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Developing and Evaluating the Sustainable Energy Security Index and its Performance in Malaysia

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ABSTRACT

There is an increasing interest in understanding the crucial factors of sustainable development in terms of security of supply, conservation, and environmental impacts. Based on the current energy perspectives, there are serious challenges in achieving energy security and sustainability. Sustainable energy security (SES) must not only consider the security of energy supply-demand in the long-term and short-term, but also emphasise the balance between energy, economy, social, and environmental factors. Based on the five dimensions of energy security (availability, accessibility, affordability, acceptability, and develop-ability), this study aims to develop and evaluate SES index for Malaysia. The weight of energy security indexes was determined using the entropy weight method. Also, the security and rank performance of the five dimensions of energy security and sustainability were calculated using the Technique for Order of Preference by Similarity to Ideal Solution method. Then, the five dimensions' scores between 2005 and 2016 were measured. The results reveal that the weight of develop-ability and affordability were the most important weights in Malaysia's SES index system. This implied that the energy supply security greatly influenced the SES of Malaysia. In addition, the highest score in develop-ability reflected the sustainable development capacity of the energy system in low carbon, clean, and optimised mode, which plays a crucial role in Malaysia's energy sustainability. The results also reflected the affordability and ability to resist the negative impact of rising energy prices in Malaysia.

Keywords: Energy Security, Sustainability, Performance, Ranking, Weight Entropy Technique, Technique for Order of Preference by Similarity to Ideal Solution Model, Malaysia
JEL Classifications: N75, Q41, Q56

1. INTRODUCTION

Since the 1970s, most studies on energy security focused on the instability of oil prices and geopolitical supply tensions (Winzer, 2012; Kruyt et al., 2009; Dyer and Trombetta, 2013; Bekhet and Yusop, 2009; Downs, 2004). This is because an increase in oil price can affect the energy security of many countries. In 1973 and 1979, the Organization of Petroleum Exporting Countries oil embargo demonstrated the great attention given to energy security and the concern continued to grow during the rapid oil price increases in 2004 (Asia Pacific Energy Research Centre [APERC], 2007; Wesley, 2007). Meanwhile, in the 1990s, maintaining energy supplies and its perceived threats and risks to national security became a great concern for politicians, governments, and various energy-related agencies due to the high dependency on a few oil-producing countries (International Energy Agency [IEA], 2007). This brought about the introduction of energy diversification policies (i.e. five-fuel diversification policy and renewable energy policy), which were specifically designed to reduce the risk of dependency on fossil fuel resources and switching to other energy resources.

In defining energy security, some researchers focused on the security of supply aspects such as energy availability and prices (Spanjer, 2007; Jamasb and Pollit, 2008), whereas others argued for a more comprehensive definition that includes downstream effects like the impact on economic and social welfare (Vivoda, 2010). As energy technologies advanced, awareness of climate change and sustainability increased, and the relevant facets of energy security were reshaped (Ang et al., 2015). Despite the varying definitions of energy security, there seems to be a consensus among researchers that the security of energy involves risks (Rutherford et al., 2007; Ölz et al., 2007; Wright, 2005; Keppler, 2007).

In the late 2000s, the concept of sustainable energy security (SES) emerged and became a global policy interest due to the recent economic and environmental policy, which emphasised on global warming, climate change, and sustainable development. Sustainability can be defined as the ability to meet the demand for energy service needs in reliable circumstances through a great period (The Cambridge-MIT Institute, 2006). Since then, the energy security concept experienced evolution, whereby its scope and definition have varied over time (Ang et al., 2015). Moreover, energy security has become an important aspect of sustainable development in modern society. On the other hand, SES is defined as "provisioning of uninterrupted energy services in an affordable, equitable, efficient, and environmentally benign manner" (Narula and Reddy, 2015). The sustainable security of energy has become an end goal of every country's energy policy. By considering the differences in energy systems between different countries and regions, scholars have assessed energy security at different levels and from different perspectives (Bekhet and Sahid, 2016; Fang et al., 2018). Nevertheless, SES must not only consider the security of energy supply-demand in the long-term and short-term, but also emphasise the balance between energy, economy, social, and environmental aspects. Indeed, energy security is strongly related to other policy issues that concern energy system (such as affordable energy, climate change, and environmental policy). This implies that it is imperative to examine the energy security consequences of different development pathways (Kruyt et al., 2009). Although the term "energy security" is widely used, the interest in investigating the methodology for evaluating energy security performance together with sustainability is low. Besides including harmonisation and sustainability of energy, economic, social, and environmental development, the high efficiency and diversity, and degree of vulnerability of the energy system due to political instability and international risk exposures should also be incorporated. Moreover, given the increasingly interconnected energy systems in the world and Asia in particular, an energy security framework must consider the reactions in other geopolitical areas, diversification of supply, vulnerable risks, and impact on national energy systems. Thus, based on the above definition of SES, this paper aims to develop a framework for the SES index to evaluate Malaysia's SES performance.

The rest of this paper is structured as follows. Section 2 discusses some findings from the literature, while section 3 presents the Malaysian framework of SES. Section 4 describes the data sources and methodology. In section 5, the empirical results and sensitivity analysis are presented. Finally, conclusion and policy implications are discussed in section 6.

2. LITERATURE REVIEWS

Energy security is an important issue in many countries. Various dimensions and numerous definitions of energy security have been covered in the literature. In the 1970s, after the first oil crisis, IEA (2007) proposed a national energy security concept on "stabilising crude oil supply and crude oil prices." Interest in energy security is based on the notion that uninterrupted supply of energy is critical for the functioning of an economy (Kruyt et al., 2009). The definitions and dimensions of energy security appear to be dynamic and evolve as circumstances change over time (Ang et al., 2015). For instance, Winzer (2012) defined energy security as "continuity of energy supplies relative to demand." On the other hand, APERC (2007) defined energy security as the "ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy." Furthermore, APERC has identified three main elements of energy security, namely, physical (availability and accessibility of resources), economic (affordability of resource acquisition and energy infrastructure), and environmental (acceptability of resource supply). Nevertheless, an exact definition of energy security is hard to be derived as it has different meanings to different people at different times (Alhajji, 2007). New approaches to energy security have emphasised on the need to take into further consideration the environmental and social aspects (Sovacool, 2013). Thus, the concept and definition of energy security have widened over time. In this century, factors that affect fuel supply stability and increase energy price have been added to the previous energy security definition. These factors include political conflicts, unexpected natural disasters, concern on terrorism, and energy-related environmental challenges (APERC, 2007).

Besides the issues of definition and conceptualisation of energy security, there has also been an increasing interest among policymakers and researchers in evaluating the performance of energy security using indicators and indexes. Based on a review of relevant literature, various studies have proposed a wide variety of energy security indexes (ESIs), either to compare performance among countries, regions or to evaluate changes in a country's energy security performance over time. Most existing studies have established an index system to evaluate energy security performance because a single indicator cannot reflect the actual energy situation (Fang et al., 2018). Hughes (2012) suggested that research on energy security should begin with the 4 Rs, i.e., review, reuse, replace, and restrict. Meanwhile, Kruyt et al. (2009) proposed four main elements of energy security, which were availability of energy to the economy, accessibility which involves acquiring access by geopolitical implications, cost element of energy security, and environmental sustainability. In addition, APERC (2007) classified four main elements concerning SES, namely, availability that relates to geological existence, accessibility that relates to geopolitical elements, affordability that relates to economical elements, and acceptability that relates to environmental and societal elements. Apart from that, Sovacool (2013) extended the concept of energy security by a comprehensive consideration of "demand side" and "governance." They developed an ESI consisting of five dimensions, i.e. availability, affordability, efficiency, sustainability, and governance. Later, IEA (2004) developed short-term and long-term approaches to energy security, whereby energy security was defined as "an interrupted availability of energy sources at an affordable price." The short-term approach considers energy security as the system's ability to meet a country's energy needs, in which the absolute focus in on the security of supply (Sovacool and Mukherjee, 2011; Kanellakis et al., 2013).

On the other hand, Ang et al. (2015) introduced seven dimensions of energy security, which were availability, infrastructure, energy prices, social effects, environment, governance, and energy efficiency, which covered almost all aspects of the energy system. In developing countries, Narula and Reddy (2015) divided the energy system into supply, conversion, distribution, and demand subsystems, and the four dimensions of SES (availability, affordability, efficiency, and acceptability) were further evaluated for each subsystem using quantitative metrics. The sustainable dimension was proxied by the develop-ability dimension (Narula and Reddy, 2015). This was followed by data collection and normalisation, weighting and aggregation of the chosen indicators to produce one or more composite ESIs. A review of previous energy security studies revealed some gaps and overlapping in the choice of indicators and indexes, as well as how such composite ESIs are developed. As the aim of this study is to develop an SES index, the definition, indicators, and SES framework by Fang et al. (2018), APERC (2007), Narula and Reddy (2015), Ang et al. (2015), and Sovacool (2013) were chosen as the framework to achieve the research objective. Therefore, five dimensions of indicators that have been identified, i.e. availability, accessibility, affordability, acceptability, and develop-ability, were selected to construct Malaysia's SES index. In next section, the framework of this index is discussed.

3. SES FRAMEWORK

Based on the linkages and overlaps between energy supply-demand dimensions and the dimensions of environmental sustainability and sustainable development, a framework for evaluating and measuring the relative attributes of different approaches to energy sector development is highly needed. Such a framework should be designed to help identify the relative costs and benefits of different possible future scenarios driven by suites of energy and other social policies. Based on the energy supply-demand itself, as well as its interactions with the economy, social, and environmental aspects, the framework is developed. As such, the entropy-weight Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, which is an objective evaluation method, is used to build an evaluation model to assess Malaysia's SES index. In this paper, the evaluation criteria is adopted from the real evaluation system, which can truly reflect Malaysia's SES index performance. Five main dimensions with 15 sub-indicators were proposed to develop Malaysia's SES index. Details of the indicators, equations, and data sources are tabulated in Table 1.

3.1. Availability (A1)

There are three sub-indices under availability dimension, which are A11, A12 and A13 (Table 1). A11 index is represented a national energy supply capacity and equality resources. While A12 index is energy reserve-to-production ratio which represents the weighted average of the reserve to-production-ratio of main energy sources, such as oil, natural gas and coal, and the weight value is the corresponding variety's share in the total primary energy supply. This indicator indicates the years of production left at current production level. The third one is energy self-sufficiency ratio (A13). This ratio has been used to compute the weighted average of the self-sufficiency ratio of energy sources such as natural gas, oil, natural gas, primary electricity power, and employs the variety's share in total primary energy supply as the weight value. These sub-indicators are positive indexes, which is the more is the better.

3.2. Accessibility (A2)

The accessibility dimension reflects the possibilities of energy supply in the transport channel and geopolitical aspects (Fang et al., 2018). This includes providing stable and uninterrupted energy supply from grid connection to people as well as oil and

Table 1: Framework of Malaysia's sustainable energy security index

Dimension	Indicator	Index	Equation (per year)	Objectives/target
Availability (A1)	Total primary energy production	A11	TPEP/population	+
	Energy reserve-to-production ratio	A12	Weighted average of reserve-to-production ratio of fossil energy	+
	Energy self-sufficiency ratio	A13	Weighted average of energy self-sufficiency ratio every kind of energy	+
Accessibility (A2)	Access to electricity	A21	Access to electricity rate (%)	+
	Crude oil market concentration risk	A22	Political risk coefficient of the importing country times with crude oil import share in Malaysia's total crude oil supply	+
	Oil market liquidity	A23	World oil exports/Malaysia's oil imports	+
Affordability (A3)	Domestic fuel price fluctuation ratio	A31	Fluctuation ratio of domestic retail price index of fuel goods	−
	Crude oil price fluctuation ratio	A32	Average crude oil price fluctuation ratio	−
	GDP per capita	A33	GDP/average population	+
Acceptability (A4)	Share of non-fossil energy	A41	Non-fossil energy consumption/TPEC	+
	Energy intensity	A42	TPEC/GDP	−
	Carbon emission intensity	A43	CO_2 emission/GDP	−
Develop-ability (A5)	TPEC per capita	A51	TPEC/Average population	−
	Carbon emission per unit energy consumption	A52	CO_2 emission/TPEC	−
	Energy diversification index	A53	Shannon-Weiner index	+

Source: APERC (2007), Narula and Reddy (2015), Ang et al. (2015), Sovacool (2013) and Fang et al. (2018). TPEC: Total primary energy consumption gas transportation through pipeline. The reliability of power system is crucial to prevent shortage of supply. In these regards, the percentage population or electricity customers to the electricity or electrification access (A21) and crude oil market concentration risk, COMCR (A22) are included. Gupta (2008) highlighted that the geopolitical risk can be described as oil market concentration risk and oil market liquidity (OML). In addition, IEA (2007) and Fang et al. (2018) proposed energy security market concentration and ESI to measure the market power in assessing interaction between energy security and climate policy. Following above studies, the crude oil market concentration risk (A22) and OML (A23) indicators are adopted and written as follow:

$$\text{A22} = \sum_{i=}^{N} r_i \times p_i^2$$

where r_i is the political risk coefficient of the importing country; and p_i represents crude oil import share in Malaysia's total crude oil supply and i (i = 1, 2, 3, 4) is the top four countries of Malaysia's crude oil imports (UAE, Kuwait, Qatar, and Saudi Arabia). In order to derive the value of r_i, the data of the political stability, absence of violence/terrorism index and the regulatory quality index were taken from the "2018 Worldwide Governance Indicators Report" by the World Bank. Since a high score indicates a high energy-security risk, COMCR is a negative indicator. The crude oil import data used for this indicator was taken from Malaysia energy information hub (MEIH) database. While for A23, the data of world oil exports and Malaysia's oil imports data were taken from MEIH. A23 index is a positive indicator as a higher OML is conducive to reduce the risk of supply market concentration and improving energy security.

3.3. Affordability (A3)

Affordability reflects the possibilities of energy supply economically (APERC, 2007; Fang et al., 2018). The "provision adequate and uninterrupted supply at reasonable price" is the earliest and primary meaning of energy security (Daniel, 1988). The prices refer to both domestic and import energy (Fang et al., 2018). This dimension is covered by three indicators. The first one is domestic fuel price fluctuation ratio (A31) which calculated through retail price index of fuel commodities. The greater the fluctuation of domestic fuel price ratio, the lower the stability of energy security, so it is a negative impact indicator (Fang et al., 2018). Second is crude oil price fluctuation ratio (A32). It is defined as average value of the Dubai, Brent, and West Texas intermediate crude oil prices published on 2014 by "BP Statistical Review of World Energy" (Dudley, 2015). The third one is GDP per capita (A33) which reflects an individual's ability to pay. The higher the per-capita GDP, the stronger the ability to resist the negative impact of rising energy prices. Therefore, the A33 is a positive indicator.

3.4. Acceptability (A4)

Acceptability reflects the impact of energy production and utilisation on the economy and the environment (Fang et al., 2018). The main concern of acceptability dimension is the interaction between energy, economy and environment (i.e., energy structure changes towards low carbon and improvement in energy efficiency). Thus, three indicators have been identified under this dimension. Firstly, is the share of non-fossil energy consumption (A41). This share is represented by the ratio of non-fossil energy consumption to total primary energy consumption (TPEC). Second is energy intensity (A42). It represents by the ratio of TPEC to GDP. The decline in energy intensity indicates an increase in energy efficiency and has positive effects on energy security, so it is a negative indicator. Lastly, is the carbon emission intensity (A43). The development of the low-carbon economy is the consensus of all countries around the world. In environmental perspectives, the decline in carbon emission intensity is the better of energy security performance, thus A43 index is a negative indicator.

3.5. Develop-ability (A5)

Following Narula and Reddy (2015), the develop-ability index has been used to measure the sustainability dimension. In this regards, three indicators have been identified to define the sustainability dimension. The first one is TPEC per capita (A51). It measures the ratio of TPEC to the average population. This ratio reflects individual energy consumption level. The raise in TPEC per capita will increase the risk of energy security, so it is a negative indicator. Next is carbon emission per unit energy consumption (A52). It represents by the ratio of CO_2 emissions to TPEC. It reflects the relationship between energy structure and carbon emission through the consumption of fossil energy i.e. oil, gas and coal for power generation and combustion, thus it is a negative indicator. Lastly, is energy diversification index (A53). Energy security indicator (ESI) developed by IEA (2004) was adopted to measure the diversification of primary energy demand by modifying the Shannon-Weiner Index (SWI) and a diversity index used to measure biodiversity. This index was utilised since it considers both the significance of diversification in terms of abundance and equitability of sources. The indicator, adapted from this index is shown below:

$$SWI = -\sum_{j=1}^{m} \tau \ln \tau_j$$

where τ_j represents the share of coal, oil, natural gas and primary electricity consumption in relation to total energy consumption. The final value acquired from this indicator is normalised on a (0-1) scale. A value close to zero implies that the economy is dependent on one energy source and a result close to 1 implies that the economy's energy sources are evenly distributed among the main energy sources. Thus, a lower SWI value reflects a higher risk of energy supply security. Since the diversification of energy consumption can reduce the vulnerability and insecurity of excessive dependence on an energy source, the diversification index is a positive indicator.

4. DATA SOURCES AND METHODOLOGY

4.1. Data Sources

This study used economic, energy system, environmental, and demographic data between 2005 and 2016. GDP data were based on the real 2005 GDP price index, and the unit was in million USD. Also, the total primary energy production and consumption, and final production and consumption by types of energy were based on the unit of million tonnes of oil equivalent. On the other hand, Malaysia's oil and crude oil import and export were measured in the unit of USD per barrel of oil equivalent. All energy, economic, and demographic data were retrieved from the MEIH database, while raw political risk coefficient data were extracted from the World Bank Reports. The political risk coefficient data were utilised to estimate the crude oil market concentration risk to reflect the influence of geopolitics risk on energy security.

4.2. Methodology

The entropy weight and TOPSIS methods are used to develop Malaysia's SES index and to evaluate its performance. The TOPSIS method developed by Hwang and Yoon in 1981 was adopted for this study. It was proposed as an alternative method to the ELECTRE model by Yoon and Hwang (1981). In 1987, it was modified by Yoon (1987) and then by Hwang et al. (1993). TOPSIS is a technique to evaluate the performance of alternatives through similarity with the ideal solution. This method is based on the idea that when an alternative has the shortest distance to the ideal solution, it can be considered as the best one (Zavadskas et al., 2014; Behzadian et al., 2012; Bhuyan and Routara, 2016). Besides that, TOPSIS allows trade-offs between criteria, whereby a poor result in one criterion can be negated by a good result in another criterion (Hwang and Yoon, 1981; Zavadskas et al., 2014). In other words, TOPSIS method attempts to choose alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Behzadian et al., 2012; Bhuyan and Routara, 2016). This solution consists of all the best (maximum) attribute values that can be achieved, whereas the worst (minimum) solution consists of all the worst obtainable attribute values (Bhuyan and Routara, 2016; Hwang and Yoon, 1981). Therefore, the goal is to propose a solution with the shortest distance to the ideal solution within the Euclidean space (Streimikiene and Balezentiene, 2012). TOPSIS method makes full use of the attribute of information, provides a cardinal ranking of alternatives, and does not require attribute preferences to be independent (Chen and Hwang, 1992; Yoon and Hwang, 1995). To apply these techniques, attribute values must be numeric, monotonically increasing or decreasing, and have commensurable units (Behzadian et al., 2012). Furthermore, the entropy weight method is a common objective weighting method that has been widely used in TOPSIS (Fang et al., 2018). This method reflects the importance of indicators by calculating the difference between the numerical values of the objective indicators (MacCrimmon, 1968). The greater the difference, the larger the weight, and vice versa. Besides, for every indicator in the same dimension, its weight can be obtained via the entropy weight method. Hence, in this study, the entropy weight and TOPSIS methods were combined to establish the Entropy-Weight TOPSIS evaluation model. Hwang and Yoon (1981) and MacCrimmon (1968) introduced seven stepwise procedures to evaluate the TOPSIS model. Mathematically, these steps can be summarised as follows:

4.2.1. STEP 1: Create an evaluation matrix

The TOPSIS method creates an evaluation matrix, X_{ij}, consisting of m alternatives ($A_1, A_2, \ldots, A_m$) that are evaluated by n attributes ($C_1, C_2, \ldots, C_n$), can be viewed as a geometric system with the m-points in n-dimensional space (Kabir and Hasin, 2012). An element of the matrix (X_{ij}) indicates the performance rating of the i^{th} alternative, A_i, with respect to the j^{th} attribute, C_j, as shown in Eq. (1).

$$\begin{matrix} & C_1 & C_2 & \cdots & C_n \end{matrix}$$

$$X_{ij} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where attributes (C_j, $j = 1, 2, \ldots, n$) should provide a means of evaluating the levels of an objective. A number of attributes can characterize each alternative. Alternatives (A_i, $i = 1, 2, \ldots, m$) are mutually exclusive of each other.

4.2.2. STEP 2: Standard normalization matrix calculation

This step transforms various attribute dimensions into non-dimensional attributes, which allows comparison across criteria (Roszkowska and Wachowicz, 2015). To eliminate the influence of each dimension on incommensurability, (Li et al., 2011) suggested that it is necessary to standardize or normalize the matrix, X_{ij} (Eq. 1). Under this procedure, the X_{ij} matrix is normalized which represents by r_{ij} to form the matrix $R = (r_{ij})$. Using the normalization method, the vector normalization approach divides the rating of each attributes by its norm to calculate the normalized value of X_{ij}. Thus, the normalized value is scaled from 0 to 1 and calculated as in Eqs. (2,3), respectively.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i}^{m} x_{ij}^2}} \quad (i = 1, 2, \ldots, m;\ j = 1, 2 \ldots, n) \quad (2)$$

Then, we can write the R_{ij} matrix as in (Eq. 3).

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (3)$$

4.2.3. STEP 3: Calculate the weight of ESI

The next step is to put weight on each attribute. The weight of each index is determining through entropy weight method. It represents useful information of the evaluation index. The weight values (w_j) represent the relative importance of each attribute to the others (Kabir and Hasin, 2012). Therefore, the bigger the entropy weight of the index is the more useful information of the indexes and vice versa (Li et al., 2011). The information entropy, e_j, represents the disorder degree of information and the greater the information entropy, the smaller the contribution of the attribute index to the energy security evaluation. On the contrary, the greater the contribution will be. Following Shannon entropy method (Shannon, 1948), the calculation of entropy weight of ESI process is calculated as follows.

i) Eq.4 is used to calculate the proportion, p_{ij}, of index value of i under index j

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad (i = 1,2,\ldots,m; j = 1,2\ldots,n) \tag{4}$$

ii) Eq.5 is applied to measure the entropy "e_j" of evaluation index.

$$e_j = -k \sum_{(i=1)}^{m} p_i j. \ln p_{ij} \tag{5}$$

Where e_j represents the entropy of indicator j with k and the p_{ij} is the proportion of samples in time t in the j indicator. Where "k" can be calculated as in (Eq. 6),

$$k = \frac{1}{ln\, m} \tag{6}$$

iii) While Eq. 7 is employed to calculate the entropy weight "w_j" of index j

$$w_j = \frac{(1 - e_j)}{\sum_{j=1}^{m} (1 - e_j)} \qquad j = 1, 2\ldots,n \tag{7}$$

where, $0 \leq w_j \leq$ and $\sum_{j=1}^{m} w_j = 1$

4.2.4. STEP 4: Form the weighted standardization decision matrix

Eq. 8 is used to form this matrix, V_{ij}. This can be done by multiply each of the normalized decision matrix, R_{ij} (Eq. 3) by its associated weight, w_j (Eq. 7).

$$v_{ij} = \begin{bmatrix} w_{1r_{11}} & w_{2r_{12}} & \cdots & w_{nr_{1n}} \\ w_{1r_{21}} & w_{2r_{22}} & \cdots & w_{1r_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ w_{1r_{m1}} & w_{2r_{m2}} & \cdots & w_{nr_{mn}} \end{bmatrix}$$

(i, j as defined before)

4.2.5. STEP 5: Calculate the ideal solution or optimal value

In this step, we determine the ideal solution, "V^+" and the anti-ideal solution "V^-." According to standardized values of the "V_{ij}" of weight (Eq. 8), the "V^+" and "V^-" values are calculated as in Eqs. (9-10).

$$V^+_j = \max \{v_{ij}|1 \leq i \leq m\},\ V^-_j = \min\{v_{ij}|1 \leq i \leq m\} \tag{9}$$

$$V^-_j = \min \{v_{ij}|1 \leq i \leq m\},\ V^-_j = \max\{v_{ij}|1 \leq i \leq m\} \tag{10}$$

Where,

$V^+_{j=}$ {j = 1, 2,…, n; j associated with benefit, positive criteria or optimal value}.

V^-_j = {j= 1, 2,…, n; j associated with cost, negative criteria or negative impact}.

While j^+ (Eqs. 9 and 10) represents the most optimal value of index j is a probability index set; so "j^-" (Eqs. 9-10) represents the worst value of index j is a loss index set.

4.2.6. STEP 6: Calculate the Euclidean distance

Hwang and Yoon (1981) originally proposed Minkowski's metric to calculate the distance between target alternatives, V_{ij} and the worst condition. While MacCrimmon (1968) proposed Euclidean to calculate distance between any two point in the range (0, 1). In this study, we employ MacCrimmon (1968) of Euclidean distance, S_j to calculate distance from each feasible solution, v_{ij} to the ideal solution (A^+ and A^-). This procedure is shown in (Eqs. 11-12), respectively. The S_j^+ is the separation from positive ideal (optimal objective) v_j^+ with each feasible solution, v_{ij} and S_j^- similarly is the separation from the negative ideal *(worst objective)*, v_j^- with each feasible solution v_{ij},

$$S_j^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - V^+{}_j)^2} \tag{11}$$

$$S_j^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - V^-{}_j)^2} \tag{12}$$

Where, "S^+" represents the closeness between each feasible solution evaluation and the ideal solution or optimal objective. The smaller value of "S^+" is, the closer the distance from feasible solution to ideal solution objective is, and superior the program/project is, and vice versa. Eqs. (11-12) are later being used to calculate the approach degrees of dimensions, performance level, of Malaysia's SES, MSES (step 7).

4.2.7. STEP 7: Calculate the approach degree of ideal solution "P*" for performance level of MSES

The approach or closeness degree is used to calculate the performance level, P_i of each attributes. This can be done by dividing the value of feasible solutions to negative ideal solution, S_j^- with the sum of feasible ideal solutions $(S_j^- + S_j^+)$, (Eq. 13). The value of closeness degree is in the range of 0-1, namely (0, 1). Sorting all the evaluation objectives from small to large according to the value of "P_i^*," the larger value of the "P_i" is, the better the evaluation performance objective is. When the approach degree equals 1, the indicators of the MSES level reaches its highest levels. On the contrary, when the approach degree reaches 0, the indicators of MSES is at its lowest level.

$$P_i = \frac{S_j^-}{S_j^- + S_j^+} \tag{13}$$

In order to measure the target of all attribute's indicators of MSES level, the closeness degrees of dimensions (Eq. 13) are taken as the raw data. That is, the standardization decision matrix of MSES is A = (P'_i) where P'_i is the normalized value of the P_i as in (Eq.14).

$$P'_i = \frac{S'^-_j}{S'^-_j + S'^+_j} \tag{14}$$

At this stage, we calculate the S'^{+} which is the distance between each dimension sample and the positive ideal solution and S'^{-} represents the distance between each dimension sample of MSES level and the negative ideal solution. Eqs. (9-10) are used respectively to calculate the positive ideal solution (optimal value) and negative ideal solution (worst value).

5. EMPIRICAL ANALYSIS AND DISCUSSION

5.1. Empirical results of SES

Based on Eq.1, the raw value of each indicator (A11, A12… A53) was calculated (Table A.1). Then, Eqs 2 and 3 are used to normalize the element values in Table A.1 (Table A.2). Based on step 3, (Eqs 3-7), the weight of each indicator, w_j, was calculated. Meanwhile, the positive ideal solution, v^{+} and the negative ideal solution, v^{-} were calculated (Eqs. 9-10). The results of weight and positive and negative ideal solutions for the TOPSIS analysis are shown in Table A.3. According to Eqs. 11 and 12, the Euclidean distance of each indicator from the ideal solution was calculated (Table A.4). Then, Eq. 13 was applied to calculate the approach degree of dimensions of performance level, P_i, of each attribute (A1, A2, A3, A4, and A5), which are reported in Table A.5.

To calculate the overall target of SES index level, the TOPSIS procedure's steps were applied again using data in Table A.5. In other words, approach degree data (P1 to P5) were used as the raw data to assess the overall target SES index (A1 to A5) for every year between 2005 and 2016. However, the weight and standardization of the weight of each dimension for SES target level were calculated again using Eqs. 7 and 8, respectively (Table 2).

Once again, the positive (S^{+}) and negative (S^{-}) ideal solutions were calculated (Eqs. 11-12). The normalization decision matrix of SES was $A = (S'_i)_m$, where S'_i was the normalised value of S_i in Eq. 13. The approach degree of SES for 2005-2016, Eq. 14 was used to calculated the SES index level, P'_i (Table 3).

Then SES level (P'_i) was applied to classify the SES index into three levels, i.e. danger, warning, and safe, which will be discussed further in the next section.

5.2. SES Performance Index Analysis

The discussion on SES performance index analysis is divided into two parts, namely, dimensional and classification.

5.2.1. Dimensional analysis

Figure 1 illustrates the five dimensions' index scores for energy security level between 2005 and 2016 for Malaysia. Measurement of SES performance index was based on three levels (safe, warning, and danger). Table 2 shows that the weight of develop-ability (A5) and affordability (A3) were relatively large, i.e. 0.258 and 0.246, respectively. The highest weight in develop-ability index reflected the sustainable development capacity of the energy system in low carbon, clean, and optimised mode, which

Table 2: Weight and ideal solution for overall SES Level

Index	Weight, $W'i$	Positive ideal solution, $V'i^{+}$	Negative ideal solution, $V'i^{-}$
A1	0.0280	0.0207	0.0029
A2	0.2402	0.1721	0.0471
A3	0.2463	0.1479	0.0560
A4	0.2267	0.1476	0.0188
A5	0.2588	0.1853	0.0219

Table 3: Sustainable energy security level during 2005-2016

Year	S_i^{+}	S_i^{-}	P_i
2005	0.1798	0.2557	0.5871
2006	0.1592	0.2448	0.6059
2007	0.1198	0.2066	0.6330
2008	0.1554	0.2026	0.5658
2009	0.1292	0.2166	0.6264
2010	0.1648	0.2145	0.5655
2011	0.1337	0.1844	0.5797
2012	0.1261	0.1960	0.6085
2013	0.1452	0.2135	0.5953
2014	0.1315	0.2185	0.6243
2015	0.1148	0.2036	0.6394
2016	0.2038	0.2189	0.5179

plays a significant role in Malaysia's SES. The achievement of the develop-ability index (A5) will be a good sign for Malaysia towards its sustainable development plan. Additionally, within the develop-ability index, the value of energy diversification index (A53) also quite high (0.3385) (Table A.3). The high weight value of diversification reflects the importance of diversifying energy resources in Malaysia. Specifically, the five-fuel diversification policy and renewable energy policy were introduced in 2001 and 2009, respectively. This result is supported by the empirical findings of Sovacool (2013). The study found that Malaysia has achieved some favorable impacts because of its diversification and almost universal energy access due to a large number of fuel subsidies. Since the diversification of energy resources can reduce the vulnerability and insecurity of excessive dependence on an energy source, the diversification index has positive impacts on SES. Moreover, Malaysia's power sector is diverse with a balanced energy supply consisting of different energy types. The electrification programme and the Small Renewable Energy Power Programme were introduced to expand access to energy services and further diversify the energy mix (Sovacool, 2013), besides increasing the diversity of energy production technology.

On the other hand, affordability (A3) indicated an adequate and uninterrupted supply at a reasonable price. In other words, it reflected the affordability and ability to resist the negative impact of rising energy prices in Malaysia. This revealed that the threats and volatility affect the economy because higher oil prices have been absorbed according to the fuel subsidy policy of Malaysia, especially for end-user consumers. For instance, in 2015, Malaysia paid a high level of subsidies, which amounted to USD 6.7 billion or 0.011% of the total global fuel subsidies (Yusoff and Bekhet, 2016:2017). However, the volatility of affordability is high, mainly because the fluctuation and trend of international crude oil prices cannot be predicted. The results also established that the index revealed trade-offs within different dimensions of ESI, which could explain why many countries continue to struggle in their attempt to improve any holistic sense of energy security (Sovacool, 2013).

5.2.2. Classification analysis

Based on MacQueen (1967), the *k*-means clustering analysis method was used to classify the SES performance index into three levels: (1) Danger zone level (<0.4276) (2) warning zone level (0.4276-0.5668); and (3) safety zone level (>0.5668). So, Table 4 shows the k-means clustering results for Malaysia for the 2005-2016 period. The SES level for Malaysia was stable between 2005 and 2016, whereby the SES index was above 0.5668, except in 2008, 2010 and 2016 in which the SES level was in the warning zone. In addition, the highest SES level was in 2007.

Based on the results, Malaysia's SES performance was quite stable throughout 2005-2016, implying that the energy and environmental policies and regulations were effective in sustaining the energy security level. This proves that Malaysia's five-fuel diversification policy (2001), renewable energy policy (2009), and the new energy policy (2011-2015) have emphasised on diversification of energy resources to renewable energy, energy security, and economic efficiency and that environmental and social considerations have brought significant favourable impacts to the nation. Malaysia's higher level of energy security, as revealed in this study, is supported by the findings of Sovacool (2013), which investigated 18 countries' energy security. Their study confirmed that among South East Asian countries, Malaysia had achieved the highest in terms of energy security improvements, i.e. an improvement of 31% between 1990 and 2010, followed by Brunei (28%). Furthermore, the improvement level of ESI for Malaysia was higher than the achievement of developed countries like Australia, USA, Japan, and New Zealand (Sovacool, 2013).

5.3. Sensitive Analysis

Finally, a sensitivity analysis was carried out to investigate the stability and robustness of the ranking with respect to the weights of SES. It was very important for this study to perform the sensitivity analysis by changing the weights of the five indexes of SES. According to the equal weight method, an alternative weight was assigned to each indicator within each

Figure 1: Sustainable energy security level of dimensions (2005-2016)

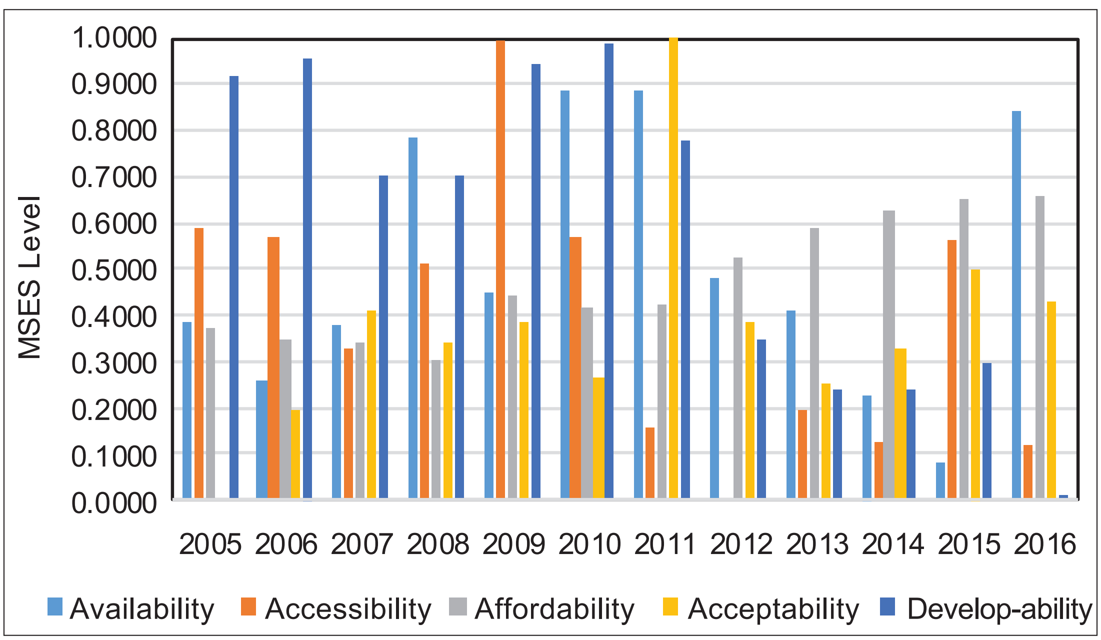


Table 4: Malaysia's sustainable energy security classification

Year	MSES	Safety line
2005	0.5871	Safety
2006	0.6059	Safety
2007	0.6330	Safety
2008	0.5658	Warning
2009	0.6264	Safety
2010	0.5655	Warning
2011	0.5797	Safety
2012	0.6085	Safety
2013	0.5953	Safety
2014	0.6243	Safety
2015	0.6394	Safety
2016	0.5179	Warning

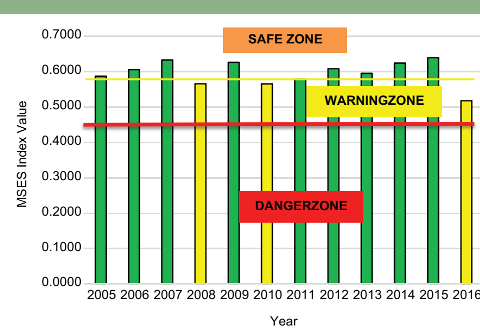
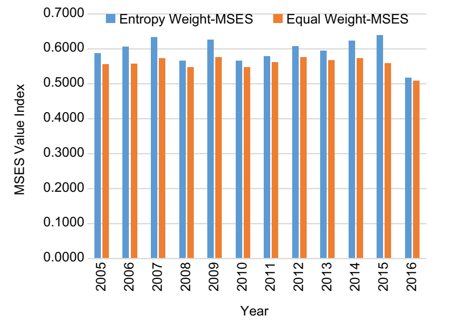


Table 5: Sensitivity analysis of SES

Year	Entropy weight-MSES	Safety Zone	Equal weight-MSES	Safety zone	Gaps
2005	0.5871	Safety	0.5559	Safety	0.03
2006	0.6059	Safety	0.5583	Safety	0.05
2007	0.6330	Safety	0.5737	Safety	0.06
2008	0.5658	Warning	0.5476	Warning	0.02
2009	0.6264	Safety	0.5761	Safety	0.05
2010	0.5655	Warning	0.5469	Warning	0.02
2011	0.5797	Safety	0.5613	Safety	0.02
2012	0.6085	Safety	0.5757	Safety	0.03
2013	0.5953	Safety	0.5675	Safety	0.03
2014	0.6243	Safety	0.5728	Safety	0.05
2015	0.6394	Safety	0.5587	Safety	0.08
2016	0.5179	Warning	0.5096	Warning	0.01



dimension. This method is one of the most popular weighting methods used to evaluate energy security (Fang et al., 2018). The results are presented in Table 5. It reveals that variation in the ranking of the alternatives was quite robust and insensitive with respect to the weight. Hence, the level of SES had the same changing trend under both the entropy and equal weight methods.

6. CONCLUSION AND POLICY IMPLICATIONS

This study had performed an assessment of SES for Malaysia. The dimensional indexes were calculated for the 2005-2016 period. Five dimensions of energy security (availability, accessibility, affordability, acceptability, and develop-ability) were used to develop the SES index model for Malaysia. The weight of ESIs was determined using the entropy weight method. Security and rank performance of the five dimensions were determined using the TOPSIS method. Based on the evaluation model, the five dimensions' scores between 2005 and 2016 were measured. The results illustrated that the weight of develop-ability and affordability were the most important weights in Malaysia's SES index system. This implied that the energy supply security had a great influence on the SES of Malaysia. The high value of develop-ability index reflected that Malaysia's energy security systems received some favorable impacts due to its diversification policies, specifically, the Five-fuel Diversification Policy and Renewable Energy Policy introduced in 2001 and 2009, respectively.

Additionally, the results of the SES index showed the weights of energy diversification index (A53) was quite high (0.3385). Even though this value was quite high, it did not reach the ideal index of 1.0. Regardless, the relatively higher weight value of diversification index as compared to other indexes' value demonstrated the importance of diversifying energy resources in Malaysia. Diversification of energy resources can reduce the vulnerability and insecurity of excessive dependence on an energy source, besides positively impacting Malaysia's SES. In addition, affordability indicated the adequate and uninterrupted supply at a reasonable price. This reflected the affordability and ability to resist the negative impact of rising energy prices in Malaysia due to its fuel subsidy policy for end-users. This study has presented enough evidence to evaluate the performance of Malaysia's energy security performance as the results are strongly supported and in line with other studies. Since the weights were derived based on only the Euclidean distance in the Entropy-Weight TOPSIS technique, other parameters, i.e. Mahalanobis distance for comparison, can be included to achieve robust and better results. Not only that, other scenarios for sensitive analysis, besides the equal weight method, can be developed. In general, the assessment of SES gave new insights, which can be used to design proper policy interventions for improving the overall SES index for Malaysia.

7. ACKNOWLEDGMENTS

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APPENDIX A

Table A.1: Raw value

Year	Availability			Accessibility			Affordability			Acceptability			Develop-ility		
	A11	A12	A13	A21	A22	A23	A31	A32	A33	A41	A42	A43	A11	A12	A13
2005	2.540	31.740	1.019	98.024	0.432	0.925	100.000	54.039	25.335	0.008	0.103	0.0026	2.598	0.003	12.524
2006	2.520	32.921	1.020	98.242	0.479	0.949	98.326	64.934	26.243	0.010	0.100	0.0026	2.615	0.003	12.706
2007	2.680	32.948	1.005	98.476	0.713	0.850	96.681	71.816	27.372	0.011	0.098	0.0025	2.696	0.003	14.792
2008	2.760	31.242	1.010	98.729	0.541	0.929	140.107	98.272	28.163	0.011	0.098	0.0025	2.768	0.003	15.052
2009	2.660	32.161	0.987	99.300	0.267	1.328	168.841	62.083	27.230	0.011	0.096	0.0025	2.620	0.003	14.258
2010	2.690	29.266	0.925	99.289	0.523	0.996	211.318	79.514	28.733	0.009	0.088	0.0027	2.534	0.003	14.699
2011	2.730	30.297	1.006	99.567	0.904	0.860	299.930	106.531	29.761	0.015	0.092	0.0026	2.746	0.003	16.119
2012	2.930	34.501	0.961	99.800	1.034	0.793	435.906	107.272	30.914	0.010	0.091	0.0026	2.818	0.003	20.666
2013	3.000	35.828	0.983	99.929	0.886	0.904	648.524	106.018	31.616	0.010	0.093	0.0026	2.953	0.003	22.572
2014	3.020	37.498	0.989	99.985	0.932	0.849	1011.284	97.661	33.091	0.010	0.090	0.0026	2.992	0.003	23.025
2015	2.910	38.021	1.040	99.990	0.568	1.052	1407.131	51.676	34.288	0.011	0.088	0.0026	3.026	0.003	22.593
2016	2.950	32.966	1.065	100.000	0.938	0.844	1725.811	43.203	35.003	0.010	0.090	0.0026	3.141	0.003	27.599

Table A.2: Normalised decision matrix for TOPSIS

Year	Availability			Accessibility			Affordability			Acceptability			Develop-ability		
	A11	A12	A13	A21	A22	A23	A31	A32	A33	A41	A42	A43	A11	A12	A13
2005	0.080	0.996	0.032	1.000	0.004	0.009	0.859	0.464	0.218	0.081	0.997	0.003	0.203	0.0002	0.979
2006	0.076	0.997	0.031	1.000	0.005	0.010	0.815	0.538	0.217	0.097	0.995	0.003	0.202	0.0002	0.979
2007	0.081	0.996	0.030	1.000	0.007	0.009	0.783	0.581	0.222	0.114	0.993	0.003	0.179	0.0002	0.984
2008	0.088	0.996	0.032	1.000	0.005	0.009	0.808	0.567	0.162	0.108	0.994	0.003	0.181	0.0002	0.984
2009	0.082	0.996	0.031	1.000	0.003	0.013	0.928	0.341	0.150	0.112	0.994	0.002	0.181	0.0002	0.984
2010	0.091	0.995	0.031	1.000	0.005	0.010	0.928	0.349	0.126	0.102	0.995	0.003	0.170	0.0002	0.985
2011	0.090	0.995	0.033	1.000	0.009	0.009	0.938	0.333	0.093	0.161	0.987	0.003	0.168	0.0002	0.986
2012	0.085	0.996	0.028	1.000	0.010	0.008	0.969	0.238	0.069	0.112	0.994	0.003	0.135	0.0001	0.991
2013	0.083	0.996	0.027	1.000	0.009	0.009	0.986	0.161	0.048	0.101	0.995	0.003	0.130	0.0001	0.992
2014	0.080	0.996	0.026	1.000	0.009	0.008	0.995	0.096	0.033	0.107	0.994	0.003	0.129	0.0001	0.992
2015	0.076	0.997	0.027	1.000	0.006	0.011	0.999	0.037	0.024	0.121	0.993	0.003	0.133	0.0001	0.991
2016	0.089	0.996	0.032	1.000	0.009	0.008	0.999	0.025	0.020	0.116	0.993	0.003	0.113	0.0001	0.994

Table A.3: Weight and Ideal solution of each indicator

Indicator	Weight	Positive ideal solution, V+	Negative ideal solution, V−
A11	0.3563	0.0326	0.0272
A12	0.2394	0.2386	0.2383
A13	0.4044	0.0134	0.0106
A21	0.3030	0.3029	0.3029
A22	0.3487	0.0036	0.0009
A23	0.3483	0.0047	0.0028
A31	0.3223	0.3222	0.2523
A32	0.3371	0.1960	0.0084
A33	0.3406	0.0755	0.0069
A41	0.3387	0.0546	0.0274
A42	0.3173	0.3163	0.3132
A43	0.3440	0.0009	0.0009
A51	0.3174	0.3158	0.3149
A52	0.3441	0.0004	0.0003
A53	0.3385	0.0423	0.0343

Table A.4: Euclidean distance

Year	A1		A2		A3		A4		A5	
	S_i^+	S_i^-	S_i^+	S_i^-	S_i^+	S_i^-	S_i^+	S_i^-	S_i^+	S_i^-
2005	0.0013	0.0048	0.0008	0.0025	0.0466	0.1687	0.0031	0.0271	0.0307	0.0000
2006	0.0009	0.0057	0.001	0.0023	0.018	0.1948	0.0059	0.0218	0.0302	0.0005
2007	0.002	0.0041	0.0016	0.002	0.0000	0.2116	0.0113	0.0161	0.0226	0.0082
2008	0.0042	0.0027	0.0011	0.0022	0.0223	0.1987	0.0096	0.0179	0.0231	0.0076
2009	0.0024	0.0037	0.0019	0.0027	0.0967	0.1176	0.0108	0.0166	0.0230	0.0077
2010	0.0055	0.0021	0.0012	0.0021	0.0969	0.1174	0.0076	0.0199	0.0193	0.0114
2011	0.0048	0.0028	0.0022	0.0017	0.1069	0.1086	0.0271	0.0031	0.0187	0.0121
2012	0.0037	0.0025	0.0027	0.0019	0.1403	0.0745	0.0107	0.0167	0.0075	0.0232
2013	0.0034	0.0029	0.0022	0.0016	0.1669	0.0471	0.0074	0.0202	0.0056	0.0251
2014	0.0031	0.004	0.0023	0.0017	0.1887	0.0244	0.0091	0.0183	0.0054	0.0254
2015	0.0023	0.0054	0.0014	0.0019	0.2076	0.0042	0.0137	0.0136	0.0067	0.0240
2016	0.0046	0.0025	0.0023	0.0018	0.2116	0.0000	0.0119	0.0155	0.0000	0.0307

Table A.5: Approach degree dimensions

Year	P1	P2	P3	P4	P5
2005	0.7860	0.7578	0.7837	0.8974	0.0013
2006	0.8659	0.7040	0.9156	0.7862	0.0174
2007	0.6699	0.5518	1.0000	0.5871	0.2659
2008	0.3925	0.6663	0.8991	0.6517	0.2484
2009	0.6047	0.5860	0.5488	0.6072	0.2498
2010	0.2768	0.6469	0.5479	0.7232	0.3709
2011	0.3700	0.4326	0.5040	0.1026	0.3926
2012	0.4091	0.4140	0.3467	0.6094	0.7566
2013	0.4587	0.4219	0.2200	0.7326	0.8163
2014	0.5655	0.4285	0.1144	0.6668	0.8257
2015	0.6988	0.5813	0.0197	0.4987	0.7825
2016	0.3550	0.4281	0.0000	0.5652	0.9987