The Development of a Measurement System for Fortifying Malaysia's Energy Security

SALEH SHADMAN

Under the advisory and supervision of

Dr Christina Chin M.M.

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Abstract

Energy security (ES) is a complex concept requiring a multifaceted approach to quantify through any set of dimensions, indicators, or variables. For the past two decades, researchers in energy management, policy, and sustainability have studied ES intensively. A critical issue identified in Malaysia is the lack of a consolidated framework and policy documentation for ES. The over-reliance on fossil fuels for energy generation, driven by the need for affordable, always-available energy, often overshadows environmental sustainability. This study's first objective is to create system dynamics models using primary and secondary data to map the most feasible dimensions of Malaysia's ES. Stakeholder engagement follows to further add input and context to this data, leading to primary data collection that identifies five ES dimensions. These dimensions are then used to create a framework for quantifying ES through indicator mapping, data normalization, and aggregation.

The methodology involves creating system dynamics models using Vensim based on secondary data from energy policies and reviews and complemented by primary data from stakeholder engagement and semi-structured interviews (SSIs) to identify five critical ES dimensions. The interviews, analysed with Quirkos using an inductive grounded theory approach, identified five dimensions from seven emerging themes focused on reducing fossil fuel dependency and enhancing energy efficiency. These themes include the role of renewable energy, fossil fuels, technology applicability, the 4A's of energy security, environmental sustainability, economic development, and governance. The Malaysian ESI is constructed using data normalization and aggregation techniques, visualized through radar charts, showing an improvement in energy security scores from 4.88 in 2006 to 6.64 in 2018.

The study underscores the need to reduce Malaysia's fossil fuel reliance by shifting to renewable energy and energy-efficient technologies, crucial for enhancing energy efficiency, affordability, and availability. While energy equity is central to Malaysia's energy trilemma, environmental sustainability also requires equal focus. The findings reveal inadequacies in addressing current ES dimensions, with some dimensions showing deterioration in scores, highlighting the need for a targeted ES policy. This study advocates for the development of a dedicated ES policy, emphasizing a data-driven and stakeholder-engaged approach to secure natural resources, promote sustainable economic growth, and mitigate environmental impacts.

Publications

Published:

1. Article in Online Magazine of University of Nottingham Asia Research Institute: SHADMAN, S.*, CHIN, C.M.M. and SAKUNDARINI, N., 2018. **Energy Security of Malaysia: Current and Future Scenario**

2. SHADMAN, S*., CHIN, C.M.M., YAP, E.H., SAKUNDARINI, N. and VELAUTHAM, S., 2021. **The role of current and future renewable energy policies in fortifying Malaysia's energy security: PESTLE and SWOT analysis through stakeholder engagement** in Progress in Energy and Environment. 16, 1-17

3. SHADMAN, S.*, CHIN, C.M.M., SAKUNDARINI, N. and YAP, E.H., 2020. **Quantifying the impact of energy shortage on Malaysia's energy security using a systems approach in Recent Trends in Manufacturing and Materials Towards Industry 4.0**, Springer Lecture Notes in Mechanical Engineering.

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Conference Proceedings and Poster Presentations

1. ASEAN Emerging Researchers conference 2018 – Oral highlights presentation
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   Identifying the dimensional indicators of energy security for Malaysia using system dynamics in Postgraduate Colloquium for Environmental Research (POCER 2019), Malaysia.

3. Faculty of Science and Engineering Postgraduate Research Poster Competition 2019- Poster Presentation
   Quantifying Malaysian Energy Security Using System Dynamics Approach

4. Innovative Manufacturing, Mechatronics & Materials Forum 2020 (iM3F 2020)- Oral Presentation
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5. The 2nd International Conference on Innovative Technology, Engineering and Sciences 2020- Oral Presentation
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   Methodological Review of Malaysia's Energy Security Measurement: A Systems Approach using Stakeholder Engagement.

6. Innovative Manufacturing, Mechatronics & Materials Forum 2021 (iM3F 2021)- Oral Presentation

SHADMAN, S., CHIN, C.M.M., SAKUNDARINI, N., YAP, E.H., and KHALID, P.K., 2021.
The impact of a decrease in energy reserve to production ratio on Malaysia's energy security

Contributions and Achievements in Research

1. Assistant Guest Editor of Special Issue ***"Energy recovery, Sustainability, and Waste Management"*** in Sustainability (ISSN 2071-1050, IF 3.251), MDPI.

2. Reviewer for the following journals: 1) Fuel, Elsevier, 2) Biocatalysis and Agricultural Biotechnology, Elsevier, 3) Scientific Reports, Springer Nature.

3. ***Vice Chancellor's Medal*** recipient for contribution to research and postgraduate community along with high performance sports development in University of Nottingham Malaysia.

4. Invited expert guest for '***Scenario workshop for the Malaysian energy transition***' by Asia Business School (ASB) and Institute of strategic and international studies (ISIS), 6-7th December 2021, Kuala Lumpur, Malaysia.

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Statement of Originality

I hereby certify that, to the best of my knowledge, the work contained in this thesis has not been previously submitted for a degree, master's, or PhD, to any other higher academic institution. I also certify that the work and intellectual property of this thesis are solely my own, and any form of techniques and knowledge adoption/adaptation has been properly acknowledged and referenced.

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Abbreviation

ES- Energy security

GHG- Greenhouse gas

IEA- International Energy Agency

Malaysian ESI - Malaysian Energy Security Index

APERC- Asia Pacific Energy Research Centre

SEDA- Sustainable Energy Development Authority

SSI- Semi-Structured Interview

GT- Grounded Theory

QDA- Qualitative Data Analysis

R/P- Reserve to production ratio

TPES- Total Primary Energy Supply

TFEC- Total Final Energy Consumption

GDP- Gross Domestic Product

TPEC- Total Primary Energy Consumption

CO_2- Carbon dioxide

RE- Renewable Energy

AV- Availability of Energy

APE- Applicability of Technology and Efficiency

AF- Affordability of Energy

AC- Accessibility of Energy

ENV- Environmental Sustainability

ESI- Energy Security Index

RETR- Renewable Energy Transition Roadmap

SD: System Dynamics

kWh- kilowatt-hour

1. Introduction

1.1. Understanding the multi-dimensional concept of energy security

Energy Security (ES) is a phenomenon that can be drawn back to as early as the stone age roughly 2000 years ago where the need for flammable materials like wood was important to make a living. A stable and adequate supply of these would lead to a stable ES for livelihood (Valentine, 2011). However, the concept of ES has evolved over the decades and has been defined by different groups of distinguished researchers in the field of ES and sustainability in the context of a country's or a region's energy demand and security of supply (García-Gusano et al., 2017); (Balat, 2010), energy policies, energy reserves, import and export policies, geopolitics, environmental sustainability goals, economic planning, technological advancement, and efficiency. Hence, (Chester, 2010) has argued ES to be "multi-dimensional" in nature, as later quoted by (Cherp & Jewell, 2014). This concept is multi-dimensional, and "fluid" and it does not have fixed dimensions with a fixed set of indicators that can quantitatively or qualitatively assess the ES of a nation or a region finitely (Technologies & Practices, 2019). This gives researchers the independence to design a framework with a set of dimensions that suits the energy outlook of a country or a region, hence, there have been several definitions of ES suggested in the literature.

For example, (Augutis, Krikštolaitis, et al., 2015) have stated the earliest definition of ES was by Winston Churchill in 1913 as "assurance of oil supply security lied only in the diversity of the supply." According to (Liu et al., 2019), the ultimate goal of ES is to maintain energy independence by having higher production than consumption irrespective of importing or exporting energy to or from other countries. This is a simplified definition of what can be more complex like, "the continuity of specific commodity or service supplies, or the impact of supply discontinuities on the continuity of the economy" (Winzer, 2011) and "feature (measure, situation, or status) in which a related system functions optimally and sustainably in all its dimensions, freely from any threats" (Azzuni & Breyer, 2018a). (Shepard & Pratson, 2020) has stated that "ES not only relies on the global flow of primary and secondary energies but also on the trade of goods and services produced using energy."

Daniel Yergin (2006) (Yergin, 2006) has stated that diversification will remain the essential starting point of ES for both oil and gas. Today, however, it will almost certainly necessitate the development of a new generation of nuclear and "clean coal" technologies and the encouragement of a more significant role for a range of renewable energy sources as they become more competitive. It will also necessitate investment in new technologies, ranging from those that are now available, such as the conversion of natural gas into liquid fuel, to others that are in the lab, such as energy supply biological engineering. Today, investment in technology across the energy spectrum is soaring, which will have a beneficial impact on the future of energy and the environment. Yergin emphasises that energy is not a problem that occurs in a controlled silo. The book's greatest strength is its ability to extract generally practical ideas from history lessons, high-level technical overviews, and enlightening stories. Interconnections with major worldwide events exist in the energy realm, as Yergin demonstrates (Krupa, 2014).In the present time, overlapping indicators and dimensions that are not only limited to the affordability or availability of energy are important too like social acceptance, the applicability of technology, and improving the efficiency of energy resources and end products while ensuring a lower emission level of GHG that has equal importance as availability and affordability of energy.

The aim for developing nations has always been to achieve energy resources at an affordable price with supply security at the same time ensuring minimal environmental impacts (Dincer & Rosen, 1998). (Kumar & Tewary, 2021) have mentioned that the world is now striving towards the use of cleaner energy resources to achieve ES which is often disrupted by the rise in population by the unprecedented urban development. ES is a multi-dimensional phenomenon that can be conceptualised based on several factors such as the energy demand pattern, export or import-dependent state (Ashari, 2013), the geopolitics of resources, energy policy structure of a nation, etc. It is vital to understand which of these factors dominates within a country's energy framework that further defines the ES of that respective nation. (Ashari, 2013) has stated that ES which used to be a non-traditional security issue now plays a key role in the national security of any nation. (Winzer, 2011) believes that the lack of a consolidated ES definition has made it difficult to measure and balance it against other policy objectives.

Over the years, ES has been defined by researchers in several ways that give an indication of the existence of numerous dimensions within this complex system of ES. Table 1 represents a few simplified definitions of ES. The motive behind tabulating the definitions is to understand the pattern of how the term is defined and what are the key dimensions reflected in the definitions.

Table 1: Definitions of ES as quoted by researchers.

Source	***Definition***
(Azzuni & Breyer, 2018a)	"Feature (measure, situation, or status) in which a related system functions optimally and sustainably in all its dimensions, freely from any threats."
(Shepard & Pratson, 2020)	"ES not only relies on the global flow of primary and secondary energies but also on the trade of goods and services produced using energy."
(Tongsopit et al., 2016) (Tongsopit et al., 2016)	"Enough energy supply (quality and quantity) to meet all requirements at all times of all citizens in affordable and stable price, and it also leads to sustained economic performance and poverty alleviation, a better quality of life without harming the environment."
(Kucharski & Unesaki, 2015)	"Assessing various types of risk in the energy system."
(Liu et al., 2019)	The goal of ES is to maintain energy independence by having higher production than consumption irrespective of importing or exporting energy to or from other countries
(Augutis, Krikštolaitis, et al., 2015)	"Assurance of oil supply security lied only in the diversity of the supply."
(Winzer, 2011)	"The continuity of specific commodity or service supplies, or the impact of supply discontinuities on the continuity of the economy"
(Jewell et al., 2014)	"Low vulnerability of vital energy systems"
(IEA (International Energy Agency), 2020)	"Availability of sufficient and uninterrupted energy sources at a fair price."
(Sovacool et al., 2013)	"Equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed, and socially acceptable energy services to end-users."
(Azzuni & Breyer, 2018b)	"The status of a system that functions optimally and sustainably without any threats where all dimensions are considered."
(Nair et al., 2021)	"Sufficient availability of energy at all times at an affordable price to ensure consumer satisfaction coupled with a gradual improvement in environmental

	sustainability to ensure better ES."- This is the definition that has been defined for Malaysia through this research.

After assessing the definitions of ES for respective countries and following the research carried out for Malaysia, the definition of ES for Malaysia has been defined in the last row of table 1.

1.2. The motivation of the research, the problem statement, and the knowledge gap assessment

The importance of energy in the current era is unprecedented for the development of human activities and livelihood. Energy should be used in a way that not only serves the current activities but is also sustainable for future use. Sustainable use of energy requires planning and competent management of the available energy resources at our disposal. The efficient management of energy resources in terms of cost-effectiveness, lower wastage and improved access requires specific skillsets to be developed within the management structure of corporate organisations, industries, and even households.

Current Challenges: ES remains a pivotal aspect for sustainable development globally and specifically in Malaysia, a country still grappling with the challenges posed by its heavy reliance on fossil fuels and the environmental repercussions that follow. As the world faces an energy crisis with increasing demand outstripping supply, Malaysia has managed to maintain its energy industry relatively stable. However, the urgency to shift towards more sustainable practices is felt more acutely now than ever. This is underscored by Malaysia's initiatives such as the National Energy Transition Roadmap which aims to reduce carbon emissions and foster a green economy, reflecting a broader recognition of the need for sustainable energy practices. This defines ES in the simplest way where energy must be always available at an affordable price. Hence, understanding ES is of utmost importance to ensure that we are not only focused on the availability and affordability of energy but also the dimensions that are equally important and closely knitted with these two dimensions.

Gaps in Knowledge: Despite these efforts, Malaysia's ES strategy requires a more cohesive and comprehensive approach, particularly in integrating renewable energy sources into the national grid. The recent strides towards a 20% renewable energy mix by 2025 and initiatives like Feed-in Tariffs and Net Energy Metering highlight progress yet also reveal gaps in achieving a balanced energy trilemma of affordability, accessibility, and sustainability (Husain et al., 2021). The transition is not just about adopting new technologies but also about ensuring these changes contribute positively to Malaysia's socio-economic fabric without exacerbating current environmental challenges. The importance of ES is also very well known to everyone in recent days yet lacking the necessary attention that is required to fortify ES. The traditional sources of energy for industrial and household use in most of the country to date comes from non-renewable sources such as coal and natural gas. This is one of the concerns that every country is aware of, and goals have been set to find alternate options to improve their ES and to sustain in the future in terms of energy. With the increase in world population, there is an increase in demand for energy worldwide while the supply remains quite stagnant and not fulfilling all the demand in the most sustainable way. There is an improvement in living standards with the increase in GDP, urbanisation, and globalisation which imposes more pressure on the energy sources of the country. The motivation behind this research is to look deeper into the field of ES in Malaysia by conceptualising the ES dimensions, its indicators, ESI, and SD approach to make futuristic predictions for policies.

However, (Sovacool, 2013) has quoted that Malaysia has the best ES performance out of the 18 countries that were assessed in the study. This result is motivating towards quantifying Malaysia's ES performance even further. Notable amongst the research of ES for Malaysia, the work by (Sharifuddin, 2014) discussed the methodology that can be used to create an ESI for Malaysia. Nevertheless, the work did not display or discuss results that can be generated using the methods described. (Sharifuddin, 2014) has selected the ES dimensions based on the detailed work of (Sovacool, 2013; Sovacool et al., 2011). The attempt was to overcome the shortcomings of APERC's tool of measuring ES in the study 'A quest for energy security in the 21st century' (APERC, 2007a) where the results are not unidirectional and not clear whether the results can develop an overall assessment index for ES.

The other energy security indexes (ESI) developed for Malaysia were by (Endang Jati Mat Sahid, 2018; Endang Jati Mat Sahid & Sin, 2019; Yusoff & Bekhet, 2020). The methods and strengths of these studies have been discussed in Table 1. The study of (Foo, 2015) discusses in depth the various energy profiles of Malaysia and the development of energy policies towards ES, while (Khattak et al., 2018) reviewed the ES status of Malaysia and the strategic approach to enhance the future of ES in Malaysia. These studies lack the quantification process of ES that is aimed to consolidate in this research. None of these studies engaged any stakeholders from Malaysia or ASEAN member nations to understand the suitability of their dimensions towards Malaysia's energy outlook.

Research Motivation: The motivation behind this research is to provide a structured and quantifiable approach to understanding and improving ES in Malaysia. By focusing on system dynamics models and the development of a Malaysian Energy Security Index (Malaysian ESI), this study aims to capture the complex interdependencies of the energy sector and provide actionable insights for policymakers. This research attempts to bridge this gap by identifying the key dimensions of ES for Malaysia. This is done through thorough engagement with 16 stakeholders via semi-structured interviews and 117 participants of a survey who are a part of the Ministry of Energy, Energy Commission of Malaysia, the Sustainable Energy Development Authority (SEDA), and various energy research institutes and individual researchers in this field. (Sovacool et al., 2011) had initiated engaging stakeholders through interviews, surveys, and workshops with the energy experts which builds a foundation for the work that has been done with the experts in this study.

1.3. Research objectives

The key research objectives (RO) of this research can be outlined into 3 aspects (see Table 2). The RO's have been listed below and related with part of the problem statement that it targets to clarify.

Table 2: Research Objectives

RO	Objectives
1	To identify the key dimensions of energy security for Malaysia and the respective indicators of each dimension through appropriate and the most relevant stakeholder engagement.
2	To create a causal link between the dimensional indicators of ES for Malaysia using the system dynamics approach of modelling and to draw policy implications.
3	To develop the Malaysian Energy Security Index (MALAYSIAN ESI) and compare the ESI performance with neighbouring countries

The following objectives aim to address the gaps identified in the problem statement, focusing on a systematic and future-ready framework for Malaysia's energy sector:

1. **RO 1: Identifying Key Dimensions and Indicators**

   The first objective involves identifying the key dimensions of energy security tailored to Malaysia's unique needs and the respective indicators for each dimension. This step is crucial as it addresses the problem of an insufficiently articulated framework for energy security in Malaysia. By engaging with relevant stakeholders, this objective ensures that the dimensions and indicators identified are not only theoretically sound but also practically relevant and grounded in the real-world context of Malaysia's energy sector.

2. **RO 2: Creating Causal Links with System Dynamics Modelling:**

   The second objective tackles the issue of fragmented and often reactive policy measures by proposing to use system dynamics modelling. This approach will enable a holistic understanding of the interactions between various dimensions of energy security. By creating these causal links, the research will provide a foundation for policymakers to anticipate outcomes and effects of potential changes in the energy sector, thus contributing to more robust and forward-looking energy policies.

3. **RO3: Developing and Comparing the Malaysian Energy Security Index (Malaysian ESI):**

   Finally, the development of the Malaysian ESI addresses the need for a quantifiable, clear benchmark to measure Malaysia's energy security and compare it with regional counterparts. This comparative analysis is essential to evaluate Malaysia's performance and identify areas of strength and potential improvement. It also facilitates regional cooperation and learning, which are vital in the context of global and regional challenges in ES.

Each of these objectives not only addresses specific gaps identified in the problem statement but also contributes to a comprehensive strategy aimed at enhancing Malaysia's energy security. By systematically tackling these issues, the research aims to foster a sustainable, efficient, and secure energy future for Malaysia.

1.4. Research contribution and significance

1.4.1. Contribution

The contribution of the research is towards the development of a consolidated body of knowledge and methods to understand the impact that ES has on various dimensions, sectors such as the economy, environment, and social aspects of living. Engaging stakeholders to collect qualitative data towards identifying the key dimensions have not been done in the existing body of literature for Malaysian context it is important to involve stakeholders. The system dynamics approach of modelling has been applied for the first time in ES research of Malaysia to create causal connections and links between the dimensional indicators and this have been developed by engaging further 117 participants from energy and sustainability background. Finally, the development of Malaysian ESI using a 5-dimensional framework is also a novel contribution to the body of knowledge and research for Malaysia's ES. The Malaysian ESI can quantify ES on a scale of 1-10 to rank each year's performance based on the availability of data.

The Malaysian ESI is constructed around a comprehensive framework known as the 4A's of energy—Availability, Affordability, Accessibility, and Applicability—combined with a critical fifth dimension: Environmental Sustainability. This five-dimensional framework ensures a holistic approach to evaluating energy security, integrating both traditional energy metrics and sustainability considerations.

Measurement Parameters and Indicator Selection: The development of MALAYSIAN ESI involved a rigorous process to establish relevant indicators. Initially, semi-structured interviews were conducted to extract emerging themes, leading to the preliminary identification of potential dimensions for the index. Through an extensive review of 18 research articles, 93 indicators were initially identified. These were then narrowed down to 25 key indicators based on their significance and relevance in the selection process. The final selection of indicators was subject to a validation test against three crucial criteria:

1. **Policy Relevance:** Ensuring the indicators are useful for informing and shaping energy policies.

2. **Availability of Quantitative Data:** Indicators must be quantifiable with accessible data.
3. **Stakeholder Perspective:** Reflecting the views and insights of key stakeholders involved in energy management.

After this validation, 18 indicators were finalized, each weighted equally to prevent bias and ensure a balanced representation of all dimensions.

1.4.2. Significance of research

The significance of the research lies within the development of a measurement system for ES of Malaysia using a mixed-method qualitative and quantitative approach. The data collection from stakeholders involving semi-structured interviews and surveys are done in detail and depth to avoid any bias in dimension selection for ES. The measurement system involves two methods of quantification of ES through system dynamics (SD) approach and development of the Malaysian ESI. Malaysian ESI states the overall level of ES for Malaysia using quantitative data collected from the energy reporting bodies and regulatory bodies under ministry of energy. While the SD approach involves futuristic modelling of indicators of ES to predict and understand the trend for the future. This allows the policymakers and analysts to understand the better performing policies, their level of implementation and their implications. The same measurement system can be developed and curated based on country specific energy outlook using the same set of methods explained in this research hence making this a viable option for any country or region.

1.5. Thesis Outline

Chapter 1 discusses the multi-dimensional concept of ES and the various definitions of ES given by different groups of researchers. It is very important to understand this term that is often termed as “slippery” and “multi-dimensional” in nature to deep-dive about ES. The current ES status of Malaysia is also discussed in this chapter followed by identifying the knowledge gap and problem statement of the research. The research objectives are defined in this chapter which has been fulfilled upon the completion of the research throughout this doctoral study research.

Chapter 2 comprises the review of existing literature on several ES-related topics. Firstly, the energy demand and supply outlook are studied followed by the energy policies of Malaysia. The energy policy structure of Malaysia is studied from 1979-present to understand the pattern of the energy policies and their relationship with ES. This plays a key role in understanding where the ES of Malaysia stands from the viewpoint of the policymakers of the nation. Various energy security indexes (ESI's) developed to assess ES quantitatively within the Asian countries have been studied and summarised to understand the best practices and methods used to develop the index. The interaction between energy policies and the ESI's in literature is identified to develop an understanding of the best methods to design the Malaysian ESI. The current ES challenges and issues are identified through literature from scholarly articles and annual energy reports by the energy commission of Malaysia and sustainable development authority alongside the ministry of energy and natural resources. A comparative analysis is also created between the neighbouring ASEAN countries to compare the ES status of these nations. It is important to do this as the ES of each nation directly or indirectly affects the neighbouring countries due to trade relations etc. Finally, the concept of System Dynamics is introduced in this chapter to understand the fundamentals of this approach of modelling to quantitatively assess ES.

Chapter 3 describes the various methods used in this research to consolidate the concept of ES. The research workflow plan has been laid out to explain the steps chronologically and systematically. Firstly, the qualitative data collection methods, data analysis methods, and stakeholder and survey participants selection is justified. Secondly, the methods used for SD approaches have been explained. The formation of Causal loop diagrams (CLD's) and Stock and Flow Diagrams (SFD's) have been described in detail. Lastly, the methods used to quantify ES using an ESI have been discussed. The data collection, data normalisation, weightage, and aggregation have been explained alongside the data analysis techniques used to analyse the ESI data generated.

Chapter 4 conceptualises ES by engaging stakeholders and survey participants. A total of 117 survey participants and 16 stakeholder interviews have been conducted in this part of the research. 33 qualitative survey questions have been designed for the survey while semi-structured interviews (SSI's) have been designed for stakeholder engagement. 7 emerging themes have been discussed from the stakeholder engagement session using qualitative data analysis (QDA) software Quirkos. These 7 emerging themes are 1) The role of renewable energy, 2) Fossil fuels, 3) Applicability of Technology, 4) The 4A's dimensions of energy security, 5) environmental sustainability, 6) Economic development and 7) Role of governance. The emerging themes have been presented in depth to conclude the final dimension selection of ES for Malaysian ESI in chapter 6. The survey results have been used to design the CLD's and SFD's in the following chapter 5. The data collected and analysed in chapter 4 are critical towards the results obtained in chapters 5 and 6. Lastly, in chapter 7 the emerging themes were narrowed down to 5 specific dimensions including the 4A's (availability, affordability, accessibility and applicability) of ES and the fifth-dimension environmental sustainability to quantitatively define the Malaysian ESI.

Chapter 5 is the first quantification process of ES scenarios for Malaysia based on the current energy policies and their key objectives. A total of 3 scenarios in the first stage based on survey data collection and secondly 2 scenarios based on semi-structured interviews have been shortlisted after studying the energy policies in-depth as discussed in chapter 2. The 3 scenarios are (a) 20% share of Renewable energy in the energy mix; (b) energy intensity reduced by half of the original value and (c) energy shortage by 30% of the current value.

Three different CLD's are designed for these scenarios which are then compiled to create a final CLD. The CLD is converted to SFD by adding stocks and flows to the required indicators within the final CLD. The design of the scenarios and the design of the SD model have been explained in the chapter. The results are analysed, and policy implications are drawn from the analysed results to facilitate future ES policymaking in Malaysia.

Chapter 6 is the final quantification phase of ES using the Malaysian ESI developed through this research. A 5-dimensional framework has been used to design the Malaysian ESI based on the qualitative stakeholder data collected in chapter 4. The process of the data curation, data analysis, framework design, and Malaysian ESI design is described in chapter 3. The Malaysian ESI shows the result of the index for 13 years based on the average values of all 5 dimensions of ES selected for Malaysia from the 7 emerging themes discussed in chapter 4 from the SSI data analysis. The indicator mapping process for all the dimensions has been explained here. A total of 93 indicators have been studied out of which 18 indicators were listed down to develop the Malaysian ESI. The selection process for these indicators has been discussed in this chapter. This chapter concludes with policy implications drawn from the analysis of the MALAYSIAN ESI results based on the standard deviation of the data, the average of 5 dimensions, and fundamental ES questions by notable ES research literature previously. A comparative analysis between Malaysia's neighbouring countries; Thailand, Singapore and Indonesia have been done to understand the position of these countries in terms of ESI and level.

Chapter 7 concludes the overall research carried out in the 4 phases as mentioned in chapter 3. The overall establishment of the concept of ES for Malaysia, its quantitative and qualitative results are concluded here. The key findings are listed down alongside the policy implications that can be suggested to ensure Malaysia can safeguard a better ES in the future. The future scope is mentioned in this chapter to develop the Malaysian ESI and validate it through the second round of stakeholder engagement with the same set of stakeholders or more. The limitations are also mentioned here while the strengths of this research and its weaknesses are elaborated. The key takeaways from this research aim to facilitate the policymakers, decision-makers, and research analysts who work in close tandem with the government of Malaysia in designing and evaluating energy policies.

2. Literature Reviews

This chapter provides a comprehensive review of the literature on various aspects of ES relevant to Malaysia, beginning with an analysis of the country's energy demand and supply outlook. It explores the evolution of Malaysia's energy policies from 1979 to the present, examining their impact on ES and their role in shaping the national policy perspective. This chapter also assesses various Energy Security Indexes (ESIs) developed across Asian countries, summarizing the methodologies and best practices that could inform the development of the Malaysian ESI. The current challenges and issues in ES are identified through scholarly articles, annual reports from the Energy Commission of Malaysia, and other authoritative sources. A comparative analysis of secondary data with ASEAN neighbours highlights the regional interdependencies that influence ES due to trade and other relations. The potential of Malaysia's renewable energy (RE) policies and projects are discussed in this chapter to constructively discuss the future of RE in improving ES of the nation. Finally, the chapter introduces the concept of System Dynamics, laying the groundwork for its application in modelling ES quantitatively.

2.1. Energy security and energy outlook of Malaysia

2.1.1. Energy security definitions and dimensions

ES is a phenomenon that can be drawn back to as early as the stone age roughly 2000 years ago where the need for flammable materials like wood was important to make a living. A stable and adequate supply of these would lead to a stable ES for livelihood (Valentine, 2011). It has been defined in several ways by different studies and researchers in general terms and in terms of respective countries or regions around the globe. (Kamyk et al., 2021) has defined ES as "The supply of energy to a nation must be adequate and reliable and energy prices must be affordable to the population." (Winzer, 2011) has defined ES as "continuity of energy supplies relative to demand". If security is defined from the perspective of private utilities, end consumers, or public servants, the concept could further be reduced to "the continuity of specific commodity or service supplies, or the impact of supply discontinuities on the continuity of the economy". It can also be defined as the "feature (measure, situation, or a status) in which a related system functions optimally and sustainably in all its dimensions, freely from any threats" (Azzuni & Breyer, 2018a). ES can also be defined from the 4A's of energy security; availability, affordability, accessibility, and acceptability (Cherp & Jewell, 2014). (Martchamadol & Kumar, 2012) have defined energy security in their study later quoted in (Tongsopit et al., 2016) as "enough energy supply (quality and quantity) to meet all requirements at all times of all citizens in affordable and stable price, and it also leads to sustained economic performance and poverty alleviation, a better quality of life without harming the environment."

This is not an exhaustive list of the definitions, but these definitions cover the most important dimensions and aspects of ES that are to be discussed. It is important to understand that ES has been defined over the decades by different researchers and energy agencies in different ways with the existence of commonality. The most reflected dimensions in these definitions include socio-economy, availability, acceptability, affordability, and environmental sustainability. Emphasis has been given to these dimensions and quite rightly so because ES cannot be defined concerning one single dimension, it is a combination of these dimensions that need to be taken care of to ensure that a nation's ES is improving. The demand for energy increases with an increase in the world's population, households, and industries. Hence, to meet these demands, every country requires a supply of energy that is continuous, equitable, and stable. The ability of a country to have a reserve of energy and continuous supply at present and future indicates how secure it is in terms of energy. ES of a country can be further defined using various indices divided into two broad spectra of quantitative and qualitative definitions. Quantitative definitions include energy prices, energy efficiency, and energy intensity whilst qualitative definitions include energy availability, infrastructure, social and environmental impacts of energy, and involvement of government in securing energy for their country.

ES can be categorized into long and short-term scopes. Long-term ES deals with opportune national investments in supplying energy in consonance with economic developments while maintaining sustainable and environmental requirements (Energy Commission (Malaysia), 2017). Renewable energy (RE) is a key component in securing long-term ES for Malaysia as it fulfils both the criteria mentioned above for contributing to the economic development of a country simultaneously being an environmentally friendly source. While short-term ES refers to the ability of a country to respond quickly to any changes and fluctuations in the supply-demand of energy. (Zhu et al., 2020a) have suggested that diversification of the energy mix by the use of RE as an alternative source plays a major role in energy supply security. It reduces the risk of market disruption through the means of diversification of energy by using RE (Zhu et al., 2020a). (Kim & Alameri, 2020) has suggested the use of RE and nuclear energy in alliance with each other to tackle the global energy demands sustainably. Hence, securing domestic energy supply through alternative means like RE and reducing the reliance on energy imports play a key role in securing long-term ES for Malaysia.

2.1.2. Malaysia’s energy outlook

In the year 2017, 1,894 Mtoe of TPES of the world was generated from RE which is 13.5% of the total TPES of 13,972 Mtoe (IEA, 2019). Out of the 13.5%, the major contributors were biofuels and waste with 9.2%, hydro with 2.5%, and 1.8% of solar, wind, and rest of the renewable sources (IEA, 2019). Renewables accounted for the second-largest contribution towards global electricity generation after coal (38.5% share) with a contribution of 24.5% just above natural gas at 23% (IEA, 2019). At the end of 2018, RE contributed to 33% of the total installed power generation capacity globally (Miranville, 2019). These statistics are promising for the environmental sustainability of the world as there is an increasing trend towards the use of RE in the TPES and electricity generation.

In the year 2017, Malaysia’s electricity generation using RE was just below 30 TWh (“Southeast Asia Energy Outlook 2017,” 2017), which is still lower than Vietnam, Thailand, and Indonesia in the SEA region. This explains to some extent that Malaysia is not too keen yet to make a bold move towards RE as one of the major fuels for electricity generation as Malaysia has a safe and high reserve margin for electricity for the coming years. The reserve margin for Peninsular Malaysia for the year 2020 is at 32% and is expected to increase to 48% in 2021 and remain at around 44% in 2022 according to ‘Peninsular Malaysia Generation Development plan (2020-2030)’ by Energy Commission (Energy Commission Malaysia, 2020a). However, the ‘Peninsular Malaysia Generation Development plan (2020-2030)’ (Energy Commission Malaysia, 2020a) predicts that there will be a further increase in RE share for electricity generation from 9% in 2020 to 23% in 2030 and hence reducing thermal power generation capacity from 82% to 70%. The increase in RE capacity does not show a proportional decrease in thermal power plants capacity which reflects the dependence of Malaysia on thermal power plants. In the year 2018, the gas component occupied a share of 35% of the total energy mix while coal is still the most dominant source with a share of 57% with the rest coming from RE sources (Energy Commission, 2019). This is an indicator of threat towards long-term ES of Malaysia as fossil fuels dominate the energy mix with RE holding a comparatively negligible share. In the same year, Malaysia recorded approximately 6% of RE total installed capacity including hydropower with capacity up to 100MW, bringing the total capacity to 2,057MW (Miranville, 2019). Figure 1 represents the share of TPES by fuel type in Malaysia in the year 2017, which gives a clear contribution of different fuel types (Statistics, 2019).

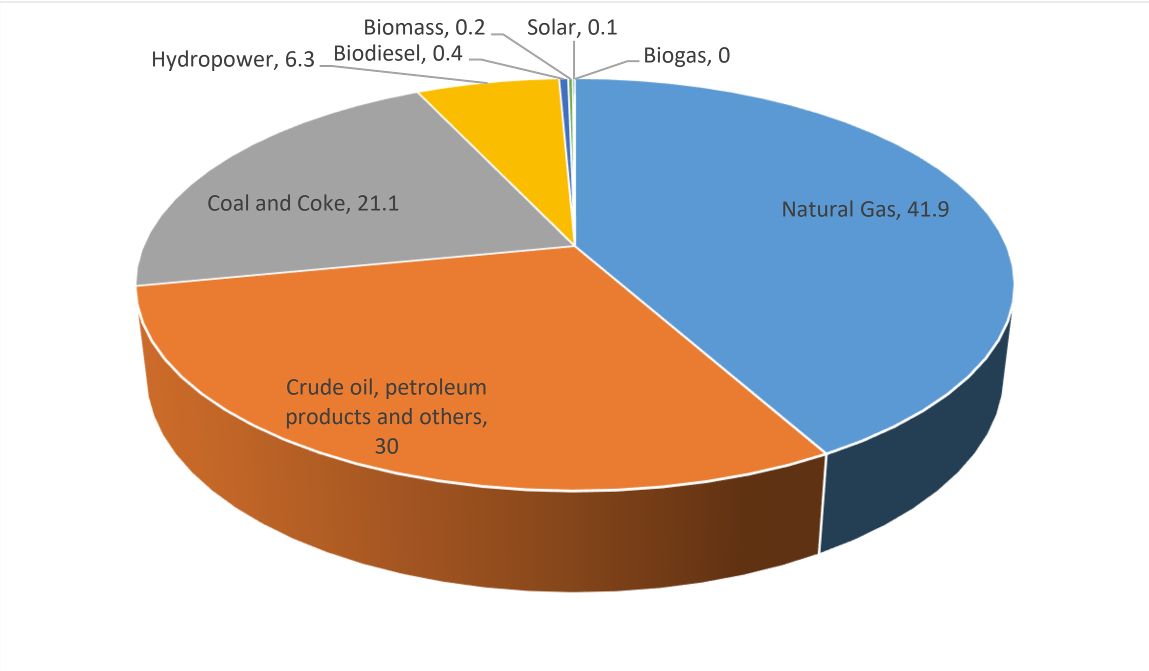


Figure 1: TPES by fuel type for Malaysia in 2017 (Statistics, 2019)

Figure 2 shows the TPES share in 2020 and it has not changed significantly compared to that of 2017.

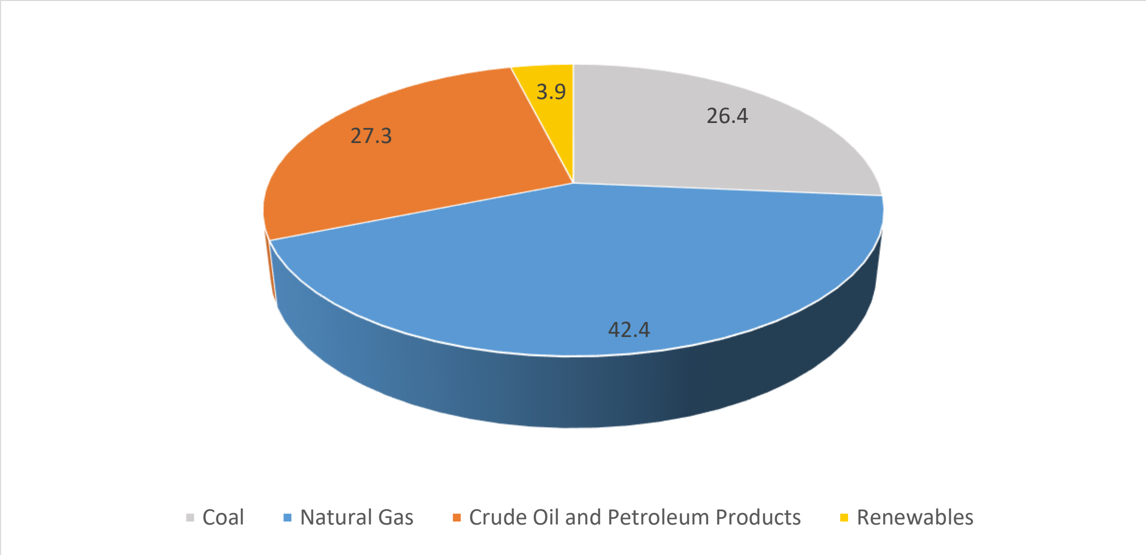


Figure 2: TPES by fuel type for Malaysia in 2020 (*National Energy Transition Roadmap*, n.d.)

Figure 3 shows the installed capacity (MW) of commissioned RE installations in Malaysia for the years 2017 and 2018 (Regan et al., 2019).

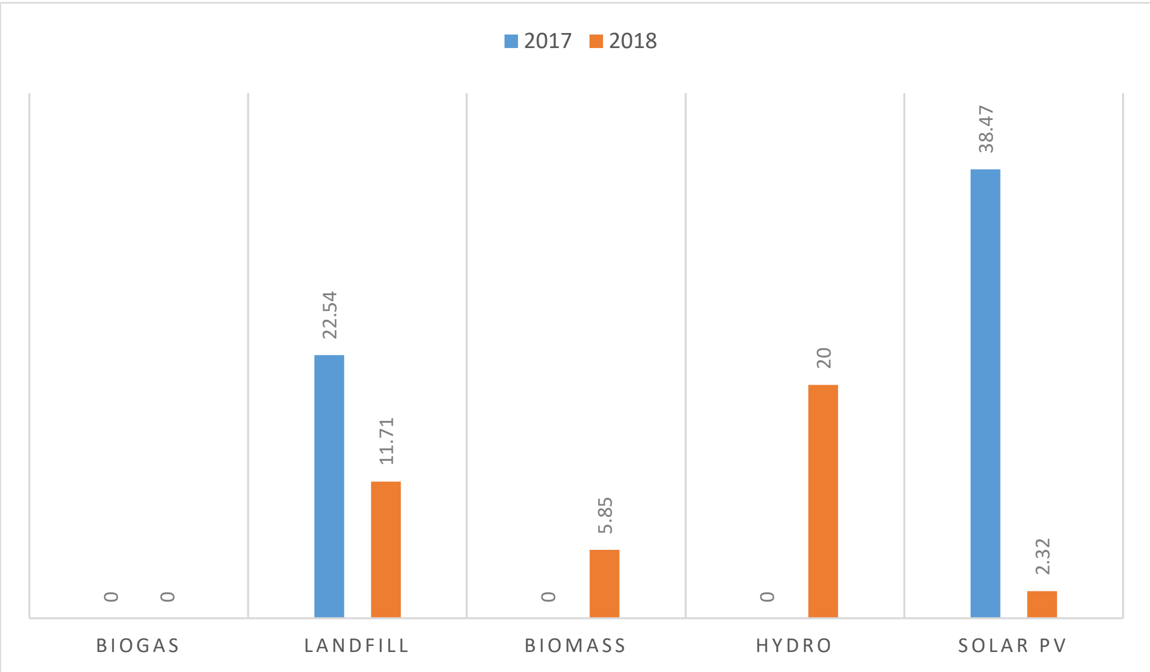


Figure 3: RE installed capacity (MW) in 2017 and 2018 in Malaysia (Data from SEDA)(Regan et al., 2019)

The RE target set by the Malaysian government is to reach a total capacity of 20% with hydropower up to 100MW by the end of 2025 according to the 11th Malaysia plan or RMK11 (Miranville, 2019) (Energy Commission, 2019). There is a gap of 11% from the target to the status of 9% (Energy Commission Malaysia, 2020a) and there are 5 years period to narrow the gap. Whether narrowing the gap is possible and what the future of RE projects and policies holds for Malaysia is to be discussed in depth with stakeholders of Malaysian energy and sustainability in this study approach. However, the most recent RE targets and the roadmaps developed to achieve them has been discussed further in depth in section 2.2 of this chapter.

Energy supply is an essential element for national economic development and ensuring the growth of sustainable trade and industry (Suruhanjaya Tenaga, 2017a). Malaysia is a country with an enormous supply of conventional energy sources as well as renewable energy sources. Malaysia has the 14th largest gas reserve and 27th largest proven crude oil reserve in the world (Sahid, 2013). As of 2017, there is a proven reserves of 5.028 billion barrels of crude oil and 87.762 Trillion Standard Cubic Feet of NG which is located mainly in Sarawak (Statistics, 2017a). Malaysia has various fuel sources for their energy production which consists of majority non-renewable sources and minority renewable sources. However, Malaysia has been working to increase its renewable sources for energy production to ensure sustainable development (Hashim & Ho, 2011).

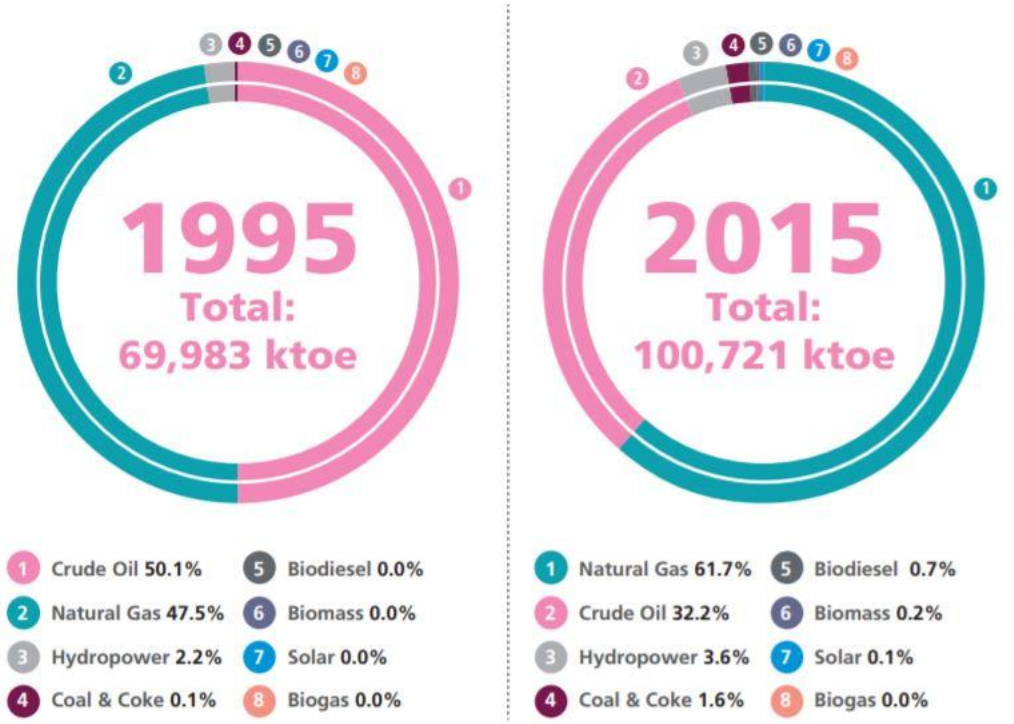


Figure 4 : Malaysia Energy Supply Mix by fuel type

Based on figure 4, the dependency on oil has been significantly reduced as NG resources is more abundant in Malaysia (Jalal & Bodger, 2009). Crude oil is now mostly being used for economic purposes as it is more beneficial for Malaysia to export crude oil than to use it for energy generation (Prambudia & Nakano, 2012).

Few of the key challenges of ES for Malaysia that were rectified from existing body of work are.

- Over-dependence on fossil fuel.
- Not moving towards self-sufficiency when it comes to energy production in own country or any source of clean energy technology.
- As of 2011, oil reserves are expected to last for the next 25 years and gas reserves for 39 years.
- The current power production and demand trends show that Malaysia has a reserve margin that will last only a few years. This calls for further investment, research, and development in the country's power sector to meet the ever-increasing energy demand. The government's diversification policy and power sector expansion plan emphasise the incorporation of renewable energy sources (RESs) and other less CO2 emitting sources like nuclear into the national energy mix.
- The primary energy demand growth rate is 6.3%. The latest import and export data for 2018 are collected from the Malaysia Energy Statistics Handbook 2020 (Energy Comission Malaysia, 2020).
    - Petroleum Products: Import- 55.2% and Export-44.8%, hence net importer of petroleum products.
    - Crude Oil: Import- 38.1%, Export- 61.9%; hence net exporter of crude oils.
    - Coke and Coal: Import- 100%, Export-0%; hence all the coal is imported.
    - Natural Gas: LNG Export- 75.6%, LNG Import- 4.0%, Piped Natural Gas Import- 16.3%, Piped Natural Gas Export- 4.1%; hence net exporter of LNG and net imported of piped NG.
- The final energy consumption growth rate between 2009–2019 was 3.1% and 2020—4,11 Exajoule (EJ), consumption by fuels only 0.04 EJ RES—0.18 EJ Hydro, Oil and Gas (1.38 EJ and 1.37), and coal 1.14 EJ (Looney, 2021).

- Total final energy consumption will rise from 59.88 Mtoe in 2017 to 177.18 Mtoe in 2050 under BAU, a 3.3% annual growth rate. Natural gas usage will have the best Average Annual Growth Rate (AAGR) of 3.7% to 2050. From 2017 to 2050, oil consumption will rise from 28.27 Mtoe to 82.17 Mtoe (a 3.3% annual increase), coal demand will rise 3.2% each year, and power demand will rise from 12.60 Mtoe to 34.23 Mtoe (a 3.2% annual increase) (an AAGR of 3.1%). Demand for alternative fuels, such as biodiesel, is anticipated to rise from 0.38 Mtoe to 0.53 Mtoe, representing a 1.0% annual growth rate (Zulkifli, 2021).

The possible solution to ES challenges is the use of renewable sources of energy in Malaysia which have been discussed in the study of (Strengthening the Future of Energy in Malaysia ProPelling with SuStainability Chasing the Sun, n.d.),(N. A. Ahmad & Abdul-Ghani, 2011). The sources of energy and their prospect have been listed in table 3.

Table 3: Alternate sources of energy and their prospect (N. A. Ahmad & Abdul-Ghani, 2011)

Type of Energy Source	**Potential Prospect**
Solar Power	Best alternative amongst all other sources. Malaysia enjoys plenty of sunshine (as much as 3 kWh per square meter) all year round with consistent radiance. Global costs will be going down annually and will be in an acceptable state in 2030. (Potential of 6,500 MW)
Wind	Have future potential with acceptable Long-Run Marginal costs for this technology. Inconsistency in wind speed limits the development. Wind does not blow uniformly which limits the ability of this source in Malaysia.
Hydropower	High cost for the infrastructure and instalment of the cables under water, but have potential competitive energy generating capacity in Malaysia. Issues are mainly the environmental impact and relocation of native residents to other locations. Monsoon in Malaysia will contribute immensely to the reserves and storage of water. (Potential of 500 MW for mini-hydro)
Geothermal	Recently discovered in Tawau, Sabah with the potential to generate up to 67MW of electricity a day to meet the energy needs of Tawau. Low significance and limited niche market in national electricity generation.
Biomass/	Substantial resources from palm oil, rubber plantation throughout the

Biogas/Waste	country, and timber waste from the natural rainforest. Land used development need to be considered. High carbon reduction compared to solar and wind energy. Issues related to labour cost and availability of raw material. Focus is needed for cogeneration technologies towards an environment-friendly system that will produce high-quality fuel. (Potential 1,340 MW for biomass, 410 MW Biogas and 400 MW Waste)
Nuclear	Only 1 MW of electricity is generated in a small reactor in Bangi, Selangor. A detailed study should be carried out pertaining to issues on national and international policies, risks, environmental impact assessment, economic, and social, and human capital development as well as a suitable location.
Tidal energy from Ocean	The wave power density of Malaysia's ocean is less than 50 kW/m^2. Hence this is not one of the most impactful sources of energy.

The global energy architecture performance index (EAPI) ranking shows the EAPI scores and ranking for the ES of Malaysia (World Economic Forum, 2013), (World Economic Forum, 2017). Malaysia is ranked as 65 with a score of 0.52 overall which is somewhere in the middle amongst 124 countries shown in this study. Economic growth score at 0.38, environmental sustainability at 0.48, and energy access and security at 0.78 respectively. Economic growth and environmental sustainability are the two main dimensions that are dragging down the overall ranking of Malaysia while its energy access and security is ranked 12th in the world which is a positive sign for the country. Other ASEAN countries like Thailand, Singapore, and Indonesia are all above Malaysia in the EAPI scores which is a matter of concern as well. The ASEAN energy demand is growing at a very quick rate and is expected to grow by 80% between 2013 to 2035 (World Economic Forum, 2013).

One main problem identified by (World Economic Forum, 2013) was the dependence of ASEAN countries on energy imports and the energy mix having less than 5% of renewable sources as the primary energy supply source. This indicates the dependency on non-renewables and them having a major share of the TPES of Malaysia. Malaysia along with Indonesia and Brunei Darussalam have access to vast natural resources which are yet to be exploited properly. The main reason behind this is the lack of supply infrastructure. It is estimated by IEA that “total of US$ 1.7 trillion of cumulative investment in energy supply infrastructure is needed to 2035; nearly 60% of this investment is required for the power sector” (World Economic Forum, 2013) for ASEAN countries. This seems to be a big challenge for these countries along with Malaysia. ASEAN integration plan for trans-ASEAN gas pipeline and power grid can have a major impact on the quality of energy supply and security. The next section investigates the current RE policies that are in place to understand whether it is viable to secure long-term ES for Malaysia.

2.2. The Role of Renewable Energy in the Energy Security of Malaysia

2.2.1. Introduction

The development and deployment of RE in Malaysia's energy mix for the total primary energy supply (TPES) and electricity generation are still at an early stage despite the early initiation of RE in the 1980s. As of 2020, four energy sources dominated the national total primary energy supply (TPES) mix. Natural gas constituted the largest portion at 42.4%, followed by crude oil and petroleum products at 27.3% and coal at 26.4%. Renewables, comprising hydropower, solar and bioenergy, constituted just a mere 3.9% (National Energy Transition Roadmap, n.d.). There are certain challenges in the form of intermittency and integration of RE in the national grid and policy implementation of RE that is holding the development of RE further in Malaysia.

The development of RE policies that promote new and enhanced RE projects is of utmost importance for Malaysia to move towards long-term ES leading to more sustainable resources at its disposal. There is a need to engage stakeholders from the public and private sector to understand from their perspective what are the key challenges faced by RE as a fuel in Malaysia and what initiatives are to be taken to tackle these challenges. This study aims to fulfil the gap by engaging various stakeholders in an in-depth discussion on the role of the RE policies that were in place previously and the future RE policies in power generation mostly to shape the ES of Malaysia towards a more secure status. RE's prospect for power generation is the key focus of this study as the transport sector relies primarily on petroleum fuels which is a threat to the ES and CO2 emissions contribution as stated in the report by the Economic Research Institute for ASEAN and East Asia (Nationally et al., 2016).

RE policies in Malaysia can be drawn back to as early as the 1980's when RE was introduced as one of the fuels in the Four-Fuel policy (Regan et al., 2019). Ever since, there has been a gradual deployment of RE in the national energy mix alongside the more dominant fossil fuel sources like oil, coal, and natural gas. RE in Malaysia plays a vital role in securing energy sustainability by moving towards a low-carbon economy and decreasing fossil imports from other countries. The RE initiatives undertaken proves that the government’s vision is in line with the global RE prospects. The RE industry is now primed to enter a new phase of growth in 2020. This is consistent with the Shared Prosperity Vision 2030 which stresses RE and green economy as two of the 15 proposed Key Economic Growth Activities (SPV 2030, 2019).

Hence, the contribution of RE towards ES in Malaysia needs to be studied more in-depth with relevant stakeholders who understand the relation of RE and ES of Malaysia. Literature reviews on the current Malaysian RE scenario have been discussed with RE policies that were in place historically and the current ones in this study. An in-depth engagement with the stakeholders has been carried out which led to qualitative data collection towards understanding the role of RE in fortifying the ES of Malaysia. The term ES has been defined by these stakeholders as what is most suited for Malaysia and discussed further in this study. These data have been analysed using the PESTLE framework and SWOT analysis indicating the direction the RE policies are heading towards in terms of strengths, weaknesses, opportunities, and threats to RE in Malaysia. This study aims to consolidate the role of RE in ensuring that Malaysia as a nation is secured in terms of its sustained energy supply in the long run especially in the context of its existing reserves of natural resources.

2.2.2. Overview of Malaysia’s Renewable Energy Policies

Historically, Malaysia has never been a nation relying on RE for electricity generation or its use in the transport, industry, residential and commercial sectors. The National Energy Policy was established in 1979 to supply adequate energy to meet the demand, minimize the impact on the environment, and utilise the resources efficiently (Mustapa et al., 2010). In 1981, the Four-Fuel policy was established to diversify the fuel sources and mostly introduced hydropower alongside oil, coal, and natural gas. Similarly, in the year 2000, the Fifth-Fuel policy was established on the potential of biogas, biomass, mini-hydro, and solar for electricity generation mostly (Chua & Oh, 2010). Most of the RE policies mentioned in the research of (Chua & Oh, 2010; Ong et al., 2016) did not reach their ultimate targets but have managed to secure and establish RE as one of the new fuels in the energy mix. One of them was the ‘Small Renewable Energy Power (SREP) Program’ in 2001, which only managed to fulfil 3% of its target by 2005 due to lack of stakeholder intervention, lengthy approval process, lack of monitoring, and capacity caps (Sovacool & Drupady, 2011).

The ‘National Renewable Energy Policy and Action Plan’ (NREPAP) was the successor of the SREP Program after 8 years of its implementation from 2001. The policy statement for NREPAP is quoted as *“Enhancing the utilisation of indigenous renewable energy resources to contribute towards National electricity supply security and sustainable socio-economic development”* (Cheng, 2020). (N. H. Ahmad et al., 2021a) mentioned that the generation mix is critical in power generation, regardless of which market model a country employs, especially when pricing and sustainability are the primary concerns. The world's generation mix is currently undergoing dramatic changes. The primary objective was to increase the RE share in the national power generation mix alongside ensuring a regular growth of RE, reduce the cost of RE generation, ensure sustainable use of the RE sources, and increase awareness of the role of RE (Cheng, 2020). There were 5 strategic thrusts designed to achieve these targets. It is believed that the success of the NREPAP not only depends on the government intervention but also on the private sector and third sector. This action plan is aimed at increasing jobs and improving new growth areas to lead Malaysia towards a more low-carbon economy.

In the 8th Malaysia plan, there was a target of generating 5% electricity or 600MW from RE by 2005, however, only a total capacity of 12MW by 2005 was built (Mustapa et al., 2010). Then, in the 9th Malaysia Plan (2006-2010) the government set a target of 300MW in Peninsular Malaysia and 50MW of RE capacity in Sabah for electricity generation (Mustapa et al., 2010). In 2010, another target was set to achieve 2000 MW of RE capacity by 2020 and that target was established in 2018 with a capacity of 2,057MW of electricity from RE (Miranville, 2019). Moving forward, the latest and current policy has a target of 20% RE penetration with hydro projects smaller than 100MW by the year 2025 set in the 11th Malaysia plan and currently have achieved 9% of RE capacity for electricity generation in 2020 (Energy Commission Malaysia, 2020a), with another 5 years in hand to achieve the target. Given that the development of renewables has not taken off as fast as expected in Malaysia, there is a need for a roadmap of the future electricity system to spur renewables penetration.

The Renewable Energy Transition Roadmap ("RETR") 2035 is being developed by SEDA in collaboration with industry stakeholders to determine strategies, comprehensive action plans and resources that are required, in-line with the energy transition of future electricity system and achieve the set RE targets. The RETR 2035 aims to strike a balance between 3 key boundary conditions (Energy Commission, 2019):

1. **Environmental targets and policies**: Aim is to reduce greenhouse gas emissions and to fulfil the target of 20% RE penetration by 2025.
2. **Affordability and economic benefits**: Affordability of inputs from key stakeholders while always maintaining it while moving towards RE.
3. **System stability**: To reach a high level for the consumers.

Lastly, the latest developments of targets, roadmap and action plans are reflected in Malaysia's **National Energy Transition Roadmap (NETR)** (*National Energy Transition Roadmap*, n.d.) which has been published in 2023. In response to the NETR, Malaysia's Ministry of Economy and the National Renewable Energy and Climate Change Council (NRECC) have updated their renewable energy (RE) policies. Malaysia has set ambitious targets for the incorporation of renewable energy into its power generation mix. The new targets set aim for a significant increase in installed RE capacity to 70% by 2050, up from the previous target of 40% in 2040. This ambitious goal is designed to attract multinational corporations, particularly those committed to using 100% renewable energy, fostering economic growth within Malaysia.

Further policy enhancements include promoting investment in the RE sector by adopting a self-contained system model, which supports the concept of a willing buyer and seller market. Additionally, the government plans to expand solar installations in public buildings and initiate cross-border RE trade by establishing an electricity exchange system. This system will not only boost Malaysia's role as a regional renewable energy hub but also support the ASEAN Power Grid (APG) initiative, particularly through the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMSPIP).

Recognizing the need for infrastructure support, the government also plans to upgrade the national power grid to better accommodate the increased RE integration. This includes modernizing the grid with smart features and enabling third-party access, ensuring it is future-ready for the upcoming surge in renewable energy usage.

Table 4 below summarises all the policies that has influenced the intake of RE as a source of energy in the TPES of Malaysia from early 2000's to date.

Table 4: A summary of the renewable energy policies of Malaysia

Source	***Policy***	***Timeframe***	***Scope***	***Objective***	***Outcome***
(Maulud & Saidi, 2012), (Dharfizi et al., 2020a).	Fifth-fuel policy	2000-2010	Renewable energy	Introduction of RE as the 5th fuel after oil, gas, coal, and hydro.	During the first ten years (2000-2010) just 41.5 MW plant has been generated. The level of fuel diversification has shown improvement but yet less than expected.
(Kobayashi, 2011a)	National Green technology policy	2009-	Green Technology	The energy aspect emphasized seeking to attain energy independence and promote efficient utilization.	Since 31 December 2017, 356 companies have obtained the GTFS Accreditation, with funding amounting to MYR 3.64 billion (USD 845 million).
(Ministry Of Plantation Industries And Commodities, 2006)	National Biofuel of Malaysia 2006	2006	Biofuel	This policy focuses on the commercialization, usage, research, technology, and export of biodiesel. It also focuses on blending processed palm oil with	It reduced the import of biofuels and hence save foreign exchange. The drawback is most of its implementation was for short-

				petroleum diesel. It involves converting palm oil into biodiesel (methyl esters), mainly for export.	term success. In the long term, it targeted to increase the share of processed palm oil in the diesel blend.
(Parliament of Malaysia,	Malaysian Biofuel Industry Act 2007	2007	Biofuel	This policy is to further regulate and facilitate the biofuel sector development.	
(Sovacool & Drupady, 2011)	Small Renewable Energy Power (SREP) Program	2001-2010	Renewable Energy	To promote small-scale renewable electricity in Malaysia from 2001 to 2010.	Managed to fulfil 3% of its target by 2005 due to lack of stakeholder intervention, lengthy approval process, lack of monitoring, and capacity caps.
(Cheng, 2020),	National Renewable Energy Policy and Action Plan'(NREPAP)	2009-	Renewable Energy	Increasing the RE share in the national power generation mix alongside ensuring a regular growth of RE, reducing the cost of RE generation and sustainable use of RE.	From 1% share in 2011 to 9% in 2020 enabling more than 30 million tonnes of CO_2 emissions to be avoided in line with the national target.
	8th Malaysia plan	2000-2005	Energy efficiency, Renewable energy, Energy supply	Set a target of generating 5% electricity or 600MW from RE.	A total capacity of 12MW by 2005 was built (Mustapa et al., 2010)

	9th Malaysia Plan	2006-2010	and infrastructure, Energy pricing, Trade etc.	The government set a target of 300MW in Peninsular Malaysia and 50MW of RE capacity in Sabah for electricity generation. Enhancing energy sufficiency and efficiency, including diversifying sources of energy.	
	10th Malaysia plan	2011-2015		A target was set to achieve 2000 MW of RE capacity by 2020.	It was established in 2018 with a capacity of 2,057MW of electricity from RE.
	11th Malaysia plan	2016-2020		A target of 20% RE penetration with hydro projects smaller than 100MW by the year 2025.	It has achieved 9% of RE capacity for electricity generation in 2020, with another 5 years in hand to achieve the target.
(Energy Commission, 2019)	Renewable Energy Transition Roadmap (RETR) 2035	2020-2035	Renewable Energy	To reduce greenhouse gas emissions and to fulfil the target of 20% RE penetration by 2025. Improve system stability. Improve affordability of energy.	As of the most recent updates, Malaysia's renewable energy (RE) capacity in the national installed capacity mix stands at 25%. This marks

					a significant step towards the country's target of achieving a 31% RE share by 2025.
(National Energy Transition Roadmap, n.d.)	National Energy Transition Roadmap (NETR)	2022-onwards	A part of national energy policy (2022-2040)	31% RE installed capacity by 2025 70% by 2050	Malaysia is very close to achieving their 2025 target while 2050 target results or trajectory is yet to be understood

Malaysia's energy policies over the past few decades have made significant strides toward establishing a sustainable and diversified energy mix. The achievements under these policies highlight the country's commitment to addressing ES and environmental sustainability. However, the varying degrees of success across different initiatives also reveal critical areas that require continuous improvement.

1. **Incremental Progress**:
    - **Fifth-Fuel Policy**: Despite its limited success, the policy marked an important step towards diversifying Malaysia's energy sources by introducing renewable energy as a critical component of the energy mix. This initiative, although it fell short of expectations, laid the groundwork for future policies by highlighting the need for stronger regulatory frameworks and incentives to support renewable energy adoption.
2. **Green Technology and Biofuels**:
    - **National Green Technology Policy**: The significant financial investments and company accreditations under this policy reflect a robust effort to foster green technology. However, the true test of its effectiveness will be in the broader adoption and integration of green technologies at all levels of society,

including households and small businesses, which requires enhanced consumer incentives and infrastructure development.

- **National Biofuel Policy**: This policy successfully reduced biofuel imports and promoted palm oil biodiesel. However, its focus on short-term goals and export markets suggests a need for more balanced policies that also prioritize domestic energy security and long-term sustainability.

3. **Small-Scale Renewable Energy**:
   - **SREP Program**: The program's limited success underscores the importance of efficient regulatory processes and active stakeholder engagement. Future policies must streamline approval processes, enhance monitoring, and remove capacity caps to facilitate the development of small-scale renewable projects.
4. **National Renewable Energy Policy and Action Plan (NREPAP)**:
   - The substantial increase in RE share from 1% in 2011 to 9% in 2020 demonstrates the effectiveness of clear targets and action plans. This progress highlights the potential for further growth if such strategic frameworks are maintained and enhanced. The avoided CO2 emissions indicate significant environmental benefits, reinforcing the importance of continued investment in renewable energy.
5. **Malaysia Plans**:
   - The progressive targets set in the Malaysia Plans reflect a growing commitment to RE and energy efficiency. Meeting the 10th Plan's RE capacity target and the ongoing efforts under the 11th Plan showcase the country's capability to achieve ambitious goals. However, the uneven progress across these plans suggests that consistent policy support and adaptive strategies are essential for sustained success.
6. **Renewable Energy Transition Roadmap (RETR) 2035**:
   - The RETR 2035's goal of reducing greenhouse gas emissions and achieving 20% RE penetration by 2025 is nearly realized, with current RE capacity at 25%. This indicates effective policy implementation and a strong foundation for future targets. The roadmap's emphasis on system stability and energy

affordability highlights the need for continuous innovation and investment to address emerging challenges and maintain progress.

7. **National Energy Transition Roadmap (NETR)**:

    - The NETR's ambitious targets of 31% RE capacity by 2025 and 70% by 2050 reflect Malaysia's long-term vision for a sustainable energy future. Achieving these targets will require adaptive policies that respond to technological advancements, market dynamics, and potential socio-economic impacts. Continuous stakeholder engagement and transparent communication of progress and challenges will be crucial for maintaining momentum towards these goals.

2.2.3. Recommendations for Future Policies

Enhanced Stakeholder Engagement: Effective energy policies require active participation from all relevant stakeholders, including government agencies, private sector, academia, and civil society. Regular consultations and feedback mechanisms can ensure policies are responsive to the needs and concerns of different groups.

Regulatory Efficiency: Streamlining regulatory processes and reducing bureaucratic hurdles are essential for accelerating the deployment of renewable energy projects. Clear guidelines, faster approval processes, and robust monitoring systems can significantly enhance the effectiveness of energy policies.

Integrated Energy Strategies: Future policies should adopt a holistic approach that integrates various aspects of energy security, including supply diversification, technological innovation, and environmental sustainability. This requires coordinated efforts across different policy areas and sectors.

Long-Term Planning and Adaptation: While short-term goals are important, policies must also focus on long-term sustainability. This involves anticipating future challenges and opportunities, adapting strategies as needed, and ensuring continuous improvement based on empirical evidence and best practices.

Investment in Research and Development: Continuous investment in R&D is crucial for developing new technologies and improving existing ones. Support for innovation in renewable energy, energy storage, and efficiency technologies can drive significant advancements in energy security.

Public Awareness and Education: Increasing public awareness and education about the benefits of renewable energy and energy efficiency can foster greater acceptance and adoption of sustainable practices. Policies should include initiatives to educate consumers and promote energy-saving behaviours.

2.3. ASEAN Energy Outlook and Energy Security Performances of Selected Countries

The ES performances of Singapore, Thailand and Indonesia are assessed from secondary data point of view because these countries are within the same region as Malaysia with a good geopolitical relationship of being ASEAN members. On the other hand, Norway is selected as a benchmark with a very high ES performance. At the same time, there is also a need to understand the energy outlook of the ASEAN countries to assess where the region stands in terms of its energy policy development and achievements.

2.3.1. ASEAN Energy Outlook

The Southeast Asian (SEA) region faces significant challenges in transitioning to a sustainable and secure energy system, despite its rich reserves of fossil fuels such as coal, natural gas, and oil. The Association of Southeast Asian Nations (ASEAN) has set an ambitious target to increase renewable energy's (RE) share to 23% of total primary energy supply (TPES) by 2025 (ACE, 2015). However, the demand for primary energy in this region has surged by 80% since the year 2000, a demand largely met by an ever-increasing consumption of fossil fuels. Fossil fuel usage has doubled since 2000 to meet 85% of this growing energy need (“Southeast Asia Energy Outlook 2017,” 2017).

This heavy reliance on fossil fuels not only undermines long-term energy security (ES) but also threatens the environmental sustainability of the region. Currently, renewable energy sources in the SEA region meet less than 20% of the primary energy demand. This shortfall occurs despite the considerable potential for expanding renewable energy, especially given the declining costs of renewable technologies which should encourage their wider adoption in electricity generation.

Significant renewable resources such as hydropower, geothermal, and bioenergy have been harnessed, yet the potential for solar and wind energy remains largely untapped. Expanding these sources could significantly improve the sustainability and security of the region's energy system. It is imperative that ASEAN countries increase their investment in and adoption of these technologies to mitigate the environmental impacts of current energy practices and enhance their energy independence. The transition to a more renewable-based energy system is not just beneficial for short-term energy security but is crucial for the long-term sustainability and economic stability of the region (Rogowska et al., 2016), ("Southeast Asia Energy Outlook 2017," 2017).

2.3.2. Singapore

Singapore is the best country in the SEA in terms of ES while being one of the smallest countries in SEA with a very small number of natural resources compared to its neighbours Malaysia and Indonesia. This shows that Singapore has been very efficient in managing its country and its energy.

About 90% of Singapore's electricity supply is generated using Natural Gas (NG) while the rest are generated from fuel oil, wastes, and renewable energy mainly imported from Malaysia and Indonesia through gas pipelines (Wong, 2017). Since Singapore is mainly an energy importing country, Singapore needs to pay for energy sources at a competitive price to ensure its ES.

As a country that is expected to double its energy demand by 2030, Singapore, with very limited land and natural resources, has its challenges to ensure ES. One of the biggest challenges for Singapore is to import more energy sources to meet its ever-growing demand. To solve this, Singapore is planning to build a liquefied NG (LNG) terminal (Marusiak, 2018a). LNG is NG that is compressed to a fraction of its original volume which enables it to be transported in more volume from around the world rather than depending on NG from Malaysia and Indonesia (Marusiak, 2018b).

2.3.3. Thailand

Thailand shares the same climate, natural resources, and demographics as Malaysia. To meets Thailand's rapidly increasing demand, it imports oil, coal, gas, and electricity which account for up to 46% of the total energy consumption with an estimated reserve to production ratio of 12.5 years in NG (Ait, 2009). Thailand's energy challenges consist of import dependency especially in NG which makes it vulnerable to disruption in international energy supply or rises in prices of imports. An increase in the price of imports will hurt Thailand economically so to overcome this, the government plans to diversify its energy supply system such as investing in renewable energy (Kamsamrong & Sorapipatana, 2014a).

2.3.4. Indonesia

Indonesia is mainly an exporting country as being the largest exporter of steam coal and also possesses huge reservoirs of NG and oil (Dutu, 2016). Indonesia also holds the largest geothermal energy reserves at around 40%. Being a small country but having a population of 240 million poses a threat to the ES of Indonesia (PoliticalInsights.org, 2015a). The challenges faced by Indonesia in terms of ES are the increasing demand and consumption of energy. To solve this, investment is proposed of 70 billion USD by building 117 new coal-fired power plants to generate more electricity. These new coal-fired power plants will also pose a threat to Indonesia's environmental sustainability as burning coals will emit large quantities of GHG such as carbon dioxide which will only increase pollution and global warming (PoliticalInsights.org, 2015b).

2.3.5. Norway

In all the studies so far, Norway has topped the charts for the best-performing country in the ES sector. This can be used to set Norway's ranks and scores as a benchmark to judge how other countries are performing. Mostly the strong performers are EU and OECD countries (World Economic Forum, 2013). The overall score of Norway is 0.75 and ranked at the very top of the list with scores of 0.69, 0.60, and 0.96 in the 3 different dimensions as shown in Table 3. All these scores are out of 1 and no country can reach the perfect score. There are several reasons behind Norway's scores being this high. Norway is one of the major producers of energy and at the same time, they are exporting energy to other countries in huge amounts (Godzimirski, 2014) They are being able to do this due to their availability of resources, which are mostly exported while they meet their country requirements by the use of renewable sources of energy mostly hydropower. From the study by (Godzimirski, 2014) this has been mentioned as a potential threat for Norway's future ES if their non-renewable sources do run out due to heavy export. Norway's role as a major supplier of energy in the global market plays an important role in its economy as a contributor to the economy of Norway.

In the study by (US Chamber of Commerce Fundation, 2016), the lower the risk score the better it is for the ES of the country where Norway tops the chart with a score of 733 amongst all other countries with Mexico in 2nd position with 766. Since 2006, Norway has never dropped the 1st position and amongst the 20 metrics used in this study, Norway was in the top 5 in 11 of these metrics and 3 in the bottom five. Norway had high scores in energy imports, expenditure, energy intensity, transportation, and energy risk while they scored poorly compared to OECDs in per capita energy expenditure and per capita energy use. On the other hand, the average risk score of the OECD countries is around 869, which is 16% higher than that of Norway (US Chamber of Commerce Fundation, 2016).

All these factors mentioned are the reasons behind Norway's consistent growth and performance in the energy sector.

2.4. Assessing the existing energy security indexes and their dimensions

The literature reviewed in this process is filtered to involve the ESI's of Asian countries only with a similar if not same energy outlook and overview. The strengths of these respective studies have also been discussed to ensure that the selection of either one method or a combination of the methods also known as an ‘integrated approach’ can be justified in this research. These studies have been categorised into two broad categories: 1) Energy Security Index of Malaysia in Table 5 and 2) Energy Security Index of other Asian countries or the ASEAN region in Table 6. The review of these studies has been critical towards understanding the importance of each approach and how the researchers have justified their selection of materials and methods to construct the framework followed by designing the index to quantify ES. (Zhou et al., 2018) have pointed out the importance of bibliometric analysis along with co-citation analysis to develop further motivation amongst research groups to carry out further investigations.

The notable thing about the approach to quantify the ES of any nation is in the multidimensional analysis towards the complex ES phenomenon. Most of the researchers have historically developed broad dimensions based on, energy supply security (Su et al., 2020); (Augutis, Martišauskas, et al., 2015), environmental sustainability and efficiency (Lee et al., 2020), energy availability, and the economic aspects of ES. These dimensions have been defined based on; the country’s energy policy structure, the availability of the raw data for these dimensions, and the analytical soundness of the indicators in terms of their validity and their construction based on scientific principles as stated by (Yao & Chang, 2014).

Some of the notable research has always given their viewpoint on which are the most important dimensions of ES and what makes them so important, for example (Dincer & Acar, 2015) has described it as a potent challenge to meet the growing energy demands in an environmentally benign and sustainable way mostly for the rapidly developing nations. Similarly, the study of (Safari et al., 2019a) have mentioned how the economic growth of a nation takes a toll on the environment leading to environmental constraints. In Malaysia, there is a rise in energy consumption within the industrial and commercial sectors due to an increase in economic activities and an increase in population from 28 million in 2010 to 32 million in 2019. This would eventually lead to an increase in energy demand by 5-7% annually in the next two decades (Hosseini & Abdul Wahid, 2014; Zakaria et al., 2020). To meet this ever-increasing demand, the energy supply is expected to become 11,400,000 MW by 2030 with an average increase of 4.7% annually (Zakaria et al., 2020). In Malaysia, the conventional power generation system and the total primary energy supply (TPES) are dominated by natural gas, coal, and oil (Zakaria et al., 2020).

Hence, it is of utmost importance to meet this increase in demand in a manner that is sustainable for the energy resources, environmentally friendly, and at the same time affordable and reliable in terms of supply security. Major stakeholders and the government of Malaysia had recognised the need to diversify the fuel mixture as a strategy to enhance national ES, a new policy was introduced in 1981 (Dharfizi et al., 2020b). However, fuel diversification policies in Malaysia only had partial success in the past (Dharfizi et al., 2020b). The government of Malaysia had implemented several energy policies that targeted better energy sustainability and security since 1981 with special attention attached to the supply side security of energy (Lim & Goh, 2019), hence focusing more on natural gas, coal, and oil. The current target by the government is to maintain a Herfindahl-Hirschman Index (HHI) of below 0.5 by 2025 for the diversification of the fuel mix to ensure an improved ES (Energy Commission Malaysia, 2020b).

(Gasser, 2020) has pointed out the importance of stakeholder engagement to minimise subjectivity while selecting the ES dimensions. The lack of stakeholder engagement has been identified as one of the major gaps in Malaysia's ES research. The studies of (Endang Jati Mat Sahid, 2018; Endang Jati Mat Sahid & Sin, 2019; Yusoff & Bekhet, 2020);(Sharifuddin, 2014) attempted to quantify ES for Malaysia by developing an energy security index (ESI) using different dimensional frameworks. While the study of (Foo, 2015) discusses in depth the various energy profiles of Malaysia and the development of energy policies towards ES. (Khattak et al., 2018) reviewed the ES status of Malaysia and the strategic approach to enhance the future of ES in Malaysia. It is worth mentioning that none of these studies had involved stakeholders to identify the key dimensions of ES for Malaysia to validate the results obtained.

Table 5:Malaysia ES index assessment

No.	***Source***	***Framework / Approach***	***Dimensions***	***Number of Indicators***	***Key methodology followed***	***Strengths of the method/study***
1	(Sharifuddin, 2014)	5-Aspects of ES Framework	Availability, Stability, Affordability, Efficiency, and Environmental Impact	35	**Normalisation**: Alternative approach/ Variance approach **Scale:** 0-1 **Weighting:** Ascending scale	The methodology mentioned in this study aims to overcome the shortcomings of the APERC's tool for measuring ES using score transformation and normalization. The indicators were weighted according to their importance.
2	(Sahid, 2018)	4A's Framework	Availability, Applicability, Affordability, and Acceptability	10	**Normalisation:** Min-Max approach **Weighting**: Equal weight	Simple approach to data normalisation and taking the average of each dimension to analyse the results. This does not involve the complicacy of adding weightage to indicators before their ordinal values are calculated.
3	(Sahid & Sin, 2019)	Case Study: Effect of Renewable Energy on ES	Energy Supply and Demand and, Economic dimensions.	6	**Normalisation:** Min-Max approach **Weighting**: Equal weight	
4	(Yusoff & Bekhet, 2020)	Sustainable Energy Security (SES) framework	Availability, Accessibility, Affordability,	15	**Normalisation:** Vector method **Weighting**: Entropy	This method does not require the attribute/dimensions preferences to be independent and it makes full use of the

			Acceptability, and Develop-ability		weight technique for order of preference by similarity to ideal solution (TOPSIS)	attribute of information and provides a cardinal ranking of alternatives.
5	(Sovacool, 2013)	Malaysia was selected as a case study for the most improved ES from 1990-2010.	Availability, Affordability, Efficiency, Sustainability and Governance	20	**Normalisation:** Min-Max approach **Scale:** 0-100 **Weighting**: Equal weight	

Some critical reflection of the 5 key studies is as follows:

1. The study of Sharifuddin in 2014 enhances the APERC's measurement tool by addressing its limitations through advanced score transformation and normalization techniques. The weighting according to importance allows for a more tailored analysis of energy security, recognizing that all indicators do not contribute equally to the energy security framework. However, the study might be limited by the subjective assignment of weights and the complexity of its normalization method, which could affect the reproducibility and transparency of results.
2. Sahid's approach in 2018 is noted for its simplicity and ease of application, avoiding the complexities of weighted indicators. This could make the model more transparent and easier to replicate across different contexts. However, the equal weighting of indicators might oversimplify the analysis, potentially overlooking the nuanced impacts of each dimension on overall energy security.

3. Sahid and Sin’s study in 2019 offers valuable insights into the specific impacts of renewable energy on energy security. However, the use of only six indicators and equal weighting might not fully capture the complex interactions between renewable energy initiatives and broader economic or supply metrics.
4. Yusoff and Bekhet in 2020 developed the SES framework. This method's strength lies in its robust statistical techniques that do not require independence among attributes, allowing for a comprehensive utilisation of attribute information. This approach provides a nuanced, ordinal ranking that can be crucial for policymaking. However, the complexity of the Entropy and TOPSIS methods might require deeper statistical expertise and could limit its application to more generalist policy environments.
5. Sovacool’s study provides a comprehensive overview of Malaysia’s progress in energy security from 1990-2010, highlighting the role of governance alongside other dimensions. The equal weighting and straightforward normalization make the findings accessible but might not accurately reflect the varying impact of different dimensions on energy security.

Overall, these studies demonstrate the diversity of approaches in energy security modelling, each with its strengths and limitations. The choice of methodology can significantly influence the insights derived and thus should align closely with the specific objectives and contexts of energy security assessments. These reflections can guide further research and refinement of energy security models to better support decision-making in energy policy.

Table 6: Energy security index assessment for other Asian countries

No.	***Source***	***Framework / Approach***	***Dimensions***	***Number of Indicators***	***Key methodology followed***	***Strengths of the method/study***
1	(Tongsopit et al., 2016)	4A's framework	Availability, Applicability, Affordability, and Acceptability.	16	**Normalisation:** Min-Max approach **Scale:** 1-10 **Weighting**: Equal weight	The normalisation technique is simple and does not involve any complicacy. It is easier to analyse the data generated and gives a clear overview of the ES dimensions and their trend over 5 years period. The limitations mentioned by the authors is that this model does not consider any exogenous energy shocks in the global market.
2	(Yao & Chang, 2014)	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	The authors ensured equal weightage is added to each indicator because unequal weights for different indicators will require objective justification. Strong support to this approach is in a similar index such as the Human Development Index (HDI) used by UNDP (United Nations Development Programme) that studies the dimensions of human development.
3	(Malik et al.,	4 A's framework	Availability,	16	**Normalisation:** Min-	This study has followed the study of

	2020)		Applicability, Acceptability, and Affordability		Max approach **Scale:** 1-10 **Weighting**: Equal weight	(Tongsopit et al., 2016; Yao & Chang, 2014) closely to design the framework and shows a similar set of advantages of using this framework and method of assessing ES quantitatively. The indicators for each of the dimensions are selected based on the national energy policies and the energy outlook of Pakistan.
4	(Abdullah et al., 2020)	Pakistan's energy security index	Availability, Affordability, Technology Development, Environmental Sustainability and, Governance and Regulation	22	**Normalisation:** Z-score approach **Scale:** 1-10 **Weighting**: Principal component analysis (PCA)	The authors believe that the z-score normalisation technique treats all the variable input i.e. the indicators are treated equally and not scaled to any specific unit. In this case, the sample size has to be considerably large.
5	(Fang et al., 2018)	China's Sustainable Energy Security (CSES) index	Availability, Accessibility, Affordability, Acceptability, Developability	15	**Normalisation:** Min-Max approach **Weighting**: Entropy weight technique for order of preference by similarity to ideal	The methods are simple, and the results obtained are reliable and accurate. This has been seconded by the study of (Abdullah et al., 2020). Data does not have to be considerably large as compared to the z-score technique of

					solution (TOPSIS)	normalisation in this case.
6	(Erahman et al., 2016)	Energy Security Index (ESI)	Availability, Accessibility, Affordability, Acceptability, and Efficiency	14	**Normalisation:** Min-Max approach **Scale:** 1-10 **Weighting**: PCA and equal weight	The PCA technique also reduces large numbers to smaller components without causing it to lose any information. The use of PCA, weighting, and aggregation that is done simultaneously improves the accuracy of the result.
7	(Martchamadol & Kumar, 2013)	Aggregated Energy Security Performance Indicator (AESPI)	Social, Economy, and Environmental dimensions.	25	**Normalisation:** Mean zero and standard deviation 1 **Weighting**: PCA	The AESPI aims to present the future pathway for ES of a country rather than just the comparison among countries.
8	(Sovacool et al., 2011)	Energy Security Index for 18 countries from 1990-2010 over 5 years period.	Availability, Affordability, Technology development and efficiency, Environmental sustainability and Regulation and governance	20	**Normalisation:** Min-Max approach **Scale:** 0-100 **Weighting**: PCA	The scoring system avoids any arbitrary value judgment rather relies on the actual performance.
9	(Wu et al., 2012)	Energy Security Index of China	2 broad dimensions of *Energy Supply Security*	14	**Normalisation:** Min-Max approach	The data normalisation technique is simple and does not involve any

		from 1996-2009	and *Energy Using Security* have been defined.		**Scale:** 0-1 **Weighting**:	complicacy. The normalised results obtained are easy to analyse.
10	(Ang et al., 2015a)	Singapore Energy Security Index (SESI)	Economic, Energy Supply Chain and, Environmental.	22	**Normalisation:** Banding approach **Scale:** 0-4 **Weighting**: Subjective weight allocation	The weighing is done externally and has the flexibility to be reallocated by stakeholders or with a change in the circumstances or changes in policies. Hence, making this a more flexible approach in terms of assigning weights to the indicators.
11	(D. Wang et al., 2020)	Dynamic Energy Security Index (DESI) for China.	Energy Supply, Energy Consumption and, environmental.	17	**Normalisation:** Min-Max approach **Scale:** 0-1 **Weighting**: Functional entropy weight and dynamical aggregation	A dynamic weighing mechanism is followed in a continuous time domain. In this method information is represented in the form of continuous curve and it is highly flexible because the time series for the indicators do not have to be identical and hence cases with missing data are also acceptable.
12	(Q. Wang & Zhou, 2017)	Framework for evaluating global energy security	Security of Energy supply-delivery (SESD), Safety of energy utilization (SEUD), and Stability of political-	23	**Normalisation:** Z-score and banding approach **Weighting**: Kaiser-Meyer-Olkin (KMO),	An integrated approach of subjective and objective weight allocation (SOWA) method has been used. This approach has not been taken before in the previous studies as discussed in Tables 1 and 2.

	economic environment (SPED) dimensions.	Bartlett's test, PCA, and Varimax rotation	Weight allocation is done by the subjective weight allocation (SWA) method and the shortcomings of this method are overcome by determining the weight indices with SOWA.

The methodologies reviewed in Table 6 suggest a robust and evolving field of ES assessment, with significant implications for Malaysia. Adapting and integrating these diverse methodologies could enhance Malaysia's ability to not only assess but also improve its energy security in alignment with both national goals and global best practices. The continued development and refinement of these models, especially in incorporating real-time data and dynamic scenario analysis, will be critical in navigating the complex interplay of energy needs, environmental goals, and economic development in Malaysia

Reflective Analysis of the Methods:

1. **Methodological Diversity:** The studies showcase a range of normalization and weighting techniques, from simple Min-Max approaches to more complex methods like Principal Component Analysis (PCA) and Entropy Weighting. Each method has its strengths, such as the simplicity and clarity of Min-Max or the data-driven nature of PCA, which reduces large datasets into manageable components without significant information loss.

2. **Challenges in Energy Security Modeling:** Common challenges across these studies include managing data complexity and ensuring the relevancy of selected indicators. For instance, the application of Z-score normalization requires a large sample size, which might not be feasible in all scenarios. Similarly, the Min-Max approach, while straightforward, may oversimplify the nuances of energy security dynamics.

3. **Comparative and Dynamic Models:** Some studies, like those by Sovacool et al. and Wang et al., go beyond static analysis to offer dynamic modeling of energy security or comparisons across multiple countries. These approaches provide deeper insights into how energy policies and external factors like technological advancements and international relations impact energy security over time.

4. **Adaptability to Local Contexts:** The relevance of these methodologies to Malaysia's context is particularly critical. Malaysia's unique energy landscape, characterized by its rapid development and specific policy environment, necessitates adaptations of these frameworks. For instance, Sovacool's inclusion of governance and regulatory dimensions is crucial in a Malaysian context where policy efficacy significantly impacts energy security outcomes.

5. **Flexibility and Stakeholder Engagement:** Ang et al.'s use of subjective weight allocation reflects a flexible approach that can adapt to changes in policy or stakeholder priorities. This flexibility is essential for Malaysia, where energy policy and priorities are evolving rapidly in response to both internal development needs and external pressures like climate change commitments.

6. **Innovative Approaches for Future Applications:** The integration of newer techniques such as dynamic weighing mechanisms and continuous data adjustment in the models by D. Wang et al. suggests a trend towards more adaptive and real-time energy security assessments. These innovations could be particularly beneficial for Malaysia as they allow for more responsive and agile policy-making in a fast-changing energy sector.

2.5. Dimensions of ES of Malaysia

This section discusses few of the key dimensions of ES that have been observed in most of the ES studies in the literature. In exploring the dimensions of ES in Malaysia, the analysis of the literature identifies key areas pivotal to understanding and improving the nation's energy framework. Each dimension—Availability, Affordability, Applicability and Efficiency, Environmental Sustainability, and Accessibility—is crucial, yet the interdependencies between them and the broader implications for policy and strategic energy planning warrant further discussion.

2.5.1. Availability of Energy

Availability is one of the two key dimensions of Malaysia's ES alongside affordability. It has been mentioned repeatedly in Malaysia's energy policies where the availability of energy supply at a reasonable price is of utmost importance (Ashari, 2013). This dimension has been recommended in classic literature reviews of ES (Deese, 1979; Yergin, 1988) that relates closely to the geological existence of energy sources. Malaysia has been relying on fossil fuels for the past few decades due to their availability in the country itself (S. S. Ahmad et al., 2017). At the same time, Malaysia has also been relying on other countries for fossil fuel imports. Recent data and news suggest that Malaysia has been relying on coal to generate electricity that forces the country to use 90% of its coal imports to generate about 40% of the country's electricity (Raman, 2020). This scenario is possible to lead Malaysia from a net exporter country to a net importer country. Therefore, the availability of fuel reserves relates both domestically and by external suppliers through imports of energy sources.

The meaning of this dimension lies within the term existence of resources (Azzuni & Breyer, 2018a) and its importance lies within its support of economic and welfare growth. While (Ang et al., 2015b) have stated that diversification of energy sources and geopolitics are key towards determining the availability of energy. (Chang & Yong, 2007) have simply defined this dimension as the geological existence of fossil energy resources. The indicators that have been finalised for this dimension are the energy reserve to production (R/P) ratio of crude oil, coal, and natural gas, total primary energy supply (TPES) per capita, and the energy self-sufficiency ratio. The reserve to production ratio indicates how much oil, gas, or coal reserves will remain at the end of the year to the production of it (Sahid, 2018). A higher share of the R/P ratios, TPES per capita, and the energy self-sufficiency ratio indicate a higher share of availability which is a direct reflection of a better ES within the Malaysian ESI.

2.5.2. Affordability of Energy

Affordability of energy in simple terms means access to energy at a reasonable price (Tongsopit et al., 2016). It is one of the dimensions to be prioritised because the transition to RE would cost more compared to using fossil fuels. This is because the cost of the technology to utilise RE is high compared to conventional fuels for TPES or power generation. Therefore, this dimension is closely related to the economic status of the country. Other than that, the affordability of energy resources closely relates to the volatility of energy sources. For an instant, the volatility of fossil fuels can be explained by the imbalances between supply and demand (APERC, 2007b). While (Sovacool & Brown, 2010) have added equitable access to energy services which in other words means energy should be available to people of all income groups (Malik et al., 2020). A study of (APERC, 2007a) defines this dimension as the profitability of energy investment, and (Kruyt et al., 2009) have mentioned it as the low energy prices for consumers. Two of the indicators selected are a direct reflection of the price of natural gas and crude oil which indicates how high or low the prices have been and their fluctuation over the period. The other two are indirect indicators of energy consumption per capita which indicates how much energy can be afforded by every individual within the country and GDP per unit of energy consumed which indicates for every unit of energy used how much is contributed to the GDP of the nation. These two indirect indicators are selected to indicate the affordability of energy with respect to the population and GDP of the country which are two key metrices.

2.5.3. Applicability of Technology and Efficiency

This dimension discusses the use of more energy-efficient technologies to ensure a low energy intensity which is a measure of the energy inefficiency of an economy. Its attributes are attached with the cost of converting energy into GDP hence a lower energy intensity is always desirable. (Sovacool & Brown, 2010); (Ren & Sovacool, 2014) has mentioned the importance of innovation, R&D to ensure this dimension performs well and it is key towards securing energy for the future mostly for the non-renewable sources of energy. (Malik et al., 2020) added to the importance of energy conservation within this dimension to extend the availability of the reserves of the energy resources. The indicators selected for this dimension are total energy intensity (TPEC/GDP), energy supply intensity (TPES/GDP) and the industrial energy intensity to assess the performance of the dimension.

2.5.4. Environmental Sustainability

This dimension has been defined in most of the studies that have been assessed as the 'acceptability' dimension which is preferably termed as environmental sustainability to point out the impact that human activities involving the use of fossil fuels can have on the environment (Gong et al., 2021). The emission level of carbon dioxide plays a major role within this dimension. Three indicators based on CO2 emission are CO2/POP, CO2/GDP, and CO2/TPEC which are indirect indicators that give an insight on the impact that the level of CO2 emission has concerning other key economic metrics that are also a part of several dimensions within our measurement index. The 4th indicator of this dimension is the share of RE in electricity generation which is a direct indicator that allows us to know the share of RE in electricity generation which is directly proportional to saving the environment of GHG emissions. (Kosai & Unesaki, 2020); (Zhu et al., 2020b); (Álvarez-Ramos et al., 2020) stated that diversification of fuels for electricity is widely considered as a factor in long-term energy security, hence RE will play a key role in this diversification. More studies like (Khan et al., 2020) are needed to understand how certain human activities impact environmental sustainability. (Sovacool & Brown, 2010) has termed this as environmental stewardship dimension towards ES and they have mentioned that it emphasizes sustainability. (Adedoyin et al., 2020) has emphasized the need for reformation in environmental policies and regulations to improve the environmental quality of a nation.

2.5.5. Accessibility of Energy

This has been defined as the supply of energy in the transport channel and from the geopolitical aspect (Fang et al., 2018). Access to energy is very important as well alongside affordability and availability because without access to energy the dimension of availability is incomplete. A few studies have made accessibility dimension as a part of the availability of energy to avoid the use of an extra dimension. Two indicators for this dimension have been selected, electricity access (% of the population) and access to clean fuel for cooking and technology. These two indicators are sufficient to indicate whether there are any issues related to access to energy within Malaysia and the results mostly suggest that access to energy in the current time is not a major concern in Malaysia.

Overall, we can conclude by stating that the exploration of ES dimensions in Malaysia reveals a complex landscape where availability, affordability, applicability and efficiency, environmental sustainability, and accessibility are deeply intertwined and collectively influence the nation's energy policies. While the focus on fossil fuel reliance underscores the urgency for diversifying energy sources to enhance availability and reduce environmental impacts, the analysis highlights the need for comprehensive policy approaches that address not only the macroeconomic implications of energy costs but also the socioeconomic disparities in energy access. The critical role of technological innovation in improving energy efficiency suggests that advancements in technology could drive the future sustainability of Malaysia's energy sector. However, these technological solutions must be deployed alongside robust regulatory frameworks that ensure equitable access to energy and promote environmental stewardship. Overall, this integrated approach would not only bolster Malaysia’s energy security but also align it with global sustainability goals, positioning the nation to better navigate the dynamic and evolving global energy landscape

2.6. Introduction to System Dynamics in Energy Security Modelling

ES modelling is an essential tool for analysing complex and interconnected energy systems. As nations grapple with the twin challenges of ensuring reliable energy supplies and transitioning to sustainable energy sources, the ability to model and predict outcomes of various policy interventions and market conditions becomes crucial. System dynamics tools, particularly Vensim, offer a robust framework for simulating the dynamic interactions between energy supply, demand, and policy impacts over extended periods. Vensim's capability to integrate both qualitative scenarios and quantitative data through Causal Loop Diagrams (CLDs) and Stock and Flow Diagrams (SFDs) makes it a powerful instrument for revealing the underlying complexities and feedback loops within energy systems.

In this research, 'renewable energy' penetration in the energy mix has been identified as one of the key indicators of ES from the environmental sustainability dimension. This indicator affects the three different dimensions of ES mentioned earlier and their impact on the overall ES of Malaysia has been analysed further in this paper. An approximate total of US$ 8billion worth of investment is required for reaching this target and a public-private partnership and private financing are needed alongside government financing to fulfil this target (Malaysia Renewable Energy 2025: Private Financing Key to Reaching Target, n.d.). Currently, Malaysia is falling short of its national Renewable energy penetration target of 20% capacity as stated in the 11th Malaysia plan (Eleventh Malaysia Plan 2016-2020 | ESCAP Policy Documents Managment, n.d.); (Energy Commission, 2019). This is concerning for the ES of Malaysia, as the long-term ES of Malaysia relies heavily upon the performance of this indicator.

There is a need to quantitatively assess the policies that are in place to judge the potential and the feasibility of the objectives and expected outcomes. The findings of this study aim to address the importance of successful implementation of RE policy targets to achieve higher ES for a sustainable future of the existing natural resources. Policy implications have been suggested to ensure RE policies are evidence and data-driven and achievable within the proposed timeframe. The futuristic modelling approach using system dynamics (SD) aids as a tool to understand how current policies will perform within the proposed timeframe to check the feasibility of the policies for the future. This is believed to change the dynamics of policy design and implementation due to the presence of quantitative data provided through the SD model. The study of (Noorollahi et al., 2021) has backed this method and approach by stating that energy system modelling and sustainable energy planning important tools to assist policymakers in making an appropriate decision by receiving reliable data and information from the energy models.

Eventually we can conclude from the literature that Vensim has been applied across diverse facets of energy security, demonstrating its versatility and effectiveness:

1. **Renewable Energy Integration:**

Vensim can be effectively used to model the strategic integration of renewable energy into national grids. It can be studied whether there is potential of renewables to enhance ES by reducing dependency on imported fossil fuels, which are subject to geopolitical and price volatility.(Chentouf & Allouch, 2021) has studied different interactions of the components of the Moroccan electricity sector and their behaviours on this complex system under various scenarios. The studies of (Acar, 2018a); (Toquica et al., 2021); (Kaya et al., 2021a); (Safari et al., 2019b) and (Pupo-Roncallo et al., 2021)believes that RE can be a promising choice to overcome ES if the issues of intermittency and discontinuous supply can be overcome. (Furubayashi, 2021) suggests the use of more stable supplies of energy (depending on which region and country) to increase system stability to reduce the intermittency challenges of RE. There is a very important relationship between the increase of RE share in the energy mix leading to the improvement in a nation's energy security (ES). The increase in the share of RE reduces the share of fossil fuels in energy systems. (Thommessen et al., 2021) have stated that electricity generation from renewable energy sources is growing that simultaneously creates jobs and decreases the cost.

2. **Energy Transition and Evaluating Policy Impacts on Energy Security:**

    - Vensim has the potential to simulate various transition pathways towards a low-carbon economy. Their models evaluated the impact of different policy levers, such as carbon pricing and renewable energy subsidies, on achieving national energy security goals. The study by (Kit et al., 2023) developed a SD model to address the broader socio-economic challenges associated with Singapore's energy transition. The findings indicate that the energy transition requires a comprehensive approach that includes not only technological innovations but also improvements in labour and energy efficiencies. A significant challenge identified is balancing the need for skilled local labour with the potential increase in foreign workers as new technologies are introduced. Singapore may look to international examples of policies that enhance energy efficiency and labour productivity to navigate these issues effectively.

    - Vensim can be used to understand the effectiveness of energy efficiency policies. By incorporating economic, environmental, and supply security dimensions into their model, the study offered a holistic view of the trade-offs and synergies between various policy measures. The findings suggest that while energy efficiency can significantly contribute to reducing energy demand and emissions, it must be coupled with other policies to address supply-side challenges effectively.

Some of the key benefits that has been identified from the use of SD modelling are;

Vensim allows researchers and policymakers to visualize and understand the complete system, including nonlinearities and feedback loops, which are often overlooked in traditional linear models. It also enables the simulation of various policy scenarios, helping policymakers anticipate outcomes and adjust before actual implementation, thus reducing the risks and unintended consequences. Adaptability wise Vensim's models can be continuously updated and refined as new data becomes available, making them highly adaptable to changing conditions and emerging technologies.

Certainly, there are some challenges that has also been identified during the research as well as the literature of SD modelling.

- **Complexity in Modelling**: Building accurate system dynamics models requires deep knowledge of the system being modelled and the ability to abstract relevant features while omitting inconsequential details. This complexity can be a barrier for new users.
- **Data Requirements**: Effective modelling requires high-quality data, which can be a limitation in regions where data collection is inconsistent or unreliable.
- **Interpretation of Results**: The results of system dynamics models can be misinterpreted without a proper understanding of the underlying assumptions and limitations. This requires careful communication and collaboration between modelers and decision-makers.

The use of Vensim in ES research provides critical insights that can help nations navigate the complexities of modern energy systems. While there are challenges in model construction and interpretation, the benefits of informed policy-making and strategic planning are substantial. As global energy landscapes evolve, tools like Vensim will play an increasingly important role in crafting policies that ensure long-term energy security while advancing sustainability goals.

2.7. Review of Mixed Methodologies

This section of the thesis addresses how the combination of qualitative and quantitative data analysis can be used in ES research to utilize the best of both approaches in consolidating the concept of ES and its impact on any country. The combination of different methods to study the same concept is called the 'Triangulation' of methods (Jick, 1979). The combination of qualitative and quantitative data is actively debated (Östlund et al., 2011) yet it is one of the most effective ways to validate the results generated using each method. The mixed-method approach has not been studied and practiced widely in energy research and ES specifically. ES is a complex phenomenon comprised of several dimensions.

Hence, studying ES is not straightforward when it comes to a single method of research, either qualitative or quantitative solely. A combination of both methods gives the research an edge over single methods because qualitative data from stakeholders discuss the causal relationship between ES dimensional indicators while quantitative analysis using system dynamics gives quantitative results in the graphical form of these dimensions to understand the extent to which they are affected.

This is a combination of methods that have not been practiced widely in the field of ES hence giving a good opportunity to explore these methods followed in this research. The methods have been discussed in depth in this study and explained step by step to understand the flow. The advantages of this mixed method should outweigh the limitations given that the researcher has ample time to carry out the research. This research approach has the scope of exploring similar fields of research for social studies and engineering research and is an example of how social research can blend in the field of energy engineering.

2.7.1. Mixed Method Approach

Mixed-method approaches began as early as 1985 and are an Anglo-American invention primarily popularised by writers like Greene from the USA and Bryman from England (Creswell & Hirose, 2019). On the other hand, 'Triangulation' is the term defined by Denzin, 1978 as the combination of different methods to study the same phenomenon (Jick, 1979). (Fusch & Ness, 2015) have referred to triangulation as 'looking through a crystal' to perceive all the viewpoints of the data. Triangulation is beneficial compared to the singular method because it allows a more holistic and contextual portrayal of the phenomenon under study (Jick, 1979). In this field of research, it helps to validate the results to ensure that the variance reflected that of the trait and not the methods as stated by (Campbell & Fiske, 1959) (Jick, 1979).

The key assumption made in triangulation is that the weaknesses of each of the single methods are compensated by the strengths of the other and vice versa (Jick, 1979). Mixed method research with triangulation as the metaphor has been proven to help researchers get clarity over theoretical propositions and to bridge the gap between theoretical and empirical findings and develop new theory according to study (Östlund et al., 2011). Studies based on mixed methods and triangulation have become a successful practice over the years motivating the use of mixed method approach in different fields of research. This research method also aims to motivate the practice of mixed methods and triangulation in the ES research as it can be beneficial for policy suggestions by quantifying the variables of ES from the qualitative data for Malaysia and ASEAN countries.

It is equally challenging to understand how to mix the methods to achieve the best out of each of the singular methods used. There are 'convergent mixed method design' which allows comparing the results of both databases enabling us to understand them better, while there is 'explanatory sequential design' where data is collected first using a certain instrument to understand it and then followed up by another method or instrument to further enhance the data collection (Creswell & Hirose, 2019). There are certain key characteristics as mentioned in the research by Creswell and Hirose (Creswell & Hirose, 2019) which can be summarised as.

- Collecting both qualitative and quantitative data by the researcher using a quality instrument designed by them or pre-designed instruments. Choosing an adequate sample size and knowing when data saturates.
- 'Integration' is the systemic procedure to combine both the databases with the aim to provide new insights.
- The researcher should use one of the mixed methods approaches of either converging or comparing the responses.
- The portrayal of the results in the form of a theory or conceptual model using these methods keeping in mind the philosophical assumptions made in designing the study.

Keeping these characteristics in mind, this research has integrated the use of semi-structured interviews of qualitative data collection with the system dynamics approach of modelling these data using Vensim as the tool to quantify the dimensional indicators or the variables to quantify ES for Malaysia. This can fall in the category of 'exploratory sequential design' of mixed method where qualitative data collection is done after analysing the literature followed by a quantitative method of system dynamics approach based on the qualitative data that generates the ES framework. (Hitchcock et al., 2015) have broken down the two terms into "exploratory" meaning the use of qualitative data to explore the phenomena and followed by "sequential" representing the use of quantitative methods of analyses. The sequence is explained in Table 8 which shows the flow of work of this study. Sections 3.3 to 3.6 of this study is the detailed breakdown of these phases.

Research contribution to mixed-methods studies and advantages of using this approach

The triangulation of two or more methods has been rare in the field of ES research. It leaves a gap for researchers to fill because triangulation as discussed gives a wider scope to broaden the knowledge and dig deeper into the variables and reasonings that are directly or indirectly related to ES of Malaysia and ASEAN countries. The mixed-method approach taken in this study combines SSIs for qualitative data collection and GT approach for analysis along with systems thinking and system dynamics approach to model these data to quantify them is unique on its own. This combination of methods to collect data and analyse them leaves a lesser gap in the knowledge in the field of ES as you can visualize data from different aspects and dimensions. This approach involves a lot of rigors in the field of research hence solidifying the dimensions and variables of ES and their causal relationship between each other. This set of methods gives the freedom to the researchers to model their qualitative data along with quantitative data collected.

Modelling of these data using a systems approach makes room for futuristic prediction of scenarios for ES of Malaysia in this study which may benefit the policymakers to take note of future policy design for ES. Previously, there have been either pure qualitative or quantitative analysis of ES of different countries or even regions of the world. Systems thinking adds depth to these qualitative and quantitative data by creating the links between the dimensions and their variables of ES. There are benefits of using these methods individually but when combined the results generated for this study become more valuable and in-depth. The value lies in the fact that the ES framework followed by the ES model created in Vensim is validated by the qualitative data of the expert in phase 2. The phase 4 engagement of stakeholders as shown in Table 8 works as the validation stage of the research. The results of this study validated by stakeholders give this kind of study the added value in terms of implementation in the future in its respective field. This study should encourage the use of this mixed-method approach widely in social science and engineering research as it possesses a lot of benefits in terms of quality and adding depth to the data been analysed.

2.7.2. Qualitative Data Collection

Design of SSI Questions: Designing the right set of questions for the data collection is primarily important to collect the desired dataset. (Charmaz, 2014) stated that it is very important to frame the correct questions and requires skills that a researcher can develop as they continue to carry out more interviews on different topics. The questions must explore the interview topic and fit the participant's experience and has also explained in-depth how questions are to be framed and how to conduct interviews to extract the best possible outputs from the participants and these steps have been followed very closely to design this study.

Sampling: There is no “one-size-fits-all” method to data saturation because of the differences in study design depending on whether it is ethnography, meta-analysis, or phenomenological study (Fusch & Ness, 2015). The uniqueness of each study requires the researchers to determine how much data is enough for analysis, depending on when no new theme, no new data, and the concept are generated from the data been collected. Data triangulation and data saturation are dependent on each other in the way that one ensures the other (Fusch & Ness, 2015). The triangulation of different methods ensures that data saturation is reached (Fusch & Ness, 2015). Data saturation is critical to qualitative results as failure to reach saturation can hamper the quality and validity of data (Mouraviev, 2021); (Fusch & Ness, 2015).

Semi Structured Interviews: SSI allows interviewers to be well prepared ahead of time and allows the interviewer to express his opinions during the interview *(Megel & Heermann, 1994)*. This method is used to extract rich descriptive data from personal experiences and to ascertain participants’ perspectives regarding an experience pertaining to the research topic *(Mcintosh & Morse, 2015)*. The construction of SSI follows certain steps according to the research by (Turner, 2010) *(Mcintosh & Morse, 2015)* which have been followed in this study to maximize the output of these interviews.

Grounded Theory Approach: Grounded Theory (GT) approach is inherently flexible yet a complex methodology to be carried out according to the study in (Chun Tie et al., 2019). Originating from the work of Glaser and Strauss in the 1960s, GT is designed to develop theories grounded in real-world observations. This methodology is particularly valuable for exploring processes, actions, and interactions within social contexts. One of the key strengths of GT is its flexibility. Unlike traditional research methods that begin with a hypothesis, GT allows the theory to emerge from the data itself. Researchers enter the field without preconceived notions, enabling them to remain open to new insights and directions as they gather and analyze data. This inductive approach ensures that the resulting theory is closely aligned with the participants' experiences and the context of the study.

2.7.3. Quantitative Data Collection

Quantitative data can be usually collected using multiple techniques such as questionnaire surveys with scales like nominal scales, interval scales, and ratio scales (Megel & Heermann, 1994). The quantitative data collection process is more structured than qualitative data collection and it only allows the participants to answer what is required. The quantitative data used in this study is collected from published energy reports and statistics by the Ministry of Energy and Natural Resources of Malaysia and other energy agencies like the Energy Commission, Sustainable Energy Development Authority (SEDA), and International energy agency (IEA), ASEAN centre for energy (ACE) in publications like (Rogowska et al., 2016) (Energy Commission, 2015) (IEA, 2016) (Suruhanjaya Tenaga, 2017b) (Energy Commission, 2019) (ELEVENTH MALAYSIA PLAN 2016-2020 ANCHORING G ROWTH ON PEOPLE, n.d.). These are secondary data that are readily available in the public domain and are easily accessible. The advantage of using secondary data from these sources is that they are highly validated as these are published by government bodies of Malaysia and ASEAN countries and data are available in large quantity and requires no cost to obtain them. Much of the background work of literature review, case studies, published texts, and statistics are already carried out in secondary data (Megel & Heermann, 1994).

2.8. Research Gap

The literature indicates a critical need for comprehensive frameworks that can integrate renewable energy effectively into Malaysia's energy mix while addressing socio-economic and environmental impacts. This gap is particularly poignant given the country's heavy reliance on fossil fuels and the imperative shift towards sustainable practices, as highlighted by initiatives like the National Energy Transition Roadmap.

1. **Integration of Renewable Energy:** While the literature outlines the progression of RE policies in Malaysia, there is a notable gap in the effective integration of these policies into the national energy framework. The existing studies focus predominantly on policy development without a thorough examination of implementation outcomes or the socio-economic impacts of these policies.
2. **Quantitative modelling of energy policies:** The review highlights a lack of comprehensive quantitative models that incorporate real-time data and dynamic scenario analysis. This gap is critical for understanding the long-term impacts of energy policies under various economic and environmental conditions.
3. **Stakeholder engagement in energy policy:** There is limited discussion on the depth of stakeholder engagement in shaping and refining energy policies. Previous studies often overlook the influence of stakeholder perspectives and their potential to identify practical challenges and solutions in policy implementation.
4. **The lack of combined or mixed-method studies:** The absence of studies employing both qualitative and quantitative methods limits the depth and applicability of research findings. Qualitative methods, such as interviews and surveys, are crucial for capturing nuanced, context-specific insights from stakeholders directly involved in or affected by energy policies. These insights reveal the real-world complexities and challenges that are often missed by purely quantitative research. Conversely, quantitative methods, such as the development and application of the Malaysian ESI, provide a measurable, data-driven perspective that can assess performance, track progress over time, and benchmark Malaysia against other nations.

The correlation between the identified research gaps and the defined objectives is crucial because it ensures that the research is strategically aligned with addressing specific deficiencies within the existing body of knowledge and practice. By directly linking objectives to the gaps, the research not only aims to enhance theoretical understanding but also seeks to deliver practical solutions tailored to the real-world challenges faced by Malaysia's energy sector. This alignment is essential for the research to have a tangible impact, enabling it to contribute effectively to the development of robust, sustainable energy policies. It ensures that the research outcomes are relevant, actionable, and capable of fostering significant improvements in ES, thereby supporting Malaysia's transition towards a more sustainable and resilient energy future. Such a focused approach also enhances the credibility and utility of the research, making it a valuable resource for policymakers, industry stakeholders, and the academic community.

Objective 1 (Identifying Key Dimensions and Indicators): This objective directly addresses the need for a clearly articulated framework for energy security, which has been lacking. By identifying key dimensions and indicators through extensive stakeholder engagement, this research will provide a grounded and nuanced understanding of the energy security landscape in Malaysia. This approach ensures that the framework is not only theoretically sound but also reflective of the practical realities and challenges faced by the energy sector in Malaysia.

Objective 2 (Creating Causal Links with System Dynamics Modelling): The second objective tackles the problem of existing static and fragmented energy policy assessments by introducing system dynamics modelling. This will allow for a dynamic and interconnected view of the energy sector, helping to predict the outcomes of policy interventions and market changes over time. By doing so, the research will offer actionable insights that can guide policymakers towards more effective and adaptive energy strategies.

Objective 3 (Developing and Comparing the Malaysian Energy Security Index): Developing the Malaysian ESI is crucial for quantifying and benchmarking Malaysia's energy security against its neighbours. This objective addresses the gap in current research where a comprehensive, quantifiable measure of energy security is missing. By comparing Malaysia's performance regionally, the research will not only highlight areas of strength but also pinpoint sectors needing urgent attention, thereby fostering targeted and effective policy interventions.

Supporting the Research Hypotheses

The research hypotheses that integrating modelling techniques, comprehensive stakeholder engagement, and a quantifiable security index can significantly enhance the framework for ES in Malaysia are well-founded. With the integration of mixed-methods this research aims to leverage the strengths of each method. The qualitative aspect involves engaging with stakeholders to identify the most relevant dimensions of energy security specific to Malaysia. This engagement ensures that the dimensions and indicators developed are grounded in the actual experiences and needs of those within the Malaysian energy sector. Meanwhile, the quantitative component, utilising system dynamics modelling and the construction of Malaysian ESI, quantifies these dimensions to evaluate Malaysia's energy security performance comprehensively. This dual approach allows for a more nuanced understanding and robust analysis, offering a balanced view that can inform more effective and sustainable energy policies. These methodologies promise to deliver a more robust, adaptable, and comprehensive toolset for policymakers, directly addressing the current shortcomings in the energy sector's strategic planning.

This research aims to fill critical gaps in the current understanding and management of ES in Malaysia. This not only supports the development of informed, effective, and forward-looking energy policies but also contributes significantly to the academic and practical discourse on energy security in emerging economies. The findings from this study will ideally serve as a model for other nations with similar energy profiles, promoting broader applications and implications in the field of global energy security management.

3. Methodology

This chapter highlights the key methodologies adopted and developed for conducting this research. The key focus here in on the qualitative and quantitative aspects of defining ES for Malaysia and eventually how the two are integrated to extract the best results while addressing the research gaps highlighted in sections 2.8.

3.1. Research Workflow Plan

The research workflow plan is shown in Figure 5 which is divided into 4 phases of the methodological approach to analyse ES for Malaysia.

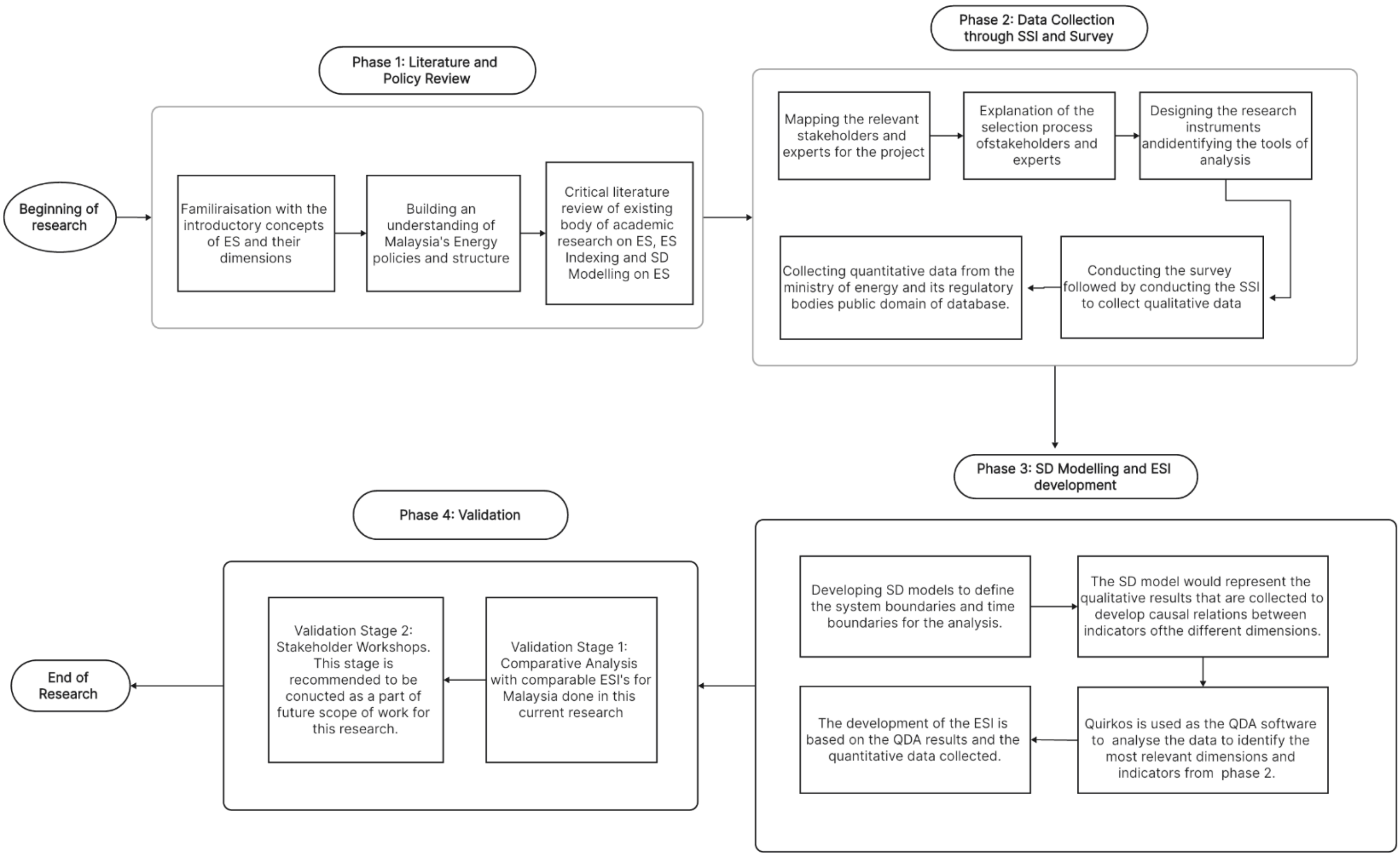


Figure 5: Research Workflow Plan

The study 4 phases including, a Phae 1: Literature and Policy Review, Phase 2: Data Collection through survey and SSI, Phase 3: SD modelling, simulation and ESI development (Quantitative analysis), and Phase 4: Validation. These 4 phases are critical to this study as it shows the step-by-step procedure of how the methods are merged and the dependency of these approaches on each other i.e. phase 2 cannot be designed and conducted without prior knowledge of phase 1 and similarly phase 3 cannot be designed unless the ES framework is established in phase 2. Qualitative data validate the quantitative model that has been built in phase 3, hence proving that triangulation is important for convergent validation (Jick, 1979).

3.2. Understanding and Selecting the Methods

The development of a framework based on the qualitative data analysis from stakeholder engagements and literature and creating a quantitative system dynamics model to quantify ES are two key research objectives that this research aims to achieve using these mixed methods. A measurement system is to be established to quantify the current and future ES of Malaysia using its dimensional indicators. These dimensional indicators are identified using the ES framework created from the qualitative data from stakeholder engagement. This section discusses the methods individually and sequentially used for the study as shown in Table 8. Four phases have been planned out for this research which include literature review, stakeholder engagement, modelling and simulation, and validation and verification. Phase 1 is a literature review of the existing academic research and energy policies that has been done on the ES of Malaysia and neighbouring ASEAN countries which is followed up by phase 2 of stakeholder and experts' engagement. Stakeholder engagement is one of the crucial phases of the research as data is collected for designing the framework of ES. Phase 3 is the development of CLD's and SFD's based on the data collected from the stakeholder engagement. Phase 3 also involves the development of the Malaysian ESI which quantifies the level of ES on a scale of 10 and this enables us to compare the Malaysian ESI with existing ESI's and with that of neighbouring countries. The last phase of the research involves validating the Malaysian ESI by comparing it with existing ESI's for Malaysia. This is a form of empirical validation of the ESI while the future work should involve the utilisation of stakeholder focus group sessions to validate the model.

3.3. Stakeholder Engagement

In this research, data collection plays a very crucial role in fulfilling the research objectives, and hence data collection is done with utmost importance and care. The data collection for this research follows the steps as shown below in table 7.

Table 7: The Workflow of Data Collection

Sampling	***Instrument/Tool***	***Data collection procedure***
Selection of Stakeholders and Interviewees from government sector, private sector, and research institutes	Semi-Structured Questions for Interview of stakeholder. Survey sheets for experts for true/false questions to develop causal link between indicators. Collecting quantitative data from energy reports and statistics of Malaysian ministries and energy agencies published online.	Conducting Semi-Structured Interviews ➢ Face-to-face ➢ Video Call with researchers abroad through Skype, Teams, Zoom etc. Transcribing the recorded interviews using verbatim intelligent transcription method

Qualitative data is collected from stakeholders in the form of a semi-structured interview. The qualitative data collection is used to create the framework of ES which is based on the important dimensions and its respective indicators for ES of Malaysia. This framework lays the structure and base for the creation of the SD model which generates quantitative results. The quantitative data is solely collected for Malaysia and other ASEAN countries from energy reports published by the energy regulatory bodies. These data are used in the system dynamics model to generate quantitative results for ES of Malaysia. Hence, the best approach would be a mixed method for the data collection as the data collected through this method is rich and comprehensive (Ahrq, n.d.).

The qualitative approach allows the researchers to understand the reasons, opinions, and motivations of ES of Malaysia and its impact. This understanding comes from Phase 1 of the research where qualitative research has been done on ES of Malaysia and researchers have shared their perspective of ES. A quantitative approach is important here because of the availability of historical data and documentation of the values of the energy security indicators. Further analysis of historical data tends to give an insight into how the future of these indicators might shape. Although, several external factors do not necessarily let the historical data to be repeated in the upcoming years. This is where analytical skills are needed to understand each indicator well and expert opinion becomes valuable. Interview of experts i.e., stakeholders as mentioned in phases 2 and 4 is of utmost importance to this research as it adds value and justification to the qualitative research done so far as well as verify and validate the quantitative research that has been done in this study.

The addition of quantitative research to the existing work will quantify the problem with the addition of CLD's, SFD's, and numerical values and data. The numerical results are easier to analyse and give a clear concept of ES current and future scenarios for Malaysia. Once the quantitative data is collected alongside the qualitative data from stakeholder engagement, both are used in combination with phase 3 of the research where the SD model is created alongside the ESI that is called the Malaysian ESI. Post simulation of the SFD's and development of Malaysian ESI, the results were validated and verified through presenting the published work of each of the research objectives to the same set of stakeholders who have given their feedback on the ES framework and the SD model results that are generated.

There are few stages in qualitative and quantitative data collection, and it has been adapted from (Datamixed, 2006) where the Table 8 shows a comparison of the two methods in different phases. This research follows a mixed-method approach of Quantitative and Qualitative data hence it is important to know how both vary and their similarities in the different stages from choosing the sample size and participants to administering the data collected from that specific sample size.

Table 8: Breakdown of the stages of data collection for the two different approaches

Stages	***Qualitative***	***Quantitative***
Consent	• From individuals who	

	are interviewed or institutes giving access to resources. Consent must be taken from the source of data been collected	
Sampling	• Finding the right people for data collection • A small number of participants in the form of stakeholders of Energy Security and policies in Malaysia and the ASEAN region.	• Random sampling is done in this approach • A larger number of participants to reduce sampling error
Data Sources and Instrument	• Open-ended, semi-structured interviews • Documents and historical data	• True/False Questionnaire • Checklists in the questionnaire
Recording the data	• Through interviews and observation. Transcribing the recorded data.	• Through documenting the data collected.
Administering the data	• A standardized procedure for data collection from all the participants • Ethical approval from the participants before data collection	

The advantages of using both approaches are valuable for this research. There is methodological flexibility in this mixed-method as it combines the best of two approaches to collect high-quality and more comprehensive data through the integration of the two (Ahrq, n.d.). The mixed-method also allows the participants to share their points of view and opinions that are recorded alongside the quantitative data. The stakeholder opinions and views in the current research add more insight into the historical data collected from documents and existing energy policies. Despite having these advantages, this approach does have a few drawbacks and limitations. This can be time-consuming as an integration of both approaches will require time and labour to bring all the resources together. It can be complex and requires systematic planning to select the sample and collect data from the stakeholders of this research. Quantifying a term like ES comes with its challenges as there are several variables linked to each other with causal relation and factors like time delay and intervening factors that change from time to time.

3.3.1. Stakeholder Selection

The samples for the interview in this study is very selective and targeted towards the ministries, government agencies, research institutes, and private organization who work directly working with ES policies and dimensions. There is a certain limitation to the number of stakeholders that can be engaged due to the filtering process used as shown in Figure 2. Also, keeping in consideration that the entire process of data collection has been done by a single researcher (Lillis, 1999) and facing time constraints, the selected number of stakeholders are considered sufficient to get emerging themes as outputs from the semi-structured interviews (SSI). Sample size in the grounded theory (GT) approach of coding the number of interviews to be conducted also depends on data saturation.

In this research, a total of 16 stakeholders were interviewed. The first 10 stakeholder interviews led to generating new themes in higher frequency and number. After 10 interviews, lesser themes started to emerge out of the data coded using the GT approach. As the GT approach follows emergent coding, every possible chance of finding new themes was explored in this study until no new themes could be found from the transcripts of SSI. Hence, a sample size of 16 is sufficient to do the thematic analysis of the qualitative data that is collected for designing the ES framework of Malaysia.

The selection of the correct stakeholders for this research is very important as most of the data for Malaysia and ASEAN countries comes from their knowledge and expertise. Phase 2 and 4 of this research requires the strong engagement of the stakeholder for justifying the literature and data collected and at the same time to validate and verify the CLD’s and SFD’s that are created. There are a few criteria to be fulfilled by the stakeholders for their successful selection as shown in Figure 6.

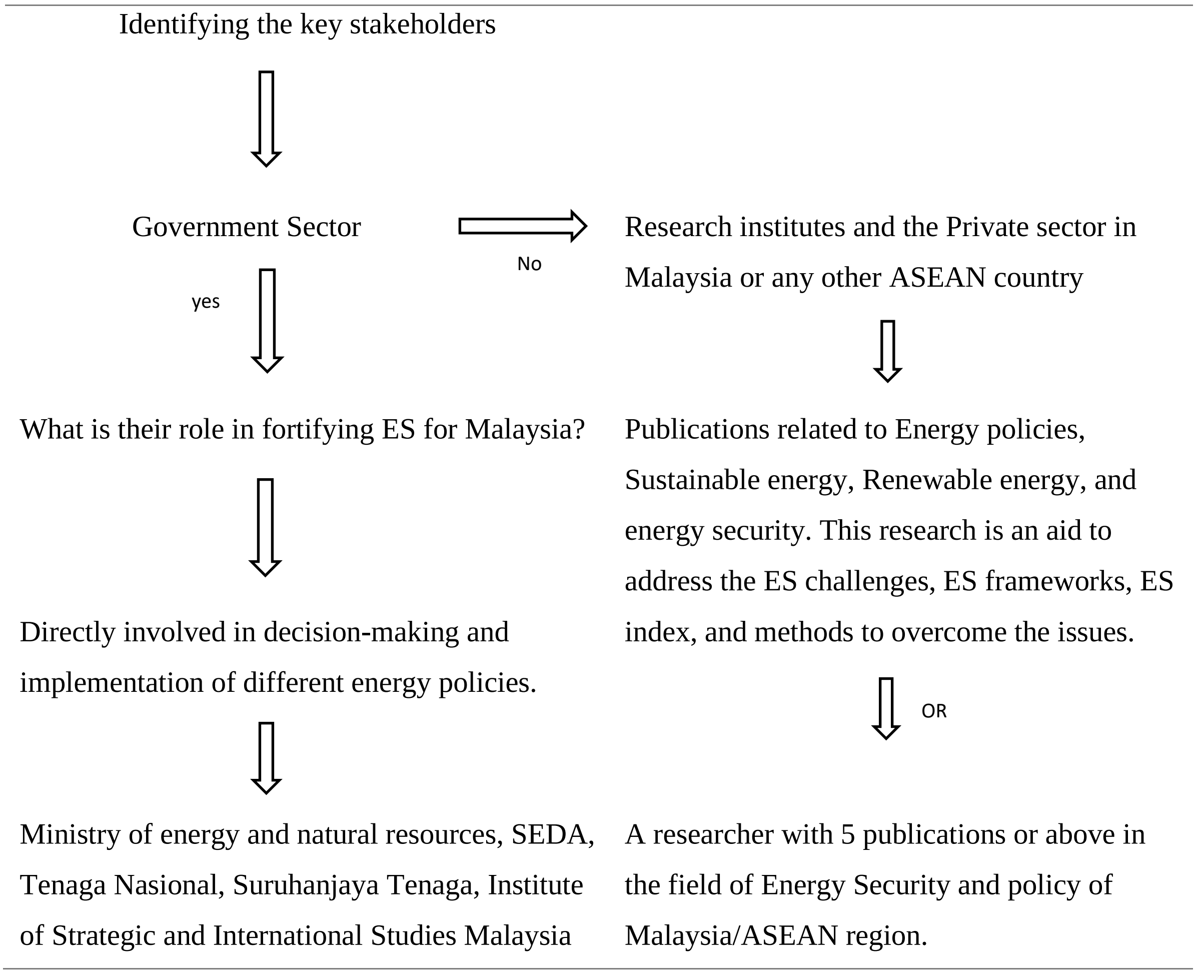


Figure 6: Stakeholder justification process

Table 9 shows the list of stakeholders who have been interviewed as a part of the stakeholder engagement for data collection. The selection has been done following the method explained in Figure 5.

Table 9: List of stakeholders

Stakeholder	***Organisation***	***Position held in current organisation***
1	Energy Commission, Malaysia	Deputy Manager
2	Energy Commission, Malaysia	Electricity Market Operations
3	Energy Studies Institute, National University of Singapore	Senior Principal Research Fellow (Head of Division)
4	UiTM Energy and Facilities and UiTM Solar Power, Malaysia	Head of Sustainable Asset investment, CEO of UiTM solar power

5	Energy Studies Institute, National University of Singapore	Senior Research Fellow
6	Saab-NTU Joint Lab, Nanyang Technological University, Singapore	Programme Manager
7	Tenaga Nasional Berhad Malaysia	Transformation Partner
8	Agilent Technologies, Malaysia	Researcher
9	University of Technology Sydney, Australia / Economic Planning Unit, Malaysia	Researcher and Assistant Director, Economic Planning Unit, Malaysia
10	Energy Studies Institute, National University of Singapore	Post-Doctoral Fellow
11	Institute of Strategic and International Studies Malaysia	Research Fellow
12	Institute of Strategic and International Studies Malaysia	Senior Director of Research
13	Ministry of Energy and Natural Resources, Malaysia	Principal Assistant Secretary
14	Sustainable Energy Development Authority (SEDA), Malaysia	Chief Executive Officer
15	Tenaga Nasional Berhad Malaysia	Consultant
16	Single Buyer, Malaysia	Chief Corporate Officer

3.3.2. Design of Research Instrument

Stakeholder interview and engagement as mentioned in phase 2 and phase 4 is a very crucial part of the research. Interviewing the stakeholder to gain further knowledge which is otherwise not available in literature adds value to the research beyond the literature. The purpose of the semi-structured questions is to know the opinion and expert advice on the current ES scenario with ways to improve and/or suggest new policies. To understand the definition, the dimensions, and the key indicators that are involved in Malaysian ES it is important to blend the data of literature and the in-depth qualitative data collected from the SSI's. The design of the SSI questions is based on current literature and as per the requirement of the research objectives. The questions are designed with the primary aim to answer the research questions and to work well with the proposed method of data analysis, in this case, a GT approach. In this research some important studies such as that by (Turner, 2010), are referred to develop the necessary steps to be followed in designing the semi-structured interview questions. The steps to ensure that the researcher is prepared to conduct these interviews and collect data are as followed.

- ***Preparation for the interview***: The preparation stage is very important as the researcher can prepare in advance on how the interview will be conducted and what the flow of the interview will be like, and this stage will provide an unambiguous focus on how the interview will be conducted to maximise the benefits of the interview and collect the most relevant data.

- ***Selecting participants***: Section 3.3.1 discusses in-depth this part of selecting the correct stakeholders and participants for the interview so that the data collected answers the research questions and matches the objectives.

- ***Pilot testing the interview**:* The interview questions and the time taken to respond to each question has been recorded to ensure the timeliness of the interviews. The data recording methods such as the use of online video meeting platforms and voice recorder for physical engagements has been tested prior to the actual interviews.

- ***Constructing effective questions**:* Each question asked in the interview should allow the interviewee to think deeply and from their experience on how they can answer the questions. It is important to frame the questions to allow the interviewee share experiences. Questions are open-ended, and they are neutral that does not influence the answer. These two criteria mentioned by Turner in (Turner, 2010) are very important in creating the questions for the interview.

The following steps were used as a guideline in creating the SSI questions for the data collection. The questions used in stakeholder data collection are listed in Table 12 but are not just limited to these questions. Follow-up questions based on where the interviewee answers lead to is very important. The questions designed for this research are flexible and allow the interviewee to answer them with their perspective and, hence sharing their experience. The confidence on these questions have been gained through pilot testing and through mock interview of faculty members within UNM to assess the strength of the instrument and the methods. The results of the pilot test for the questions have shown a positive response in generating emerging themes of ES through Quirkos in the QDA.

The questions are designed to keep the interviewee on focus with the context of the question and to ensure thaexplore the interviewers' topic and fit the interviewees' experience. The construction of SSIs follows certain steps suggested by (Turner, 2010); (Mcintosh & Morse, 2015) which have been followed in this study to maximise the output of these interviews. Table 10 is a non-exhaustive list of the questions that were asked to the stakeholders.

Table 10: Stakeholder Interview Questions

	Stakeholder interview questions
1	How would you define Energy security?
2	Why is it important for us to address Energy Security challenges and their impacts?
3	Is there any specific energy policy that addresses the Energy Security of your country? What more can be added to the existing policies to address the energy security of Malaysia?
4	Socio-economy, Environmental Sustainability, and Energy Availability are listed as 3 key dimensions of Energy security that we can name. Is there any other dimension that can be added and why?
5	Can you suggest ways to improve the Energy Security scenario and tackle the challenges of Malaysia and other ASEAN countries?
6	What are your thoughts on quantifying energy security using an energy security index and further using system dynamics modelling? What other ways can you suggest quantifying the energy security of Malaysia?

These questions are not exhaustive and not the only questions that were asked during the interviews.

3.3.3. Semi-Structured Interviews

SSI is the qualitative method of data collection that has been adopted for this research using semi-structured questions that have been tabulated in Table 2. These are open-ended questions with a designed structure that allows the interviewee to express their opinion within the context of it. This also gives the flexibility to the interviewer to ask questions that can be answered in several ways varying with different individuals and allows the interviewee to express his opinion more openly on the topic of discussion or phenomenon.

The SSIs of this research are recorded with the consent of the participants to generate intelligent verbatim transcripts that are analysed using the software 'Quirkos' which gives a richer insight into the data that has been collected through these SSI's. Stakeholders abroad are contacted through video calls and SSI's have been conducted over the video call. This is an easier, cost-effective, and convenient option to conduct one-on-one interviews with the stakeholders who are not residing in Malaysia. The SSI's in this research aims to collect data from the stakeholders and experts on their opinion and thoughts on ES, ES issues and challenges, the current and future policies to address ES, and the causal relations between the dimensional indicators of ES for Malaysia. The stakeholders are expected to put forward their opinions and views on each of these questions which are to be analysed and compared with all the participants. The systematic approach is as shown below adapted from the studies.

- Identifying the domain of the topic
- Identifying the categories
- Identifying the items
- Writing the question stems
- Piloting the interview schedule
- Testing

3.3.4. Grounded Theory Approach for Qualitative Data Analysis

Grounded theory (GT) is the adopted in this research to analyse the data that has been collected through the detailed process explained in this research methodology chapter. The data collection is done using SSI's lasting from 40-60 minutes with the stakeholders before the grounded theory (GT) is applied to analyse these recorded and transcribed data. This is an inductive approach of concluding theories and frameworks from observations which in this case is from the data collected and recorded from the stakeholders through semi-structured interviews. The GT follows the inductive approach as shown by Charmaz in (Hesse-Biber & Leavy, 2004).

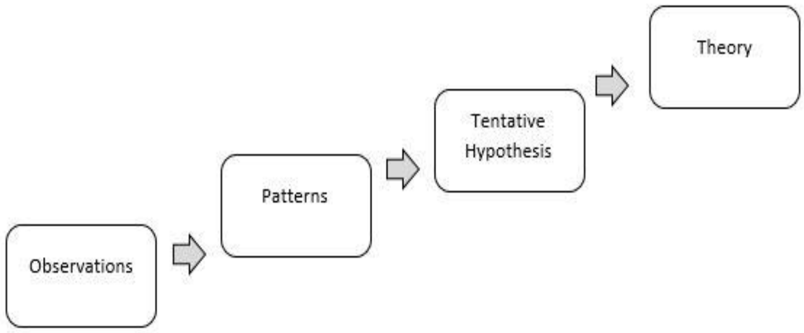


Figure 7: Inductive approach of Grounded Theory

Figure 7 summarises how the GT approach works from recording observation to finding patterns in the observation that leads to a tentative hypothesis and hence a theory which in this case is the Malaysian ESI created for ES of Malaysia using the hypothesis and theory formed.

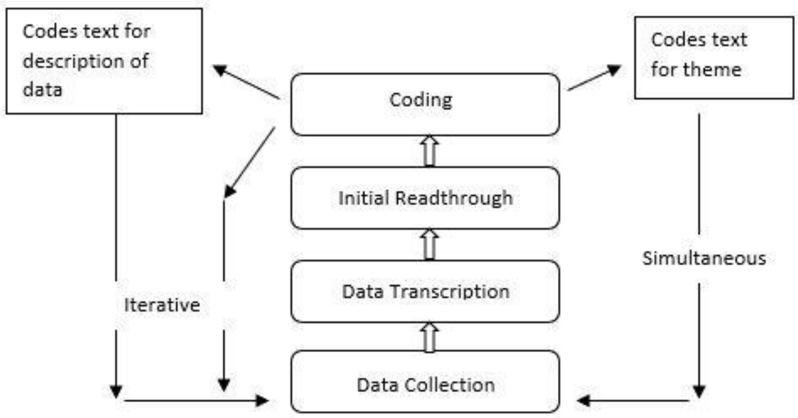


Figure 8: The iterative process as explained by Charmaz

Figure 8 shows the iterative and simultaneous process of data collection coding that has been implemented in this research. These steps are followed in the research to code the collected data through SSI and analyse them using grounded theory. The GT approach follows emergent coding where the codes emerge as we read the text and structural coding where there is a preconceived notion of what is necessary to code according to the ES of Malaysia and ASEAN countries. This combination of emergent coding with structural coding makes it the best approach to analyse the SSI data collected.

To collect the appropriate data for coding, the stakeholders chosen is through purposive sampling. Purposive sampling allows us to choose the stakeholders who are expected to answer the SSI questions and answer them using their experience, expertise and knowledge. Purposive sampling makes the process of data analysis faster and more accurate in the context of this research. On the other hand, as explained in (Charmaz, 2014) theoretical sampling is also more commonly carried out as a process to choose the interviewees. Theoretical sampling is to elaborate the theory by gaining more information from different samples and hence expanding the chances of exploring new themes from the data collected. In this research, the field of ES of Malaysia and ASEAN countries are not very broad with a limited number of stakeholders in the field of ES, hence purposive sampling is done and listed in Table 11.

Once, the sample size is determined and data is collected the data preparation stage begins. In this stage, the data collected is transcribed using an intelligent verbatim transcription method and read through thoroughly before coding can begin. The constructivist approach of coding is the one followed by(Charmaz, 2014). The constructivist approach of the GT follows mostly two stages of coding; the first is initial coding followed by focused coding. Initial coding is done by the following line by line coding and reading the fragments of the texts and coding them as we read through for the analytical import. Focused coding is where the most appropriate and relevant codes are picked from the initial code where data with data is compared and then data with codes.

This is also known as the constant comparative analysis (Chun Tie et al., 2019) where new concepts are generated through constant comparison of incidents in a category with other incidents and further categories with other categories. This entire process is iterative as explained in Figure 8 and it continues until data saturation occurs where no new categories or themes are generated from the SSI of stakeholders.

The analysis steps that were followed are.

Open Coding: This initial phase involves identifying, naming, and categorizing the phenomena found in the data.

Axial Coding: In this phase, the categories were related to their subcategories, forming a more coherent picture of the data. It involves identifying relationships and patterns among the codes.

Selective Coding: The final stage involves integrating and refining the theory. The focus on core categories, systematically relating them to other categories, validating relationships, and filling in any gaps.

3.3.5. Quantitative Data Collection

The collection of secondary data in this study leverages a highly efficient and reliable approach, minimising time and resource expenditure while ensuring the integrity and relevance of the information gathered. The data sources—ranging from government bodies like the Ministry of Energy and Natural Resources of Malaysia to international agencies such as the International Energy Agency (IEA) and the ASEAN Centre for Energy (ACE)—are recognised for their high standards of data accuracy and comprehensive coverage of energy-related metrics. Utilising these sources provides a robust foundation for the research, as they offer extensively validated and authoritative datasets that underpin the credibility of the analysis. Furthermore, the systematic use of secondary data from these esteemed entities ensures a consistent and rigorous assessment of Malaysia's energy security landscape, aligning with global standards and enabling meaningful comparisons and evaluations.

3.4. System Dynamics Modelling using Vensim

Systems thinking is used to provide a tool to better understand difficult problems (System Analysis I Compendium for Students, 2009a). System dynamics is a methodology of systems thinking which is used to understand and model complex systems (Aslani et al., 2014). his approach is integral to our research, where we employ system dynamics to explore and quantify the multidimensional aspects of energy security (ES) for Malaysia.

The use of system dynamics in this research involves the creation and simulation of causal loop diagrams (CLDs) and stock and flow diagrams (SFDs) through the Vensim software.

CLDs help visualize and understand the causal relationships and feedback loops between different variables within the ES framework. By mapping these relationships, we can identify key leverage points and potential unintended consequences of policy interventions.

SFDs, on the other hand, provide a more detailed and quantitative representation of the system, showing how different stocks (e.g., energy reserves) and flows (e.g., energy consumption) change over time. By simulating these diagrams, we can explore various scenarios and their impacts on energy security, allowing for a more dynamic and predictive analysis.

The development of CLDs and SFDs is grounded in a thorough understanding of the causal relationships between the dimensional indicators of ES, which are derived from both qualitative and quantitative data. This data-driven approach ensures that the models reflect real-world complexities and interactions, making the insights and predictions more robust and applicable.

In summary, the integration of system dynamics into our research methodology allows for a holistic and dynamic analysis of ES. It enables us to not only quantify the dimensional indicators but also to simulate the potential impacts of various policy measures and external factors on Malaysia's ES. This comprehensive approach provides valuable insights that can inform more effective and sustainable energy policies.

3.4.1. Causal Loop Diagrams

Causal loop diagrams are visual aids that help understand how different variables in a system are interrelated. A positive sign represents a positive relation and vice versa for a negative sign. A positive relation means, an increase in one variable will lead to an increase in the next if they are related by the '+' sign, or a decrease in the previous will led to a decrease in the next variable. A '-' sign indicates that there will be a change in the opposite direction compared to the previous variable. CLD's can form closed cycles that form either a balancing loop or a reinforcing loop. In a balancing loop if a variable increases, the cycle will lead to a decrease in the same variable and vice versa. In a reinforcing loop, the increase in a variable would further lead to more increase in the same variable because of the effect in the cycle.

CLD's also have 'delays' in their loops which is used in cases where time is consumed before the effect plays out. It also means the target is overshoot and hence it oscillates around the goal. Closed loops are essential to CLD's because each loop gets linked to another which forms a chain of reaction. An example is shown below which shows all the above-discussed features of a CLD (System Analysis I Compendium for Students, 2009a). The CLD in Figure 9 comprises of 3 balancing feedback loops with energy reserve to production ratio and imported energy as common indicators in 2 different loops. In each of these CLD's, there will be an added external variable or an auxiliary variable that will be added for simulation purposes. The CLD shows the link between energy wastage and the direct causal link with 3 other variables in one of the balancing loops.

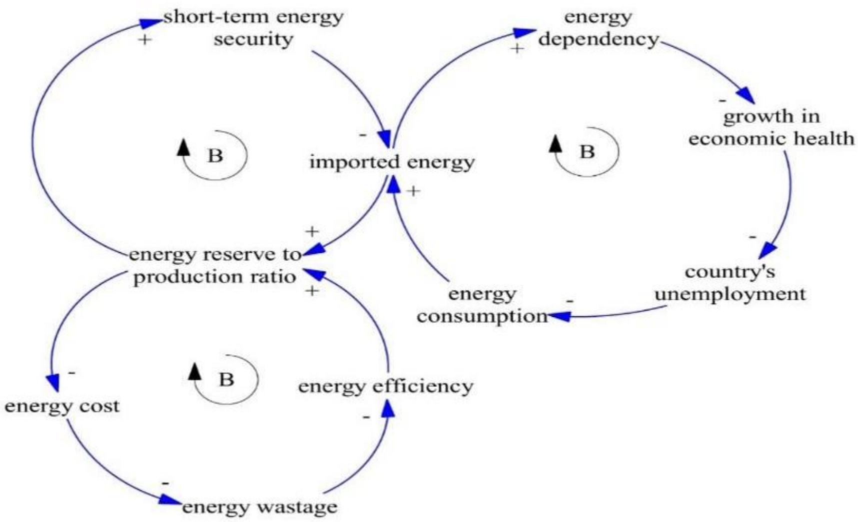


Figure 9: CLD with 3 balancing loops

3.4.2. Stock and Flow Diagrams

Stocks are fundamental to generate behaviour in the system. It determines the current state of the system (Osgood, n.d.-a). Stocks can be measured one instant at a time and can only be changed by flows in and out of the system. Flows are expressed per unit time which means it measures over a period. The representation of stocks and flows is shown below in Figure 10.

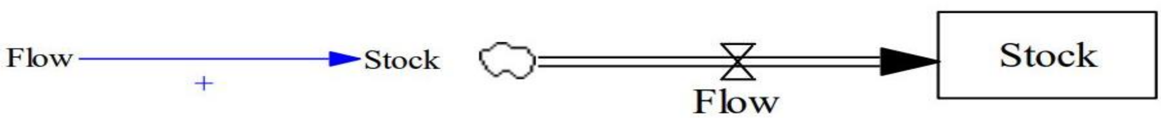


Figure 10: Stock and Flow representation

All the causal loops must involve at least one stock, without which the loop becomes instantaneous. Auxiliary variables influence stocks but adding or removing an auxiliary variable does not change the mathematical structure of the system (Osgood, n.d.-b). Figure 11 shows 1 stock of production to reserve ratio and 2 flows assigned imported energy and short-term ES. The relation suggests that a flow of imported energy into the stock of production to reserve ratio increases and, hence increasing the short-term ES.

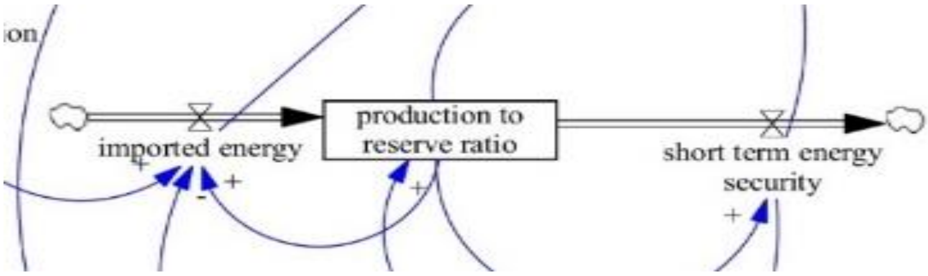


Figure 11: Stock and Flow example for this research

3.4.3. Equations for stocks and flows

To quantitatively model any process, it is essential to establish defined quantitative values and equations that represent each variable and their interactions. According to Morecroft and Sterman in the study (Sterman, 1994), two fundamental assumptions in system dynamics are: (1) flows within processes are continuous, and (2) flows do not contain a random component (System Analysis I Compendium for Students, 2009a). These assumptions allow us to create deterministic models that can be analysed and understood systematically.

Using these assumptions, we can liken any stock and flow system to a ‘plumbing system,’ where stocks act as tanks and flow as valves regulating the rate of input and output. This analogy helps simplify the understanding of complex systems by visualizing how variables accumulate (as stocks) and change over time (through flows). For accurate system dynamics modelling, each stock must have an initial value, and the flows must be defined by precise equations. These flow equations are typically derived from empirical data, theoretical relationships, or expert judgment. They dictate how the stocks change over time based on various influencing factors.

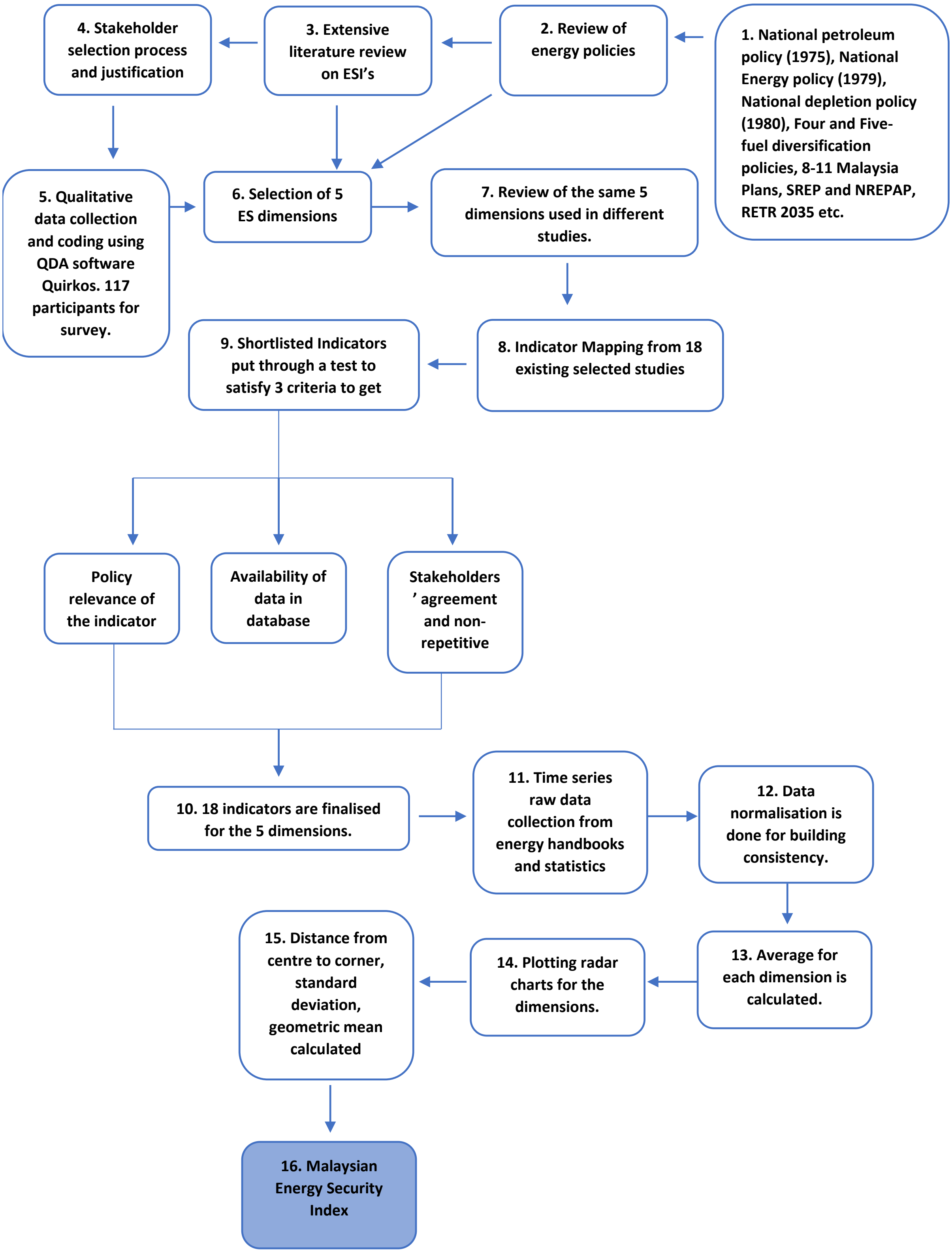
Once these initial values and flow equations are set, the model can be implemented in Vensim. Vensim solves the equations iteratively to simulate the system's behaviour over time. This simulation generates graphical representations that illustrate how different variables evolve, interact, and impact one another. These visual outputs are crucial for understanding the dynamics of the system and for identifying potential leverage points for intervention.
Moreover, by running simulations under different scenarios, we can assess the potential outcomes of various policy decisions and external conditions. This capability makes system dynamics a powerful tool for strategic planning and policy analysis. It provides stakeholders with a clear picture of how changes in one part of the system can ripple through and affect the entire system.

3.5. Development of Malaysian Energy Security Index

This part of the chapter discusses in detail the methods used to develop the 5-dimensional framework that eventually leads to the development of the Malaysian ESI to evaluate and measure the level of ES for Malaysia on a scale of 1-10. The results of Malaysian ESI have been discussed in-depth in chapter 6 of this research.

3.5.1. The 5-Dimensional Framework to Develop Malaysian ESI

The 5 dimensions selected in designing the Malaysian ESI are Availability of Energy (AV), Accessibility of Energy (AC), Affordability of Energy (AF), Applicability of Technology and Efficiency (APE), and Environmental Sustainability (ENV). This framework adds an extra dimension to the study of (APERC, 2007a) and (Ren & Sovacool, 2015) which follows the classic 4A's framework of ES, which has been widely adopted by a few notable groups of ES researchers. The flow chart below shows the development process of the Malaysian ESI using the 5-D framework.


1. National petroleum policy (1975), National Energy policy (1979), National depletion policy (1980), Four and Five-fuel diversification policies, 8-11 Malaysia Plans, SREP and NREPAP, RETR 2035 etc.
2. Review of energy policies
3. Extensive literature review on ESI's
4. Stakeholder selection process and justification
5. Qualitative data collection and coding using QDA software Quirkos. 117 participants for survey.
6. Selection of 5 ES dimensions
7. Review of the same 5 dimensions used in different studies.
8. Indicator Mapping from 18 existing selected studies
9. Shortlisted Indicators put through a test to satisfy 3 criteria to get
Policy relevance of the indicator
Availability of data in database
Stakeholders ' agreement and non-repetitive
10. 18 indicators are finalised for the 5 dimensions.
11. Time series raw data collection from energy handbooks and statistics
12. Data normalisation is done for building consistency.
13. Average for each dimension is calculated.
14. Plotting radar charts for the dimensions.
15. Distance from centre to corner, standard deviation, geometric mean calculated
16. Malaysian Energy Security Index

3.5.2 Data Collection

The first set of qualitative data is collected through a stakeholder engagement (Mohamad-Ali et al., 2018) to understand the key dimensions of ES for Malaysia and other ASEAN countries. A total of 16 stakeholders were interviewed using a set of SSI questions (refer to table 10) and the data collected were audio/video recorded and transcribed. The transcribed data were coded using qualitative data analysis (QDA) software Quirkos to create emerging themes out of the data. This is an inductive approach of concluding theories and frameworks from observations which in this case is from the data collected and recorded from the stakeholders through semi-structured interviews. The Grounded Theory (GT) approach is inductive as described by Charmaz in the study of (Hesse-Biber & Leavy, 2004).

A further 117 people from the energy sector either in the private or public sector in Malaysia have taken part in a survey that asks simple questions to understand the relationship between various ES dimensions and their indicators to draw a clear picture of which dimensions are of higher priority. The qualitative data and its analysis to identify the 5 ES dimensions is a valuable addition to ESI research in this region and Malaysia in particular. (Von Hippel et al., 2011) have also highlighted the importance of qualitative data assessment to address issues from the angle of cultural impact, social acceptance, and similar attributes for which quantitative measures may not exist.

Raw data for the Malaysian ESI indicators are collected mostly from the Energy Commission of Malaysia's official website. Annual reports, energy statistics, energy outlook, industry outlook, national energy balance, and similar reports are published annually containing valuable data and information that represents the overall energy picture of the nation. The raw data were collected from the following documents (Statistics, 2019)(Ministry of Natural Resources and Environment Malaysia, 2015) (Malaysia - Countries & Regions - IEA, n.d.)(Malaysia Energy Production and Consumption, n.d.).

3.5.3 Data Transformation and Coding

The 18 finalised indicators of the Malaysian ESI have different units of measurement. It is critical to convert all the indicators to one common scale for the standardisation of the data to maintain consistency throughout the index. This process is called data normalisation. The *min-max* method of data normalisation is selected for the current study. This method measures performances based on the best and worst scores (Abdullah et al., 2020). The studies of (Malik et al., 2020; Sovacool et al., 2011; Tongsopit et al., 2016; Yao & Chang, 2014) have been followed strictly to validate the min-max approach of data normalisation. This method is simple, accurate, and justifiable for either a small or a large set of raw data. The 5 dimensions have been given equal weightage or importance. This is to avoid objective justification for adding different weights to different indicators. (Tongsopit et al., 2016) has mentioned a key weakness of this method was not considering any exogenous energy shocks in the global market. Also, the scale needs to be recalibrated if any additional indicator or dimension is added to the index (Abdullah et al., 2020). From Malaysia's perspective, there is no clear indication of which dimensions can hold what weight in terms of priority or importance, and this remains unclear even after stakeholder engagement in this research. Hence, the min-max method with equal weights for dimensions has been selected.

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

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

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

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

$$X' = 1 + \left(\frac{X - MaxA}{MinA - MaxA}\right) \times (10 - 1) \quad \text{----Equation 2}$$

This scale measures the relative performance of the indicators based on the scale set (max and min of A) and any addition or removal of indicators from this range will require changing the max and min accordingly which can be tedious and difficult to monitor for larger datasets.

3.5.4 Radar Chart Plotting

The normalised values of the dimensions are calculated by taking the average of all the indicators of that respective dimension.

$$Dimensional\ value = \frac{Indic.1 + Indic.2 + ..Indic.n}{n}$$ ----Equation 3

For environmental sustainability (ENV), there are 4 indicators, hence the value of the ENV dimension would be calculated by the equation.

$$ENV = \frac{ENV1 + ENV2 + ENV3 + ENV4}{4}$$ ----Equation 4

Since there are 5 dimensions been analysed in this study, the radar chart plots a pentagon with 5 points. The data spans over more than a decade and hence it gives a clear picture of how ES has performed in Malaysia over more than a decade. The closer the plotted values to the corners of the pentagon represents a stronger share of that respective dimension for that particular year. On the other hand, an overall higher ES for that particular year.

Overall ES performance for any respective year is calculated as the average of the 5 dimensions for that year.

$$ES = \frac{AV + AC + APE + ENV + AF}{5}$$ ----Equation 5

3.6 Limitations and Future Scope of Improvement

3.6.3 Limitations of mixed-method approach

Firstly, this research involves two stages of stakeholder engagement. Studies like this involving stakeholder engagement in two phases (phases 2 and 4) can be lengthy in duration and time-consuming. The process of selecting stakeholders, connecting to them, and getting approval to interview them can be time-consuming. The number of stakeholders involved depends on the type of study. The transcription of the recorded data and emergent coding using the GT approach can be time-consuming as well. Systems thinking and modelling involve creating a relation between the variables found from the qualitative data. This entire process can be tedious for an individual researcher and involves rigor. As it is an 'exploratory sequential design' study, it involves a systemic procedure to be followed and needs to go through the sequence which cannot be disrupted as shown in Table 8.

There are limitations in the system dynamics approach of modelling these variables as these variables and their relationships with each other can take drastic turns depending on various factors like geopolitics, socio-economy, environmental disaster, or any form of a global pandemic affecting the economy, infrastructure, and environment. The process is dynamic, which changes with time and hence needs to be updated frequently to represent the ES scenarios that are relevant to date. Systems thinking also involves one's perception of the qualitative data and how the researcher develops the connection between the variables. It does not necessarily have to be the same as any other researcher and can vary depending on the researcher's perception of a certain ES scenario.

3.6.4 Future Scope for Mixed-Method Research Approach

This mixed-method approach of qualitative data collection and systems approach to modelling the output of the data to get quantitative results can be used in various energy-related studies. It is not restricted only to energy studies but also can be implemented in studying other social causes and policy studies within a community, country, or even a region. Environment, economy, sustainability, politics, and technological innovations are a few of the fields of research where this approach can be used in understanding the links between each of these dimensions. Studying the relations between these dimensions and modelling them to quantify a certain aspect of it can be beneficial for policymakers and government bodies too. Futuristic modelling using system dynamics opens the door for policymakers to make rough judgments of how scenarios will shape out in the future. Hence, this leaves a lot of room for exploration within their field for researchers using this mixed-method approach.

For the fourth phase of the research, it is recommended that a stakeholder focus group discussion and workshop is conducted for the validation of the Malaysian ESI. This involves organising workshops and focus groups with key stakeholders, including policymakers, industry experts, and representatives from energy sectors. During these sessions, the results, and the methodologies of the Malaysian ESI and findings should be presented to gather feedback and insights directly from those who are impacted by or have expertise in ES for Malaysia. The major benefit of this method is that it allows for interactive feedback and the ability to address concerns or suggestions in real-time. It also helps in understanding the practical implications and potential operational challenges of implementing Malaysian ESI to make judgements on the current ES scenario.

To summarise the empirical validation suggested for this research is as follows.

Validation in the future through "Stakeholder Workshops":

- Through organizing workshops and focus groups with key stakeholders, including policymakers, industry experts, and representatives from energy sectors. During these sessions, we will need to present the findings to gather feedback and insights directly from those who are impacted by or have expertise in energy security.
- **Benefits**: This method allows for interactive feedback and the ability to address concerns or suggestions in real-time. It also helps in understanding the practical implications and potential operational challenges of implementing the MESI.

Currently, as a part of validation the method of **"Comparative Analysis"** with other energy security indexes developed by different researchers and research groups has been used. This enables the comparison outcomes produced by MESI with those from established indices to identify discrepancies and validate the accuracy of the model.

Benefits: This approach helps validate the Malaysian ESI by comparison, showing how it performs relative to other models and where it might offer improved insights or results.

3.6.5 Conclusion

The contribution of this study is in encouraging the use of a mixed-method approach for analysing the ES of Malaysia and neighbouring ASEAN countries. Triangulation of different methods is encouraged in this study to analyse ES which is not only limited to this field of research but also can be implemented in other social science and engineering research. The advantages of this mixed method outweigh its limitations if this kind of research is carried over a larger period of 2-3 years. To add more validity and depth to this method, it is encouraged to have more than one researcher doing this as the limitations suggest that this can be time-consuming. Also, the fact that data coding using the GT method of emerging coding can be cross verified between the researchers and to avoid bias towards certain data and negligence towards certain data too. The advantage of adopting the triangulation of methods from this study has been the fact that ES of Malaysia and ASEAN countries can be looked upon from different angles and perspectives as it involves secondary data from literature combined with more consolidated primary data from stakeholders. These data combined are analysed using a system dynamics approach which bridges the links between the variables and their dimensions overall.

The simulation of the model gives a graphical representation of future results for respective variables which can be very handy in policymaking for ES of Malaysia. This method also enables the researchers to understand the crucial relationship between dimensions that would otherwise be neglected while analysing a tricky topic like ES. Overall, this mixed-method approach is feasible to develop a critical relation between ES dimensions yet not easy to develop because of the limitations mentioned. This mixed-method approach has the scope of exploring topics like this in the field of energy engineering on a local community scale or larger scale in the country or a region.

3.7 Chapter Summary

This chapter considers the analysis of Malaysia's Energy Security (ES) using a mixed method of inquiry. A combination of qualitative and quantitative methods known as the "triangulation of methods" was used to build a solid understanding of ES from the standpoint of Malaysia within the Association of Southeast Asian Nations (ASEAN). Qualitative data were collected from 16 stakeholders and experts in the field of energy security and sustainability from Malaysia and the ASEAN region using semi-structured interviews (SSI). These data were coded using grounded theory (GT) that follows emerging coding techniques to allow for emerging ES themes to develop, hence creating the ES framework, used as the basis for a systems approach – quantitative research on ES. Quantitative data were collected from energy reports and statistics published by ministries, agencies, and relevant departments in Malaysia and ASEAN. The dimensional indicators identified from the ES framework are causally linked using system dynamics (SD) modelling, underpinned by systems thinking, where SD models are designed and simulated to yield meaningful insights on Malaysia's ES for future policy recommendations. This mixed-method approach has enabled research through the modelling of scenarios to inform policymaking within the contexts of the problem space of ES.

4 Conceptualising the Energy Security Dimensions of Malaysia

4.1 Introduction

In this research, the various ES dimensions have been studied in-depth by engaging stakeholders from Malaysia, Singapore, and the Philippines to understand the criticality of the different dimensions towards paving a pathway for ES policies in Malaysia. Thematic analysis has been done from the emerging themes of semi-structured interviews with the stakeholders. One of these themes of "Role of renewable energy in ES" has been analysed in the study by (Saleh Shadman & Chin, 2021). These themes have been discussed thoroughly from the perspective of the stakeholders to develop concrete knowledge of ES that would facilitate the making of an ESI to quantitatively assess ES. A total survey of 117 participants from Malaysia's energy sector has also been surveyed to consolidate the concept of ES by developing a causal relationship between the dimensional indicators. The first objective is to identify the key dimensions of ES for Malaysia that would lead to the second objective of the selection of indicators for these dimensions using an indicator mapping process. This will eventually lead to policy suggestions and implications that can facilitate the policymakers of the nation to incorporate ES in their future action plans. Upon fulfilling these two objectives of the research, it will be easy to design an ESI to quantify ES for Malaysia or any other country with a similar energy outlook and profile.

4.2 Semi-Structured Interview Inputs and Thematic Analysis

The SSI results have been summarised here in the form of tables for each of the 7 themes that have emerged because of the SSI's. The data in these tables are utilised further to extract the final set of dimensions for ES of Malaysia. A total of 16 stakeholders have been interviewed to extract high-quality qualitative data to shed light upon the key themes that influence and pave the way for the ES of Malaysia. The SSIs of this research are recorded with the consent of the participants to generate intelligent verbatim transcripts that are analysed using the software 'Quirkos' which gives a richer insight into the data that has been collected through these SSI's. Stakeholders abroad are contacted through video calls and SSI's have been conducted over the video call (Journal, 2014). This is an easier, cost-effective, and convenient option to conduct one-on-one interviews with the stakeholders who are not residing in Malaysia. The names of the participants are confidential as per the research ethics guidelines and only the list of stakeholders is shown Table 12.

A total of 7 important emerging themes and energy policy implications have been shortlisted from the Quirkos database after coding the 16 interview transcripts. The data collected from the stakeholders have been compiled and tabulated according to these themes and the findings have been presented here in this section. The results section is solely based on the stakeholders' perspective, and nothing has been quoted in this section 4.2 from the literature or energy policies. The term stakeholder has been referred to as "ST" in the following sections.

1. Renewable Energy
2. Fossil Fuels
3. Applicability of Technology
4. 4 A's of Energy Security
5. Environmental Sustainability
6. Economic Development
7. The Role of Governance

4.2.1 The Role of Renewable Energy

(Acar, 2018b); (Cai et al., 2012); (Kaya et al., 2021b); (Safari et al., 2019a) believe that RE can be a promising choice to address climate change issues and ES if the issues of intermittency and discontinuous supply can be overcome. This can be done using energy storage options that are affordable, reliable, and efficient at the same time. RE has been always preferred as a very clean and sustainable source of energy (Olatomiwa et al., 2015). The study of (Vaka et al., 2020) is detailed research carried out on the impact of the Covid-19 pandemic on solar energy and RE as a whole in Malaysia. (Kim & Alameri, 2020) has suggested the use of RE and nuclear energy in alliance with each other to tackle the global energy demands sustainably. (Saleh Shadman & Chin, 2021) has discussed in detail the SWOT analysis results of RE research as one of the themes of the stakeholder interview results. A key study by (Kardooni et al., 2016) has highlighted that people in peninsular

Malaysia have the perception that the use of RE requires a high level of effort hence creating a negative attitude towards the RE technologies and impairing the share of RE in the energy mix.

The results suggest that the strength of RE in Malaysia lies within the strong national energy policies including the RE policies and the green technology policies to strengthen the share of RE as major fuel in both TPES and electricity generation. These policies are regulated by regulatory bodies like SEDA and also the Energy Commission. The intentions are strong to reach the target of 20% RE penetration by 2025. The intermittency challenges will always exist for RE sources for electricity generation mostly (Sabry et al., 2019). The capital cost increases due to the need for thermal powerplants to back the intermittency challenges of RE. Thus, increasing the overall cost-per-unit of the energy supplied. The price per unit in kWh is not competitive enough as of now to cope up with that of fossil fuels like coal and natural gas. Poor supply of electricity or energy can thus lead to consumer dissatisfaction which is not desired.

The RE policies and targets that are currently in place need to be implemented well enough to achieve the given targets. Malaysia as a country has a lot of opportunities to explore more solar (Fadaeenejad et al., 2015) and marine RE sources. Neighbouring countries like Singapore have utilised the opportunity of implementing floating solar farms, this similar prospect is possible in Malaysia too. The new targets for RE have been projected to increase to 40% by 2035 and solar usage is expected to reach 30% of the projected peak demand in 2035 (Energy Commission Malaysia, 2020b). These targets are motivating towards an overall betterment for the ES of the nation.

4.2.2 Fossil Fuels

All the stakeholders involved in this research have agreed to the fact that fossil fuels like coal, oil, and natural gas will be irreplaceable as fuels from the TPES and electricity generation in Malaysia backed by studies like (Zakaria et al., 2021) and (Hannan et al., 2018). The energy mix is still dominated by more than 90% of fossil fuels (Saleh Shadman & Chin, 2021) while it is projected that by the end of 2039 the coal share will reduce from 37% in 2021 to 22% in power generation (Energy Commission Malaysia, 2020b). Whether this is feasible is yet to be proven given that the dependency on fossil fuels is still very high. ST1 believes that the use of coal and gas is not expected to change till 2025 as the Power Purchase Agreement (PPA) is still in effect till 2025. ST2 believes that downstream activities bring in a lot of benefits like employment, improved standard of living, and development of infrastructure. In Malaysia, downstream activities are going well with almost 30 years in operation with one of the recent developments of the Pengerang Integrated Petroleum Complex (PIPC) in Johor, Malaysia.

ST4 has stated that larger economies like China's contribution towards climate change can have an impact while smaller contributors like Malaysia will not have a major impact in the climate change issues with the use of fossil fuels. ST4 also stated that coal power capacity is around 8000Mw with ITP and TNB compared to 500,000MW in China. Almost all the stakeholders have also discussed how the trade of higher-grade oil in return of lower grade oil which are later refined benefits the economy immensely due to a positive trade-off. ST9 in support of this has stated that Malaysia leverages on the ability of Petronas and their connection all over the world. They are in a comfortable position in terms of petroleum as they have both domestic and international profiles for fossils. Petronas has good cooperation with other companies in Japan and Korea and can shift cargo easily. This reflects upon the cooperation between these countries and its geopolitics. ST 14 is quoted "We are moving into a globalised era where trade is an important aspect. Trade of fossil fuels will help the world to evolve in terms of import and export in exchange for economic growth." (Sutrisno et al., 2021) has backed this statement of ST14 but also mentioned the importance of contracts and flexibility of energy infrastructures within the global energy market. ST13 has also reflected upon the boundaries set by energy policies to ensure fair usage of the resources and sustainably e.g., the national depletion policy for crude oil allows the use of 700,000 barrels per day, which could be otherwise pumped up to 1million barrel per day.

4.2.3 Applicability of Technology

The world is chasing new technology and improving existing energy technologies to get better efficiency and more cost-effectiveness (Salehi et al., 2020). Technological advancement is one of the key dimensions in determining whether a country is heading towards long-term ES or not. "Necessity is the mother of innovation" stated by ST6 means, moving towards new technology and innovation as there is no alternative options.. In the case of Singapore, a resource-scarce country, technology can play a vital role. This is backed up by ST5 as well, where he feels there is a need to improve technology given that Singapore is a first-world country and should lead the way forward in the ASEAN region. ST5 has also mentioned that technology can make a huge difference in, national energy supply, local energy access, and poverty alleviation. The most feasible technology arriving at the right time is the key. The question remains whether Malaysia is willing to adapt to new technologies by scraping the conventional methods. Certainly, technology is not matured enough yet in Malaysia to be able to say that Malaysia in terms of energy technology is at its best. There is a scope for improvement in RE technologies, energy-efficient (EE) technologies, and power generation. New technology setup comes with a capital cost and also the risk of failing but once it is established, it can reduce the cost-per-unit of energy.

In Malaysia, investors are not too keen to invest in new technologies as there is a risk of failing, therefore, a risk of losing money and investment. ST2 has mentioned, it is better to wait until technology matures enough before Malaysia can embark on using them to avoid the risk of losing investment if these technologies fail. On contrary, ST4 has said that Malaysia has technology that is matured but needs to look forward to more green technology. ST9 suggests that ride e-hailing can be improved in Malaysia. This is where people from the same neighbourhood or locality can share rides to workplaces in an attempt to reduce their carbon footprint. Adoption of new technology would create a circular economy around it by creating jobs and, hence boosting the national economy. Malaysia has an abundance of natural resources as of now, hence there is not as much effort and room for novel technologies as discussed before as it comes with a cost of failing. Technology in Malaysia has improved in terms of PV cell efficiency of roughly 11% to 20% (Kaya et al., 2021b) now and change of coal plants from sub-critical to super-critical boilers according to ST14. In Malaysia, Tenaga Nasional Berhad (TNB) the utility operator is giving some benefits to consumers for saving electricity.

Photovoltaic (PV) plants in Malaysia have developed over the years and it is amongst one of the most developed technologies in Malaysia and EE technologies are fast developing as well. The government can look to have a higher share of EE technologies in the market and work towards green buildings. Technological advancement has no boundaries and there is always a scope to improve, now it is for the government to decide what they want to adopt at what scale that will benefit the nation to become more energy-efficient and at the same time cost-effective.

4.2.4 The 4 A's dimensions of energy security

This theme is a combination of the 4 commonly practiced and discussed dimensions of ES in various ES literature. The stakeholders have given their inputs on these 4 dimensions, and it has been formed into a single theme in this research.

Affordability:

Out of the 4A's most emphasis is given to affordability of energy alongside the availability of enough resources to make sure the living is sustainable. Affordability refers mostly to the price of the energy in terms of energy tariff and electricity tariff for different sectors in Malaysia or simply the prices that are equitable for people of all income groups. One of the most common demands of the community in a developing economy is to have affordable energy and a stable supply. Sometimes, these two do not go hand in hand as ensuring a stable supply of energy can be costly in a developing economy, yet the effort of the Malaysian government is to ensure energy price is low and the supply is stable with a high reserve margin. Coal is not a clean source of energy, yet the cheapest source of energy followed by natural gas and then RE. It is at the stake of the government to decide how much is needed to compensate for getting lower energy prices and what their future strategies will be towards maintaining the same price yet reducing environmental impact.

Green energy and renewable energy are not the cheapest options of fuel in Malaysia and the pricing of RE is not competitive with coal, but it may compete with that of natural gas per unit. This means Malaysia cannot increase its RE share by a large extent all at once because it will impair affordability and lead to consumer dissatisfaction. For electricity, the tariff is subsidized by the government and the same for fuels to some extent. The prices do not reflect the real market price as it would not be considered affordable and would lead to consumer dissatisfaction. Whenever there is a surplus in the fund the money goes into the stabilisation fund for electricity and these surpluses are used to compensate for when there is an increase in the original market price so that the impact of this increase is not felt by the consumers. There are laws and regulations in place to ensure that the utility operator makes the supply secured and cost-effective.

In contrary to this, one of the stakeholders believes that the price should reflect that of the original market so that people do not indulge in wasting energy. It is unfair for the poor and rich to have similar subsidies on fuel and electricity as the rich can afford more and at the same time waste more energy. There can be certain regulations that can ensure that the subsidy for electricity is at least based on income amongst the population to ensure more equity. The electricity tariff is kept competitive with neighbouring countries like Thailand and Singapore to attract international business investors within the Malaysian grid. International supply of energy does decide to some extent the price and availability of energy for import-dependent countries. Malaysia has energy reserves to sustain itself, but they are also a net exporter of gas and oil and importer of all the coal that is used. Coal has a share of 60% in the energy mix of TPES and roughly all are imported, hence there is a risk of price volatility if the countries from where coal is imported decide to increase the price. This will affect the affordability dimension of ES in Malaysia.

Accessibility:

Accessibility is one of the dimensions that we do not worry too much about but still holds a key role because there is no point in having a continuous supply of energy at an affordable price if people do not have continuous access to it. Access to energy in urban areas does not pose much of a threat as it does in rural and remote areas. Delivering energy there without any disruption and much resilience is the challenge for the utility operators and the government. By right every person in the nation has equal rights to the accessibility to energy resources. In Malaysia, accessibility is not much of an issue as it can be in some parts of the Philippines as stated by ST10. According to ST10, equity and access are very much interrelated as there is no equity if everyone in the population does not have equal access to energy.

In the Philippines, it is believed to have a disparity between the access of energy between rural and urban areas. In recent days, delivering energy to all parts of the nation is not as much a challenge as it was probably 20 years ago. ST5 mentions that we have to look at the distributed energy, RE, and the technical aspects when we talk about accessibility. According to ST3, there is no point in having energy resources in the form of natural resource reserves if the technology of extracting them is not matured enough. Immature technology will not help in the cause of full exploration of the resources available and hence this will lead to poor accessibility of the energy sources. Overall, the stakeholders believe that accessibility of energy in Malaysia is not worrying, so not many have spoken much about it which proves that there is good access to energy in all parts of Malaysia.

Acceptability:

Acceptability of energy is at the disposal of the people and to some extent the government. It is most important to ensure that the energy resources within the TPES and electricity generation are acceptable amongst the majority of the population to ensure their satisfaction. Nuclear energy is one of the most debatable sources of energy despite being the cleanest of them all and long-lasting at the same time according to ST 3. The recent accidents with nuclear reactors have given it a bad image and perception amongst the population therefore they will not accept it despite its benefits and advantages over traditional power plants. This is where the government plays a role and decides whether they want to go with nuclear by making their population unhappy or stick to coal, oil, and gas as the primary sources.

ST 7 believes that research institutes should take the lead role in designing and ensuring safe working conditions for nuclear plants in Malaysia and by doing this they can convince people and change their mindset on safety measures also backed by (Şen, 2019). This is always a difficult choice for the government to make and there are policies and laws in place for this. On the other hand, the acceptability of RE in Malaysia is quite high amongst people but the efficiency of RE as a source of power generation is not the most efficient of them all and comes with additional costs due to intermittency challenges. To ensure a continuous supply of energy mostly in power generation, thermal power plants will always be the key in Malaysia. This compensation comes with a cost and hence RE is not the most efficient source, yet it is highly acceptable.

Acceptability of RE is also poor within the business that has invested in coal power plants and CCGT plants as they fear losing business. So, the dilemma will always remain when it comes to choosing between nuclear and RE as the next major fuel for energy in Malaysia. In Singapore, new technologies are adopted at a faster pace, like smart metering for electricity and EV, but there are still a certain group of people in the community unaware of the advantages of these. There is a need to educate people on the transition from traditional technology to modern technologies as such to become more efficient. The acceptability of new technologies is still not very high in the ASEAN region according to ST10 and this can be improved. According to ST6, to tackle ES challenges the technical solutions must be economically feasible and socially acceptable. These suggest that the acceptability dimension of ES plays a key role in deciding the fate of ES of Malaysia as well.

Availability:

Availability of abundant natural and renewable resources is what every country aims to have to serve their population and thrive in economic activities. Malaysia is not any different, all the stakeholders have prioritised having an abundance of resources at their disposal as one of the key dimensions amongst all the other ES dimensions. If energy is not available at all times, it will hamper economic growth and living condition. Availability of energy resources means strong geopolitical connections between countries with whom Malaysia has a trade of natural resources and at the same time safeguarding the domestic available resources in the best possible way. This requires having policies like the national depletion policy in place to ensure fair usage of the available resources. This may come with the use of more fossils, yet this dimension is always kept in check to ensure there are no power outages or the market price of energy does not reach ceiling height. One of the key dimensions to keep the population motivated and happy is the availability of resources, and the Malaysian government has managed to successfully do so at all times. This comes at the cost of sacrificing the environmental dimension in terms of higher usage of coal and gas that contributes to higher greenhouse gas (GHG) emissions.

In this case, the government is looking forward to alternate sources that will decide the fate of fossils in Malaysia and according to all the stakeholders. The share of fossil fuels will not reduce drastically anytime soon in Malaysia. Malaysia has around 40-42 years of reserves within their energy reserve domestically. ST8 like most of the stakeholders feels that a good share of RE in the energy mix is important and Malaysia should look forwards to that to make sure higher availability of resources. ST9 has suggested educating people on wasting less energy, which is a sustainable solution for the future. Tax on a higher carbon emission than a set level can also work as a penalty to ensure that fossil fuels are used wisely. There should be incentives for those wasting less. These initiatives have to come from the government of Malaysia to ensure supply security at all times while ensuring lower waste and higher efficiency of the resources.

4.2.5 Environmental Sustainability

Energy is the backbone of all the economic activities within a country and all dimensions of life are supported by energy (Yildiz, 2019). (Singh et al., 2018) have stated that equity of energy resources, ES of existing resources, and environmental stewardship and sustainability form the energy trilemma that needs effective policy formulation to maintain a balance of the three (Kim & Alameri, 2020). According to ST13, energy in Malaysia has a lot of interaction between demand and supply-side as well as economy and environment. In a developing economy like Malaysia, the availability of energy (energy equity) for boosting economic growth takes up the priority in the energy trilemma followed by equity and lastly environmental sustainability. Most of the stakeholders have discussed this and agreed that environmental sustainability targets come last in Malaysia and economic growth priority.

ST4 mentions that the aim is towards economic ascendency in a developing economy rather than environmental ascendency. It is more important to ensure there is enough savings and good lifestyle rather than thinking about climate change. ST8 believes that the impact of ES on the environment must be addressed with importance to avoid future generations from suffering from climate change adversities. This is quite rightly said and there is a need to address the depleting natural resources and carbon-based emissions due to the conventional power plants. There is a need to move towards greener energy sources that are less polluting and have a lower impact on climate change. The Malaysian government aims to be a greener economy and has small-scale plans to mitigate climate change challenges in its energy policies. ST14 believes that in Malaysia the decision between the trade-offs of how much affordability vs how much of environment is critical. Whether to rely on coal or try to cut down coal and increase RE share within TPES and electricity generation.

Malaysia aims to increase RE capacity by 20% in the energy mix for power generation by 2025, currently it has been amended to 31% by 2025 in the latest NETR. Currently, the share of RE in electricity generation is at 9%, but this needs to be increased and a subsequent reduction in conventional plants to reduce pollution and reach the CO2 emission targets. There is a scope of improvement in more energy-efficient technologies that support cars and buildings. The number of electric vehicles in Malaysia in public transport and private vehicles can be increased while the office buildings and residential buildings can be turned into more energy-efficient ones by adopting new technologies. Overall, there needs to be a lot of emphases given on this dimension of ES as it indicates a clear picture of the status of a country's ES. Always having energy with affordable rates is important but that should not come at the expense of comprising the environmental health of a nation. Having higher availability of energy and low tariff does improve ES but at the same time, higher carbon-based emissions will reduce the long-term ES of the country. Hence, equal importance should be attached to these dimensions as well.

4.2.6 Economic Development

Economic development is given one of the most important priorities in any developing economy. Malaysia as a nation is heading towards a high-income country status with an economic growth rate of 5.4% from the year 2010. In Malaysia, economic development will be given more priority than any other dimension of ES. When taken a look into the energy trilemma energy equity comes first and environmental sustainability comes last for most of the studies. According to all the stakeholders interviewed in this study, the Malaysian government will attach the most importance to economic growth while a lower priority to the activities that affect the environment and contributes to climate change. This means conventional thermal power plants of coal and CCGT plants will remain to power Malaysia for a very long time in the future as well. These power plants compared to RE plants are more efficient and cost-effective. They are cheaper to operate and hence reduces the cost per KW h. RE projects in Malaysia are looked upon as an opportunity to invest in new business according to ST4 rather than to mitigate climate change challenges. Not just that, they also create job opportunities, hence boosting the economy.

According to ST2, downstream activities in Terengganu, Malaysia have given employment, infrastructural development, and the ability to trade these resources with the rest of the world. This leads to the development of the local economy, employment for locals, and also improvement in education and living standards in these areas. ST3 suggests that Malaysia has enough resources to sustain economic activities and there is good income on fossil fuel export and stable fossil fuel supply that means the country has a good subsidy on fossil fuels. Addressing ES challenges have to be feasible, economically viable, and socially acceptable according to ST6. There are a lot of opportunities for investment in terms of RE in Malaysia that will boost the Malaysian economy as more business opportunities bring in more tax which increases the national gross domestic product (GDP). The trade and finance industry looks at RE as a new business opportunity and not just for the climate change matters.

Malaysia is also a net exporter of oil and gas. They export high-quality oil and gas in return for lower-grade oil and gas for a positive trade-off. This benefits the economic growth of the nation. Trading in these current times is a key aspect to maintain geopolitical relations as well. There is a positive net gain in this trade, but this also strengthens the trade relationship between countries which is essential. In the ASEAN region, there are certain agreements of trade to help out each other in the region. According to ST14, if the trade is bringing economic benefit and helps the region to bond stronger by helping each other then it is healthy for the nation.

4.2.7 Role of Governance

The governance of the energy resources is completely in the hand of the ruling government and its relevant ministries. Hence, they are at the forefront of decision-making in terms of policy setting, laws, regulations, and legislation on the energy-related matters of the nation. Whether they have the vision and aim to have high ES will decide what kind of energy policies they will set and what kind of depletion policies the government will set for natural resources. These policies are monitored and regulated by the government agencies like SEDA and Energy commission. In Malaysia, the government holds the highest authority in this decision making and they aim to become a green economy. Hence, the policies should reflect their aim as well. The government's decision towards transitioning to green energy will have an impact on the long-term ES of the nation.

To achieve long-term ES, it is essential to have clean energy sources that are sustainable and environmentally friendly. At this point, in Malaysia, the key priority is towards the high availability of energy and at an affordable rate. This comes with the compromise of clean energy as clean energy is not cheaper than coal or natural gas. Hence, prioritising the need, Malaysia is still not looking towards a transition phase to alternate fuel sources as of yet as it can impair affordability and hence lead to consumer dissatisfaction. The decision of new powerplants and how much capacity is to be increased and how to replace the aging plants with new ones lies at the disposal of the government as well. All these decisions in turn do have an impact on the ES of the nation. Bigger economies and countries like China need to take these bold steps first as their contribution towards climate change can be more impactful than smaller developing economies like Malaysia. According to ST4, Malaysia's contribution to climate change is minimal compared to the bigger players and hence Malaysia should not be extremely concerned and rather focus on the economic growth of the nation.

The government of Malaysia also feels the same way and they have provided opportunities for RE business to grow and gradually be bigger in numbers and scale. This creates jobs, boosts the economy, and improves living conditions mostly in rural areas. An entire circular economy can grow around large power plants and power projects mostly in areas where the living standards have a chance to improve. According to most of the stakeholders of this research, there is government intervention in the vertical electricity market and there is a scope to slowly move towards a more horizontal free market. Singapore has adopted the free market structure. There are advantages and disadvantages of both, in a free market, the price does not stay within the control of the government. Hence the government cannot intervene much if there is a sudden hike in prices, the community will feel the burden of the rise in prices in that case. In Malaysia, the natural gas market is moving towards a freer market approach, but the electricity market remains vertical and monopolized.

Nuclear energy is one of the most debatable sources of clean energy. Nuclear energy has various advantages of being long-lasting, lower cost, and cleaner form of energy but has the stigma of being unsafe due to the reactor accidents in the recent past according to ST 3 and 15. The government will play a vital role in deciding when nuclear energy can be introduced or whether there will be any nuclear energy at all. The public acceptability will always be very low due to the risks attached and the government trying to champion this technology will face backlash from their supporters and the population. This will always be a tricky topic and challenge for the Malaysian government. Having said that, most of the decisions that seal the fate of the ES of Malaysia lie within the hands of the government and their vision of how they see the ES of the nation.

4.3 Key Policy Implications from Stakeholders Perspective

The energy policies of a country decide how energy resources would be used efficiently, the trade of energy between countries, energy mix for different sectors, and many other factors that affect the ES of a country directly or indirectly. Similarly, Malaysia has its energy policies and acts in place by the government that is regulated and monitored by their regulatory and statutory bodies alongside the relevant ministries. The stakeholders have indicated that the Malaysian government makes the final call for setting the targets in the energy policies, like the RE penetration target of 31% for power generation by 2025 (Energy

Commission Malaysia, 2020b). Others include national depletion policy that limits the use of oil to merely 700,000 barrel/day which could otherwise be increased to 1 million barrel/day, but the policy does not allow. Power purchase agreement (PPA) tackles the problems related to power plants and how different fuels are allocated for power plants and to what extent.

According to ST2, the policies should be able to target specific issues, hence it calls for specific policies to address them. There should be incentive-based policy making so that incentives are given to those following them and penalise the ones not following according to ST6. Most of the stakeholders have said that energy policymaking should be evidence, fact, and science-based, where targets to be set needs to be realistic and achievable within a given time frame. To do so, the energy planners of the nation need to be well aware of the situation around them. This requires proper training and a lot of research to be done in the respective field.

In the end, the decision still lies in the hands of the government to whether accept or reject certain proposals from the policy setters. Historically in Malaysia, the RE projects have not fulfilled their ultimate targets within the given time and this raises questions for the future RE policies as well. Despite that, there is a push for more RE in Malaysia according to all the stakeholders. They want a higher share of RE in the energy mix for Malaysia as it can bring positive results for the ES of the nation. Increasing this will require proper planning and implementation of the policy, there need to be viable strategies to fulfil the targets set in the policy documents. SEDA was formed to take the charge of RE policies and their regulation in Malaysia. Large scale solar (LSS) projects and Feed-in-tariff and net metering (NEM) are a part of the RE policies in Malaysia aim to improve the sustainability of energy resources in Malaysia. Renewable energy transition roadmap (RETR) 2035 will come up with the strategies to reach the RE targets by 2035 which is set and regulated by SEDA. A higher share of RE generation would require more policies and roadmaps with a conducive environment for these investments to be made. ST8 has suggested having a policy in place that can enforce a tax on industries that emits carbon-based emissions above allowed limits. ST9 has suggested having an emergency response mechanism to any sort of challenge that Malaysia may face. This can be during a pandemic-like situation of covid-19.

The mitigation plans for energy issues and challenges are in different departments and agencies but are not documented. Similarly, no ES policy addresses the ES challenges and their mitigation plans. There can be a single policy document in place that can mitigate any immediate challenge or long-term ES challenge for Malaysia. (Nupueng et al., 2018) have mentioned the need for stable and consistent policies addressing these issues to ensure the successful outcome of the objectives. Energy wastage needs by industries or households need to be monitored regularly. There can be a policy in place that looks after this and hence it will have an impact on the energy availability dimension of ES. ST13 believes Malaysia needs to have better synchronization between the agencies and ministries to make sure the responsibilities are distributed evenly to ensure work efficiency.

ST14 mentions few other policies like Malaysian national energy policy 2021-2040, natural gas roadmap, and action plan 2021-2025 that are been drafted to tackle future challenges. All three coupled with RETR talks about RE and energy for Malaysia. ST15 says that mostly demand and supply are considered during policy setting and security issues are not given much importance. However, this should be changed and more security issues like ES must be considered. ST16 mentioned that we should make policies for long-term solutions and set long-term goals instead of short-term quick fixes. 2-3 years is a very short time for any objective to be achieved within the energy policies. Policies need to be well planned with proper targets set with sufficient time given to achieve them to make sure they are effectively achieving targets.

4.4 Conclusion and Recommendations

The main contribution of this chapter was towards developing a consolidated knowledge of ES for Malaysia by studying emerging themes from SSIs with key stakeholders. The gap of stakeholder engagement to analyse ES dimensions and themes was mentioned in the introduction section. Upon completion of this chapter, the 7 themes that have emerged from the interviews are described in detail to understand the interaction between the energy policy structure of Malaysia and how it has an impact on the ES of Malaysia. It is recommended to conduct more research following the methods mentioned because it is believed to be a robust way to deep-dive the ES challenges and ways to mitigate them. There is a need for an ES policy within the energy policy framework of Malaysia to ensure that a single document lists down the challenges, the mitigation plan, and the outcome of these plans. Currently, there are mentions of ES in different policies including green technology policy, renewable energy transition roadmap (RETR), and in few energy supply policies that mention supply security of the resources.

There are key selective takeaways from this research that have been listed down for achieving higher ES status and sustainable development in Malaysia.

i. The increase in the share of RE in the TPES and power generation will be the key in deciding whether there will be a reduction in the dependency on fossil fuels as the only form of energy source.
ii. The successful implementation of the objectives mentioned in the policy documents including the most recent "REPORT ON PENINSULAR MALAYSIA GENERATION DEVELOPMENT PLAN 2020 (2021 – 2039)" by (Energy Commission Malaysia, 2020) will be vital towards shaping a sustainable future for Malaysia. Most of the energy policies in place need to achieve their targets at the same time to make sure that ES challenges are mitigated.
iii. Environmental sustainability needs to be at the forefront of the energy trilemma if ES is to be improved.
iv. The ESI needs to be developed following the indicator mapping process explained in section 3.4 and the dimension selection process from the emerging themes to ensure that the term ES can be quantified to reflect upon the overall performance over a period.
v. A combination of qualitative (stakeholder engagement and survey) and quantitative (ESI development) analysis needs to be carried out in parallel to ensure that the data generated are validated throughout the process. A futuristic approach of system dynamic modelling of the dimensions and different ES scenarios can also be studied to develop a causal relationship between indicators and dimensions.

These recommendations can be implemented to ensure that the concept of ES of Malaysia is defined in-depth with a strong data-driven and evidence-based approach. This research provides the flexibility of implementation within any country with a similar energy outlook to establish an ESI by selecting the ideal dimensions and indicators of ES.

4.4.1 Recommendations from a Global Context

A similar set of recommendations are applicable to countries with the same pattern for energy demand, energy consumption, and energy policy structures. Countries with heavy dependency on fossils fuels that are available within as reserves would require policies, such as “Depletion policy” or anything similar that can limit the use of fossils per year from the reserves. This would improve the reserves to production ratio (R/P) of the fossil fuels hence improving the long-term availability of these sources at the same time lowering GHG emissions and hence climate change impact. On the other hand, countries dependent on energy import need to look for alternative sources within their geographical location to ensure that a future cut or reduction in import would not hamper the accessibility of energy within the country. Improved research and development of energy-efficient technologies for renewable energy generation and distribution would hold the key in this case.

Environmental degradation policies need to be strengthened based on regional meets and global agreements, such as the Paris Agreement and Kyoto protocol. However, the implementation of these protocols and agreed mitigation measures and emission levels need to be improved to ensure the targets are achieved. An improvement in tracking the progress of the countries bound by these agreements needs to be set up for better implementation and monitoring purposes. Overall, it can be concluded that each of these seven themes conceptualise ES in a consolidated manner with causation and relation between indicators from each theme and dimension. This further proves the multi-dimensional nature of ES and the need to develop these themes and dimensions further for quantification of these dimensions with greater accuracy, completeness, and transparency.

4.5 Findings and key indicators from stakeholder engagement

The tables 11-17 in this section are the summary of all the data collected from the 16 stakeholders in the form of 7 emerging themes. Figures 11-12 are the representation of the Quirkos dashboard for QDA coding.

Table 11: Summary of the SSI results for the "Role of RE" in the ES

No.	*Key Findings*	*Key Indicators*
ST1	• The goal is to reach 20% capacity of RE by 2025 as set by the ministry. • Currently looking after the Large scale solar (LSS) project in Malaysia. A total of 2GW generation capacity from 3 LSS projects. LSS1 (200MW and above), LSS2 (300 MW) and LSS3 (500MW). A tender has been opened for LSS3 with bidding in process. • Total RE penetration is 6GW of power generation including mini-hydro, biomass, biogas, and these LSS projects.	1. Energy consumption 2. Energy efficiency 3. RE penetration rate 4. RE policy
ST2	• The priority before deploying RE is to have stable supply security of energy and it has to be affordable. RE will only follow. • RE deployment cost is decreasing gradually and becoming more price competitive with other conventional forms of energy like coal and natural gas. • There are technological challenges in terms of integrating RE in the grid and deploying RE on a larger scale and these challenges need to be addressed. One of the major challenges is the capital cost of RE projects, it is not cheap.	1. Supply Security 2. Cost of energy 3. Intermittency issue 4. Capital cost 5. RE policy 6. Economic growth

	• The initial plan by the government was to achieve 2000MW of RE and we were on track to achieve it but after the new government was elected the target became 20% capacity of RE by 2025. • RE will always face a challenge in developing economies as long as they have alternate cheaper options like coal and natural gas. The second challenge is that of intermittency of RE in the national grid. RE cannot be deployed overnight, it needs proper planning and takes time to do so. • RE is believed to boost the economy, projects can generate employment and hence help the nation overall.	
ST3	• Malaysia has a larger land space compared to many other SEA countries and hence can build utility size of PV which can generate decent capacity which could have an impact on the national electricity grid. • For most countries including the SEA countries RE is a means of diversifying the electricity supply • The use of RE will lead to low carbon electricity and low carbon emission hence fulfilling our environmental sustainability targets. • RE is self-sufficient and this is the advantage of using RE while it also gives scope for further research towards energy storage systems to store them. • If there is no business case in investing in RE means no one will invest and hence make RE more expensive than any other form of fossil energy no matter what feed-in-tariff you have. • The Challenge of RE lies in integrating them into the grid as they contribute a very small amount to the national grid. • The scale of use of RE is also a challenge in a country like Malaysia. RE in the community or small scale like PV solar can address off-grid electrification. • PV seems to be the most common and reliable source of RE for Malaysia while bioenergy is debatable because it is unsure whether it is carbon neutral or not. Also, it does compete with food security in	1. Diversification of energy sources 2. Self-sufficiency 3. Carbon emission 4. Cost of energy 5. Energy storage 6. Intermittency issue 7. Communal RE penetration 8. Food security

	terms of sacrificing agricultural land for energy production.	
ST4	• Solution of ES by channeling more RE. An enhancement of fuel market mechanism, an expansion of suppliers. Under BAU we are pretty okay in terms of RE. • Smaller countries do not go to RE for environmental reasons but because it becomes a new economic driver for the nation. • To make an impact in global climate change there needs to be a huge capacity of RE. 1000 MW RE plant needs to be in numbers of 100's to make that happen. • Currently selling at 30-40 cents per kWh compared to CCGT at 25 cents per kWh. We are viewed as a non-firm supplier so that the capacity payments for the conventional generators are paid and capitalised. • It is natural to have intermittency with RE but if you do not want that then we need batteries to store power. • Batteries are the alternatives to combat aging and decommissioned thermal plants. • The big companies will push back as RE takes away existing shares from thermal plants. • The intermittency can lead to issues of bidirectional power flow into the grid and hence keeping the reliability high is difficult but needed to maintain consumer confidence. There is an additional cost in terms of the thermal plants, and I am not sure if it can be recovered from the tariff. • With an increasing RE capacity, the question arises on what is going to happen to the conventional plants and who is going to foot the bill for the capacity payments and grid cost. • Solar has a utilisation factor of 15 % only because 50% is gone anyways as there is no sun in the daytime. For solar only we have 1300MW now and by next year we will have 2000MW from the LSS. • The corresponding rules following the policies need to be looked at and rendered if any. • At the moment we should aim for 5% TPES overall by 2025 but I want it to become 50%. For	1. Intermittency issue 2. Energy storage system 3. Consumer confidence 4. Grid cost 5. Infrastructural cost 6. Economic growth

	20,000MW solar, I need 80,000 acres of land and 50-billion-ringgit investment. • Malaysia needs to manufacture its own solar PV cells and other related equipment to ensure that economy grows.	
ST5	• Singapore is working on CCGT plants and all their electricity comes from gas and they are working on solar as well. Floating solar on reservoirs is innovative technology-wise. • Intermittency remains the main issue with RE in terms of integration into the national grid. It is not an issue of supply security but a new dimension itself.	1. Technological innovation/advancement 2. Intermittency issue 3. Supply security
ST6	• In the Philippines perspective, there are RE laws and policies in place yet not followed strictly. • There are political repercussions of not eliminating fossil fuel-based power generation. It is believed that the transition to RE will happen eventually but slowly. • The Philippines does aspire to be a more sustainable country. But the country did not put in the necessary resources to address the lack of capability to reach out to those ambitions. • The need for a RE roadmap is essential when it comes to national policymaking. • RE is going to be a backup for the traditional sources of energy for power generation as of now. • Expectations were high from Singapore to be a leading country in ASEAN in terms of RE and their policies in terms of net energy metering (NEM) and similar approach. They could have improved energy efficiency in buildings and cars. Singapore as a progressive country should be adopting these very fast. • In developing countries, the priority is given to address poverty and the economy, not environmental problems.	1. Poverty 2. Energy shortage 3. Political influence 4. RE penetration rate 5. Energy efficiency
ST7	• RE intermittency challenges remain a problem for Malaysia in terms of grid-connected supply. It is difficult to combine small RE projects like solar PV projects which are split into several places and	1. Intermittency issue 2. Grid-connected supply

	bring them under the national grid. • For example, solar power at night is not available. It will require an additional system like an energy storage system to store the energy in daylight and use them at night. This adds to the cost of it. • Most emphasis should be given towards clean and more reliable sources like nuclear.	3. Energy storage system 4. Infrastructural cost/additional cost
ST8	• RE penetration as of now is not enough because energy density, energy efficiency, and energy technologies are not advanced yet in Malaysia. • The country may run into a situation where the reserves of natural and indigenous resources may run out and the RE technologies are not advanced enough to power the nation. This can lead to energy shortages. • It is important to ensure that a certain percentage of our energy portfolio is coming from RE like solar, hydro, and biomass.	1. Energy efficiency 2. Energy density 3. Energy technologies 4. RE penetration rate 5. Energy shortage
ST9	• RE is important for Malaysia as it is facing the issue of depleting natural resources. • Malaysia is headed towards the right direction in terms of RE but not fulfilling its targets yet. The Malaysian government is looking towards future RE policies and ways to implement them. • There are technical and engineering challenges faced by RE in Malaysia as well as business model challenges. • Malaysia is more inclined towards solar PV for electricity generation. Biomass is far from ideal because of the capital cost of such projects. • Businesses need to invest in RE projects and they have to look into their returns keeping in mind the poor feasibility and intermittency of RE in the national grid. • The cost of production and transmission also needs to be taken into consideration and whether TnB is willing to purchase power from these projects.	1. RE penetration rate 2. Depletion of natural resources 3. RE policy 4. Investment in RE projects 5. Intermittency issue 6. Infrastructural cost 7. Capital cost

	• Anecdotal consultation with experts suggests that wind energy is not feasible for Malaysia given its geographical location. Geothermal has certain prospects in places like Perak and Sabah which can be connected to the national grid for electricity. • Ministry and agencies like SEDA are working towards exploring the best possible RE solutions but the challenges mentioned remain valid.	
ST10	• The communal use of RE needs to be increased. RE is used mostly in an individual household which is not good enough to increase the contribution of RE on a larger scale. • Philippines is pushing towards higher RE penetration by 2030, which is around 3 times that of the current value of 23-25% capacity. • Malaysia has the scope to look forward to the ocean and marine RE because of its water space. The cost of ocean RE deployment can be a reason behind its underdevelopment in RE or lesser attention in Malaysia. • Lack of governance on marine RE in ASEAN countries. There is governance towards fishing and food security aspect of it but not towards the energy side of it and it lacks a framework to deal with this.	1. Communal RE penetration 2. RE penetration rate 3. Infrastructural cost 4. Food security
ST11 **ST12**	• RE will contribute towards better ES for Malaysia in terms of socio-economics and environmental sustainability. • Intermittency of RE is a challenge. • RE policies are not matured yet in Malaysia.	1. Socio-economic and environmental benefits 2. Intermittency Challenges
ST13	• 11th Malaysia plan had included the target of 20% RE installed capacity by 2025. Excluding any hydropower plant above 100MW as RE. • The target of the RE set is mostly for electricity generation and not overall energy. Looking at primary energy supply RE capacity is art 2-3% but looking at RE for electricity generation it contributes almost 15-17% currently.	1. RE penetration rate 2. Electricity generation 3. Intermittency issue 4. Infrastructural cost 5. Energy tariff

	• For peninsular Malaysia achieving a high target of RE has to be met through solar energy because hydro is no longer available for Peninsular Malaysia. The intermittency issue is one of the biggest challenges for RE in electricity generation. • The maximum that solar can contribute is 27% of the grid off-peak demand and 21% is converted to the total capacity. This is the maximum that the current grid can take from solar power and anything beyond will need additional infrastructure and hence additional costs. • The need for an energy storage system increases with an increase in RE penetration. • In terms of tariff, solar can compete with natural gas but it is not cheap enough to compete with coal. Currently, the grid cannot integrate much solar or RE power unless the grid is strengthened, or distributed generation is used.	6. Energy storage
ST14	• By 2018 the RE capacity for electricity generation was 6% in the energy mix. • SEDA is working on the RETR 2035 to address more strategies of policy, frameworks, and technology towards achieving a higher RE penetration rate in Malaysia. • Projection load or the compound annual growth rate (CAGR) is increased to reach a 20% RE penetration target by 2025. There is a progressive interjection of government through policy and framework to achieve higher RE targets for Malaysia at least for electricity generation. • Evidence-based policymaking in place for RETR 2035. It looks at the Business as usual (BAU) of the projects approved for RE. FiT and NEM are also in place and their rate of uptake is monitored by awareness programs, policy interjections, and financial support. • The best way forward to achieve sustainability and hence secure ES is through moving towards RE technologies, conservation technologies, and energy-efficient technologies.	1. RE penetration rate 2. Projection load 3. Compound annual growth rate 4. Energy efficiency 5. Electricity generation
ST15	• RE policies not in sync with the RE objectives because we are still at 70% thermal power plants and if we have to reach the 20% target then we need to shut down a few of these plants which will lead to	1. Production to Reserve margin

	shock for the oil and gas industry. • PPA will give a new reserve margin of 25-30% for electricity for the next 10-20 years. So, with this reserve margin, there is no need to have extra RE but the RE target is just to keep it hyped up in the market. • We are still opening up PPA and hence that does not align with our RE policies. Having a 20% share of RE should mean a 20% reduction in conventional thermal powerplants but that is not the case. • Intermittency is an issue because of the natural characteristics of it and we cannot do much about it. We do not have a significant capacity of RE that they will cause system instability and hence these can be fulfilled by thermal powerplants.	2. RE penetration rate 3. Intermittency issue 4. Electricity generation
ST16	• Malaysia aims to go green like many other developed economies and the government is putting efforts to do so but the challenge remains in terms of affordability. • Green energy is still not cheap enough compared to fossil fuels and hence it is not competitive enough yet. In Malaysia, solar PV is dominant while the wind does not have many prospects. • There are intermittency issues and how much RE or solar the grid can hold at one time. The RE sources in Malaysia become one-dimensional without wind hence thermal plants need to back up when there is no sunshine. • Solar energy may be cheap per unit but the cost of setting up the project is not cheap and also during poor sunshine, the backup using thermal generators requires additional investment. • Some people are reluctant in adapting to new technologies like smart metering but that will not stop the advancement in technology of RE and EE in Malaysia.	1. Electricity tariff 2. Intermittency issue 3. Price of energy 4. Infrastructural cost 5. Energy-efficient technology

Table 12: Summary of theme fossil fuels in Malaysia's ES

No.	*Key Findings*	*Key Words*
ST1	• Malaysia’s main energy supply fuel is still coal and natural gas, the major energy fuel is not expected to change till 2025 as the Power purchase agreement is still in effect till 2025. • All the coal and natural gas plant are regulated by the Department of Environment under the clean air regulation act	1. Power purchase agreement (PPA) 2. Clean air regulation act
ST2	• Established upstream business and oil exploration in Sarawak as early as the ’70s and also tried to get oil from offshore Terengganu and we started our venture in downstream activities. • Downstream activities bring in a lot of benefits like employment, improved standard of living, and development of infrastructure. • Downstream activities are going well with almost 30 years in operation and now we are starting PPIC in Pengerang Johor. • We have matured into a certain level of expertise as a nation and we can deliver high-quality products. • The hydrocarbon business is just not about utilizing the oil and the sour and sweet product but also transform them into more valuable things like additive, refined products, and even plastic. • We have embarked onto more coal plants in the past 10 years it is to help cushion the impact of us moving from subsidised regime to a more market-based regime on gas.	1. Upstream business 2. Downstream activities 3. Employment 4. Improved standards of living 5. Infrastructural development 6. PPIC in Johor 7. Hydrocarbon business 8. Subsidised regime 9. Market-based regime

ST3	• If there is a fixed carrying capacity of fossils in the world, then they are in the state of depleting. • Fossil has a volatile market and is subject to geopolitical issues. • RE can offset the demand of Fossil even if it is on a small scale. • With the subsidy, the price of fossil becomes so cheap that even with feed-in-tariff the price of RE seems more expensive. • Buying electricity from the grid at a cheaper price will be the option chosen by most and hence the entire industrial supply chain grows. This is the current situation of the fossil-rich countries in the SEA region.	1. Carrying Capacity 2. Geopolitical issue 3. FiT 4. Industrial supply chain
ST4	• 50% of our power generation comes from coal and hence it is important to get coal. • CCGT has reduced power output during covid. It has dropped to 30% and coal at 60%. The CCGT's are not dispatched as often as before but we still need 30% of CCGT. • New coal plants are coming in, the latest is minjung 5. Added another 1000MW to the grid. Oil is not something used for electricity. Mostly we use east coast gas and LNG from the middle east. • Coal is more polluting, coal contributes 1kg of co2 per KW h and CCGT around 0.6kg per KW h. • Coal power capacity is around 8000Mw with ITP and TNB compared to 500,000MW in China. Our pollution does not dent the climate as much compared to these bigger countries. • Oil is not used for power generation and they are more expensive than coal. • For 30% of the gas, 2/3 comes from the east coast and 1/3 comes from abroad. 100% of all the 60% share comes from abroad for coal hence there are issues of supply security.	1. Co2 per KW h 2. Supply security

ST5	• ES issues began in the 1970s. The issues were related to oil and the physical security of supply and its price. • Malaysia is a net exporter of gas. • Malaysia still uses a lot of coal. This raises a question on the environmental aspect.	1. Security of supply 2. Physical security 3. Net exporter of gas
ST6	• Resource wise SG is a very resource-scarce country. They have to import their LNG from Indonesia and Malaysia. • In SG there is no local energy production on SG to sustain the society. • In the Philippines, without trade of fossil, they can run all sectors at least by 60% of capacity with their domestic resources.	1. Resource scarce nation
ST7	• We buy fuel at the generation side from different sources and geographical locations. • If people are educated on the use of nuclear then the use of fossils can be reduced. • Gas is a comparatively less dirty source of fossil. • The cheapest and the dirtiest is coal.	1. Generation side 2. Nuclear
ST8	• Fossil comes from coal, natural gas, etc and these are limited in numbers as they are natural resources. • We are very much dependent on natural resources. We live in a society of limited resources and unlimited demands and wants. These will eventually finish and if RE technology does not improve or mature then we will face a shortage of energy.	1. Limited natural resource 2. Natural resources 3. Unlimited demand 4. Net gain from trade

	• There is a net gain from the trade of oil. Malaysia sells higher quality oil and imports lower quality oil.	
ST9	• Pengerang rapid plant (PPIC) is to boost fossil fuel in Malaysia mostly refined products. • There are petrochemical products that are not energy sources, but petroleum products used in industry. • Diversification of fuel sources to avoid dependency on one particular fossil fuel. • We have reserves for almost 40 years, but they are depleting very fast as well. Looking for more resources, the job is of Petronas as they are the custodian of natural petroleum. They are discovering resources in difficult places, in ultra-deepwater. • Malaysia also needs to import other sources into Malaysia. • Our refineries in port Dickson, Melaka, and Kedah are very good and they can convert low-grade fossil mostly from the middle east to well-refined products. • Petronas has Petro refinery and petrochemicals they are looking into the refining business. • Malaysia leverages the ability of Petronas and their connection all over the world. We sit at a comfortable position in terms of petroleum as they have both domestic and international profiles for fossils. Petronas has good cooperation with other companies in Japan and Korea and can shift cargo easily. Friendliness and cooperation are good for Malaysia with other countries. • Petronas has taken mitigation measures with regards to the interconnectivity of part plants in between platforms.	1. Pengerang rapid project 2. Petrochemical products 3. Diversification of fuels 4. Refineries 5. International trade
ST10	• Due to geographical conditions, it is very hard for SG to be sustainable and fully independent from	1. Independent from

	importing. Its 90% or more natural gas is imported from abroad. • Malaysia is using coal and should look for alternate options at a similar price instead of coal as it is dirty. I think these decisions are made by the government rather than the policymakers.	importing
ST11		
ST12		
ST13	• Natural resources are depleting. • People want more greener energy rather than fossils. • People want the cheaper price of energy as well at the same time. • Within the next 20 years, we might not have a gas supply in peninsular Malaysia and hence we started to build an LNG terminal and also expanding our refinery capacity. • Solar energy price is low enough to compete with gas but not with coal. Due to intermittency challenges, we do not embark on solar as much until we can strengthen the grid or use a different system like distributed generation. But all these will need more investment. • We have a national depletion policy for crude oil. We use 700,000 barrels per day, but we could pump up to 1million barrels per day, but the policy does not allow us to do so to ensure the security of oil. • For gas, the law says anyone can buy or sell gas. Price from offshore is cheap and not enough demand for gas to buy. • For electricity decentralisation will occur naturally once there is 3rd party access.	1. Depleting resources 2. Green energy 3. Cheaper energy 4. LNG terminal 5. Refinery capacity 6. National depletion policy 7. 3rd party access 8. Decentralisation of electricity

ST14	• We are moving into a globalised era where trade is an important aspect. The trade of fossil fuels will help the world to evolve in terms of import and export in exchange for economic growth.	1. Globalised era 2. Trade 3. Economic growth
ST15	• Interaction between fuel and electricity market is interesting and is a challenge because fuel and electricity tariff is subsidized. 70% is subsidized the rest are fully regulated and cross-subsidized. • If you want o to liberalise the electricity market, then maybe have to open up the field market as well because if you only liberalise the electricity market then you will get a significant impact in terms of the electricity price. Might also review the fuel market that contributes to the cause of electricity. • We are still using 70% thermal plants and if RE is to increase by 20% then these need to decrease by 20% but that is not the case. • There are new PPA opened for coal plants and hence it defeats the RE goals of the country. • RE and sustainability are not disruptive yet to change the existing market and Malaysia is dependent on fuel export and ASEAN agreement to buy coal is also there. Phasing this out will cause huge disruption and lead to more economic problems. • In Malaysia, the conventional plants are still based on the PPA agreement which is long term contract based on capacity and some portion on energy payment. • It is not encouraging for the conventional power generators to boost up their capacity due to the RE intermittency issue. There is a need to ramp up the commercial fund which is the cost to generators but now due to long-term contracts,s it is not encouraging.	1. Subsidized tariff 2. Cross-subsidized 3. Liberalisation of the electricity market 4. Electricity price 5. Fuel market 6. Conventional plants 7. PPA 8. OPEC country 9. Price volatility

	• We need to have a capacity market to replace the PPA market but that will not happen now. • For gas, we import from OPEC country and hence we are exposed to price volatility. Having ASEAN market for oil and stock depot we also consider having a storage depot to store our supplies and control the price within ASEAN countries.	
ST16	• Coal is much cheaper than RE and it comes in as a replacement for it. Intermittency is a challenge for RE and to address these coal plants are used. • Thermal powerplants are replacing the power that is lost during no sunshine or rain for solar. • In this case, the thermal plants will not be running at full efficiency as they only come in as a backup to solar plants. The efficiency decreases as a result cents per kWh are more.	1. Thermal power plants 2. Poor efficiency 3. Intermittency issues

Table 13: Summary of applicability of technology theme for ES

No.	*Key Findings*	*Keywords*
ST1	NONE	NONE
ST2	• We are moving towards EE technology even without us realising it like LED lights. • These are not driven by government policies, but we have to realise that we need to spend initially to save. • I would want to wait for technology to mature a bit before we can embark on things like electric vehicles so that the risk is not there for losing money in the form of	1. EE technologies 2. Investment on technology 3. Mature technology

	investment.	
ST3	• Accessibility of the energy available will be hindered if the technology is not good enough to explore them and utilise them.	1. Accessibility 2. Availability
ST4	• Technology in Malaysia is already matured and to support RE and EE there are a lot of technologies out there already. • I would like to improve the technology by investing more in it to support more green technology for Malaysia.	1. EE technology 2. RE technology 3. Investment on technology 4. Green technology
ST5	• Technology can make a huge difference in national energy supply, local energy access, and poverty issues. Technology arriving at the right time is the key. • In Britain, the marketisation happened when gas and CCGT technology was there. Now with RE technology and poverty, it is creeping in very slowly because of the cost issue. • In Singapore, few buildings are advanced and eenergy-efficient but I do not see them as a pioneer yet in this.	1. Marketisation 2. Energy supply 3. Energy access 4. Poverty 5. RE technology 6. Cost issue
ST6	• Incineration plants for waste. A whole circular economy can grow around them in Singapore. Generates 2000 tonnes of ashes from the inorganic waste and use for landfill. • Necessity is the mother of innovation. • Singapore improved its water purification and production technology when Malaysia stopped supplying water. • Technology needs to be harnessed and not only for their end product. • Techno-economics is the economics of the technology itself which is the number in	

	terms of costing and benefits of using that technology.	
ST7	• Nuclear is the best way forward if the technology is advanced enough to ensure security. Technology can help in disposing of radioactive waste at a cheaper cost then it will be a boon. • Technological innovation towards nuclear-powered cars and having the energy stored in batteries where you dispose the battery like after 10 years of use.	1. Nuclear powered vehicles 2. Disposable batteries 3. Cost reduction
ST8	• Malaysia is looking towards technological advancement. • This is highly contextual based on where you are • Technological advancement will be one of the key dimensions to measure ES of Malaysia	1. Key dimension
ST9	• Ride e-hailing technologies must be looked at and need to motivate people to share rides. Technology can bridge this gap by figuring out who lives in the same neighbourhood and goes to work in a similar direction etc. • Technological innovation is good but at the same time, Malaysia is leveraging on the capabilities of the national oil company, Petronas.	1. E-hailing 2. Techno-innovation
ST10	• Techno-innovation approach as they do not have a lot of land space for example for coal plants in Singapore. • Funding for technology is available in Singapore. • The focus is on energy efficiency and smart grids. • SG allows test beds for novel technologies. • There is a development of finance and banking the regulatory framework with improvement in technology and more investment in technology.	1. Techno-innovation 2. Lack of land space 3. EE technology 4. Smart grid
ST11		

ST12		
ST13	NONE	NONE
ST14	• Technology is very important because e.g. solar PV cells had an efficiency of 11% which has increased to 20% now with mono-crystalline materials. In solar technology is changing and hence the price is also reducing gradually. • Change of coal plants from sub-critical boilers to super-critical boilers. • Technology will have a great impact on designing strategies and roadmaps. • In developing countries, new technologies come and get tested if they fail then a lot of money is wasted on them. That is why it is important to know whether we want matured technology or innovative technology and at what level we allow them to take part.	1. Matured technology 2. Innovative technology 3. Mono-crystalline technology 4. Roadmap and strategies 5. Cost of new technology
ST15	• Solar PV technology is improving, we are in about top 5 in the world in the manufacturing of solar PV equipment. • Nano-technology is improving and so are EE technologies. • Saving energy is important by using EE technologies and TNB is giving some benefits to consumers for saving electricity.	1. PV equipment 2. Nano-technology 3. EE technology
ST16	NONE	NONE

Table 14: Summary of the 4A's dimensions of ES

No.	*Key Findings*				
	Affordability	***Accessibility***	***Acceptability***	***Availability***	***Key Words from 4A's***
ST1	• Competitive energy tariff with neighbouring countries like Thailand and Singapore. This will attract foreign investment in the national grid.	NONE	NONE	• The responsibility of the energy commission is to make sure consumers get a continuous supply at an affordable price.	1. Competitive tariff 2. Foreign investment 3. Continuous supply
ST2	NONE	NONE	NONE	NONE	
ST3	• For the development of a country or a city the energy needed must be affordable and clean to power all the economic activities. • When we contextualise ES,	• If you have energy underground but no technology to extract it then the accessibility is denied and poor.	NONE	• Affordable and available energy is needed which is resilient against disruptions to ensure ES. • Malaysia has enough oil and gas to sustain its economic	1. Affordable 2. Reliable 3. Resilient 4. Abundant fossil 5. Extraction technology

	energy must be affordable and available at all times. • Energy must be affordable, reliable, and resilient against any disruption.			activities. • They have control of ES availability because of the abundance of fossil fuels. • Comparatively, SG imports all its energy from other countries to make sure ES. How much RE a country can absorb is also a question. • SG is a net importer of energy and hence always has to worry about where they will get their energy from at a reasonable price.	
ST4	• Gas from Sarawak is sold at a much higher price in japan or Korea compared	NONE	NONE	NONE	1. The high price of gas 2. Trade of gas

	to peninsular Malaysia. Hence, the question is whether people in peninsular would pay as much for the gas hence the question is of affordability.				
ST5	• So, it is the international supply that decides the price, availability, and even domestic dimensions of ES. • In developing countries, the price becomes an issue like $150/barrel. Access at affordable rates is the key domestically in poorer countries.	• 20 years ago, it was a challenge to give access to energy to everyone. • When we talk about access, we have to look at distributed energy, RE, and technology.	NONE	• It is the international supply for SG that determines the availability of energy for ES.	1. Electricity price 2. International supply 3. Distributed energy 4. RE 5. Combined cycle gas turbine

	• In the '70s and 80's the CCGT plants led to a decrease in the price of electricity.	• In the 70's and '80s in Britain due to the use of CCGT plants, there was a decrease in electricity prices.			
ST6	• Affordable energy is important mostly for developing nations.	NONE	• To tackle ES challenges the technical solutions must be economically feasible and socially acceptable.	• Energy availability would discuss how much resources are available and whether they are indigenous or imported. How much is the price of the energy?	1. Indigenous resources 2. Imported energy 3. Energy Price 4. Economically feasible 5. Socially acceptable
ST7	• The government has already made laws and regulations to ensure the utility operator makes the supply secured and cost-effective.	NONE	• Acceptance of nuclear energy is poor because of the safety lately. • Academic institutions have to research to find out ways to	NONE	1. Supply security 2. Cost-effectiveness 3. Poor safety

			make it more acceptable		
ST8	NONE	NONE	NONE	• I would like to ensure a certain percentage of energy comes from RE as every country does not have a similar portfolio as the availability of natural resources can vary.	1. RE penetration 2. Natural resources
ST9	• The price of fuel must reflect that of the actual market price to reduce wastage by people. • Both rich and poor are getting the same subsidised price and hence it is unfair for the one riding luxury vehicle compared to a two-wheeler.	NONE	NONE	• Important to change the behaviour of people towards wasting less energy which will also ensure more energy is available at a given point in time.	1. Wastage 2. Price subsidy 3. People's behaviour

ST10	NONE	• Access and equity are related. If there is no power in decision-making, then the rural community will not get access to energy hence equity and access to have a relation here. • In the Philippines, the issue is of equity and access mostly. Having an alternative source of	• Acceptance of technology and energy. In SG e.g. there are a lot of good innovations, technology-friendly buildings, and recycling projects that the community is not aware of. • A change of behaviour is needed for people in SG, there are a lot of studies been done but behavioural studies are lacking on how the energy transition can affect everyday lives especially the elderly. E.g., acceptance of smart meters amongst the	NONE	1. Equity 2. Alternative energy source 3. Sustainable development 4. Recycling projects 5. Behavioural studies 6. Energy transition 7. Smart meter 8. Conventional power plants

		energy in form of RE does not always mean all communities and everyone has access to it in developing countries like the Philippines. • Equity means the ability to use energy for sustainable development.	elderly is tough. • Acceptability of alternative sources of energy amongst people not there. Mostly the ones in the business of conventional power plants.		
ST11					
ST12					
ST13	• Affordability is social security. • Making electricity affordable is crucial for the nation hence	NONE	NONE	NONE	1. Social security 2. Electricity tariff 3. Price subsidy

	tariff is subsidised. This is done by saving up when there is a surplus to ensure that discounts can be given later on in tariff.				
ST14	• The affordability of acquiring consistent reliable sources of energy takes precedence in Malaysia most of the time. • Malaysia is now at a stage to decide on how much affordable energy they want vs the impact this has on the environment.	NONE	NONE	NONE	1. Environmental impact 2. Reliable sources
ST15	NONE	NONE	NONE	NONE	
ST16	• Post covid-19 the	NONE	• People will not	NONE	1. Recession

world will go to recession hence it is important to ensure affordability of energy and mostly electricity. • Green energy is good but has to keep in mind consumers are always demanding affordable energy. • The issue of affordability is of too high importance in Malaysia.	accept sources of energy that are polluting and hence solar is popular for acceptability. • Nuclear will not be accepted widely but eventually, we might have to look at it as an option. • I would go for an open electricity market but if the price increases initially then people will not accept it.	2. Green energy 3. Covid-19 4. Open market for electricity

Table 15: Summary of environmental sustainability theme of ES

No.	*Key Findings*	*Key Words*
ST1	• 6GW of RE expected from 5 sources, solar, mini-hydro, biomass, biogas, and geothermal for increasing RE penetration to decrease carbon emissions. • Ministry has set a goal towards a sustainable future and a 20% RE penetration target. Solar is expected to contribute 2GW of electricity after completion of all 4 LSS.	1. RE penetration
ST2	NONE	NONE
ST3	NONE	NONE
ST4	• The environmental dimension Is not too strong in Malaysia hence there will be more conventional power plants and co2 emissions will not hamper the decision much. • The aim is towards economic ascendency in a developing economy rather than environmental ascendency. It is more important to ensure we have enough savings and a good lifestyle rather than thinking about climate change. • I care about climate change because I am in the RE business hence it helps my business, I am not too concerned about climate change because of this. • I would personally want to go green and change towards a more green economy but not at the expense of the electricity tariff going up heavily. So, affordability is also a key here.	1. Conventional powerplants 2. Co2 emission 3. Economic ascendency 4. Green economy 5. Affordability
ST5	• The dimensions priority changes over some time, 20 years back energy access was an issue now it is not, but the environmental concerns started increasing. • Climate change and air pollution issues are there. These dimensions change the nature of its seriousness in different fields. • Socio-economics and the environment play a key role in the ES of a nation.	1. Energy access 2. Climate change 3. Air pollution 4. Socio-economics

ST6	• Most of the countries do not have the environmental dimension as their priority may be the last.	
ST7	NONE	NONE
ST8	• The impact of ES on the environment must be addressed early in order to avoid the future generation from suffering. • Not enough attention is paid to the environmental aspects of ES. • Another policy that can be implemented is to tax the industries based on their carbon emissions from everybody. So, that everyone can only emit a certain percentage or else they would be fined.	1. Tax on carbon emission
ST9	NONE	NONE
ST10	• Equity means using energy for sustainable livelihood or development. It should look at long-term sustainable livelihood and not just for small-scale use. • Some scholars are pushing to change the definition of ES to that of sustainable energy.	1. Sustainable energy 2. Sustainable livelihood
ST11		
ST12		
ST13	• Energy in Malaysia has a lot of interaction between demand and supply-side as well as economy and environment. Energy is the backbone for everything, without energy economy will not move forward.	1. Demand supply interaction 2. Economy environment interaction
ST14	• In energy trilemma for the nation, the environmental dimension would come last. • We are in the midst of deciding between the trade-offs of how much affordability vs how much of environment we want, like do we go coal or try to cut down coal and increase RE share.	1. Energy trilemma 2. Affordability vs environment 3. RE share
ST15	NONE	NONE
ST16	NONE	

Table 16: Summary of economic development theme of ES

No.	*Key Findings*	*Key Words*
ST1	• Economic priority is first in the nation. • The RE projects create job opportunities.	
ST2	• Downstream activities have given a lot of benefits like employment, infrastructural development, and the ability to trade with the rest of the world. • Development of local economy, employment for locals, and also improvement in education and living standards.	1. International trade 2. Infrastructural development 3. Employment 4. Living standards
ST3	• Malaysia has enough oil and gas to sustain economic development. • If there is good income on fossil fuel export and stable fossil fuel supply that means the country has a good subsidy on fossil fuels • The priority of economic development will always be higher than the environment in a developing economy. • For Malaysia and Indonesia, it is a way to diversify the commodity output and sell more LNG to the market which gives good profit.	1. Sustain economic development. 2. Fossil export 3. Subsidy on fossil 4. Supply of fossil 5. LNG
ST4	• Smaller countries do not move towards RE for saving the environment rather they see it as a business opportunity hence the economy is benefitted only. • We should be aware of climate change but in developing economy it is more about economic ascendency, not environmental ascendency. • In Malaysia, the system reliability is high and adequate as well hence the social aspect is not an issue and does not affect the economy. • Malaysians do not believe that we can make a huge impact on climate change issues and our main aim is to	1. Business opportunity 2. System reliability 3. System stability 4. Climate change

	ensure the economy is running smoothly.	
ST5	• Irrespective of how ES affects the economy we should not compromise on the environmental dimension of ES. • The social aspect as well, socio-economics as well. These have different priorities in different countries. • International and domestic ES issues are not the same. China said ES issues were due to the international oil trade, but I told them it was domestic. The lights were going out because the GDP growth was 13% a year and the construction of new powerplants was banned for 3 years. It was a domestic issue for them. • SG has a GDP per head of 6 times more than most of the neighbouring SEA countries.	1. Social dimension 2. Socio-economics 3. International oil trade 4. International ES 5. Domestic ES challenges 6. GDP per head 7. GDP growth
ST6	• Solutions to ES challenges have to be well balanced and feasible. Like you can have a technological solution, but it has to be economically feasible or socially acceptable. The solutions will not please all, but you have to prioritise. You are aware of the triple bottom line. • E.g., wind turbines, whether we import them, or we manufacture them locally to create jobs as well. • People are waiting for opportunities to invest in RE technology in Malaysia. Whether to allow them or not will decide whether we can get benefits economically or not. There is a need to educate and increase communication through training. • Increasing business means increased taxes which means more contribution to the national economy. • The trade and finance industry looks at RE as a new business opportunity and not just for the climate change matters.	1. Well balanced solution 2. Feasibility 3. Tax from new business
ST7	NONE	NONE
ST8	• There is the net gain from selling higher-grade oil and importing lower grade oil. Economic gain. • Developing infrastructure for energy would need time, not just 2-3 years, the timeline has to be revised. This will require major restructuring and development across different locations and policies as well, which	• Economic gain • Infrastructural development

	would have an impact on the economy.	
ST9	NONE	NONE
ST10	• When we talk about RE it should be on a communal scale and not just a small scale at individual homes. This will lead to long-term economic development. • Socio-economy is educating people and encouraging them towards sustainable development.	1. Sustainable development 2. Socio-economic 3. Communal scale
ST11		
ST12		
ST13	NONE	NONE
ST14	• SEDA aims to promote the utilisation of RE in society but the fact remains that economic development priority for the nation comes first followed by social development and then environment. • The economy is the measure of the welfare of people, the standard of living and these things are affected by the amount of GDP and growth in the economy, hence a pandemic does not help this. • Trade is important for the world to evolve in terms of import-export for economic growth. • If trade is bringing economic benefit and helps the region to bond stronger by helping each other then it is healthy for the nation. • Drop is peak demand during covid 19 in 3 months by 6000MW and it is not good for the nation. To energise the industry, it is important to have this energy. This will lead to job creation and the social development needed for a better life and these are the indicators of how well the country is doing.	1. Utilisation of RE 2. Economic development 3. Social development 4. Standard of living 5. GDP growth 6. Trade of fossil 7. ASEAN bond 8. Energising industries
ST15	• International trade of fuels with Malaysia adds economic gain for the nation.	1. International trade 2. Economic gain
ST16	NONE	NONE

Table 17: Summary of the role of governance theme of ES

No.	Key Findings	Key Words
ST1	• The government decides on the policies that are to be set and how to achieve them. The target is given to us to achieve and regulate.	
ST2	• Lack of legislation on EE technologies. There are a lot of studies carried out, but the missing link is the allocation of resources to drive the program and legislation.	1. EE technologies 2. Legislation
ST3	• Why the countries are not fulfilling their targets this question is politically sensitive. The entire ASEAN is falling short of its targets by a significant percentage mostly for the RE policies and their roadmaps. The governments do need to address this. • The question is whether there is government support towards RE policies. • Nuclear energy is also sensitive. How the politics around it are developing needs to be looked upon. • E.g., France, where 70-80% of electricity comes from nuclear, but you expose yourself to political sensitivity. • In the SEA region, a lot of ES depends on the political affairs as they control a fair bit of how ES will shape up and also keeping in mind that the voting has an impact on their decision making.	1. Political sensitivity 2. Nuclear 3. RE target
ST4	• Political parties take it as an opportunity to say that they are giving incentives for RE but they look into the economic benefit of it. • The legal and political aspects will be given the most important because they decide the policies and whether new powerplants will be built in coming years or we will stop building them. • Whether the RE targets will be 50% by 2030 or not all depends on them. So, the biggest driver of ES is the government because if they do not take the right decisions and make the right policies then the powerplants that need to be built will never be built and it will affect ES and on the legal side they want to execute the policies with the rules and regulations.	1. Incentives for RE 2. Driver of ES

ST5	• The key is sustained and robust leadership from the government. • Malaysia has a lot of resources and there are lobbies for coal, gas, and oil and hence it depends on the sustained leadership of the government on what they want. If not, then we will not go anywhere in terms of the energy mix.	• Coal, gas lobby • Sustained and robust leadership
ST6	• If there is no government support then it does not matter how good your technology is or how cheap it is, they will stick to their decision irrespective. • At private and small scale RE is possible but that cannot influence at national scale or level unless government deploys it. • There is a need for a legal framework as we cannot do any business without a legal framework. The legal framework gives mandates like portfolio standards. • There has to be some sort of an energy transition plan for the region as a whole. If the government follows up the process of transitioning by incentives like FiT or state-based subsidy or state-mandated portfolio then the business case will make more sense.	1. National scale 2. Legal framework 3. Portfolio standards 4. Energy transition 5. State-based subsidy 6. State-mandated portfolio
ST7	• The government elects the law and makes sure that everything that operates in that manner is already stipulated in the law and regulation and in licensed condition to the utility operator to ensure supply is secured and cost-effective.	1. Cost-effective 2. Supply security 3. Law and regulation
ST8	• Government should enforce a tax on industries and the public who would exceed the limit of carbon emission. These policies are there but I am not sure about the enforcement of them. • Government can allocate more funding on RE technologies and research and in overall research of technologies. • Government plays the most important role in ES as they are the policy setters and decision-makers. So, if the policy is wrong all goes wrong, and vice versa. Policymaking should always be science and evidence-based.	1. Tax enforcement 2. Carbon emission 3. RE technologies 4. R&D 5. Policymaking

ST9	• In 2008 we had the ASEAN financial crisis and then in 2009, the PM could not absorb the subsidy anymore hence the price of petrol increased and hence leading to backlash from the public and it is natural.	1. ASEAN financial crisis 2. Subsidy 3. Petrol price
ST10	• The use of coal despite being dirty is not just about policies, it is also to do with the government and their intent to use it.	1. Government intention
ST11		
ST12		
ST13	• Peninsular Malaysia has one of the best physical security of resources. The system redundancy is good. Sabah has a comparatively underdeveloped system and the government is pumping in a lot of money towards that. In peninsular government is trying its best to maintain the social dimension of ES. • Energy is one of the commodities that have a huge impact on geopolitics. • Malaysia has a vertical market for electricity. It is a regulated monopoly and the government has some control for security purposes and control of the pricing as well. • Government is directly in charge of accepting the policies that we set but the final decision is in their hands. • The past PH government has been more liberal between 2018-2020 but the current government is a bit conservative. You will not see big changes like market opening for electricity as they feel they want to take control over electricity and energy as a whole. • Things set by the PH government will not remain as it is for the current government like MESI 2.0, but some will retain 3rd party access. • For ES you must also look into regional politics like within ASEAN countries. E.g., the ASEAN power grid agreement happened in 1984 but recently only there is purchase happening between Laos, Thailand, and Malaysia after 30 years. So, I would say there is a lack of political willingness there. The	1. System redundancy 2. Physical security 3. Commodity 4. Geopolitics 5. Regional politics 6. Vertical market 7. MESI 2.0 8. 4A’s 9. RE penetration

	trust has to be high enough between these countries like buying from Vietnam, but our reserve margin is high enough. So, things like this fall under regional politics. • Each of the 4A's has a political dimension connected to it and it is necessary to study them. • The future goal of RE might be 30% penetration including large hydro.	
ST14	NONE	NONE
ST15	NONE	NONE
ST16	• In Malaysia, the energy industry is still a managed model and there is a lot of government intervention in terms of policy setting and all. • In Singapore, it is a free market. • Nuclear will be a suicide for the political party or the government whoever will try to champion it, because of poor public acceptability and lead to the party losing vote.	1. Managed model 2. Government intervention 3. Free market 4. Poor acceptability

4.5.1 Using Quirkos for Qualitative Data Analysis (QDA)

Quirkos Dashboard Overview:

The Quirkos dashboard serves as the central hub for all data analysis activities. It comprises several key components that streamline the coding and analysis process. The main project workspace displays all documents and codes. Documents are listed on the left side, while codes, known as Quirks, are displayed as bubbles on the right side. The document pane allows for the importing, viewing, and management of qualitative data documents such as interview transcripts and survey responses. The central coding pane displays the text of the documents, where coding occurs by highlighting text segments and assigning them to relevant codes. Each code is represented by a bubble, which grows in size as more text is coded to it. These bubbles can be color-coded and organized to visually represent different themes or categories. Additionally, memo and annotation tools allow for the addition of notes and comments to specific text segments or codes, aiding in documenting the analytical process and insights.

Process of Using Quirkos for Coding and Analysis:

The process began with the importation of qualitative data documents into Quirkos, which included interview transcripts and other text-based stakeholder inputs. Key themes or dimensions of ES were then identified based on the research framework, and Quirks were created for each dimension. Examples of these Quirks include ‘Availability of Energy’, ‘Affordability of Energy’, ‘Energy Efficiency’, ‘Environmental Sustainability’, and ‘Accessibility of Energy’, the detailed view is available in figure 12.

Next, the text within each document was carefully read. Relevant segments of text corresponding to each ES dimension were highlighted and assigned to the appropriate Quirk bubble, a process known as coding. For instance, discussions on the reliability of energy sources were highlighted and coded under the ‘Availability of Energy’ Quirk.

The Quirkos dashboard facilitated the organisation and visualisation of these Quirks. Related Quirks were grouped together to explore how different ES dimensions were interconnected. The size of each Quirk bubble indicated the volume of text coded to it, providing a visual representation of the most discussed dimensions.

Memoing and annotation were integral parts of the process. Memos and annotations were written to capture thoughts, reflections, and emerging patterns or insights. Specific text segments were annotated to explain coding decisions or to highlight significant quotes.

Finally, the coded data was reviewed to identify patterns, themes, and relationships between different ES dimensions. The visual representation in Quirkos allowed for an assessment of which dimensions were most prominent and how they related to each other. Reports were generated, and coded data was exported for further analysis or inclusion in the research documentation.

Transcribing Stakeholder Inputs into ES Dimensions:

Quirkos was instrumental in systematically transcribing and coding stakeholders' inputs. By assigning segments of their responses to predefined Quirks corresponding to each ES dimension, the data was categorized and analysed effectively. This method enabled a detailed and nuanced understanding of stakeholders' perspectives on each dimension of ES.

Utilising Quirkos allowed for the efficient organization, coding, and analysis of qualitative data, translating stakeholders' inputs into meaningful ES dimensions. The software's intuitive interface and visual tools facilitated a deeper understanding of the data, ensuring a robust qualitative analysis that supports the research objectives.

Figure 12: Overall Quirkos Dashboard of this project

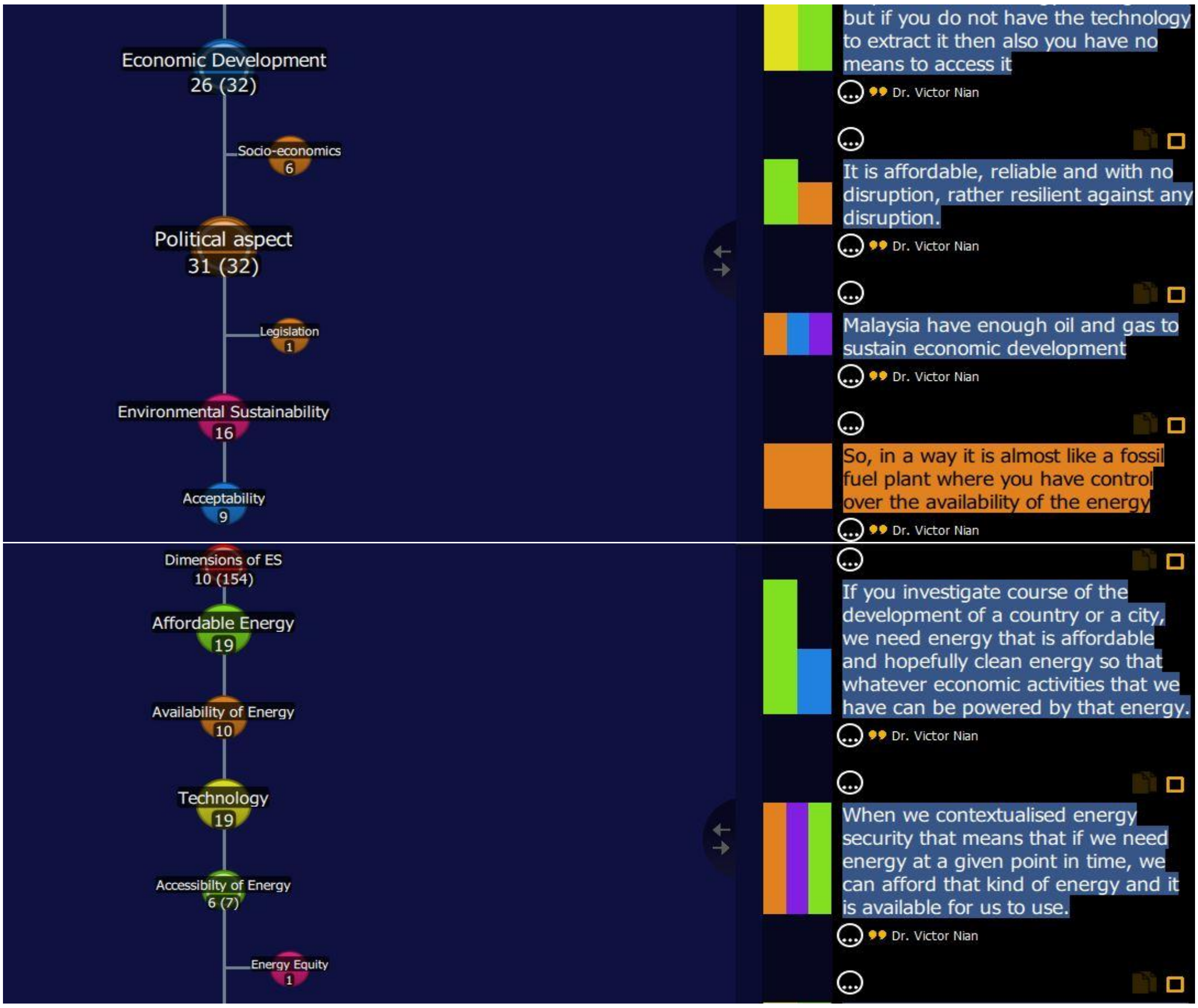


Figure 13: Dimension of ES coding and data

4.6 Chapter Summary

This chapter aims to provide an established knowledge of the multi-dimensional concept of ES through engaging stakeholders and experts. Energy security policy implications have been suggested in this study to address and mitigate the challenges of ES. A total of 7 emerging themes from semi-structured interviews have been discussed in-depth to understand the role of each theme and its interactions with energy policies. There is an urgent need to reduce the dependency on fossil fuels and look for alternative fuel options from renewable sources. Energy-efficient technology plays a major role in improving overall efficiency and leading to reduced wastage of energy.

This would in turn improve availability and the affordability of energy in Malaysia. Energy equity gets the most emphasis in the energy trilemma of Malaysia however there should be equal importance attached to the environmental sustainability and ES of the nation. The final decision of the trilemma balance and the energy policies that govern the energy use framework depends on the ministries and the regulatory bodies. An indicator mapping process has been recommended for each of these themes to quantify ES by developing an ES index. The thematic results discussed in this study have the potential to facilitate policymakers and energy analysts of countries with similar energy outlooks to design data-driven energy security policies.

5 System Dynamics Approach to Futuristic Modelling of Energy Security Scenarios for Malaysia

5.1 Introduction

In this chapter, CLD's and SFD's have been designed based on the data collected through surveys and SSI. The CLD's, SFD's, and the scenarios have been split into two broad sections; 1) CLD's and SFD's based on survey results in sections 5.2 to 5.5, and 2) CLD's and SFD's based on SSI results in section 5.6. They have been divided according to these criteria to give more clarity on the results of the data collection from these two different data collection methods. The results obtained in this chapter are critical to the research of ES for Malaysia since this is the first consolidated attempt to quantify the ES of Malaysia using the SD approach for different scenarios designed based on the current policy structure of Malaysia and its objectives.

The policy implications have been suggested for each scenario and recommended strategies to improve the overall ES based on the chosen scenario. Conclusive remarks based on the scenario results have been presented at the end of each scenario to conclude the key findings and highlight the necessary recommendations made. The development and selection of scenarios have been done solely based on the current energy policies in place and according to the objectives of the policies. Few scenarios have been based on the hypothetical situation to understand the extreme effects that it can have on the ES of Malaysia if we fail to address these issues and challenges. Scenarios in sections 5.4 and 5.5 are examples of such hypothetical scenarios where the adverse effect that these scenarios can have has been discussed by understanding how different dimensional indicators are affected.

5.2 Causal Loop Diagrams and Stock and Flow Diagrams Based on Survey Results

Based on the responses from the 117 participants of the questionnaire, the causal relations between the indicators were established and presented in the form of CLD's. The overall

CLD is split into three segments which makes it easier to analyse and understand. These segments show how the causal relation is established between the 3 different dimensions of ES of Malaysia (see Figures 14-16). The study of (Connolly et al., 2010) has discussed a similar approach with UniSyD3.0 which is a multi-regional partial-equilibrium tool for national energy and economic systems and developed using system dynamics approach.

5.2.1 CLD of energy availability and energy efficiency

The CLD in Figure 14 comprises 3 balancing feedback loops that have an energy reserve to production ratio and imported energy as common indicators in 2 different loops. In each of these CLD’s, there will be an added external variable or an auxiliary variable that will be added for simulation purposes. This comprehensive overview of the components, interactions, true/false rules, and assumptions underlying the CLD in Figure 14 provides a clear understanding of the dynamic relationships within the energy system. These elements collectively inform the system dynamics modelling, enabling the simulation of various scenarios to assess their impact on Malaysia's energy security.

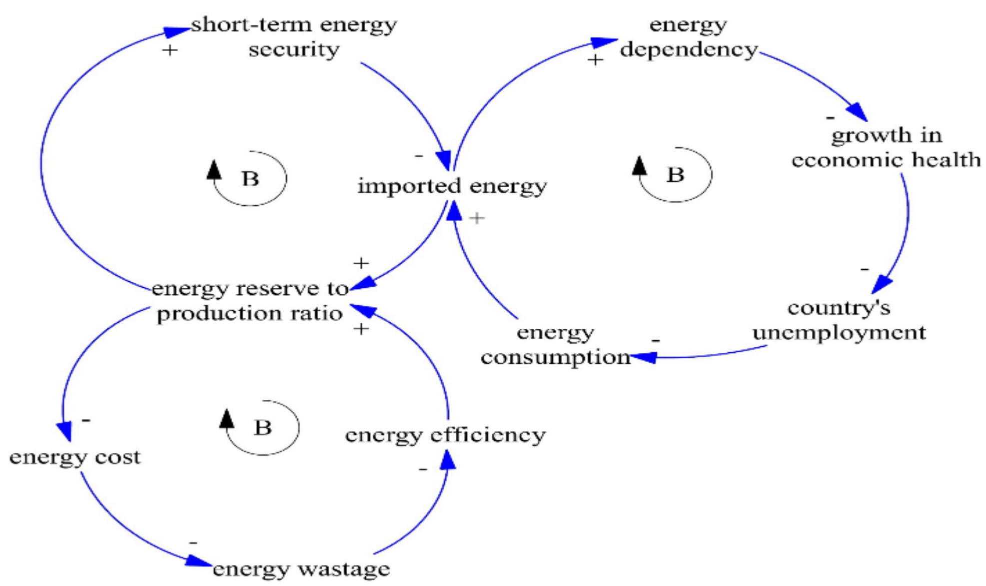


Figure 14:CLD of energy availability and energy efficiency

For the CLD designed above in figure 14, the following interactions of the components have been established alongside the true/false rules applied and their assumptions.

The assumptions for CLD's 14, 15 and 16 are the same and they are;

1. **Continuity of Flows:**
   - Assumes that the flows within the energy system are continuous and not subject to sudden, random changes.
2. **Absence of Random Components:**
   - Assumes that there are no random components affecting the flow, ensuring that all changes are deterministic and predictable.

A brief description of each component in the CLD for energy availability and energy efficiency:

1. **Short-term Energy Security:** Reflects the immediate availability and stability of energy supplies.
2. **Energy Dependency:** Represents the reliance on external energy sources.
3. **Imported Energy:** Indicates the volume of energy imported to meet domestic demand.
4. **Growth in Economic Health:** Measures economic growth influenced by energy consumption.
5. **Country's Unemployment:** Represents the employment rate, which impacts and is impacted by economic health.
6. **Energy Consumption:** The total energy used within the country, affecting energy security and economic indicators.
7. **Energy Reserve to Production Ratio:** The ratio of existing energy reserves to current production levels.
8. **Energy Efficiency:** Reflects how efficiently energy is utilized in the economy.
9. **Energy Cost:** The financial cost associated with energy consumption.
10. **Energy Wastage:** The amount of energy lost or wasted during consumption and production processes.

The interactions between components:

1. **Energy Dependency and Short-term Energy Security:**

- Increased energy dependency negatively impacts short-term energy security.
- Negative interaction

2. **Imported Energy and Energy Dependency:**
    - Higher imported energy increases energy dependency.
    - Positive interaction
3. **Growth in Economic Health and Energy Consumption:**
    - Economic growth increases energy consumption.
    - Positive interaction
4. **Country's Unemployment and Economic Health:**
    - Lower unemployment rates positively impact economic health.
    - Negative interaction with a positive outcome
5. **Energy Consumption and Energy Dependency:**
    - Higher energy consumption increases the need for imported energy, thus increasing dependency.
    - Positive interaction
6. **Energy Reserve to Production Ratio and Energy Security:**
    - Higher energy reserve to production ratio improves short-term energy security.
    - Positive interaction
7. **Energy Efficiency and Energy Wastage:**
    - Improved energy efficiency reduces energy wastage.
    - Negative interaction
8. **Energy Cost and Energy Efficiency:**
    - Higher energy costs incentivize improvements in energy efficiency.
    - Negative interaction
9. **Energy Wastage and Energy Cost:**
    - Increased energy wastage leads to higher energy costs.
    - Positive interaction

True/False Rules:

1. **If Energy Dependency increases, then Short-term Energy Security decreases (True).**
    - This rule reflects the balancing nature of the first loop, where increased dependency undermines energy security.

2. **If Imported Energy increases, then Energy Dependency increases (True).**
    - This is a straightforward positive relationship where higher imports directly increase dependency.
3. **If Growth in Economic Health increases, then Energy Consumption increases (True).**
    - Economic growth typically leads to higher energy consumption due to increased industrial activity and consumer demand.
4. **If Country's Unemployment decreases, then Growth in Economic Health increases (True).**
    - Lower unemployment boosts economic health through higher productivity and spending.
5. **If Energy Consumption increases, then Energy Dependency increases (True).**
    - Higher consumption necessitates more imports, increasing dependency.
6. **If Energy Reserve to Production Ratio increases, then Short-term Energy Security increases (True).**
    - A higher reserve to production ratio indicates better energy availability, enhancing security.
7. **If Energy Efficiency increases, then Energy Wastage decreases (True).**
    - Improved efficiency reduces wastage, making energy use more effective.
8. **If Energy Cost increases, then Energy Efficiency increases (True).**
    - Higher costs drive efforts to improve efficiency to reduce expenses.
9. **If Energy Wastage increases, then Energy Cost increases (True).**
    - More wastage leads to higher costs due to inefficient use of resources.

5.2.2 CLD of energy cost

CLD in Figure 15 has variables that are already present in the previous CLD, which shows how one variable can be linked to multiple variables in the same CLD. This CLD provides a simplified yet interconnected view of how energy cost, consumption, intensity, economic health, and unemployment are related. This diagram demonstrates the balancing feedback loop, showing how changes in one variable can have cascading effects on others within the system. By understanding these interactions, policymakers can identify leverage points to optimize energy use and economic outcomes, contributing to a more sustainable and secure energy future for Malaysia.

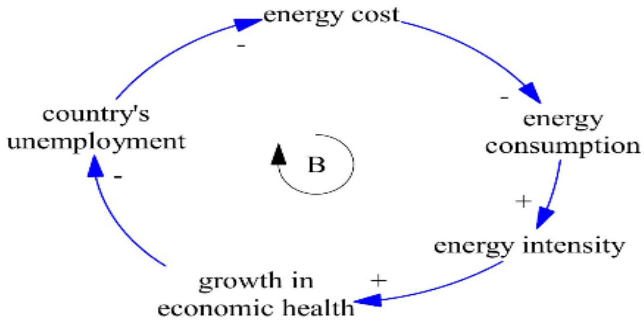


Figure 15:CLD of energy cost and the indicators directly affected by energy cost.

Components for the CLD of energy cost:

1. **Energy Cost:** The financial cost associated with energy consumption.
2. **Energy Consumption:** The total energy used within the country, impacting energy costs and economic indicators.
3. **Energy Intensity:** A measure of the energy inefficiency of an economy, typically represented as the amount of energy consumption per unit of economic output.
4. **Growth in Economic Health:** Measures economic growth, influenced by energy consumption and efficiency.
5. **Country's Unemployment:** Represents the employment rate, which impacts and is impacted by economic health.

Interactions between the components:

1. **Energy Cost and Energy Consumption:**
   - Higher energy costs typically lead to reduced energy consumption as consumers and businesses seek to minimize expenses.
   - Negative interaction
2. **Energy Consumption and Energy Intensity:**
   - Increased energy consumption generally leads to higher energy intensity, especially if energy use is inefficient.
   - Positive interaction

3. **Energy Intensity and Growth in Economic Health:**
    - Higher energy intensity can contribute to economic growth if the energy is used efficiently to boost production and services.
    - Positive interaction
4. **Growth in Economic Health and Country's Unemployment:**
    - Economic growth usually reduces unemployment rates as more jobs are created.
    - Negative interaction with a positive outcome
5. **Country's Unemployment and Energy Cost:**
    - Lower unemployment rates can lead to increased economic activity, potentially increasing energy consumption and thus energy costs.
    - Negative interaction

True/False Rules:

1. **If Energy Cost increases, then Energy Consumption decreases (True).**
    - This rule reflects the balancing nature of the loop, where higher costs drive lower consumption.
2. **If Energy Consumption increases, then Energy Intensity increases (True).**
    - Higher consumption leads to greater energy intensity if not matched by efficiency gains.
3. **If Energy Intensity increases, then Growth in Economic Health increases (True).**
    - This is true if the energy used is efficiently converted into economic output.
4. **If Growth in Economic Health increases, then Country's Unemployment decreases (True).**
    - Economic growth typically reduces unemployment by creating more jobs.
5. **If Country's Unemployment decreases, then Energy Cost increases (True).**
    - Lower unemployment boosts economic activity, which can drive up energy costs through increased demand.

5.2.3 CLD environmental and social impact

Figure 16 shows the CLD of environmental and social impact which comprises 2 balancing loops and 1 reinforcing loop. This CLD is critical to the current scenario defined in this study as it involves all the indicators that affect the renewable energy in the energy mix indicator. This CLD provides a complex yet insightful view of how various components of energy security interact with each other. By understanding these interactions, policymakers can identify critical leverage points to optimize energy use, enhance social acceptance, and mitigate environmental impacts, contributing to a more sustainable and secure energy future for Malaysia.

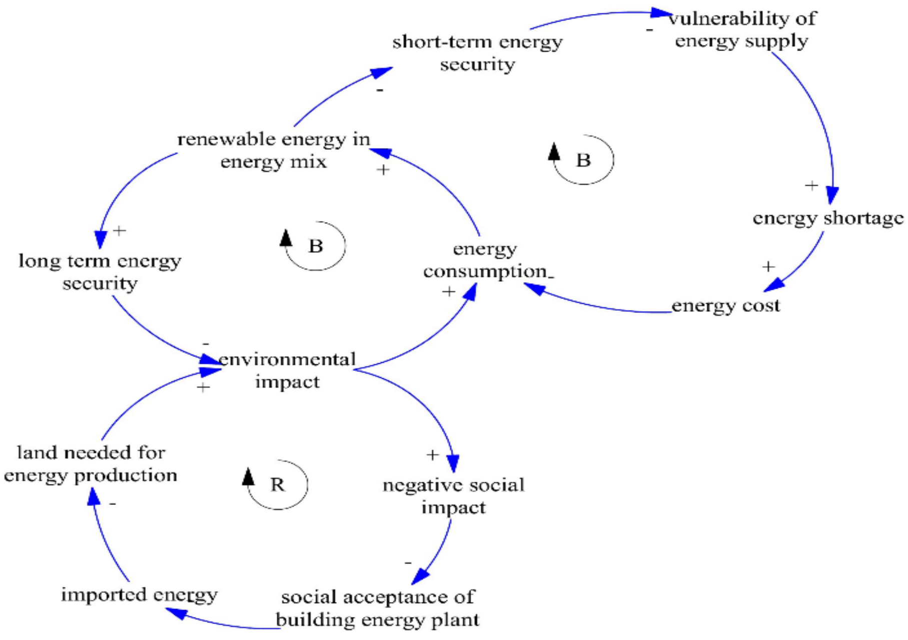


Figure 16:CLD of environmental and social impact that the increase of RE has on other indicators.

Components:

1. **Short-term Energy Security:** The immediate availability and stability of energy supplies.
2. **Vulnerability of Energy Supply:** The susceptibility of the energy supply system to disruptions.
3. **Energy Shortage:** A situation where energy demand exceeds supply.
4. **Energy Cost:** The financial cost associated with energy consumption.

5. **Energy Consumption:** The total energy used within the country.
6. **Energy Intensity:** A measure of the energy inefficiency of an economy, typically represented as the amount of energy consumption per unit of economic output.
7. **Growth in Economic Health:** Measures economic growth, influenced by energy consumption and efficiency.
8. **Environmental Impact:** The negative effects of energy production and consumption on the environment.
9. **Long-term Energy Security:** The sustainability and stability of energy supply over a longer period.
10. **Renewable Energy in Energy Mix:** The proportion of renewable energy sources within the total energy mix.
11. **Land Needed for Energy Production:** The land area required to produce energy, particularly relevant for renewable energy sources.
12. **Negative Social Impact:** The adverse social consequences of energy production, such as displacement or health issues.
13. **Social Acceptance of Building Energy Plants:** The level of community support for the construction of new energy infrastructure.
14. **Imported Energy:** The volume of energy imported to meet domestic demand.

Interactions between the components:

1. **Short-term Energy Security and Vulnerability of Energy Supply:**
   - Increased short-term energy security reduces the vulnerability of the energy supply.
   - Negative interaction
2. **Vulnerability of Energy Supply and Energy Shortage:**
   - Higher vulnerability of the energy supply increases the likelihood of an energy shortage.
   - Positive interaction
3. **Energy Shortage and Energy Cost:**
   - An energy shortage drives up energy costs.
   - Positive interaction
4. **Energy Cost and Energy Consumption:**

   - Higher energy costs typically lead to reduced energy consumption as consumers and businesses seek to minimize expenses.
   - Negative interaction
5. **Energy Consumption and Environmental Impact:**
   - Increased energy consumption raises environmental impact.
   - Positive interaction
6. **Environmental Impact and Long-term Energy Security:**
   - Higher environmental impact negatively affects long-term energy security.
   - Negative interaction
7. **Renewable Energy in Energy Mix and Long-term Energy Security:**
   - An increase in renewable energy in the energy mix enhances long-term energy security.
   - Positive interaction
8. **Renewable Energy in Energy Mix and Environmental Impact:**
   - Greater renewable energy use reduces environmental impact.
   - Negative interaction
9. **Environmental Impact and Land Needed for Energy Production:**
   - Higher environmental impact increases the land needed for energy production.
   - Positive interaction
10. **Land Needed for Energy Production and Imported Energy:**
    - More land needed for energy production reduces reliance on imported energy. (Negative interaction)
11. **Imported Energy and Long-term Energy Security:**
    - Increased imported energy decreases long-term energy security.
    - Negative interaction
12. **Environmental Impact and Negative Social Impact:**
    - Higher environmental impact leads to greater negative social impact.
    - Positive interaction
13. **Negative Social Impact and Social Acceptance of Building Energy Plants:**
    - Greater negative social impact reduces social acceptance of building energy plants.
    - Negative interaction

True/False Rules:

1. **If Short-term Energy Security increases, then Vulnerability of Energy Supply decreases (True).**
    - This rule reflects the balancing nature of energy security, where higher security reduces vulnerability.
2. **If Vulnerability of Energy Supply increases, then Energy Shortage increases (True).**
    - Greater vulnerability directly leads to a higher chance of energy shortages.
3. **If Energy Shortage increases, then Energy Cost increases (True).**
    - Shortages typically drive-up costs due to supply-demand imbalances.
4. **If Energy Cost increases, then Energy Consumption decreases (True).**
    - Higher costs lead to reduced consumption as users seek to cut expenses.
5. **If Energy Consumption increases, then Environmental Impact increases (True).**
    - More consumption results in higher environmental impact due to resource use and emissions.
6. **If Environmental Impact increases, then Long-term Energy Security decreases (True).**
    - Negative environmental impacts undermine long-term security through resource depletion and damage.
7. **If Renewable Energy in Energy Mix increases, then Long-term Energy Security increases (True).**
    - More renewables enhance long-term security by diversifying energy sources and reducing dependency on imports.
8. **If Renewable Energy in Energy Mix increases, then Environmental Impact decreases (True).**
    - Renewables generally have a lower environmental impact compared to fossil fuels.
9. **If Environmental Impact increases, then Land Needed for Energy Production increases (True).**
    - Higher impact leads to greater land requirements for mitigation and production.
10. **If Land Needed for Energy Production increases, then Imported Energy decreases (True).**

- More land for production reduces the need for energy imports.

11. **If Imported Energy increases, then Long-term Energy Security decreases (True).**
    - Higher imports reduce energy security by increasing dependency on external sources.
12. **If Environmental Impact increases, then Negative Social Impact increases (True).**
    - Greater environmental degradation leads to increased social discontent and health issues.
13. **If Negative Social Impact increases, then Social Acceptance of Building Energy Plants decreases (True).**
    - Higher social impact reduces community support for new energy infrastructure projects.

5.2.4 Overall CLD and SFD comprising of all three CLD's

The overall CLD is a combination of the 3 individual CLD breakdowns shown in Figures (14-16). These breakdowns make it easier for the readers to understand the causal relationship between the indicators from the different dimensional points of view. Figure 17 is the combination of all 3 individual CLDs to form the final CLD. In the SFD built in this study, there are 2 assigned stocks, energy production to reserve ratio, and environmental impact. Imported energy, short-term ES, land needed for energy production, and negative social impact are the flows (see Figure 18). The additional variables added are the unemployment rate, energy intensity, percentage of vulnerability, percentage of renewable energy, initial GDP, and percentage input.

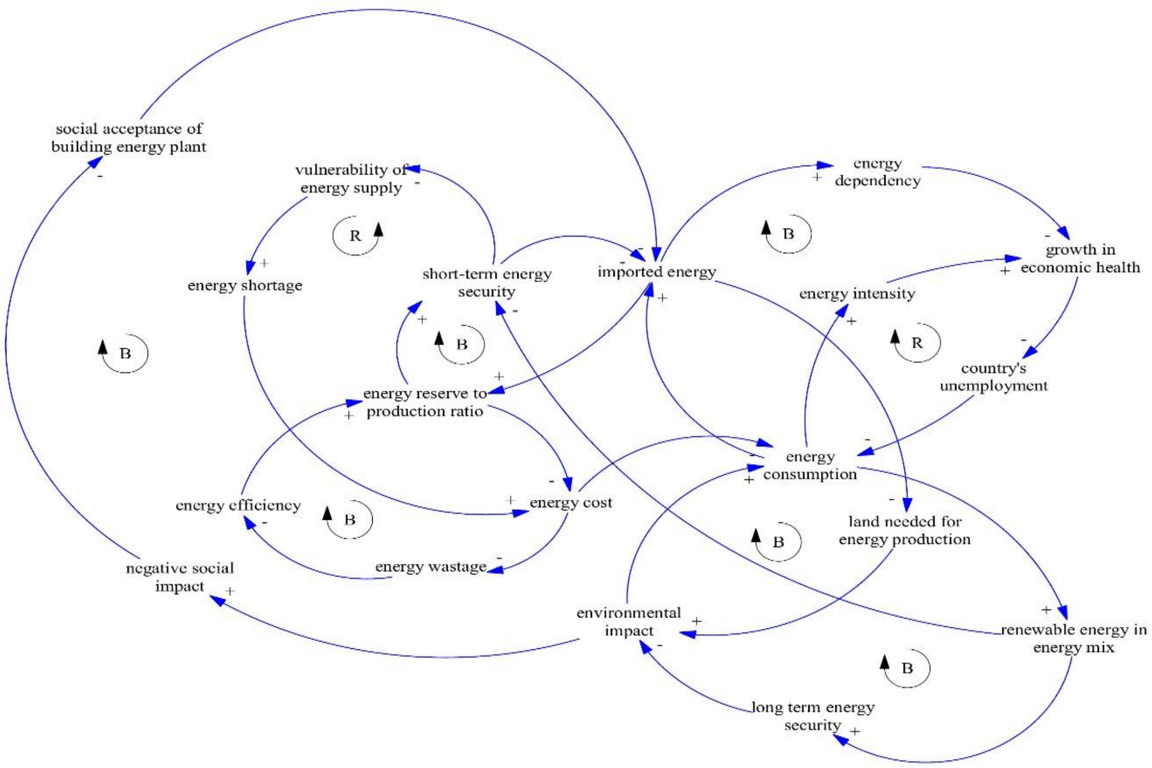


Figure 17:Combination of CLD’s 1,2 and 3 to create overall CLD

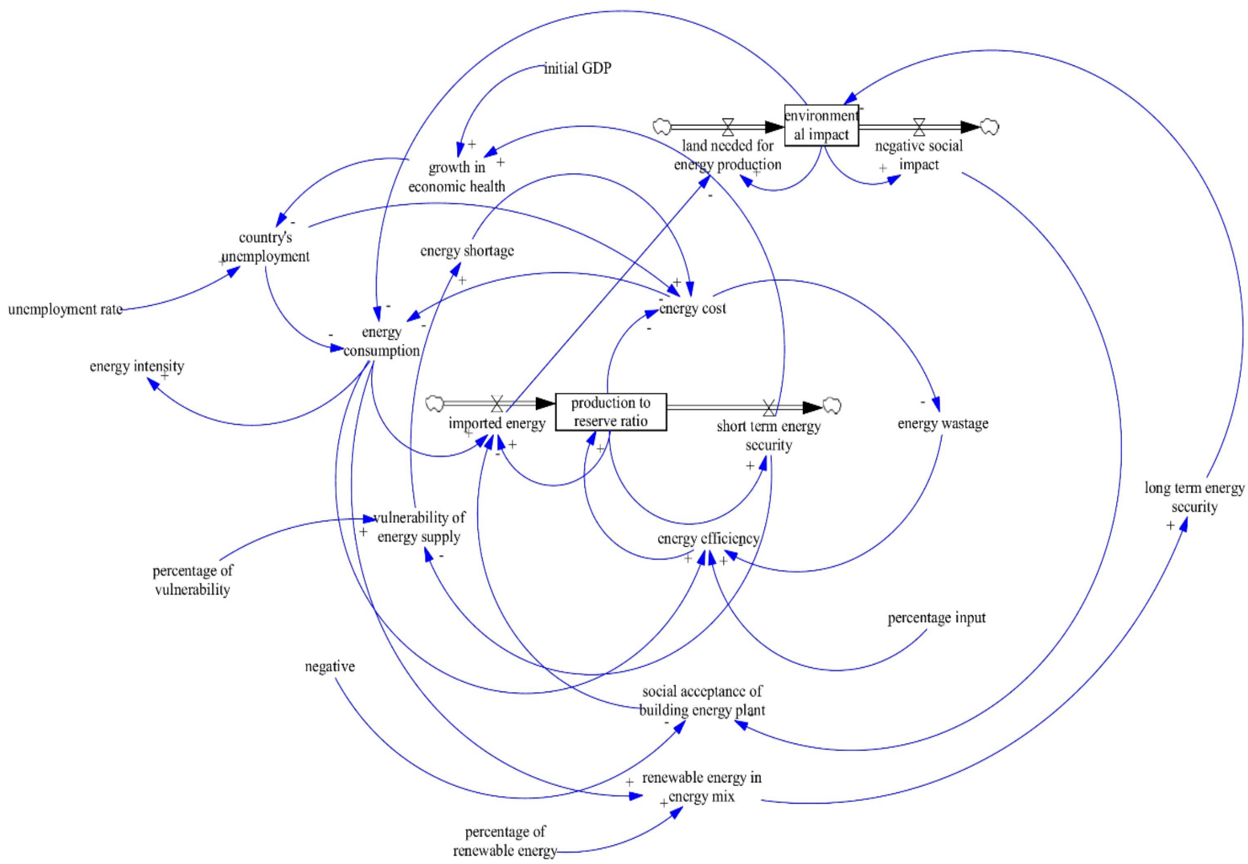


Figure 18:CLD converted to SFD after assigning stocks and flows to the respective indicators as shown in this figure.

Below are the equations for the stocks and flows in the SFD, along with the additional variables:

Stocks:

1. **Energy Production to Reserve Ratio (EPRR)**

   $$EPRR_{t+1} = EPRR_t + (\text{Imported Energy} - \text{Energy Consumption}) \times \Delta t$$

2. **Environmental Impact (EI)**

   $$EI_{t+1} = EI_t + (\text{Negative Social Impact} + \text{Land Needed for Energy Production} - \text{Renewable Energy in Energy Mix}) \times \Delta t$$

Flows:

1. **Imported Energy (IE)**
   - IE=f(Energy Consumption, Energy Cost)
   - This flow is influenced by energy consumption and the cost of energy.
2. **Short-term Energy Security (STES)**
   - STES=f (Vulnerability of Energy Supply, Energy Shortage)
   - This flow depends on the vulnerability of the energy supply and any energy shortages.
3. **Land Needed for Energy Production (LNEP)**
   - LNEP=f (Renewable Energy in Energy Mix, Environmental Impact)
   - This flow is determined by the proportion of renewable energy in the energy mix and the associated environmental impact.
4. **Negative Social Impact (NSI)**

- NSI=f (Social Acceptance of Building Energy Plant,
  Land Needed for Energy Production)
- This flow is influenced by the social acceptance of building energy plants and the land required for energy production.

Additional Variables:

1. **Unemployment Rate (UR)**
   - UR=f (Growth in Economic Health, Energy Cost)
   - The unemployment rate is affected by the overall economic health and the cost of energy.
2. **Energy Intensity (EI)**
   - EI=Energy Consumption/ GDP
   - Energy intensity is the ratio of energy consumption to GDP.
3. **Percentage of Vulnerability (PV)**
   - PV=f (Vulnerability of Energy Supply, Energy Shortage)
   - These variable measures how vulnerable the energy supply is to shortages.
4. **Percentage of Renewable Energy (PRE)**
   - PRE=Renewable energy in energy mix / Total energy mix
   - This variable calculates the proportion of renewable energy in the total energy mix.
5. **Initial GDP (IGDP)**
   - IGDP=GDP0
   - Initial GDP is the starting GDP value for the model.
6. **Percentage Input (PI)**
   - PI=f (Social Acceptance of Building Energy Plant,
     Land Needed for Energy Production)

  - This variable reflects the percentage input required based on social acceptance and land needs.

True/False Rules:

1. **Imported Energy:**
   - True if energy consumption exceeds domestic production.
   - False if domestic production meets or exceeds energy consumption.
2. **Short-term Energy Security:**
   - True if there is no immediate threat to the energy supply.
   - False if there is an energy shortage or high vulnerability.
3. **Land Needed for Energy Production:**
   - True if renewable energy projects are being expanded.
   - False if there are no new renewable energy projects.
4. **Negative Social Impact:**
   - True if the community is opposed to new energy plants.
   - False if there is broad social acceptance for new energy projects.
5. **Unemployment Rate:**
   - True if economic growth is insufficient to reduce unemployment.
   - False if economic health is improving and unemployment is decreasing.
6. **Energy Intensity:**
   - True if energy consumption per unit of GDP is increasing.
   - False if energy efficiency improvements are reducing energy intensity.
7. **Percentage of Vulnerability:**
   - True if the energy supply is highly susceptible to disruptions.
   - False if the energy supply is stable and secure.

8. **Percentage of Renewable Energy:**

    - True if the share of renewable energy in the energy mix is increasing.
    - False if the share of renewable energy is stagnant or decreasing.

5.3 The Study of the Impact of Renewable Energy in the Short and Long-Term Energy Security of Malaysia

5.3.1 Simulated Scenario, Results and Discussion

The scenario is designed in a way to imitate any future crisis or abundance of any certain variable in the SFD or in other words any of the dimensional indicator. This allows cautiousness from the present to safeguard the future. The scenario designed is based on the 11th Malaysia plan of RE penetration target of 20% capacity (ELEVENTH MALAYSIA PLAN 2016-2020 ANCHORING G ROWTH ON PEOPLE, n.d.) and the government declaration documented by the energy commission in their energy handbook 2019 (Energy Commission, 2019). The simulation of the SFD is based on the increase of the share of RE to 20% in the energy mix. The increase of RE indirectly affects other variables, by referring to the SFD, RE is affected by energy consumption. Energy consumption is affected by the environmental impact, energy cost, and unemployment rate. There are four variables (environmental impact, energy cost, unemployment rate, and renewable energy) used as an input to ensure that the simulation data is accurate. Figure 19 shows the input and output variables that were focused on in this scenario.

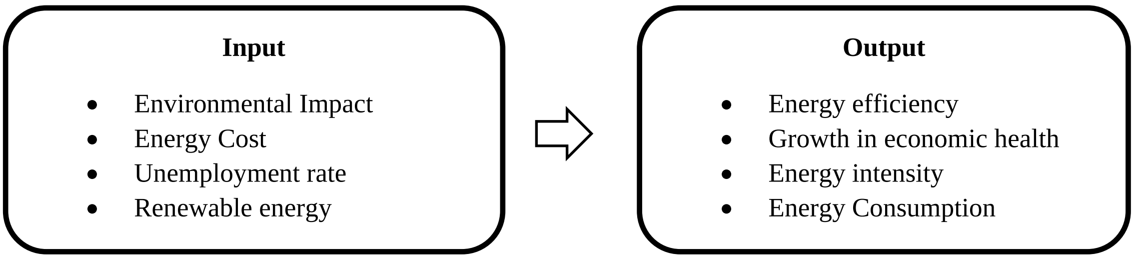


Figure 19: Inputs and Outputs for the RE scenario

Data from Table 18 is based on the year 2015, which shows the percentage of each variable used as the input into SFD. These input values are generated from secondary quantitative data collected from energy statistics of Malaysia (Statistics, 2017b) (Energy Commission, 2015). The input variables that are selected and values given as inputs will result in a graphical representation of the outputs after the simulation process in Vensim.

Table 18: Input Variables on percentage for RE scenario

Input (2015)	***Value (%)***
Country's unemployment rate	3.1
Environmental impact	1
Energy cost	31.23
Renewable energy	**20**

In this section, Figures (20-23) are the graphs generated by Vensim that show the result of the simulation for the next 5 years for each of the outputs from 2015-2020 as mentioned in Figure 19.

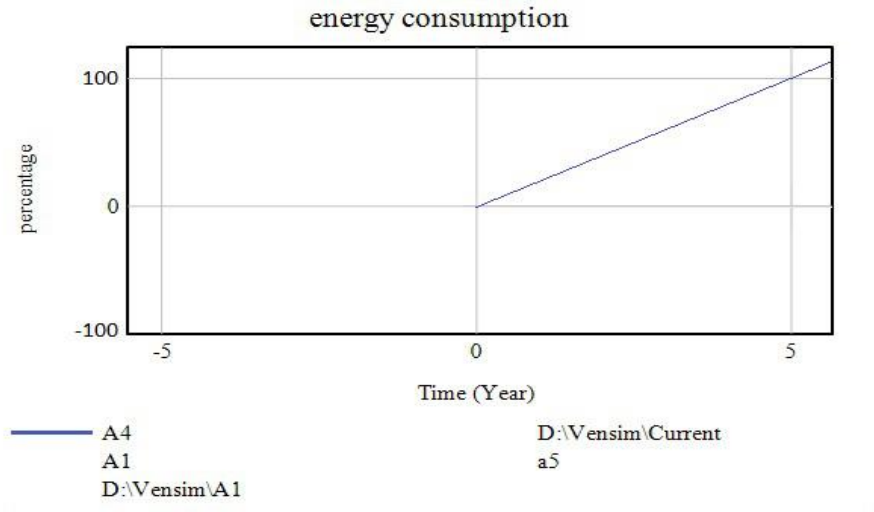


Figure 20: Energy consumption prediction for renewable energy scenario

As illustrated in Figure 20, energy consumption shows an increasing trend over the simulated period. This trend can be attributed to the direct relationship between the increase in renewable energy (RE) in the energy mix and overall energy consumption. The addition of RE capacity typically leads to higher energy availability, which can spur increased consumption across various sectors. However, without stringent regulations to monitor and curb energy wastage, the increased availability could inadvertently lead to inefficiencies and higher consumption.

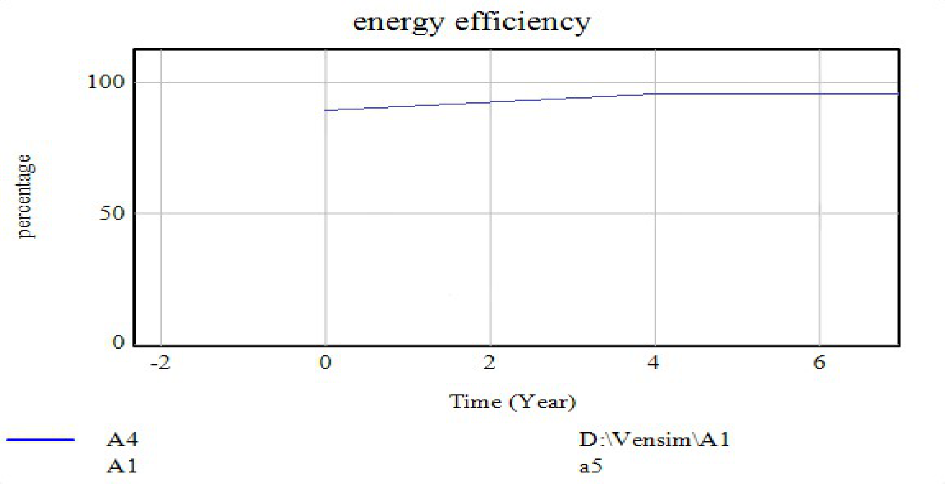


Figure 21:Energy efficiency prediction for renewable energy scenario

Figure 21 shows a positive trend in energy efficiency, which aligns with expectations. Increased RE integration usually improves energy efficiency by reducing the reliance on less efficient, conventional fossil fuels. Improved energy efficiency signifies less energy is wasted, contributing to reduced energy imports and lower carbon emissions, which is crucial for enhancing environmental sustainability. This improvement reflects the benefits of transitioning to cleaner energy sources in terms of both economic and environmental performance.

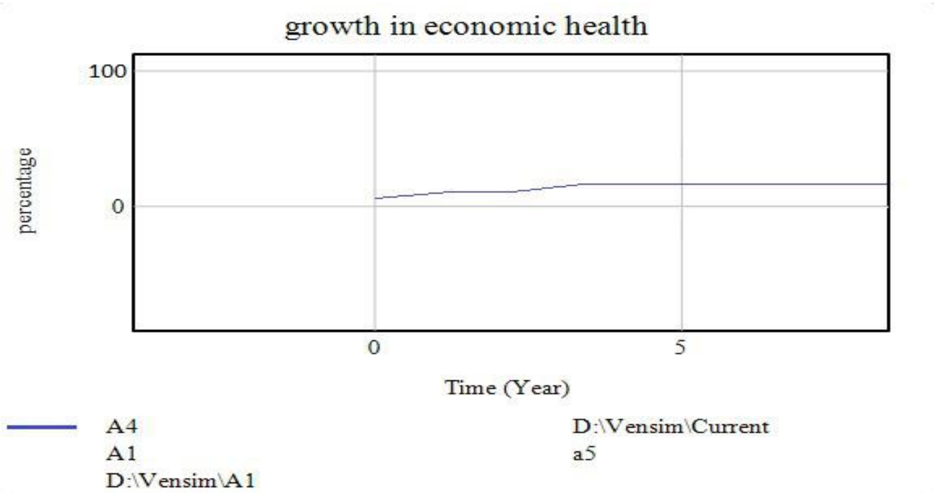


Figure 22: Growth in economic health prediction for renewable energy scenario

The growth in economic health, as seen in Figure 22, exhibits a slight upward trend. This can be linked to the indirect benefits of increased RE, such as job creation in the renewable sector and reduced energy costs over time. The positive economic impact is also supported by the interconnected relationship between energy consumption, economic activities, and unemployment rates. As energy consumption increases, it drives economic activities, which in turn supports economic growth.

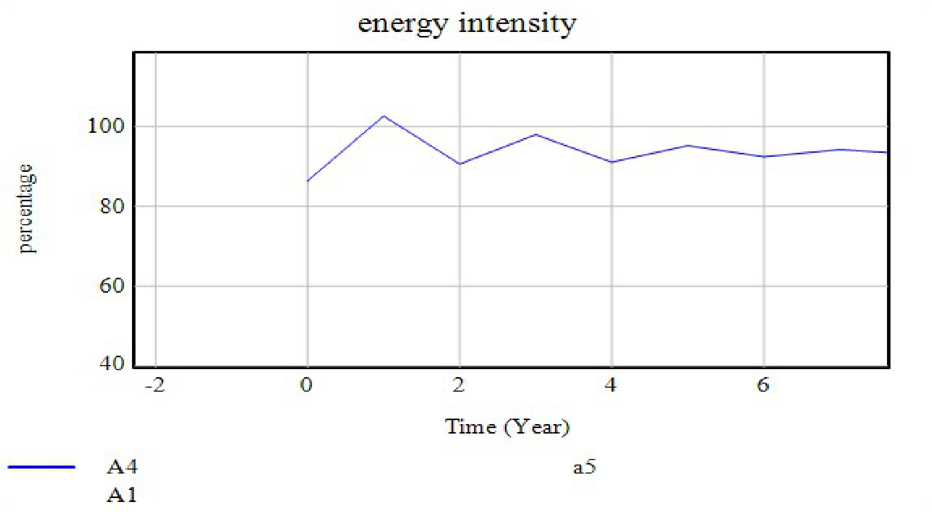


Figure 23: Energy intensity prediction for renewable energy scenario

Energy intensity, depicted in Figure 23, remains relatively stable throughout the simulation period. This stability suggests that while energy consumption increases, the economy is becoming more efficient in using energy, maintaining a balance between energy use and economic output. This indicates that the transition to RE is not only enhancing energy efficiency but also supporting sustainable economic growth without significant increases in energy intensity.

Growth in economic health reacted positively to the increase in RE in the energy mix. The relation of RE in the energy mix will increase the imported energy and energy dependency due to the decrease in short-term ES, thus causing the decrease in economic health. The link of energy cost-energy consumption, environmental impact- energy consumption and country's unemployment- energy consumption has shown to have increased the energy consumption which indirectly increases the growth in economic health. The increase from energy consumption is far higher in weightage compared to the RE link hence leading to an overall increase in growth in economic health as shown in Figure 9. Energy efficiency and growth in economic health both have been set a limit of maximum percentage, this is to ensure that the value obtained is realistic. Energy intensity has remained the same. This would be beneficial as the increase in renewable energy in the energy mix will have a great impact on the economy. This study hence contributed a depth value in comprehending the current policies stands in terms of RE for Malaysia and where it will be positioned in the next 5 years if it will be fulfilling the national set goals.

Implementation of the policies successfully can be improved in few ways to ensure long-term ES for Malaysia.

Enhancing Energy Efficiency Technologies:

- To minimize environmental impact and promote the adoption of alternative fuels, Malaysia should focus on advancing energy-efficient technologies. Policies like the 'Green Technology Application for Developing Low Carbon Cities' (GTALCC) can be pivotal in achieving this goal by promoting low carbon and zero energy buildings.

Fuel Diversification:

- Although Malaysia has a history of fuel diversification policies, their implementation has often fallen short. A more robust, data-driven approach, using System Dynamics (SD) modeling, can help predict the performance of these policies and ensure they meet future energy demands effectively.

Increasing R&D Funding:

- Investment in R&D for new RE technologies and energy-efficient solutions should be scaled up. This will foster innovation and improve energy intensity by reducing consumption. The government should ensure that funding is adequately monitored to achieve the desired outcomes.

Establishing a Comprehensive RE Policy:

- A standalone policy for RE, such as the Renewable Energy Transition Roadmap 2035 (RETR), should be detailed with clear targets and strategies. Integrating this roadmap into the broader 12th Malaysia Plan (2021-2025) will provide a cohesive framework for achieving RE and ES goals.

5.3.2 Conclusive Remarks on the Scenario

In conclusion, ES in Malaysia can be achieved through increased integration of RE in the energy mix. The country's prior goal of reaching 20% RE by 2025 which is now 31% by 2025 in the NETR, while ambitious, faces challenges given the current adoption rate. Simulation results suggest that achieving this target will improve energy efficiency, economic health, and environmental sustainability by reducing emissions and enhancing overall energy efficiency.

The current RE policy initiated by energy regulatory bodies is guiding Malaysia in the right direction, but implementation needs strengthening to meet the 2025 target. Prioritizing RE development is crucial to keep pace with global technological advancements and reduce future dependency on technology imports. A suggested approach for future RE policies is to use a 'dimensional indicator-based framework,' which helps prioritize dimensions and set realistic, achievable targets. This study advocates for stricter measures and regulations to ensure effective implementation of existing RE policies, which could significantly benefit socio-economic, environmental sustainability, and energy availability dimensions.

Future research should explore additional ES scenarios, such as energy reserve to production ratio and energy shortage, using system dynamics simulation to better understand Malaysia's current and future ES. Expanding the range of indicators and creating new causal links between existing ones can further enhance efforts to achieve long-term ES for Malaysia in a sustainable manner. The results provide a comprehensive outlook on ES, guiding necessary amendments and appropriate actions for improvement.

5.4 Quantifying the Impact of Hypothetical Energy Shortage Scenario

Energy crises can take several forms, with energy shortages being one of the most severe. These shortages often arise in countries heavily dependent on non-renewable energy sources and lacking significant alternative energy contributions in their fuel mix. For Malaysia, an exporter of fossil fuels, this presents a particular challenge. While fossil fuel exports contribute to economic development, long-term environmental sustainability is often neglected. An energy crisis in Malaysia could significantly reduce energy consumption across industrial, transport, and commercial sectors, hampering economic growth and reducing consumer confidence in national energy policies.

The key question is whether Malaysia has a contingency plan to address potential energy shortages in the near future. This section explores the possible impacts of an energy shortage on Malaysia's energy security (ES) by predicting the outcomes for ES variables directly or indirectly linked to energy shortages using system dynamics (SD) modeling. The model simulates from 2015 to 0 to predict future scenarios, comparing these predictions with actual energy reports and reviews post-2020 to understand the potential performance over the next five years. This analysis includes Malaysia's energy data, ES dimensions, and indicators, detailing the data collection methodology through surveys and SD modeling of the dimensions and indicators. A simulated energy shortage scenario of 30% is presented, with results discussed and conclusions drawn.

Malaysia's fossil fuels, such as crude oil and natural gas, are mainly exported to countries like Australia, India, and Thailand. Lower-grade coals are imported from countries like Australia, Indonesia, and South Africa. This trade dynamic has resulted in a net economic gain, with significant growth in refined petroleum product exports. Malaysia's energy security depends heavily on exporting premium fossil fuels and importing lower-grade ones for refining. To maintain its status as a net exporter, Malaysia has increased its refining capacity. The country's LNG reserves, among the largest globally, have significantly contributed to the GDP in recent years, suggesting short-term stability.

However, with economic growth and development, energy demand is projected to increase significantly. The World Energy Market Observatory (WEMO) report forecasts a 4.8% increase in overall energy usage by 2030, with final energy requirements tripling by the same year. Whether this is sustainable for Malaysia's long-term energy security is debatable. ES, defined by the International Energy Agency (IEA) as the uninterrupted availability of energy at an affordable price, hinges on dimensions such as availability, affordability, accessibility, and acceptability. For Malaysia, the current priority is socio-economic stability and energy availability, ensuring affordable energy supply while balancing trade-offs with natural resources. Environmental sustainability is given lower priority.

The Energy Commission of Malaysia addresses these concerns in its report "Shaping the future of Malaysia’s energy sector," outlining strategies for renewable energy (RE) implementation and maximizing energy efficiency. The government's focus is on protecting consumer interests in electricity and gas markets, increasing RE penetration, and reducing carbon footprints, as discussed in policy papers like "Malaysia's future energy landscape" and "Renewable Energy Transition Roadmap (RETR 2035)." The following methodology section will detail the methods used to collect data on ES dimensions and indicators and the application of system dynamics to model these data.

5.4.1 Simulated Scenario, Results and Discussion

This is a hypothetical scenario created where there is an increase in energy shortage by 30% compared to the current value in year 2015. The value of 30% assigned to energy shortage is indirectly related to the 20% RE penetration target of the government as documented by energy commission (Energy Commission, 2019).This input of 30% increase in energy shortage alongside the most relevant input variables are tabulated in Table 21 while Figure shows the causal relation between energy shortage and renewable energy in the energy mix. The causal relation indicates that an increase in RE in the energy mix leads to a decrease in short term ES indicated by '-' sign on the link. Additionally, a '-' sign from short term ES to vulnerability of energy supply shows that there is an increase in vulnerability of energy supply because a '-' sign in CLD indicates a change in the opposite direction from the initial (System Analysis I Compendium for Students, 2009b). An increase in vulnerability of energy supply in turn leads to an increase in energy shortage indicated by '+' sign in the link in . This relationship between RE in energy mix and energy shortage via the two other variables mentioned is the basis of the selection in this scenario.

It is a clear indication of the possibility of an increase in energy shortage in the future when there is a need to increase the RE in energy mix to anticipate the increasing demand and shortage. The target is to increase RE in the energy mix to 20% by 2025 (Energy Commission, 2019). While this percentage may change in the Renewable Energy Transition Roadmap (RETR) 2035, which will have its outcome documented in the 12th Malaysia plan (2021-2025) (Energy Commission, 2019). The energy shortage has been assigned a value of 30% increase assuming a change in RE in energy mix, will lead to a proportional change in energy shortage. An additional 10% have been assigned to energy shortage compared to RE in energy mix because it is clear from the energy reports that Malaysian government is going forward for higher percentage of RE in energy mix in the new 12th Malaysia plan and in the NETR it is set at 31% installed capacity by 2025, hence leading to higher energy shortage based on the causal relation.

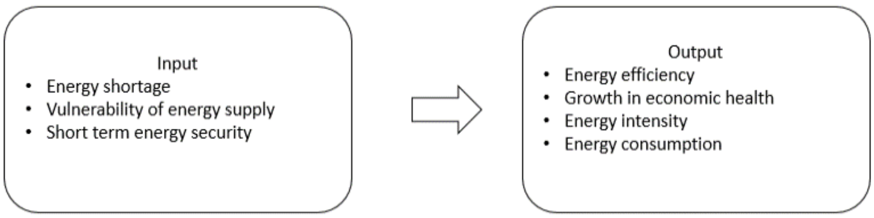


Fig. 24. The inputs and output variables measured using SD model.

Table 19: Input Values of Indicators

Input (2015)	***Value (%)***
Energy shortage	30
Vulnerability of energy supply	5
Short term energy security	80

The input values are taken from the quantitative data provided in energy statistics of Malaysia (Statistics, 2017a). Figures 25-28 show the results of the SFD simulation in Figure 18. These graphical representations depict how the 4 output variables change over a period of 5 years from 2015 to current year 2020. The input variables for the SFD and their values are extracted from Table 19.

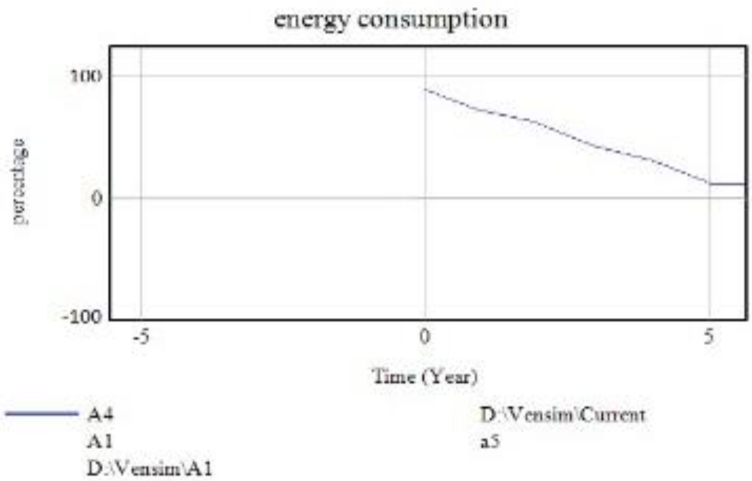


Figure 25:Energy consumption for energy shortage scenario

The simulation results in figure 25 show a significant decrease in energy consumption, nearly 50%, which aligns with the expected outcome of a reduced energy supply due to the energy shortage. This decrease indicates that sectors dependent on energy, such as industrial, transport, and commercial, would be severely impacted, potentially leading to reduced operational capacity and economic output.

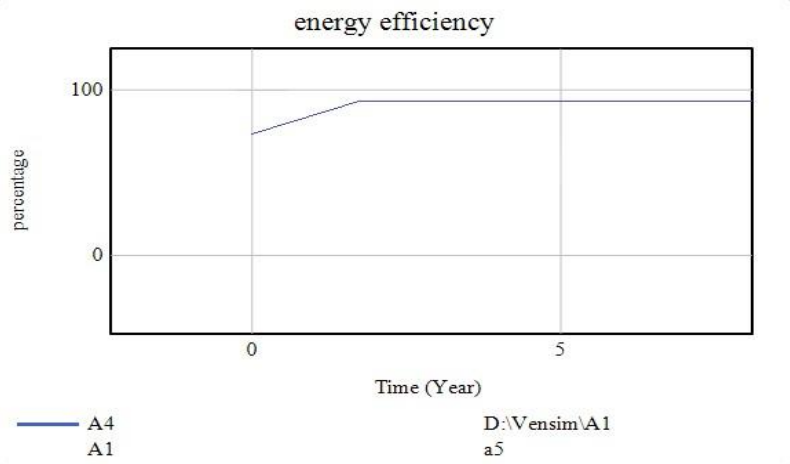


Figure 26:Energy efficiency for energy shortage scenario

Energy efficiency demonstrates a slight increase initially and then stabilizes over the five-year period. This marginal increase in efficiency is likely due to the reduction in energy wastage as higher energy costs force more efficient energy use. However, the overall increase is not substantial, suggesting that while efficiency improvements are a positive outcome, they do not fully mitigate the negative impacts of reduced energy availability.

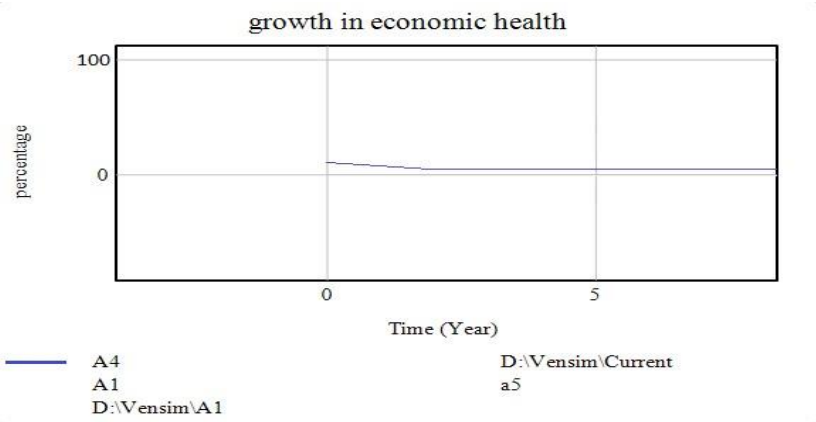


Figure 27: Results for growth in economic health

The growth in economic health shows minimal change over the period, indicating that the energy shortage does not significantly affect the economy's growth rate. This could imply that the economic system has some resilience to short-term energy supply shocks, but it does not reflect potential long-term effects if the shortage persists.

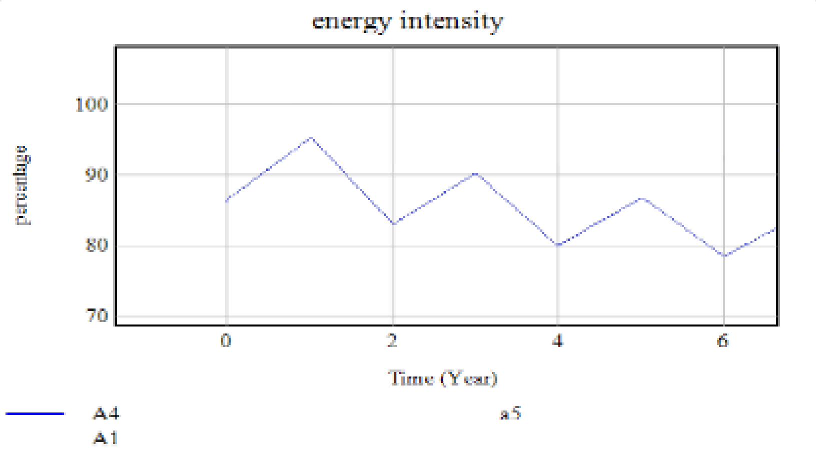


Figure 28: Results for energy intensity

Energy intensity exhibits significant fluctuations over the simulation period, decreasing overall. The reduction in energy intensity indicates that less energy is being used per unit of economic output, which can be seen as a positive indicator of improved energy efficiency. However, the volatility in energy intensity suggests instability in energy usage patterns, which can be problematic for consistent economic planning and development.

Critical Analysis

The scenario analysis indicates that an increase in energy shortage has profound implications for Malaysia's energy consumption and efficiency. The decrease in energy consumption is directly related to the increased energy shortage, leading to reduced energy availability for various sectors. This decrease in consumption can negatively impact the industrial and commercial sectors, leading to reduced economic activity and potentially increased unemployment.

Energy efficiency improves slightly due to reduced energy wastage, a silver lining in an otherwise challenging situation. However, the minimal increase in efficiency highlights the need for more robust policies and technologies to enhance energy efficiency significantly. The slight decrease in economic growth suggests some resilience, but the long-term impact of sustained energy shortages could be more severe. The fluctuations in energy intensity underscore the instability and potential inefficiencies in energy usage, necessitating measures to stabilize and optimize energy consumption.

5.4.2 Conclusive Remarks on the Scenario

There are certain recommendations that are made from the analysis of the results of this scenario.

Diversification of Energy Sources: Increasing the share of renewable energy in the energy mix can reduce dependence on non-renewable sources and enhance energy security.

Enhancing Energy Efficiency: Implementing advanced technologies and policies to improve energy efficiency across all sectors can mitigate the negative impacts of energy shortages.

Economic Resilience: Developing strategies to buffer the economy against energy supply shocks, such as energy storage solutions and flexible energy policies.

Long-term Planning: Establishing comprehensive long-term energy plans that account for potential shortages and include contingency measures to ensure continuous energy supply and economic stability.

In conclusion, the simulation results highlight the critical need for proactive measures to enhance Malaysia's energy security, emphasizing the importance of diversification, efficiency, resilience, and long-term planning. These findings provide a roadmap for policymakers to address potential energy shortages and ensure sustainable energy and economic future for Malaysia.

5.5 Energy Reserve to Production Ratio Scenario

In this scenario, the impact of a decreasing reserve-to-production ratio for different fuel types has been analyzed to derive policy implications and recommendations for addressing this challenge in the future. In this section it examines a hypothetical scenario where the energy reserve-to-production ratio is reduced by half to understand its potential effects on Malaysia's ES. This scenario assumes that energy reserves will eventually deplete unless alternative energy sources, particularly renewables, are integrated into the energy mix for total primary energy supply (TPES) and power generation more rapidly.

Malaysia's existing reserves of oil, natural gas, and coal are crucial for its energy security. However, oil reserves are maturing, and production is declining steadily due to increased consumption driven by economic activities. Coal reserves and production are primarily concentrated in Sarawak, Sabah, and Selangor. To safeguard these natural resources, Malaysia introduced the national depletion policy in 1980, which set limits on crude oil production and gas consumption to extend the lifespan of these reserves.

The scenario highlights the importance of accelerating the inclusion of renewable energy sources to mitigate the depletion of fossil fuel reserves and ensure long-term energy security for Malaysia.

5.5.1 Simulated Scenario, Results, and Discussion

This is a hypothetical scenario created based on the assumptions that the dependency on energy imports and the usage of fossil fuel makes up over 90% of the energy mix in Malaysia. To avoid this scenario to come to reality there must be a consolidated policy on the prudent use of fossil fuels and adding alternative RE sources in the energy mix. It is of utmost importance to do so, as the reserves are not going to be everlasting and at some point, in time there would be added pressure on the reserve margins of the nation. This is not desirable from the R/P point of view which impairs the energy availability dimension of ES severely. This scenario investigates the aggression of reducing the energy reserve to production ratio (R/P). R/P ratio is a key indicator of the size of energy reserves in the country or in other words for how long the reserves will last. The value represents the number of years that current reserves would last if their rate of use did not change. It can be the R/P ratio for any kind or type of fuel e.g., coal, oil, gas, etc. The reduction of energy reserve to production ratio will greatly impact energy efficiency, energy cost, and energy wastage. The energy reserve to production ratio will be set to half of its initial value.

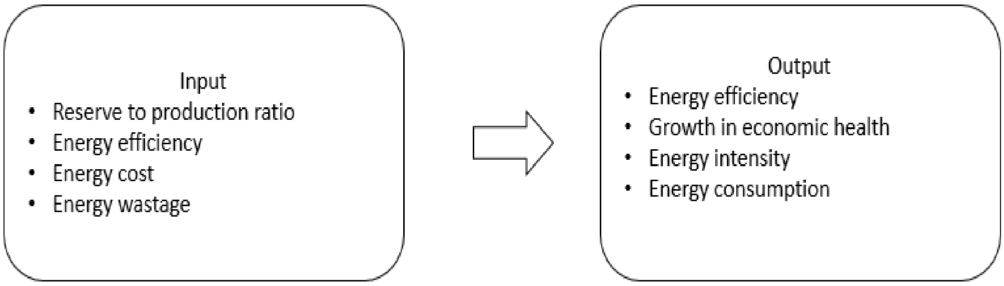


Figure 29: Input for the reserve to production scenario

Table 20: Percentage of input variable for the reserve to production ratio scenario

Input (2015)	***Value (%)***
Reserve to production ratio	600.9615
Energy efficiency	89.49
Energy cost	31.23
Energy wastage	10.51

Data from Table 20 is based on the year 2015, which will be given as input into the SFD.

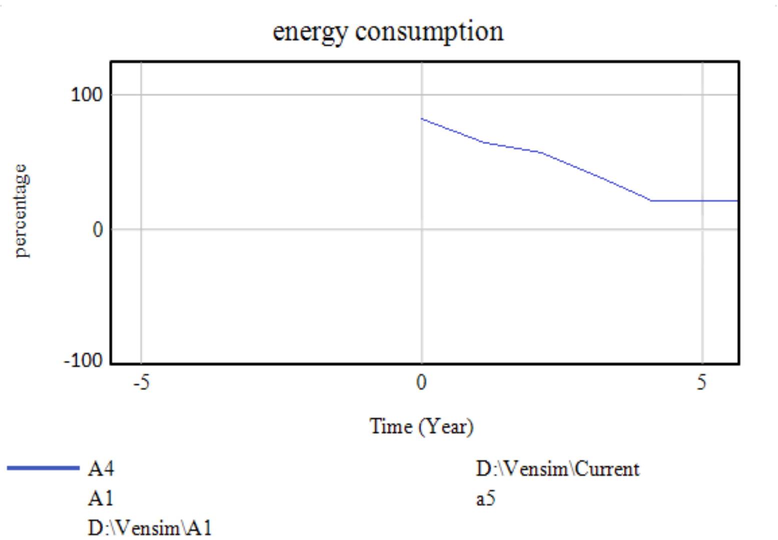


Figure 30: Energy consumption prediction for the reserve to production ratio

The reduction of the energy reserve to production ratio has caused energy consumption to decrease drastically. With decreasing reserves, the usage must be constricted to ensure the longevity of the existing reserves. This significant reduction in energy consumption highlights the direct impact of constrained energy reserves on overall energy use.

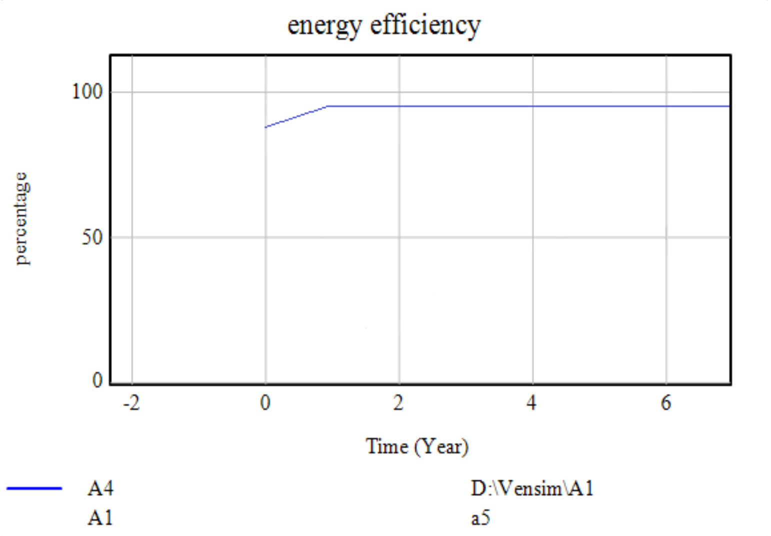


Figure 31: Energy efficiency prediction for the reserve to production ratio scenario

Energy efficiency increased rapidly to its maximum limit within a year. This rise is primarily driven by the substantial increase in energy costs due to the reduction of the reserve to production ratio. The higher energy cost discourages wastage, thereby forcing more efficient use of energy. However, this increase in efficiency is not due to technological advancements but rather a response to reduced availability, indicating careful use of limited energy resources.

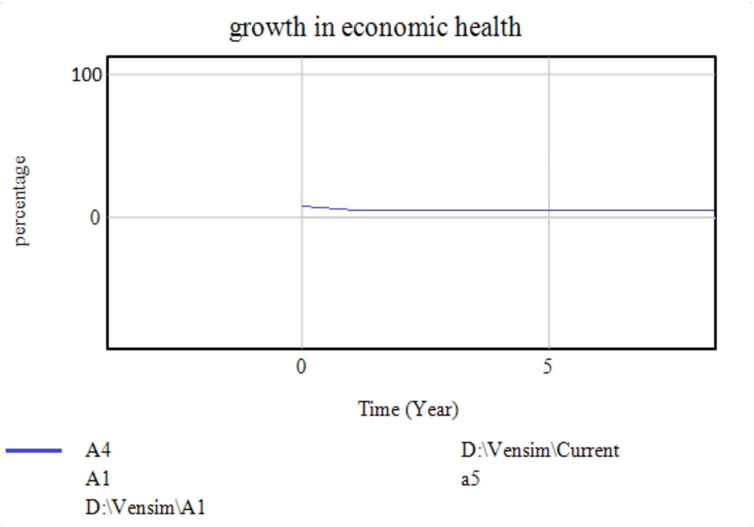


Figure 32: Growth in economic health prediction for the reserve to production ratio scenario

The growth in economic health is projected to decline to a low point of approximately 3%. This decline is a consequence of reduced energy consumption and increased energy costs. Lower energy consumption impairs industrial and commercial activities, leading to slower economic growth. Additionally, the increased dependency on imported energy further exacerbates economic vulnerability, as it makes the economy susceptible to external supply disruptions

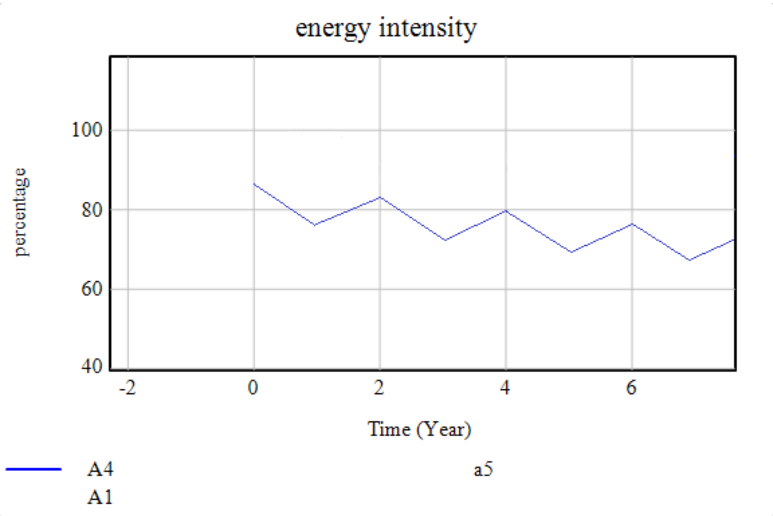


Figure 33: Energy intensity prediction for the reserve to production ratio scenario

Energy intensity has decreased from 88% in 2015 to around 70% in 2020. This reduction is indicative of a decrease in energy consumption relative to economic output. While a lower energy intensity can be a positive indicator, in this scenario, it primarily results from reduced energy availability rather than improved energy efficiency technologies.

Critical Analysis:

The scenario of reducing the energy reserve to production ratio by half reveals significant vulnerabilities in Malaysia's energy security. The immediate effect is a drastic decrease in energy consumption, necessary to prolong the lifespan of existing reserves. This reduction underscores Malaysia’s heavy reliance on finite fossil fuel reserves and the urgent need for conservation. A critical consequence of reduced consumption is a sharp increase in energy costs. As reserves deplete, extraction and processing become more expensive, reducing energy affordability and further constraining consumption. The simulation results show consumption plummeting to its minimum levels, highlighting the precarious balance between supply, demand, and affordability.

Energy efficiency appears to have improved, reaching its maximum limit within a year, but this is misleading. The increase is due to careful use of limited resources rather than technological advancements. Genuine efficiency gains require investments in new technologies and processes. Economic health is negatively impacted, with growth expected to hit a low of around 3%. Reduced energy availability hampers industrial and commercial operations, leading to increased unemployment and decreased consumer confidence. Energy intensity decreases, reflecting reduced economic activity rather than genuine efficiency improvements.

The overall impact highlights Malaysia's vulnerability due to heavy reliance on fossil fuels. Rising energy costs and adverse effects on economic health emphasize the need for a diversified and sustainable energy mix. Prioritizing renewable energy adoption and technological advancements in energy efficiency is crucial. Investing in renewable infrastructure and incentivizing energy-efficient technologies can reduce fossil fuel dependency and enhance long-term energy security. A comprehensive energy policy balancing economic growth with sustainability goals is essential to address these challenges and ensure a stable energy future for Malaysia.

5.5.2 Conclusive Remarks on the Scenario

The results of this study suggest that a decrease in the R/P ratio to half of its current value can have a drastic impact on energy consumption due to a decrease in reserve and energy intensity. Out of the 4 output variables or indicators that have been studied these two indicators will deteriorate the most while growth in economic health is not impaired to great extent, but it still shows a decline. The key policy implications that can be suggested from this research are.

1. **Policy on Prudent Use of Fossil Fuels** There must be a consolidated policy promoting the prudent use of fossil fuels and encouraging the integration of renewable energy sources into the energy mix. This policy should aim to balance the immediate energy needs with long-term sustainability goals.
2. **Increase Renewable Energy Adoption** Accelerating the adoption of renewable energy sources is crucial. This can help mitigate the impact of depleting fossil fuel reserves and ensure a more stable and sustainable energy supply. Policies and incentives should focus on increasing the share of renewables in the total primary energy supply (TPES) and power generation.
3. **Technological Advancements** Investments in energy-efficient technologies are essential. Encouraging the development and adoption of more efficient manufacturing processes, energy-saving vehicles, and household appliances can help reduce overall energy consumption and improve energy efficiency.
4. **Diversification of Energy Sources** Diversification of energy sources should be a priority to reduce dependency on a single type of fuel. This strategy can help buffer against the volatility of global energy markets and enhance energy security.
5. **Public Awareness and Engagement** Increasing public awareness and engagement on the importance of energy conservation and the benefits of renewable energy can foster a culture of sustainability. Programs aimed at educating consumers about energy-efficient practices and technologies should be promoted.
6. **Strengthening Energy Policies** Strengthening and implementing robust energy policies that address the vulnerabilities of Malaysia's energy supply is vital. These policies should include clear targets and strategies for reducing dependency on fossil fuels and increasing the resilience of the energy system.

By adopting these recommendations, Malaysia can better manage its energy resources, reduce its reliance on fossil fuels, and move towards a more sustainable and secure energy future.

5.6 Causal Loop Diagrams and Stock and Flow Diagrams Based on Stakeholder Interview and Critical Literature Review

The concept of the water, energy, and food (WEF) nexus, introduced at the World Economic Forum in 2008, highlights the interconnectedness of these sectors. Synergies occur when progress in one sector benefits another, while trade-offs occur when actions in one sector negatively impact another. Decisions in these sectors must be made carefully due to their interdependent effects. Fossil fuel burning is the primary cause of global air pollution, contributing to over 8 million deaths annually and producing significant greenhouse gases like carbon dioxide, which drive climate change. In 2019, about 84.3% of global energy came from fossil fuels, 11.4% from renewable sources, and 4.3% from nuclear energy (Ritchie & Roser, 2020).

Malaysia must prioritize energy diversification to reduce its dependency on fossil fuels. As the world moves toward sustainable development, Malaysia should increase awareness and implement measures to address energy security (ES) challenges by focusing on key ES dimensions. Identifying these dimensions and their indicators, and defining their relationships using System Dynamics software Vensim, is essential. As of 2020, Malaysia's renewable energy (RE) penetration in the energy mix is around 9%, with a target of 31% by 2025 (Energy Commission Malaysia, 2021a). RE is crucial for transitioning to a low-carbon economy, although its high initial costs can compromise energy efficiency.

In 2016, 73.2% of global greenhouse gas emissions were due to energy use, including electricity, heat, and transportation. The main barrier to RE technologies is capital cost, but this is decreasing with technological advances. This paper will provide an in-depth analysis of ES in Malaysia, specifically examining how RE can impact short-term and long-term ES.

5.6.1 The problem statement and objective of the scenario

Economic growth is vital for reducing poverty and enhancing life quality, and energy is central to this process, often described as the 'oxygen' of the economy. In 2019, Malaysia was Southeast Asia's second-largest oil and natural gas producer and the world's fifth-largest exporter of liquefied natural gas (LNG). The country's reliance on fossil fuels has been significant, with 90% of Peninsular Malaysia's electricity from fossil fuels between 1990 and 2016, leading to a decline in fossil fuel reserves and increased dependence on energy imports from countries like South Africa, Australia, and Indonesia.

This reliance on fossil fuels poses sustainability challenges, as the volatility of foreign fuel markets and the environmental impact of coal burning, which emits high levels of carbon dioxide, exacerbate global warming. With Malaysia's population growth rate at 1.1% annually, energy demand is increasing, further stressing the energy supply. Minimal research has quantified energy security (ES) in Malaysia using a system dynamics approach, highlighting the need for developing causal relationships between indicators of different ES dimensions.

This scenario aims to enhance the understanding of Malaysia's ES and the impact of renewable energy (RE) on both short-term and long-term ES. The main objectives of this section are to construct three causal loop diagrams for different ES dimensions identified through literature review and to develop two stock-flow diagrams (SFD) for scenarios analysing the impact of RE on Malaysia's ES. The goal is to provide a comprehensive view of Malaysia's ES and inform policies for a sustainable energy future.

Critical Analysis:

The dynamics illustrated in the CLD highlight the complex interactions between population growth, energy demand, supply, and cost, as well as the critical role of electricity tariffs in balancing supply and demand.

- **Population Growth:** Managing population growth is crucial as it directly influences energy demand and supply dynamics.
- **Energy Efficiency:** Investing in energy-efficient technologies can help manage demand and reduce the pressure on energy supply.
- **Electricity Tariffs:** Regulating electricity tariffs is essential to balance demand and supply, ensuring affordability while maintaining adequate supply levels.
- **Renewable Energy Integration:** Increasing the share of renewable energy in the mix can help stabilize energy costs and improve long-term energy security.

These insights emphasize the need for a comprehensive energy policy that addresses these interconnected factors, promoting sustainable energy use and ensuring long-term energy security for Malaysia.

5.6.2 Simulated Scenarios, Results and Discussion

5.6.2.1 CLD of Availability Dimension

In Figure 35, the CLD showcases the intricate dynamics between various factors influencing energy and electricity in Malaysia. The diagram includes reinforcing loops (R) and balancing loops (B) that depict how changes in one element can impact others over time.

- **Reinforcing Loop R1 (Population Growth)**
  - **Components:** Birth rate, Death rate, Population.
  - **Interactions:** An increase in the birth rate (+) boosts the population, while a higher death rate (-) reduces the population.
- **Balancing Loop B1 (Population Stabilization)**
  - **Components:** Population.
  - **Interactions:** As the population grows, resources become strained, potentially leading to higher death rates which balance the population growth.
- **Balancing Loop B2 (Energy Demand and Supply)**
  - **Components:** Population, Energy demand, Cost price of energy, Energy supply, Electricity production, Population with access to electricity (%).
  - **Interactions:** An increase in population (+) leads to higher energy demand (+). This demand increases the cost price of energy (+), reducing energy supply (-), and consequently decreasing electricity production (-). This reduction lowers the percentage of the population with access to electricity (-).
- **Reinforcing Loop R2 (Energy Production and Consumption)**
  - **Components:** Energy demand, Energy production, Energy consumption.

  - **Interactions:** Higher energy demand (+) stimulates higher energy production (+), which in turn increases energy consumption (+).

- **Balancing Loop B3 (Electricity Supply and Demand)**
  - **Components:** Electricity production, Electricity consumption, Electricity demand, Electricity tariff, Electricity supply.
  - **Interactions:** Increased electricity production (+) boosts electricity consumption (+), raising electricity demand (+). Higher demand increases the electricity tariff (+), which eventually reduces electricity supply (-) and consequently decreases electricity production (-).
- **Reinforcing Loop R3 (Electricity Tariff Dynamics)**
  - **Components:** Electricity demand, Electricity tariff, Electricity supply.
  - **Interactions:** Higher electricity demand (+) increases the electricity tariff (+), which reduces electricity demand (-) and further impacts the supply and price dynamics.
- **Balancing Loop B4 (Electricity Tariff and Supply)**
  - **Components:** Electricity tariff, Electricity supply.
  - **Interactions:** A higher electricity tariff (+) reduces electricity supply (-), which then increases the tariff again (+) in a cyclical pattern.

True/False Rules and Assumptions

1. **Population Growth and Energy Demand**
   - **True:** An increase in population leads to higher energy demand.
   - **False:** Population growth does not affect energy demand.
2. **Energy Cost and Supply**
   - **True:** Higher energy costs reduce energy supply.
   - **False:** Energy costs have no impact on energy supply.
3. **Energy Production and Consumption**

- **True:** Increased energy production leads to higher energy consumption.
- **False:** Energy production does not influence energy consumption.

4. **Electricity Tariff and Demand**
   - **True:** Higher electricity tariffs reduce electricity demand.
   - **False:** Electricity tariffs do not affect demand.
5. **Electricity Production and Access**
   - **True:** Higher electricity production increases the population's access to electricity.
   - **False:** Electricity production has no impact on access to electricity.

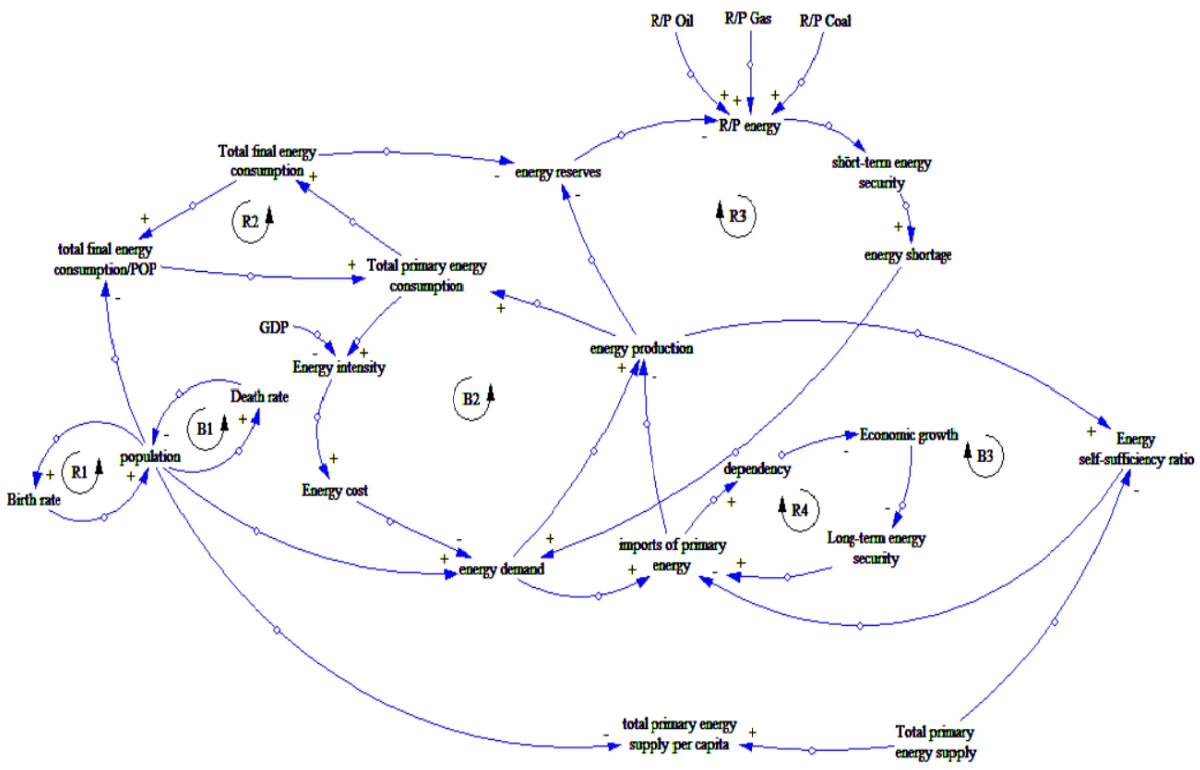


Figure 34:CLD of Availability of Energy in this study

5.6.2.2 Causal Loop Diagram of Affordability Dimension

In Figure 35, the CLD illustrates the intricate dynamics between factors influencing energy and electricity in Malaysia. The diagram includes reinforcing loops (R) and balancing loops (B) that depict how changes in one element can impact others over time.

- **Reinforcing Loop R1 (Population Growth)**
  - **Components:** Birth rate, Death rate, Population.
  - **Interactions:** An increase in the birth rate (+) boosts the population, while a higher death rate (-) reduces the population.
- **Balancing Loop B1 (Population Stabilization)**
  - **Components:** Population.
  - **Interactions:** As the population grows, resources become strained, potentially leading to higher death rates which balance the population growth.
- **Balancing Loop B2 (Energy Demand and Supply)**
  - **Components:** Population, Energy demand, Cost price of energy, Energy supply, Electricity production, Population with access to electricity (%).
  - **Interactions:** An increase in population (+) leads to higher energy demand (+). This demand increases the cost price of energy (+), reducing energy supply (-), and consequently decreasing electricity production (-). This reduction lowers the percentage of the population with access to electricity (-).
- **Reinforcing Loop R2 (Energy Production and Consumption)**
  - **Components:** Energy demand, Energy production, Energy consumption.
  - **Interactions:** Higher energy demand (+) stimulates higher energy production (+), which in turn increases energy consumption (+).
- **Balancing Loop B3 (Electricity Supply and Demand)**
  - **Components:** Electricity production, Electricity consumption, Electricity demand, Electricity tariff, Electricity supply.

  - **Interactions:** Increased electricity production (+) boosts electricity consumption (+), raising electricity demand (+). Higher demand increases the electricity tariff (+), which eventually reduces electricity supply (-) and consequently decreases electricity production (-).

- **Reinforcing Loop R3 (Electricity Tariff Dynamics)**
  - **Components:** Electricity demand, Electricity tariff, Electricity supply.
  - **Interactions:** Higher electricity demand (+) increases the electricity tariff (+), which reduces electricity demand (-) and further impacts the supply and price dynamics.

- **Balancing Loop B4 (Electricity Tariff and Supply)**
  - **Components:** Electricity tariff, Electricity supply.
  - **Interactions:** A higher electricity tariff (+) reduces electricity supply (-), which then increases the tariff again (+) in a cyclical pattern.

True/False Rules and Assumptions

1. **Population Growth and Energy Demand**
   - **True:** An increase in population leads to higher energy demand.
   - **False:** Population growth does not affect energy demand.
2. **Energy Cost and Supply**
   - **True:** Higher energy costs reduce energy supply.
   - **False:** Energy costs have no impact on energy supply.
3. **Energy Production and Consumption**
   - **True:** Increased energy production leads to higher energy consumption.
   - **False:** Energy production does not influence energy consumption.
4. **Electricity Tariff and Demand**
   - **True:** Higher electricity tariffs reduce electricity demand.
   - **False:** Electricity tariffs do not affect demand.

5. **Electricity Production and Access**
    - **True:** Higher electricity production increases the population's access to electricity.
    - **False:** Electricity production has no impact on access to electricity.

Critical Analysis:

The dynamics illustrated in the CLD highlight the complex interactions between population growth, energy demand, supply, and cost, as well as the critical role of electricity tariffs in balancing supply and demand.

- **Population Growth:** Managing population growth is crucial as it directly influences energy demand and supply dynamics.
- **Energy Efficiency:** Investing in energy-efficient technologies can help manage demand and reduce the pressure on energy supply.
- **Electricity Tariffs:** Regulating electricity tariffs is essential to balance demand and supply, ensuring affordability while maintaining adequate supply levels.
- **Renewable Energy Integration:** Increasing the share of renewable energy in the mix can help stabilize energy costs and improve long-term energy security.

These insights emphasize the need for a comprehensive energy policy that addresses these interconnected factors, promoting sustainable energy use and ensuring long-term energy security for Malaysia.

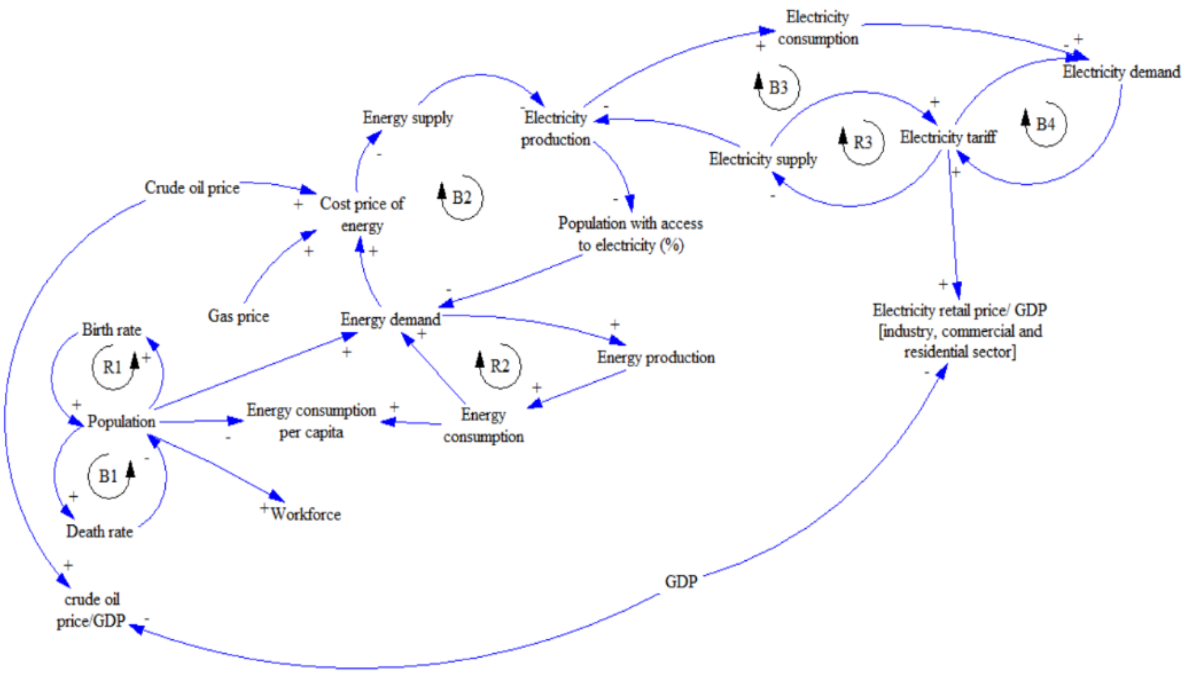


Figure 35:CLD of Affordability of Energy in this study

5.6.2.3 Causal Loop Diagram of Environmental Sustainability Dimension

In Figure 36, the CLD illustrates the relationships between population dynamics, renewable energy production, CO2 emissions, and their impacts on environmental sustainability and economic health in Malaysia. The diagram includes reinforcing loops (R) and balancing loops (B) that depict how changes in one element can impact others over time.

- **Reinforcing Loop R1 (Population Growth)**
  - **Components:** Birth rate, Death rate, Population.
  - **Interactions:** An increase in the birth rate (+) boosts the population, while a higher death rate (-) reduces the population.
- **Balancing Loop B1 (Population Stabilization)**
  - **Components:** Population.
  - **Interactions:** As the population grows, resources become strained, potentially leading to higher death rates which balance the population growth.

- **Reinforcing Loop R2 (Renewable Energy Development)**
  - **Components:** Renewable energy production, Non-carbon share/TPES, Environmental impact, Renewable Energy Capacity Development.
  - **Interactions:** Increased renewable energy production (+) raises the non-carbon share of total primary energy supply (TPES) (+), which reduces environmental impact (-). Reduced environmental impact encourages further development of renewable energy capacity (+), thus boosting renewable energy production (+).
- **Reinforcing Loop R3 (Climate Change and Sustainability)**
  - **Components:** CO2 emission, CO2 emission/TPEC, Climate change, Sustainable development.
  - **Interactions:** Higher CO2 emissions (+) increase the CO2 emission/total primary energy consumed (TPEC) ratio (+). This raises the likelihood of climate change (+), negatively impacting sustainable development (-). Poor sustainable development leads to higher CO2 emissions (+), creating a reinforcing cycle.
- **Reinforcing Loop R4 (Economic Growth and CO2 Emissions)**
  - **Components:** CO2 emission, CO2 emission/GDP, Economic Growth, Poverty, Life quality.
  - **Interactions:** Increased CO2 emissions (+) raise the CO2 emission/GDP ratio (+), which hampers economic growth (-). Lower economic growth increases poverty (+), reducing the quality of life (-). A lower quality of life can lead to higher CO2 emissions (+), continuing the cycle.

True/False Rules

1. **Renewable Energy Production and Environmental Impact**
   - **True:** Increased renewable energy production reduces environmental impact.
   - **False:** Renewable energy production has no impact on environmental impact.

2. **CO2 Emission and Climate Change**
   - **True:** Higher CO2 emissions increase the likelihood of climate change.
   - **False:** CO2 emissions do not affect climate change.
3. **Economic Growth and CO2 Emissions**
   - **True:** Higher CO2 emissions reduce economic growth.
   - **False:** CO2 emissions do not influence economic growth.
4. **Quality of Life and CO2 Emissions**
   - **True:** Lower quality of life leads to higher CO2 emissions.
   - **False:** Quality of life does not affect CO2 emissions.

Critical Analysis:

The dynamics illustrated in the CLD highlight the interconnected relationships between population growth, renewable energy production, CO2 emissions, and their broader impacts on environmental sustainability and economic health.

- **Renewable Energy Development:** Prioritizing renewable energy development is crucial to reducing environmental impact and enhancing long-term energy security. Policies should focus on increasing the share of renewable energy in the energy mix.
- **CO2 Emissions Management:** Managing CO2 emissions is essential to mitigate climate change and its negative effects on sustainable development. Implementing strict emission controls and promoting clean energy technologies can help.
- **Economic Growth and Environmental Sustainability:** Balancing economic growth with environmental sustainability is vital. Policies should aim to decouple economic growth from CO2 emissions, encouraging green technologies and sustainable practices.
- **Quality of Life:** Improving the quality of life is linked to environmental sustainability. Enhancing living conditions through sustainable development practices can reduce CO2 emissions and improve overall well-being.

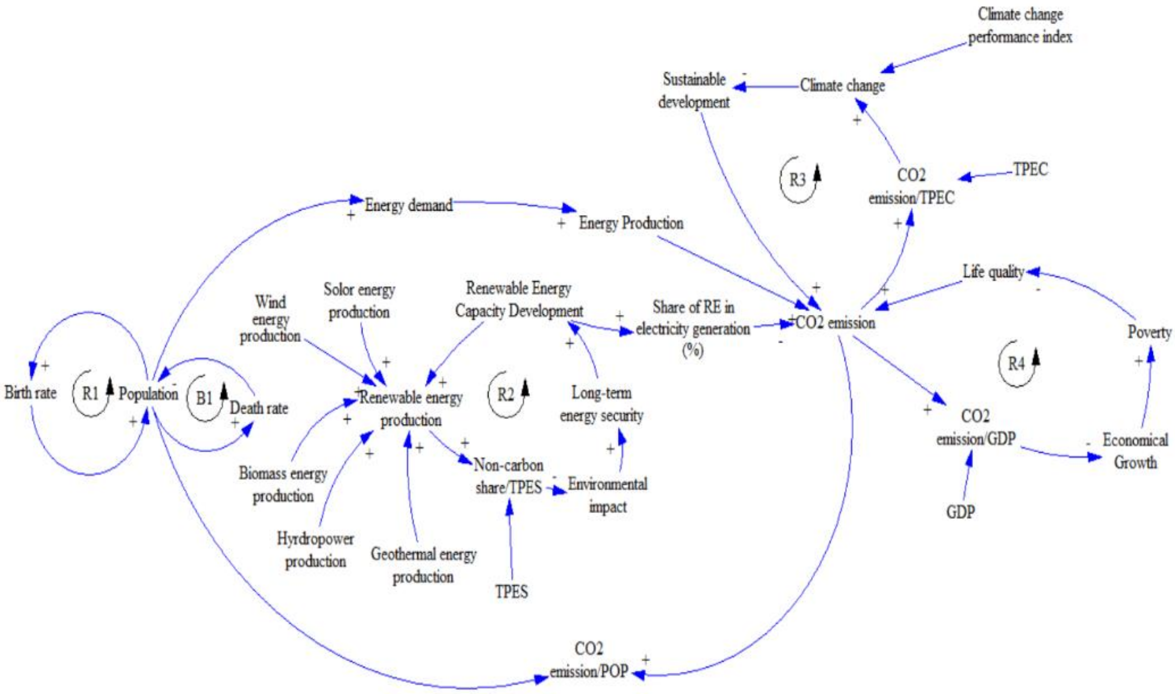


Figure 36:CLD of Environmental Sustainability in this study

5.6.2.4 Stock and Flow Diagrams

The SFD in Figure 37 discusses the impact amount of imported energy directly on the short-term ES. As of 2018, Malaysia has been relying upon coal where coal makes up 43% of electricity generation while RE sources excluding hydropower contributed only 1% of the electricity generation in 2018 (Kathirgugan, 2021). It is believed that coal power plants have an efficiency of around 44%. This directly translates to the rest of the 56% is lost to the environment. Therefore, the only advantage of using coal as an energy source is its affordability. However, the Malaysian government has been putting efforts to opt for RE sources for electricity generation in the aim to lower its dependency on coal. This can be seen in the goal to have 31% of RE in the capacity mix by 2025 (Energy Commission Malaysia, 2021b). Therefore, this would lead to a decrease in energy imports. Therefore, a prediction is done for energy production to reserve ratio as well as the short-term ES for the next 5 years if the dependency on imported energy decreases.

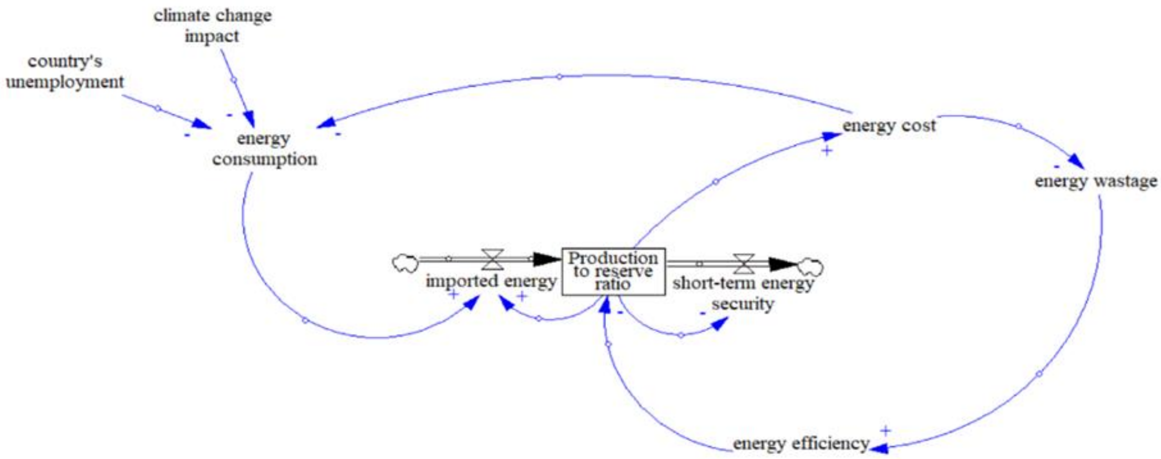


Figure 37: SFD for scenario 1

Stocks:

- Production to Reserve Ratio

Flows:

- Imported Energy
- Short-term Energy Security

Auxiliary Variables:

- Energy Consumption
- Energy Cost
- Energy Efficiency
- Energy Wastage
- Country's Unemployment
- Climate Change Impact

Components Relationships:

- **Energy Consumption:** Affects and is affected by Country's Unemployment and Climate Change Impact.
- **Energy Cost:** Affected by Energy Consumption and impacts Energy Efficiency and Energy Wastage.
- **Energy Efficiency:** Affected by Energy Cost and influences Energy Wastage.

- **Energy Wastage:** Affected by Energy Efficiency and influences Energy Consumption.
- **Production to Reserve Ratio:** Influenced by Imported Energy and Short-term Energy Security.

Mathematical Equations:

Energy Consumption

$EC = ECost \times (1 - EE) + CU + CCI$

Energy Cost

ECost=Base Cost/ Production to reserve ratio (PRR)

Energy Efficiency

$EE = 1/(1 + ECost)$

Energy Wastage

$EW = 1 - EE$

Country's Unemployment

CU= (Base Unemployment X EC)/100

Climate Change Impact:

CCI= (Base impact X EC)/100

Production to Reserve Ratio:

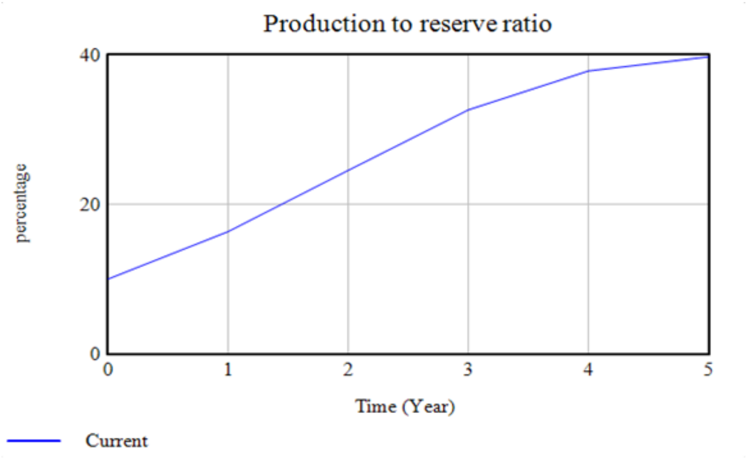
$PRR(t) = PRR(t-1) + (IE - SES) \times \Delta t$

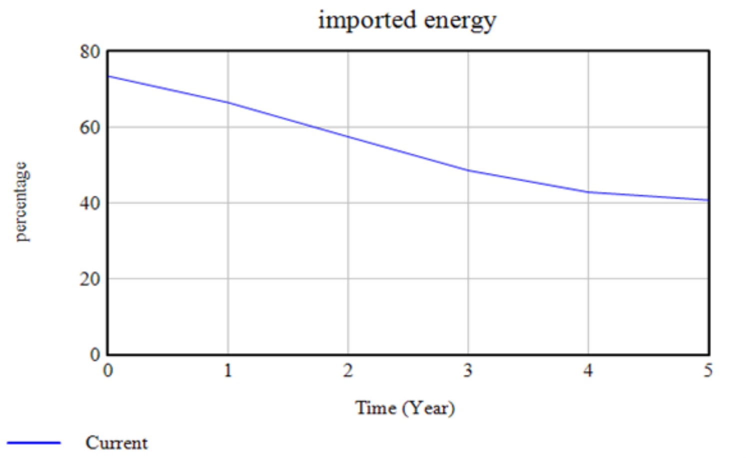
Imported Energy:

$IE = f(ECost, EE)$

Short-term Energy Security:

$SES = f(ECost, EE)$





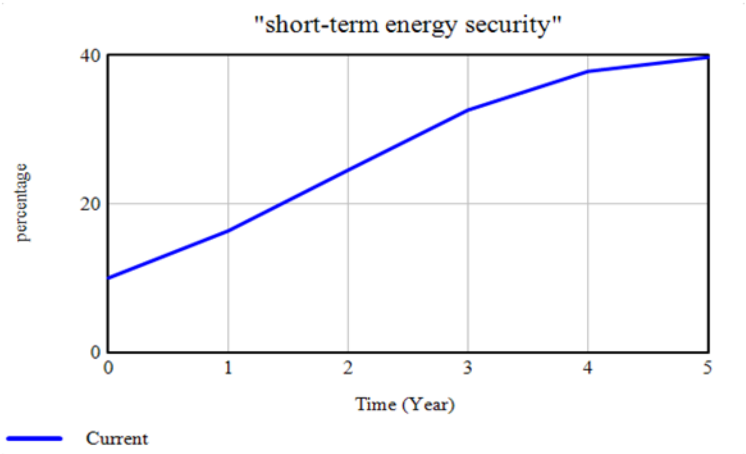


Figure 38: Results of Scenario 1

Production to Reserve Ratio

- **Observation:** The production to reserve ratio shows a steady increase from 0% to nearly 40% over the 5-year period.

- **Interpretation:** This increase suggests that the rate of production relative to the reserves is growing, indicating either an increase in production or a decrease in the reserves.
- **Implications:** An increasing production to reserve ratio might be unsustainable in the long term, as it implies that reserves are being depleted faster than they are being replenished. This could lead to energy insecurity if alternative energy sources are not developed.

Imported Energy

- **Observation:** Imported energy shows a decreasing trend, dropping from around 70% to below 50% over the 5-year period.
- **Interpretation:** The decrease in imported energy could imply a reduction in dependency on foreign energy sources, potentially due to increased domestic production or a shift towards renewable energy sources.
- **Implications:** While reduced dependency on imported energy can improve energy security and reduce vulnerability to external market fluctuations, it also raises questions about the sustainability of increased domestic production and its environmental impact.

Short-term Energy Security

- **Observation:** Short-term energy security increases steadily from 0% to about 40% over the 5-year period.
- **Interpretation:** The improvement in short-term energy security suggests better management and stability of energy supply in the short term, possibly due to increased domestic production and reduced import dependency.
- **Implications:** Enhanced short-term energy security is beneficial for meeting immediate energy demands and ensuring stable supply. However, it is crucial to ensure that this short-term gain does not compromise long-term sustainability.

Critical Analysis

The trends depicted in the graphs indicate a complex interplay between production, imports, and ES . The increasing production to reserve ratio and improved short-term energy security suggest that Malaysia is focusing on boosting domestic energy production and reducing import dependency. While these measures can enhance immediate energy security, they also pose significant risks:

1. **Sustainability Concerns:** The increasing production to reserve ratio indicates that reserves are being depleted faster, which is unsustainable in the long term. There is a need for careful management of reserves and accelerated development of renewable energy sources to ensure long-term energy security.

2. **Environmental Impact:** Reducing dependency on imported energy might lead to increased exploitation of domestic fossil fuel resources, which can have adverse environmental consequences. Transitioning to cleaner energy sources is essential to mitigate these impacts.

3. **Economic Stability:** While reducing import dependency can enhance economic stability by shielding the economy from external shocks, it is crucial to balance this with the need to maintain reserve levels and avoid over-reliance on finite domestic resources.

Figure 39 discusses the impact of the share of RE in the energy mix towards the long-term ES. The report on Peninsular Malaysia Generation Development Plan 2020 stated that from 2015 to 2020, the growth of energy demand is increasing annually by 2.3% (Energy Commission Malaysia, 2021b). However, the Covid-19 pandemic outbreak has significantly brought the overall energy demand lower. Nevertheless, a week before the implementation of the Movement Control Order (MCO), on 10 March 2020 a new peak demand was obtained. Due to the pandemic, it is predicted that the energy demand would temporarily decrease but from 2023 onwards, the growth of energy demand is predicted to be normalised as the country focuses on economic recovery. This energy demand is due to the growing population as well as the increase in energy consumption.

Following the government's plan of achieving 31% of RE in the energy mix by 2025, a prediction is made towards the energy production over reserve ratio and the long-term ES. As can be seen in Figure 40, an increase in RE in the energy mix results in an exponential increase in the energy production over reserve ratio and the long-term ES. A similar scenario-based analysis will facilitate the energy policymakers to design policies based on more data and evidence. Therefore, it would be feasible for energy policymakers to come up with policies that focus on improved and sustainable developments of the ES of Malaysia.

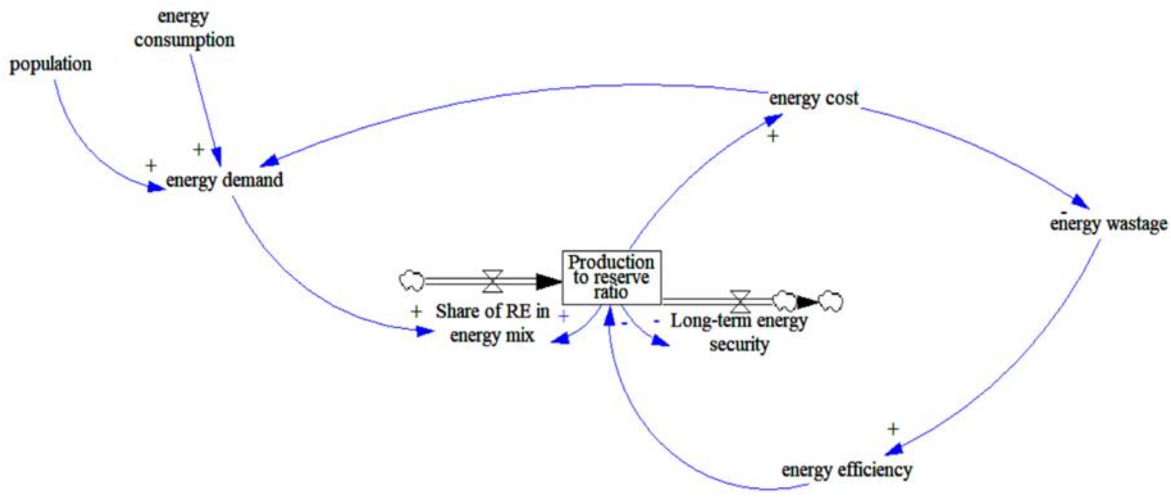


Figure 39: SFD for scenario 2

Stocks:

- Production to reserve ratio
- Long-term energy security

Flows:

- Share of RE in energy mix
- Energy consumption
- Energy cost
- Energy efficiency
- Energy wastage

Auxiliary Variables:

- Population
- Energy demand

Mathematical Equations:

Stock: Production to Reserve Ratio

- **Inflow:**
  - Share of RE in energy mix
  - Equation: Inflow= Production to reserve ratio× Share of RE in energy mix
- **Outflow:**
  - Energy consumption
  - Equation: Outflow= Production to reserve ratio× Energy consumption
- **Net Flow:**
  - Equation: Net Flow=Inflow−Outflow
- **Stock Update:**
  - Equation: Production to reserve ratio $_{t+1}$= Production to reserve ratio $_{t}$+ Net Flow

Stock: Long-term Energy Security

- **Inflow:**
  - Energy efficiency
  - Equation: Inflow= Long Term ES X Energy Efficiency
- **Outflow:**
  - Energy cost
  - Equation: Outflow= Long Term ES X Energy Cost
- **Net Flow:**
  - Equation: Net Flow= Inflow – Outflow
- **Stock Update:**
  - Equation: Long Term ES $_{t+1}$ = Long Term ES $_{t}$ + Net Flow

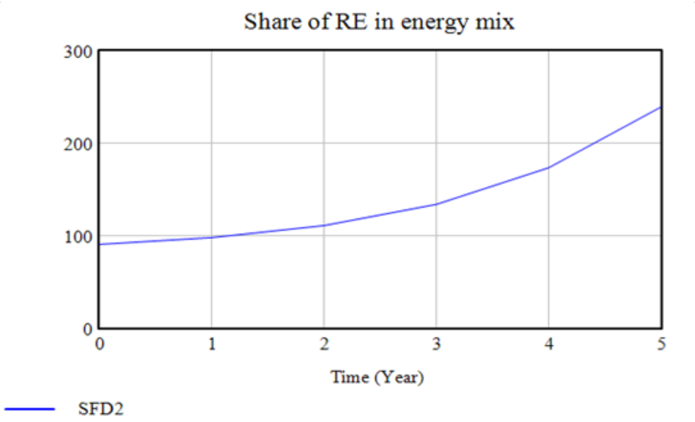
Auxiliary Variables

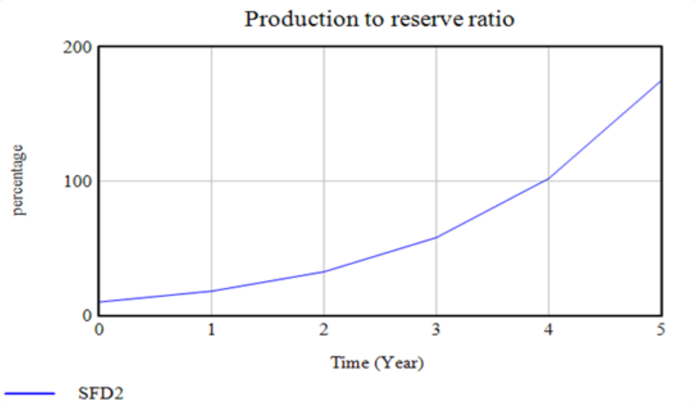
- **Population:**
  - Equation: Population= Initial Population X (1+ Growth Rate)^{t}
- **Energy Demand:**
  - Equation: Energy Demand=Population× Per Capita Energy Consumption

Relationships and Flows

- **Energy Consumption:**
  - Equation: Energy Consumption= Energy Demand×(1−Energy Efficiency)
- **Energy Cost:**
  - Equation: Energy Cost= Energy Price per Unit× Energy Consumption
- **Energy Wastage:**
  - Equation: Energy Wastage= Energy Consumption× (1−Energy Efficiency)
- **Energy Efficiency:**
  - Equation: Energy Efficiency= Base Energy Efficiency+ Improvement Factor

The results of the scenario simulation are presented in Figure 40.





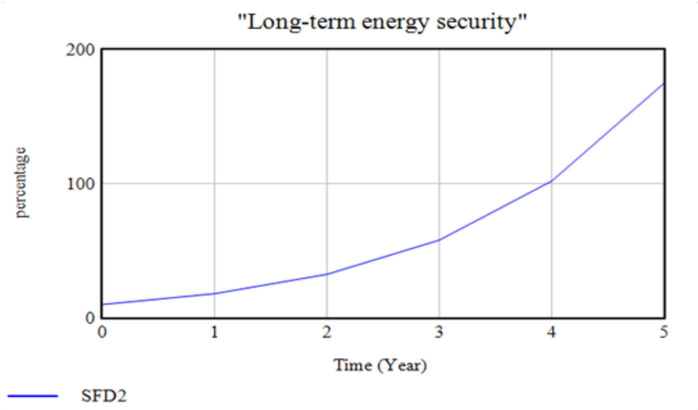


Figure 40: Results of scenario 2

The simulation of the system dynamics model with the new input variables reveals significant insights into the impact of changes in the share of renewable energy (RE) in the energy mix on the production-to-reserve ratio and long-term energy security.

Share of RE in Energy Mix: The first graph illustrates a steady and significant increase in the share of RE in the energy mix over the five-year period. This indicates that increasing the proportion of renewable energy sources, such as solar, wind, and hydropower, contributes to a higher share of RE in the overall energy mix. The upward trend suggests that policies promoting renewable energy adoption are effective and can potentially reduce dependence on fossil fuels, thus contributing positively to the sustainability and diversification of energy sources.

Production to Reserve Ratio: The second graph shows a positive trajectory in the production-to-reserve ratio, which indicates a growing capacity to produce energy relative to the reserves available. This increase suggests that as the share of RE in the energy mix grows, the pressure on fossil fuel reserves decreases, leading to a more balanced and sustainable energy production system. This is a crucial factor for ensuring long-term energy security, as it reduces the risk of depleting non-renewable energy resources and enhances the stability of energy supply.

Long-term Energy Security: The third graph displays a clear and consistent improvement in long-term energy security. The increase in long-term energy security can be attributed to the higher share of RE in the energy mix and the improved production-to-reserve ratio. As renewable energy sources are integrated more extensively into the energy system, the reliance on finite fossil fuels diminishes, thereby enhancing the resilience and sustainability of the energy infrastructure.

Critical Analysis of the scenario:

The results of this scenario underscore the importance of integrating renewable energy into the national energy mix. The positive trends in the share of RE, production-to-reserve ratio, and long-term energy security highlight the effectiveness of policies aimed at increasing renewable energy adoption. However, several critical considerations must be addressed to ensure sustained progress:

1. **Policy Implementation:** While the simulation results are promising, the actual implementation of policies supporting renewable energy adoption must be robust and consistent. This includes providing incentives for renewable energy projects, ensuring grid stability, and investing in technology and infrastructure to support the integration of renewable sources.
2. **Economic Implications:** The transition to a higher share of renewable energy may involve significant initial costs. Policymakers must consider the economic impact of this transition, including potential fluctuations in energy prices and the need for financial support mechanisms to ensure affordability and accessibility for consumers.
3. **Technological Advancements:** Continuous advancements in renewable energy technologies are crucial for maintaining the positive trends observed in the simulation. Investments in research and development are necessary to improve the efficiency, reliability, and cost-effectiveness of renewable energy systems.
4. **Stakeholder Engagement:** Effective stakeholder engagement is essential for the successful implementation of renewable energy policies. This includes collaboration with industry players, consumers, and communities to foster acceptance and support for renewable energy initiatives.
5. **Environmental Considerations:** While renewable energy sources significantly reduce greenhouse gas emissions, it is essential to consider the environmental impact of renewable energy projects, such as land use and resource consumption. Sustainable practices must be adopted to minimize any adverse effects on the environment.

5.6.3 Conclusive Remarks on the Scenario

In this section of the thesis, three CLD’s were created to analyse the relationships between the indicators of three different ES dimensions. Two scenarios were designed to evaluate the impact of increasing the share of RE in TPES and power generation on Malaysia's short-term and long-term ES. The findings suggest that achieving the government’s goal of 31% RE in the energy mix could significantly enhance both short-term and long-term ES. This shift could reduce reliance on coal and energy imports by investing in RE, which, despite higher initial costs compared to fossil fuels, offers a cleaner and more sustainable energy source with minimal carbon emissions. While intermittency issues of RE pose a challenge, advancements in energy storage technology can mitigate these concerns. It is crucial for Malaysia to commit to these RE targets and continue investing in sustainable energy solutions to improve national ES and achieve long-term sustainability goals.

6 A Quantitative Assessment of Energy Security Using a 5-Dimensional Framework

6.1 Introduction

In this chapter, the various ES dimensions have been studied in-depth by engaging stakeholders from Malaysia, Singapore, and the Philippines to understand the criticality of the different dimensions towards paving a pathway for ES policies in Malaysia. Thematic analysis has been done from the emerging themes of semi-structured interviews with the stakeholders. These themes have been discussed thoroughly and their results are discussed in chapter 4 of the thesis.

6.2 Qualitative data collection results using Quirkos and dimension selection.

The total number of codes (136) generated for different themes from the SSI results for the dimensions is listed below in Table 21. The five dimensions (emerging themes 1-5) that have been selected to design the framework and the Malaysian ESI are from these 8 emerging themes developed in the QDA in this research. Please refer to chapter 4 appendix (section 4.6) for an overview of the dashboard of Quirkos that represents the way emerging themes are formed from the interview data.

Table 21: Emerging themes from qualitative data

	Emerging themes	***Number of codes***
1	Affordability of energy	19
2	Availability of energy	10
3	Technology	19
4	Accessibility	6
5	Environmental sustainability	16
6	Acceptability	9
7	Economic development	26
8	Political aspect	31
	Total	**136**

6.3 Indicator Mapping Process

The stakeholder perspective aids to validate the dimensions that are selected in section 4.1. A total of 117 people in the field of energy in various private and public sectors in Malaysia have taken part in a survey distributed to ensure that the most important dimensions for ES have been picked based on a combination of their knowledge and expertise and our critical review of existing literature. A total of 93 indicators from the 5 dimensions have been reviewed for these 5 dimensions and through the process of indicator mapping as shown in this section. Out of the 93 indicators, a total of 25 indicators have been shortlisted before these indicators are put for another final test. Tables 22-26 show the mapping process and the total 93 indicators that were considered and used for this process. Figure 41 shows the process from emerging themes to dimensions and selection of indicators from 93 to the final 18 indicators that were quantified to determine the Malaysian ESI levels in this research.

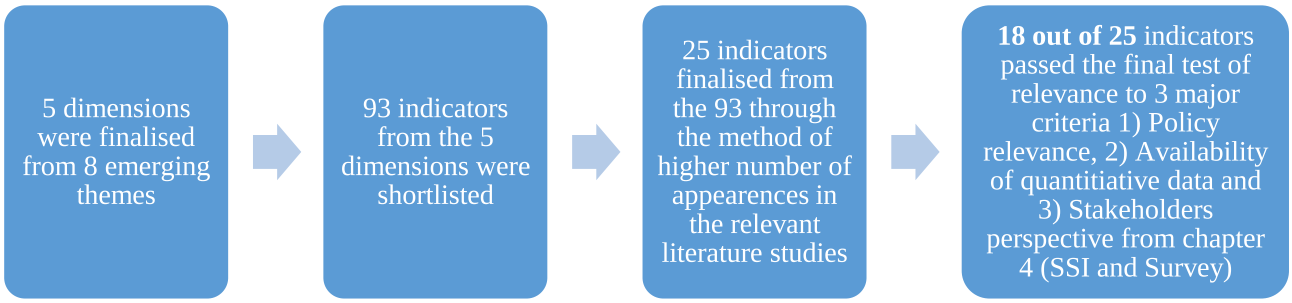


Figure 41: The flowchart for finalisation of indicators

These 25 indicators have been further tested against three major criteria to meet the need for Malaysia’s energy outlook and policy approach. The three criteria that have been added are 1) Policy relevance 2) Availability of data and 3) Stakeholder’s perspective. The indicators that have been selected for the Malaysian ESI have successfully passed all three criteria with a score of 3 and this process has been explained in Table 27.

Table 22: Indicator Mapping of Availability Dimension

Indicators	(Sahid, 2018)	**(Yusoff & Bekhet, 2020)**	(Sharifuddin, 2014)	**(Sahid & Sin, 2019)**	(Tongsopit et al., 2016)	(Malik et al., 2020)	**(Yao & Chang, 2014)**	(Abdullah et al., 2020)	**(Martchamadol & Kumar, 2012)**	(Kruyt et al., 2009b)	(Erahman et al., 2016)	(Fang et al., 2018)	(Ang et al., 2015a)	(Sovacool, 2013; Sovacool et al., 2011)	(Wu et al., 2012)	(D. Wang et al., 2020)	**(Q. Wang & Zhou, 2017)**	**SCORE (1-18)**	**SELECTION**
Total Primary energy supply per capita (TPES/pop)		✓	✓					✓	✓	✓				✓				6	Yes
Electrification level			✓						✓									2	
Net-import to consumption ratios (all energy sources)			✓														✓	2	
Reserve/Production ratio (R/P) of oil	✓	✓			✓			✓	✓	✓	✓	✓		✓	✓	✓		11	Yes
R/P of natural gas	✓	✓			✓			✓	✓	✓	✓	✓		✓	✓	✓		11	Yes
R/P of coal					✓		✓		✓	✓	✓	✓		✓	✓	✓		9	Yes
Coal import dependency ratio	✓							✓		✓			✓					4	

Oil import dependency ratio						✓	✓		✓			✓			✓	5	
Total primary energy supply over GDP (TPES/GDP)							✓		✓							2	
Energy self-sufficiency ratio	✓		✓							✓	✓		✓	✓	✓	7	Yes
Fossil fuel primary consumption			✓													1	
Renewables Consumption (TWh)				✓												1	
Share of imports in coal, oil, and gas supply (%)					✓				✓							2	
Availability factor of conventional thermal electricity						✓										1	
Availability factor of non-thermal electricity						✓										1	
Access to clean fuel (%)							✓									1	

Final Energy Consumption Per capita (TFEC/pop)	✓	✓				✓		✓		✓	5	Yes
Resource Estimates or Reserves			✓			✓		✓		✓	4	
Total primary energy production per capita (TPEP/pop)				✓	✓						2	
TFEC/GDP						✓					1	
Fuel mix of TPES						✓	✓		✓		3	
Total Energy production/Total energy consumption										✓	1	
Diversification of energy supply										✓	1	

Table 23: Indicator Mapping of Affordability Dimension

Indicators	(Sahid, 2018)	**(Yusoff & Bekhet, 2020)**	(Sharifuddin, 2014)	**(Sahid & Sin, 2019)**	(Tongsopit et al., 2016)	(Malik et al., 2020)	**(Yao & Chang, 2014)**	(Abdullah et al., 2020)	**(Martchamadol & Kumar, 2012)**	(Kruyt et al., 2009b)	(Erahman et al., 2016)	(Fang et al., 2018)	(Ang et al., 2015a)	(Sovacool, 2013; Sovacool et al.. 2011)	(Wu et al., 2012)	(D. Wang et al., 2020)	**(Q. Wang & Zhou, 2017)**	**SCORE (1-18)**	**SELECTION**
Electricity retail price to GDP ratio (industry, commercial, residential)			✓								✓							2	Yes
Liquid fuel retail price to GDP ratio (diesel, gasoline)			✓								✓							2	Yes
Energy subsidies to government budget ratio			✓															1	
Energy import cost to total export revenue ratio			✓															1	
Energy Consumption per capita	✓				✓		✓											3	Yes
Gasoline price volatility	✓				✓													2	

Electricity Tariff	✓		✓	✓			✓				4	Yes
GDP per capita		✓				✓					2	
Crude oil fluctuation ratio		✓				✓					2	
Domestic fuel price fluctuation ratio		✓							✓		2	
Share of the population without electricity			✓								1	
Gasoline price				✓			✓	✓		✓	4	Yes
Gas Price				✓			✓	✓		✓	4	Yes
Energy Supply per capita				✓							1	
Coal price volatility					✓						1	
Domestic fuel price fluctuation ratio						✓					1	
Energy cost as a percentage of manufacturing operating cost							✓				1	

Population with access to electricity (%)	✓		✓	2	Yes
Stability of electricity price	✓			1	
Households dependent on traditional fuels	✓			1	
Fixed investment share of the energy industry		✓		1	
Percentage of population with access to non-solid fuel (%)			✓	1	

Table 24: Indicator Mapping of Environmental Sustainability Dimension

Indicators	(Sahid, 2018)	**(Yusoff & Bekhet, 2020)**	(Sharifuddin, 2014)	**(Sahid & Sin, 2019)**	(Tongsopit et al., 2016)	(Malik et al., 2020)	**(Yao & Chang, 2014)**	(Abdullah et al., 2020)	**(Martchamadol & Kumar, 2012)**	(Kruyt et al., 2009b)	(Erahman et al., 2016)	(Fang et al., 2018)	(Ang et al., 2015a)	(Sovacool, 2013; Sovacool et al., 2011)	(Wu et al., 2012)	(D. Wang et al., 2020)	**(Q. Wang & Zhou, 2017)**	**SCORE (1-18)**	**SELECTION**
CO2 emission per capita (CO2 emission/pop)	✓		✓	✓	✓	✓		✓	✓	✓			✓	✓				10	Yes
Renewable Energy Output or Share of RE in total electricity generating capacity (%)	✓			✓	✓	✓	✓		✓							✓	✓	8	Yes
Share of non-fossil energy (non-fossil energy consumption/TPEC)		✓										✓						2	

Carbon emission intensity (CO2 emission/GDP)	✓						✓	✓	✓	✓	✓	✓		✓	✓	✓	10	Yes
CO2 emission/ TPEC	✓								✓	✓	✓			✓			5	Yes
CO2 emissions per unit energy (CO2 emission/TFEC)		✓												✓			2	
CO2 emission (Total GHG emission in the country)			✓														1	
SO2 emission (total)				✓		✓											2	
CO2 emission of country/ CO2 emission of the world (ratio)					✓	✓											2	
Soot emission						✓											1	
CO2 emission/ TPES							✓		✓			✓					3	
Non-carbon energy							✓	✓				✓			✓	✓	5	Yes

share/ TPES									
Share of RE/ TFEC	✓								1
The modal share of public transport					✓				1
SO2 emission per capita						✓			1
Forest Cover (% of land area)						✓			1
Water Availability (% of people with access to clean						✓			1
SO2 emission/ TPEC							✓		1
SO2 emission/ GDP								✓	1

Table 25: Indicator Mapping for Applicability of Technology Dimension

Indicators	(Sahid, 2018)	**(Yusoff & Bekhet, 2020)**	(Sharifuddin, 2014)	**(Sahid & Sin, 2019)**	(Tongsopit et al., 2016)	(Malik et al., 2020)	**(Yao & Chang, 2014)**	(Abdullah et al., 2020)	**(Martchamadol & Kumar, 2013)**	(Kruyt et al., 2009b)	(Erahman et al., 2016)	(Fang et al., 2018)	(Ang et al., 2015a)	(Sovacool, 2013; Sovacool et al., 2011)	(Wu et al., 2012)	(D. Wang et al., 2020)	**(Q. Wang & Zhou, 2017)**	**SCORE (1-18)**	**SELECTION**
Energy Supply Intensity	✓		✓		✓											✓		4	Yes
Electricity Consumption Intensity	✓															✓		2	
Industrial Energy Intensity			✓		✓	✓			✓									4	Yes
Services Energy Intensity			✓		✓													2	
RE generation status excluding large hydro (MW production capacity)				✓	✓													2	
Transport and Agriculture Energy			✓			✓			✓									3	

Intensity																			
Gas power generation efficiency						✓	✓											2	
Wells drilled for oil and gas						✓												1	
Energy Intensity (TPEC/GDP)	✓					✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	11	Yes
Crude oil distillation capacity							✓											1	
Patents owned by LME (state-owned) in coal mining and dressing and petroleum and natural gas extraction industries							✓											1	
Energy industry technical updating and transformation investment/investment in fixed assets of state-owned units in the energy industry							✓											1	
Final Energy Intensity									✓				✓	✓				3	

(TFEC/GDP)						
Commercial Energy Intensity		✓				1
Indigenous/ TPES	✓					1
Technology diversity in electricity generation			✓			1
Electricity generation efficiency			✓			1
Grid Efficiency (% electricity transmission and distribution losses)				✓		1
Research Intensity				✓		1
Energy Conversion efficiency					✓	1

Table 26: Indicator Mapping for Accessibility of Energy Dimension

Indicators	(Sahid, 2018)	**(Yusoff & Bekhet, 2020)**	(Sharifuddin, 2014)	**(Sahid & Sin, 2019)**	(Tongsopit et al., 2016)	(Malik et al., 2020)	**(Yao & Chang, 2014)**	(Abdullah et al., 2020)	**(Martchamadol &**	(Kruyt et al., 2009b)	(Erahman et al., 2016)	(Fang et al., 2018)	(Ang et al., 2015a)	(Sovacool, 2013; Sovacool et al., 2011)	(Wu et al., 2012)	(D. Wang et al., 2020)	**(Q. Wang & Zhou, 2017)**	**SCORE (1-18)**	**SELECTION**
Access to electricity (%)		✓						✓						✓			✓	4	Yes
Crude oil market concentration risk		✓										✓						2	Yes
Electrification level (EPOP/POP)			✓								✓							2	Yes
Access to clean fuel and technology for cooking (%)								✓									✓	2	Yes
% Population relying on traditional use of biomass											✓							1	
Vehicle ownership (Vehicle/1000POP)											✓							1	

Share of investment in fixed assets of energy		✓		1
Oil Market Liquidity		✓		1
Days to obtain a permanent electricity connection			✓	1
Oil market liquidity	✓			1

Table 27: Final Indicator selection

Dimension	*Indicators*	*Policy relevance*	*Availability of data*	*Stakeholder perspective*	*Repetitive indicator*	*Score*	*Selection*
Availability of Energy (AV)	Total Primary Energy Supply per capita (TPES/POP)	✓	✓	✓		3	Yes
	R/P Oil	✓	✓	✓		3	Yes
	R/P Gas	✓	✓	✓		3	Yes
	R/P Coal	✓	✓	✓		3	Yes
	Energy self-sufficiency ratio (Total energy production/ TPES)	✓	✓	✓		3	Yes
	Total final energy consumption/POP				Yes		No
Affordability of Energy	GDP per unit energy Unit: PPP per kg of oil equivalent	✓	✓	✓		3	Yes
	Liquid fuel retail price/GDP for diesel and gasoline	✓		✓		2	No
	Energy consumption per capita (TFEC/POP)	✓	✓	✓	Yes	3	Yes
	Electricity tariff Unit: sen/kWh	✓		✓		2	No
	Crude oil price Unit: USD/Barrel	✓	✓	✓		3	Yes
	Natural Gas price Unit: Henry-hub	✓	✓	✓		3	Yes
	Population with access to electricity (%)				Yes		No
E n vi	CO_2 emission/POP	✓	✓	✓		3	Yes

	CO_2 emission/GDP	✓	✓	✓		3	Yes
	CO_2 emission/TPEC	✓	✓	✓		3	Yes
	Share of RE in electricity generation (%)	✓	✓	✓	Yes	3	Yes
	Non-carbon share/TPES	✓		✓		2	No
Applicability of Technology and Efficiency	Energy Supply intensity Unit: toe/GDP in million RM	✓	✓	✓		3	Yes
	Industrial energy intensity	✓	✓	✓		3	Yes
	Overall energy intensity (TPEC/GDP) Unit: toe/GDP in million RM	✓	✓	✓		3	Yes
Accessibility	Access to electricity (%)	✓	✓	✓	Yes	3	Yes
	Crude oil market concentration risk					0	No
	Electrification level (EPOP/POP) Unit: None				Yes		No
	Access to clean fuel and technology for cooking (%)	✓	✓	✓		3	Yes

These 18 indicators will have a key role in determining the overall performance of their respective dimensions of ES. The raw data for these indicators are made available by the Energy Commission of Malaysia in the various energy statistics and reports publish annually. It is not important to define each indicator separately as most of these indicators are very much self-explanatory and they either have a positive or a negative attribute or contribution towards their dimensions and hence the overall ES.

6.4 Normalised Dimensions and Indicator Values

The 5 dimensions and their respective normalised indicators values are represented in Tables 28-32. The raw values of these dimensions and their indicators are in Appendix A, Figures 47-51 and Tables 37-41. The data were normalised using min-max approach and considering equal weight for each dimension and their respective indicators. The reason behind equal weightage is because it balances comprehensive analysis and simplicity by assigning equal importance and weight to each indicator and dimension allows for a more straightforward comparison across the board. This approach simplifies the analysis and ensures that each indicator is given an equal opportunity to impact the overall assessment of ES in Malaysia. This method allows for a clearer understanding of how each dimension contributes to ES without the complexity of varying weights, which might obscure the results.

6.4.1 Availability of energy:

Table 28 represents the normalised data of the AV dimensional indicators and the overall dimension score. In this dimension of ES, the Reserve to Production (R/P) ratio is a critical metric used to estimate the remaining lifespan of a country's reserves of fossil fuels (oil, gas, and coal) at the current production rate. It is calculated as the volume of reserves divided by the annual production volume. This ratio provides an indication of how many years the current reserves will last if production continues at the current rate without any new discoveries or changes in consumption patterns. The raw data are available in table 40 in Apppendix.

Table 28: Availability of energy normalised data

Year	TPES/POP normalised	R/P crude oil normalised	R/P natural gas normalised	R/P Coal normalised	Energy self-sufficiency normalised	Average value

2006	1.07	3.90	4.61		10.00	4.89
2007	3.50	1.00	5.44	10.00	7.65	5.52
2008	4.82	4.67	4.02	6.48	7.22	5.44
2009	3.18	5.67	5.08	2.58	5.83	4.47
2010	3.68	7.01	2.53	1.98	4.94	4.03
2011	4.35	10.00	3.57	1.10	3.69	4.54
2012	7.61	9.74	7.42	1.05	1.44	5.45
2013	8.76	9.76	8.56	1.13	1.81	6.01
2014	8.90	8.78	10.00	1.44	1.79	6.18
2015	8.26	7.21	7.88	1.66	2.18	5.44
2016	9.54	3.74	2.97	1.94	1.53	3.95
2017	9.83	2.92	1.00	1.00	1.00	3.15
2018	10.07				1.20	5.63

Availability of energy has been of key priority in both energy policies and the stakeholder's perspectives. The highest score achieved by this dimension was 5.63 in 2018 but this might not reflect the actual situation keeping in mind the unavailability of data for R/P for coal, oil, and natural gas for the year 2018. This means the dimension value is based on the performance of total primary energy supply per capita and energy self-sufficiency ratio only. On the other hand, the best performance was in the years 2013 and 2014 with scores of 6.01 and 6.18 respectively. The availability of energy has shown a downward graph from here on until 2017. This is due to an increase in demand for energy in the various with an increase in the overall population and a decrease in reserves to production ratio over the years for the different fuel types.

There is also an aim to increase the intake of RE as a fuel source in most of the energy policies since early 2000 which ideally should reduce the use of fossil fuels, hence ensuring better environmental sustainability. The energy policies discussed in Table 3 are inclined towards improving energy self-sufficiency and diversification of energy sources. The stakeholders in this research have also mentioned that the aim is to always maintain a stable supply of energy with maximum consumer satisfaction, and this can be done by increased efficiency of supply. This means that the availability of energy needs to improve, and it can be done so by, diversifying the existing pool of improving the efficiency overall in terms of the use of energy with less wastage. The reserves to production ratio can improve by ensuring that the existing reserves are carefully managed with sectors, which in other words is to improve efficiency with improved technological advancement (Hasanov et al., 2021).

The observed fluctuations in the R/P ratios are reflective of the dynamic nature of the energy sector in Malaysia, influenced by the factors mentioned above. The study's approach of using normalized data ensures that these variations are captured accurately, providing a robust basis for analysis and understanding of Malaysia's energy security landscape. This approach supports the argument that Malaysia's energy policies must be adaptable and forward-looking, considering the fluctuating nature of the R/P ratios and the broader energy market dynamics. Some of the major reasons behind these fluctuations can be;

Production Rates: Variations in annual production rates due to operational, economic, or policy changes can cause significant changes in the R/P ratio. For instance, a temporary increase in production due to higher demand or technological advancements can lower the R/P ratio.

Reserve Revisions: Updates to reserve estimates based on new discoveries, improved extraction technologies, or better geological data can cause the R/P ratio to change. For example, if new reserves are discovered or existing reserves are reassessed to be larger, the R/P ratio will increase.

Market Dynamics: Global energy market dynamics, such as changes in prices or international demand, can impact production rates and reserve evaluations. Economic downturns or booms can also affect production levels and thus the R/P ratio.

Government Policies: Policy decisions regarding energy production, such as quotas, subsidies, or restrictions, can influence the production rates of different energy sources, thereby affecting the R/P ratio. Policies aimed at reducing reliance on fossil fuels can lead to reduced production and higher R/P ratios.

Technological Advances: Innovations in extraction and production technologies can alter the efficiency and feasibility of accessing certain reserves, leading to adjustments in both production rates and reserve estimates.

6.4.2 Affordability of energy

Table 29 represents the normalised data of the AF dimensional indicators and the overall dimension score.

Table 29: Affordability of Energy normalised data

Year	Normalised price of natural gas	Normalised crude oil price	GDP per unit energy normalised	Energy consumption per capita normalised	Average Value
2006	4.07	6.98	2.87	10.00	5.98
2007	3.73	5.78	1.00	8.59	4.78
2008	1.00	2.76	1.18	8.85	3.45
2009	8.04	7.56	3.45	9.97	7.26
2010	7.40	5.71	6.83	10.03	7.49
2011	7.94	1.16	7.49	9.29	6.47
2012	9.72	1.00	10.00	6.40	6.78
2013	8.34	1.29	4.90	5.79	5.08
2014	7.45	2.83	7.39	5.91	5.89
2015	9.91	10.00		6.54	8.82
2016	10.00	10.00		4.11	8.04
2017	9.35			1.75	5.55
2018	9.19			1.00	5.09

The affordability of energy has been at its best in the year 2015 with a score of 8.82. It is because of a decrease in crude oil and natural gas prices mostly during this time. Out of the 4 indicators in this dimension GDP per unit, energy data are not available from 2014 onwards and price of crude oil from 2017-18. This would reflect upon the dimension value for the years 2014-2018 but mostly for 2017-18 with the absence of two indicator data. The sharp improvement in score for 2015 and 2016 are still acceptable in this case given the decrease in natural gas and crude oil prices irrespective of a decrease in energy consumption per capita. The overall picture for this dimension from 2006-2018 did not improve a great deal and came back to almost the same score as that of 2006. This is an indication that ES overall has not changed to a great extent neither there are a lot of incentives for reducing the cost of energy use and making it more affordable. The energy policies studied do not reflect on ways to make energy more affordable to all sectors. Stakeholders have argued that there are subsidies on electricity pricing and fossil fuel which makes them more affordable and does not reflect the market price. This means conventional thermal power plants of coal and combined-cycle gas turbines (CCGT) plants will remain to power Malaysia for a very long time in the future as well. These power plants compared to RE plants are more efficient and cost-effective. They are cheaper to operate and hence reduces the cost per kWh making it more affordable for consumers. This might not be the most viable option for the future to promote more subsidy on the fuel and electricity price and rather there should be a gradual shift towards indigenous sources of energy like solar (Heng et al., 2019) to improve the affordability dimension of ES for Malaysia.

6.4.3 Accessibility of energy

Table 30 represents the normalised data of the AC dimensional indicators and the overall dimension score.

Table 30: Accessibility of energy normalised data

Year	Access to electricity normalised	Access to clean fuel and technology for cooking normalised	Average value
2006	1.00	1.56	1.28
2007	2.20	2.13	2.16
2008	3.49	5.50	4.50
2009	6.42	4.66	5.54
2010	6.36	5.78	6.07
2011	7.78	8.31	8.05
2012	8.98	10.00	9.49
2013	9.64	6.34	7.99
2014	9.93	3.25	6.59
2015	9.99	1.00	5.50
2016	10.00	1.00	5.50
2017	10.00		10.00
2018	10.00		10.00

In this dimension, the least number of indicators have been selected. Lack of data availability for the period chosen constricts the selection of more indicators. The best performance for this dimension is a score of 10 for 2017 and 2018 which we believe is slightly contradicting the trend. This is because access to clean fuel and technology does not have data for these 2 years and the best score of access to electricity is also in these years subsequently. Whereas the worst scores for access to clean fuel and technology have been in 2015 and 2016 which suggests that 2017 and 2018 data would not have much better if not worse than this and hence the overall dimension score would roughly follow the trend. The best outcome we can get from this dimension is 100% access to electricity for 3 consecutive years 2016-2018 and it looks like this will remain consistent for the upcoming years. However, (Dahlan et al., 2021a) has stated that due to a lack of grid connection, the electrification prospects in some Malaysian rural communities are limited. Experts and energy providers are concerned about finding an alternative source of energy because of this challenge.

Data Selection and Limitations:

- **Indicator Selection**: The dimension includes the least number of indicators due to data availability constraints. Only two indicators were selected: access to electricity and access to clean fuel and technology for cooking.
- **Data Gaps**: There is a significant data gap for the access to clean fuel and technology for cooking for the years 2017 and 2018. This lack of data skews the dimension score, leading to an unrepresentative perfect score of 10 for those years.

Performance Trends:

- **Improvement and Fluctuations**: From 2006 to 2012, there is a clear upward trend in accessibility, with scores improving steadily. However, the years 2013 to 2016 show significant fluctuations, especially in the access to clean fuel and technology for cooking. The scores dropped notably in 2015 and 2016, indicating potential issues or inaccuracies in the data.
- **Perfect Scores in 2017 and 2018**: The scores for 2017 and 2018 are perfect 10s, driven solely by 100% access to electricity. However, the lack of data for access to clean fuel and technology for these years suggests that these scores might not accurately reflect the overall accessibility dimension.

Contextual Analysis:

- **Electricity Access**: The consistent 100% access to electricity from 2016 to 2018 is a positive indicator of Malaysia's infrastructure development and government initiatives to ensure universal electricity access.
- **Clean Fuel and Technology**: The fluctuating scores for access to clean fuel and technology for cooking indicate challenges in achieving consistent improvements in this area. Rural electrification remains a challenge due to limited grid connections, as highlighted by (Dahlan et al., 2021b)

The data collected during the stakeholder engagement sessions also reflects the following.

- **Government Efforts**: The government’s efforts in providing continuous and affordable energy access are acknowledged. Subsidies have played a crucial role in making energy affordable for all income groups.
- **Rural Electrification**: Despite high scores, the challenge of electrifying rural areas remains. Stakeholders emphasize the need for alternative energy sources to address the limited grid connections in rural communities.

6.4.4 Applicability of technology and efficiency:

Table 31 represents the normalised data of the APE dimensional indicators and the overall dimension score.

Table 31: Applicability of technology and efficiency

Year	Energy supply intensity normalised	Industrial energy intensity normalised	Total energy intensity (TPEC/GDP) normalised	Average value
2006	9.00	3.51		6.25
2007	10.00	4.51	9.48	8.00
2008	7.44	3.96	8.36	6.59
2009	6.67	4.21	10.00	6.96
2010	3.15	1.79	8.95	4.63

2011	2.84	3.05	8.14	4.68
2012	7.41	5.56	6.42	6.46
2013	7.39	4.10	6.98	6.16
2014	4.44	1.54	6.16	4.05
2015	1.00	1.00	2.76	1.59
2016	4.35	4.56	1.35	3.42
2017	6.33	8.36	1.00	5.23
2018	5.53	10.00	2.33	5.96

Performance Trends:

- **Initial High Score and Decline**: The dimension achieved its best score of 8.00 in 2007, driven by optimal energy supply intensity and TPEC/GDP. However, the score declined to 4.68 by 2011, indicating a drop in performance across these indicators.
- **Worst Performance**: The dimension experienced its worst performance in 2015, with a score of 1.59. Both energy supply intensity and industrial energy intensity were at their lowest during this period.
- **Fluctuating Trends**: After 2015, the scores showed fluctuations, with a slight recovery in 2017 (5.23) and a further improvement in 2018 (5.96). However, these scores still did not reach the initial high of 2007.

Indicator Analysis:

- **Energy Supply Intensity and Industrial Energy Intensity**: These indicators reflect the efficiency with which energy is used in the supply and industrial sectors. A higher score indicates lower energy consumption relative to GDP growth, which is desirable.
- **Total Energy Intensity (TPEC/GDP)**: This indicator measures the overall energy efficiency of the economy. Better performance (higher score) is achieved when there is lower energy consumption per unit of GDP.

Factors Affecting Performance:

- **Increase in Energy Consumption**: The decline in energy intensity indicators from 2007 to 2011 can be attributed to increased energy consumption rates due to population growth and higher energy demand in the industrial sector. This increased consumption outweighed GDP growth, resulting in poorer performance.

- **Declining R/P Ratio**: A declining reserve-to-production (R/P) ratio for different fuel types also contributed to the lower scores, as it indicates increased energy use and dependency on external energy sources.

Improving energy efficiency and reducing energy wastage through advanced technologies are crucial steps to enhance the Applicability of Technology and Efficiency (APE) dimension scores. Adopting energy-efficient technologies and exploring indigenous resources are essential to achieving these improvements. The government's Green Technology Policy (2009) aims to promote energy independence and the efficient utilization of energy resources. This policy is expected to boost national capability in green technology innovation and improve Malaysia's competitiveness in the international arena.

Significant investments have been made in green technology projects. The Malaysian Investment Development Authority (MIDA) authorized 479 projects with a total investment of RM2.23 billion under the Green Technology Financial Scheme (GTFS) from January to September 2020. These investments are a positive sign of the growing interest and potential in green technology within Malaysia. Additionally, the 9th, 10th, and 11th Malaysia Plans have emphasized the importance of improving energy efficiency to ensure better performance of the APE dimension and overall energy security (ES).

The analysis of the APE dimension underscores the critical need for continuous efforts in promoting energy-efficient technologies and reducing energy wastage. While there have been improvements in recent years, a sustained focus on green technology policies and investments is essential to achieving long-term energy efficiency and security for Malaysia.

6.4.5 Environmental sustainability

Table 32 represents the normalised data of the ENV dimensional indicators and the overall dimension score. In this dimension, the indicators are explained in the following manner.

There is a need to consider the significance and contributions of each ratio and the fourth indicator of share of RE in electricity generation to overall environmental sustainability.

CO2 Emission per Population (CO2/POP):

- **Definition**: Measures the total CO_2 emissions divided by the population size.
- **Importance**: Indicates the per capita environmental impact. A lower value implies a smaller carbon footprint per individual, reflecting more sustainable living practices and efficient energy use by the population.

CO_2 Emission per GDP (CO_2/GDP):

- **Definition**: Measures the total CO_2 emissions divided by the Gross Domestic Product.
- **Importance**: Reflects the carbon intensity of the economy. A lower value suggests that the country is able to generate economic output with fewer emissions, highlighting efficient industrial processes and the integration of green technologies in economic activities.

CO_2 Emission per Total Primary Energy Consumption (CO_2/TPEC):

- **Definition**: Measures the total CO_2 emissions divided by the total primary energy consumption.
- **Importance**: Indicates the carbon intensity of the energy supply. A lower value shows a cleaner energy mix with a higher proportion of renewable energy sources and less reliance on fossil fuels.

By averaging these three ratios, a comprehensive indicator that reflects the overall environmental sustainability in terms of CO_2 emissions can be created. The justification is provided from three different perspectives.

- **Holistic View**: Each ratio provides insights into different aspects of environmental impact. CO_2/POP focuses on individual contributions, CO_2/GDP on economic efficiency, and CO_2/TPEC on energy efficiency. Averaging them gives a balanced view that considers all these dimensions.
- **Equal Importance**: Given the lack of detailed stakeholder input on the weightage studies, treating these indicators with equal importance ensures no bias towards any single aspect. It maintains a neutral stance while providing a robust measure of overall environmental impact.

- **Simplified Analysis**: An average value simplifies the comparison across years and allows for straightforward trend analysis, making it easier to track improvements or deteriorations in environmental sustainability over time.

Table 32: Environmental Sustainability normalised data

Year	CO_2/population normalised	CO_2/GDP normalised	CO_2/TPEC Normalised	Share of RE in electricity generation normalised	Average value
2006	8.01	0.94		8.99	5.98
2007	7.98	2.36	5.17	10.00	6.38
2008	6.91	2.65	4.24	7.03	5.21
2009	10.00	3.43	7.60	4.18	6.30
2010	4.83	2.08	4.03	3.97	3.73
2011	5.60	3.67	5.73	3.33	4.58
2012	3.03	3.46	3.07	2.35	2.98
2013	2.79	4.05	4.88	1.88	3.40
2014	1.48	4.68	4.91	1.00	3.02
2015	1.53	5.74	2.01	1.84	2.78
2016	1.00	6.35	1.00	2.24	2.65
2017	4.15	9.06	6.06	1.29	5.14
2018	4.30	10.05	10.00	1.68	6.51

The indicators of this dimension related to carbon dioxide emission are inversely related to ES performance hence they have been normalised with the inverse relation to maintaining consistency of higher score been better performance. The environmental sustainability dimension scores have seen a steep decline from 2006 until 2016 with the scores decreasing from 5.98 to 2.65 which was the worst performance recorded. A decrease in the score for this dimension indicates more harm has been done to the environment in terms of GHG emission and lower contribution of RE as a source of energy in the TPES and electricity generation. There has been a gradual decrease in the performance of the CO_2 emission per capita indicator and a decrease in the share of RE in electricity generation that has done the most damage to the overall score of this dimension. The year 2006 and 2007 have recorded two of the highest scores for the ENV dimension indicating that in terms of ES we are worse off now and only in 2018 the score has revived back to 6.51. This improvement in the dimension score is due to an overall decrease in CO_2/GDP and CO_2/TPEC which have successfully reduced the impact of emission and lower share of RE was having in the previous years. Since the year 2009, the Malaysian government and its energy policies are heavily inclined towards addressing the environmental damage been done using conventional fuels and their emission. NREPAP (2010 onwards) has managed to reduce the emission of carbon dioxide as mentioned in Table 3. Similarly, the new policies like RETR 2035 have targets to improve stability of supply, reduction of GHG emissions, and promote the use of RE in a more efficient manner. The stakeholders have a similar perspective towards this, although they have mentioned the importance of these policies succeeding to improve the ES of the nation, yet again they are not confident in the implementation of these policies to extract the best possible outcomes. For this dimension to improve even further, more research needs to be done to suggest ways to promote RE as a key source in the TPES and electricity generation and at the same time adapt new energy-efficient technologies to reduce emissions. Subsidies or incentives can be awarded from the government to the consumers in all sectors to keep the emission to an acceptable level or penalise the industries in different sectors exceeding the limit set for GHG emission.

Key Observations from table 32 are;

1. **Fluctuations in Environmental Impact**:
    - The average value fluctuates over the years, reflecting changes in the underlying CO2 ratios and the share of renewable energy. For example, in 2009, there was a spike in the average value due to high CO2 emissions per capita and GDP despite a higher share of renewable energy.
    - In 2012 and 2013, the average value was lower, indicating better environmental performance, likely due to improvements in energy efficiency and a cleaner energy mix.
2. **Trends and Improvements**:
    - There is a notable improvement in the average value from 2014 to 2016, suggesting enhanced environmental sustainability. This period likely saw efforts to reduce CO2 emissions and increase the share of renewable energy in the energy mix.

- However, a rise in the average value in 2017 and 2018 indicates a potential setback, possibly due to increased economic activity and energy consumption outpacing the adoption of cleaner technologies.

Figure 42 represents the time-series performance of the 5 dimensions from 2006-2018.

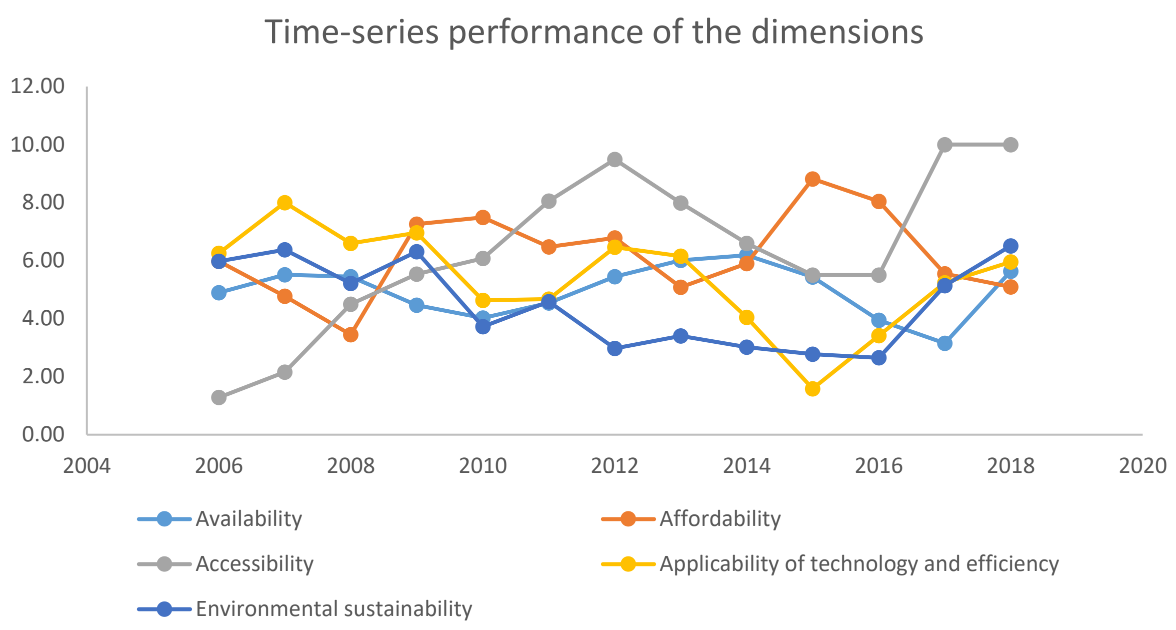
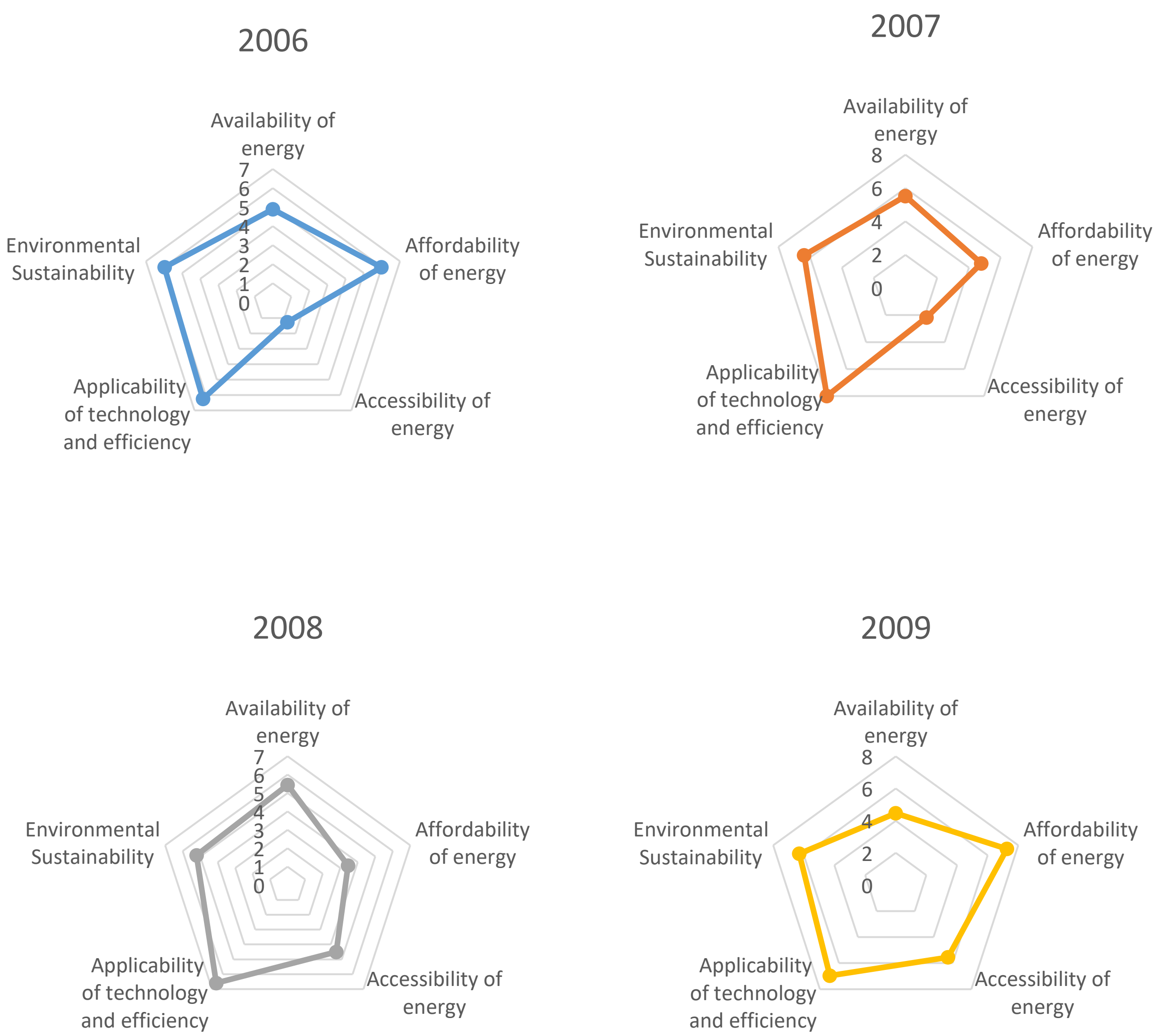
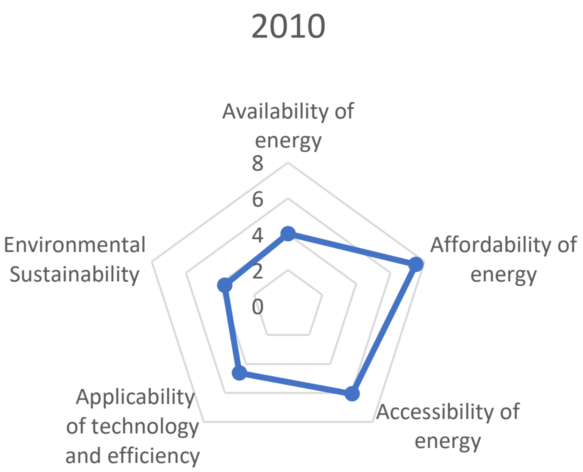


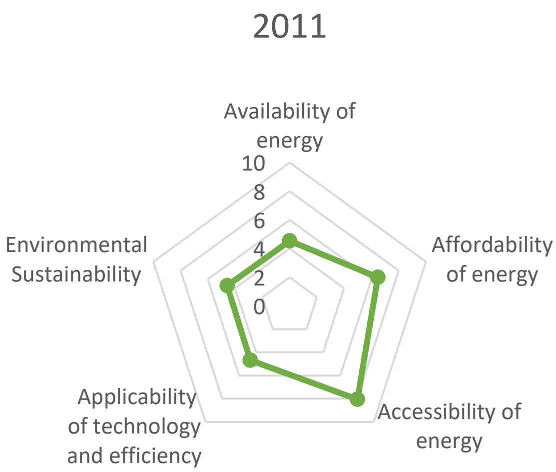
Figure 42: Overall time-series performance of the 5 dimensions from 2006-2018

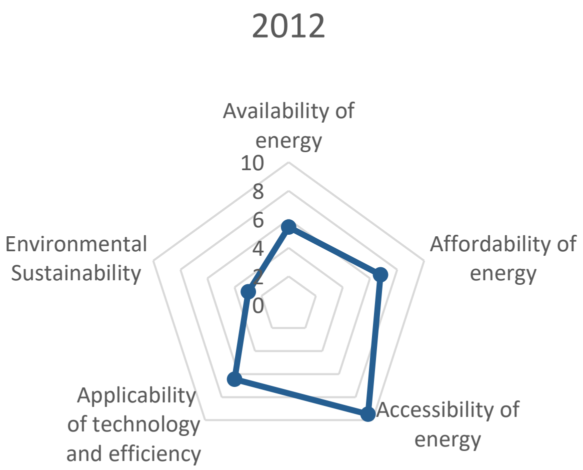
6.5 Radar Chart Assessment for Balance of ES Dimension

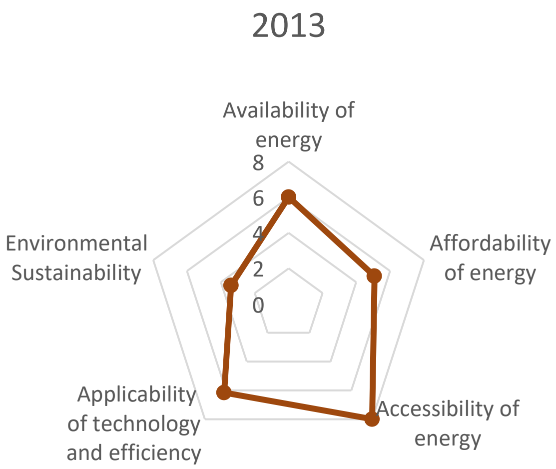
The average value of the indicators which is also the dimension value for each year has been plotted in radar charts to form pentagon-shaped charts that represent the performance of each of the dimensions for that respective year. Figure 43 shows a total of 13 radar charts that represent data from 2006-2018 and assess the balance between the 5 dimensions.




2010
Availability of energy
8
6
4
2
0
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability


2011
Availability of energy
10
8
6
4
2
0
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability


2012
Availability of energy
10
8
6
4
0
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability


2013
Availability of energy
8
6
2
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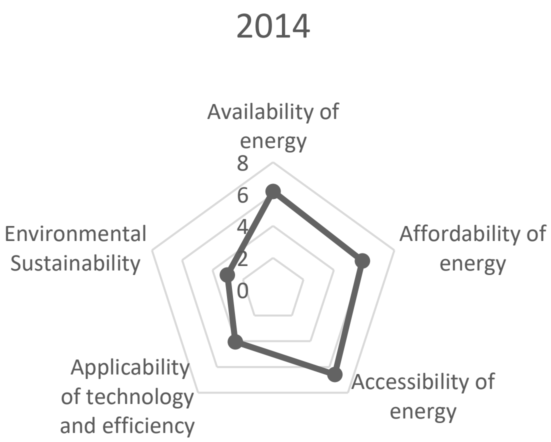
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability


2014
Availability of energy
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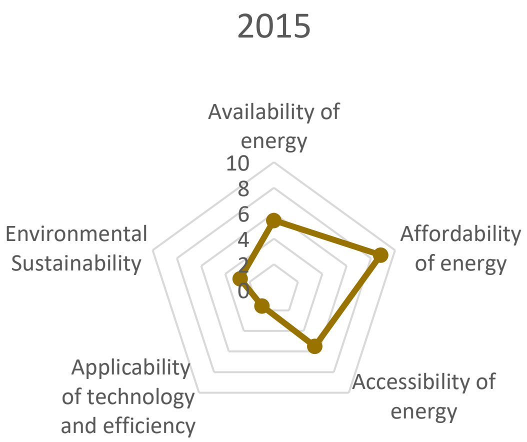
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability


2015
Availability of energy
10
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4
Affordability of energy
Accessibility of energy
Applicability of technology and efficiency
Environmental Sustainability

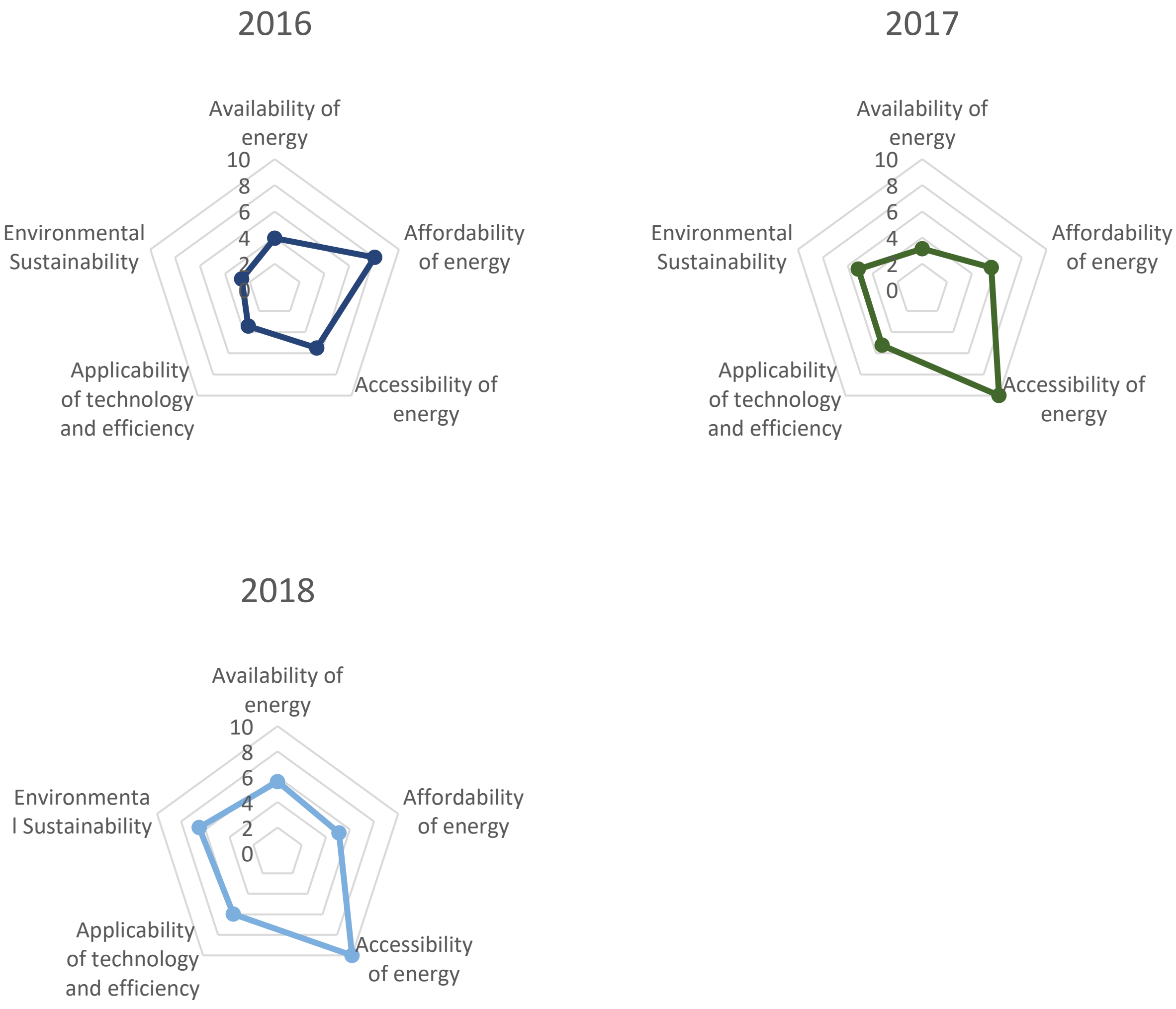

Figure 43: Radar Chart plots for years 2006-2018 for the ES dimensions

The more balanced pentagon near to the regular shape represents the overall stability of the ES for the respective year. 2008 and 2009 are the two consecutive years with a more balance between the ES dimensions which indicates a more stable ES performance. 2013, 2015, and 2016 are relatively the least stable in terms of the balance of the ES dimensions. This indicates that some dimensions have done extremely well in these years while others have performed poorly.

The radar charts from 2006 to 2018 illustrate the variation in stability and balance among the ES dimensions for each year.

- **2006-2007**: These years exhibit a relatively balanced shape, indicating a moderate level of stability across the ES dimensions. The performance in these years is fairly uniform without extreme highs or lows.
- **2008-2009**: These two consecutive years display the most balanced and regular pentagon shapes, signifying the highest level of stability and balance among the ES dimensions. This suggests that during these years, all ES dimensions performed well and were in harmony with each other.
- **2010-2011**: The shapes become slightly less regular, indicating some instability in the ES performance. While still balanced, there are slight variations, suggesting that some dimensions may have performed better than others.
- **2012-2013**: The shapes show significant imbalance, particularly in 2013, where one dimension outperforms the others significantly. This indicates that while some aspects of ES were strong, others lagged, leading to overall instability.
- **2014-2015**: Like 2013, these years show considerable imbalance. The irregular shapes suggest that certain ES dimensions excelled while others did not perform well, leading to a less stable overall ES performance.
- **2016**: This year shows a highly irregular shape, indicating significant instability and imbalance among the ES dimensions. Some dimensions performed exceptionally well while others performed poorly.
- **2017**: The shape becomes more balanced compared to 2016 but still indicates some instability. Certain dimensions have improved, bringing more balance, but there is still room for improvement.
- **2018**: The shape in 2018 shows an improvement in balance compared to previous years, indicating a trend towards better stability. While not as balanced as 2008-2009, it suggests that efforts to improve ES performance across all dimensions are starting to pay off.

Overall, the trend from 2006 to 2018 indicates fluctuations in ES performance with periods of high stability (2008-2009) and notable instability (2013, 2015-2016). The recent years show an improving trend towards a more balanced ES performance, suggesting positive developments in policy and technology implementation. However, continuous efforts are needed to maintain and enhance this balance for long-term sustainability.

6.6 Discussion of Results

6.6.1 Overall ES Performance

Figure 44 shows the overall time-series performance of the Malaysian ESI.

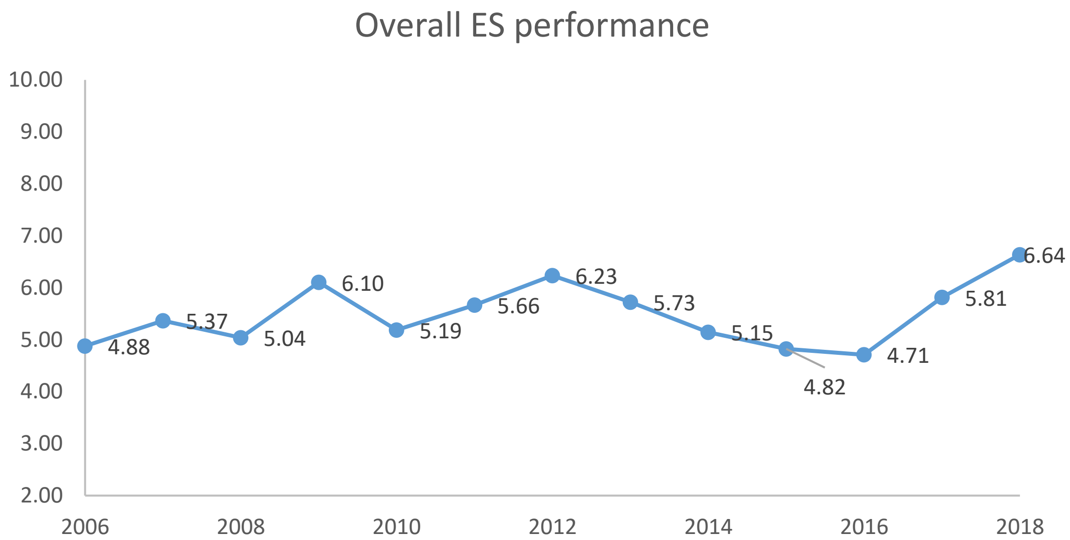

Figure 44: Overall ES time-series performance

The overall trend from 2006 to 2018 demonstrates an improvement in ES performance, albeit with significant fluctuations. Using 2006 as a baseline provides a comprehensive view of long-term progress. The recent improvement from 2016 to 2018 indicates positive developments, suggesting effective policy implementations and technological advancements. However, continuous efforts are required to maintain and further enhance ES to ensure long-term sustainability and resilience against potential future challenges.

The analysis of the overall Energy Security (ES) performance from 2006 to 2018 shows a fluctuating trend with notable peaks and troughs. Here are key points and reasoning behind the trends observed in Figure 44:

Initial Base Year Selection (2006):

- **Baseline Reasoning**: The year 2006 is chosen as the baseline for comparison as it marks the beginning of the data set, providing a starting point for tracking long-term changes in ES performance. Establishing a baseline is essential for evaluating trends over an extended period.
- **Long-Term Perspective**: By using 2006 as the base year, the analysis captures the cumulative impact of policy changes, economic conditions, and technological advancements on ES over a significant period. This approach helps in understanding the overall trajectory of ES improvement.

Fluctuating Trend Analysis:

- **2006-2008**: The initial period shows a slight improvement in ES performance, likely due to early policy implementations and moderate economic growth. The increase from 4.88 to 5.37 and a subsequent slight drop to 5.04 reflects minor policy adjustments or economic fluctuations.
- **2008-2012**: A significant upward trend is observed, peaking at 6.23 in 2012. This period likely benefited from substantial policy interventions, investments in energy infrastructure, and possibly global economic recovery post-2008 financial crisis.
- **2012-2016**: The trend shows a decline, reaching a low of 4.71 in 2016. This period could have faced challenges such as global oil price volatility, policy inconsistencies, or slower economic growth, impacting ES negatively.
- **2016-2018**: A marked improvement is seen from 4.71 to 6.64, indicating successful policy implementations, increased investment in renewable energy, or technological advancements improving energy efficiency and sustainability.

Significance of the Improvement:

- **36% Improvement Calculation**: The improvement is calculated by comparing the initial value in 2006 (4.88) to the final value in 2018 (6.64), resulting in a 36% increase. This long-term perspective highlights the overall progress made despite interim fluctuations.
- **Short-Term Comparison**: If comparing only 2016 (4.71) and 2018 (6.64), the improvement appears more pronounced, exceeding 36%. This highlights a recent surge in ES performance, likely due to accelerated policy actions or economic recovery.

Factors Influencing ES Performance:

- **Economic Conditions**: Economic growth or downturns significantly impact energy demand, production capacity, and investment in energy infrastructure.
- **Policy Interventions**: Government policies aimed at promoting renewable energy, improving energy efficiency, and ensuring stable energy supply directly influence ES performance.
- **Technological Advancements**: Innovations in energy extraction, production, and efficiency technologies contribute to better ES outcomes.
- **Global Market Dynamics**: Fluctuations in global energy prices, geopolitical tensions, and international trade agreements affect energy availability and cost.

The use of forecasted indicator data has been avoided from 2018 onwards to avoid any bias in data selection. Therefore, the use of proxy indicators and data are also avoided to ensure that the Malaysian ESI created is solely based on the data and indicators that are available, relevant to the energy policies, and have been filtered by stakeholders' opinions and perspectives. (Endang Jati Mat Sahid & Sin, 2019) have used forecasted indicator data for up to 2040 to predict the trend for the future ES of Malaysia using only 6 indicators. This is insufficient to judge the overall ES performance. While in another study by (Sharifuddin, 2014), has defined a similar methodology to that of this study but did not present and discuss the results that can be generated using the methodology. The objective was to build up from the already existing work as mentioned here and improve the validation aspect of the dimension that was lacking in most of the research done for Malaysia.

Engaging stakeholders provided the extra information to extract the best possible dimensions and then filter the indicators. A total of 93 indicators were studied to find the best possible 18 indicators for these 5 dimensions to draw a conclusion on the ES performance of Malaysia. The Malaysian ESI created using the methodology discussed is suitable for any country with a similar energy demand pattern and a similar set of energy policies hence not limiting this research results and methodologies to within Malaysia’s ES. Changes in few indicators and the indicator data will be sufficient to use this framework for future work for different countries within Asia or even other regions.

6.6.2 Standard Deviation and Geometric Mean Analysis

Table 33 shows the standard deviation from the best performance of each dimension from 2006-2018 and the geometric mean of the dimension value for two consecutive years e.g., 2006-2007 and 2007-2008.

Table 33: Standard deviation from the best performance for each year and the geometric mean of the dimension values

		2006	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Standard Deviation	**AV**	0.64	0.33	0.37	0.86	1.08	0.82	0.6	0.09	0.00	0.37	1.12	1.51	0.27
	AF	1.42	2.02	2.69	0.78	0.66	1.17	1.02	1.87	1.46	0.00	0.39	1.64	1.86
	APE	0.87	0.00	0.71	0.52	1.69	1.66	0.77	0.92	1.98	3.21	2.29	1.38	1.02
	AC	4.36	3.92	2.75	2.23	1.96	0.98	0.26	1.00	1.71	2.25	2.25	0.00	0.00
	ENV	0.26	0.07	0.65	0.10	1.39	0.96	1.77	1.56	1.75	1.87	1.93	0.69	0.00
		2006-2007	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**	
Geometric Mean	**AV**	5.20	5.48	4.93	4.24	4.28	4.98	5.72	6.09	5.80	4.63	3.53	4.21	
	AF	5.34	4.06	5.00	7.37	6.96	6.62	5.87	5.47	7.21	8.42	6.68	5.32	
	APE	7.07	7.26	6.77	5.67	4.65	5.50	6.31	4.99	2.53	2.33	4.23	5.58	
	AC	1.66	3.12	4.99	5.80	6.99	8.74	8.71	7.26	6.02	5.50	7.42	10.00	
	ENV	6.18	5.76	5.73	4.85	4.13	3.69	3.18	3.20	2.90	2.71	3.69	5.78	

The standard deviation values give an insight into the extent to which the dimension values have deviated over the years from their best performance which is set to be the benchmark for the 13 years of results that have been generated. The closer the score to 0 represents a lesser deviation from the benchmark score and hence a better performance for the dimension from the angle of stability. An overall minimal deviation in the dimensions also proves that they are stable in their performance and the policies designed to control them are executed well to some extent. Availability of energy in Malaysia has deviated the least compared to all 5 dimensions and it is an indication of a more stable score achieved.

According to literature in section 2.5 it also suggests that the availability of energy has been of utmost priority in Malaysia with a lot of importance given to the security of supply. Affordability of energy has also been a key dimension in all the policies and the stakeholder's opinions besides availability. Both these dimensions are most of the time mentioned in conjunction with each other where the objective is to achieve a secure supply of energy at an affordable price. AF dimension values have also shown smaller deviation alongside environmental sustainability. The environmental sustainability dimension also shows a stable trend in its results with the best performance being in 2018 which is motivating towards the nation's goal of achieving lower carbon emission and improving the sustainability of the existing energy resources. APE and AC dimensions have shown more fluctuation in their performance over 13 years. AC dimension deviation has proven to be beneficial with a sign of improvement each year with their best result been achieved in 2017 and 2018. APE has proven to deviate from their best results in 2006-2009 to a poorer score after 2009 till 2018.

The geometric mean, also used by (Ang et al., 2015a) to smoothen the average values of the dimensions over 2 years. The geometric mean is most useful when numbers in the series are independent of each other or if numbers tend to make large fluctuations. In this case, the higher score of the geometric mean resembles a better performance e.g., the AC dimension in 2006 had a score of 1.66 and in 2018 it was 10 showing a drastic improvement in the score and hence the overall performance.

6.6.3 Fundamental Energy Security Questions

(Cherp & Jewell, 2014) have asked three fundamental questions believed has always been neglected in the ES literature: 1) Security for whom? 2) Security of which values? and 3) Security from what threats? A similar set of questions has also been asked by (Von Hippel et al., 2011) in his study; 1) What to protect? 2) From which risks? 3) By which means? In both cases, the authors have explained that there is no definite answer to these questions, and it depends on how the situation is interpreted for different countries.

Answering these questions is critical to validate ES research as the authors of (Cherp & Jewell, 2014) argue that developing a viewpoint on ES through interviews and surveys is not robust enough. The results suggest that in Malaysia,

1) There is a need for security of the existing natural resources within the country to ensure sustainable development and sustainable economic growth for the future. Availability of resources is at a greater threat as Malaysia's energy mix of TPES and electricity generation are still dominated by conventional non-renewable fuels. Energy should be affordable and equitable to all income groups and there needs to be a security or an assurance of this to maintain an equal share of energy resources for everyone within the nation. So, this suggests that security for those from a lower income group should be ensured with improved affordability of energy be it fuel pricing or electricity tariff because a poorer affordability dimension will have a greater impact on the lower-income group of the population. Security for the environment in general with context to GHG emission from different sectors needs to be attained as well for the ES of a nation to improve backed by the study of (Nutongkaew et al., 2019). These are the three key dimensions of our study that needs to be secured to ensure a better ES performance for Malaysia.

2) The authors have mentioned that there is a gap in the knowledge of the connection between energy systems and important social values. It has been mentioned in the future scope of studies that a system's approach of modelling these same set of indicators through a causal relationship to understand the connection between these set of indicators within an energy system will develop a better interlinkage between the indicators. It has been discussed that certain indicators within some dimensions need protection or security to improve their metrics score within the Malaysian ESI which in return will improve the ES of the nation. Also, (Augutis et al., 2012) have mentioned a special index that gives numerical values to security indicators only. These security indicators can be studied more in-depth in future scopes.

3) Lastly, what are the threats? (Gracceva & Zeniewski, 2014) have categorised threats to ES into three broad categories and have also discussed in detail what are the properties of secure supply chain. In the Malaysian ESI, the threats that can be identified towards Malaysia's ES are a lack of emphasis on ES in the policies. ES policies can have a set of targets to meet and the threats to mitigate which will give a clearer interpretation of the concept of ES within Malaysia's energy outlook. There are threats such as a Covid-19 pandemic that can largely impair certain indicators which in turn will affect the ES overall. Intermittency of RE, aging technology that is less efficient, and threats of GHG emission to the atmosphere need to be mitigated and these have been reflected in the interviews with the stakeholders. (Saleh Shadman & Chin, 2021) have discussed some of the stakeholder interview results that have

touched these topics in-depth and suggested ways to tackle these threats to ensure better ES for Malaysia. Therefore, the research approach which is a mix of qualitative and quantitative data analysis is better prepared to answer and rectify what the threats are towards Malaysia's ES.

6.7 Energy Security Index Measurement for Thailand, Singapore, and Indonesia

This section compares the ESI level of Indonesia, Thailand, and Singapore to that of Malaysia. The same data collection and curation methods has been implemented for measuring the ESI levels. This has been done to show the applicability of the methods for ASEAN countries and to compare the ESI levels of these countries with Malaysia based on primary findings. Table 36 outlined the dimensional values for Indonesia's ESI from the year 2010-2018.

Table 34: 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

Figure 45: ESI level for Indonesia from the year 2010-2018

While Figure 45 is the overall level of ESI for Indonesia, suggesting a very positive trend of increasing 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 largely grown. 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.

- Energy availability has increased from year 2010-2018, but it does not indicate an increase in the share of renewables or alternative fuel sources by a great extent. The rise in availability represents more of 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 in 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.

Table 37 illustrates the dimensional values for Indonesia's ESI from the year 2010-2018.

Table 35: 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

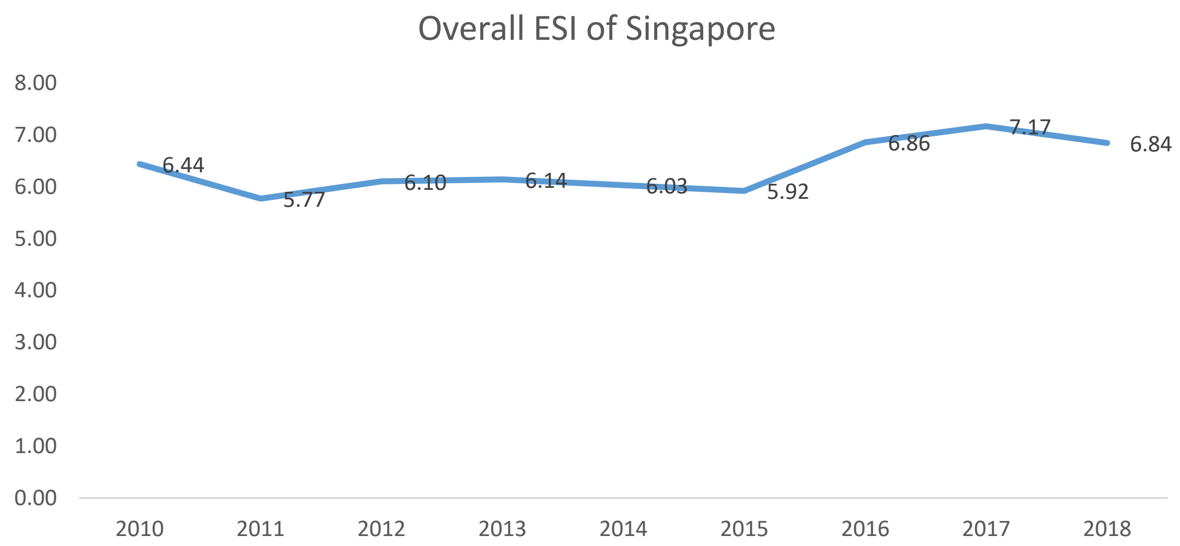

Figure 46: ESI level for Singapore from the year 2010-2018

The above figure 46 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 always has access to electricity and fuel. This is possible with 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 neighbouring countries where the imported fuels received by Singapore. Hence, the long-term 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.

The following Table 36 shows the dimensional values for Thailand's ESI from the year 2010-2018.

Table 36: 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

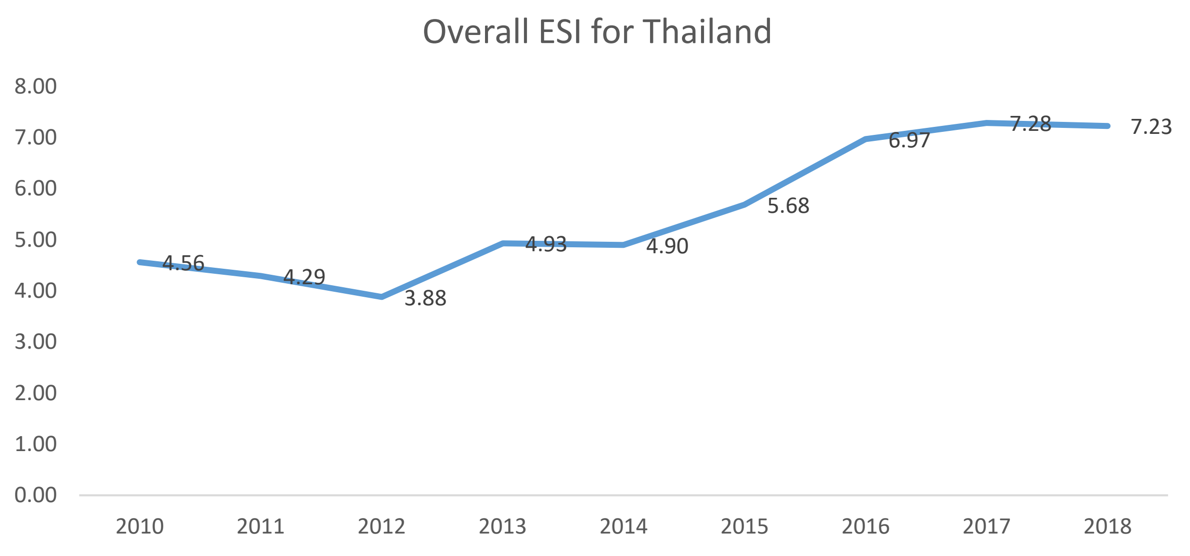

Figure 47: ESI level for Thailand from the year 2010-2018

Figure 47 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 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 tariff 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.

In conclusion it can be stated that the assessment in this study has shown an increase in ES level for all the 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 confident 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 always ensure energy availability 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, 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 of energy can reached to 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.

6.8 Limitations and Future Scope for Malaysian ESI

This framework of the Malaysian ESI does not consider any exogenous energy shocks in the global market. It has been assumed that there are no significant shocks to any of the indicators such as supply disruption and import-export relation due to the current Covid-19 pandemic. Few important indicators like electricity tariff have been omitted from the affordability dimension solely due to the lack of data for the time frame chosen. Some indicators have met the criteria of policy relevance and stakeholder perspective and yet were omitted due to lack of data.

These limitations can be met and improved by the approach of system dynamics modelling of the ES scenarios to better understand the correlation of the indicators between different dimensions with each other. In a system's approach, the development of a causal relationship between the indicators holds the key role in determining the structure of the model. Also, this approach can make a futuristic forecast of the indicator performance.

6.9 Conclusion and Policy Implications

The key objective of developing the Malaysian ESI was to quantify the 5 dimensions selected to ensure that some robust decisions can be made to counter the ES challenges. The results suggest that the overall ES performance has improved from 4.88 in 2006 to 6.64 in 2018. The availability of energy and affordability of energy are the two most important dimensions playing a major role in indicating the overall ES performance. The overall performance of these two dimensions is not satisfactory despite been given heavy importance in all the energy policies since 1979 as discussed in Table 7. Availability of energy was at its best in the year 2015 which has seen a decrease in 2018 to 5.63 and the same trend for affordability with the best score of 8.82 in 2015 which decreased to 5.09 in 2018. This should be concerning for the policymakers because of the poor performance irrespective of their efforts to ensure a more upward growing curve for availability and affordability dimensions. More to our surprise and contradicting the stakeholder's opinion the environmental sustainability dimension has shown a gradual improvement after a slump in performance in 2010. This is an indication of the policies implemented well since 2010 and the trend suggests an upward growth from here on.

Stakeholders in this study have always believed that in a developing economy like Malaysia, the use of energy for boosting economic growth takes up the priority in the energy trilemma followed by equity and lastly environmental sustainability. The performance of applicability of technology and efficiency dimension will be the most important dimensions to look after in the future. This is to ensure more efficient technologies are available at our disposal and also to explore more indigenous energy resources for the future. One of the ways to reduce wastage of energy is to improve the efficiency to ensure energy consumption is reduced which in turn gives a better energy intensity. Accessibility of energy has been performing the best since 2016 and it is expected to maintain a high score in the future as well with more clean fuel access and 100% access to electricity for the Malaysian population.

To conclude this research, some policy considerations are suggested to improve the ES performance of Malaysia.

1. It is noteworthy that there is no policy as such in Malaysia that solely talks about the ES challenges and ways to mitigate them. Most of the existing policies discuss

different dimensions of ES and ways to improve them but do not mention energy security in their objectives. Including a separate policy in one of the futures “Malaysia Plan” that discusses solely these dimensions of ES might prove to be handy in keeping track of the overall ES performance of the nation. It is recommended to use a similar framework-based index like the ‘Malaysian energy security index’ in this research, to create more evidence and data-driven policies towards addressing the ES of Malaysia.

2. A broader balance needs to be created in the supply within the energy mix of Malaysia’s TPES or power generation. Diversification of fuel has been widely documented in existing energy policies like the Four-Fuel diversification policy and the Fifth fuel policy. These policies have either partially achieved or failed to achieve their outcomes as documented in Table 7. This is a reason why fuel sources like RE do not have a major share in the energy mix. Whereas the criticality of having renewable resources within the energy mix is unprecedented for the sustainability of the existing energy resources for Malaysia. It will contribute to lesser CO_2 emission and hence improving the environmental sustainability too. In Malaysia, the opportunities to explore more indigenous resources are much higher compared to neighbouring countries like Singapore. The efficient utilisation of these resources will hold the key towards an improved ES performance in the future by reducing dependency on fossil fuels and their reserves within the country.

3. There is room for improvement in energy efficiency and the energy optimisation structure. The energy policies are inclined towards the use of fossil fuels to meet the ever-increasing energy demand within the country. The use of conventional fuels is a cheaper alternative towards contributing to the economy, but they are not a sustainable solution. Hence, it is recommended to divert the policies towards lesser use of these fuels by substituting them with RE sources for the future. Energy efficiency will eventually improve with technological advancement through research and development within Malaysia. It can still be costly to acquire technology from other countries compared to developing them in Malaysia, hence it is recommended to invest more towards research and development to improve energy efficiency.

Lastly, the 5 dimensions discussed in this study are closely stitched to each other. Improved performance of one dimension eventually leads to the improvement of the other and vice-versa. The multi-dimensional analysis of Malaysia's ES using the Malaysian ESI in this research has the potential to facilitate the policymakers to document ES-based policies for the nation.

6.10 Chapter Summary

Over 90% of Malaysia's total primary energy supply comes from conventional fuels like coal, natural gas, and crude oil. The energy policy structure of Malaysia is inclined towards the use of fossil fuels to meet the ever-increasing demand for energy. This study has successfully quantified the ES of Malaysia using a 5-dimensional framework from the year 2006-2018. The overall energy security score has seen an improvement from 4.88 in 2006 to 6.64 in 2018 on a scale of 10. There was no significant improvement within the 5 dimensions of energy security. Few dimensions have deteriorated instead, indicating that there has not been much emphasis given to designing an energy security policy to address these issues. Malaysia needs security for its existing natural resources to ensure sustainable economic growth, at the same time mitigate the threats of decreasing reserves of fossil fuels and increased greenhouse gas emission. Few aspects that have performed well within this period are better access to energy within the nation and the emphasis on green technology policies and renewable energy policies to reduce overdependence on fossil fuels. The Malaysian ESI is feasible for research analysts and policymakers to design data-driven and evidence-based policies for the future of ES of not only Malaysia but other countries with a similar energy policy structure.

7 Conclusion

7.1 Interlinkages Between Research Objectives and Findings

Research Objective 1: Identification of Key Dimensions and Indicators of Energy Security

Through extensive stakeholder engagement, five key dimensions of ES were identified: Availability, Affordability, Accessibility, Applicability of Technology and Efficiency, and Environmental Sustainability. Each dimension was represented by specific indicators that reflect the overall ES status of Malaysia.

The identification of these dimensions and indicators laid the foundation for creating the Malaysian ESI and provided a structured approach to assess and compare ES performance. By establishing these dimensions, the research ensures that all critical aspects of energy security are considered, offering a holistic view of the nation's energy landscape. This comprehensive framework is essential for developing targeted and effective policies that address the unique challenges faced by Malaysia in its pursuit of energy security.

Research Objective 2: Creation of Causal Links Using System Dynamics Modelling

The SD approach enabled the development of causal loop diagrams (CLDs) and stock-flow diagrams (SFDs) that illustrated the intricate relationships between various ES indicators. Scenario analysis revealed the impact of different policy measures and external factors on the ES dimensions. This dynamic modelling provided a deeper understanding of how individual components interact within the energy system, highlighting potential feedback loops and long-term consequences of specific actions.

The causal links provided insights into how changes in one indicator affect others, helping to predict the outcomes of various scenarios and informing policy decisions. This understanding is crucial for policymakers to anticipate potential ripple effects of their decisions, allowing for more proactive and adaptive management of the energy system. Moreover, the SD modelling approach supports the identification of leverage points where interventions can have the most significant impact, thereby optimizing resource allocation and policy effectiveness.

Objective 3: Development of Malaysian ESI and Comparative Analysis

The Malaysian ESI was developed, normalising data across the identified dimensions and indicators. Comparative analysis showed Malaysia's ES performance relative to neighbouring countries, highlighting strengths and areas for improvement. This index serves as a critical benchmarking tool, enabling Malaysia to measure its progress over time and against regional peers, fostering a competitive and collaborative spirit in enhancing energy security.

The Malaysian ESI provided a quantitative measure to track progress, identify trends, and benchmark against other countries, facilitating targeted policy interventions. By offering a clear and objective assessment of Malaysia's energy security status, the ESI helps policymakers prioritize actions and allocate resources effectively. Additionally, the comparative analysis underscores the importance of learning from best practices and innovations in other countries, promoting a culture of continuous improvement and adaptation.

7.2 Significance of Research

The key research gap that was identified in this research was the lack of a measurement system for ES of Malaysia and other ASEAN member nations. Prior to the research conducted here, there were a handful number of studies that addressed Malaysia's ES as mentioned in section 1.2. The involvement of stakeholders and experts was the critical missing factor in most of Malaysia and ASEAN studies. This research has aimed to fill the gap and engage stakeholders and experts in multiple stages to collect high-quality primary data, validate the model created and framework developed. The overall validation process has also been consolidated through comparison of ESI's developed for Malaysia in this research and other peer research conducted in the similar field. The peer-review of published work in journals also provides an unbiased, impartial, and neutral feedback on the novel research findings. However, there are scope of further empirical validation of the work through Stakeholder Workshops involving stakeholders who are experts in the field to validate the methods, the data collected, sources of data and the final Malaysian ESI framework.

The Malaysian ESI developed in this research represents a significant advancement in measuring and understanding ES within a specific timeline and system boundaries. By utilising high-quality quantitative data sourced from government websites and portals, this research ensures a high level of confidence in the secondary data used. The incorporation of SD modelling, as detailed in Chapter 4, provides a comprehensive framework for assessing ES across Malaysia and its neighbouring countries. This approach not only measures the current state of ES but also predicts the outcomes of various scenarios, offering a robust tool for strategic planning and policy development.

Furthermore, the systematic methods outlined in Chapter 3 are a notable contribution of this research. These methods meticulously explain the research process and workflow, making them accessible and replicable for policymakers and decision-makers involved in energy policy formulation. The detailed and structured approach ensures that the research can be easily adapted and applied in different national or regional contexts, enhancing its practical utility.

The development of the 5-dimensional framework for the Malaysian ESI is another critical aspect of this research. By identifying key dimensions—Availability, Affordability, Accessibility, Applicability of Technology and Efficiency, and Environmental Sustainability—the framework provides a holistic view of ES. This comprehensive perspective allows policymakers to identify strengths and weaknesses within each dimension and develop targeted interventions. The framework's adaptability ensures that it can guide future work, supporting continuous improvement in energy security strategies.

This thesis aimed to explore and analyse the ES landscape of Malaysia by focusing on three main research objectives. These objectives were closely interlinked with the findings derived from the Malaysian ESI, scenario analysis using SD modelling, and comprehensive policy implications and recommendations. This chapter summarizes the key findings and highlights the connections between the research objectives and the results.

In summary, the significance of this research lies in its innovative approach to measuring and modelling ES, the replicable methodology, and the practical framework it provides for policymakers. By integrating high-quality data and advanced modelling techniques, this research offers a powerful tool for enhancing energy security in Malaysia and beyond. The insights and methods developed here have the potential to influence policy decisions, drive strategic planning, and contribute to the overall sustainability and resilience of energy systems.

7.3 Future Direction and Limitations

The research can be improved further through the engagement of more stakeholders from the ASEAN member countries to make the discussion more country-specific for better ESI development for each nation. This research is more focused on Malaysia's energy policies and structure rather than any other country, however, countries with similar energy outlooks can adopt these methods for developing a measurement system for ES. The other limitations lie within the SD modelling where hypothetical scenarios are designed to replicate the energy system. No system in terms of SD modelling will be perfect or accurate as there is no set system boundary or functional boundary within SD modelling. The boundaries are set based on the system being studied and the scenarios designed. Lastly, the data unavailability for a few indicators for certain years would lead to a discrepancy within the ESI level, however, the analysis is still accurate when the standard deviation and geometric mean are assessed to overcome the discrepancies. Finally, the validation stage for the final validation can be done by the ministry of energy and the regulatory bodies within Malaysia. The model can be studied to understand the correlations and causation are correct and the ESI level depicts the correct trend of ES as portrayed and analysed in this research.

The future direction of the research can be towards improving the framework through collaborative development through workshops with all the stakeholders involved in the project along with new experts and their opinions to avoid bias. Involving more stakeholders to check if there are new emerging themes and coding the SSI transcripts through one or more researchers to compare the codes and nodes of the interview transcripts. If new codes and themes emerges from 2nd or 3rd researcher or research group, then the dimensions can be re-designed to adopt to the changes. However, the current research has already seen a trend of data saturation, which gives the confidence that the current data is valid and complete with a scope of no new emergence of codes.

For the Malaysian ESI, this equal weighting approach is a simplification necessitated by the constraints of this study, including the lack of comprehensive stakeholder engagement to validate different weightages and the absence of comparative studies that provide a clear basis for differentiated weightage. While this may not fully capture the nuanced importance of each energy source, it ensures a straightforward and unbiased analysis across all dimensions.

Future studies could incorporate more sophisticated methods such as the "Ascending Scale" or "Entropy Method" to assign weightages to indicators based on their relative importance and impact. These methods can provide a more granular and accurate representation of the significance of conventional versus renewable energy sources. Engaging stakeholders through workshops and consultations can also offer valuable insights to validate the weightages and ensure that the model better reflects the priorities and realities of Malaysia's energy landscape.

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Appendix

The raw data for the 5 dimensions and their respective indicators are provided in the Tables 37-41 below. Figures 48-52 is the graphical representation of how the overall dimension score varied from 2006-2018.

Applicability of technology and efficiency

Table 37: Raw data of APE

Year	Energy Supply intensity Unit: (toe/GDP at 2015 Prices (RM Million))	Industrial energy intensity (toe/GDP 2015 RM million)	GDP at 2015 Prices (RM million)*	TPEC (Total primary energy consumption) MMBTU	TPEC/GDP (toe/GDP at 2015 prices RM million)
2006	50.04	45.13	770,698		
2007	50.79	47.14	819,242	6.8E+07	83.42
2008	48.87	46.04	858,826	7E+07	81.34
2009	48.29	46.53	845,828	7.1E+07	84.38
2010	45.65	41.69	908,629	7.5E+07	82.43
2011	45.42	44.22	956,731	7.7E+07	80.92
2012	48.85	49.23	1,009,097	7.8E+07	77.72
2013	48.83	46.31	1,056,462	8.3E+07	78.77
2014	46.62	41.2	1,119,920	8.7E+07	77.24
2015	44.04	40.12	1,176,941	8.3E+07	70.93
2016	46.55	47.23	1,229,312	8.4E+07	68.31

2017	48.04	54.82	1,300,769	8.8E+07	67.66
2018	47.44	58.1	1,362,815	9.6E+07	70.13

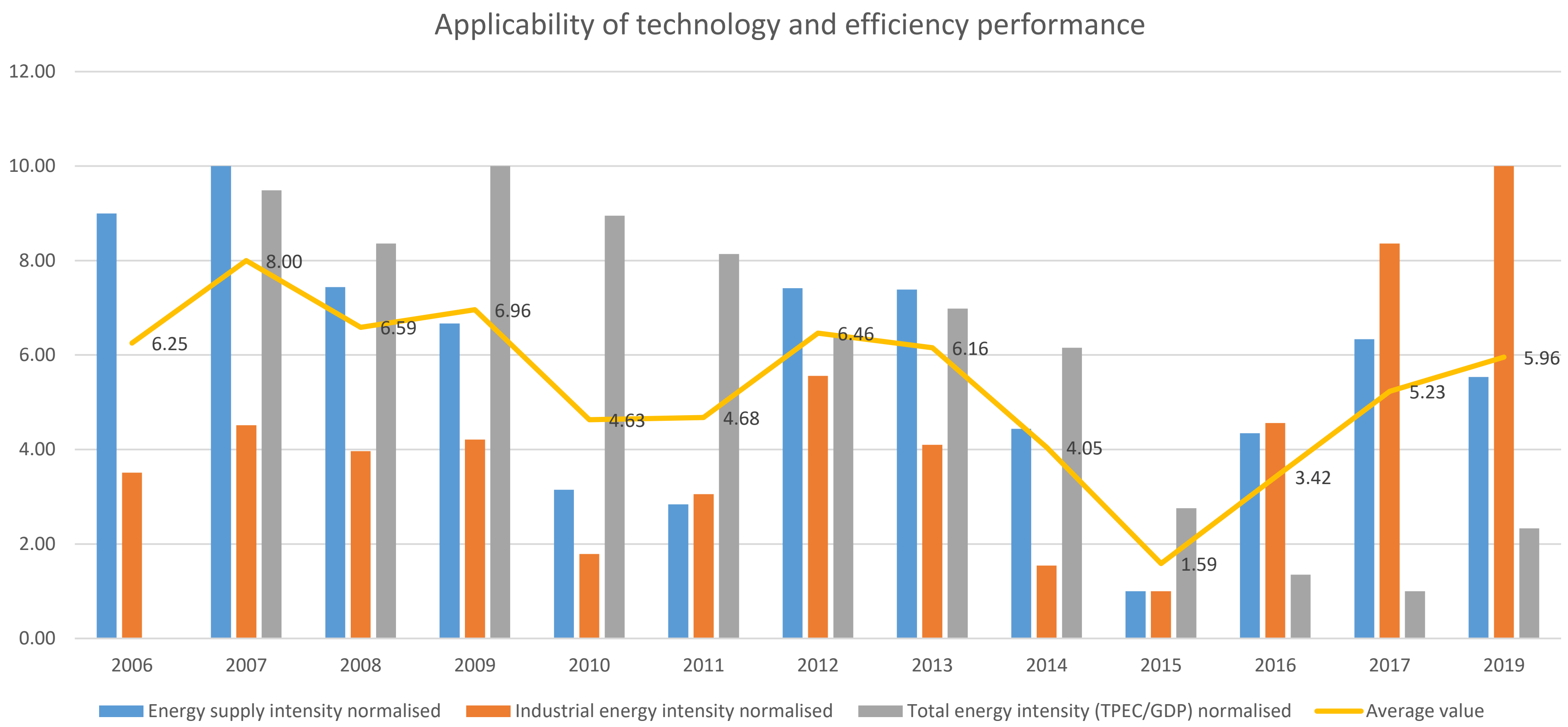

Figure 48: Normalised Data for APE dimension

Environmental Sustainability

Table 38: Raw Data for ENV

Year	CO2 emission (M mt)	GDP at 2015 Prices (RM million)*	TPEC (Quadrillion Btu)	Share of RE in electricity generation (%)	Population	Co2/pop	Co2/GDP	Co2/TPEC
2006	186.81	770,698		16.23	26,550	0.007036	0.000242	
2007	190.48	819,242	2.71	17.5	27,058	0.00704	0.000233	70.28782
2008	197.91	858,826	2.77	13.77	27,568	0.007179	0.00023	71.44765
2009	190.3	845,828	2.83	10.19	28,082	0.006777	0.000225	67.24382
2010	213	908,629	2.97	9.93	28,589	0.00745	0.000234	71.71717
2011	213.62	956,731	3.07	9.13	29,062	0.00735	0.000223	69.58306
2012	226.79	1,009,097	3.11	7.9	29,510	0.007685	0.000225	72.92283
2013	233.14	1,056,462	3.3	7.31	30,214	0.007716	0.000221	70.64848
2014	242.2	1,119,920	3.43	6.2	30,709	0.0078	0.00021	70.61224

						87	6	
2015	245.75	1,176,941	3.31	7.25	31,186	0.00788	0.000209	74.24471
2016	251.45	1,229,312	3.33	7.76	31,634	0.007949	0.000205	75.51051
2017	241.43	1,300,769	3.49	6.56	32,023	0.007539	0.000186	69.17765
2018	243.47	1,362,815	3.79	7.06	32,382	0.007519	0.000179	64.24011

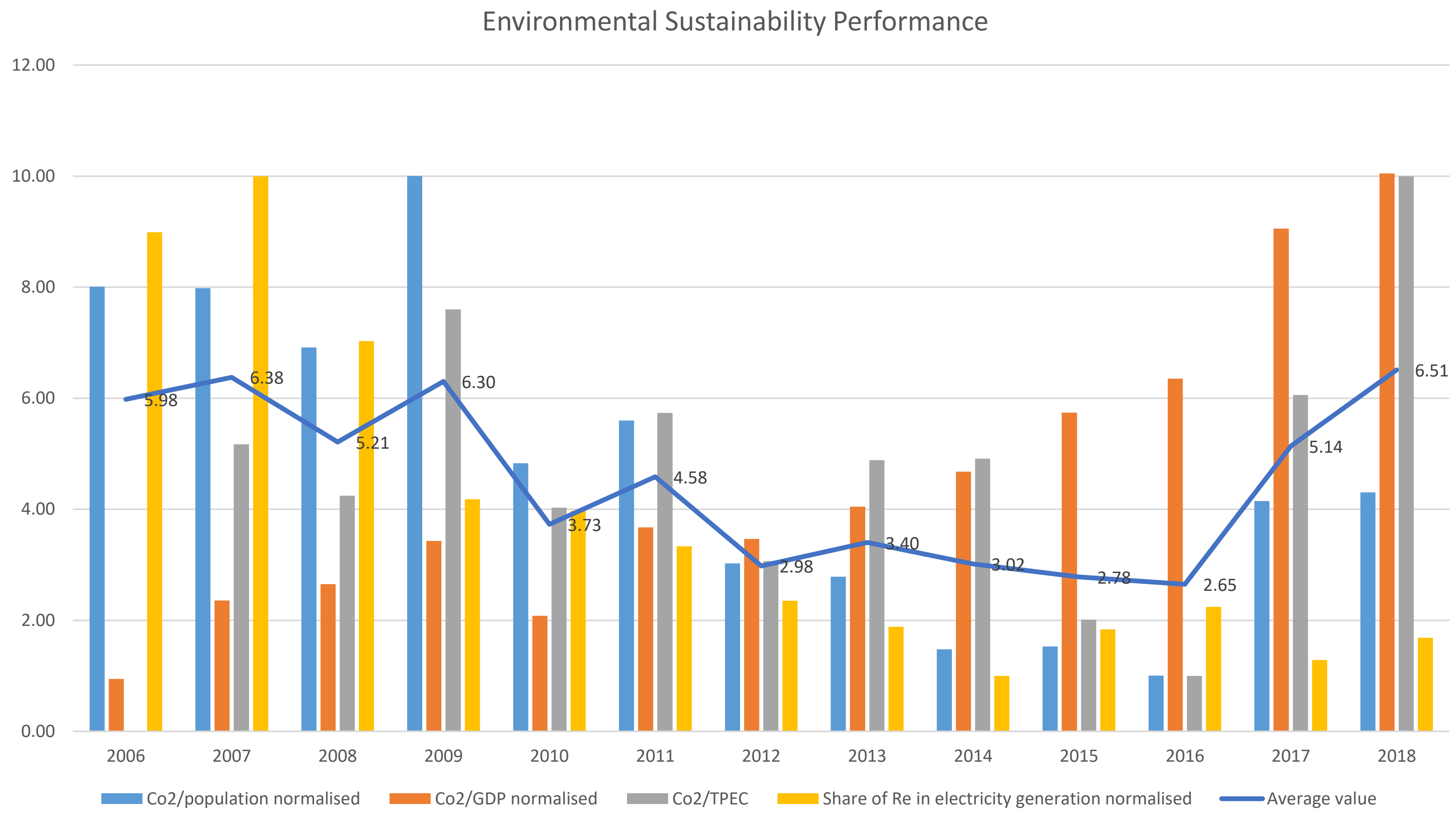

Figure 49: Normalised data for ENV dimension

Accessibility of Energy

Table 39: Raw Data for AC dimension

Year	Access to electricity (%)	Access to clean fuel and technology for cooking (%)
2006	98.242	96.32
2007	98.476	96.34
2008	98.729	96.46
2009	99.3	96.43
2010	99.289	96.47
2011	99.567	96.56
2012	99.8	96.62
2013	99.929	96.49
2014	99.986	96.38
2015	99.999	96.3
2016	100	96.3
2017	100	
2018	100	

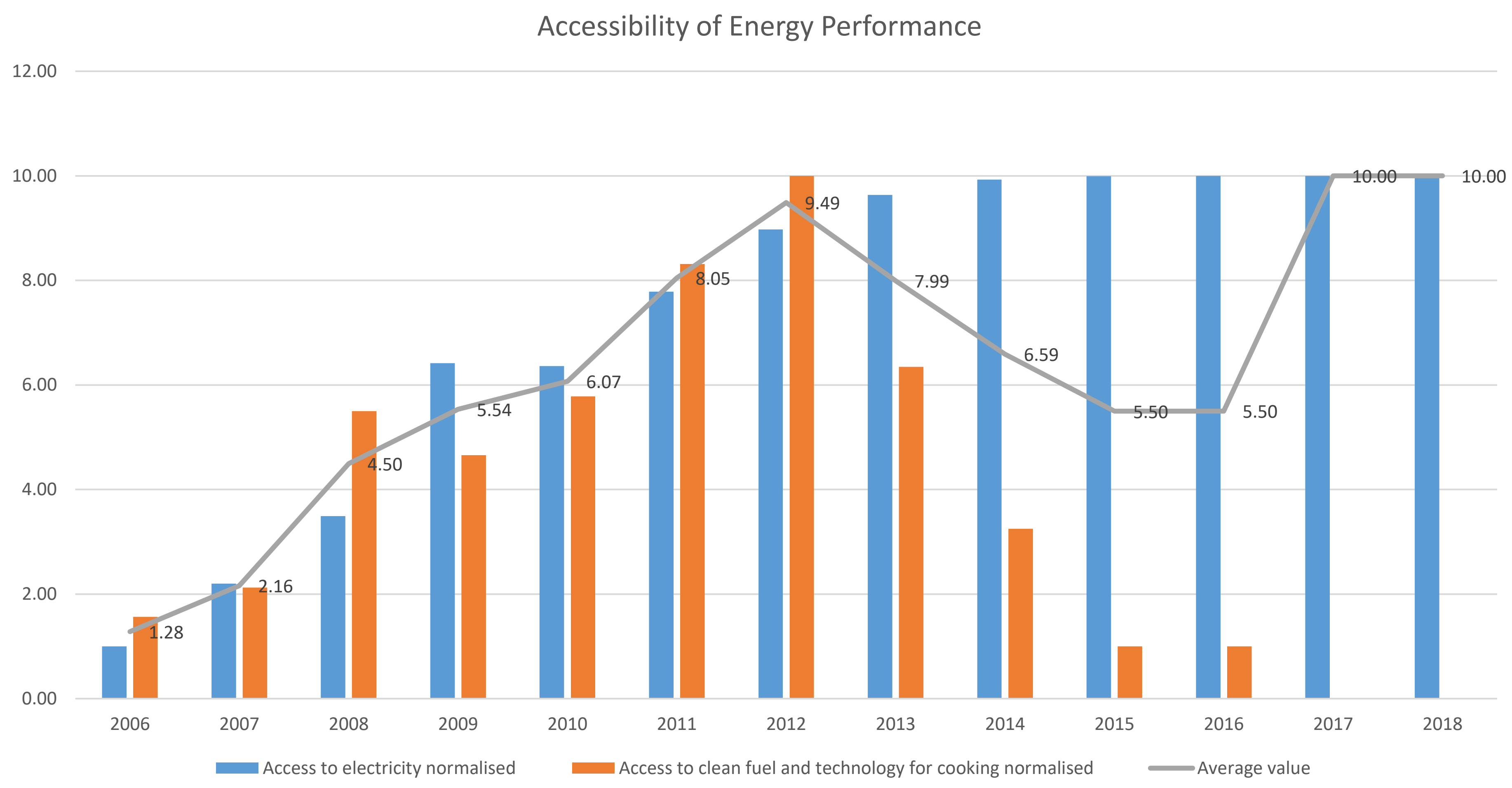

Figure 50: Normalised data for AC dimension

Availability of Energy

Table 40: Raw Data for AV dimension

Year	Population (POP) (‘000 people)*	Total primary energy supply (ktoe)	Reserve of crude oil and condensates (Billion Barrels)	Reseves of natural gas Trillion Standard Cubic Feet (TSCF)	Reseves of coal in (short tons)	Production of crude oil (ktoe)	Production of natural gas (ktoe)	Production of coal (ktoe)	Total energy production (Mtoe)
2006	26,550	67,021	5.254	87.95		34386	65752	569	92.23
2007	27,058	72,389	4.316	88.925	198.42	33967	64559	576	92.04
2008	27,568	76,032	5.458	88.01	198.42	34195	67191	791	95.22
2009	28,082	74583	5.517	87.968	198.42	32747	64661	1348	88.76
2010	28,589	76809	5.799	88.587	198.42	32163	71543	1511	88.39
2011	29,062	79289	5.858	89.988	198.42	28325	69849	1838	86.83
2012	29,510	86,495	5.954	92.122	198.42	29115	62580	1860	86.04
2013	30,214	90,730	5.85	98.32	198.42	28576	64406	1824	91.75
2014	30,709	92,487	5.792	100.662	198.42	29545	63091	1694	93.44
2015	31,186	92677	5.907	100.413	198.42	32440	67209	1614	95.22
2016	31,634	96525	5.03	87.762	198.42	33234	69673	1522	96.41
2017	32,023	98298	4.727	82.897	198.42	32807	71140	1884	95.84
2018	32,382	99,873							98.25

Year	TPES/POP	R/P crude oil	R/P of natural gas	R/P of coal	Total production/TPES
2006	2.52	0.000152795	0.001337602		0.001376136
2007	2.68	0.000127065	0.001377422	0.34447917	0.001271464
2008	2.76	0.000159614	0.001309848	0.25084703	0.001252367
2009	2.66	0.000168473	0.001360449	0.14719585	0.001190084
2010	2.69	0.0001803	0.001238234	0.13131701	0.001150777
2011	2.73	0.000206814	0.001288322	0.1079543	0.001095108
2012	2.93	0.000204499	0.001472068	0.10667742	0.00099474
2013	3.00	0.000204717	0.001526566	0.10878289	0.001011242
2014	3.01	0.00019604	0.001595505	0.11713105	0.001010304
2015	2.97	0.00018209	0.001494041	0.1229368	0.001027439
2016	3.05	0.000151351	0.001259627	0.13036794	0.000998809
2017	3.07	0.000144085	0.001165266	0.10531847	0.000974994
2018	3.08				0.000983749

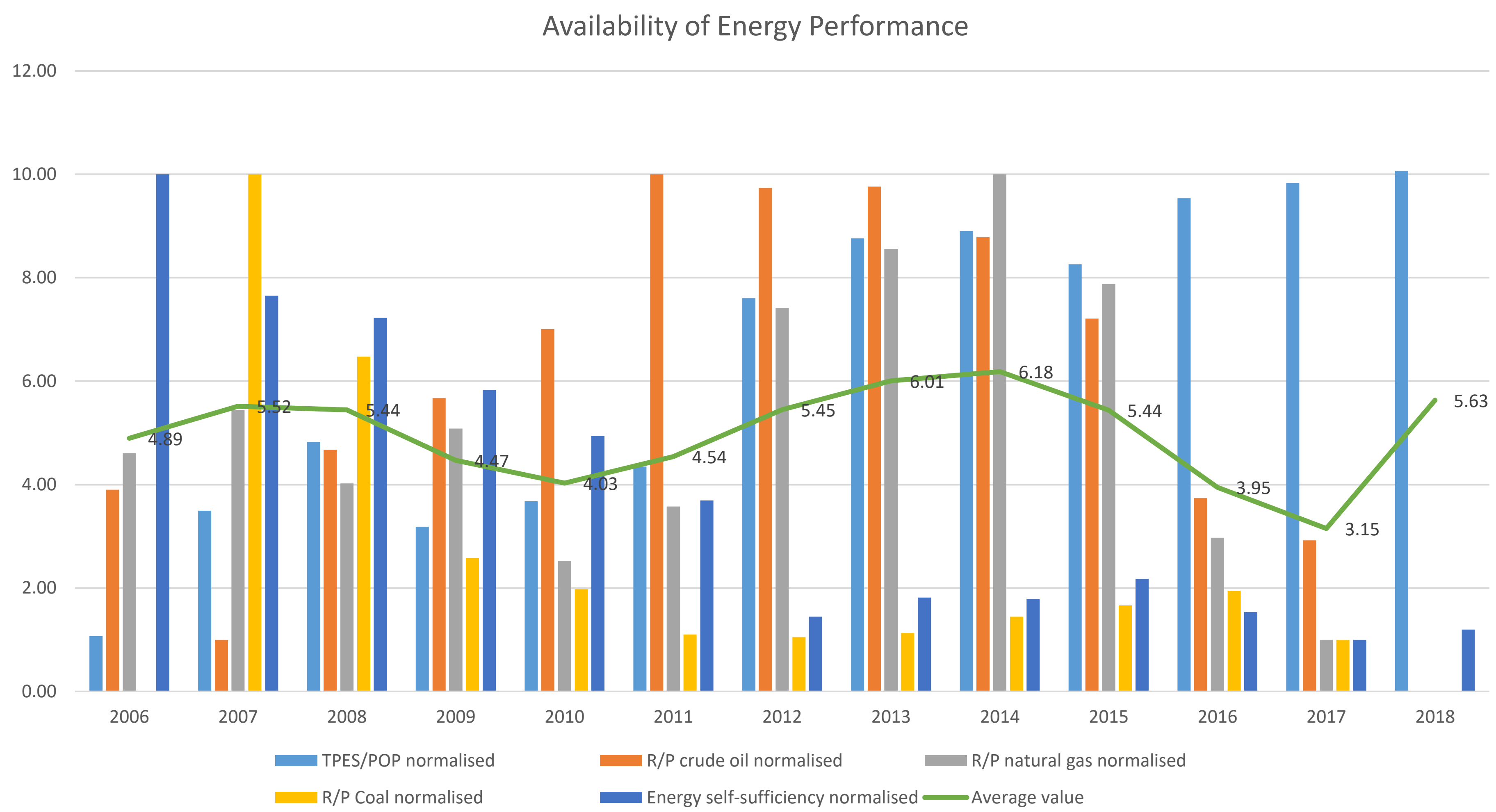

Figure 51: Normalised data for AV dimension

Affordability of Energy

Table 41: Raw Data for AF dimension

Year	GDP for industry, commercial, and residential sector	Population	Total final energy consumption (TFEC) (ktoe)	Price of crude oil in USD/barrel	Natural Gas price (henry hub)	GDP per unit energy PPP per kg of oil equivalent	Energy consumption per capita (TFEC/POP)
2006	406,056	26,550	38,567	69.14	6.73	7.615	1.452618
2007	417,734	27,058	41,606	78.56	6.97	7.392	1.53766
2008	420,639	27,568	41,968	102.37	8.89	7.414	1.522345
2009	395,287	28,082	40,845	64.56	3.94	7.684	1.45449
2010	424,530	28,589	41,476	79.1	4.39	8.086	1.450768
2011	438,593	29,062	43,455	114.92	4.01	8.165	1.495252

2012	456,449	29,510	49,291	116.21	2.76	8.464	1.670315
2013	471,292	30,214	51,583	113.95	3.73	7.857	1.707255
2014	495,773	30,709	52,209	101.83	4.35	8.153	1.70012
2015	518,360	31,186	51,829	45.37	2.62		1.661932
2016	532,752	31,634	57,219	45.38	2.56		1.808782
2017	559,204	32,023	62,489		3.02		1.951379
2018	573,670	32,382	64,658		3.13		1.996727

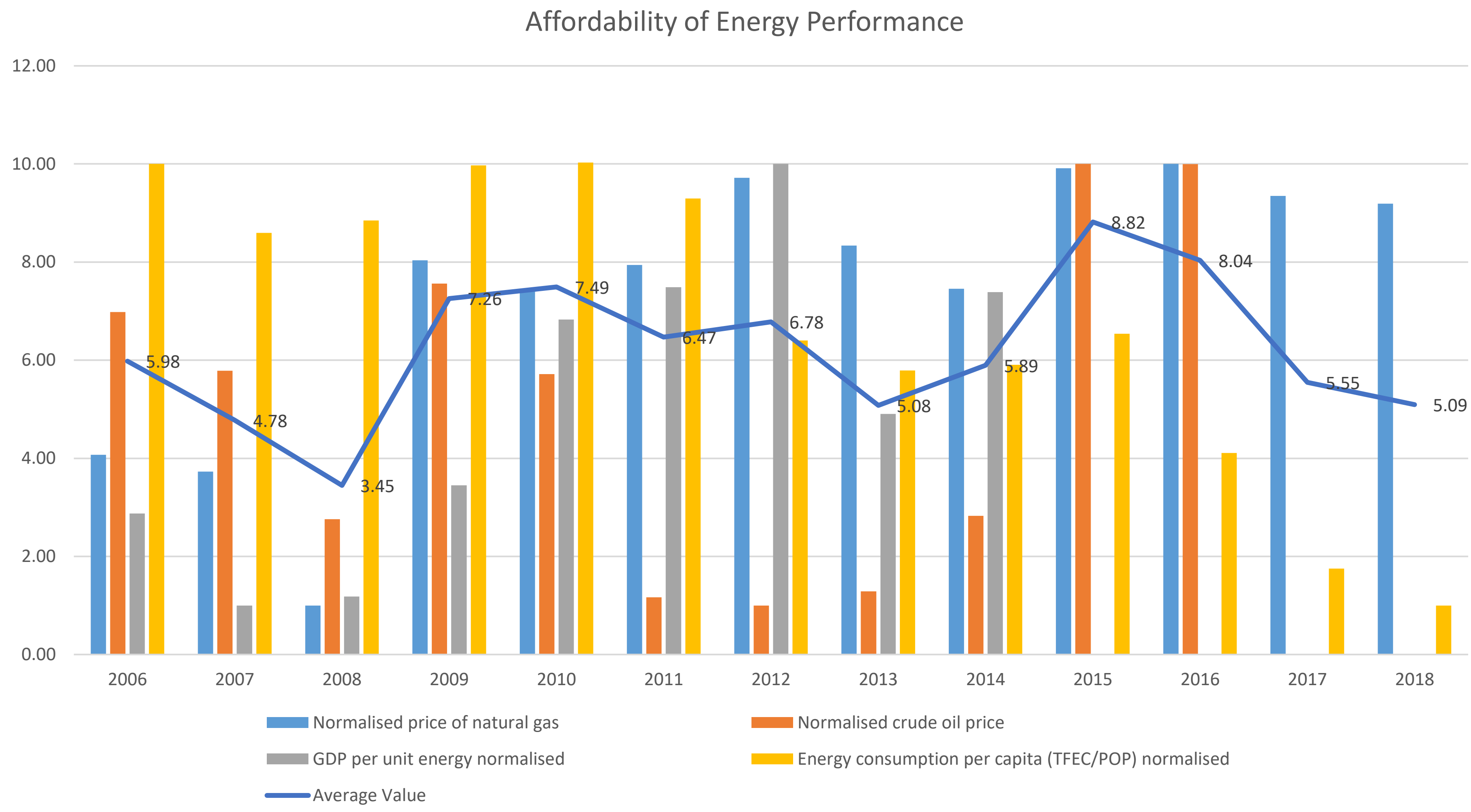

Figure 52: Normalised data for AF dimension