowest. Indonesia and Malaysia have a similar growth pattern for ESI but not a significant one indicating the need to implement the current energy policies to their potential best. ASEAN as a region has very high potential to achieve higher ES scores with better regional coordination and understanding of the critical challenges.

Keywords: Energy security · Sustainability · Renewable energy · Environment · Technology

1 Introduction

Different groups of distinguished researchers in the field of energy security (ES) and sustainability have defined the concept of ES in the context of a country's or a region's energy demand and security of supply [1, 2], geopolitics, environmental sustainability goals, economic planning, technological advancement, and efficiency [3, 4]. As a result, Chester (2010) [5] stated that ES is "multi-dimensional" in nature, thus allowing researchers to create a framework with a set of dimensions on their own [6, 7]. The ultimate objective of ES, according to Liu et al. (2019) [8], is to preserve energy independence by having better and higher production than consumption, regardless of whether energy is imported or exported to or from other nations. This is a simplified version of a more detailed description, such as the feature in which a connected system works ideally and sustainably in all dimensions, free of any dangers [9]. ES relies on

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the global flow of primary and secondary energies and the trade of commodities and services generated using energy [10].

According to Dincer and Acar (2015) [11], meeting escalating energy demands in an environmentally friendly and long-term manner is a daunting job, particularly for developing nations. Safari et al. (2019) [12] discussed how a country's economic expansion has an environmental footprint, resulting in environmental constraints. Environmental issues are often regarded as humanity's most significant issue today. In 2019, it was estimated that 84.3% of energy will come from fossil fuels, which are a non-renewable source of energy, while 11.4% will come from renewable sources of energy such as hydropower, the solar, wind, and biofuels, with nuclear power accounting for the remaining 4.3% [13]. When compared to the year 2000, fossil fuels provided 86.1% of energy. ASEAN should make diversification of energy sources a top priority in order to minimize its reliance on fossil fuels. ASEAN should promote diversification of energy sources as a primary concern in an effort to reduce its dependency on fossil fuels. As the world advances toward more sustainable development, ASEAN should increase awareness of ES vulnerabilities and mitigate them by ensuring that the ES components are addressed. The issue stems from an over-reliance on fossil fuels such as coal and natural gas, which strains these energy sources and energy reserve to output ratio. The issue also arises from a policy framework that relies on fossil fuels to satisfy the majority of its energy needs [14].

There is a lack of studies that quantitatively assess the ES of the ASEAN region. Few studies [15–18] initiated the process and have successfully quantified it through various data collection methods and data curation. However, there is a gap in engaging stakeholders to verify and validate the indicators and hence the quantitative data of these indicators are being studied. Some studies have quantified ES for certain countries, but very few have assessed a region overall or multiple countries within a region. In this study, the gap assessment suggests a need to determine ES for the ASEAN region quantitatively. The current study aims to fill this gap by analyzing 5 dimensions of ES; availability, affordability, environmental sustainability, the applicability of technology and accessibility of energy. These dimensions have been identified through thorough stakeholder engagement in the previous studies [19]. A total of 26 indicators from these 5 dimensions have been quantified. The initial assessment was done for Malaysia as the dimensions, and the indicators were selected for Malaysia. However, these same sets of dimensions and their indicators can be applied to Singapore, Thailand, and Indonesia as well based on a similar energy outlook and pattern of energy demand and consumption.

Upon successful completion of the study's objective, a comparison was made to the four countries within ASEAN to understand the level of ES of each country. However, there are certain data limitations in terms of data unavailability for the listed indicators in Table 1. Firstly, the country-specific analysis of the results is done in Sect. 3.1 followed by an overall comparison of the ES level in Sect. 3.2. The results are followed by discussion and policy implications in Sect. 4, finally conclusive remarks, limitations, and future direction of the framework developed in this study.

1.1 Existing Frameworks for the ASEAN Region

There are multiple existing frameworks and data curation, normalisation, and weighting methods for the quantitative data collected for ES measurement. Table 1 summarises some of the studies with a similar approach in terms of data normalization but different frameworks with different numbers of indicators and dimensions based on the requirements of the study.

In Table 1, the cases within Asia have been selected with the same data normalization approach to ensure consistency is maintained throughout the study. While other literature quantify ES using different approaches are excluded.

Table 1. Existing frameworks for ES assessment in Asia

Source	Framework	Dimensions	Indicators	Key methodology followed
[17]	4A's framework	Availability, applicability, affordability, and acceptability	16	**Normalisation:** Min-Max approach **Scale:** 1–10 **Weighting**: Equal weight
[20]	4 A's framework	Availability of energy, applicability of technology, acceptability by the society, and affordability of energy resources	20	**Normalisation:** Min-Max approach **Scale:** 1–10 **Weighting**: Equal weight
[21]	4 A's framework	Availability, applicability, acceptability, and affordability	16	**Normalisation:** Min-Max approach **Scale:** 1–10 **Weighting**: Equal weight
[22]	Case study basis	Availability, affordability, efficiency, sustainability, and governance	20	**Normalisation:** Min-Max approach **Scale:** 0–100 **Weighting**: Equal weight
[15]	Case study	Energy supply and demand and, economic dimensions	6	**Normalisation:** Min-Max approach **Weighting**: Equal weight

2 Methods and Data

In this study, the primary data sources play the most crucial role in terms of data validation. The entire method is designed based on the previous research by Shadman et al. (2021) [23], which solely described the practices utilized to collect data and engagement with stakeholders. Data collection plays a vital role in addressing the research objectives in this study. Hence it is treated with the highest significance of protocol. A semi-structured interview was used to obtain qualitative data from stakeholders. The framework of ES was then created through qualitative data gathering and based on the main characteristics and the associated indicators for Malaysia ES. This framework provides the structure and foundation for establishing a quantitative system dynamic model and energy security index (ESI).

2.1 Data Collection Tools and Methods

To identify the essential characteristics of ES for Malaysia and other ASEAN nations, the first set of qualitative data was collected through stakeholder engagement [24]. In prior research by Shadman et al. (2021) [19], the data collecting procedure includes sample selection, rationale and with a list of stakeholders described in detail. A total of 16 stakeholders were questioned utilizing a series of semi-structured interview (SSI) questions, and the information gathered was captured and transcribed on audio/video. To construct emergent themes from the transcribed data, researchers used the qualitative data analysis (QDA) program Quirkos. This is an inductive method of producing theories and frameworks based on empirical evidence; in this instance, the data was gathered and recorded from stakeholders via SSI. As explained by Charmaz in the research by Hesse-Biber and Leavy [25], the grounded theory (GT) method is inductive, and its approach is iterative, as depicted in Fig. 1.

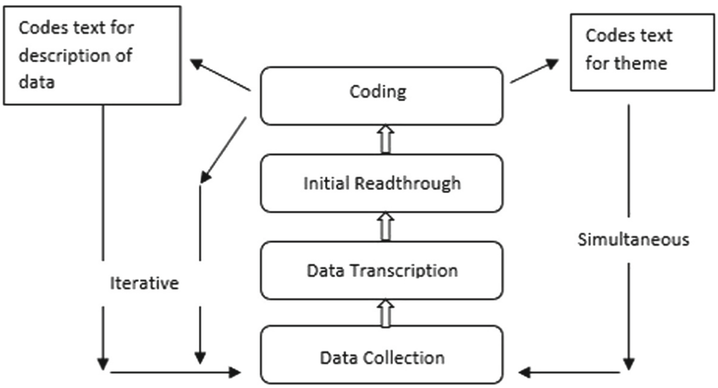

Fig. 1. The grounded theory process by Charmaz [25]

Quantitative data are collected from verified sources and under regulatory and statutory bodies of the respective countries. This is to ensure that secondary data collected from the public domain are of high quality and accuracy. The raw data, in particular, were collected from the following documents and websites within the public domain and are freely available for use [26–34]. The benefits of adopting secondary data from these sources are highly verified because Malaysian and ASEAN official agencies release it and are available in huge quantities at no cost. Additionally, secondary data has extensive background work, including literature reviews, case studies, published texts, and statistics [35].

Table 2 consists of the dimensions and the indicators resulting from the data collection process to be explained in this section. A combination of critical and systematic literature review as shown in Table 1 and stakeholder engagement process leads to the final set of dimensions and the indicators in Table 2.

Table 2. Dimensions and their respective indicators

Dimension	Indicators
Availability of energy (AV)	Total Primary Energy Supply per capita (TPES/POP)
	R/P oil
	R/P gas
	R/P coal
	Energy self-sufficiency ratio (total energy production/TPES)
	Total final energy consumption/POP
Affordability of energy (AF)	GDP per unit energy Unit: PPP per kg of oil equivalent
	Liquid fuel retail price/GDP for diesel and gasoline
	Energy consumption per capita (TFEC/POP)
	Electricity tariff Unit: sen/kWh
	Crude oil price Unit: USD/barrel
	Natural gas price Unit: Henry-hub
	Population with access to electricity (%)
Environmental sustainability (ENV)	CO_2 emission/POP
	CO_2 emission/GDP
	CO_2 emission/TPEC
	Share of RE in electricity generation (%)
	Non-carbon share/TPES
Applicability of technology and efficiency (APE)	Energy supply intensity Unit: toe/GDP in million RM
	Industrial energy intensity
	Overall energy intensity (TPEC/GDP) Unit: toe/GDP in million RM

(*continued*)

Table 2. (*continued*)

Dimension	Indicators
Accessibility (AC)	Access to electricity (%)
	Crude oil market concentration risk
	Electrification level (EPOP/POP) Unit: None
	Access to clean fuel and technology for cooking (%)

2.2 Data Coding, Curation and Normalisation

To ensure consistency across the index, it is necessary to convert all of the indicators to a single standard scale for data standardization. Data normalization is the term for this approach. For this investigation, the min-max method of data normalization was chosen. This approach evaluates the performance by comparing the best and worst results and to validate the min-max technique of data normalization, the research of [17, 18, 21] and [20] were rigorously followed. This technique is easy, accurate, and reasonable for a small or large amount of raw data. The weighting of the five dimensions has been equalized and maintained to avoid bias since there is no clear indication of the weight of each dimension.

The raw values for the indicators were transformed into normalized values with a range of 1–10. The following formula was used for the transformation of the indicators with positive attributes to ES. The high value of X' corresponds with high ES.

$$X' = 1 + \left(\frac{X - MinA}{MaxA - MinA}\right) \times (10 - 1)$$

For inversely related indicators like CO_2 emission per capita, the higher value would indicate to lower ES. Hence, for these indicators, the formula is changed to ensure that the maximum value in the scale is considered Min A and vice versa. The procedure used for the inversely proportional indicators is

$$X' = 1 + \left(\frac{X - MaxA}{MinA - MaxA}\right) \times (10 - 1)$$

X': The transformed value of the indicator
X: Raw value of the indicator
A: Range of the raw value
Max A: Maximum value of the indicator in the scale
Min A: Minimum value of the indicator in the scale.

Finally, the value of the dimension is calculated using the formula below, which is a simple average of each of the indicators for that respective year since the weight of each indicator within the dimension is considered equal.

$$Dimensional\ value = \frac{Indic.1 + Indic.2 + ..Indic.n}{n}$$

3 Results and Discussion

The results for Malaysia, Singapore, Indonesia and Thailand are presented in this section and discussed. All the tables in this section represent the normalized data generated following the methods in Sect. 2.2.

3.1 Malaysia

Table 3 shows the values of the respective dimensions after the indicators have been normalized and the average is taken to calculate the dimension value.

Table 3. Dimensional values for Malaysia

Year	AV	AF	AC	APE	ENV
2010	4.03	7.49	6.07	4.63	3.73
2011	4.54	6.47	8.05	4.68	4.58
2012	5.45	6.78	9.49	6.46	2.98
2013	6.01	5.08	7.99	6.16	3.4
2014	6.18	5.89	6.59	4.05	3.02
2015	5.44	8.82	5.5	1.59	2.78
2016	3.95	8.04	5.5	3.42	2.65
2017	3.15	5.55	10	5.23	5.14
2018	5.63	5.09	10	5.96	6.51

With scores of 5.19 and 6.64, the total ESI has increased from 2010 to 2018 as shown in Fig. 2. This improvement is an indication that Malaysia is moving in the righteous trajectory in terms of ES. However, it is only a 27.9% growth over 8 years, which might have been higher if environmental sustainability, technological applicability, and efficiency dimension performance had been better. This highlights the need for more significant research into energy-efficient technology, as well as the necessity to protect the environment from carbon-based emissions and raise the percentage of renewable energy to enhance the economic state, as documented in [36, 37] and [38]. Policy implications are required to ensure strict measures are taken against emission levels [39]. Danish et al. (2020) [39] have also highlighted that economic policy uncertainty may negatively impact environmental quality. Thus a nation's policy framework must be consistent. Expanded research and development funding and infrastructure can improve

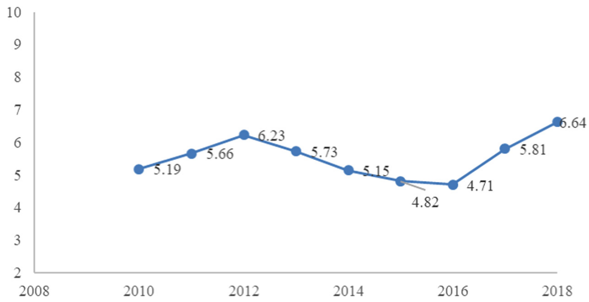

Fig. 2. Overall ESI level of performance for Malaysia from the year 2008–2018

the application of technology to enable more effective use of available assets, therefore protecting the current dimension of energy availability. The availability of energy has decreased dramatically from 2014 to 2017, affecting overall performance; otherwise, the ESI by the end of 2018 would have been higher.

3.2 Indonesia

Table 4 outlined the dimensional values for Indonesia's ESI from the year 2010–2018.

Table 4. Dimensional values for Indonesia

Year	AV	AF	ENV	APE	AC
2010	2.76	2.89	6.41	5.91	1.00
2011	4.17	5.31	2.68	5.42	2.63
2012	5.62	6.28	4.51	6.08	4.78
2013	5.16	5.59	8.97	5.84	6.09
2014	4.47	6.74	5.29	3.56	7.41
2015	4.39	4.89	5.61	2.60	8.53
2016	4.02	5.52	7.36	2.01	9.08
2017	3.88	8.22	5.89	2.62	9.24
2018	5.71	10.00	3.13	5.98	10.00

While Fig. 3 is the overall level of ESI for Indonesia, suggesting a very positive trend of increasing the level of ESI from 3.79 in 2010 to 6.96 in 2018 out of the highest achievable score of 10. This indicates that the ES of Indonesia has grown to a great extent. However, after 2013, the expected ESI, according to the trend, should have been higher for the upcoming years, which would eventually mean that by 2018, the ESI score should have been better than 6.96. There are a few key takeaways from the analysis of Indonesia, namely;

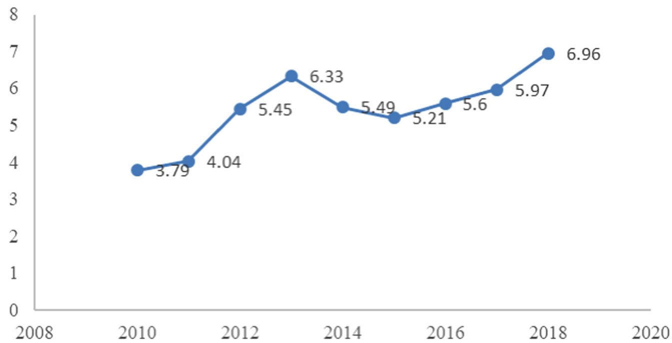

Fig. 3. ESI level for Indonesia from the year 2010–2018

- Energy availability has increased from the year 2010–2018, but it does not indicate an increase in the share of renewables or alternative fuel sources to a great extent. The rise in availability represents more fossil fuels over alternative sources. To achieve long-term ES, fuel diversification will be the most valuable.
- There is an overall degradation in the environmental sustainability dimension. This is alarming regarding climate change impact and Indonesia's environmental and energy policies, greenhouse gas (GHG) emission management and mitigation strategies. Government stakeholders would be responsible for shaping the future direction of this dimension with vision and policies towards climate change
- Access to energy in terms of electricity and fuel to households and the population in different sectors have shown the greatest improvement, and it is a positive takeaway from Indonesia's ES assessment of this study.

3.3 Singapore

In Table 5, it illustrates the dimensional values for Indonesia's ESI from the year 2010–2018.

Figure 4 shows the overall ESI level of Singapore for 8 years. The most notable point in the assessment of Singapore's ES is the consistency in its level. However, the ESI score was 6.44 in 2010 and increased to only 6.84 in 2018 after 8 years. In the years between, the lowest score was 5.77, followed by the highest in 2017 with 7.17. A consistent ESI level shows lower fluctuations and improved stability that prevents exogenous shocks to the energy demand-supply and price, but the ESI scores are still not highly satisfactory in this case. Ideally, Singapore's ESI score should be high due to its accessibility which has been 100% or a score of 10, indicating that all the population within the country has access to electricity and fuel at all times. This is possible with a small population allowing it to be maintained consistently and with overall perseverance by Singapore's effort to ensure good access.

The most noteworthy issue within the ESI framework for Singapore is the unavailability of reserves and energy production, indicating the heavy reliance on energy imports to meet the needs. This is coupled with a strong geopolitical relationship with its neighboring countries where the imported fuels are received by Singapore. Hence, the long-term

Table 5. Dimensional values for Singapore

Year	AV	AF	ENV	APE	AC
2010	2.76	6.10	3.63	9.68	10.00
2011	1.00	6.08	2.15	9.63	10.00
2012	3.81	5.19	4.91	6.61	10.00
2013	6.31	4.57	5.81	4.03	10.00
2014	7.06	3.99	7.17	1.92	10.00
2015	8.18	4.22	6.17	1.05	10.00
2016	7.45	6.98	7.44	2.42	10.00
2017	9.00	5.95	8.32	2.57	10.00
2018	7.53	6.46	8.56	1.66	10.00

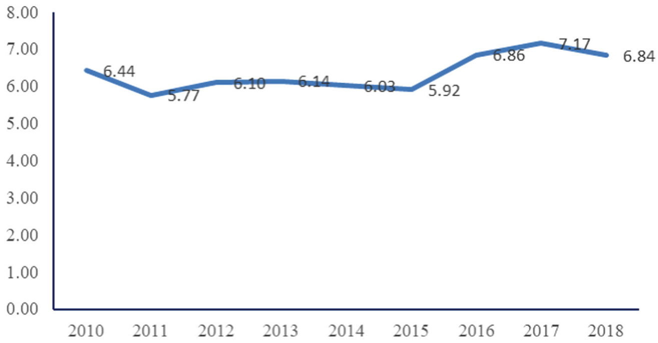

Fig. 4. ESI level for Singapore from the year 2010–2018

ES of the nation is heavily affected by this within this current assessment. Environmental sustainability has improved drastically, and this is in line with the nation's efforts to mitigate GHG emissions and exemplary implementation of existing measures within the energy policies of Singapore.

3.4 Thailand

The following Table 6 shows the dimensional values for Thailand's ESI from the year 2010–2018.

Figure 5 shows the ESI level for Thailand from 2010–2018. A similar trend has been observed in Malaysia and Indonesia, but with a higher overall score. The ESI level has increased and improved by a significant margin of 58.6% from 2010 to 2018, indicating a positive sign for Thailand's ES. Thailand also achieved the highest overall score in comparison to the three countries in this assessment. Environmental sustainability, the applicability of technology, and accessibility have shown increasing trends hinting at successful implementation of environmental policies and better frameworks for applying

Table 6. Dimensional values for Thailand

Year	AV	AF	ENV	APE	AC
2010	4.28	7.08	2.82	4.24	4.36
2011	2.77	5.40	3.99	5.76	3.53
2012	4.93	3.51	3.42	4.61	2.93
2013	6.51	4.35	3.05	4.98	5.75
2014	6.07	4.05	3.73	4.65	5.99
2015	7.47	4.93	3.79	4.15	8.08
2016	6.52	7.42	6.01	5.17	9.72
2017	6.64	6.79	7.31	5.69	10.00
2018	6.66	6.51	8.25	5.61	9.09

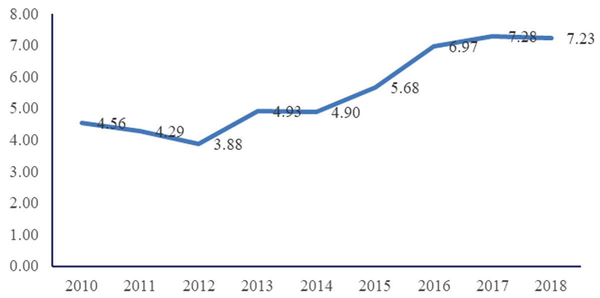

Fig. 5. ESI level for Thailand from the year 2010–2018

new and efficient existing technologies. Although affordability has deteriorated, and the availability of energy does not indicate an outstanding share of renewable energy (RE) within the energy mix of Thailand. The affordability of energy can be increased with a higher subsidy to the electricity tariff to compensate for high tariffs or lower ceiling prices for fossil fuels. Imported fossil fuels need to be of the same price or cheaper than the locally produced fuels in the reserves. The reserve to production ratio should improve availability while integrating RE as alternative sources for a clean start with lower GHG emissions.

4 Conclusion

The assessment in this study has shown an increase in ES levels for all four countries. Thailand is the country with the most significant improvement, followed by Malaysia, Indonesia and Singapore. Singapore's consistency in ES level shows a stable overall outlook with lower exogenous energy shocks. However, to secure long-term ES, there needs to be alternative plans and policies that can generate alternative fuel sources efficiently within Singapore and not heavily rely on imports. For Malaysia, Thailand, and

Indonesia, the stakeholders within the study have stated the confidence in a developing economy, as the use of energy for boosting economic growth takes up the priority in the energy trilemma followed by equity and lastly, environment. The perfect balance within these three is challenging because the primary aim is to ensure energy availability at all times at an affordable price. This prioritizes the two dimensions over the other three and hence leading to higher negligence and poor performance.

ASEAN as a region has abundant energy availability. Thus, the reserves are high, excluding Singapore, while other nations have been able to produce within the country. This secures the dimension. However, it comes at the cost of lower RE share and lower non-carbon-emitting sources share, hence higher risks of climate change and degradation. New and existing technologies can be made efficient with better research and development funds while ensuring access to energy can be reached 100% within the population throughout the countries. These can overall change the ES scenario of the ASEAN region, and with stronger geopolitical relationships and regional bonds, it will eventually be beneficial to all the countries in long-term ES.

The same set of dimensions and indicators can be developed further to create systems models to study and predict the future direction of the ESI level. This has been done in previous studies by Shadman et al. (2021) [40, 41], and it can be explored further. The limitations of this study lie within some data unavailability for specific years and certain indicators that have not been covered up using any proxy indicator or predicted data. There is a scope to increase the number of stakeholders within each country to validate the ESI scores and level further to improve the policy implications for the respective countries for future work.

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