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Electricity Generation Options for a Future Low Carbon Energy Mix for Malaysia

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Malaysia's electricity generation mix is mainly based on fossil fuels, particularly natural gas and coal with a smaller share of large hydroelectric and non-hydroelectric renewable energy resources. The present work aims to analyse and assess the ongoing search for alternatives to fossil fuel for electricity generation that the country has been pursuing both environmental preservation and national energy security considerations, thereby suggesting the way forward including potential options to be deliberated. This paper surveys alternative, both practical and theoretical that can be considered technically and economically attractive for Malaysia over the period to 2050. The overall national energy supply and demand situation are first analysed to develop projections that account for the role of renewable energy, particularly that of solar photovoltaic (PV). Next, the paper discusses the progress achieved, and the current status of the national solar PV industry presents the advantages or benefits offered and outlines the remaining challenges. In the same manner, electricity generation from the biogas produced from methane recovery in treating palm oil mill effluent (POME) is assessed. In the final analysis, the paper considers other potential low carbon power generation options to make up the Malaysian energy mix, which include small hydroelectricity, municipal solid waste decomposition in suitably-engineered landfills, nuclear energy using thorium-based technology, and renewable marine energy particularly ocean thermal energy conversion (OTEC), in tandem with savings expected from energy efficiency and conservation (EE&C) initiatives.

Keywords: energy supply; energy demand; energy projections; energy mix; sustainable energy; low carbon

I. INTRODUCTION

Malaysia's primary energy supply consists of oil, gas, coal, hydroelectric, and renewable resources. The nation's electricity generation mix is also largely based on fossil fuels, particularly natural gas and coal with a small share of renewable energy (RE) resources, including hydroelectricity. As of 2015, a major share of the current generation mix (see Figure 1) is heavily dependent on fossil fuels (88.4%) with the remaining contribution from hydroelectric (10.7%) and non-hydroelectric renewables (0.8%) (Energy Commission Malaysia 2016c). The search for alternatives to fossil fuels is vigorously pursued for environmental and energy security considerations.

Promoting sustainable future energy options augurs well for Malaysia to reduce the environmental impacts of air pollution, greenhouse gas (GHG) emissions, and the resulting climate change effects as well as to contribute towards waste management and cost control. Energy generated from indigenous renewable resources enhances primary energy security and also eliminates pollution from agricultural residues since a significant proportion of

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renewables use such materials. A key issue in energy production and management is how to quickly replace fuels such as coal and petroleum products, which produce carbon dioxide besides other toxic emissions, with other energy sources that can be generated without producing such emissions.

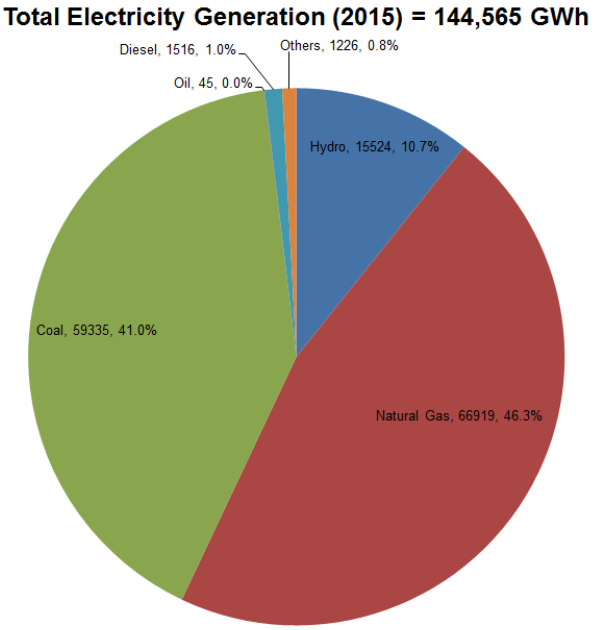

Figure 1. Malaysia: Electricity generation mix (GWh) in Malaysia for 2015 (Energy Commission Malaysia 2016c). (Note: "Hydro" includes mini hydro; "Oil" includes distillate products; "Others" includes non-hydroelectric renewables such as biomass, solar, biogas, biomass and diesel (biodiesel), natural gas and diesel.)

A number of reviews are available covering various aspects, issues, and perspectives related to the Malaysian energy landscape particularly on RE (Ahmad *et al.*, 2011; Hashim *et al.*, 2011; Ong *et al.*, 2011; Shafie *et al.*, 2011; Mekhilef *et al.*, 2014; Basri *et al.*, 2015). A recent one is by Oh *et al.* (2018) with a similar focus on alternative, mainly renewable forms of energy for the Malaysian energy policy, which serves as an update to an earlier article by the same main author and one of the co-authors (Oh *et al.*, 2010). Ahmad *et al.* (2014) present a numerical modelling approach for multiple-criteria decision making (called analytic hierarchy process) to select RE sources and technologies for developing a sustainable electricity generation system for Malaysia. This paper's authors have also published a critical review on sustainable options for electricity generation in Malaysia (Khor *et al.*, 2014), intended as policy advisory representing the views of the Academy of Sciences Malaysia, which publishes this journal.

This paper analyses the opportunities for these energy options for Malaysia by reviewing the progress and status of renewable energy in Malaysia. By setting the premise of the present situation, the work aims to examine the prospect of renewable energy development and uptake in Malaysia, supported by quantitative analyses, and to highlight the remaining challenges ahead in the endeavour.

II. CURRENT STATUS OF RENEWABLE ENERGY IN MALAYSIA

Malaysia has a variety of RE resources that can be utilised for carbon free or low carbon electricity generation to displace reliance on fossil fuels. The available economically viable options have been detailed in the SEDA mechanism for the promotion of such renewable energy-powered electricity generation (Abdul Malek 2010). These have been restricted to small hydroelectricity, photovoltaic (PV), biomass and biogas (especially from palm oil plantation waste), solid waste particularly from municipals (i.e., MSW), and geothermal energy focusing on the geothermal power plant development project at Tawau in Sabah. In particular, Malaysia possesses substantial hydroelectric resource, especially in the East Malaysia state of Sarawak, which is by far the largest renewable energy resource deployed in the country. Large hydroelectric dams are also in operation in West Malaysia such as in Temengor, Perak and Kenyir, Terengganu.

The strategy of diversifying the nation's energy mix by including RE is aimed at increasing supply reliability and security by relying less on imported fossil fuels while continuing to monitor the overall reliability of the electricity generation and supply system. As regards promoting sustainability through renewable energy, Malaysia's electricity generation mix is planned to be less dependent on fossil fuels, which currently comprises about 46.3% from natural gas and 41.0% from coal in terms of energy (Energy Commission Malaysia 2016c).

On the whole, the major contributors to the planned RE generation capacity are PV, biomass and biogas, small hydro, waste to energy, and geothermal, as shown in Figure 2. Other potential RE options that are exploited in many countries such as marine RE (wave, tidal, and ocean thermal energy conversion (OTEC)), as well as wind (both onshore and offshore), have been excluded as their resource potential in Malaysia and the equatorial zone, in general, are found to be inadequate for commercial exploitation (SIRIM 2013).

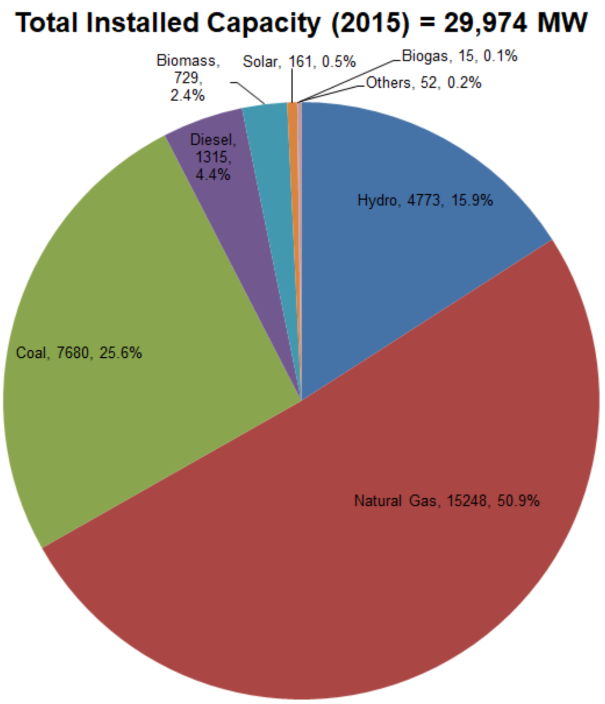

Figure 2. Installed power generation capacity (MW) (both on-grid and off-grid) in Malaysia for 2015 (Energy Commission Malaysia 2016b)

Contribution of renewables to the country's electricity generation mix has grown with the implementation of a feed-in tariff (FiT) scheme under the Renewable Energy Act 2011 (RE Act). The Act was supplemented by the formation of Sustainable Energy Development Authority (SEDA) as the legally designated agency for its implementation, supported by a funding mechanism to pay the increased or "top-up" tariff under FiT by way of a 1.6% levy on the electricity bills for affected consumers.

RE Act particularly through FiT aimed to achieve a RE capacity share of 11% (2080MW) in 2020 and 17% (4000MW) by 2030 for Peninsular Malaysia (i.e., excluding Sabah and Sarawak). FiT has promoted electricity generation from renewables, particularly from solar PV systems as the scheme is very lucrative, and it is easy to install PV systems quickly. The FiT regime for PV was terminated in 2017, but FiT for the other RE technologies remains.

Following the termination of the FiT scheme for PV, further promotion of PV systems was modified with greater emphasis on large scale solar (LSS) systems, which is also called utility-scale solar (USS) systems besides through the Net Energy Metering (NEM) scheme (see Section IV(A) for more details) and for self-consumption (SelCo), which aimed to maintain the high pace growth of solar PV capacity. These systems do not qualify for any FiT incentive but are based on NEM for SelCo and consumers' own, typically rooftop, installations.

The LSS/USS installations are however subject to tender auctions by the Malaysian Energy Commission (or Suruhanjaya Tenaga) at RE tariff rates based on the tendered quotes. They are paid directly by the authorised electricity suppliers (i.e., Tenaga Nasional Berhad (TNB) in Peninsular Malaysia or Sabah Electricity Sendirian Berhad (SESB) in the East Malaysia state of Sabah, referred to as the single buyer off-taker) under individual power purchase agreements.

The NEM and SelCo schemes did not take-off as well as expected because of perceived unfavourable tariffs offered; the "net energy" was not on actual net energy metering basis. The apparent drawback has been rectified recently by a decision by the Malaysian minister in charge of the energy portfolio (under the Ministry of Energy, Science, Technology, Environment and Climate Change or MESTECC) to make the NEM a true net energy metering and billing system (Yeo 2018). Such change and reclassification of NEM beginning January 2019 are anticipated to make the financial viability more attractive to prospective consumers to take advantage of the revised billing mechanism. Hence, going forward, the take-up capacity of NEM and SelCo is likely to accelerate.

Also, the MESTECC Minister has announced a revised national target for RE generating capacity share of 20% by 2025, which excludes large hydroelectric power plants. In this respect, the large hydroelectric plants are defined as those with generating capacity of over 100MW (see Table 1 for a list of hydroelectric plants in Malaysia grouped according to this classification).

In the Appendix of the paper, Section 9.1 provides a concise summary of policies related to energy, particularly renewable energy in Malaysia (see Table 14 and Figure 11). While various policies, programs, and initiatives have been undertaken to promote renewable energy in the country, the level of penetration attained still leaves room for improvement. Adopting a wider range of technologies is desirable as it has been acknowledged that there is not a silver bullet solution to address the energy trilemma of meeting energy needs for the nation's growth while ensuring environmental sustainability and promoting the welfare of the people.

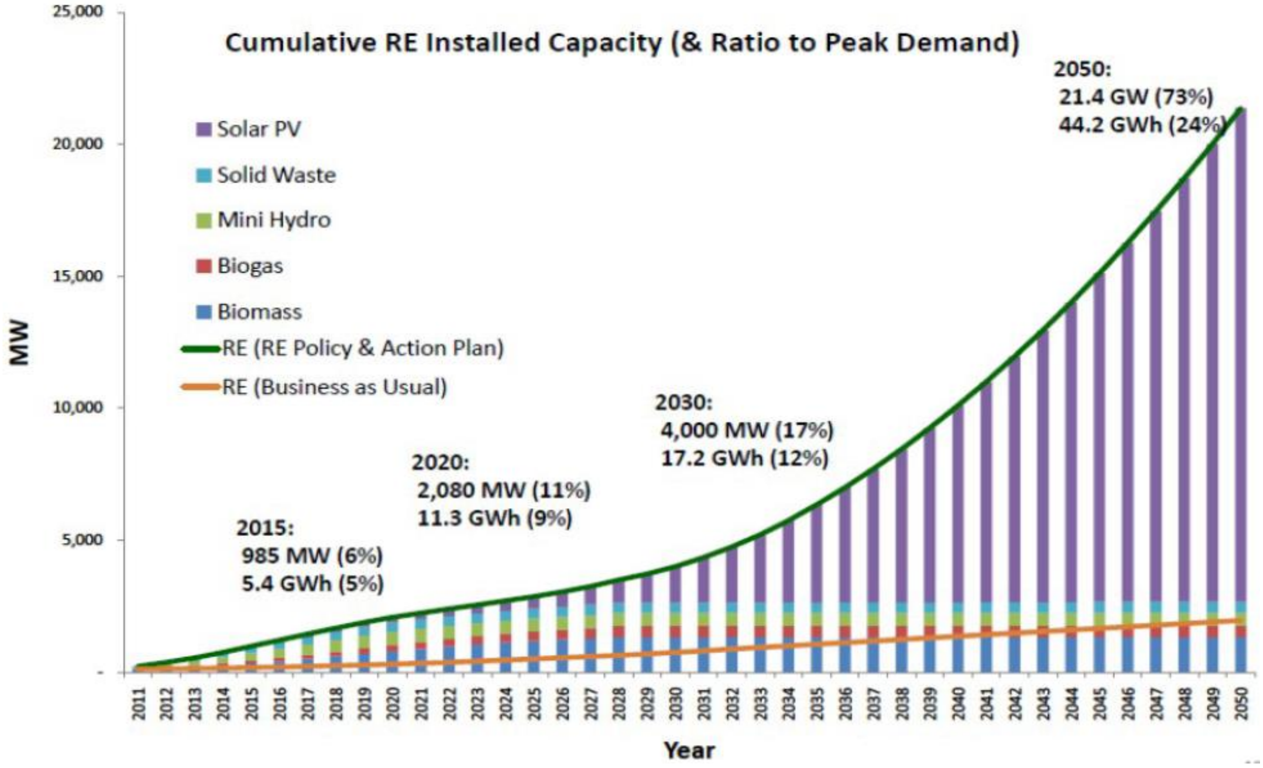

Figure 3. Malaysia: Current and projected cumulative renewable energy installed capacity (KeTTHA 2008b)

Table 1. Malaysia: Hydropower plants categorised according to generation capacity size (Energy Commission Malaysia 2015b)

State/River	Location	Capacity (MW)
Capacity greater than 100MW		
Perak	Temengor	348
	Kenerong	120
Pahang	Cameron Highlands (Jor and Woh)	250
	Ulu Jelai	372
Terengganu	Sultan Mahmud Kenyir	400
	Hulu Terengganu	250
Kelantan	Pergau	600
Sarawak	Batang Ai	108
	Bakun	2400
	Subtotal	4848

Capacity less than 100MW		
Perak/Sungai Perak	Chenderoh	40.5
	Bersia	72
	Upper Piah (Sg. Piah Hulu)	14.6
	Lower Piah (Sg. Piah Hilir)	54
Pahang	Cameron Highlands	11.9
Kelantan	Kenerong Upper	12
	Kenerong Lower	8
Sabah	Tenom Pangi	69
	Subtotal	282.0
Mini-hydro		
Perak	Sungai Renyok	1.6
	Sungai Perdak	0.342
	Sungai Bil	0.225
	Sungai Kinjang	0.325
	Sungai Asap	0.11
	Sungai Chempias	0.12
	Sungai Tebing Tinggi	0.152
Kedah	Sungai Tawar Besar	0.552
	Sungai Mahang	0.454
	Sungai Mempelam	
Terengganu	Sungai Cheralak	0.48
	Sungai Berang	0.364
	Subtotal	4.724
	Grant Total	5134.724

III. MALAYSIA'S ENERGY SUPPLY AND DEMAND

A. Current Scenario

Based on the Malaysian Energy Commission (or Suruhanjaya Tenaga) data as of 2015 (see Figure 2), the current renewables installed generation capacity including large scale hydroelectricity is 5730MW or 19.1% of the fuel mix (Energy Commission Malaysia 2016b). The installed capacity excluding large scale hydroelectricity is 957MW or 3.2% of the total. Note that the Energy Commission data may have reported a higher installed biomass capacity (801MW) than that of the SEDA data (142MW) due to the inclusion of self-generated electricity (i.e., non-grid connected) from palm oil mills.

In terms of 2015 energy generation, renewables including hydroelectricity contributed 11.6% (16,750GWh) to the fuel mix; the figure is 0.9% (1226GWh) without hydroelectricity. While the non-large-hydroelectric renewables share is forecast to increase to 20% by 2025 (Yeo 2018), its use is still to complement that of fossil fuels partly due to the intermittency effect of solar PV output and ease of access. Overall, the installed capacity and energy generation shares are mainly contributed by fossil fuels and large hydroelectricity.

Data for 2011 to 2015 shows an average consumption load factor of about 70%, which is a ratio of electricity consumed to its maximum demand. Over the same period, an average capacity factor (ratio of electricity generated to its installed generation capacity) of greater than 50% is indicated for Malaysia. A study commissioned by the Academy of Sciences

Malaysia reports both factors within the stated range (Akademi Sains Malaysia 2015).

B. Energy Supply and Demand Projections

Official statistics on the power generation capacity (in MW) mix for Peninsular Malaysia with projections to the year 2026 is shown in Figure 4. The projections show a large capacity increase from 2019 to 2020, which then stays fairly constant till 2024, but is then expected to decrease. No specific strategies that can contribute to such capacity (or demand) decline are indicated although the national energy efficiency or demand-side management (DSM) initiatives appear to be the main rationale for the projected demand trend. Based on the authors' awareness of similar initiatives for Denmark and California in the United States, such an eventuality is unlikely especially because Malaysia has yet to implement its DSM program (see Figure 5 and Figure 6which show rising energy trend for both locations). National DSM initiatives, when implemented, can help to moderate the demand growth rate over time.

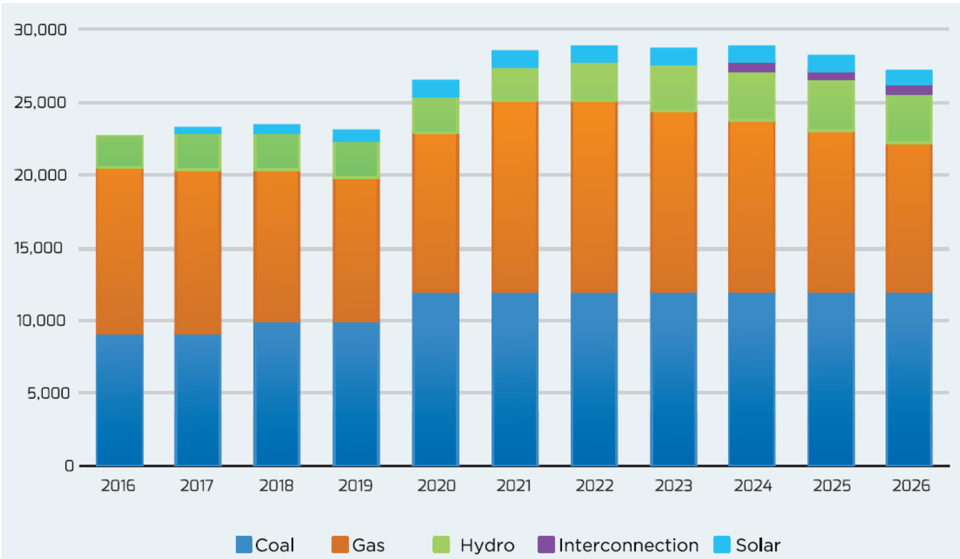

Figure 4. Peninsular Malaysia: Power generation capacity (in MW) mix with projections to 2026 (Energy Commission/Suruhanjaya Tenaga Malaysia 2017)

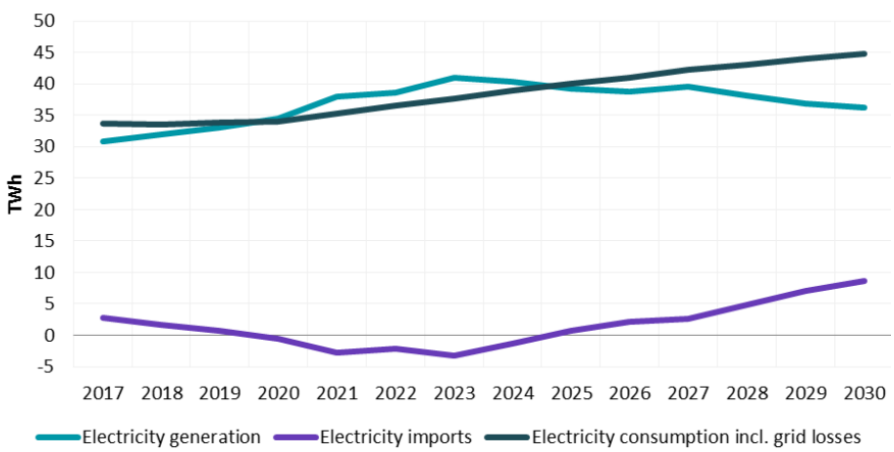

Figure 5. Denmark: Electricity consumption (projected in TWh), generation, and imports for 2017–2030 (Danish Energy Agency 2018)

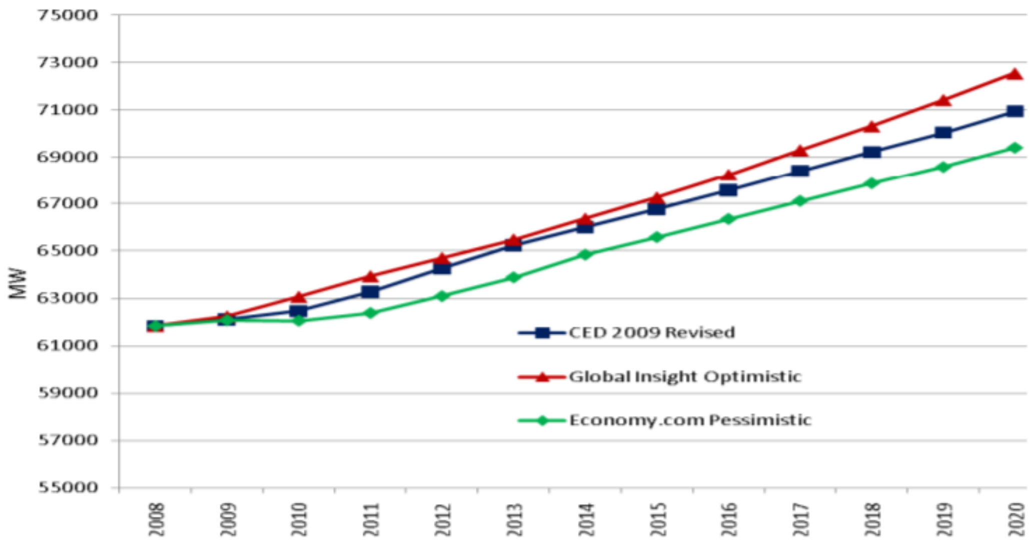

Figure 6. California (USA): Peak energy demand (projected in MW) for 2008–2020 (Kavalec and Gorin 2009)

To compare, such a decline in energy use is only seen after about three decades in a country such as Sweden. In the latter case, the reason can be attributed to its manufacturing industries moving abroad to take advantage of cheaper labor cost, which is partly reflected in its reduced final energy use in the residential and services sector observed over more than four decades (1971 to 2013) as shown in Figure 7 (Swedish Energy Agency 2015).

As Malaysia's energy demand is expected to continue to rise (Energy Commission Malaysia 2017), it is imperative for the energy supply sector to ensure adequate generation, transmission, and distribution facilities are in place to meet the nation's needs. The current and projected RE capacities under different categories of technologies and programs are tabulated in Table 2.

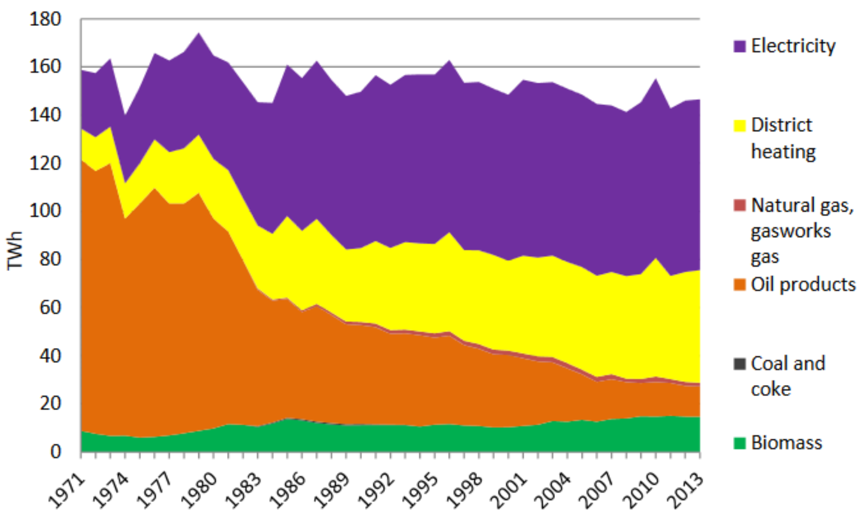

Figure 7. Sweden: Final energy use (in TWh) in residential and services sector by energy carrier for 1971–2013 (Swedish Energy Agency 2015)

However, Figure 8 taken from Energy Commission statistical documents shows a decline in the growth rates of electricity generation projections after 2015 (Energy Commission Malaysia 2017). The forecasts imply reduced growth rate in general that can be due to one or a combination of several factors (Sovacool 2010) such as increasing energy use efficiency; structural changes in economic activities, e.g., from energy-intensive manufacturing to less energy-intensive service-based industries; declining overall economic development; or demand-side management initiatives, which have yet to be implemented consistently in Malaysia (Economic Planning Unit, 2018a). The projections by Energy Commission have correctly considered the declining growth rates that are in part due to energy efficiency and conservation especially by large consumers through initiatives such as smart buildings and high technology or high-efficiency appliances (e.g., chillers). Nevertheless, these projections do not indicate any reduction in the demand, only a declining growth rate.

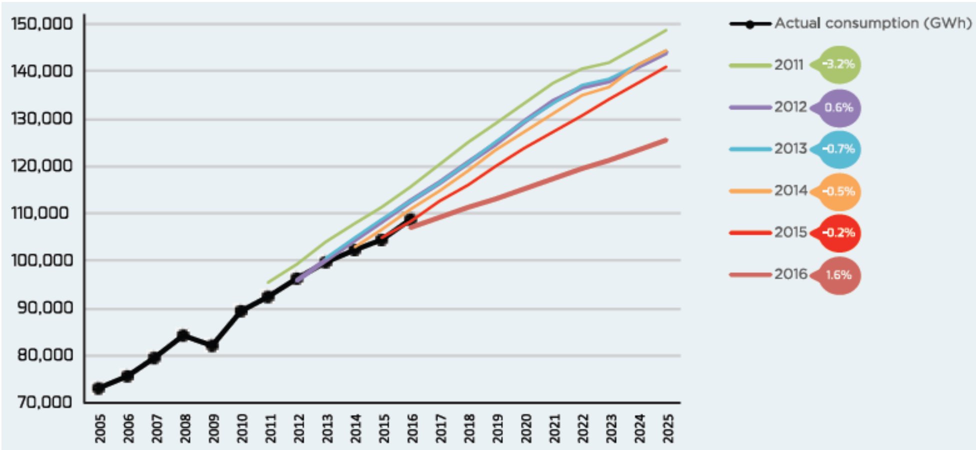

Figure 8. Official statistics by Malaysian Energy Commission on forecast versus actual electricity consumption (in GWh) (Energy Commission Malaysia 2017)

Table 2. Current and projected capacities of renewable energy resources for Malaysia (SEDA 2018; 2019)

Technology	Approved Capacity Up to 2020 (MW)	Installed Capacity Up to 2020 (MW)	Potential Additional Capacity (MW)		Total Capacity Up to 2025 (MW)
			Tendered (Up to 2022)	Planned (Up to 2025)	
Solar PV					
PV Farm (FiT)	330.16	5.14	n.r.	n.r.	335.30
Rooftop (FiT)	98.43	9.32	n.r.	n.r.	107.75
LSS/USS	1500	34.5	500	230	2000
NEM	34.53	9.877	500	462	1006.407
SelCo	n.r.	n.r.	n.r.	n.r.	n.r.
Biomass	396.19	55.00	12.40	0	463.59
Biogas	220.86	20.14	0	0	241.00
Small hydro	538.48	30.30	41.70	32.84	643.32
Waste to energy*	104.42	13.36	30.00	0	147.78

Notes: *Includes landfill, agriculture waste, solid waste; n.r. = not reported

C. Role of Solar Photovoltaic

Malaysia adopts a 25% reserve margin principle of generation capacity over maximum demand. This means for a nominal maximum demand of 17.0GW for Peninsular Malaysia; the total generation capacity needs to be about 21.3 GW.

For a pre-year 2020 scenario projection, a target cumulative solar PV systems of 3.0 GWp of installed capacity can reduce maximum demand from conventional electricity generation by approximately 2.4GW based on the actual on-site maximum generation of about 80% of the nominal capacity due to ambient thermal effect (Nelson, 2011).

For a post-2020 scenario, it is estimated that by installing about 5.0GWp of solar PV systems capacity, we can reduce maximum demand by about 4.0GW from 23.5GW to 19.5GW as based on empirical data trends in Figure 9 applied to Energy Commission data for 2017 projected to 2035 (Energy Commission Malaysia 2017). This strategy can reduce the generation capacity needed (i.e., including a 25% reserve margin) to 24.4GW (i.e., 1.25 times 19.5GW) instead of 29.4GW (i.e., 1.25 times 23.5GW). Based on similar assumptions, doubling the installation of solar PV capacity to 10.0GWp can reduce maximum demand by about 8.0GW based on the Outlook 2017 projection, i.e., from 23.5GW to 15.5GW in 2035. This reduction is realistic if it is equal to or higher than the trough demand during the off-peak consumption. The detailed calculations for the projections are available in the Appendix.

The maximum power demand can be further reduced through energy efficiency measures. A preliminary study on demand-side management (DSM) by the Malaysian Economic Planning Unit (2018b) estimates a demand saving of 3.315GW is expected to accrue over the entire DSM program duration up to 2030.

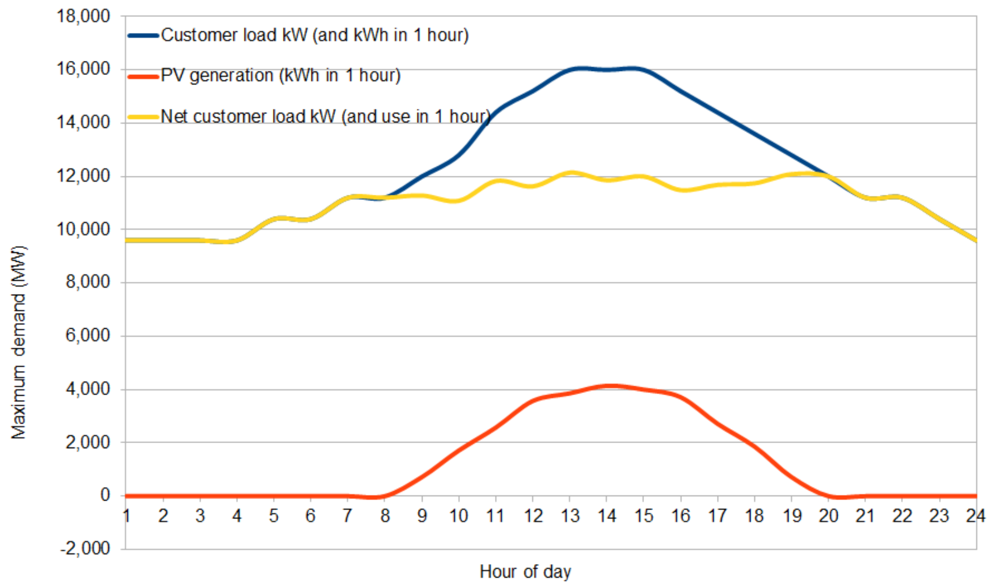

Figure 9. Peninsular Malaysia: Impact of solar photovoltaic (PV) generation on maximum demand.

D. Role of Energy Efficiency and Conservation

Energy efficiency and conservation (EE&C) serves to reduce the total electricity demand, thereby increasing the relative proportion of renewable energy contribution. Thus EE&C is a contributory component to enhance the relative share of renewable energy in the national electricity mix. To illustrate, in the preceding projection in Section III(C) in which solar PV can potentially reduce maximum demand by 8.0GW, the resultant proportion of renewable energy will be higher.

By the relatively low investment required for their implementation, EE&C measures are touted as low-hanging fruits relative to the benefits offered. Further, the initiatives encourage local participation and ensure community resilience as they are largely carried out locally. Table 3 summarises the advantages or benefits alongside several energy efficiencies and conservation initiatives that have been undertaken (Lalchand 2012; Chin *et al.*, 2013).

Most commercial and some industrial users have significant air-conditioning cooling loads. The efficiency of new large centralised chiller technology has improved compared to that found in older plants. One of the author's experiences from energy audits for some commercial consumers show their air conditioning energy use share at 50 to 60% and lighting energy use share at up to 30%. The share of air conditioning and lighting energy use for industries are not as well known, but they may be of the conservative order of about 10% of their respective total consumption (KeTTHA 2009). The calculation details for the estimated saving is given in the Appendix.

Table 3. Advantages or benefits and initiatives to promote energy efficiency and conservation in Malaysia

Advantages/Benefits	Initiatives
• Energy cost savings for air conditioning and lighting in commercial buildings and industries by better insulation • Tax benefits for companies under Investment Tax Allowance (e.g., for replacing centralised chillers with newer efficient ones) • Encourage local participation and ensure community resilience as they are largely carried out locally	• Implement cogeneration and trigeneration of power and heating and cooling duties to reduce efficiency losses in transmission and distribution of electric power • Replace commonly used tubular T8 fluorescent lamps for commercial and residential use with more efficient LED alternatives that give the same lighting level but at about two-thirds of the energy consumed • Use 5-star energy efficient refrigerators—KeTTHA has promoted them under its Sustainability Achieved Via Energy Efficiency (SAVE) program since 2011 • Replace window or split type air-conditioners with the 5-star or inverter type equivalent models—also applicable to other home appliances such as televisions and fans • Install and enhance insulation for roof, wall, and window to help reduce cooling power demand

Thus, it is cost-effective to replace older chillers to benefit from the higher efficiency of new chillers due to current electricity tariffs and their anticipated increase in line with the government's declaration to remove fuel subsidies gradually. This suggestion is more so since such companies can avail tax benefits (Investment Tax Allowance, ITA) that the government has provided for the adoption of energy efficiency and conservation initiatives. Replacing every ton of refrigeration of centralised chiller plant with more efficient plant can offer energy cost saving on the order of about RM528 per annum (based on an estimated saving of 0.5kW per ton of refrigeration on an average operation of 10 hours per day and 22 days per month at average tariff of 0.40RM/kWh) for typical users such as offices, shopping malls, and hospitals.

To illustrate the magnitude of potential energy saving, we consider Malaysian statistics for 2015 that reports commercial and industrial electricity use to be 36,645GWh and 43,754GWh, respectively (Malaysia *et al.*, 2015). Thus, a conservative energy demand saving an estimate of only 10% for the cooling load equates to about 1,832GWh saving for commercial users and 438GWh for that of industrial consumers, making a total saving of about 2,270GWh per annum. This energy saving implies a demand saving of about 370MW, hence avoiding a need for power generation capacity of about 463MW (including a 25% reserve margin). Based on one of the author’s experience (during his involvement in the design of the LEO (Low Energy Office) building for the then Ministry of Energy, Green Technology, and Water (KeTTHA) in Putrajaya), the actual saving from replacing old chillers with state-of-the-art energy efficient chillers can be as much as 25% without sacrificing the cooling capability required, which gives a correspondingly higher reduction in maximum demand and generation capacity need.

Similarly, energy efficient lighting for commercial and industrial users would provide additional saving. Based on shares of energy used of 20% for commercial and 10% for industrial users, and conservative prospective saving to be achieved of about 48% (up to 50%) for T8 fluorescent tubes replaced with LED, changing existing lighting to the latter more efficient alternative can save 1173GWh a year. Further, there can be additional saving for air-conditioning due to a lighting energy saving of about 20%, which equals to 235GWh. Thus the combined lighting and air-conditioning energy saving would equate to a demand saving of about 229MW, implying a reduction in power generation capacity required of about 287MW.

The total potential energy saving from using energy efficient lighting and replacing existing older centralised chillers with new more efficient units can be as much as 3677GWh, which would equate to a demand reduction of 600MW. Allowing for a 25% reserve margin, this would equate to a reduction in required power generation capacity of 750MW.

Energy-efficient air-conditioners can contribute an annual saving of 76.65GWh per year up to a total potential saving of 919.8GWh. This estimate is made by assuming 1 million units are changed (or installed) annually with 20% (i.e., 200,000 units) being the energy-efficient 5-star air-conditioners over a 12-year period (thus giving a total replacement of 2.4 million out of 12 million units) with a conservative 25% energy saving for an average daily use of 6 hours at 70% utilisation factor. Carrying out such replacement of domestic air-conditioners can reduce demand by 975MW and power generation capacity by 1.219 GW.

Table 4 Summarises the estimated annual saving in terms of energy, cost, and capacity from these initiatives, which amounts to a total on the order of 3,181 MW corresponding to 13,604GWh per year with a cost saving of RM16.0 billion.

Table 4. Estimated annual saving through representative energy-efficient device replacement initiatives

Energy-Efficient Device Replacement Initiative	Electricity Saving (GWh/year)	Cost Saving (RM)	Demand Reduction (MW)
Chilling in industrial and commercial sectors	2,270	9.08 billion	370
Lighting in industrial and commercial sectors	11,257	4.50 billion	1,836
Air conditioning in the residential sector	76.65	2.39 billion	975
Total Saving	13,604	16.0 billion	3,181

IV. NATIONAL-LEVEL INITIATIVES FOR RENEWABLE ENERGY DEVELOPMENT

Since the middle of the 2000, several efforts have been undertaken nationwide to spur the development and uptake of renewable energy in Malaysia (Chua *et al.*, 2010; Oh *et al.*, 2010). Two such initiatives are delineated, namely developing a national solar energy industry and producing biogas through methane emissions recovery from the palm oil mill effluent (POME) treatment process.

A. Development of National Solar Energy Industry

1. Progress and status

Malaysia has established grounds in the solar photovoltaic manufacturing industry since First Solar; a USA-based company began its operations in Malaysia in 2007 with four manufacturing lines in Kulim. The initiative continued with the Malaysia Building Integrated Photovoltaic (MBIPV, 2005–2011) project administered by the Malaysian Ministry of Energy, Green Technology and Water (KeTTHA) and supported by the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP) (Haris *et al.*, 2009). The industry has expanded to become a major economic development sector with international market reach (Academy of Sciences Malaysia 2010). After First Solar, several other international companies have set up solar PV manufacturing facilities in Malaysia such as SunPower (USA) (SunPower Corporation 2014) and Hanwa Q Cells (Germany) (Hanwa Q Cells GmBH 2014).

The ongoing Net Energy Metering (NEM) scheme allows industrial, commercial, and residential consumers to install rooftop solar PV systems for self-consumption and for the excess electricity to be exported to the national grid at a set selling rate or displaced cost. However, the overall response has been dismal (Joshi, 2018). The TNB-declared displaced cost is fixed at 31 cent/kWh for low voltage connection but only 23 cent/kWh for medium voltage connection, which is lower than the current average generation cost of 26.39 cent/kWh (see Figure 10 for a delineation of the tariff cost structure), thus disincentives the NEM scheme (Energy Commission Malaysia 2016a). As mentioned earlier in Section II, this deficiency has since been addressed through an announcement in October 2018 to offer a selling rate equal to the tariff rate (Yeo 2018). Further as has also been stated, under the 11th Malaysia Plan, ST has continued to pursue establishing a national solar energy generation industry by approving contract awards to implement solar PV projects of the order of 30 to 50MW per plant size through the LSS/USS program starting in 2017 (see Table 5 for details of the awarded generating capacity). The target is to achieve a total capacity of 1000MW by 2020 or 250MW per year on average (SEDA 2017).

Table 5. Malaysia: Large scale solar (LSS)/Utility scale solar (USS) project contracts awarded

Award Round	Commercial Operation Year	Peninsular Malaysia	Sabah (and Labuan)	Total Projects	Total Capacity (MW)
Cycle 1	2017/2018	383.996	16.9	18	400.896
Cycle 2	2019/2020	506.388	50.6	40	556.988
Cycle 3	2021/2022	220	50	8	270
	Total	1110.384	117.5	66	1227.884

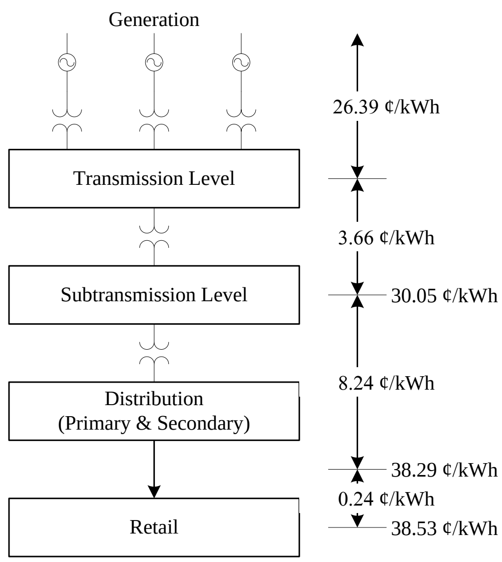

Figure 10. Electricity base tariff components and their associated costs as implemented under the Malaysian Government's incentive-based regulation (IBR) framework (Energy Commission Malaysia 2016d)

2. Advantages and benefits

The creation of a large scale national solar PV industry has realized the following advantages and benefits to the nation: setting up a new technology sector with high growth potential that creates thousands of job opportunities, establishing Malaysia as a world-leading solar PV equipment manufacturer using imported technology, generating revenues with direct returns for reinvestment for the industry and contribution to national gross domestic product (GDP), and providing direct benefits to local industries that form part of the value chain (Academy of Sciences Malaysia 2010).

3. Technical and commercial challenges

Several supporting governmental strategies have been implemented to build a national solar PV industry, namely by nurturing a conducive market environment, enhancing industry participation, building the required infrastructure, and promoting research, development, and innovation. These initiatives are summarised in Table 6. Further efforts to ensure a sustainable national solar PV industry necessitate the need to address the management of hazardous waste generated during the production phase through proper treatment of its effluent. In the foreseeable future, we face challenges associated with the disposal of end-of-life solar PV panels (Larsen 2009; International Renewable Energy Agency (IRENA) 2016; Malandrino *et al.*, 2017).

Table 6. Supporting governmental strategies to build a national solar PV industry in Malaysia

Strategy	Plan
Nurture a conducive market environment	• Promote public awareness and implement advocacy programs • Install solar PV systems in government buildings and promote Green Building Index (GBI) compliance • Design a long-term national energy policy based on renewable energy particularly solar PV
Enhance industry participation	• Intensify human capital development through industry missions, sponsored exchange programs such as apprenticeships, and training abroad • Facilitate partnerships between multinational companies and local industries • Upgrade targeted local industries to solar PV-related activities (e.g., wafer fabrication in the electronics industry) to leverage on lower costs, lower entry levels, and faster implementation • Introduce industry demonstration and quality programs and award schemes
Build infrastructure	• Introduce business facilitation packages, e.g., soft loan schemes and focus grants for local industries to enter and expand • Promote intellectual property acquisition and foreign direct investments with a focus on direct benefits for local industries to trigger domestic direct investments • Identify government or government-linked company (GLC) investments in new promising solar PV technologies and catalyse development, incubation, and creation of fast spin-off companies
Promote research, development, and innovation	• Design and implement a national solar PV research and development (R&D) roadmap with a focus on technology innovation and cost reduction • Establish internationally-certified test facilities and solar PV R&D centre to support required activities • Increase R&D budget for technology and process development with constant industrial monitoring and feedback • Establish review and an advisory committee comprising local and international experts • Enhance collaboration between industry and academia • Exploit the Brain Gain Malaysia program with a special focus on solar PV technology • Foster growth of technopreneurs

B. Methane Recovery and Biogas Production from Palm Oil Mill Effluent Treatment

1. Progress and status

It is now mandated for all palm oil mills to recover or avoid methane gas emissions in treating the wastewater discharge of palm oil mill effluent (POME) to meet regulatory discharge limits. There is potential to use the methane for electricity and heat generation subject to appropriate treatment and upgrade to suitable quality as biogas (Wu *et al.*, 2010).

The Malaysian Government's Economic Transformation Programme (ETP) under Entry Point Project 5 (EPP5) requires palm oil mills to install facilities to generate biogas or avoid methane emissions by 2020 (PEMANDU 2010). The biogas can be used internally within a mill through co-firing with biomass or replacing the fuel in a boiler to generate steam and chilled water. In the former approach, there is an opportunity to use fewer biomass sources such as oil palm mesocarp fibres and make them available for other downstream higher value uses. Another possibility is to supply the captured biogas to local communities through pipelines or in bottles (Malaysian Industry-Government Group for High Technology (MIGHT) 2013). A mill can also supply the biogas-generated electricity to the national grid to get additional income under the Feed-in-Tariff scheme (SEDA (Sustainable Energy Development Authority of Malaysia) 2012). As of July 2017, biogas plants have been constructed at 94 mills in Malaysia with another eight facilities under construction while 144 sites are under such planning (Astimar *et al.*, 2017).

2. Advantages and benefits

Trapped biogas from palm oil milling sector to be used as an energy source can potentially avoid about 17 million tonnes (Mt) (1.7×10^7) of CO_2 equivalent (CO_2e) (Astimar *et al.*, 2017). In particular, unrecovered methane emissions from POME that escape to the atmosphere may contribute towards greater global warming and climate change, because methane is a more potent greenhouse gas that has 72 times the global warming potential of CO_2 measured over 20 years and 21 to 25 times over 100 years. This problem has been exacerbated by an increasing number of palm oil mills in Malaysia from just about 10 mills in 1960 to 454 operating mills in 2017 (Malaysian Palm Oil Board 2018), and oil palm has the largest agricultural plantation acreage and production in the country compared with other major crops (Department of Statistics Malaysia 2017).

A life cycle assessment study on Malaysian palm oil milling reveals that uncaptured methane emissions from POME contributes the highest environmental impact towards climate change in the country and is responsible in making the overall industry, not environmental friendly (Subramaniam *et al.*, 2008). The unrecovered and unutilised methane-rich biogas from the aerobic decomposition of the POME wastewater treatment process has also been highlighted in a post-evaluation of the BioGen project (Aldover *et al.*, 2010). Additionally, the potential revenue from generating bioenergy may be used to offset POME treatment cost. Based on the reported amount of oil palm fresh fruit bunch processed in 2015, an estimated 548MW of electricity can potentially be generated (assuming power output at 40%) (Astimar *et al.*, 2017).

3. Technical and commercial challenges

By 2020, it is not allowed by regulations to treat POME in Malaysian palm oil mills through the current conventional way of using open ponds or lagoons (i.e., open digesting tanks) because valuable biomethane is released to the atmosphere in such systems besides being a GHG emission source (Loh *et al.*, 2017). An alternative to converting the bulk of POME to biomethane is to use a closed anaerobic digester system in the first treatment stage to handle the high organic matters in the wastes. A covered lagoon system can be installed directly and cost-effectively using floating plastic membranes on open ponds; in that way, the released biomethane is captured and retained within the floating covers (Lam *et al.*, 2011). Such a biogas capture system has been applied in Malaysia in flaring, as boiler fuel in power and heat generation, and as feedstock in hydrogen production (Tong *et al.*, 2004; 2005; NOVAVIRO Technology Sdn Bhd 2010). Moving forward, we can employ high-rate anaerobic digesting tank systems for optimal biogas generation to produce electricity (Najafpour *et al.*, 2006; Poh *et al.*, 2009; Ahmed *et al.*, 2015). However, to benefit from the FiT scheme incentive by connecting to the national electricity grid, a constraint is the remote location of most mills. In this regard, we advocate implementing a smart grid for renewable resources remote from the national grid (Electric Power Research Institute (EPRI) 2008). An example pertains to mills in Sabah, in which it is expected to be costlier to subsidise diesel generation than to put up a smart grid interconnection to a few such mills.

V. EMERGING RENEWABLE ENERGY OPTIONS FOR ELECTRICITY GENERATION IN MALAYSIA

Several electricity generation alternatives from low carbon energy options are available or currently considered under various development stages in Malaysia. They include the following (in no particular order): small hydroelectricity (Table 7), fuels and electricity from oil palm biomass, municipal solid waste decomposition (Table 9), thorium-based nuclear power (Table 10), ocean thermal energy conversion (OTEC) (Table 11), and hydrogen using fuel cells (Table 12). This section provides an overview of the advantages or benefits within the Malaysian context and delineates several challenges faced for these alternatives. A summary of the potential of these options considered is given in Table 13.

Small scale hydropower stations offer low operating cost besides the reliability of employing a mature technology. A small hydroelectric facility is especially suitable for implementation in locations far away from the main electricity grid that faces difficulty to receive grid-fed power supply (Ong *et al.*, 2011). According to SEDA statistics, there are 60 applications with feed-in tariff approval for small hydropower projects in 2017. The cumulative capacity of 538.48MW of small hydropower projects are in progress under the FiT scheme with a total commissioned installed capacity of 30.30MW with annual energy generation of 64.60GWh in 2017 (SEDA 2018). An estimated 490–500MW of small hydropower is potentially available in Malaysia by 2020 (KeTTHA 2008a).

Second-generation fuels (such as bio-oil) derived from palm oil biomass offers more advantages at least from an ethical perspective in replacing fossil fuels by obviating competition and conflict with human food supply and animal feed. An estimate indicates the potential of generating 1340MW grid-connected electricity from palm biomass by 2030 (Haris *et al.*, 2009) (Malaysian Industry-Government Group for High Technology (MIGHT) 2013). The Malaysian National Innovation Agency (AIM, now non-operational) has created a biomass processing hub in the East Malaysian state of Sarawak, which is billed as the first of such a facility in Southeast Asia. The hub receives investment from Brooke Renewables, a consortium of international biofuel companies and includes a commercial second-generation bioethanol plant supported by enzyme technology from Beta Renewables, which operates the world's first second-generation bioethanol plant in Italy (Crescentino) (PEMANDU (Performance Management & Delivery Unit of Malaysian Government) 2013).

Apart from methane recovery from POME, biogas can also be produced from landfills in Malaysia by decomposing municipal solid waste (MSW). The captured landfill gas (LFG) can be upgraded to pipeline-quality gas to produce electricity or directly as fuels for powering homes, factories, buildings, and vehicles. It is easier to design a new and sanitary landfill for LFG utilisation than retrofitting at a later stage as shown through the Bukit Tagar project by KUB–Berjaya Enviro, which operates a 4-MW gas engine to generate electricity and is reported to be in process of connecting a larger capacity to the grid (as of end of 2018) (KUB–Berjaya Enviro 2019). There is potential in harnessing and further developing waste-to-energy options using MSW to produce bioenergy forms in Malaysia (Chien Bong *et al.*, 2017).

As for nuclear energy, addressing its real and perceived dangers is of the utmost importance for its deployment in Malaysia, which may have generated greater concern in light of the Fukushima Daiichi accident in 2011. In this regard, use of thorium as a main fuel cycle for nuclear power shows potential, particularly liquid fluoride thorium reactors (LFTR) as compared to uranium which is the basic material in today's commercial technology. However, the present

Malaysian political administration helm, which changed after its 2018 general election does not favour nuclear power use (Malaysiakini 2017). Further, nuclear may no longer be considered the cheapest clean power type given the declining production cost of solar and biomass power (SEDA 2017).

Energy from OTEC uses heat from the Sun stored in ocean surface water layers to generate electrical energy or energy products (Jaafar 2015). Although argued to be one of the main potential renewable energy sources in Malaysia (Academy of Sciences Malaysia 2015), the entailed high capital and operating cost remains its biggest challenge to be economically viable. Implementation of OTEC remains to be at a pilot scale such as the 1MW demonstration unit carried out in Hawaii (Vega, 2010; Jaafar, 2017).

Potential exploitation of geothermal energy resource revolves around the Apas Kiri area in Tawau, Sabah based on data around the year 2008. The discovery of this resource with an electricity generation potential of 67MW was made by the Minerals and Geoscience Department under the purview of the then Ministry of Natural Resources and Environment. However this initiative led by Tawau Green Energy Sdn. Bhd. reportedly has been abandoned (Editorial of Malay Mail 2018).

Fuel cells using hydrogen has been identified as a national priority research area (especially during 1996 to 2007 with up to RM34 millions of federal grant money) by the then ministry-in-charge (Ministry of Science, Technology, and Innovation (MOSTI), now subsumed under MESTECC). It is noteworthy that hydrogen is an energy carrier, not a primary energy source unless it is generated from non-fossil fuel resources (e.g., via electrolysis of water). On the other hand, fuel cells are not a RE resource by themselves; they are energy conversion mechanisms.

Table 7. Advantages and challenges of power generation from small hydroelectricity

Advantage	Challenge
• Reliable (mature technology) • Low operating cost • Low levelized cost of electricity • Not affected by fossil fuel prices • No environmental and socioeconomic consequences (as compared to large hydropower) • Also provides flood and irrigation control • Promotes eco-tourism • Suitable for places far away from the main grid, e.g., an alternative to diesel generators for remote villages in Sabah and Sarawak	• Remote location for connecting to the national electricity grid to capture advantage given by FiT scheme

Table 8. Advantages and challenges of energy generation from oil palm biomass

Advantage	Challenge
• The abundance of palm biomass resource • Several technologies available for conversion of biomass to energy	• High capital investment • Inconsistent biomass supply chain • Unattractive electricity tariff for grid-connected generation

Table 9. Advantages and challenges of energy generation from municipal solid waste (MSW) landfill gas

Advantage	Challenge
• Highest methane generator in Malaysia; expected to rise with more MSW generated due to increased population and urbanisation besides poor recycling • Captured biogas can be upgraded to pipeline gas to generate electricity or as fuels	Heterogeneous feedstock has varying sizes, shapes, and compositions that need pre-treatment to avoid unsteady operation and uncertain product quality (in this regard, refuse-derived fuel as a form of processed MSW form is not viable because of the high cost)

Table 10. Advantages and challenges of nuclear energy generation using thorium-based technology (Mathieu, 2006; Cooper *et al.*, 2011; Forsberg *et al.*, 2011; Schaffer, 2013)

Advantage	Challenge
• Thorium is more abundant in nature than uranium and available in Malaysia (4500 ton) • Thorium extraction (e.g., in rare earth metals mining), although complex incurs relatively cheap chemical separation from its ore impurities • Low amount of radioactive waste production, storage, and disposal • Resistance to nuclear weapon proliferation • Higher thermal efficiency and power generation efficiency at less cost • Inherently safe thus potentially avert catastrophic accidents • Relatively smaller radiation risk	• Significant deviation from current operating commercial technologies • No commercial operating unit yet, hence difficult to assess design and performance • Political hurdles for commercial deployment

Table 11. Advantages and challenges of ocean thermal energy conversion (OTEC) development

Advantages	Challenge
• Generation potential of up to 105 GW of electricity is estimated from harnessing the heat in the water depths of over 700 m off Sabah and Sarawak in East Malaysia as based on a marine survey by the Malaysian government of the South China Sea • Can generate spinoff products that include temperate foods and produce, marine culture, lithium metal, mineral water, cosmetics, and health products.	• Plant cost is prohibitive at EUR80–100 per watt (RM395–495 per watt) of electricity produced for a 1 MW plant size (Jaafar 2017) • High cost to transmit generated electricity to land (onshore) particularly for the cable • Significant electricity transmission losses due to large distance (a few hundred kilometres) involved

Table 12. Advantages and challenges of energy generation from hydrogen using fuel cells

Advantages	Challenges
• A fuel cell is considered the most viable energy conversion device for hydrogen especially in transportation • Certain fuel cell variants (e.g., proton exchange membrane type) can be coupled with solar PV (Academy of Sciences Malaysia 2017)	• Low efficiency • Hydrogen source needs to be renewable to render it as sustainable • Safe transportation means to end users

Table 13. Summary of the potential of emerging renewable energy options considered for electricity generation in Malaysia

Electricity Source	Projected Availability	Remark
Biomass from oil palm/Palm biomass	Annual projected biomass availability (in 2012) = 94.00 million ton (wet weight) (Malaysian Industry-Government Group for High Technology (MIGHT) 2013)	Has the potential to provide 1.3 GW of electricity but constrained by other economic uses and assured availability of feedstock resources
Geothermal	79 manifestation areas (61 in Peninsula, 8 in Sarawak, 10 in Sabah (REEP, 2010)	Minimal resources available and not cost-economic to explore (further Malaysia is out of the Ring of Fire)
Wind, wave, tidal	No official statistics reported	No resource viably exploitable in the country
Hydrogen-based fuel cell	Power capacity = 20,198 MW (capacity factor = 0.9) and energy generation 54.162 GWh (share = 15.7%) by 2050 with hydrogen generation contribution by OTEC, wave, tidal current, solar PV, and nuclear (based on projection of zero fossil fuel used for energy generation by 2050) (Academy of Sciences Malaysia 2015)	Low efficiency; hydrogen source has to be renewable to render this as a plausible option. Economic viability has yet to be established.

VI. CONCLUSIONS

The preceding discussions have considered the potential and practically viable options for Malaysia to aim for low carbon power generation options for the future, and show that it can be achieved to a certain degree. As evidenced through the paper, Malaysia has limited practical RE options to achieve its low-carbon aspirations, with solar PV being the dominant resource, both to help achieve the self-declared carbon intensity reduction target of 45% by 2030 as well as to attain a 20% non-large-hydroelectricity RE share of generation capacity by 2025, with small hydroelectricity, biomass, biogas, and municipal solid waste contributing smaller shares.

Also, diligent adoption of energy efficiency initiatives and practices is expected to contribute a significant share under the DSM program which is expected to be rolled out with the forthcoming legislation for the Energy Efficiency and Conservation Act in 2019. RE from wind energy, marine RE resources and even geothermal (in Sabah) appear to be not available or viable for Malaysia to exploit, while the nuclear option is avoided on safety and political considerations.

Solar PV in its various modes such as rooftop and ground-mounted farms built to date and the approved LSS/USS systems form the bulk of RE capacity. Similarly, anticipated greater take-up of NEM and SelCo with the revised *true* net energy metering as approved with effect from January 2019 can greatly enhance the share of the low carbon RE generation capacity going forward.

Also as mentioned in the paper, the potential to harvest the biomass and biogas generation capacity can be significantly enhanced with the recommendation to develop biomass–biogas grids to encourage and incentivize the exploitation of these resources, especially to build up adequate generation capacity in the east-coast region of Sabah, where generation capacity shortfall has contributed to poor supply reliability. With judicious strategies and cost-effective incentivisation, the 20% RE share can be exceeded by 2025 to enhance national energy security while contributing to the global carbon emissions reduction challenge.

VII. APPENDIX

A. Energy and Renewable Energy Policies in Malaysia

Table 14. National-level policies and programs related to renewable energy in Malaysia

Period	Policy/Plan	Aim	Achievement/Status
1979	National Energy Policy	Address energy supply, utilisation, and environmental objectives in the long term	Diversified energy supply sources to non-renewables
1981	Four-Fuel Diversification Policy	Avoid overdependence on petroleum as the main energy supply by an increased emphasis on gas, hydroelectric, and coal in power generation mix	Diversified energy supply sources besides petroleum especially coal use for power generation
1999–2009	Malaysian Industrial Energy Efficiency Improvement Project (MIEEIP)	Remove barriers and build capacity to improve industrial energy efficiency through policy, planning, research, and implementation for 11 sectors: wood, food, pulp and paper, rubber, iron and steel, ceramic, glass, cement, plastics, textile, and oleochemicals	Developed benchmarks, equipment rating programs, and auditing; documented and disseminated information; trained local energy service companies; demonstrated and implemented technologies
2000	Fifth Fuel Policy	Recognise renewable fuel sources in generation mix that includes biomass, biogas, municipal waste, solar, and mini (not large) hydroelectricity	Promoted renewable energy generation and use besides large hydroelectricity
2001	Energy Commission Act	Establish Energy Commission (or Suruhanjaya Tenaga) as a regulator of electricity and piped gas supply industries	Established Energy Commission whose role includes advising the government on energy efficiency and renewable energy issues
2001–2010	Small Renewable Energy Power (SREP) program	Encourage small private power generation projects using renewables	Met less than targeted 5% of renewable electricity supply by 2005
2002–2010	Biomass-based Power Generation and	Reduce GHG emissions growth rate from fossil fuel-fired combustion of unused	Finalized Renewable Energy Power Purchase Agreement

	Cogeneration in the Malaysian Palm Oil Industry (BioGen)	biomass wastes through power generation and combined heat and power (CHP); also explores another energy potential	(REPPA) Pro-forma (precursor to FiT under SREP); established business facilities (e.g., one-stop centre); conducted mill energy audits and policy and biomass availability studies
2005–2011	Malaysia Building Integrated Photovoltaic (MBIPV)	• Reduce solar PV technology cost in the long term by integrating with building design • Create sustainable BIPV market through wide applications	Connected 45.9MW to the national grid (versus Ninth Malaysia Plan target of 350MW)
2006	National Biofuel Policy	Use environmentally sustainable biofuels to reduce fossil fuels dependence, exploit the global economic opportunity, and stabilise crude palm oil prices	Implemented B5 blend palm-based biodiesel use countrywide (see another entry)
2009	National Green Technology Policy	Increase capability and capacity in green technologies to contribute to economic growth in energy, buildings, water and waste management, and transport sectors	Set up Green Technology Financing Scheme (GTFS) under Pusat Tenaga Malaysia (later called GreenTech Corporation); promoted cogeneration and renewable energy use in power generation
2010–2015	New Energy Policy (2013–2050)	Enhance energy security in economic, environmental, and social aspects through market pricing, energy efficiency, change management, holistic governance, and supply-side initiatives	Adopted market-based gas price; implemented Sustainability Achieve Via Energy Efficiency (SAVE) program by SEDA; developed marginal natural gas fields; building PETRONAS RAPID refinery and petrochemical site
2011	Renewable Energy Act	Set up SEDA to implement a feed-in-tariff (FiT) scheme for RE	Implemented FiT system under SEDA's purview
2011	National Biomass Strategy 2020	Recognise biomass waste use mainly for high value-added products (especially in the palm oil industry)	Marketed high-quality solid fuels of briquette or pellet from palm biomass waste (empty fruit bunch)
2011–2014	Biodiesel B5 Program	Implement palm-based biodiesel (B5 blend) use countrywide; reduce crude palm oil local inventory to stabilise its price	Biodiesel blended locally = 295,451 tonne (2014); total installed capacity = 2.1 million tonne
2016–2020	Demand Side Management (preliminary study)	Implement demand-side initiatives on electrical and thermal energy in building,	Increase registered electrical energy managers and energy

		industry, household, and transport sectors	service companies; implement energy performance contracting including to retrofit 100 government buildings; introduce an enhanced time of use electricity tariff (targets are set to the year 2020)
2016–2020	Net Energy Metering (NEM) (and Self-Consumption (SelCo, 2017))	Complement FiT by effecting electricity self-consumption from solar PV and allowing excess electricity generated to be sold to TNB	Award 500MW quota over 5 years (annual maximum of 90MW for Peninsula and 10MW for Sabah)
2017–2020	Large Scale Solar (LSS)	Develop solar PV plants that generate 1–50MW electricity	Award projects quota of 1000MW over 4 years (annual 200MW for Peninsula and 10MW for Sabah)
2016	Biodiesel B7 and B10 programs	Increase to B7 and B10 biodiesel blends including for commercial and power generation use	Field trials for B10 palm biodiesel (e.g., by MPOB) showed good engine performance with no modification needed

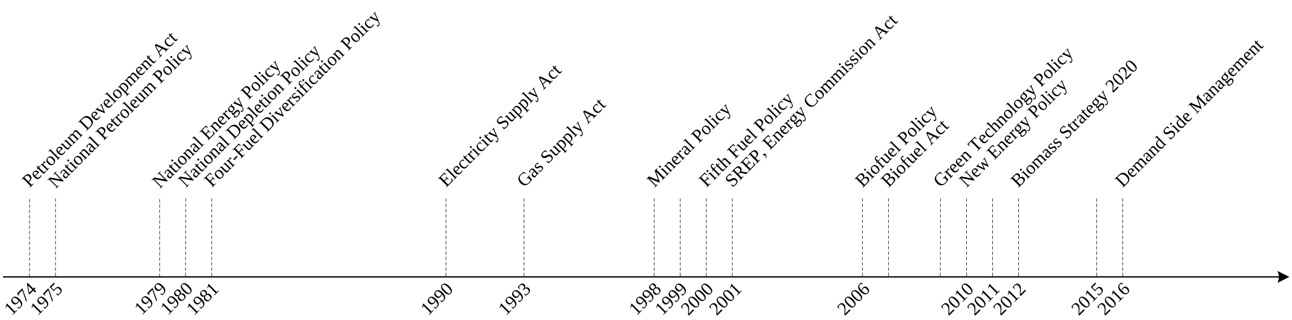

Figure 11. Malaysia: Timeline of energy-related policies and initiatives

B. Energy Efficiency Saving Estimations for Electricity Use in Cooling Load

The efficiency of older chillers = 1.2kW per ton of refrigeration.

The efficiency of newer chillers = 0.7 kW per ton of refrigeration.

Efficiency gain = (1.2 – 0.7) = 0.5 kW per ton of refrigeration.

Annual operating time = (10 hour/day) × (22 day/month) × (12 month/year) = 2640 hour/year.

Annual electricity saving = (0.5kW/ton refrigerant) × (2640 hour/year) = 1320kWh/ton refrigerant-year.

Commercial electricity tariff (average) = 0.40RM/kWh.

Annual electricity cost saving in commercial sector = (0.40RM/kWh) × (1320kWh/ton refrigerant-year) = 528RM/ton refrigerant-year

C. Energy Efficiency Saving Estimations for Electricity Use in Air Conditioning

Assumption on user population: 8.0 million domestic (residential) users, 1.0 million commercial users, 0.1 million industrial users.

Table 15. Energy efficiency saving estimations for electricity use in air conditioning

Sector	No. of User (in a million)	No. of Unit Per User	Total No. of Unit (in a million)
Domestic	8.0 (household)	40% with 3 unit	9.6 (8.0 □ 0.4 □ 3)
Commercial	1.0	5 unit	5.0
Industrial	0.1	2 unit	0.2
		Total =	14.8

Assumption: 20% energy-efficient 5-star air-conditioners, 80% older 3-star refrigerators.

Total no. of air-conditioners to be replaced = 80% × (14.8 million) = 12 million units.

The assumption on air-conditioners replacement rate: 1 million unit/year over the next 12 years.

Assumption: 20% of replaced air-conditioners are 5-star split wall mounted units.

Number of energy efficient units installed annually = 20% × (1 million) = 200,000 units.

Assumption on air-conditioners use: 6 hours/day at 70% utilisation factor (i.e., operating load factor = 0.7) => (0.7) × (6 h/d) = 4.2kWh/day.

Daily energy saving per unit = 25% × (4.2kWh/day) = 1.05kWh/day.

Annual energy saving per unit = (0.42kWh/day-unit) × (365 day/year) = 383.3kWh/year-unit.

Total annual energy saving = (383.3 kWh/year-unit) × (200,000 unit) = 76.65GWh/year.

Cumulative energy saving over replacement period = (76.65GWh/year) × $\sum_{Year=1}^{12} Year$ = 5979TWh.

D. Energy Efficiency Saving Estimations for Electricity Use in Lighting

Table 16. Energy efficiency saving estimations for electricity use in lighting

	Nominal Load (W/tube)	Actual Load (W/tube)	Energy Saving versus LED (W/tube)	Energy Saving Ratio for LED Replacement (%)
Fluorescent T8	36	42	20 (42–22)	48
Fluorescent T5	28	30	8 (30–22)	27
LED Tube	18	22	-	-

The following calculations are based on Energy Commission Malaysia (2015b) data for the year 2015 as applied to the commercial sector.

Lighting share of annual electricity used = 20% × (36,645GWh) = 7329GWh.

Assumption on electricity use: 60% T5, 20% LED, and 20% other lamp types (e.g., compact fluorescent tubes).

Annual electricity use for T5 tube = 60% × (7329GWh) = 4397GWh.

Annual energy saving if T5 is replaced by LED (after 4 years) = 27% × (4397 GWh) = 1173 GWh.

Assumption: Air-conditioning coefficient of performance = 5.0.

Additional saving from air-conditioning = (1/5.0) × (1173GWh) = 235GWh.

Cumulative energy saving due to lighting efficiency (after 12 years) = (9381 + 1876) GWh = 11,257GWh.

Assumption: Load factor for commercial use = 40%; reserve margin = 25%.

Electricity demand saving = (11,257GWh)/(40% × (8760 h/year)) = 1836MW.

Generation capacity saving (reduction) = (1836MW) × 125% = 2295MW.

A similar procedure can be applied to the industrial sector. The total saving from both sectors gives the estimates reported in the main text of the paper.

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