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Evaluating Malaysia's fuel diversification strategies 1981–2016

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ABSTRACT

Since the introduction of Malaysia's own Four-Fuel Diversification Policies 1981, and the updated Five-Fuel Diversification Policies in 2001, no studies have been conducted to measure and evaluate the success and progress of these policies. This study aims to address this issue by quantitatively measuring the extent of fuel diversification in Malaysia since the conceptualisation of these policies in 1981 through the Herfindahl-Hirschman Index and supported by an analysis through the Shannon-Weiner Index. Statistical data from the Malaysia Energy Commission on the Primary Energy Supply and Final Energy Demand were chosen for this purpose. The findings suggest that whereas Malaysia has managed to reduce its over-dependency on crude oil/ petroleum as its primary fuel, this dependency has been replaced partly by a dependency on natural gas, on the supply side. As for the demand side, the transportation sector's continuing dependency on petroleum has also affected the level of fuel diversification. Thus, the level of fuel diversification, while having shown improvement, was less than expected. Further incorporation of renewable energy in the future may hold the key to a genuine and more successful energy diversification for Malaysia.

1. Introduction

Following the oil crises of 1973 and 1979, Malaysia has adopted a series of national energy policies to secure these strategic resources for its own survival. These energy policies began with the introduction of the National Energy Policy in 1979 (NEP 1979), followed by the National Depletion Policy of 1980 (NDP 1980). The former was introduced to address domestic dependency on oil as primary fuel, both for transportation and power generating purposes and the latter outlined its three main components namely the Supply Objective, the Utilisation Objective and the Environmental Objective. A year later, the NDP 1980 was implemented to augment the aforementioned "Supply Objective" stated in NEP 1979 (Hitam, 1999; Sairan, 2007). NDP 1980 aims at safeguarding the depleting oil reserves and extending the life of the domestic energy resources by limiting the crude oil production rate at 650,000 barrels per day, extending it for an additional 16 years. A similar measure was implemented upon the natural gas sector by imposing a production ceiling of 2 billion standard cubic feet per day (BSCFD), giving a reserve extension for another 70 years (Yatim et al., 2016).

Recognising the need to diversify the fuel mixture as a strategy to enhance national energy security, a new policy was introduced in 1981. Aptly named the Four-Fuel Diversification Policy 1981 (4FDP 1981), the policy introduces an energy mix classification consisting of petroleum, natural gas, coal and hydroelectricity. This diversification strategy is essential to reducing the country's over-dependency on oil as energy source (Hitam, 1999; Kementerian Tenaga Teknologi Hijau dan Air, 2011). As a result, the percentage of energy sourced from oil and petroleum which once stood at 78.83% in 1981 was reduced to 33.54% in 2016 and at its lowest, representing 31.94% of national fuel/energy mix in 2010 (Suruhanjaya Tenaga, 2017a). After twenty years, in 2001, the government decided to revise the 4FDP 1981. The advancement of silicone, semi-conductor and other relevant technology has lead the government to consider the potential of renewable energy sources as the viable fifth fuel to be incorporated into the newly coined Five-Fuel Diversification Policy 2001 (5FDP 2001). Complementing the previous policy, 5DFP 2001 attempts to encourage the utilisation of various renewable resources which exist in abundance nationwide upon consideration of the geographical location, economic activities and the climate of Malaysia. This includes the harnessing of solar energy, as well as further development of biomass and biofuel technology (Kementerian Tenaga Teknologi Hijau dan Air, 2011). This is in tandem with the national palm oil industry, that the biomass initiatives may provide a suitable solution for the palm oil mills' waste disposal and management

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problem (Lalchand, 2004). Located near the equator with abundant sunlight, solar energy is an attractive power option as the average daily solar radiation in Malaysia is estimated at around 5.5 kW h per square meter or 15 MJ (Mega Joule) per square meter (Mohamed and Teong, 2010). In 2011, the Renewable Energy Act 2011 was legislated and a statutory body, the Sustainable Energy Development Authority (SEDA) was established to oversee and facilitate any related initiatives such as the implementation of the Feed-in-Tariff project by the home-owners (Badriyah, 2011).

At the moment of writing, 18 years have passed since the last major revision on Malaysia's energy policy took place through 5FDP 2001. With increasing energy demand due to economic and population growth, the declining domestic fuel reserves and the dawn of the Industrial Revolution 4.0, it is essential to re-evaluate, and examine the efficacy and effectiveness of the policies which have been implemented, and perhaps refine them if necessary. Whereas the level of oil dependency has since been reduced from peak consumption in 1981, it remains crucial to analyse if such over-dependency has been eliminated entirely, resulting in a truly diversified energy mix. It is therefore essential to assess the consequences of the implemented energy policies, whether they have fulfilled their intended objective, and subsequently contribute towards enhancing overall national energy security through fuel diversification.

This study seeks to undertake that responsibility, addressing the current level of fuel diversification in Malaysia's energy mix utilising statistical data provided by the Malaysia Energy Commission. By applying the Herfindahl-Hirschman Index (HHI) and the Shannon-Weiner Index (SWI) to the statistical data representing Malaysia's PES and FED, it is possible to measures the level of fuel-use diversification across various fuel types, enabling the refinement of future energy policies.

2. Literature review

Fuel diversification is a common strategy adopted by various nations around the world, aimed at reducing vulnerability in the event of an unexpected supply disruption. This may happen in the case of political conflict leading to an economic embargo which is particularly disrupting to energy importing countries, or technical difficulties which may affect countries with their existing reserves. Through fuel diversification, over-reliance on a particular fuel type can be reduced as alternatives are being developed. In the event of supply disruptions, these alternative fuels may compensate for the resulting shortages to fulfil the energy demand.

Unless explicitly defined by the country's own policy document, fuel-type classifications and categorization may differs across various third-party publications due to author's preferences or editorial style. A statistical compendium by BP has the countries diversify their energy needs into six main categories which consist of crude oil, natural gas, coal, nuclear energy, hydroelectricity and various renewable sources (BP, 2018). In another report published by the Asia-Pacific Economic Co-operation (APEC) Energy Demand and Supply Outlook 6th Edition, 2016, the primary energy supply was categorised into coal, (crude) oil, (natural) gas, nuclear, hydro (electric) and other renewables (Asia Pacific Energy Research Center (APERC), 2016). The International Energy Agency (IEA) on the other hand listed coal, natural gas, nuclear, hydro, geothermal/solar, biofuels and waste and primary as well as secondary oil as their main fuel mix components or categorization (International Energy Agency, 2018). However, in another publication by IEA, "new" renewable energy may be divided into further subcategories such as bio-energy, solar and wind, separate from hydroelectricity or geothermal which are regarded as "old" or "conventional" renewable energy (International Energy Agency, 2016). Despite these various diversification or classification methods, the final ratio of national energy mix however may be subject to the country's own technological capability, availability of domestic resources and geographical features among other things. Malaysia in this instance is fortunate that the related statistical data was prepared, compiled and standardised by the Energy Commission (Suruhanjaya Tenaga) in accordance to the national Four/Five Fuel Diversification Policy, thus facilitating with the analysis.

This editorial choice may also lead to different styles of fuel categorization in various publications. One publication on Thailand Primary Energy Supply, listed the fuel mix categories into coal, (crude) oil, (natural) gas, hydro(electricity), new renewable energy (NRE), nuclear and electricity net-import (Asia Pacific Energy Research Centre, 2009). In another publication fuel classification was divided six-ways, consisting of crude oil, natural gas, bio-energy, coal, hydroelectricity, solar and wind. Here, unlike the first publication, the new renewable energy was divided into sub-categories of bio-energy, as well as solar and wind. Furthermore, the Thailand Power Development Plan 2015–2036 (PDP 2015) listed hydro(electricity), natural gas, fuel oil, diesel, lignite, renewables, coal import, regional grid-interconnection (Thailand-Malaysia) and nuclear as components of potential energy/fuel options (The Energy Policy and Planning Office, 2015). A similar situation is also apparent in publications involving Vietnam's national energy mix. A publication by the Asian Development Bank listed coal, oil, natural gas, electricity and non-commercial sources (Asian Development Bank, 2016a). On the other hand, the Danish Energy Agency listed, coal, crude oil, natural gas, hydroelectricity, non-commercial biomass and electricity import as fuel mix categorization (Danish Energy Agency, 2016). It is only through the latter publication one may gain better insight and understanding on what "non-commercial" energy refers to, which is biomass. The latter publication also listed electricity import as a separate categorization of primary energy supply although the former did not. This provides a greater transparency on the real composition of a nation's fuel mix. Echoing similar sentiment, the Thailand Energy Policy and Planning Office (TEPPO) also considered importing power from neighbouring countries through regional grid-inter-connection to be a legitimate strategy to improve power system reliability (The Energy Policy and Planning Office, 2015).

Indonesia has a rather simplistic version of energy mix and primarily relies on coal and oil for its energy needs, making up 76% of their primary energy supply as of 2011. During the same year, oil accounted for 50% of the total energy mix, coal representing 26%, 20% from natural gas and 4% from new renewable energy (Asian Development Bank, 2016b). As of 2015, the situation has improved slightly with crude oil constituting 37% of their primary energy mix whereas coal represents 33%. 22% of their national primary energy mix was derived from natural gas and the remaining 8% from new renewable energy. However, there are plans to improve energy diversification for a more equitable utilisation share in the near future. By 2025, Jakarta plans to reduce oil dependency from the aforementioned 37% in 2015 to 28%, coal from 33% to 28%, maintaining gas utilisation at 22% and increasing the utilisation share of new renewable energy to 22%. This reduction of oil dependency may continue until 2050, with the objective of attaining 20% oil dependency and increasing the new renewable energy utilisation share to 31% (Fitriana et al., 2016).

In 2012, oil represented 27% of Vietnam's national energy mix, whereas coal represented 26%. 25% of the national primary energy mix was supplied by non-commercial (biomass) sources, 8% from electricity and 14% from natural gas (Asian Development Bank, 2016a). In 2015, the dominance of coal in the national energy mix remained and increased to 34.86%. 27.68% of national energy was derived from crude oil, 13.53% from natural gas, 6.84% through hydroelectricity and 16.89% from non-commercial biomass. A miniscule 0.19% of the national energy mix was derived from electricity import (Danish Energy Agency, 2016). For Thailand, crude oil amounted to 39.3% of the primary energy supply, followed by natural gas at 28.2%, bio-energy at 18.4%, coal at 12.9%, hydroelectricity at 0.4% and 0.1% generated from solar and wind in 2013. Furthermore, in 2015, TEPPO published the Thailand Power Development Plan 2015–2036 (PDP 2015). It focuses on the policies pertaining to electricity generation through various fuel types, listing hydro(electricity), natural gas, fuel oil, diesel, lignite, renewables, coal import, regional grid-interconnection (Thailand-Malaysia) and nuclear (The Energy Policy and Planning Office, 2015).

Based on these publications, one may conclude that nations in the Southeast Asia region are heavily dependent on oil, although the secondary fuel choice may vary from coal or natural gas. The level of fuel-type diversification across these nations is also rather limited. These scenarios are comparable to Malaysia in the early years of the 1980s, with heavy crude-oil dependency. Unlike most works on energy security or energy policies which utilise the Tons of Oil Equivalent (TOE) as the unit of measurement, PDP 2015 adopted the Gigawatt Hour (GWh) which may complicate unit conversion across publications. However, as it focuses on the electric sector, this decision is understandable.

For the purpose of measuring the energy diversification level, two popular quantitative methods are the Herfindahl-Hirshman Index (HHI) and the Shannon-Weiner Index (SWI). In 2010, Karlsson suggested the utilisation of both index in measuring the level of energy security in Sweden. He further elaborated on the modification of the existing SWI measurement formula to take imported resources into consideration, resulting in the "Net Energy Import Dependency" value. On the third indicator he used, a non-Carbon Fuel Portfolio index was developed where the sum of all non-fossil fuel primary energy demands (renewables and nuclear) are divided with total primary energy demand, with the aim of attaining an index value close to one (Karlsson, 2010). This demonstrates that the existing HHI and SWI do not stop other scholars from proposing other means and metrics for quantitative evaluation. In another article published in 2014, the author proposed 35 indicators, representing five aspects of energy security namely Availability, Stability, Affordability, Efficiency and Environmental impact (Sharifuddin, 2014). These five aspects echoes the 4A's concept of energy security proposed by APERC which encompasses Availability, Accessibility, Affordability and Acceptability, where the component of environmental impact may be incorporated into Acceptability and Efficiency being grouped together with Affordability, being the economic dimension (Asia Pacific Energy Research Center (APERC), 2007). Whereas Sharifuddin did consider incorporating the HHI or the SWI as part of his indicators, it was suggested as part of his "Stability (Supply Security)" components instead of as an independent component. Other works have also attempted to measure the fuel diversification in Malaysia. APERC, through its publication measured the diversification index of Malaysia Primary Energy Supply (PES) for the year 2000, 2010, 2013, as well as projection for the year 2020, 2030, and 2040. For the aforementioned years, the HHI values were recorded at 0.44, 0.33, 0.64, 0.31, 0.30 and 0.30 (Asia Pacific Energy Research Center (APERC), 2016). This does not however provide the basis for projected figures. In 2008, through a brief presentation, the Classic HHI application on fuel options for power generation in Malaysia was stated to be at 0.38 (Razak and Ramli, 2008). Another figure suggested an initial value of 0.46, which may deteriorate with the switch to coal, but improve to 0.44 through the Sarawak grid interconnection (ISIS Malaysia, 2014). Both of these figures however relate to the fuel-mix for power generation purposes in Peninsular Malaysia instead of nation-wide energy consumption, across all fuel options, all sectors/purposes. Even the figure provided by ISIS Malaysia only takes coal and natural gas into consideration, with the third fuel option being ambiguously labelled as "Others." Furthermore, another publication states that as far as electricity generation is concerned, the sector only aims at attaining a sub 0.5 HHI value (Energy Commission, 2015).

In the Balkan region, Pavlović, Banovac and Vištica developed a Composite Index to measure the Croatia's natural gas supply security (Pavlović et al., 2018). Combining the HHI and SWI, as well as four other statistical indicators, the proposed Composite Index provides a more comprehensive picture on how economic situation, or domestic production volume among other things may affect natural gas consumption, or the completion of another energy infrastructure (an LNG terminal) may enhance natural gas supply security for Croatia. It is uncertain if the composite index may be applicable for exporting nations without further modification, as the focus would lies on demand security rather than supply security.

Chuang and Wen (2013) on the other hand developed the diversity reliability index and co-vary diversity reliability index to study the contributions of different energy sources to the general energy system, analysing their impacts on energy security, and their influence of energy diversity to mitigate the risk of supply shortages and cost fluctuations (Chuang and Wen, 2013). For Malaysia, these indices are potentially significant to analyse the coal-import dependency and how its supply disruption or cost increment may affect national energy security.

Vivoda (2019) covers the issue of LNG import diversifications among major Asian countries, utilising the Herfindahl-Hirshmann Index and the Shannon-Weiner Index. The finding suggests that Japan, South Korea and Taiwan has the best rate of diversification being mature LNG importers since 1969, 1987 and 1990 respectively. Between 2001 until 2012, Japan diversified its LNG suppliers from 8 (in 2001) to 19 (in 2012), whereas South Korea recorded the change from 7 (2002) to 16 (2012) (Vivoda, 2019).

3. Method

The paper began with choosing suitable and relevant energy datasets. For this purpose, two sets of energy data as provided by the Malaysia Energy Commission are utilised. The first would be the "Primary Energy Supply 1981–2016," (PES) which represents the value of energy supplied and generated within the entire national energy infrastructure, whereas the second set of statistical data would be the "Final Energy Demand 1981–2016" (FED) which is based on the final consumption of each fuel-type. For the purpose of this analysis, crude oil (petroleum) and its derivatives shall be grouped together as to maintain consistent fuel classification based on the 5FDP 2001. Similar treatment is applied to Biomass, Biogas, Solar and Biodiesel by grouping them under "Renewable Energy" sources. Renewable energy data shall be included based on available statistical record (Suruhanjaya Tenaga, 2017a,b).

3.1. Herfindahl-Hirshman Index

Although it was usually employed as an indicator for evaluating market concentration as well as the issue of monopolistic practices and tendencies, the Herfindahl-Hirshman Index is also a useful tool to evaluate the energy supply and consumption concentration. This was attested by APERC in assessing whether a particular country is heavily dependent on one fuel-type source (Asia Pacific Energy Research Center (APERC), 2016). The formula for the calculation is as shown in Equation (1), with s_i representing the percentage or share of supply or consumption of the particular fuel type in a given year and N is the number of types of fuel in the overall diversification policy strategy.

Herfindahl-Hirshmann Index Formula

$$H = \sum_{i=1}^{N} s_i^2 \tag{1}$$

As both statistical data (PES and FED) were provided in thousand tons of oil equivalent (ktoe), initial calculations need to be conducted to measure the percentage value of each fuel for any given year. The final HHI value shall therefore be the sum of the squared value for each fuel type based on their percentage of any given year. Whereas the raw value generated from the formula would range from between 0 and 10,000 for the purpose of this index it shall be normalised between 0 and 1.

For result analysis, the classification for fuel concentration index is based on the definitions used by the United States Department of Justice and the Federal Trade Commission. Based on their definition, any HHI values below 1500 (0.150) shall be an indication of low concentration, indicating low dependency on a particular fuel type. Moderate concentration level would be indicated by the HHI values ranging between

1500 (0.150) and 2500 (0.250), whereas those above 2500 (0.250) is an indication for high concentration and incidentally, high dependency level on one fuel type or energy source (U.S. Department of Justice and Federal Trade Commission, 2010). Another scholar argued that a sub-1000 (0.100) value is to be regarded as an indicator of absence in concentration, whereas values beyond 1800 (0.180) are to be regarded as problematic with potential exposure to supply risk (Krey and Zweifel, 2008). In essence, a successful fuel diversification policy should aims for decreasing trend of preferably lower HHI end values overtime. However, it was also stated that an existing dominant fuel (high HHI score) does not necessarily imply energy insecurity, but rather it may suggest a higher risk for supply disruption which may be mitigated by sufficient domestic production (Asia Pacific Energy Research Center (APERC), 2016).

3.2. Shannon-Weiner Index

Another method of analysis is the Shannon-Weiner Index (Kharbach, 2016). It was designed with the assumption that fewer suppliers (lesser diversification) will result in more risk of exposure for the energy infrastructure to the effects of monopoly. Although it is often used by biologists to measure the species diversity in a given community, it is also applicable as a measure of fuel diversification for a particular country. The proportion of a specific fuel type (p_i) is calculated and then multiplied by the natural algorithm of the resulting proportion ($\ln p_i$). The result is then summed across before being multiplied with −1 to obtain a positive value. In its basic form, a value below 1.000 is an indication of low diversification of fuel mix, and therefore may result in energy insecurity in the event of supply disruption (Krey and Zweifel, 2008). Thus, a high index value which is a sign of a diverse and equally distributed fuel-mix is preferred, as lower value represents a less diversified fuel mix. In extreme cases, a value of 0 would be an indication of just one fuel type dependency. The mathematical formula is as shown in Equation (2).

Shannon-Weiner Index Formula

$$SW = -\sum_{i=1}^{m} -p_i \ln(\rho_i) \tag{2}$$

Another value which may be obtained from this calculation is a measure of equitability, or evenness within the different fuel types. This can be calculated by dividing the obtained basic Shannon-Weiner Index with the maximum theoretical SWI value. In this case, it will be a scenario where each fuel proportion is divided equally. Equitability assumes a value between 0 and 1 with 1 being complete evenness (Beals et al., 2000). For this purpose, the value closer to 1 is therefore preferred. Although the Shannon-Weiner Index does not calculate the cost for each fuel type in respect to the energy generated, this issue falls beyond the scope of this study and thus shall not be addressed (Kharbach, 2016).

3.3. Justification for combining indices

Cursory examination would suggest that utilisation of both HHI and SWI might be redundant as both formula derive its results from a similar dataset. Therefore, it is not uncommon for scholars to choose one over the other as being more suited. Stirling favours the SWI index over the HHI (which he referred to as Simpson Index) as he finds the former to be more robust basis for measuring diversity, and the latter as disruptive to the concept of variety and balance (Stirling, 1998). In a work on European Union External Energy Supply Security, Le Coq and Paltseva chose HHI over SWI. Since SWI place more weightage on the impact of small energy suppliers whereas HHI puts more emphasis on large energy suppliers, they argued that disruptions of large energy suppliers may pose more problems for energy security, and therefore better suited to capture the risk associated with non-diversified energy portfolios (Paltseva and Le Coq, 2009). Corollary to the argument posed by Le Coq and Paltseva, and in justifying the choice of adopting HHI in his work, Cohen argued that SWI emphasizes more on the contributions of options whereas HHI on the number of options (Cohen et al., 2011).

The utilisation of HHI or SWI however are not mutually exclusive. Despite the preferences of some scholars for one over another for the purpose of their works, it does not prevent other others from utilising both indices as it may generates increased confidence on the qualitative conclusions as HHI generates results consistent to those of SWI (Grubb et al., 2006). Their combined use may also assist in discounting the diversity overestimation and uncertainties, therefore offering deeper insights into the evaluation of fuel diversity (Chalvatzis and Rubel, 2015). Essentially whereas HHI measures concentration, SWI measures diversification and while they are almost similar, they are different and complementary to one another (Chalvatzis and Ioannidis, 2017). It is based on this complementary nature of HWI and SWI that a decision was made to utilise both indices for this work.

4. Results and discussions

4.1. Analysing diversification index

As previously mentioned, two statistical datasets were chosen, namely the “PES 1981–2016” and the “FED 1981–2016.” This resulted in four different HHI and SWI values. As displayed in Figs. 1 and 2, the data on PES 1981–2016 and FED 1981–2016 have shown that the national energy mix, both on the supply and demand side are highly concentrated on crude oil. This is particularly evident in 1981 with crude oil and other petroleum derivatives constituting 78.829% of national energy mix on PES and 86.560% on FED. Over the years since the implementation of 4FDP 1981, and subsequently the 5FDP 2001, the dependency on crude oil and petroleum derivatives has significantly reduced to the recorded minimum of 31.940% in 2010 for the PES and a recorded minimum of 52.738% for the FED in 2012. However, it is unfortunate that in an attempt to diversify the energy fuel mix, this Crude Oil and Petroleum Derivatives (COPD) dependency was replaced with natural gas dependency. Whereas natural gas only accounted for 16.711% of national energy fuel mix in 1981, it peaked at 52.551% in 2006 before slightly declining, with a recorded value of 40.666% in 2016. Figs. 1 and 2 shows the shift of dependency from crude oil in 1981 towards natural gas as primary fuel since 1998.

This finding is consistent with the highest recorded HHI value or 0.651 for PES and 0.763 for FED, both in 1981. Since then, analysis has shown a relatively consistent decrease on the HHI value, with the minimum recorded value of 0.321 for PES in 2016 and 0.373 for FED in 2012. In 2016, the latest HHI value for FED was recorded at 0.375. This is a decrease of 50.691% for PES and 50.852% for FED over the period of 35 years, which can be improved through early and proper incorporation of renewable energy options. The overall HHI values are recorded in the following Table 1 and Fig. 3.

As both the table and the figure indicate, the general trend suggests improved diversification since the policies were initiated in 1981 and 2001. However, it is worth noting that the lowest HHI values for both PES and FED remains above the threshold level of 0.250, which indicates that the level of concentration on certain fuel types remain relatively high throughout the study period. This fuel types concentration on the demand side might be explained by the dominance of the Transportation sector on the FED, as shown in Fig. 4. As Fig. 1 has previously shown, instead of proper diversification, the overall national energy mix on the supply side only shifted its reliance from crude oil to natural gas, albeit to a lower percentage, whereas the dependency for crude oil and petroleum derivatives in Malaysia remain dominant on the demand side as shown in Fig. 2.

Furthermore, these HHI values are different from those suggested in earlier publications. Whereas 0.38 was recorded for 2007/2008, this analysis recorded the values of 0.394/0.393 for PES and 0.426/0.412 for

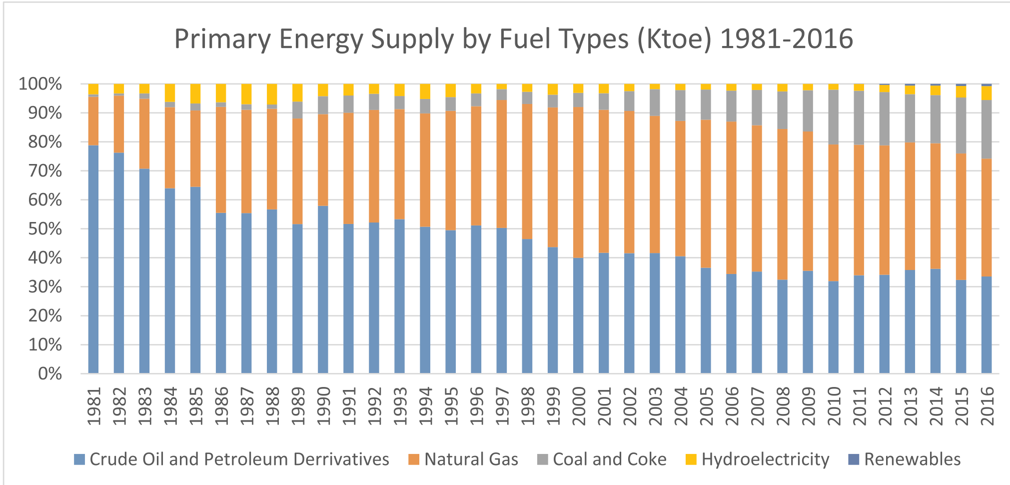

Fig. 1. Primary energy supply by fuel types (ktoe) 1981–2016. Sources: (Suruhanjaya Tenaga, 2017a).

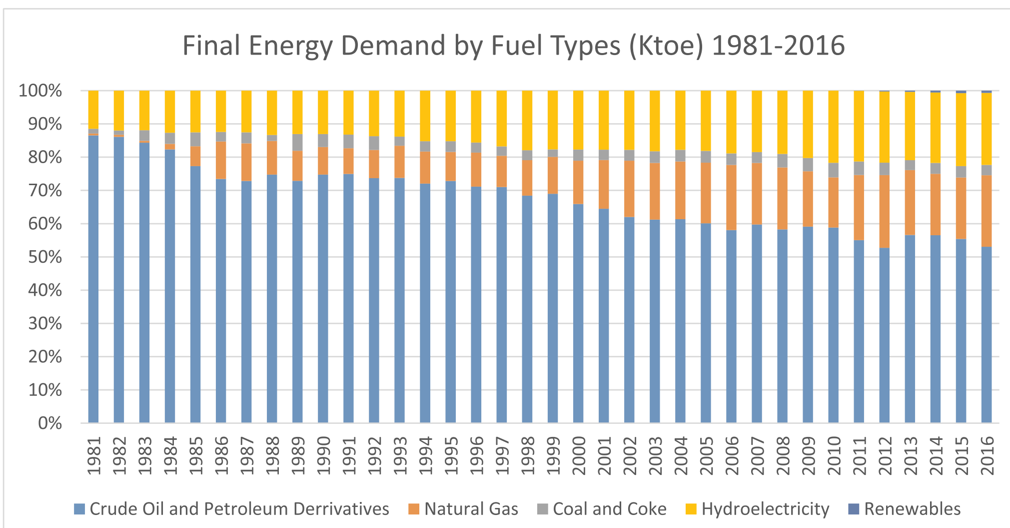

Fig. 2. Final energy demand by fuel types (ktoe) 1981–2016 (Suruhanjaya Tenaga, 2017b).

Table 1
Herfindahl-Hirschman index (normalised) for primary energy supply and final energy demand 1981–2016.

Year	HHI for Primary Energy Supply 1981–2016 (normalised)	HHI for Final Energy Demand 1981–2016 (normalised)
1981	0.651	0.763
1985	0.490	0.618
1990	0.441	0.584
1995	0.419	0.562
2000	0.434	0.484
2005	0.406	0.429
2010	0.361	0.418
2015	0.334	0.390
2016	0.321	0.375

the FED for the year 2007/2008 (Razak and Ramli, 2008). The figures and patterns also deviate from those published by APERC at 0.40 (instead of 0.434 for 2000), 0.33 (instead of 0.361 for 2010) and 0.34 (instead of 0.351 for 2013). This discrepancy may have resulted from different datasets utilised for the calculations. As stated, this study chose to adopt the statistical data provided by the Malaysia Energy Commission (Suruhanjaya Tenaga, 2017a,b).

Further analysis through the SWI was also conducted, similarly to measure the level of success in the fuel diversification policy in Malaysia. Similar to the HHI, this portion of the analysis relies on both PES as well as FED statistical datasets. From these two datasets, two values will be derived, namely the original index value, and the equitability value of the index. The following Table 2 lists all the generated values, followed by its graphical representation in Fig. 5.

In contrast to the HHI which favours lower index value, SWI favours a higher index value, above 1.000. For the SWI, a value nearing 1.000 is preferred as it represents an equitable or even distribution of fuel mixture. The general trend of SW Indices for both the PES and FED suggest improved diversification since 1981, despite the recorded dip in mid-1990s for the PES.

For the PES, the first time the SWI recorded a value above 1.000 was in 1989 with the value of 1.046. This is consistent with the lowering supply percentage for crude oil and petroleum derivatives, constant natural gas supply percentage as well as increased supply for coal and coke during that year as shown in Fig. 1. It will take another six years 1995 when COPD actually represents less than half of national PES at 49.494% in 1995. Since 2003, the SWI for PES has remained above 1.000, recording an all-time high of 1.238 in 2016. This value corroborates the finding of the HHI for the same year, suggesting the best

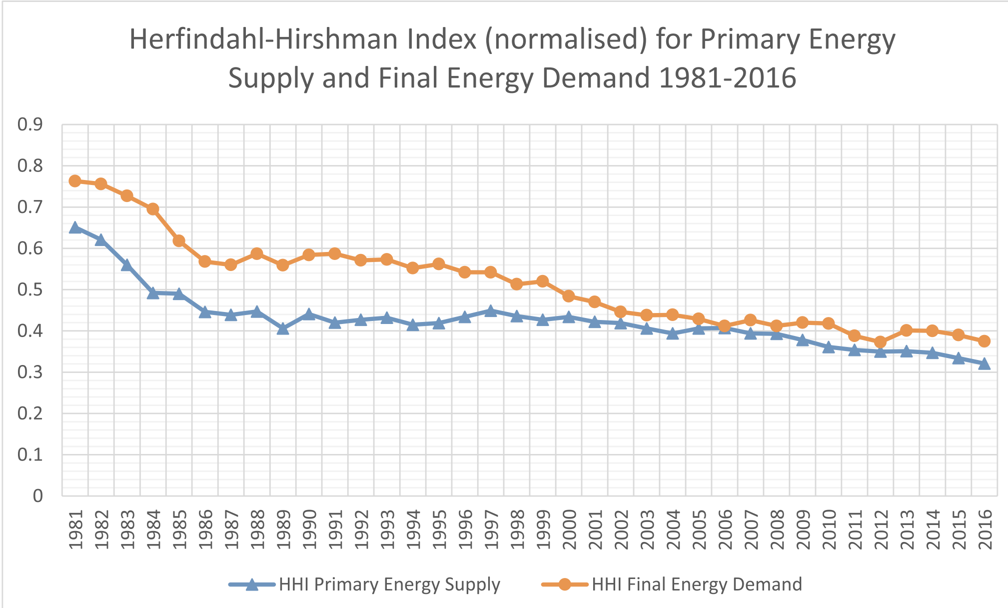

Fig. 3. Herfindahl-Hirschman index (normalised) for primary energy supply and final energy demand 1981–2016.

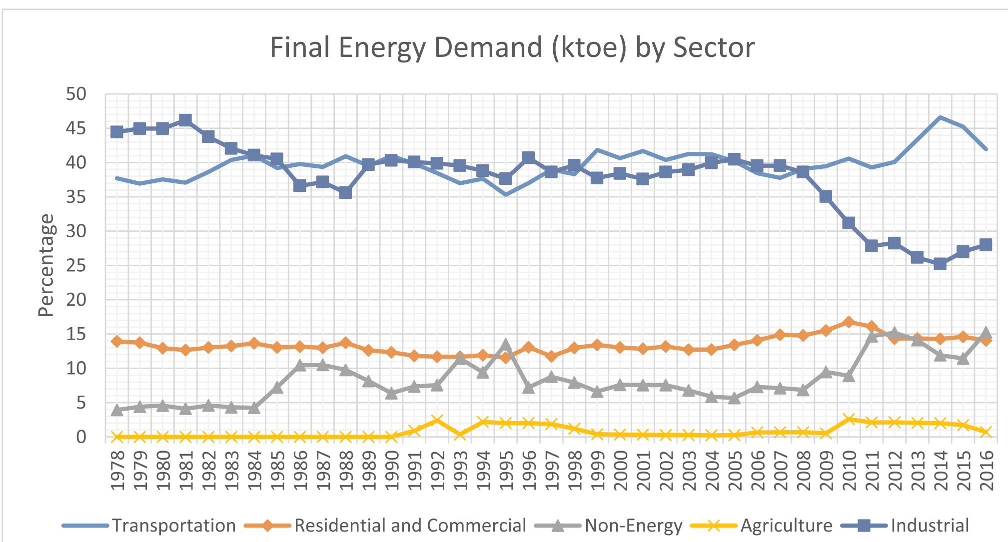

Fig. 4. Percentage for final energy demand (ktoe) by sector. Source: (Suruhanjaya Tenaga, 2017e).

Table 2
Shannon-Weiner index for primary energy supply and final energy demand 1981–2016.

Year	SWI for Primary Energy Supply 1981–2016	SWI_E for Primary Energy Supply 1981–2016	SWI for Final Energy Demand 1981–2016	SWI_E for Final Energy Demand 1981–2016
1981	0.647	0.402	0.463	0.287
1985	0.906	0.563	0.761	0.473
1990	0.987	0.613	0.817	0.507
1995	0.999	0.621	0.841	0.522
2000	0.962	0.597	0.960	0.597
2005	1.024	0.636	1.044	0.649
2010	1.112	0.691	1.066	0.663
2015	1.209	0.751	1.124	0.699
2016	1.238	0.770	1.140	0.708

recorded case of fuel diversification for PES in Malaysia so far.

The FED on the other hand has recorded an above 1.000 value since 2002. Whereas it recorded the highest value in 2016 with 1.140, it also recorded another relatively high value of 1.137 in 2012. The decreased Final Energy Demand for crude oil and petroleum derivatives and increased natural gas demand for that year might have contributed to the relatively high SWI value. Between 2002 and 2006, the SWI for FED was also recorded to be higher than those of PES of the same period, signifying better diversification on the demand side. This was partly due to the increased demand and consumption for natural gas (relative to hydroelectricity) as well as continuously declining crude oil demand. The level for FED derived from hydro-electricity as well as coal and coke during this time-frame remains stable and inconsequential to the changes in the calculated SWI. Similar to the PES, the shift in FED for different fuel types is evident in Fig. 4.

As for the Equitability Index Value for both the PES and the FED, both of them show a pattern nearing 1.000 which is a measure of even

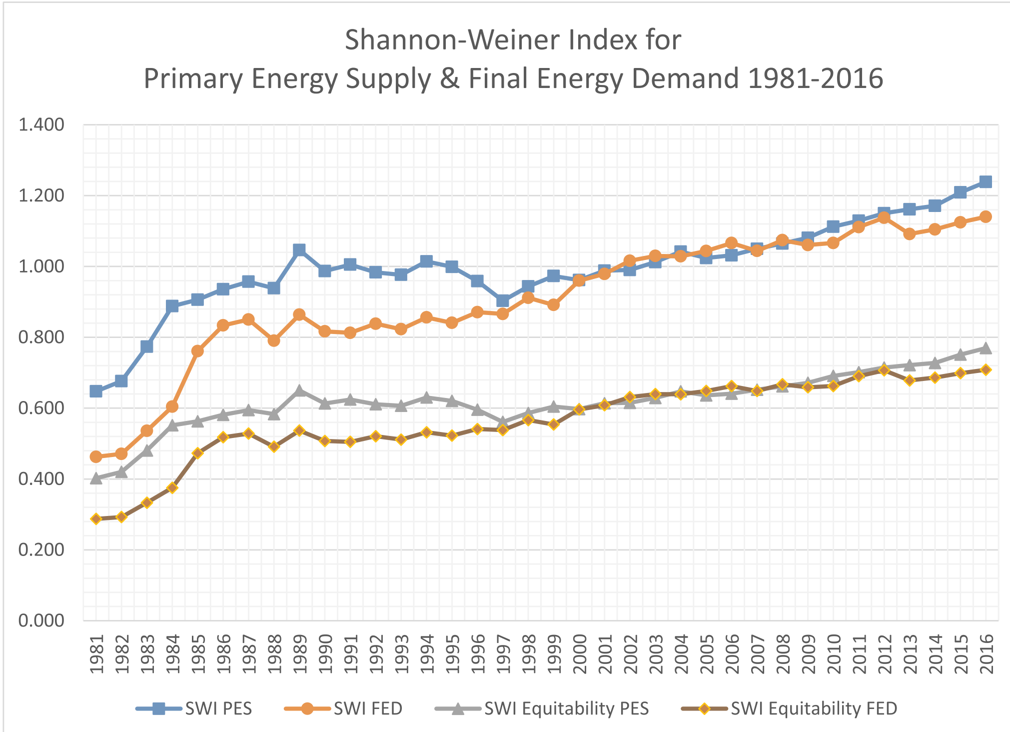

Fig. 5. Shannon-Weiner index for primary energy supply & final energy demand 1981–2016.

and equitable distribution among different fuel types. Whereas the value of 1.000 would be an indication of ideal scenario for low single fuel dependency/concentration and improved fuel diversification, the data shows the maximum values of 0.770 for PES and 0.708 for FED in 2016. While this again supports the findings from the HHI on the least concentrated energy mix on record so far, it also confirms the central role of crude oil and other petroleum derivatives in affecting the final index score. The dip in Equitability Index Value for FED between 2013 and 2015 was due to a shift in energy demand from natural gas to crude oil, although hydroelectricity maintained its utilisation share. In 2016, hydroelectricity recorded a FED value of 21.657% against 21.503% for natural gas and 53.040% for crude oil and petroleum derivatives.

Despite its implementation spanning over three decades, energy diversification remains an elusive goal in Malaysia energy security policy. Both the values acquired through the HHI and SWI suggest consistent dependency on hydrocarbon fossil fuel, and insufficient fuel diversification. The switch of dependency from crude oil to natural gas, instead of true diversification of equal proportion across four (and subsequently five) fuel types might explain why the lowest recorded HHI value for both PES and FED remained above 0.250, and SWI Equitability values below 0.800. After 35 years, the fuel diversification strategy may therefore be regarded as only partially successful.

Based on the analysis, diversification is more successful on the supply side than on the demand or consumption side. As inferred, the heavy dependency on petroleum by the transportation sector best explain this situation. Furthermore, whereas the government or the independent power producers may choose to diversify fuel for power generations, ordinary consumers in Malaysia are usually dependent on two main forms of energy supply, namely hydrocarbon fuel for motor vehicles and electricity for daily and domestic needs. This again explains why the supply side is more diversified in contrast to the demand or consumption side.

Beyond the statistical data, there is also the issue of political will. Although the Five Fuel Diversification Policy (5FDP) was formulated in 2001, the regulatory body responsible for renewable energy, the Sustainable Energy Development Authority (SEDA) was only established in 2011. The legal framework for regulating renewable energy generating activities, the Renewable Energy Act 2011 was also only legislated and gazetted during the same year (Sustainable Energy Development Authority Malaysia, 2018). This explains the lack of proper record-keeping on renewable energy statistics, which only systematically began in 2011. As it took the Malaysian government ten years since policy formulation to pursue its implementation and regulate the related sector, the seriousness of the government in adopting the renewable energy options and incorporating renewable energy as a policy item in 2001 is therefore justifiably questionable.

4.2. *Explaining the lack of diversification*

Despite the attempts for fuel diversification, it is apparent that Malaysia continues to remain largely dependent on fossil fuel for power generation. There are two main reasons which may explain this partial success of fuel diversification. The first being the way energy is being utilised in Malaysia, whereas the second reasons are the technical limitations of existing technology.

4.2.1. *Transportation sector and oil (over)Dependency*

As shown in Fig. 4, since 2008 the transportation sector is the single largest consumer of energy followed by the industrial sector, the residential and the commercial sector. Population growth, a growing number of motor vehicles as well as increased urban sprawl might have contributed this situation (Abdullah and Mohd, 2009; Malaysian Automotive Association, 2018; Suruhanjaya Tenaga, 2017c). The transportation sector recorded a peak consumption percentage of 46.595% in 2014, a value driven by an increasing needs for motor fuel (gasoline) and diesel fuel (Suruhanjaya Tenaga, 2017c). This is not particularly surprising, considering the percentage of car ownership percentage of private motor vehicles have drastically risen since early 1990s, due to the poor public transportation system (Caisarina and Mat, 2008). As shown in Table 3, between 2008 and 2015, the rate of vehicles on the road significantly exceed the rate of population growth (Jabatan Perangkaan Malaysia, 2015; Malaysia Ministry of Transport, 2016).

Table 3
Vehicle and population growth rate in Malaysia 2008–2015.

Year	Number of Vehicles on the Road	Malaysian Population	Vehicles on the road per capita	Vehicle Growth Rate (Percentage)	Population Growth Rate (Percentage)
2008	13,578,457	27,567,600	49.255		
2009	14,271,570	28,081,500	50.822	5.105	1.864
2010	15,053,772	28,588,600	52.657	5.481	1.806
2011	15,906,655	29,062,000	54.734	5.666	1.656
2012	16,570,294	29,510,000	56.151	4.172	1.542
2013	17,368,234	30,213,700	57.485	4.815	2.385
2014	18,026,509	30,708,500	58.702	3.790	1.638
2015	18,619,514	31,186,100	59.705	3.290	1.555

It was claimed that the transportation sector represents 35% of the nation's oil consumption, and only 5% of Malaysians used public transportation nationwide as private vehicles continue to be the main means of travel of urban living following economic expansion and rapid urbanization (Dahalan et al., 2015; Shariff, 2012). However, the 2016 National Energy Balance recorded that 74.2% of all the petroleum products in Malaysia are consumed in the form of petrol fuel (gasoline) and diesel, which suggests higher dependency of the transportation sector to petroleum (Energy Commission, 2016). Furthermore, throughout the 1990s until 2008, the price for retail petroleum was heavily subsidised, further contributes towards private ownership of motor vehicles (Suruhanjaya Tenaga, 2016).

Considering the high dependency of the transportation sector and high rate of private vehicle ownership, it is equally worthy to note that the adoption rate for plug-in hybrid electric vehicles (PHEV) or electric cars in Malaysia remain minimal due to its higher cost (Leng et al., 2017). Cars in Malaysia are subjected to high taxation rate, with those manufactured domestically and from within ASEAN being subjected to 60–105% excise duties, whereas those imported from outside ASEAN, subjected to 90–135% excise duties, excluding the final 10% sales tax upon purchase (Transportation Technology Division, 2018). This taxation mechanism was meant as a protectionist policy for local car manufacturers, Proton and Perodua (Rosli, 2006). At the time of writing, the cheapest PHEV car model available in the local market is a B-segment Honda Jazz costing RM 80,091 whereas the most popular car model is locally manufactured B-segment Perodua Myvi with the price tag starting at RM 41,807.74 ("Hybrid and EV," 2019; Zainul, 2019). Studies conducted shows that Malaysians may be ready to adopt PHEVs if they are cost similarly, or its value reduces up to $10,000 to $20,000 in general (Adnan et al., 2016). As the cheapest hybrid is double the cost of the most popular car model, it remains a fundamental factor limiting wider adoption.

The combination of limited and poor public transportation facilities outside the Klang Valley, higher cost of PHEV and electric car due to the existing government policies and subsidised gasoline price which have led to high rate of private car ownership, and subsequently high dependency on petroleum. Whereas there are policies in place to promote the development of hybrid and electric vehicles and related infrastructure, they remain insufficient (Ministry of International Trade and Industry, 2009).

4.2.2. Natural gas, coal and the power-generation sector

Another factor which may explain the partial success of fuel diversification, and the continuous dependency on certain fuel types may best be explain through the technical nature of its utilisation. On average, between 1981 and 2016, the energy input to the power stations represents 30.2% of annual Malaysia's total PES (Suruhanjaya Tenaga, 2017a, 2018a).

Furthermore, the dependency in the power generation sector for diesel and fuel oil in 1981 has been largely replaced by natural gas since 1992, with coke and coal complementing natural gas as main fuel option since 2010. The use of other renewable energy sources such as solar, biogas and biomass on the other hand has been rather minimal. Since the first recorded statistics for 2012, the highest utilisation of renewable energy sources was in 2013 at 0.23% (Suruhanjaya Tenaga, 2018a). This is due to the failure of previous studies to prove the feasibility of utilising wind energy, or limited initiatives on solar energy, focusing on rural-electrification and individual investment (Ho, 2016; Mekhilef et al., 2012; Sufiah et al., 2017; Suruhanjaya Tenaga, 2018a).

The existing thermal-type power plants are highly reliant on natural gas, as well as coke and coal as the main fuel (apart from hydroelectricity), and has a limited energy conversion efficiency rating. As shown in Fig. 6, whereas on average 30.2% of annual Malaysia's total primary energy supply is directed to these power plants, on average, only 36.1% of these fuel are converted into useable electrical energy (Suruhanjaya Tenaga, 2017d, 2018a). This conversion inefficiency further exacerbates the dependency on these fuel types to generate sufficient electricity for the consumers nationwide.

Although the residential and commercial sector represents only an average of 13.4% of overall final energy demand by sector, the third largest after the transportation and industrial sector, it represents an average of 51.25% total national electricity consumption during the same period of 1981–2016 (Fig. 4). In 2016, 80.16% of energy needs from the residential and commercial sector are in the form of electricity (Fig. 7). In contrast, the industrial sector which represents the second largest consumer of energy (Fig. 4) in general consumes on average a smaller percentage of electricity than those of residential and commercial, averaging at 48.60% (Fig. 7). Its sectoral energy mix is also more varied, recording the highest electricity dependency peaking at 38.54% in 2014, with an average of 22.62% throughout the defined period. The other two sectors recorded minimal electric consumption, although the agricultural sector experienced irregular electricity dependency in 2009 and 2016.

The price factor is another reason behind the lack of fuel diversification. Both natural gas and coal are relatively cheaper as fuels compared to other means of generating electricity. Due to the vast domestic natural gas reserve, Malaysia is capable of providing cheap source of energy to its population, as the power sector receives heavy subsidies through lower gas prices. This resulted in a relatively cheaper electricity tariff, despite regular price increment of natural gas since 2007. Fig. 8 demonstrates the price differences, between various users of natural gas and the Applicable Coal Price. Furthermore, the price factor may also explain the decision to adopt coal as the complementary fuel for the thermal-type power plants, despite the need to import the coal from Indonesia and Australia (Yee, 2018).

Both the reasons summed up into one major factor, namely the economic consideration. Whereas the choice for natural gas was due the existence of vast domestic supply and reserves, the adoption of coal was predicated upon the assumption that the economic cost of gas shall be related indefinitely to the cost of coal, that peninsular Malaysia shall never be an LNG importer and future shortfalls would be met through imports of coal or hydroelectricity. Thus, the substantial decline of international coal prices in the 1990s has led to the Malaysian government's decision to heavily invest in coal-fired plants (Lankester, 2012). For the transportation sector, the issue of urban sprawl and lack of proper public transportation options outside the Klang Valley area has resulted in mass adoption of privately-owned motor vehicles (Osman et al., 2012). Yet the higher price labels on PHEV and electric vehicles has made the conventional gasoline-powered cars to be preferred, exacerbating the dependency of transportation sector on petroleum.

4.3. Impacts of National Biofuel Policy (2006

In 2006, the government of Malaysia decided to undertake the National Biofuel Policy 2006 (NBP 2006), as a measure to enhance its sustainable practice and diversify the source of renewable energy. This decision was made amidst concern over rising crude oil prices,

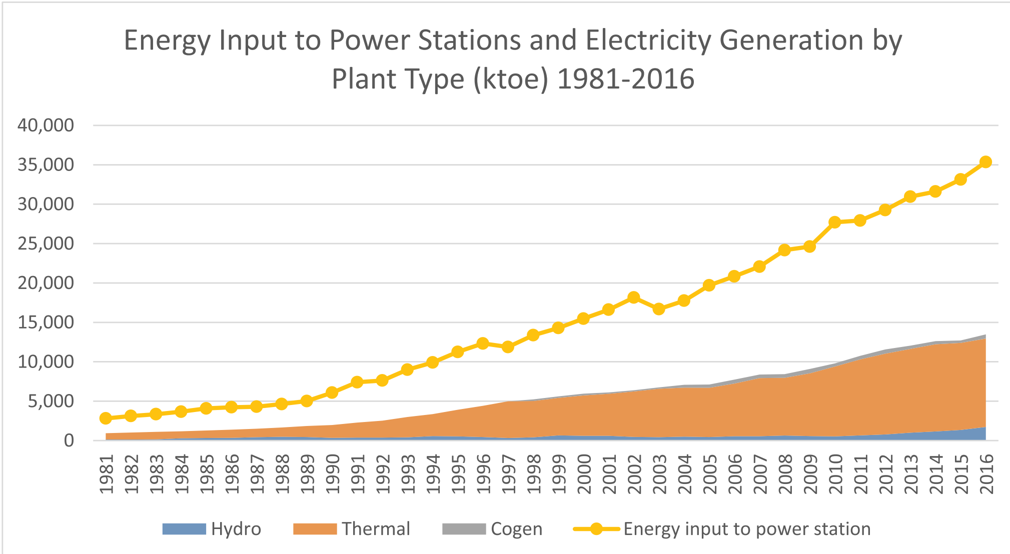

Fig. 6. – Energy input to power stations and electricity generation by plant types 1981–2016 (Suruhanjaya Tenaga, 2017d, 2018a).

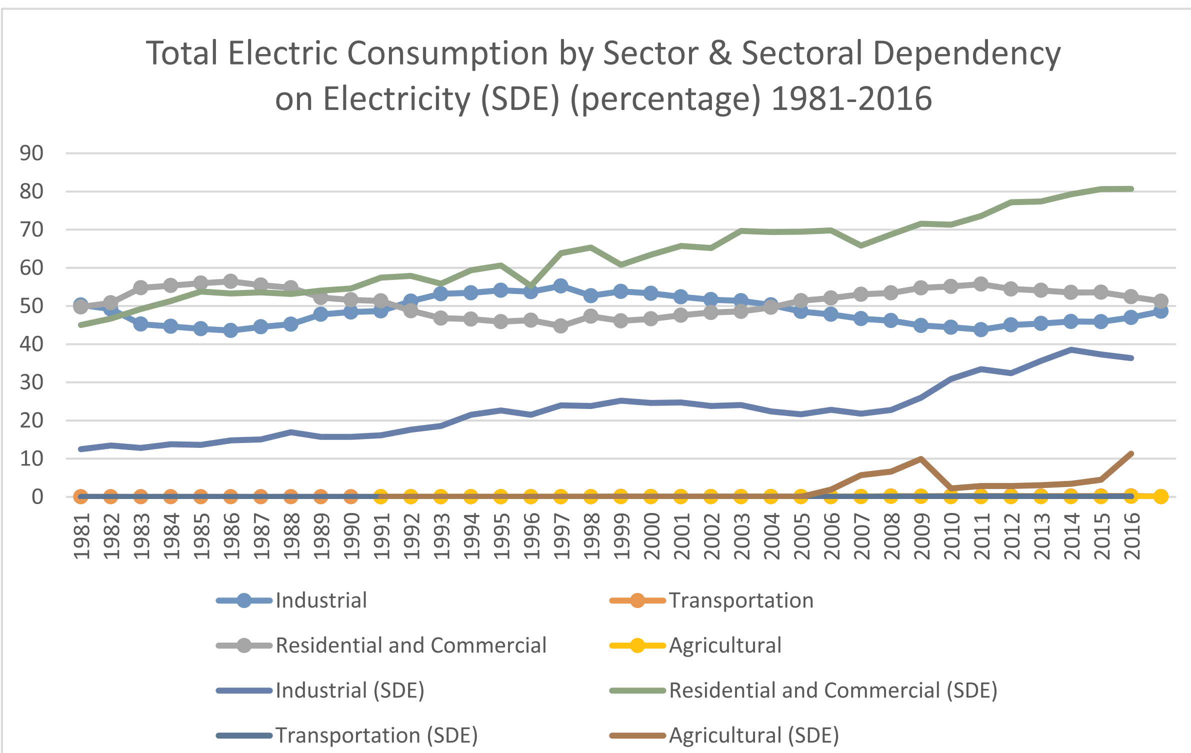

Fig. 7. – Total electric consumption by sector and sectoral dependency on electricity (SDE) (percentage) 1981–2016 (Suruhanjaya Tenaga, 2017e, 2018b).

increasing greenhouse emission level and as additional mean to augment national energy security. Among the strategic thrusts of this policy are nationwide utilisation of the biofuel diesel the transportation sector, as well as the use of biofuel to the purpose of firing boilers in manufacturing, construction and generators (Ministry of Plantation Industries and Commodities, 2006).

To facilitate the NBP 2006, the Malaysian Parliament passed the Biofuel Industry Act to implement the biofuel blend mandate, which dictates 5% palm methyl ester mix in the regular petroleum diesel (known as B5), and therefore slightly reducing the conventional diesel utilisation by the transportation sector (Chin, 2011). Small fishing vessels are also targeted recipient and beneficiary of this policy, in addition to conventional motorised land vehicles. Furthermore, apart from the transportation sector, the industrial sector was also targeted as the beneficiary to this policy, for the use of biofuels in diesel boilers (Wahab, 2018).

NBP 2006 however suffers from poor implementation. Whereas the B5 standard was initially planned for national rollout in 2008, in reality, it only took place in 2014, as its implementation in the preceding years are only limited to the central region of Malaysia (Ministry of Primary Industries, 2019). This hampers the overall effort of reducing the petroleum diesel dependency by the transportation sector, and increasing

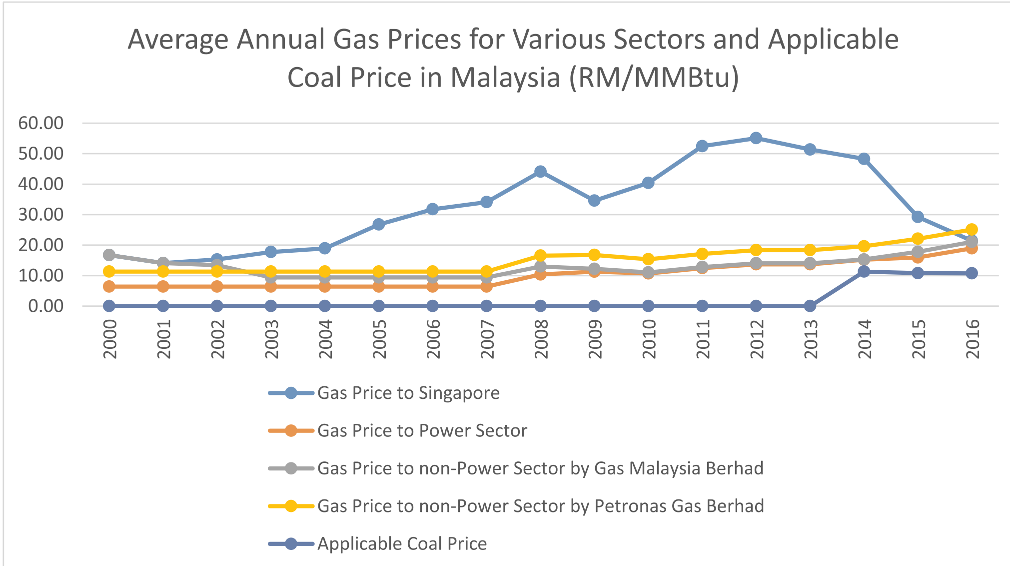

Fig. 8. – Average annual gas prices for various sectors (2000–2016) and applicable coal price in Malaysia (2014–2016) (Suruhanjaya Tenaga, 2018c, 2019).

the renewable energy share of fuel mix for the statistical purpose. Additionally, there are no concrete plans on rolling out the biodiesel for the consumption of the industrial sector (Wahab, 2018).

Following the change of government through the national general election in 2018 and the toppling the 61 years rule of previous incumbent, interests on NBD 2006 has been revived. Currently, there is a plan to implement the B10 biodiesel program for the transportation sector and the B7 for the industrial sector in 2019 ("Budget 2019: Govt to implement B10, B7 biodiesel," 2018). Furthermore, there is also a plan to roll out the B20 biofuel standards for the transportation sector by 2020 ("Malaysia seeks to implement B20 for transport sector in 2020," 2019).

The transportation sector will be the largest beneficiary from this move to the biodiesel, as it simultaneously resulted in decreased dependency in petroleum diesel while at the same time, increasing the share of renewable energy utilisation in the fuel mix. Based on Table 4, the utilisation of diesel fuel in the transportation sector averaged at 40.116% from 2010 until 2017, with continuous drop recorded since 2015, after the nationwide implementation of B5 standard was made in 2014. Further introduction of a mandatory B20 biofuel standard will equally reduce the dependency on petroleum diesel by 20%. This shall also increase the share of renewable energy deployment and utilisation in the PES and FEP statistics, therefore resulting in lower HHI value and higher SWI value overtime.

Whereas the NBP 2006 may have minimal impact under the previous administration, through the combination of external pressure from European Union palm-oil biodiesel ban, new administration and low Crude Palm Oil (CPO) price, there is presently an opportunity for better policy execution and implementation which results in improved fuel diversification (Wahab, 2018). The impact of this renewed interest on NBP 2006 however may only be apparent upon examining the fuel mix in the incoming years, which are not part of this study.

5. Conclusions and policy implications

Based on the trends, it is evident that there has been significant change on the level of fuel diversification in Malaysia national energy mix since its first formulation in 1981. Being a continuation of the NEP 1979 and NDP 1980 with the aim to reduce the dependency on crude oil, the policy has shown some level of success. Whereas crude oil and its petroleum derivatives represented 78.829% of the PES in 1981, it recorded a minimum value of 31.940% in 2010 before recording 33.542% in 2016. However, as previously discussed, this oil-dependency has unfortunately been replaced with natural-gas dependency, reaching a maximum value of 52.551% in 2006. This is counter-productive towards the general aim of reducing dependency on

Table 4
Gasoline, Diesel and Jet Fuel Use History (Million Litres) 2010–2019 (2018 & 2019 estimates) (Wahab, 2018).

Fuel Use History (Million Litres)										
Calendar Year	2010	2011	2012	2013	2014	2015	2016	2017	2018e*	2019e*
Gasoline Total	11,103	9470	10,358	14,699	14,766	14,870	15,576	15,621	15,791	15,974
On Road	8163	8478	8523	9309	10,319	9125	9004	9147	9284	9432
Agriculture	907	942	947	1034	1147	1014	1000	1016	1032	1048
Construction & Mining	0	0	0	0	0	0	0	0	0	0
Shipping & Rail	202	209	210	230	255	225	222	226	229	233
Industry	806	837	842	919	1019	901	889	903	917	932
Heating	0	0	0	0	0	0	0	0	0	0
Diesel Total	10,078	10,467	10,522	11,492	12,739	11,266	11,116	11,292	11,462	11,645
Jet Fuel Total	562	238	596	708	746	740	713	1644	1775	1917
Transportation Fuel Total (Gasoline Total + Diesel Total + Jet Fuel Total)	20,030	18,395	19,687	24,946	26,086	24,960	25,515	26,638	27,079	27,556
Diesel Transportation Total (On Road + Shipping & Rail)	8365	8687	8733	9539	10,574	9350	9226	9373	9513	9665
Diesel Transportation Percentage	41.762	47.225	44.359	38.239	40.535	37.460	36.159	35.187	35.131	35.074
Total Fuel Market	21,743	20,175	21,476	26,899	28,251	26,876	27,405	28,557	29,028	29,536

single fuel-type through diversification.

There is also the issue of energy consumption by the transportation sector. Increasing reliance on private cars, the rate of urban sprawl and absence of proper public transportation infrastructure outside of the Greater Kuala Lumpur/Klang Valley Area contributed towards increasing demand for crude oil and its petroleum derivatives. This explains the difficulties being faced by the nation in managing and reducing its "oil addiction" that despite the lowering percentage and proportion for crude oil in both primary energy supply and final energy demand, the energy demand in the transportation sector keeps on rising. Enhancing the public transportation sector and introducing alternative fuel options might assist in addressing this problem. The introduction of B5 and subsequently planned B20 biodiesel standards as a (renewable) energy source shall also decrease the overall dependency on petroleum diesel by the transportation sector, further contributing to improved fuel diversification.

For a fully successful fuel diversification policy, there needs to be a reduction in the dependency on the finite, non-renewable sources of petroleum and natural gas. The supply and utilisation percentage of the renewable energy sectors must also be enhanced and increased. A New National Automotive Policy which encourages the utilisation of energy-efficient and/or electric vehicles can be introduced. Similarly, the availability of public transportation infrastructures should be widened beyond the Greater Klang Valley area to lessen the consumption of gasoline through privately-owned vehicles. The same goes for the PES generated from hydroelectricity and the FED from coal and coke, although these phenomenon are best explained with the existing technological limitations, in a sense that there are less end-users for coal and cokes apart from the industry and power generating plants, few of which remain dependent on coal and cokes for electricity generating purposes.

As reflected in both indices, one may fairly conclude that fuel diversification policies in Malaysia have been a partial success. One of the highlighted reasons was the complacency and lack of the government's political will to properly pursue the renewable energy initiatives and agenda as outlined during the first 10 years since its inclusion in the policy framework. Although Malaysia currently enjoys a state of energy security, it is important to realise that this is due to Malaysia's own vast crude oil and natural gas reserves which are not only capable of fulfilling domestic demands but also compensates for potential import dependency. Nonetheless, with the coming of Industry 4.0 where the consumption pattern and reliance on the energy grid is expected to rise, as well as ongoing climate change, Malaysia needs to enhance its renewable energy sector, both for national energy security through true diversification, as well as reduction of the national carbon footprint.

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