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A Systematic Optical Sorting System and Food Waste Valorisation to Renewable Energy in Malaysia

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Food waste (FW) is an omnipresent phenomenon and there is no exception in Malaysia. Statistics compiled by SWCorp Malaysia indicate that Malaysians typically produce 38,000 t/d of municipal solid waste (MSW), in which FW encompasses about 40 % or 15,000 t/d. To make the matter worse, more than 80% of the FW ended up in open landfills with no energy recovery system, posing a serious environmental concern and energy waste. Meanwhile, the Malaysia Government proposed to reduce up to 40 % greenhouse gas emissions intensity of GDP compared to the 2005 level and realise the renewable energy mix to 20 % by 2025. While the Malaysia Government emphasises on solar and hydro powers as renewable energies, unavoidable FW should be recycled and valorised to renewable biogas and other value-added products as far as possible. Although the Malaysia Government has formulated plans to prevent and reduce FW, most of the FW is still yet to be recycled and separated from other MSW at the source. It is important to note that if FW is mixed with other MSW, it will be contaminated and cannot be recycled for beneficial use. Hence, a simple sorting process is essential to motivate the people to separate FW from the other MSW at the source. By considering the current FW management condition and societal needs in Malaysia, as well as taking reference from FW management systems in some cities such as Aarhus in Denmark and Oslo in Norway, a sustainable framework of FW collection via optic bag system and valorising to renewable biogas is proposed. The biogas could be used for generating electricity, heating gas, or upgraded to biogas vehicle fuel. Considering the 15,000 t/d of FW, it is able to supply biogas vehicle fuel to 341,250 cars which reduce CO_2 (well-to-wheel), CO, NO_X, and SO_2 emissions by 2.67×10^6 t/y, 41.4×10^3 t/y, 4.98×10^3 t/y, and 12 t/y, respectively. The CO_2 emissions reduction also accounts to about 1.07 % of total Malaysia's CO_2 emissions in 2018. Through the introduction of the optic bag system and valorisation of FW to renewable biogas, it is hoped that this proposed framework can provide a paradigm shift to the way FW planning carried out at the policy level. This, in turn, can create a more sustainable circularity waste strategy, resource-efficient, and greener economy in Malaysia.

1. Introduction

In 2016, nearly 2×10^9 t of solid waste were produced by world urban cities and are anticipated to rise to 3.4×10^9 t by 2025 (Kaza et al., 2018). Meanwhile, total energy consumption in the world has increased more than two-fold in the last 20 years (IEA, 2017). Of the solid waste requiring disposal, municipal solid waste (MSW) has turned out to be a significant environmental challenge in most urban cities. Among the gargantuan amount of MSW, a significant component is attributed to food waste (FW). Hence, relevant academic research and industrial applications have begun to focus on the valorisation of FW to valuable resources (Jin et al., 2015). With no proper disposal and treatment technologies, FW is considered as a kind of misplaced resource.

In most countries, including Malaysia, FW is generally mixed with other types of MSW and dumped in open landfills. Due to these circumstances, many suburban areas around the major cities in the developing countries have suffered degraded public hygiene, water and air pollution due to open burning, run-off leachates, and landfill fire from the dumpsites. During the FW disposal and treatment processes, three types of greenhouse gas (GHG), namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), as well as other air pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NO_X) are typically emitted. In 2016, the GHG emissions from solid waste treatment and disposal were up to 1.6×10^9 t, with large portion contributed by FW disposal in open

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landfills without landfill gas recovery systems (Kaza et al., 2018). Meanwhile, SO_2 and NO_x are toxic gases and also cause acid rain. Those gases seriously affect the environment and human activity, such as terrestrial acidification and ecotoxicity, and human toxicity. It is an undisputed fact that the use of FW to generate energy can decrease dependency on fossil fuel, rendering a reduction of GHG and other environmental concerns. Nevertheless, in most countries, including Malaysia, FW is not recognised as a valuable commodity and possible alternative fuel.

Due to the current unsustainable practise of FW management in Malaysia, this is of utmost importance to propose a framework which able to encourage the residents to separate FW from source and valorise the FW to different types of value-added resources. In line with the current FW management condition and societal needs in Malaysia, as well as taking reference from FW management systems in some cities such as Aarhus in Denmark and Oslo in Norway, this paper aims to establish a sustainable framework of FW collection via optic bag system and food waste valorisation to renewable biogas. It is hoped that this proposed framework can resolve the FW conundrum not only in Malaysia but also in other countries or regions that are facing the same dilemma in FW management.

1.1 Food waste management scenario in Malaysia

In 2016, Malaysians produced an average of 38,000 t/d of MSW, in which 15,000 t/d was FW (Albakri, 2016). Among the 15,000 t/d of FW, 20 % could be avoidable, and it can feed more than $2×10^6$ people for three meals per day. Lim et al. (2016) found that an average Malaysian household with five people wasted about 225 MYR/mth due to FW. Furthermore, Malaysia is highly dependent on the landfills for FW management, and many of that are open landfills without landfill gas recovery systems. In 2016, there were 170 operational landfills in Malaysia, which only 14 sanitary landfills in operation (The Sun Daily, 2016).

The Malaysia Government is aware of the economic, environmental and health issues caused by solid waste disposal. To effectively manage solid waste, the government has formulated a series of policies and strategic plans since the 2000s. In 2002, the National Strategic Plan for Improvement of the Solid Waste Management System was developed to plan and allocate resources based on national priorities and consensus. Under this plan, solid waste reduction and recovery are expected to be accomplished through a combination of mandatory and voluntary mechanisms (Moh and Manaf, 2017).

A Waste Minimization Master Plan was also executed in 2006 to minimise natural resource consumption and environmental load. Under this plan, “Material Cycle Society” was established to minimise waste through 3R concept (i.e., reuse, reduce and recycle). In 2007, Solid Waste and Public Cleansing Management Act 2007 (Act 672) was formulated and had been enforced since 2011. Act 672 strengthens the solid waste management by compulsorily sorting waste from the source in the areas of jurisdiction and penalising illegal dumping, from MYR 10,000 up to MYR 100,000 fine, or imprisonment of not more than five years (Moh and Manaf, 2017). Besides, two new federal institutions, namely National Solid Waste Management Department (NSWMD) and Solid Waste Management and Public Cleansing Corporation (SWCorp) were formed under Solid Waste Management and Public Cleansing Corporation Act 2007 (Act 673). NSWMD enacts related standards and practices, exercises regulatory functions, and grants licenses and approvals under Act 672, while SWCorp makes recommendations on waste-related laws and implements solid waste management and public cleansing (NSWMD, 2013).

The Malaysia Government has proposed a few national targets, which include enhancing MSW recycling rate to 30 % by 2020, reducing up to 40 % GHG emissions intensity of GDP by 2030 compared to 2005 level, and increasing the renewable energy mix to 20 % by 2025 under National Renewable Energy Policy. To materialise all these national targets, one of the initiatives taken by the Malaysia Government is to promote non-solar renewable energy projects such as biogas generation from sanitary landfill and anaerobic digestion. As such, proper segregation and treatment of different MSW compositions is much needed. Despite the fine amount and imprisonment punishment as gazette in Act 672, the FW segregation and reduction at source are still not successful implemented (Tan, 2018). Due to poor public education, Malaysians have little knowledge about generation, collection, transportation, recovery, treatment and disposal of FW. Also, the lack of enforcement of the relevant laws which are not uniform throughout the states in Malaysia has rendered FW to be discarded inappropriately. Hence, there is a big challenge to achieve all the aforementioned national targets. It is vital to note that a sustainable FW facility must fulfil the requirements of environmental protection with resource recovery and economic affordability. Currently, there are many FW collection and valorisation technologies (e.g., sanitary landfill, high-temperature aerobic composting, FW processor, and livestock feed conversion) being adopted in developed countries. Therefore, it is of utmost importance for the Malaysia Government to devise a simple yet effective FW separation and valorisation framework in accordance with the current FW management system in Malaysia and adoption of practical FW management solutions from other countries. It is interesting to note that this study also coincides with the United Nations Sustainable Development Goal 12 (SDG 12), which is to ensure sustainable consumption and production patterns. Many countries around the world, including

Malaysia, are facing acute challenges in handling solid waste and turning solid waste as a valuable commodity. It is important to note that SDG 12 has been captured as one of the significant criteria under the environmental sustainability section of the upcoming Twelfth Malaysia Plan (2021-2025).

2. Effective food waste separation and collection system

2.1 Introduction of optic bag system to separate and collect food waste at source

Parizeau et al. (2015) stated that FW production is highly related to resident awareness and convenience lifestyle. In urban cities, people opined that they did not have time or energy to sort, and tend to opt for a simple FW collection system with less behavioural change. In this proposed framework, the FW is separated with a designated green optic bag, while the other residual wastes are packed in other plastic bags. The FW should be well-sealed in green optic bags to prevent notorious odours and insect problems. For landed households, all packed wastes are discarded in the existing containers (i.e., plastic HDPE with 120 L for residential area, 240 L for shops, offices, and commercial premises) as prepared by the licensed waste collection companies such as Alam Flora Sdn Bhd.

Refuse trucks can then be sent to conduct kerbside collection twice weekly as being currently implemented in areas such as Kuala Lumpur, Putrajaya, and Pahang. Hence, the introduction of green optic bags does not alter the current waste collection system and incur any retrofitting cost. For high-rise apartments, the residents can discard the packed FW and packed residual waste via the refuse chute and collected by the refuse trucks according to the agreed schedule. In other words, only one kerbside bin or refuse chute is used for all waste categories and no need to replace with a new bin or refuse chute. Besides, all existing refuse trucks can be retained and not replaced. Due to this circumstance, this remains the business-as-usual scenario for most sanitation workers in waste collection companies. No training is required and it provides lower operational cost to the waste collection companies. Besides, as it is unnecessary to prepare several different waste containers for various MSW categories, the use of optic bag collection system saves space in urban areas which always crowded with more blocks of flats. Table 1 shows a summary of the countries that implemented waste collection with different coloured bags.

Table 1: Summary of countries/regions that implemented different coloured bags

Country	City/Region	Explanation	Source
Sweden	Eskilstuna	Household waste is collected in six differently coloured bags. Organic waste is packed with green bags, plastic packages with orange bags, paper packages with yellow bags, metal packages with grey bags, newspapers with blue bags, and burnable waste with white bags that generally obtained from the supermarket.	Guziana et al., 2011
Sweden	Linköping	Two coloured bags are applied in this city (green for FW and others for combustible waste). The optical sorting plant in Linköping sorts two fractions and is run by Tekniska verken AB.	Optibag, 2018
Sweden	Borås	Food waste and flammable waste are packed in black bags and white bags, respectively. The black and white bags are collected together in a shared container and delivered to an optical sorting plant for mechanical separation.	Rousta et al., 2015
Norway	Tromsø	This region consists of an underground vacuum transporting system combined with an optical sorting system. Household wastes are separated using five different coloured bags (green for FW, red for newspapers, orange for paper, blue for plastic, and others for combustible waste).	Optibag, 2018
Norway	Oslo	FW is collected in a green bag, plastic in a blue bag, and combustible waste in other bags. All bags are kept under the same bin and transported to sorting plants owned by Energy Recycling Administration using the same waste trucks.	Optibag, 2018
Denmark	Aarhus	FW is packed in a green bag while other residual waste is packed in a black bag. All the wastes are sorted in an optical sorting plant located at the incineration plant Århus Nord in Lisbjerg.	Tønning, 2003

Sörme et al. (2019) conducted a pilot test by introducing different coloured waste bags in an old city centre in Kalmar, Sweden. This pilot test involved a kerbside collection which was applied to 38 households with a total of 87 residents for four weeks. Results showed a 15 % decrease in residual waste and 35 % increase in the collected amount of FW. Hence, the Malaysia Government can start to implement the optical sorting process in a small neighbourhood and check the willingness of acceptance by the residents. The geographical boundary of implementation can then be expanded if the sorting efficiency is satisfactory. In addition, the cost of green optic bags (about 0.1 SEK/bag or 0.05 MYR/bag based on a Swedish case) can be borne by the consumers to promote extended producer responsibility. Rousta et al. (2015) concluded that visible and easily understood information, which is seen every day and at the time of sorting, improves a convenient source separation system. Therefore, it is recommended that the Malaysia Government should conduct more awareness program to promote proper FW separation at source using the green optic bag throughout its execution.

2.2 Food waste separation from other residual waste at an optical sorting plant

After collecting all the packed wastes in bulk using the refuse trucks, the collected wastes are transported to an optical sorting plant. At the optical sorting plant, all the packed waste bags are channelled to the central conveyor belt and passed through an optical unit. At the optical unit, an infra-red camera system is adopted to detect the colour of the waste bag. Once a green optic bag is identified, a signal is sent from the system to push the green optic bag from the central conveyor belt to a secondary conveyor belt. The green optic bag can then be separated and collected at a designated container for further treatment. Meanwhile, the other separated packed waste bags can be transferred to existing sanitary landfills for disposal or advanced incineration process for heat and electricity generation. Many different forms and configurations of an optical sorting plant can be constructed to fulfil specific requirements. Table 2 indicates a summary of optical sorting plant configurations. They can be built to facilitate future expansion in line with the increased MSW capacity. The separation efficiency of FW from other MSW can be reached to 98 % (Optibag, 2018). Based on the proposed framework, a two-fraction optical sorting plant to separate food waste and other residual waste can be constructed in Malaysia. The capacity and line configuration of the proposed optical sorting plant depends on the waste treatment capacity and land area provision. The capital cost of an optical sorting plant with an annual treatment capacity of 30,000 t for the sorting of two fractions is about MYR 1.4×10^7 (Optibag, 2018).

Table 2: Summary of optical sorting plant configuration (Optibag, 2018)

Separation Line[1]	Waste Fraction[2]	Capacity (t/h)	Yearly treatment capacity (t/h)	Building surface (m^2)
One	Seven	9	18,000-36,000	1,000
Two	Four	18	36,000-72,000	1,000-1,500
Three	Seven	27	54,000-108,000	1,500-3,000

[1]Number of separation line depends on the MSW treatment capacity and building surface.

[2]Number of waste fraction depends on the number of waste type to be separated.

3. Food waste valorisation to value-added resources

3.1 Renewable biogas generation from anaerobic digestion facility

The separated FW in the optical sorting plant is then stored in closed collection containers which are transported to an FW treatment facility. In the FW treatment facility, the green optic bags are conveyed to a bag opener which opens the bags. The packed FW is then pressed, and the green optic bag is dragged in a long strip. After that, the FW and the optic bag can be sent to a screener for separation. Conventionally, the collected FW can be sent to a composting plant to produce organic fertiliser (Sabki et al., 2019). Some recent studies also highlighted that FW could be turned into Polyhydroxyalkanoates (Valentino et al., 2019) and zeolites (Ong et al., 2018). Nevertheless, treatment technologies of these recent studies are yet to be commercially applied.

As mentioned in Section 1.1, the current solid waste management practices in Malaysia is unsustainable as most waste disposal companies are opting for cheaper disposal technology by dumping FW in open landfills without landfill gas recovery systems. This, in turn, generates a massive amount of GHGs to the atmosphere. Also, it is not suitable to treat FW via incineration due to high moisture content. Therefore, turning FW into renewable biogas is of highly feasible to provide sustainable energy and help Malaysia Government to achieve GHG emissions target. Therefore, it is recommended to deliver the FW to an anaerobic digestion plant, in which the biogas production from the plant can be used for heat and electricity generation.

Anaerobic digestion process has been widely applied in few countries/regions such as Sweden (Brunklaus et al., 2018), Belgium (Vandermeersch et al., 2014), Australia (Edwards et al., 2018), Singapore (Tong et al., 2018), and Hong Kong (Woon et al. 2016). While the biogas can be used for heat and electricity generation, the biogas can be further upgraded by water scrubbing, pressure swing adsorption and polyethene glycol scrubbing to remove CO_2, H_2S, NH_3, and water. The upgraded biogas can then be used as biogas vehicle fuel. According to IRENA (2018), the production cost of biogas from AD is about 0.51-2.21 MYR/m^3, biogas upgrading cost is about 0.68-10.6 MYR/m^3, and biogas compression cost for vehicle use is about 1.19-6.93 MYR/m^3. Figure 1 shows the proposed framework of FW collection and recycling for FW valorisation in Malaysia. Hafeez (2013) found that the biogas generated from one kg of FW is equivalent to 0.13 L of petrol. Taking a 1.5-litre Honda City (an average-sized car in Malaysia) as an example, the average petrol consumption of this type of car is 17.5 km/L (Tan and Timbuong, 2018). In other words, one kg of FW allows Honda City car to travel 2.275 km. Given the 15,000 t/d of FW and assuming that the vehicle is travelled 100 km/d, approximately 341,250 cars could be supplied via biogas generated from FW. This is equivalent to about 2.57 % of total cars in Malaysia (there are 13.3 M cars in Malaysia as of June 2017). Using the average exhaust emissions for passenger car fleet as reported by Lo and Woon (2016), fuel switching from petrol to biogas fuel in the 341,250 cars reduces CO_2 (well-to-wheel), CO, NO_X, and SO_2 emissions by 2.67×10^6 t/y, 41.4×10^3 t/y, 4.98×10^3 t/y, and 12 t/y, respectively. Considering Malaysia's CO_2 emissions amounted to 250.3×10^6 t in 2018, this CO_2 emissions reduction accounts to about 1.07 % of total Malaysia's CO_2 emissions of that particular year. Hence, the fuel-switching of petrol to biogas fuel for road vehicle use can help to alleviate CO_2 emissions and to a certain extent, help the Malaysia Government to achieve the GHG emissions target.

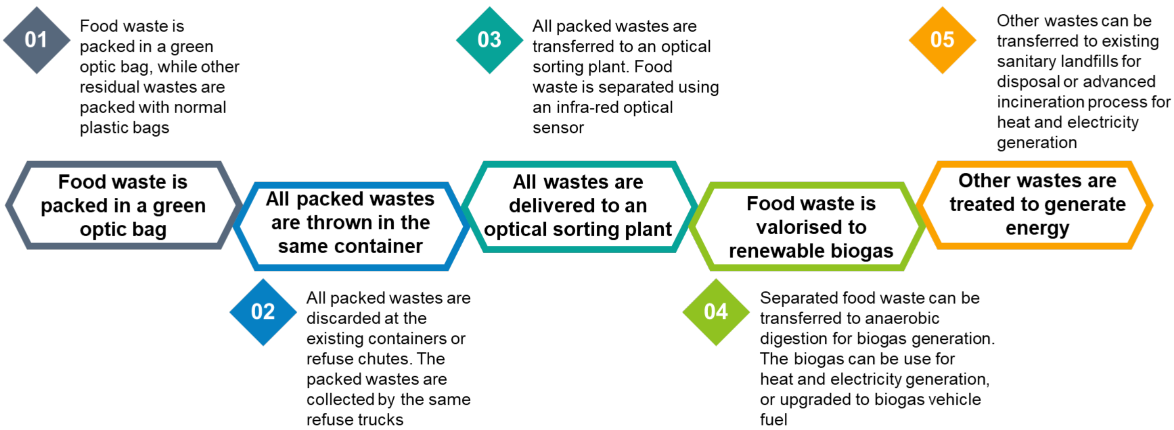

Figure 1: Proposed framework of FW collection and recycling for FW valorisation in Malaysia

4. Conclusions

The heterogeneous FW in urban cities presents an uphill challenge for policymakers to decide a sustainable FW management policy framework based on the local environmental condition and societal needs. When sorting becomes a part of everyday life, people tend to accept a simple waste sorting system with less behavioural change. The proposed optic bag system does not alter much of the current waste disposal behaviour of the people, as well as does not modify the current waste collection system and hence not to incur any retrofitting cost. The collected FW can then be separated in an optical sorting plant and delivered to the anaerobic digestion facility for further treatment. As such, FW can be valorised to renewable biogas such as heat, electricity, cooking gas, and even upgraded to biogas vehicle fuel. This, in turn, creates a green and resource-efficient economy and improve the well-being of the society, ensuring a higher quality of life for all segments of the Malaysian society. While the proposed framework is locally relevant to Malaysia, it is essential to note that the framework can be applied to other countries or regions. Hence, this proposed framework can also be beneficial for countries or regions facing a conundrum of accomplishing sustainable use of FW, resource recovery, and alleviation of environmental degradation.

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