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Review on the renewable energy and solid waste management policies towards biogas development in Malaysia

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ABSTRACT

The development of renewable energy is of paramount importance towards the energy security and environment integrity of Malaysia. The Malaysia government has been implementing various policies that could facilitate the advancement of renewable energy technology and increase its contribution to the national energy mix to reduce the country dependency on fossil fuels. On the other hand, due to rapid urbanization and population growth, there is also increasing concern over the high production rate of organic waste. Among the renewable energy available, biogas is of great interest due to its ability to treat organic waste and generate power addressing both concerns simultaneously. This paper aims to review some of the important policies on renewable energy followed by the emphasis on solid waste management policies towards effective implementation of biogas generation from municipal solid waste. The biogas network is divided into three phases on a life cycle basis, namely MSW as feedstock, biogas production and biogas utilization. Under each phase, several important stages were identified. Analysis was performed to identify the role of currently implemented policies as well as the lacking support and challenges. It was envisioned that with proper SWM policies, in terms of waste collection, waste segregation and allocation of resources, which can be further complemented with more financial initiatives and technical support under the RE policies, the biogas development in Malaysia can progress more efficiently. Several supportive actions needed were derived from the analysis and presented in three figures, representing each of the phase, which could constitute a solid biogas framework.

1. Introduction

Malaysia is a transition country which is experiencing rapid urbanization and population growth. The population is expected to reach 33.4 million by year 2020 and 37.4 million by year 2030 [1]. The development leads to two major concerns, which are solid waste management (SWM) and energy security. In the case of MSW, the production rate is 0.5–0.8 kg/ person-day and is expected to exceed 9 Mt /yr by 2020 [2,3]. The energy demand on the other hand, is predicted to increase by 4.7% annually [4] where the electricity consumption having an annual growth rate of 8.1% [5].

In year 2000, under the eighth Malaysia Plan (MP), the Fifth Fuel Diversification Policy was launched and Renewable Energy (RE) was included to be the fifth major energy source, following oil, gas, coal and

Abbreviations: RE, Renewable energy; 3Rs, Reduce, Recover, Recycle; ABC, Action plan for a Beautiful and Clean Malaysia; Biogen, Biomass generation and demonstration project; CDM, Clean Development Mechanism; CER, Certified emission reduction; CETDEM, Center for Environment, Technology and Development Malaysia; DECs, Dedicated energy crops; EE, Energy efficiency; EFB, Oil palm empty fruit bunches; EPP, Entry Point Projects; ETP, Economic Transformation Program; FFB, Oil palm fresh fruit bunches; FiT, Feed-in tariff; FV, Fruit and vegetable waste; FW, Food waste; GHG, greenhouse gases; GTFS, Green technology financial schemes; GW, Green waste; IPP, Independent power producers; ITA, Investment tax allowance; KeTTHA, Ministry of Energy, Green technology and Water Malaysia; KW, Kitchen waste; LFG, Landfill gas; MHLG, Ministry of Housing and Local Government; MIPV, Malaysia building integrated photovoltaic technology application project; MP, Malaysia plans; MPOB, Malaysia Palm Oil Board; MPSJ, Subang Jaya Municipal Council; MSW, Municipal solid waste; NKEA, National Key Economic Areas; NSWMD, National Solid Waste Management Department; OPP, Outline perspective plan; POME, Palm oil mill effluent; PTM, Malaysia energy center; PV, Photovoltaic; REBF, Renewable energy business fund; SEDA, Sustainable Energy Development Authority; SREP, Small renewable energy program; SWM, Solid waste management; TNB, Tenaga National Berhad; UM, University of Malaya

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hydropower. Following this, there has been continuous implementation of RE-promoting policies and actions, such as the Small Renewable Energy Program, National Green Policy 2009, National RE Plan 2010, Renewable Energy Act 2011, Feed-in Tariff (FiT) mechanisms, RE business fund and Green Technology Financial Schemes under different Malaysia Plans.

The RE resources included energy from biomass, solar, mini-hydro power, municipal waste and biogas. Among these resources, biogas is important as it can offer a win-win situation towards the nation effort to achieve energy security while combating waste accumulation. Biogas is the product from anaerobic digestion (AD) of organic waste where it can be utilized to generate electricity. The major sources for biogas in Malaysia are palm oil mill effluent (POME), livestock manure and municipal solid waste (MSW) [6,7]. The electricity potential from biogas is estimated to be 100 MW by 2015 [8] with an energy reserve of 410 MW by 2030 and of 360–400 MW by 2020 [9]. However, according to Malaysia Sustainable Energy Development Authority (SEDA), to date, the cumulative installed capacity for biogas is only 6.48 MW and 6.36 MW (from landfill/ agricultural waste) by 2015. There is high RE potential from biogas which could be harvested from MSW and this could be better achieved if there are more supporting policies. The harvesting of biogas from MSW is highly dependent on the solid waste management (SWM) policy as it involves effective waste segregation and collection for a stable supply of feedstock for biogas production. RE policy is also important to provide legal structure and financial incentives to encourage the installation of AD plant, which is usually costly.

Several authors had performed excellent reviews and analysis on the development of energy policies in Malaysia. For example, [10] on Malaysia energy strategy towards sustainability, [9] on sustainable power generation in Malaysia to 2030, [6] on Malaysia's RE policies and programs with green aspects, [11] on RE policies and initiatives for sustainable energy future, and [12] on selection of RE sources for sustainable development of electricity generation. These papers highlighted the potential energy and important role of biogas in the RE mix but seldom overlapped their discussion with the SWM policy. In this paper, the authors aim to explore the niche where SWM and RE policies can be complementing to effectively utilize MSW as a source of biogas and facilitate the development of a sound biogas framework.

This paper is arranged into several sections. The first section provided an overview on the RE policies and SWM policies that are related to biogas development respectively. The second section presented the potential sources of biogas but with emphasis on MSW. This is followed by an analysis on the research gap to facilitate biogas development, namely from the aspect of supply and demand, technical issue, financial initiative and social concerns. Recommendation and supporting policies are provided to improve on the implementation gap as derived from the analysis in Section 3. It was envisioned that with proper SWM policies, in terms of waste collection, waste segregation and allocation of resources, which can be further complemented with more financial initiatives and technical supports under the RE policies, the biogas development in Malaysia can progress more efficiently as to benefit from a resource-oriented bio-economy.

2. Overview on the Malaysia's renewable energy and solid waste management policies

2.1. Renewable energy policies and plans under the Malaysia's government

Power and electricity generations in Malaysia are highly dependent on finite resources such as oil, natural gas and coal [8] which is unsustainable as studies showed that reserves for oil will be exhausted within 15 years from now [6] whereas electricity production by gas will be significantly reduced by year 2030 [13]. As mentioned, there is an annual growth rate of 8.1% for energy consumption. In year 2008, the RE is officially included to be one of the major energy source besides oil, gas, coal and hydro. In this section, several important policies that facilitate the RE framework are presented.

2.1.1. An Overview of the development of RE policies in Malaysia

The successful implementation of biogas and any other RE technologies is dependent on the government RE policy that favours RE development. The Eighth Malaysia Plan (2001–2005) introduced the Five Fuel Diversification Policy which first included RE as the fifth source of energy after oil, gas, coal and hydro. The RE available in Malaysia includes solar PV, biomass, biogas, municipal solid waste (MSW) and wind energy. The 8th MP had a target to utilize RE to contribute 5% of the total energy mix by 2005 but only 0.3% was achieved [14].

This target was then brought forward to the 9th MP (2006–2010) with greater emphasis on energy efficiency [15] and a series of programs where initiated, including the Small Renewable Energy Power Program (SREP) (2001–2010) which successfully installed 12 MW to national grid, the BioGen project (2002–2010) and the establishment of Malaysia Building Integrated Photovoltaic Technology Application Project (MIPV) (2005–2010) [10]. Furthermore, companies employing RE technology could also benefit from incentives based on energy efficiency, RE resources uses and green buildings under the 9th MP budget [10]. Despite such efforts, RE still constituted less than 1% of the total energy mix supply [14].

The 10th MP introduced the New Energy Policy circling on energy pricing, strategic supply developments, end use energy efficiency, energy governance and regulation as well as management of change and affordability [16]. In 2009, the National Green Technology 2009 was implemented with the aim to increase energy supply from RE into the national energy mix to 5.5% by 2015. In addition to that, the RE act 2011 also introduced the feed-in tariff (FiT) mechanism which benefits RE developers and also contributing to the RE fund. Others financial aids available include Renewable Energy Business Fund (REBF), Green Technology Financial Scheme (GTFS) as well as Renewable Energy and Energy Efficiency Scheme [10,11].

The recently announced 11th MP (2016–2020) also highlighted green growth for sustainability and resilience as one of the six main strategic trusts where energy is one of the core aspects in natural resource management. One of the focus area is to adopt the sustainable consumption and production (SCP) concept. Under this plan, waste to landfill is treated as resource that can be reused through recycling and recovery, for power generation, and other waste to wealth initiatives. The plan aims to transform to a resource and energy efficiency society by creating green markets, increasing share of RE in energy mix, enhancing demand side management, encouraging low carbon mobility and managing waste holistically [17].

2.1.2. The national green technology policy 2009

The National Green Technology Policy stated green technology (GT) to be the driver to accelerate the national economy and promote sustainable development. GT is defined as technology that minimizes the degradation of the environment, has zero or low GHG emission, improved environment, conserves the use of energy and natural resources and promotes the use of RE. RE is one of the green technology. This policy had five main strategic thrusts to encourage RE development, which are Institutional Framework, Green Technology Development, Human Capital Development, Green Technology Research and Innovations as well as Public Awareness [11,15,18]. Under thrust 2, a Green Technology Financing Scheme (GTFS) is available for GT operators. The fund provided a maximum of RM 100 million with tenure up to 15 years being available to company practicing green technology for energy, water and waste management [19]. The GTFS fund has been increased by RM 2 billion in Budget Malaysia 2013 with extension of application till 31 December 2015 [20]. Furthermore, the Malaysia government will also bear 2% of the total interest rate of the loan approved and providing a guarantee of 60% on the financing amount to assist company involving in green technology.

2.1.3. The national renewable energy policy 2010 and action plan

This action plan has 5 major thrusts: introduce appropriate legal framework, create conducive business environment for RE, intensify human capital development, enhance RE research and development and lastly, increase public and stakeholder awareness and RE policy advocacy.

Under thrust 1, the Feed-in Tariff (FiT) is implemented together with the establishment of the RE Fund. SEDA Malaysia is appointed as the main authority to implement FiT for RE producers. The FiT mechanism allows the RE users to generate income through the sale of electricity generated from RE source to the national grid based on different payment rates over a certain period of time. For instance, the FiT rate is 0.28–0.35 RM/kWh for biogas based on feedstock including palm oil, agro-based stock and farming manure, over a payment period of 16 years. Additional incentives of 5 sen per kWh, 8 sen per kW h or 2 sen per kW h is applicable when plant operator incorporated home-grown technology, use agricultural waste as feedstock or adopt efficient gas technology respectively [21] as shown in Tables 1 and 2.

2.1.4. Renewable energy act 2011

In addition to the FiT mechanism, the Renewable Energy Act 2011 stated that an additional 1% surcharge will be applied on electricity consumers except for domestic consumers using less than 300kWh per month or currently paying electricity bill of less than RM77 per month to encourage energy efficiency among consumers and also funding the RE fund. The RE fund is managed by the Sustainable Energy Development Authority (SEDA) and had already collected RM427 million by end of August 2013 [23]. To date, biomass and biogas projects are allocated with 222 MW (MW), or 37 per cent, of the total 601 MW renewable energy quota.

2.1.5. Incentives for RE sources

Incentives are provided by the government to encourage the use of RE and facilitate its development, mainly in terms of financial assistance on tax relief. These incentives include the Pioneer Status with offers 25% exemption on income tax over 100% of statutory income for 10 years, the Investment Tax Allowance where 100% qualified capital expenditure incurred within 5 years can be used for 100% on the statutory income and lastly the Exemption on Import Duty and Sales for imported machinery, equipment, materials and other consumables [11,20].

2.1.6. Current RE status in Malaysia

According to SEDA, hitherto policies see positive results in 2012 and 2013 in the installed capacities for RE, for example for biogas, the installed capacity increased from 5.16 MW in 2012–6.58 MW in 2013 where its annual power generation increase from 7563.51 MW h in 2012 to 18,571.43 MW h in 2012. By 2030, installed capacity for RE is expected to be 11% (2080 MW) of the energy mix [7]. The following table showed the installation of RE and their cumulative installed capacity for year 2012–2015 (Table 3).

Table 2
FiT rates for Biogas (Landfill/Agri Waste) with 16 years from FiT Commencement Rate as updated by 01 Jan 2015 [22].

(A)	Basic FiT rates having installed capacity of	FiT Rates (RM per kW h)
(I)	Up to and including 4 MW	0.31844
(II)	Above 4 MW and up to and including 10 MW	0.2985
(B)	Bonus FiT rates having the following criteria (one or more)	
(I)	Use of gas engine technology with electrical efficiency of above 40%	+0.0199
(II)	Use of locally manufactured or assembled gas engine technology	+0.0500
(III)	Use of landfill, sewage gas or agricultural waste including animal waste as fuel source	+0.0786

The installation of biogas capacity has been progressing rather slowly whereas major attention has been given to solar PV and mini hydro. However, it could be seen that various types of RE has been increasing in their capacities along the years, which is the effort fruiting from the continuous facilitation of RE policies by the Malaysian government over the past 30 years [24]. In addition to that, it is worth noticeable on the increasing numbers in biogas capacities, especially those from landfill and agricultural waste, from year 2015 to 2017. Municipal solid waste (MSW), which contains high portion of organic composition, can also be a promising biogas source though it has not been widely utilized in Malaysia, mainly because non-sanitary landfilling remains the dominant disposal method for MSW. However following the increasing waste production and energy demand coupled with rising of landfill price due to the scarcity of land [24], the capability to convert such organic waste into biogas turns out to be a promising disposal alternative. This could be reflected in or contributed by the solid waste management policies such as the National Solid Waste Management Policy 2008, the Solid Waste and Public Cleansing Act 2007 and Act 627 on 2011 on improving the current management system for solid waste collection, treatment and disposal.

2.2. Solid waste management scenarios in Malaysia

Solid waste management policy is important for biogas development due to the high potential of biogas generation from the organic waste portion of the MSW landfill. Methane gas constitutes 50–55% by volume of LFG and has 21–23 times global warming potential than carbon dioxide [25]. A study by Johari et al. [26] estimated that the methane emission from landfills in Peninsular Malaysia is of 310,220 t in year 2010 and will increase to 350,000 and 370,000 t per year by 2015 and 2020 respectively. Policies tackling on the prevention of the escape of methane gas to the atmosphere through biogas trapping is of high importance as less than 10% of the landfills are sanitary [27].

2.2.1. An overview of the SWM policy and action in Malaysia

Under the Local Government Act 1976, local authority is respon-

Table 1
Total RE capacities (MW) granted with Feed in Approvals under the FiT mechanism including those not yet achieving FiT Commencement Date [22].

Year	Biogas	Biogas (Landfill/ Agri waste)	Biomass	Biomass (solid waste)	Small hydro	Solar PV	Total
2012	0.00	0.00	0.00	0.00	0.00	0.04	0.04
2013	0.00	2.00	0.00	0.00	0.00	4.40	6.40
2014	0.00	3.90	24.50	0.00	12.00	23.44	63.84
2015	0.00	44.77	35.50	4.09	26.94	66.22	177.52
2016	0.00	32.35	46.74	0.00	112.60	0.00	191.70
2017	0.00	21.40	30.00	22.20	57.25	0.00	130.85
Cumulative	0.00	104.42	136.74	26.29	208.79	94.09	570.33

Table 3
Annual Power Generation (MWh) of Commissioned RE installations (year 2012–2015) and respective cumulative installed capacity [23].

RE Technology	Year 2012	Year 2013	Year 2014	Year 2015	Cumulative installed capacity (MW)
Biogas	98.11	12,217.15	16,123.27	0.00	6.48
Biogas (Landfill/ Agri waste)	7465.4	9477.59	23,395.72	0.00	6.36
Biomass	101,309.87	209,407.59	186,969.51	36,764.99	55.00
Biomass (Solid Waste)	3234.52	11,144.25	3785.52	0.00	7.00
Small hydro	25,629.78	73,032.12	55,935.78	4574.86	11.70
Solar PV	4714.01	48,415.83	148,774.21	5728.10	191.51

sible to provide public cleansing services of equitable and acceptable quality and dispose all collected waste sanitarily [24]. In 1998, the Action Plan for a Beautiful and Clean Malaysia (ABC) was launched by the Ministry of Housing and Local Government (MHLG) in order to establish an integrated solid waste management system through improving the disposal of collected waste, encourage recycling and resource recycling, support privatization service, improve public education on cleanliness and resources recovery as well as strengthen research and development for MSW management [28]. The effort for an integrated SWM is carried forward to the subsequent MPs, such as the 3rd outline perspective plan (2001–2010), Integrated Solid Waste Management (2001), National Strategic Plan for Solid Waste Management (2005), Master Plan on National Waste Minimization (2006), Solid Waste and Public Cleansing Management Act (2007), Scheme for Household Waste Management (2011) and enforcement of Act 672 (2011).

For the 8th MP (2001–2005), the government adopts waste management policy circling 3Rs (reduce, recover and recycle) which is consistent with the 3rd Outline Perspective Plan (OPP) as well as waste management hierarchy. The 8th MP had stated that “A clearing house mechanism be established to facilitate industrial symbiosis, whereby one industry's waste could be another's resource.” (8th MP:550) to encourage 3Rs policy. Recycling program had been launched as early as in 1993 in Malaysia but without much significant progress. In consistent with the government effort for better waste management, MHLG re-launched the 3Rs program including waste reduction, reuse and recycling program in 2001 and declared 11 November as National Recycling Day. The current recycling rate by 2012 is 5% [29] whereas full commitment from the community is expected to be able to divert 20% of MSW from disposal sites [24].

In 2005, the National Strategic Plan for Solid Waste Management (NSP) (2005) was implemented with the emphasis to upgrade non-sanitary landfills and construct new sanitary landfills. The NSP established a target of 22% reduction and recovery as well as a 100% recovery for urban source separation by 2020. It also provided the framework for the development of several SWM master plans, such as the Waste Minimization Master Plan (MWM) (2006). The main objective of MWM is to minimize the amount of solid waste disposal in Malaysia with a target to achieve a recycling rate of 11% in 2010. This is supported by the National Solid Waste Management Policy (2006) which emphasized on the 3Rs activities and waste management hierarchy. This is followed by the Solid Waste and Public Cleansing Management Act (2007) which deals with waste minimization and 3Rs, as well as the privation of solid waste collection and mandatory waste segregation. This Act will be discussed further in Section 2.2.2.

For the 10th MP (2011–2015), it was acknowledged that solid waste is one of the three major environmental problems in Malaysia. Due to rapid urbanization and population growth, the amount of solid waste is expected to exceed 23,000 t by year 2020 whereas for now, only less than 5% of the waste is being recycled. For the 11th MP (2016–2020), the government had revised the Solid Waste and Public Cleansing Management Act 2007 (Ac 672), with emphasis to strengthen the institutional framework and reinforcing coordination among relevant ministries and agencies. By September 2015, under act 672, mandatory waste segregation is being implemented for household waste segregation and this act will take effective starting June 2016.

2.2.2. Solid waste and public cleansing management act 2007 (Act 672)

The act 672 was passed by the parliament to empower federal government to take over the responsibility on SWM. The implementation of the Act was commenced in September 2011 through MHLG. The government is currently aiming to reduce the amount of solid waste disposed in landfills by 40% and GHG from solid waste disposal by 38% [30].

Solid waste is defined as controlled solid waste that includes those from commercial, household, institutional and public activities by the Solid Waste and Public Cleansing Management Act 2007. It is estimated that the amount of solid waste would reach 31,000 t/day in Malaysia 2020 with 60% being food waste [31]. The improper disposal of such waste to landfill can lead to foul odour, toxic leachate, GHG emission and vermin infestation [32] due to high organic and moisture content [24], which is highly undesirable.

The Act was gazette on 30th August 2007 and was enforced on 1st September 2011. The Act will be responsible on the licensing of solid waste management and public cleansing, control of solid waste and the duty person possessing the solid waste and lastly, to enforce on waste reduction and resource recovery of solid waste [33]. Furthermore, Act 672 also empowers the Director General of NSWMD to fine an amount of not exceeding RM1000.00 to those who failed to conduct proper separation, handling and storage of solid waste [28].

Due to the current low recycling rate of 5%, the 10th Malaysia Plan thus aims to achieve household recovery of waste from 15–25% by 2015 [34] through proper waste segregation. Under the Act 672, it would be a mandatory requirement for households to separate recyclable items from other garbage before disposal. A 120-liter bin will be provided by concession companies in the respective states excluding Penang, Selangor and Perak, where each household is responsible to [33,35]:

1. Separate waste
2. Recycle and avoid trash from damage or theft
3. Make sure bins closed at all times
4. Remove barrels during the collection made

2.2.3. Solid waste and public cleansing management corporation (Act 673)

The Solid Waste and Public Cleansing Management Corporation (Act 673) was enacted and regulated by the NSWMD under the MHLG where the corporation will replace local authorities over the management of solid waste and the respective concessionaires. This act also focuses on recycling and has a special allocation for separation of wastes at the source [29]. Under this act, a fund known as the Solid Waste and Public Cleansing Management Corporation Fund is established to pay for expenses related to the management of solid waste and public cleansing.

3. Harvesting biogas from MSW and supporting actions

3.1. Sources of biogas

The palm oil industry is a significant contributor to the Malaysia economy with plantation over 4.9 million hectares of land area. 1 ha of palm oil plantation can produce 50–70 t biomass residues [36]. By July 2009, a total capacity of 4.45 MW was under construction to provide a potential power generation of 410 MW by 2028 [37]. It is estimated that about 17–20 million tonnes of CO_2 equivalent of GHG can be mitigated each year if all mills practiced biogas capturing [38]. Hence biogas trapping from oil palm mills is one of the eight Entry Point Projects (EPPs) of the palm oil sector under National Key Economic Area (NKEA) for the Economic Transformation Program (ETP) [39]. By September 2012, among the 58 palm mills, 36 had registered under CDM projects for biogas recovery [40]. The list for such mills is available on NKEA.

Landfill gas (LFG) produced during the anaerobic decomposing of wet organic waste can be harvested for heat and electricity through an internal combustion engine [22]. Landfilling remains the dominant disposal method for MSW in Malaysia with 98% of MSW generated are disposed into landfills, but most are non-sanitary and open areas. Organic solid waste make up almost 57% of the total waste stream and with current MSW production of 0.5–0.8 kg/person-day, MSW is expected to exceed 9 million tonnes per year by 2020 [2,3]. There are currently 261 landfill sites in Malaysia with 150 sites operating [14], hence offering a total technical power potential of 173 MW with 176,000 mt methane recovery potential per year. Harvesting methane gas for energy recovery is also eligible for CDM project [6]. The Air Hitam Sanitary Landfill is the first grid connected RE project in Malaysia that was commissioned in April 2004 under cooperation with TNB Energy Services Sdn Bhd. The landfill receives 3000 t of garbage per day from major parts of Klang Valley and has a power plant with a production capacity of 2.096 MW connected to the national grid. It is estimated that each well can produce biogas for 20 years with more than 55% of methane gas with an 80% moisture level at a production rate of 40 m^3/h [14].

Aside from the LFG from landfilling, MSW can be fed directly as feedstock to AD for biogas production. The biogas generation from this aspects is yet to be explored in Malaysia. The CH_4 yield is very dependent on the feedstock and operating condition. However, it is not the main aim of this paper to review thoroughly on technical aspects in optimizing CH_4 yield. Table 4 showcased the variety of feedstock of MSW, such as food waste (FW), green waste (GW), kitchen waste (KW), fruit and vegetable waste (FV), which had been used to produce biogas.

As observed from the above table, FW is a popular feedstock and has a high potential for biogas production. It is reported that Malaysia is capable to produce 8,331,589 t of FW per year (MHLG, 2016). However, most of them are only available at lab scale. The up-scaling of biogas production is hurdled by several challenges, such as high financial cost, insecure feedstock, infrastructure requirements and technical maturity. All these challenges will require supporting actions from the government to better facilitate the installation of AD. In the following section, current available policies and proposed supporting actions to overcome the challenges will be presented.

3.2. Analysis of current policies and proposed supporting actions for biogas development

In Malaysia, the policies such as the 5th fuel diversification under the 8th MP, the National Green policy 2009, National Renewable Energy Policy 2010 and Action Plan, as well as Solid Waste and Public Cleansing Management Act 2007 (SWM 2007) had been driving the RE development. Actions such as the mandatory waste segregation under SWM 2007 and the RE incentives, such as FiT, ITA and GTFS, have also been implemented. However, the progress of RE, such as the case of biogas, is still progressing slowly.

To enhance the development of biogas in Malaysia, a more holistic framework is required. The framework for biogas development is an overlapping layer between the RE policy and SWM policy. MSW management is under SWM policy and it serves as a feedstock to AD whereas the utilization of biogas in the form of energy is regulated by the RE policy. Although the Malaysia government has pursued several national policies that can facilitate the biogas development, there is still lacking of supporting actions on several aspects, especially in terms of financial supports, technical issue and securing demands, which requires the cooperation between the SWM and RE policy. The relation of SWM and RE of a biogas framework is shown in Figure 1which presents the different stages involved in the AD process based on a life cycle approach (from acquisition of waste source to production and finally utilization).

The following sections were organised accordingly to this sequence. Firstly, the biogas-to-energy roadmap is divided into three phases (as shown in Fig. 1), namely MSW feedstock, biogas production and lastly, utilization. The sub-section begins with the various stages under each phases and its challenges in terms of technical, financial and social concerns. The challenges are analyzed and respective solutions are proposed. The proposed solutions are mapped against the current RE and SWM policies where the existing policies and in-need supportive actions can be clearly identified. Toward the end of the subsection, a diagram consisting the analysis outcome of the respective stages among the three phases were presented.

3.2.1. Phase 1: MSW feedstock

3.2.1.1. Potential challenges relating to phase 1: MSW feedstock. As presented in Fig. 1, under phase 1, MSW feedstock, there is several stages, namely waste segregation, waste collection, waste allocation and waste storage. This phase is important as it regulates the availability of

Table 4
Biogas yield from different feedstock of MSW.

Reference	Type of digester	Venue	Feedstock	Biogas yield
[41]	Batch (1 L)	City of San Francisco, California	FW	435 mL CH_4/g VS
[42]	Batch (1 L)	Canteen of Beijing University of Chemical Technology, China	FW+straw	0.392 m^3 CH_4/kg VS
[43]	CSTR (2 m^3)	Beijing, China	FW, FV, Sewage sludge	0.2–0.5 m^3 CH_4/kg VS
[44]	Continuous (1.13 m^3)	Wholesale market of Sardina, Italy	FV	0.43 Nm^3 CH_4/kg VS
[45]	Batch (500 mL)	Choba community, River state, Nigeria	Cow manure+waste paper	2.2 mL CH_4/g VS
[46]	Batch (2 L)	Ohmura Commercial Company, Saitama, Japan	FW	64.7 mL CH_4/g VS
[47]	Batch (1 L)	Quaid-i-Azam University, Islamabad; rice Sheller, Faisalabad city	FW+rice husk	584 L biogas/kg VS
[48]	Batch (1 L)	Shahjalal University of Science and Technology, Surma residential area CM nearby village	KW+Cow manure	75 mL biogas/g substrate
[49]	Batch (1 L)	Waste management company, San Francisco, California	FW+GW	245 mL/g VS
[50]	Batch (2.3 L)	Kimchi factory, Korea	Cabbage waste	389 mL CH_4/g VS
[51]	Batch (100 mL)	Indian Institute of Technology Guwahati, Assam, India	FW+livestock dungs	227 mL CH_4/g VS

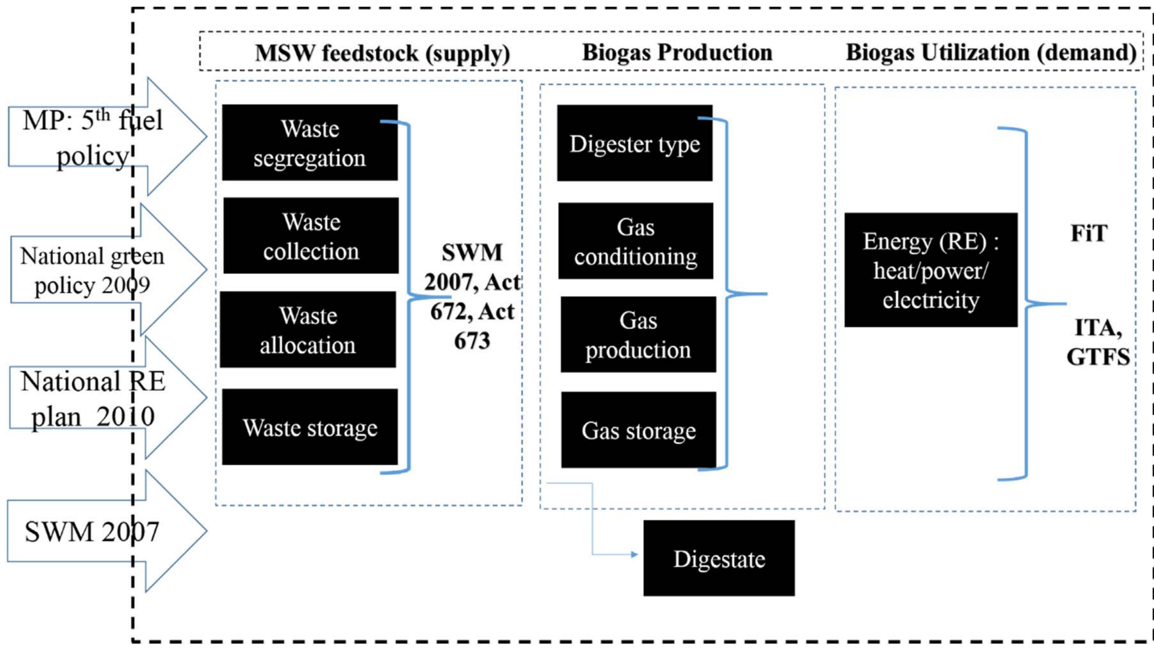

Fig. 1. Stages of AD based on life cycle approach and the implemented policies.

feedstock to the AD system. Its main challenges include technical (proper waste segregation, efficient waste collection, appropriate waste allocation and storage), financial cost (increasing coverage of waste collection) and social participation (proper waste segregation and 3Rs).

(a) Waste segregation and collection

In terms of technical issue, proper waste segregation and effective waste collection might be the core issue. One of the significant factors in affecting biogas yield is the input feedstock, as in its purity. The input to AD should only consider organic waste, which can be decomposed by microbes and produced biogas under anaerobic condition. Undesirable materials such as plastics, glass and electronic waste will hinder the overall AD process. On the other hand, the waste collection in Malaysia is operated by multiple agencies, making it difficult to coordinate. Effective waste collection is often associated with high financial cost. The Malaysia government is reported to have 50% of the municipal operating budget spent on the management of MSW. Out of the 50%, 70% is spend on the collection of wastes [52]. Furthermore, there is lack of social awareness among the public on the importance of waste segregation.

(b) Waste allocation

Another major issue is to deal with proper allocation of waste. Organic waste can be used as raw materials for many waste-to-energy and waste management technologies, such as composting, AD, incineration and thermal treatment (combustion, pyrolysis and gasification). There would be a competition among these technologies players to acquire substantial amount of waste to be fed into their systems continuously for a long period.

3.2.1.2. Mapping initiatives with current policies and needed policies for phase 1: MSW feedstock. (a) Waste segregation and collection

In September 2015, under the SWM 2007, the Malaysia government has officially enforced mandatory waste segregation for household for recycling purposes. The government has provided an adaptation period, 1st September 2015 to 1st June 2016, for residences to be familiar with the waste segregation system. By June 2016, a maximum fine of RM1, 000 can be imposed to residents who refuse to separate their solid waste, as according to Act 672. This initiative will take immediate effect in several states such as Johor, Negeri Sembilan, Malacca, Pahang, Perlis and Kedah as well as the two Federal states, namely Kuala Lumpur and Putra Jaya. The residents will require to separate their solid waste according to 4 categories: recycled, waste remnants, bulk garbage and garden waste, as stipulated by the Solid Waste Management and Public Cleansing Corporation (SWCorp). According to different residential area, the waste will be collected at different days, with a collection frequency of once per week for recyclable waste and twice a week for residual waste. The successful implementation of this act will help to ensure the quality and quantity of the incoming feedstock to the AD system (stage: waste segregation and collection). As for the waste collection and transportation, the federal government contracted out the management services to private contractors on a regional basis under its privatization program to improve the quality of services, which can be compensated by the high cost. However, the challenges remain as there is absence of a centralised coordination on the collection and distribution of waste.

(b) Waste allocation

The Malaysia government is currently preparing the National Strategic Plan on Food Waste Management (NSP). The NSP has 6 major strategies for FW management, namely strategy 1: establishment of baseline data about FW generation, strategy 2: establishment of a “FW recycling regulation”, strategy 3: FW minimization/reduction at source, strategy 4: FW treatment at source, strategy 5: proper centralised system for FW treatment and lastly, strategy 6: effective CH_4 recovery from landfill sites. Under strategy 4, the three main treatments includes composting, AD and incineration where strategy 5, the major treatments are composting and AD. As the major constituents of the MSW is FW, biological treatment such as composting and AD are more preferable due to the high moisture of FW. Thus there is a challenge in allocating the collected waste based on the capacity and demand of products between the two systems. In the composting market, the major drive will be the need of biofertilizer to substitute certain proportion of chemical fertilizer and peat. This helps to reduce fossil fuel consumption to produce chemical fertilizer and minimize carbon emission during peat extraction and transportation. In terms of AD, the main highlight will be to harvest the biogas to generate heat and electricity via CHP and produce biomethanol that can replace natural gas through gas conditioning process. AD also generates significant amount of digestate that can either be directly applied to land or as composting feedstock. Thus there is a necessity for a policy

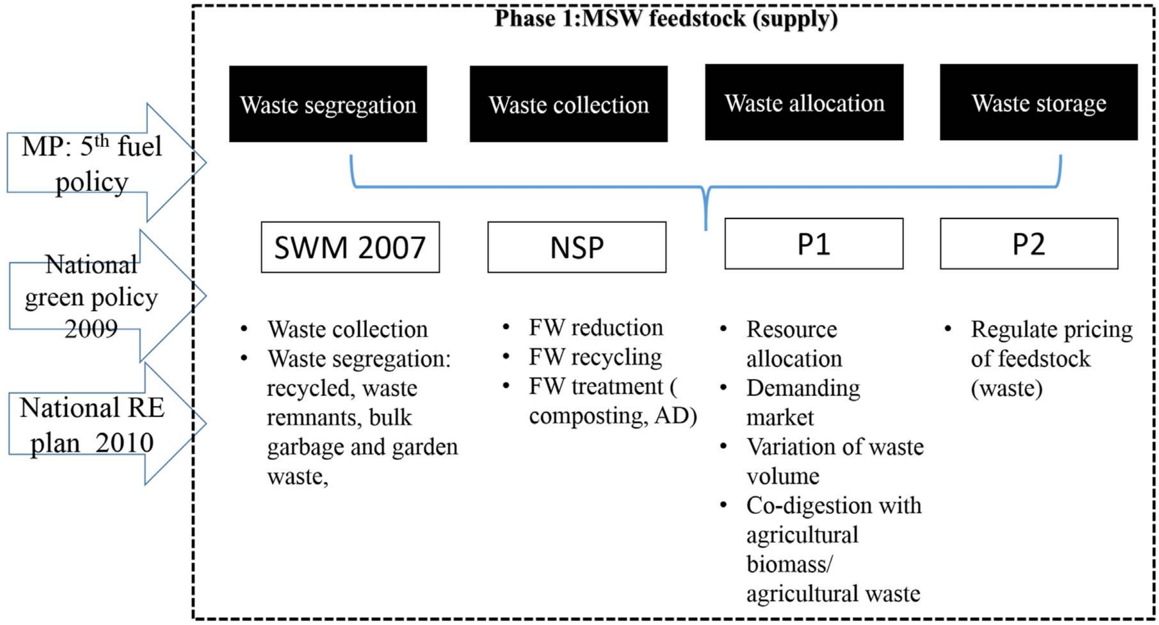

Fig. 2. Proposed action to support phase 1: MSW feedstock as supply.

which could determine the resource allocation effectively.

Studies have pointed out waste quantity varied seasonally and during festive season. In the case where MSW could not provide sufficient feedstock, there would need to be a mechanism where agricultural biomass and agricultural waste can be channelled to the system. This would have competition among different stakeholders who utilizes the biomass for different purposes and should be considered by the regulatory in charge.

As mentioned, the organic waste that is normally discarded is regarded as valuable resource in the AD market. In parallel with the effort to ensure stable supply of feedstock for AD, there is also a need of constant regulation on the pricing of feedstock. Regular fluctuation of the feedstock pricing will hinder the continuous supply of the feedstock and affect the interest of investors. In the case where the feedstock pricing is too high and the cost could not be compensated by the FiT mechanisms, this will draw out potential investor and stakeholders.

Fig. 2 presented the current policies and proposed policies to overcome the challenges in phase 1 of AD installation.

As seen in Fig. 2, it is envisioned that with the implementation of SWM 2007 and NSP, the installation of AD will be at better ease as the waste will be collected and segregated efficiently to be utilized as AD feedstock. The implementation of mandatory waste segregation is a great starting point to embark towards a waste-to-resource oriented bioeconomy. In addition, following the implementation of NSP in the future, biological treatment such as composting and AD, would have high market potential for resource recovery from waste. On the other side, there is still a need of action to regulate the feedstock market. Two policies, P1 and P2, are proposed to govern issues related to the feedstock supply, namely “waste” allocation for various waste conversion technology, price regulation for “waste” and ensuring “waste” supply.

3.2.2. Phase 2: Biogas production

3.2.2.1. Potential challenges relating to biogas production and upgrading. The two main challenges for the stages of biogas production are estimated to be technological maturity [12] and financial viability. Technological maturity includes the inexperience and unfamiliarity in the AD process, its design and operation, maximisation of biogas yield, handling of digestate and upgrading biogas to value-added product. In terms of financial viability, construction of AD plant and its subsequent maintenance and operation can be significantly high. This thus draws off potential investors due to higher financial risk, which is associated with minimal payback period and issues to secure bank loan. The calorific value of biogas is dependent on the CH_4 content. The installation of purification unit and gas conditioning unit requires higher technical maturity as well as investment cost.

In terms of technological aspect, AD is a complex system which involved several stages of biotransformation of OM, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis. Each of these steps have their own operational requirements, especially for methogenesis, where methanogenic bacteria convert acetate and CO_2 into CH_4. Improper operation of the AD will lead to low biogas yield, especially when the FW in Malaysia consisted high amount of fat. Fat consisted high biomethane potential (BMP). [56] showed that increasing fat content in MSW (< 60%) could increase CH_4 yield significantly. The study also observed decrease in CH_4 yield when the fat content is higher than 65% and displayed inhibitory effect on biogas production. There is still lack of research and development (R & D) effort in this aspect. In addition, the operation and maintenance of the AD plant will require skilful engineers and technicians, which could be lacking in Malaysia as AD is still not a common practice [7]. There is also high financial burden in installing the processing units for pre-treatment, the AD unit itself and the conditioning and purifying units. In terms of social aspect, the public is generally not aware of AD plant and can be reluctant to have the AD plant near residential area and city area.

3.2.2.2. Initiatives relating to biogas production and up-grading. In order to maximise biogas production, there would be a need to improve the technical know-how on the AD process. Supporting actions such as trainings and workshops on operational knowledge of AD, safety issue of AD plant, operational and maintenance. It is practically attractive to have a board of experts from both government and private sectors that could provide technical support to operators or investors with little experience. In terms of financial aspect, the government should provide more tax exemption on AD technology due to its high capital and operational cost. The government should encourage more R & D to maximise the biogas yield. This should be parallel with the construction of infrastructure to access to the national grid where the RE producer can access to the financial benefit granted under the FiT mechanism under SEDA. In addition, joint ventures should also be welcomed, especially from countries such as Germany and Japan, who have great experience in AD process. This can serve as a good platform to learn the technical know-how of AD plant and attract foreign investment simultaneously [24].

3.2.2.3. Mapping initiatives with current policies and needed policies for phase 2: Biogas production and up-grading. Current policies in Malaysia have several actions that supported capital development and R & D development. For example, the National Green Policy and National RE plan, both had strategic thrusts to encourage professional development and international collaboration. However there is lack of solid actions to tackle the challenges specifically in AD operation. A new policy, P3, is suggested to deal specifically with the technical immaturity and financial issues related to technical support.

In Malaysia, there are several key players in energy development which are: Petroliam Nasional Berhad (Petronas), Tenaga Nasional Berhad (TNB), Malaysia Energy Commission, Ministry of Energy, Green Technology and Water (KeTTHA), Malaysia Energy Center (PTM) and Center for Environment, Technology and Development Malaysia (CETDEM). Fragmented implementation from legal and regulatory framework leads to overlapping function and unclear responsibilities over responsible authorities [9,14]. This could also lead to ineffective utilization of resources and hurdling the efficiency of overall programs in terms of man power, collection service provided and inadequate legal provisions [24].

More effort should be put on to facilitate collaboration between government agencies and private institutions to overcome limitations, such as in terms of technical and finance issues [7]. Weak political support, monopolistic and oligopolistic energy market [53] can discourage both local and foreign investors to participate in the RE development. Strong policy shift that favours RE development such as the Renewable Energy Sources Act and FiT can encourage industrial and political involvement for RE. For example, China has introduced a regulation based on the EEG model from Germany and has planned to spend 50 billion Euros on the RE development for the country [54]. Thus, another policy P5, which can complement the current FiT schemes, is proposed. This policy aims to unite the energy players in Malaysia where there would be a standardised mechanism to encourage more private and industrial players in the AD scenario. In addition, there could also be another mechanism which provided different financial schemes when the biogas is converted to biomethanol, which involves additional setting cost. Biomethanol can be used to replace natural gas which lighten the country's dependency on non-renewable fossil fuel.

Digestate is another major by-product from the AD process. The end quality of the digestate is highly dependent on the input feedstock and operational conditions. It is suggested that a policy, P5, can be helpful by regulating the incoming feedstock to ensure a high quality digestate that is of high nutrient and free from heavy metals and toxic substances.

Fig. 3 presented the proposed supportive actions to overcome the challenges in phase 2: biogas production of the installation of AD.

As AD is fairly new in Malaysia, there is no concrete policy in enhancing the production of biogas and its subsequent use. There is much to be done for this phase as it is significantly related to phase 3. With sufficient technical know-how to operate and maximise biogas yield, which coupled with conversion technology to upgrade biogas to of higher value, the return of investment is more attractive.

3.2.3. Phase 3: Biogas utilization

3.2.3.1. Potential challenges relating to phase 3: biogas utilization. (a)Biogas utilization

The utilization is dominantly the decision factor for the economic feasibility of the implementation of AD plant. In terms of technical issue, there is lack of infrastructure to ease the distribution and utilization of biogas, such as connection to national grid and underground pipe line. From the perspective of financial concern, biogas is generally considered to be an expensive energy source due to high investment cost as compared to the heavily subsidized fossil fuel. Furthermore, there is lack of social acceptance towards AD as Malaysian often prefers cheaper option. This is associated with the lacking of awareness in the importance of green and sustainable development as well as acknowledgement of the decreasing reserves for fossil energy.

(b) Digestate utilization

Digestate from AD is rich in nutrient and can be used to fertilize

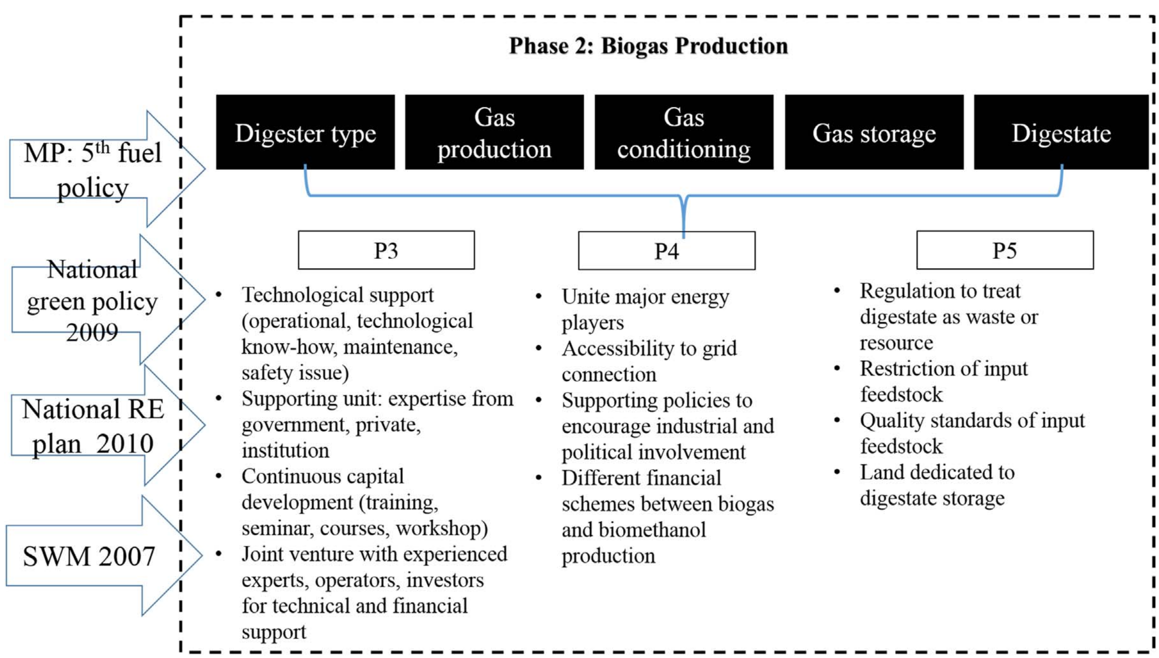

Fig. 3. Proposed action for phase 2: Biogas production.

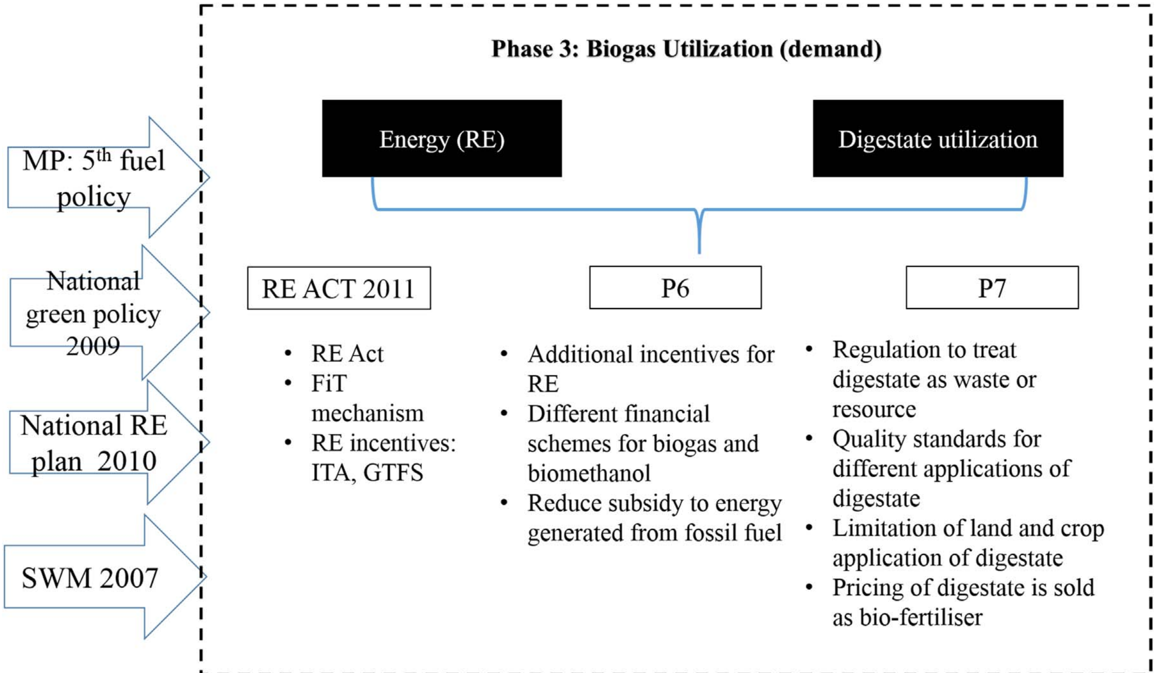

Fig. 4. Proposed supportive actions for phase 3: Biogas utilization.

crops. The major hurdle for the land application of digestate is derived from the inconsistency of nutrient content which is affected by feedstock quality and operational condition. This thud led to low market acceptance due to inconsistent performance. There is also concern over the safety issues of digestate to be applied to crops, such as pathogens and heavy metals that could originate from the source.

3.2.3.2. Initiatives relating to phase 3: biogas utilization. (a) Biogas utilization

In order to maximise the benefits from AD of organic waste, firstly there must be significant improvement on the infrastructure, which allows the biogas to be injected into the natural gas pipe. There must also be proper infrastructure to generate electricity from the biogas and channelled it to grid lines. In terms of financial support, there would be incentive for sales of RE. This incentives should allow RE to be sold at the same price with fossil fuel in order for a fair competition. Similarly for the social aspects among the three phases, governments will need to organize various seminars, talks and demonstrations towards the public to increase their social awareness and acceptance towards green technology and the impacts of such technology towards a better quality and sustainable living.

(b) Digestate utilization

To ensure the quality of digestate, there would be a need of regulation on the characteristic of incoming feedstock and its potential end use. As digestate can be a potential competitor for chemical fertilizer, the government will have to implement supportive action to increase its competitiveness with clear regulation and standards to build public confidence, as well as provides financial schemes for digestate utilization to make it cost attractive.

3.2.3.3. Mapping initiatives with current policies and needed policies for phase 3: Biogas utilization. (a) Biogas utilization

FiT is considered as the critical success factor for the implementation of RE in Germany. The most common barrier is often associated with the high investment cost due to limited equipment from suppliers, expensive research and development as well as low public awareness and also the financial risk of unexpected payback period as RE is fairly new in Malaysia [7]. Government policies to provide financial security is important to attract more investment such as the FiT mechanism, which had shown significant results in many countries like Germany. For the success of the FiT mechanism, the government must ensure that a reasonable profit can be obtained through the FiT rates over a certain period of time and also provide adequate degression rates for grid connection by competent agency in order to attract more investment [53].

RE has often lead to the thought of being more expensive as compared to conventional energy as the latter is heavily subsidized which shadowed the low operating cost of RE [53]. It is estimated that more than US$200 million is spend globally on the subsidization for conventional energy. Sovacool [54] pointed out the four most effective policy mechanism towards RE and energy efficiency (EE) are elimination of subsidies, establishment of accurate electricity prices, making RE mandatory and increase public awareness in order for RE to be on par with conventional energy and RE being acknowledged of its beneficial impacts for the country. Currently Petronas has been subsidizing up to 60% of the natural gas sold to utilities [14] in which should be gradually reduced to reallocate more for RE development [7]. Thus in addition to the current FiT mechanism, it is proposed that a supplementary policy, P6, can be practised to include a financial schemes to facilitate either biogas or biomethanol, depending on the market requirement. This new FiT act should set an equal tariff for both RE and fossil fuel to increase a fair share of RE in the energy mix.

(b) Digestate utilization

Another by-product from the AD of organic waste is the digestate. Currently there is no regulation in Malaysia for the disposal of the digestate from AD. The digestate can be used for several purposes, for example direct land application, direct application to crop, utilize as composting feedstock or to other products [55]. In UK, the application of digestate is regulated by the Quality Protocol and PAS 110 (England & Wales) and the SEPA position statement (Scotland). The Quality Protocol defines the standard for the quality of digestate but are not obliged to comply by producers and users. In this occasion, the digestate will be treated as waste and will be handled by the waste management act. The Publicly Available Specification (PAS 110) stated the requirement for the waste-derived digestate to be considered as fully recovered and can be sold as bio-fertilizer.

Therefore, similar approaches can be adopted by the Malaysia government to ensure the safety use of the digestate, especially in terms of heavy metal, toxic compounds and N runoff to nitrate sensitive areas. It is proposed that policy P7 to be responsible in regulating the utilization of the digester as fertilizer or soil conditioner. This policy also set the standards for the ultimate use of digestate that would not render environmental and human health benefits. In addition, as the digestate is rich in nutrients, there would be a competition with the conventional chemical fertilizer. It is suggested that a regulation body, such as SEDA, can be appointed to regulate and monitor the utilization of digestate, proper disposal, adequate crop and land application, as well as the market pricing as a bio-fertilizer.

Fig. 4 presented the existing policies and proposed policies to facilitate biogas utilization in AD installation.

4. Conclusion

As a conclusion, this paper presented several key policies in the RE development and sustainable SWM which favours biogas installation. Among the proposed actions, such as attract foreign investors, human capital development, collaboration among sectors and more have already been one of the strategic thrust of several plans, such as the National Green Technology Policy 2009 and National Renewable Energy Policy 2010 and Action Plan. However, there would need to be more concrete actions to strengthen the infrastructure of the biogas installation. In addition, waste segregation and collection are critical factors in ensuring a stable supply of feedstock that can be utilized for continuous biogas production. Regulation surrounding the allocation of “waste” as “resources” and pricing of feedstock might be the primary concern for a better progress to increase RE from biogas to the energy mix.

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