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An Overview of Banana Biomass as a Potential Renewable Energy Source in Malaysia

(Gambaran Keseluruhan Biojisim Pisang sebagai Bahan Berpotensi untuk Sumber Tenaga Boleh Diperbaharui di Malaysia)

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ABSTRACT

Electricity is a vital component necessary to stimulate the growth of a country whereby Malaysia relies upon non-renewable fossil fuel for much of its needs. Since the 70's oil crisis, Malaysia has attempted to preserve its oil resources and increase the contribution of renewable energy which subsequently has boosted the rapid increase of renewable energy supply, particularly in hydropower but under the 5th Fuel Diversification policy, the country prioritises to diversify its fuel sources. Banana waste has been identified as one of the potential sources due to its abundance in natural resources in Malaysia for being widely planted in agricultural sector. It has been used by neighbouring country, namely Thailand and also efficiently recycled by developed nations worldwide. This paper will discuss the potential biomass feedstock, and banana plant is chosen for the nature of its abundance, fast growth rate, and disposal after harvest. Conversion from biomass into energy can be done by direct combustion, solid biomass briquette, bioethanol, and biogas. Theoretically, all the methods except direct combustion are viable for energy generation but bioethanol and biogas suffer from compatibility issues with existing infrastructure designed for fossil fuel thus making solid fuel a topic that should be researched further to improve its uses in cogeneration and boilers. Hence, banana biomass is feasible for use as a source of renewable energy in Malaysia.

Keywords: Biofuel; banana; biomass; renewable energy

ABSTRAK

Tenaga elektrik adalah komponen penting dalam menggalakkan pertumbuhan sesebuah negara dan Malaysia bergantung kepada bahan api fosil yang tidak boleh diperbaharui. Sejak krisis minyak 70'an, Malaysia telah berusaha untuk mengekalkan sumber minyak sekali gus meningkatkan sumbangan tenaga boleh diperbaharui, dan berjaya membantu peningkatan pesat pada tenaga boleh diperbaharui terutamanya tenaga hidro tetapi di bawah Dasar Peleburan Bahan Api negara kelima, kepentingan diletakkan kepada mempelbagaikan sumber bahan bakar. Sisa pisang telah dikenal pasti sebagai salah satu bahan yang berpotensi berikutan keadaannya yang mempunyai lambakan dari sektor pertanian negara yang meluas. Ia telah digunakan di negara jiran Thailand dan dikitar semula oleh negara maju di seluruh dunia. Kertas kajian ini akan membincangkan potensi bahan mentah biojisim dan pokok pisang telah dipilih kerana lambakan, kadar pertumbuhan yang tinggi dan pelupusan selepas penuaian. Penukaran daripada biojisim kepada tenaga boleh dilakukan melalui pembakaran langsung, briket biojisim pejal, bioetanol dan biogas. Secara teori, semua kaedah kecuali pembakaran langsung disifatkan sebagais berdaya saing untuk penjanaan tenaga tetapi biogas dan bioetanol menghadapi masalah keserasian dengan infrastruktur sedia ada yang direka untuk bahan api fosil *menjadikan bahan bakar pejal sebagai sebuah topik yang wajar dikaji dengan lebih mendalam untuk kegunaan dalam dandang dan kogenerasi. Oleh itu, biojisim pisang boleh digunakan sebagai sumber tenaga bahan bakar boleh diperbaharui di Malaysia.*

Kata kunci: Bahan api bio, pisang, biojisim, tenaga boleh diperbaharui

INTRODUCTION

Electric energy is a vital element necessary for the development and growth of a country and any shortage in supply of electricity will either cause negative effects or limit its potential growth, or both. On the other hand, electricity oversupply is wasteful since electricity surplus could not be stored (Zakaria & Shamsuddin 2016). According to Shafie et al. (2011), it is projected that Malaysia energy demand will rise to 116 Mtoe by 2020 in order to sustain industrial development which applies to the entire world including the Asia Pacific region based on the energy report released by British Petroleum (2020), which reported that in 2019, the Asia Pacific region exhibited a 3.3% growth in primary energy consumption per annum while Malaysia exhibited growth of 1.3%.

In 2017, the Malaysian Energy Balance report was published by Malaysian Energy Commission (2017) as shown in Figure 1. The installed capacity as of 31 December 2017 indicates the heavy reliance on non-renewable fossil fuels namely natural gas, coal, and diesel to power the thermal plants powering the country. This poses an environmental concern as fossil fuels are non-renewable resources that release carbon dioxide into the atmosphere during combustion process and since the 1700's, the concentration of carbon dioxide has increased by 30% and this greenhouse gas can contribute to global warming (Tock et al. 2010). If left unchecked, the increasing greenhouse gas emission may result in rising global temperature which will affect the livelihood of people across the world. Centre & Office (2013) suggested that steps should be taken to mitigate carbon dioxide emission or face an increase of more than 2 °C within the next 20 years.

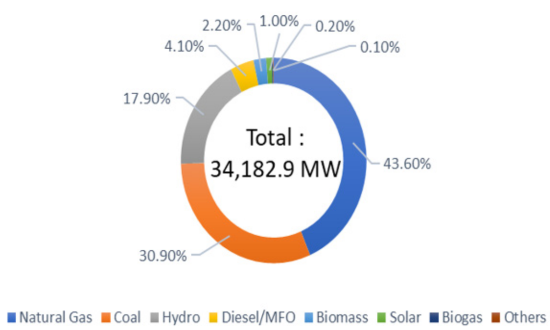

FIGURE 1. Installed capacity as of 31 December 2017

As part of the efforts to mitigate the dependency on fossil fuel, the government of Malaysia has introduced several measures since the outbreak of the 70's energy crisis, beginning with the "Four-Fuel Diversification Strategy" in 1980 by increasing natural gas, coal, and hydropower to reduce the use of oil. This is then followed with fifth-fuel strategy in the 8th Malaysian Plan from 2001-2005 to introduce renewable energy to address the rising issue of climate change with a target of 350MW of electricity generation from renewable sources but failed to achieve the target (Hashim & Ho 2011). However, this has not deterred the country from taking measures to address the environmental concern by introducing policies such as National Energy Efficiency Action Plan 2016-2025. The Plan's mission is to improve efficiency of energy use, adoption of green energy with SIRIM Eco-Labelling Scheme, and to develop installation of power plants utilising renewable energy through the Sustainable Energy Development Authority (SEDA) (Au Yong 2018).

While hydropower and solar provide the highest potential in the country due to the abundance of river and annual long sunlight, biomass sources are also being promoted by the government for alternative power sources in line with the 5th Fuel Diversification Policy (FDP) introduced in 1999 in order to reduce oil dependency (Mekhilef et al. 2011). With the abundance of palm oil agriculture in the country, natural oil palm residue has been a major biomass source but the competition for the use of the waste in furniture production, the value of the palm oil compared to using it for energy generation, and disruption to food chain presents a drawback for its use as an energy source. This brings to the use of alternative agriculture waste such as rice husk and banana plant biomass which is discarded after bearing fruit once (Tock et al. 2010). In addition to research by Clarke et al. (2008), it was found that in Australia, up to 30% of the banana fruits are discarded which makes the prospect of utilising banana waste for biomass energy rather promising since there are few available research done on the material. This paper will discuss the cultivation and composition of banana plant, available method of power generation using banana biomass as feedstock, the potential challenges, and potential energy generation.

BANANA FEEDSTOCK

CULTIVATION

Being located in the tropical region makes Malaysia a suitable location for the growth of banana plant that requires an average temperature of 26.67 °C and 10 cm of minimum rainfall monthly since the plant could only grow between 30° north latitude and 30° south latitude (Aditiya et al. 2016). Requiring a period of 10-12 months from planting to harvesting, the trees are then cut after bearing fruit since it only bears once in a lifetime which according to Abdullah et al. (2013), approximately four tonnes of waste are produced for every 100 kg of fruit harvested. Based on the annual statistic from Malaysian Ministry of Agriculture in 2019, banana land use covers a total area of 8 084.50 hectares making it one of the most widely grown fruit in the country. It is spread over two species of cooking banana and red banana with total yields ranging from 44 550 kg to 250 000 kg for the banana species (Department of Agriculture 2019). Total yield of Malaysian banana production also showed an upward trend with an increase in 2007 to 2012 and according to the calculated 2.4 ratio of biomass/production, results in 806 337.6 tonnes of potentially available banana biomass in 2012 as shown in Table 1 below (Aditiya et al. 2016).

COMPONENTS

Biomass is obtained from banana in the form of pseudo-stem, peels, and spoiled fruits with the pseudo-stem forming most of the mass since the tree dies after bearing fruit and is unusable for the next harvest. The pseudo-stem grows to a height of 3-6 m depending on the species, and the mass of the pseudo-stem also contains 10-20 oblong or elliptic leaves that can reach 3-3.5 m in length and 65 cm wide. Once the plant bears fruit, the pseudo-stem is cut in order to allow new suckers, or shoots to grow from the rhizome of the tree to produce a new trunk within a period of roughly six months (Encyclopedia Britannica n.d.). Average yield depends on the species of banana but the commercially available Cavendish variety produces 40 to 50 tonnes per hectares of yield and reaches up to 60 tonnes in established producers such as India and Philippines, while smaller producers only reaches up to 30 tonnes per hectares (Food and Agriculture Organization of the United Nations n.d.).

In Malaysia, the amount of fruit potentially produced by each banana species varies which according to the Department of Agriculture (2019) goes as low as 22 tonnes up to 30 tonnes per hectares for planting due to the variation in amount of optimal space required for the tree to grow, and red bananas possess the highest potential for producing biomass at 2 400 trees and 30 tonnes output per hectares. Approximately around 30% of the total banana production is potential feedstock for renewable energy comprising of the fruits rejected at the packing shed for not fulfilling consumer quality expectation or the rotten fruits. Since the decomposition of banana waste releases noxious gases such as hydrogen sulfide and ammonia which poses an environmental hazard, the option of turning them into biomass feedstock provides a better solution to waste management since rejected fruit can be easily stored by being chopped into cubes and stored at temperature around 20 °C (Tock et al. 2010).

TABLE 1. Malaysia banana production 2007-2012

Year	Banana produced (tonnes)	Total biomass produced (by 2.4 ratio of biomass /production, in tonnes)
2007	260,911	626,186.4
2008	273,331	655,994.4
2009	279,762	671,428.8
2010	332,639	798,333.6
2011	306,283	735,079.2
2012	335,974	806,337.6

CURRENT UTILISATION

Banana and its waste are useful and could be utilised in many ways with each component having different uses. The spoiled fruits can be processed into animal feed, the leaves as food packaging while the pseudo-stems can be processed into fibre based product such as textiles or boards while the other parts could be utilised as organic fertiliser after undergoing composting process (Abdullah et al. 2013). With the use of anaerobic bacteria, the banana waste could also be processed into methane gas which had been successfully performed by Clarke et al. (2008) in Australia by utilising anaerobic digester seeded with cattle dung sludge which will be discussed later in this paper.

However, the above methods require resources and investment which are not yet available to Malaysian farmers who currently only consume the fresh fruits directly for food and leaves as food wrapping. Banana leaves form an essential part in traditional Malay cooking in the sense that it can either be used for food packaging or enhancing food aesthetic by wrapping grilled meat since the high moisture content of the leaves protects the meat while also imparts fragrant aroma (Raji et al. 2017). Currently in Malaysia, the rejected fruits are used as animal feed while the pseudo-stem are left to decompose as organic fertiliser or mixed into animal feed along with the rejected fruits (Tock et al. 2010). Studies done in the state of Terengganu by Abdul Ghani (2018) shows that 99% of total crop residue in the state was used as compost fertiliser, animal bedding, feedstuff product, landfill, chemicals, value added products, or it is just simply burned.

ENERGY GENERATION METHOD

DIRECT COMBUSTION

Direct combustion is the process of directly burning the biomass to turn the stored chemical energy into heat and electricity, but this process is not ideal due to the high moisture content inside the banana residue resulting in low energy efficiency as heat are expended to vaporize the moisture content. This is significant for banana since the moisture content in banana's parts such as the peel is estimated to be around 87% (Tock et al. 2010). In order to tackle this issue, Aditiya et al. (2016) suggested that mass conversion of banana waste into higher value added product such as biofuel or bioethanol can be done by converting the naturally fibrous waste.

In the experimental data conducted by Abdullah et al. (2013), calorific heating value of banana was measured using Adiabatic Bomb Calorimeter (Nenken 1013-B, Japan). It was found that the fruit-bunch-stem value is 12.7 MJ/kg while the banana stem is 15.5 MJ/kg which are lower than literature data indicating value of 17.1 MJ/kg for banana leaves and other crops such as palm oil empty fruit bunch (EFB) of 19.4 MJ/kg. The result is in line with the same experiment that recorded moisture content of 10.2 mf wt.% for banana pseudo-stem, 11.42 mf wt.% for banana FBS, and 7.9 mf wt.% for banana leaves indicating potential loss of biomass energy generation from direct combustion.

SOLID BIOMASS FUEL

As a lignocellulose source, the entire banana tree could be converted into solid fuel briquettes as done by De Oliveira Maia et al. (2014) using the leaves, Merry M. Mitan & Fakhrur Radzi Sa'adon (2019) using the peel, and banana tree waste by Ku Ahmad et al. (2018) including the pseudo-stem. In general, this process involves densification in the formation of biomass briquettes to produce solid fuel in the shape of brick or briquettes to improve ease of storage and transportation. This method improves the overall calorific and mechanical value since experimental data from De Oliveira Maia et al. (2014) found the briquettes exhibited lower moisture content at 7.2%, higher mechanical compressive strength bulk and energy density with higher heating value of 17.7 MJ/kg which is important for long term storage and preventing breakage during transportation.

The usage in existing boilers biomass is different from solid fossil fuel such as coal. Therefore, the data is insufficient since the performance is dependent on quantity and type of feedstock, desired energy output, economic standards, environmental standards, and other factors. However, fluidised bed combustion is the best technology in combustion of burning high ash content, low quality, and low calorific value fuels (Saidur et al. 2011).

BIOETHANOL

First generation of bioethanol utilised existing food or cash crops for fermentation into alcohol using biomass but encountered the issue of competition for food-versus-fuel risk as well as potential loss of profit. This is followed by second generation bioethanol using non-edible lignocellulosic and starchy materials from forestry and agricultural waste for bioethanol production increasing the available biomass for conversion by up to 16 times and lowering cost with potential of USD 14-23/GJ by 2030. The abundant agricultural sector of Malaysia containing oil palm biomass and other tropical fruits including banana makes the country in an excellent position to pursue development of second generation bioethanol production (Aditiya et al. 2016).

Besides that, agricultural waste from the banana plantation and packing shed for second generation bioethanol process are also applicable for rotten banana from markets. It can be conducted at smaller scale without the specified fermentation equipment as conducted by Alshammari et al. (2011) using yeast as fermentation bacteria and rotten banana but this results in low bioethanol concentration per volume of water up to only 7.08% (v/v) which nevertheless indicates the potential of banana feedstock.

BIOGAS

Banana waste biomass could also be processed into gas form by anaerobic breakdown to produce biomethane that can be done with any fibrous biomass and liquid waste. Experiment conducted by Awedem Wobiwo et al. (2017)

successfully recovered fibers from banana peduncle for conversion into soft tissue and later biogas by incubation for 10 days at 35 °C. This is similar to the experiment by Housagul et al. (2014) utilising up-flow anaerobic sludge blanket (UASB) reactor to convert brownish glycerol waste with 63.9% glycerol purity and banana peel cut into size of 0.5 x 1 cm to produce gas composition of 64% methane content. This versatile fermentation process allows the mixture of banana with other waste as well as fibre recovery from the peduncle which is the harder part of the tree. However, this method is not without its drawback since the experiment conducted by Clarke et al. (2008) using batch fed reactor produces output of 7.5 kW from one tonne of banana daily but high moisture content of feedstock increases the size of the digester.

According to Tock et al. (2010), by using data for banana production for year 2003-2008, the potential energy generation could be significantly enhanced by biogas conversion compared to direct combustion. Assuming average energy content for banana waste to be 13.1 MJ/kg and residue/product ratio of 2.4, the estimated energy potential for direct combustion of annual banana production in the country only reaches 80-95 MW while anaerobic digestion could enhance the potential generation ranging from 190 to 270 MW.

POTENTIAL CHALLENGES

However, the use of renewable energy faces potential issues among them which is technical in nature. One of the technical issues is logistics constraint due to the size of the feedstock (Gonzales et al. 2013; How et al. 2016), volatility issues (Verma et al. 2019), or storage. Long term storage is an issue for banana biomass due to the high moisture content and rich organic matter in the waste contributing to the highly biodegradable properties of the waste biomass which will influence the entire supply chain from harvest to transportation (Tock et al. 2010).

Logistic constraint is present in first generation biofuel that relies on local biomass that presents the issue of bulky raw biomass, poor flowability properties, and aerobically unstable requiring supply chain within 80 km in order to minimise transportation cost in the United States of America (Gonzales et al. 2013). But this has limited the amount of biomass available and hence the scale of biorefineries prevents it from being cost competitive compared to fossil fuel. This requires a cost-benefit analysis on the method of transport used but this data is currently not available in Malaysia. How et al. (2016) conducted a case study in Johor using trucks to deliver EFB, sugarcane bagasse, pineapple waste, rice husk, paddy straw, and palm kernel shell (PKS) to develop graphical decision-making tool based on different biomass. It was found that considering four different types of trucks (m1, m2, m3, and m4), the limiting factor is bulk density of the biomass shown in Table 2 which requires processing of the biomass to increase bulk density for competitive transportation cost. In addition, drying process is also favourable to increase the shelf life of the biomass and Ozturk et al. (2017) suggests either dry storage with moisture content of less than 20% or wet storage with 80% moisture. In order to minimise transportation cost, Chan et al. (2019) suggests that plants located within 20-30km radius from biomass sources but on site densification process would improve the logistical management.

TABLE 2. Bulk density of biomass

Biomass	Bulk density [t/m^3]
Empty fruit bunch	0.355
Palm kernel shell	0.560
Sugarcane bagasse	0.603
Pineapple waste	0.350
Rice husk	0.380
Paddy straw	0.194

In addition to logistical constraint that affects the cost competitiveness of biomass based renewable energy, financial limitation is present in Malaysia that is yet to achieve satisfactory level of commercialisation compared to neighbouring country, Thailand (How et al. 2019) as shown in Table 3. According to the same paper, the lack of monitoring system and smart grid are detrimental compared to Austria that fully utilises its biomass resources in energy (38%), animal feed (37%), material use (18%), and food (7%). This is hindering Malaysian policy makers from obtaining crucial data necessary to stimulate stakeholders comprising of researcher, supplier, government, customer, and industry to commercialise biomass waste energy generation.

Lack of data on biomass flow does not only hinder policy makers and potential commercialisation but also contributes to significant amount of wastage. In studies done by Abdul Ghani (2018) using Terengganu as location of study, it was found that only 1% or 9 PJ/year of crop residue are converted into biomass energy while the remaining 500 PJ/year goes into other uses. There is no power station in Terengganu utilising any agricultural waste for power generation and Terengganu Agriculture Census 2016 does not record any raw data on agricultural waste recycling activities.

Failure of previous government policy poses another challenge to use banana and biomass waste in general where prior to National Renewable Energy Policy 2010 there was a period of eight years of market failure to attract investors resulting from high tariff on renewable energy and lack of FiT program which has been proven to be an effective mechanism (Hashim & Ho 2011). Poor state assistance discourages the adoption of expansive and technical knowledge on heavy equipment technology such as supercritical water gasification of wet biomass (SCWG). It can also entirely avoid the cost and process associated with drying the biomass limiting the country to a simpler anaerobic digestion (Tock et al. 2010) or processing into solid fuel biomass briquette as conducted by Wilaipon (2009) in Northern Thailand using banana peel.

TABLE 3. Benchmarking with foreign countries

Country	FiT	Tax incentive	Act	R&D grant	Smart grid	Monitoring System	Subsidy/loan
Malaysia	Yes	Yes	Yes	Yes	No	No	Yes
New Zealand	Yes	No	No	Yes	No	Yes	Yes
Philippines	Yes	Yes	Yes	No	No	No	Yes
Thailand	Yes	Yes	No	Yes	Yes	Yes	Yes
Vietnam	Yes	Yes	No	No	No	No	Yes
China	No	Yes	Yes	Yes	Yes	No	Yes
Austria	Yes	Yes	Yes	No	Yes	Yes	Yes
United States	Yes	Yes	Yes	Yes	Yes	Yes	Yes

TABLE 4. Biodiesel fuel properties

Specifications/ Ranges	B0	B20	B40	B60	B80	B100
Density (15°C) (kg/m³)	825	840	852	864	876	885
Viscosity (40°C)(cSt)	2.493	3.039	3.384	3.73	4.075	4.729
Surface tension (N/m)	0.02600	0.02637	0.02674	0.02711	0.02748	0.02800
Cetane number	50	-	-	-	-	55
Stoichiometric A/F ratio	14.5	14.10	13.69	-	-	12.48
Lower heating value [MJ/kg]	43.3	42.18	41.06	-	-	37.7

Another technical issue arising from the use of biomass waste as energy source is incompatibility with existing fossil fuel engines and infrastructure due to the different chemical and physical properties. Issues related to the use of biofuel have arisen in Indonesia with the recent implementation of B20 biodiesel mixture containing 20% crude palm oil (CPO) biodiesel blend that resulted in bus operators complaining of poor engine performance caused by sediment in vehicle engine (The Jakarta Post 2020). This is the direct result of the higher surface tension of biodiesel compared to fossil fuel which increases its Sauter mean diameter (SMD) as well as increasing volume mean diameter (VMD) and arithmetic mean diameter (AMD) with increasing biofuel blends. Through experimentation by Tziourtzioumis & Stamatelos (2017), the comparison on estimation of fuel burning rates of 60 000 droplets' samples for a blend with no biodiesel (B0) to 100% biodiesel (B100) showed a pattern of decreasing lower heating value and lower burning rate which is shown in Table 4. This presents an issue to unmodified engine with pump-line-nozzle injection system designed for fossil fuel leading to sediment produced by incomplete combustion and the higher viscosity hence higher friction increases wear between the fuel and nozzle surface.

These results agree with Xue et al. (2011) which indicated that while biodiesel reduces particulate matter (PM) by 53-69%, literature data shows 70.4% of 27 references which suggest a decrease in power performance of engines. However, there are potential for oxygenated additives usage that may solve biodiesel problems and alcohol- based fuel to improve fuel atomisation and fuel-air mixing due to lower viscosity and density. However, it comes at the cost of lower energy density that may affect engine performance since the pure alcohol fuel dimethyl carbonate (DMC) possesses lower heating value of only 15.7 MJ/kg compared to diesel value of 40-45 MJ/kg (Verma et al. 2019).

POTENTIAL ENERGY GENERATION

As of 2019, Malaysia possess available gasification, pyrolysis and liquefaction technology for solid agriculture waste and hydroprocessing for biomass-derived oil. Despite that, the available technologies are mainly focused on palm oil and timber industry waste while existing biomass companies operate plants by utilising only palm oil waste notwithstanding the available research on other sources. This is mainly due to the high risk of Malaysian green energy sector to stimulate private sector involvement which is only made worse by the national policy to subsidise fossil fuels that prevents green energy from being economically attractive for commercialisation (Chan et al. 2019). Biomass plants for energy generation have been available in Malaysia since 2001 for steam turbines and 2007 for gas turbines but all of them rely on palm waste empty fruit bunch and biogas derived from the same industry (Mekhilef et al. 2011) leaving the potential of other agricultural waste untapped for energy generation. In order to encourage adoption of renewable energy, the government of Malaysia through its agency Sustainable Energy Development Authority (SEDA) has undertaken measures to enhance renewable energy generation with potential for USD 4.4 billion economic value a year and 66 000 new jobs indicating the business potential for further developing the biomass industry. However, this effort is mainly concentrated on utilising palm oil waste to power small scale power plants with initiatives such as agreement between the public sector involving Tenaga National Berhad (TNB) and Federal Land Development Authority (FELDA) agreement to develop 10 MW power plants (Chan et al. 2019). In addition, the effort by the public and private sectors are encouraged to engage in developing renewable energy in Malaysia through the Feed-in Tariff (FiT) implementation in 2013 enforced by SEDA. In this system, private renewable power generation by individual or non-individual are allowed to sell electricity up to 30 MW to utility firms at a fixed premium price that is varied according to the amount of current contribution by the renewable energy source. It is also to encourage adoption of new renewable resources if the private sector wants to take advantage of higher FiT rates (Tam 2013). Table 5 below indicates the higher rates for the less developed biomass energy. In addition to the sale of electricity under the FiT scheme, the government also allocated funds for financing renewable energy project which amount to RM 2 billion under budget for the year 2019 that is accessible for potential private sector or individual with a prerequisite of approval either by SEDA or Energy Commissions (Green Technology Financing Scheme 2016).

Besides that, state funded program considered another method available which is decentralised small scale system that is less dependent on centralised energy supply made possible by alternatives presented by technological advancement. In this system, instead of centralising the power generation, the system works in either grid connected (GC) or stand-alone (SA) which is especially applicable for biomass waste that can be processed for

TABLE 5. Basic FiT rates for renewable energy resources

Description Of Qualifying Re Installation	FiT RATES (RM per kWh)	
	2013	2014
Biogas		
i) ≤4MW	0.3184	0.3168
ii) Above 4MW-10MW	0.2985	0.297
iii) Above 10MW-30MW	0.2786	0.2772
Biomass		
i) ≤10MW	0.3085	0.3069
ii) Above 10MW-20MW	0.2886	0.2871
iii) Above 20MW-30MW	0.2687	0.2673
Small hydro power		

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i) ≤10MW	0.2400	0.2400
ii) Above 10MW-30MW	0.2300	0.2300
Solar PV		
i) ≤4kW	1.1316	1.0411
ii) Above 4kW-24kW	1.104	1.0157
iii) Above 24kW-72kW	0.944	0.7552
iv) Above 72kW-1MW	0.912	0.7296
v) Above 1MW-10MW	0.76	0.608
vi) Above 10MW-30MW	0.68	0.544

either cogeneration and gasification among which banana waste is a suitable candidate (Bazmi et al. 2011). Cogeneration and gasification existing boiler shows a promising result since the major source of emission in boilers is carbon dioxide from fossil fuel combustion and according to Saidur et al. (2011), co-firing biomass waste product leads to fuel cost reduction and mitigation of hazardous CO2, NOx, CH4, SOx and CO, but this is a highly complex process due to the different types of boilers available and uncertainty from the unstable prices of biomass waste available for power generation.

Decentralised biomass energy generation model for small scale energy generation is suitable for rural areas in Malaysia implicated by energy poverty such as Sabah where electricity coverage in 2013 is only 79% compared to 99.62% in peninsular Malaysia (Borhanazad et al. 2013). Evaluation conducted by Suzuki et al. (2017) from official publication calculated the energy potential by biomass with palm oil making up the majority from the abundant palm oil plantation in the eastern part of the state shown in Table 6 indicating high potential of biomass waste power generation which is higher than the electricity need of Sabah. According to experiment conducted by Clarke et al. (2008), banana waste usage as supplemental feedstock for energy generation in Australia in which a tonne of banana daily produced an output of 7.5 kW of electricity is sufficient for 6-8 houses. Meanwhile, according to calculated values by Tock et al. (2010), total utilisation of banana waste by direct combustion yields a potential output of 80.52MW annually for the year 2007 with the theoretical residue/product ratio of 2.4 and residue energy value of 13.1MJ/kg as shown in Table 7. This potential output can then be further increased by utilisation of and anaerobic digestion which could yield potential output of 949.65MW as shown in Table 8. Besides rural power generation, banana biomass could also be processed into solid biomass briquette either using only banana or mixed with other biomass for home cooking or cottage industry purposes as done in Malawi using a briquettes from blend of saw dust and banana peel (Thulu et al. 2016).

TABLE 6. Electricity potential by biomass

	Unit (MWh)
Oil Palm	2382
Coconut Shell	1
Rice	6
Livestock	7
Forest	17
Total	2413

In enhancement of biomass energy generation, it is important for Malaysia to develop biomass flow screening (Abdul Ghani 2018; Chan et al. 2019). Whereas, Thailand is considered as a suitable role model with a target of 25% renewable energy consumption by 2021 by offering high FiT rates increasing with core inflation rates, income-corporate tax exemption to maximum of eight years and community-based biomass pilot project in education institutions, military camps, and 540 localities around the country (Jacob & Visvanathan 2012). It has also become the highest country in Southeast Asia (SEA) for producing 68% of total bioenergy in the region (How et al. 2019). However, despite effort by government of Thailand, the energy output is still unstable as exhibited by the Rayong municipality anaerobic digestion waste to energy (WTE) plant designed to treat 70 tonnes of organic waste daily. In actuality, the capacity output is only 20 tonnes daily due to limited waste separation that requires public participation in order to be effective (Jutidamrongphan 2018) which is similar to Malaysian situation shown in Figure 2 implying the available capacity as of 2017 for biomass to be much lower than the installed capacity (Malaysian Energy Commission 2017).

TABLE 7. Banana residue yield and their potential power generation

Year	Yield (kt/year)	Residue/ product ratio	Biomass residue (kt/year)	Residue energy (MJ/kg)	Potential power (MW)
2003	274	2.4	659	13.1	83.35
2004	317	2.4	761	13.1	96.31
2005	262	2.4	629	13.1	79.65
2006	258	2.4	620	13.1	78.50
2007	265	2.4	636	13.1	80.52

TABLE 8. Total potential power generation of the banana plant

Banana component	Method	Potential power generation (MW)
Pseudostem and leaf	Direct combustion	80.52
Banana peels	Anaerobic digestion	269.13
Reject banana	Anaerobic digestion	60.0
	Total	949.65

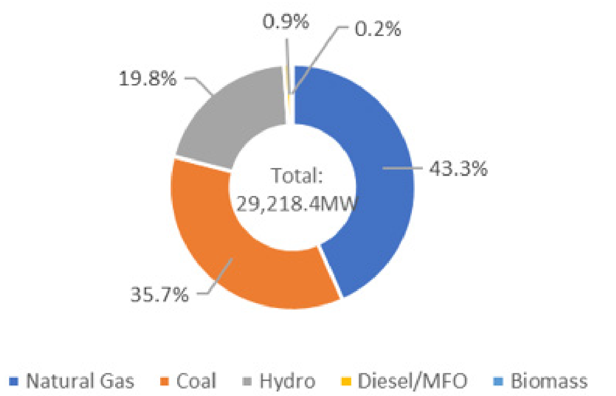

FIGURE 2. Available capacity as of 31st December 2017

CONCLUSION

Malaysian energy sector is still heavily dependent on non-renewable fossil fuel as a source of energy that will run out in the future. Therefore, there is urgency to further grow the renewable energy sector in order to provide for the growing needs of the country to achieve the status as a developed nation. As part of the overall national strategy on renewable energy, biomass waste can act as supplemental source of energy and banana waste is one of the potential feedstock. From the discussion, it is implied that the implementation of biomass flow screening and adoption of biomass processing technology could significantly increase the potential energy generation from wasteful direct combustion with maximum potential power of 80.52 MW to 869.13 MW using anaerobic digestion process of banana waste including reject bananas. However, despite the feasibility of banana waste feedstock, the compatibility issues of biomass waste-based fuel with existing fossil fuel infrastructure is still a concern making solid fuel briquette for use in cogeneration boilers a topic that should be researched further.

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DECLARATION OF COMPETING INTEREST

None

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