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Green Energy Potential from the Organic Fraction of Municipal Solid Waste in Malaysia

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ABSTRACT

Global waste generation keeps increasing over the year and requires innovative solutions to minimize their impacts on environmental quality and public health. Predicted 2.2 billion tonnes per year of global municipal waste generation in the year 2025 which 1.6 fold is higher than in 2012. Hence, a strategic plan must be ascertained to overcome the future challenges of MSW locally and globally. Universiti Putra Malaysia (UPM) coined an initiative to demonstrate a showcase pilot plant for green energy production from MSW. Therefore, the data was obtained from the survey and actual sampling within the UPM compound to estimate the MSW generated and it's potentially used for green energy production. It is estimated that 5.0 – 7.0 tonne per day of MSW generated which about 30 - 35% is an organic fraction. Upon separation, the organic fractions were digested into biogas through anaerobic. At the maximum conversion of organic fraction, about 775 kWh of electricity may able to generate from the waste. In this study, the complete biorefinery setup and utilize organic components from the MSW generated in UPM was proposed that the biogas subsequently will be used to produce green energy in the form of electricity or flammable fuels.

Keywords: Anaerobic digestion, green energy, municipal solid waste, organic waste, biogas

1. Introduction

Municipal Solid Waste (MSW) is a solid waste other than effluent or emission. It is regarded as an inevitable and valueless by-product due to community activities. The MSW is one of the main waste source streams beside commercial and industrial waste and construction waste. The MSW generally comprises of food waste, plastics, paper, glass, metal, landscape waste etc [1]. The food waste is the major proportion of household waste. The food waste needs to reduce the food waste by half as stated in the United Nations sustainability goal SDG 12.3 [2]. The accumulation of food waste in MSW has created another burden to the society and urban setting [3]. The composition and amount of MSW generated are varied from place to place and country to country due to geographical regions, living standard, urbanisation, the degree of industrialisation, socio-economic grouping, and public habits [4, 5]. World bank predicted 2.2 billion tonnes per year of global municipal waste generation in the year 2025 from 1.3 billion tonnes in 2012 [6]. Malaysia is one of the Asian countries that has recorded remarkable economic development consistently. Malaysia's is about $10, 570 per capita with a population of about 30 million in 2016 [5]. As a developing country, Malaysia is experiencing an increase of urban population growth that leads to the development, rapid urbanisation and industrialisation and finally contributes to the increment of MSW generation [7]. In 2007 approximately 18000 tons of household waste was generated in Malaysia and the amount doubled in 2012 about 1.00 to 1.33 kg/capita/day on average respectively. The number expected to increase by 49,670 tonnes per day in the year 2020 [8].

Education institutions are expected to drive an effort towards efficient waste management for the sustainability of the environment. Waste management is one of society's main issues that must be discussed in universities in the form of research, teaching and outreach activities [9]. In Malaysia, a few public and private universities were conducting on solid waste management and producing a final report as an output. However, the data obtained from these researches still in the lab studies [10-12]. The lack of comprehensive collaboration, on-site experience and understanding, networking between the government agencies and universities are one of the barriers suppress the cradle-to-cradle strategies [13]. Filling a gap of the MSW management is crucial to foresee the potential solution may be provided by the university in the specific scope and its capability [9].

Anaerobic digestion (AD) is likely to be one of the most promising technologies for converting organic waste into bioenergy, such as methane-rich biogas and fertilizer products [14, 15]. AD is a complex biochemical process where combinations of chemical and physicochemical reactions occur in series, involving different microbial species that potentially treat organic waste, and also may produce renewable energy [6, 16]. The energy generated considers as green energy since it produced from renewable sources that are less harmful to

the environment than fossil fuels [17]. The biogas (CH_4) is a feed-stock for electricity generation and could be used as flammable fuel for cooking and heating purposes [18]. Capturing and utilizing methane are important to contribute to CH_4 emissions reduction and to be used as a renewable energy source [19].

Universiti Putra Malaysia (UPM) one of the leading research universities in Malaysia has committed to carter the issues of environment and sustainability as well as to support the Malaysia National Renewable Energy Policy and Action Plan. Therefore, the appropriate setting of waste management is tremendously important for the best practices in MSW management for green energy production. Thus, the scope of this study is to evaluate the current generation, composition and management of MSW in Universiti Putra Malaysia as a showcase for the reference and finally to propose improved utilization options of the organic waste for the waste-to-wealth projects in Malaysia.

2. Materials and methods

2.1 . Field survey activity

The survey was involved in three major groups; (1) residential and colleges, (2) administrative offices and (3) restaurant premises. The administrative offices including department offices, faculty offices and centres in UPM compound (Table S1). The student staying at colleges and staff staying at quarters were the main respondent from the residential and colleges group. The main organic contributors were predicted from the restaurant and cafeteria inside the campus. All the data obtained were evaluated and quantified to represent the statistical acceptance for the assessment.

The study of MSW generation in UPM campus consisted of three main stages: (1) estimation of the MSW generation via questionnaire and interview, (2) organic waste sampling and quantification and (3) analysis of the chemical composition of the organic fractions.

2.2. Questionnaires

A different set of questions were prepared and disseminate via face-to-face interview or an online survey to the targeted respondent. The questionnaires consisted of 3 parts; general info, waste management and awareness programme. The questions mainly on the MSW composition and management, on-going awareness program, future plan and budget allocation were asked. On the other hand, the question to the restaurant

representative mainly focuses on the operation handling and amount of organic fraction generated from their premises. All the question was validated by independent experts from a different background (refer to the acknowledgement section).

2.3. Statistical analysis of the questionnaires

IBM SPSS Statistics software was used to validate the survey question by conducting a reliability test to obtain α-value. This α-value will determine whether the question will produce a stable and consistent answer. This is to avoid the respondent from giving a random answer. Referring to Krejcie and Morgan [20], the sample size for survey distribution should be between 377-379 since UPM populations are between 20,000-30,000.

2.4. Sampling activities of waste generation from the restaurant

Sampling was carried out within the UPM compound. The sampling activities consist of two different periods, a first the sampling was conducted during normal semester running with full student capacity (October – February) and the second stage during the fasting month. Eleven and five restaurants were chosen for MSW generation sampling at the first and second stage, respectively. During the fasting month, most of the restaurants were closed in the daytime and the operating hour begins from 4.00 pm until midnight. The sampling was done for 5 consecutive days for each restaurant. The waste generated daily was recorded, and characterization was done based on the organic and inorganic fractions.

2.5. Physical and chemical analysis of organic MSW

The organic fraction was characterized based on its physical properties, total solid, volatile solid, ash and moisture content [21]. Whereas, the chemical oxygen demand (COD), biological oxygen demand (BOD), total Kjeldahl nitrogen (TKN) and heavy metals were measured using standard methods APHA [22]. All the analysis was done triplicate from independent samples to represent average data.

2.6. Biogas production potential

The number of organic wastes generated from the restaurants was used as an indicator to evaluate biogas generation through anaerobic digestion. The COD and total organic amount were measured and quantify the potential methane and green energy generation based on stoichiometry [18].

3. Result and Discussion

3.1. Solid waste management in UPM

UPM is a world-renowned centre of learning and one of the leading research universities in Malaysia. The main campus is located in Serdang, Selangor next to Malaysia's administrative capital city, Putrajaya. In 2018, UPM has ranked at 202 of world university ranking and 34 of Asian University Rankings by Quacquarelli Symonds (QS) World University Rankings 2018/2019 [23]. In general, UPM's consist of 19000 students and about 2274 academies staff and another 1000 are the supporting staff made up to 23000 people at one time [23]. Due to the huge population in the campus, UPM predicted to receive a tonnage amount of MSW generated daily from the students and staffs through their administrative activities and daily life [9]. The tonnage generation of MSW has caused the management to spend over USD 480 000 a year on waste management. About 50-55% of the allocation was used to pay the contractor and local municipalities and the rest of the allocation was used for public and street cleansing. The actual waste management cost in UPM might be higher than the stated budget since the other waste such as hazardous and clinical waste generated from laboratories and medical centres were handled separately by Occupational Safety and Health Management Office UPM.

The MSW generated in UPM is collected daily (six days a week) by a specific contractor appointed by University through the division name Development Office and Asset Management, UPM (PPPA UPM). The MSW was transported to the landfills at Tanjung 12, Putrajaya for final disposal twice a day. Landscaping and street cleansing waste were collected separately from the MSW by another private company for disposal at Dengkil inert landfills. To date, no data on solid waste generated within the UPM campus had been reported. The estimation of daily generation was carried out based on the weight of MSW generated in UPM and collected by the private company. Table 1 shows a total amount of MSW collected monthly by the contractor from May – December 2018. The lower amount observed during semester break compared to the normal semester, June – September 2018 and October to December 2018, respectively. Maximum MSW collected on December (240 tonnes) and lowes from June (118 tonnes). In average about 170 - 230 tone of MSW generated in UPM campus monthly and around 5.5 – 7.5 tonne daily.

Table 1: Municipal solid waste collected by a private company in UPM compound from May to December 2018.

Month	Weight (tonne)	Description
May	125.65	Fasting month
June	118.79	Semester break
July	190.41	Semester break
August	NA	
September	123.49	Semester break
October	230.34	Normal semester
November	222.06	Normal semester
December	240.80	Normal semester

NA: data not provided due to a technical problem in the field

3.2. Waste generation from administrative offices

Waste management in the administrative offices basically self-management, whereas MSW disposal and collection in the offices compound were done by the staff member except for sweeping and cleaning. From the survey data, most of the offices do not have their specific information on the budget for MSW management and choose to not answer the question that represents 39% of respondents (Table 2). However, a certain office which dealing with e-waste, chemical and clinical waste such as medical, veterinary and a few other faculties have spent between USD 1200 – USD 2400 and up to USD 4800 a month which represent 23% of the respondent, respectively (Table 2). Some of the offices such as engineering faculty, the budget allocation quite high due to a huge population and bigger land area for cleaning and maintenance that allocated more than USD 7200 per month.

Table 2: Survey data on the estimated budget allocation by the offices for municipal solid waste management.

Description	Budget allocated (USD/month)	Respondent (%)
The overall internal budget allocated by the offices for municipal solid waste management includes:	0*	39
	0	4
- Cleaning services	Less than 1200	4
- E-waste disposal	1200 – 2400	23
- Chemical and clinical waste disposal	2400 – 4800	23
- Other maintenance regarding waste management	4800 – 7200	4
	More than 7200	4

*Some of the respondents did not answer the question since they do not have information on the budget allocation

In general, MSW was disposed in bulk collection bins and collected by a contractor appointed by PPPA UPM. The MSW generation and composition from an administrative office based on the survey were depicted in figure 1a. Most of the offices producing MSW between 70 – 200 kg a week (65%). Amount of waste produced corresponds to their population size for instance Faculty of Engineering and Library cater up to 5000 student/staff/public per day which gave between 751-1000 kg of waste per week. Another office entity reported less than 100 kg/week as the office consist of less than 15 permanent staffs at one time and not directly dealing with student and staff as a daily basis. One of the offices in UPM name as Equine unit was producing horse manure (animal waste) which being disposed internally to oil palm plantation in UPM. Thus, the amount of MSW generated from the administrative office depend on their routine activities and the size of the population (staff and student) of the specific office compound. On the other hand, various types of waste generated from the office (Figure 1b). Papers, plastics (packaging and pet bottles) and kitchen waste are the dominant compositions present in the MSW generated followed by the e-waste and tetra pak. Kitchen waste generated mainly from their staffs and some of the faculties have their own pantries and restaurants placed within the

building. Most of the recyclable papers and plastics were collected by a cleaner and sold to the third parties as their side income. However, it is hard to obtain the actual amount of the specific waste generated in the office due to lack of inventory and monitoring by the officer in charge. In term of awareness, most of the offices are supporting waste separation at source but the level of implementation is dependent on each office administration.

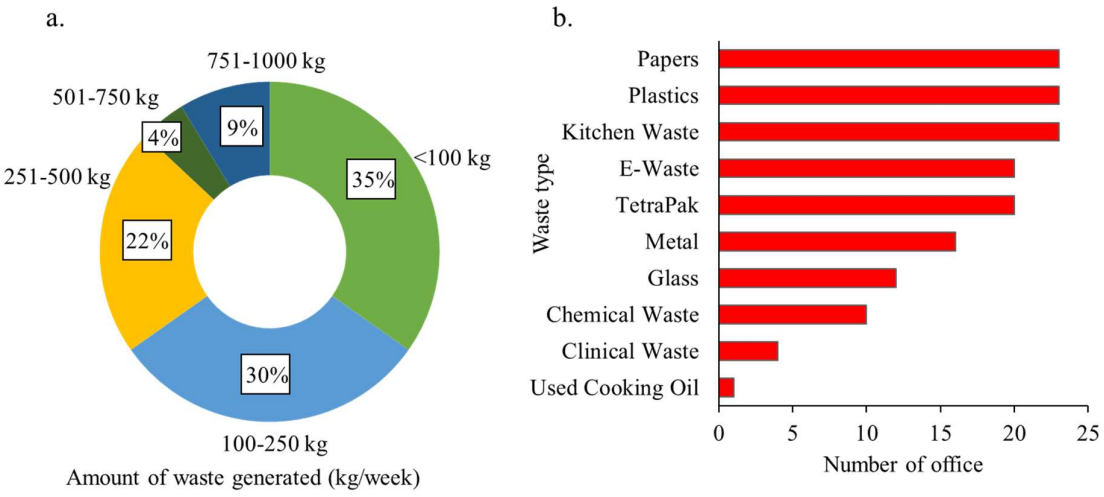

Figure 1: Estimated amount and municipal solid waste (MSW) composition obtained from Administrative offices in UPM over the week. a) Estimated weight range of MSW generated (kg/week) and percentage (%). b) The composition of waste present in the MSW from the administrative offices.

3.3. Waste generation from Residentials

UPM Serdang consists of 17 residential colleges that may accommodate more than 5000 students at one time. Some of the colleges, the MSW management were handled by UPM and a few of them were handled by a private entity. A group of 600 respondents answered the survey via interview and online form (Figure 2a). In the residential college, the students disposed their waste into small bins in front of their room and collected daily by cleaners before dumped into curbside bin prepared by a contractor. Based on the result, less than 2 kg and 2 – 3 kg of waste generated per student in a week that represents 45.2% and 21.1 % of the respondent, respectively. The other answers are scattered differently since they just estimated the amount of waste without any proper

measurement. In term of composition, food waste, plastic and paper were the main compositions in the MSW generated from residential college (less than 1 kg/week for each component). Glass is the lowest which 20% respondent answered producing 0.1-1.0 kg/week (Figure 2b). It is indicated, most of the MSW from residential college consists of food waste, plastic and paper only. Then, most of the paper will be collected for recycling purpose. However, from house residential, 28% of respondents produced within 9-10 kg a week and 18 % of the respondents generate 7-8 kg a week (Fig. 2c). The data showed that a group of the family consist of around 3-5 people per house generate more waste compared to the student residential suggested due to the cooking activities occur in the living house but not in the residential college. It is supported that an additional component of used cooking oil was observed from the house residentials.

Most of the respondents answer that food waste one of the dominant components in their MSW but in term of the amount, house residential generate more food waste as they may produce kitchen refuse rather than just left-over waste. The other components were tetra pak, metal and glass (Figure 2d). As similar practice from the offices, a recyclables paper was collected by cleaner and sold to third parties. It shows that the composition of waste from college and house residential were the same except for the amount generated was higher from house mainly inorganic fractions (Fig. 2). As stated earlier, it was due to cooking activities and number of family member per house.

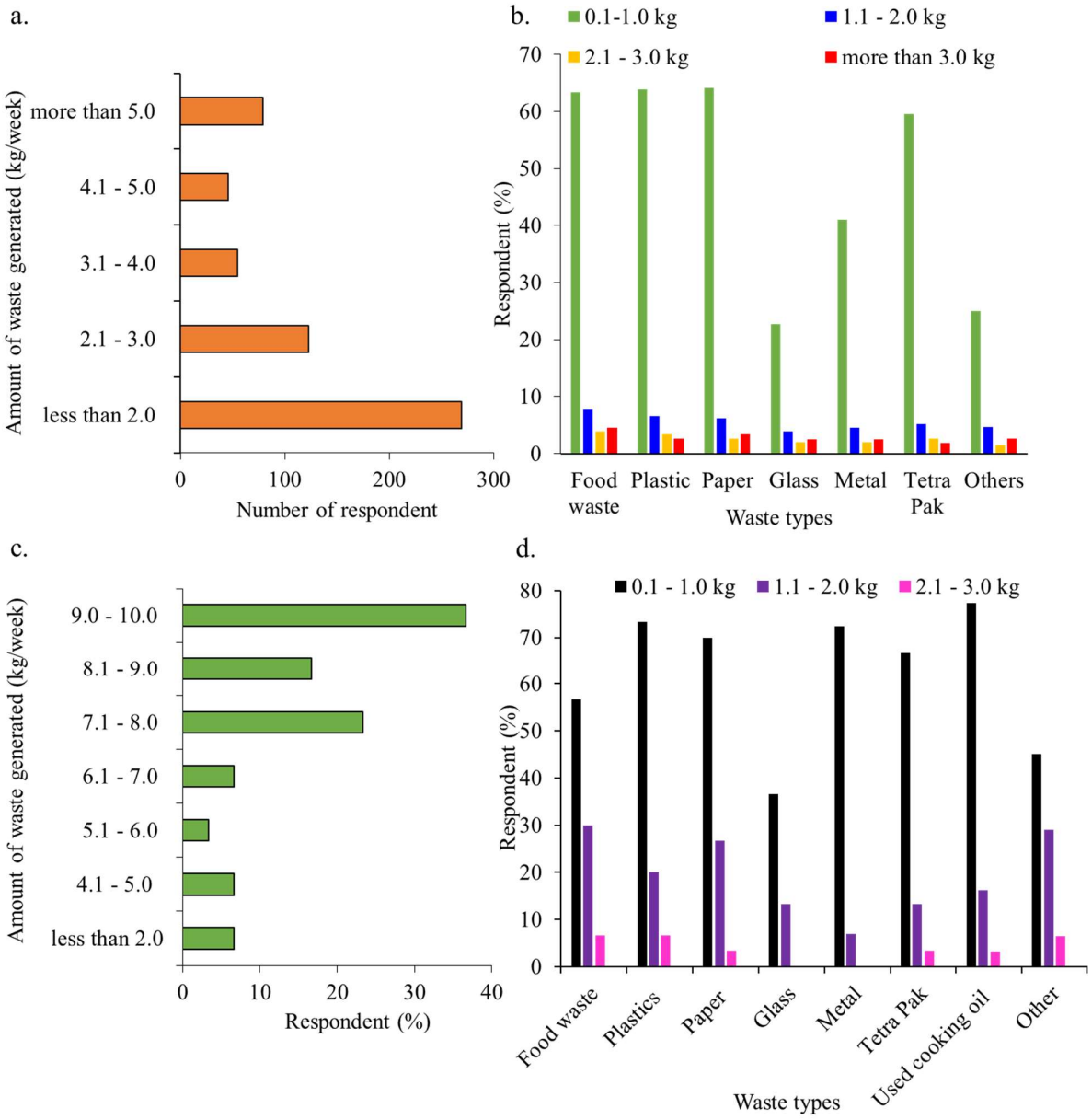

Figure 2: Amount of municipal solid waste and specific waste generated from residential college and house in UPM over the week. a) The total amount of waste generated from the residential college per week. b) The range amount of different types of waste generated from residential college. c) The total amount of waste generated from the residential house. b) The range amount of different types of waste generated from a residential house.

3.4. A survey from restaurant and cafeteria

According to the survey, most of the restaurant just discarded their refuse into the curbside bin twice a day which were before lunchtime and before the closing time around midnight. Hard to find the restaurant practising waste segregation at the source due to awareness and no regulation implemented by the University management. However, they are willing to participate in segregation at the source if the facilities are in place and if they are requested to do so. For the composition, MSW generated in this premise was about 10 – 15 kg/day that symbolizes from 45% respondent followed by 5 – 10 kg/day (27% respondent). About 18% respondent generate 15 – 20 kg/day (Figure 3a). Nevertheless, the amount quite discordant that depends on their customer. The restaurant that generates plenty amount of kitchen waste usually from the stall that offers a buffet menu rather than the à la carte menu. The amount from the meals prepared and left-over meals from the buffet menu.

The MSW generated from the restaurant premise mainly consist of food waste, plastics and used cooking oil (Figure 3b). The food waste and plastic were contributed by kitchen refuse and left-over food and plastic mainly from packaging materials, respectively. The used cooking oil generated from the kitchen and usually collected by third parties for further process. The other waste was metal and tetra pak from canned food and drinks, respectively. Some of the recyclable's materials such as boxes, pet and cans were collected by operators and sold to the third parties for their side income. The organic fraction is the main composition from the restaurant activities including preparation and left-over food waste. It shows a good indicator for the source of raw material to be used in anaerobic digestion.

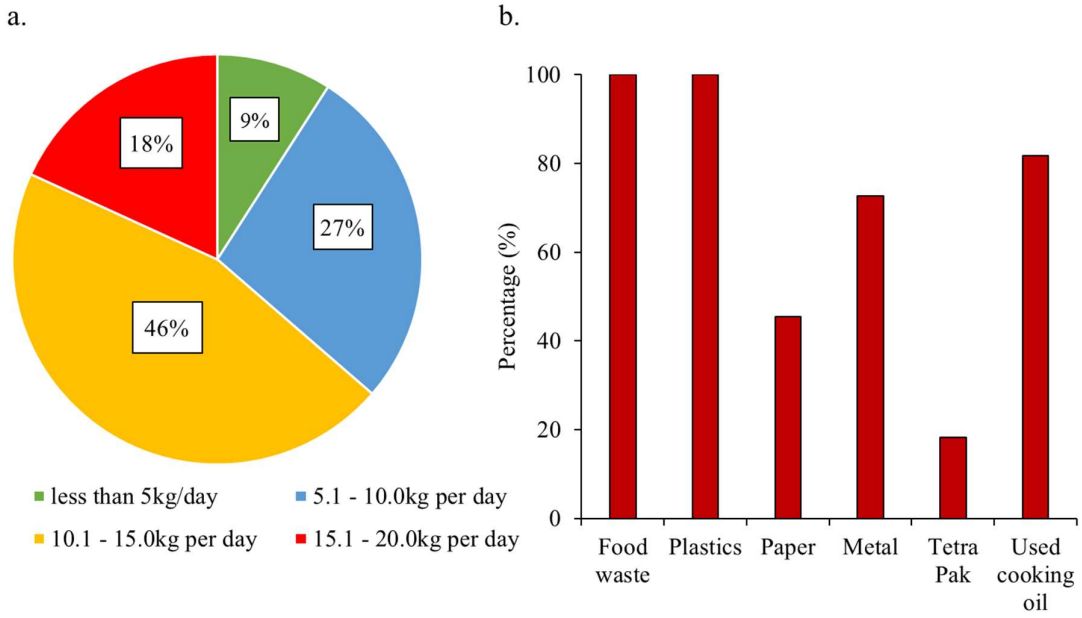

Figure 3: Estimated amount and types of municipal solid waste (MSW) generated from selected restaurant premises in UPM. a) Estimated weight range of the MSW generated in the restaurants (kg/week). b) The percentage composition of specific waste posed in the MSW.

3.5. Amount of organic and inorganic waste generated from the restaurant

The restaurants were grouped in three different categories, group 1 is the restaurant that only offers buffet menu, group 2 is the restaurant that offers only à la carte menu than the restaurants that offer both menus name as group 3. The categories were formed to understand their relationship between the nature of business and waste generation. The demerit factor was seen from group 2 whereas the amount of waste really depends on the walk-in customer (Figure 4a). If the less customer, it will devote the less amount of waste generated on the day. In contrast, a large amount of MSW obtained from group 1 on average, as they need to prepare a variety of meals daily regardless of the number of customers. In general, the total amount of MSW generated from the restaurant was around 18 – 23 kg/day/premise, higher than the data obtained from the interview (5 – 10kg/day/premise) (Fig.3a and Fig. 4a), respectively. The main component of the MSW generated is the organic waste represents 80-85% from the total amount. The other 15-20% is the miscellaneous items such as straw, plastic and paper packaging, canes and glass bottles.

On the other hand, the data obtained during fasting month delivered a different situation. About half of the waste generation reduced during the period compared to the normal period (Figure 4b). The amount of waste

reduced due to many students buy their meals from an independent stall in a market rather than from a restaurant inside UPM. Provided, the restaurant only opens from late afternoon until midnight. Thus, operation time and fasting period become a bottleneck for the waste generation during fasting month in UPM. The data from this period is important to estimate a minimum organic waste available in the campus even during normal semester running. It is a necessity to know for the further application of organic waste. It may indicate less substrate available for the anaerobic digestion for the green energy production.

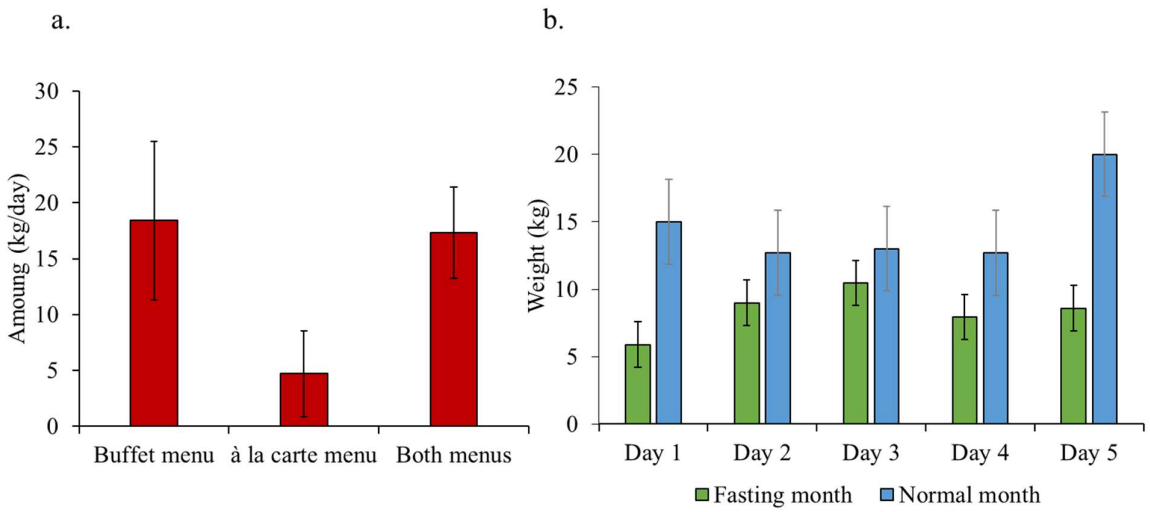

Figure 4: Amount of municipal solid waste generated from premises. a) The average amount of MSW from three different categories of the restaurant. b) A comparison of the MSW generated between fasting month and normal month.

In addition, during the fasting month, it was estimated about 40 - 60% reduction of each MSW component compared to the normal period (table 3). In average, total MSW generated about 21.7 kg/d/premise against 11.5 kg/d/premise during the fasting month, respectively. From the organic fraction obtained, about 80% of the MSW was an organic fraction and the other 20% were other components (Table 3). This data gave a very good insight into the utilization of organic fraction for the other value-added products. Whereas, most of the organic factions come from kitchen preparation and left-over food. Thus, the detail composition was further analysis for its physical and chemicals properties.

Table 3: Average MSW generated from the restaurant based on the random sampling from the different restaurant during normal semester running compared to MSW generated from the same restaurant in the fasting month.

Day	Types of waste									
	Organic		Plastic		Paper		Metal		Others	
	Normal	Fasting	Normal	Fasting	Normal	Fasting	Normal	Fasting	Normal	Fasting
1	19.0	7.0	3.5	2.3	1.4	0.8	0.12	0.1	0.23	0.3
2	14.7	5.9	2.4	1.7	0.7	1.3	0.17	0.1	0.1	0.5
3	15.4	9.0	2.3	2.3	1.0	1.1	0.10	0.1	0.14	0.13
4	14.4	11.2	2.7	1.7	0.9	0.4	0.12	0.2	0.23	0.24
5	22.4	8.6	4.1	1.54	1.2	0.8	0.24	0.1	0.5	0.3
Average	17.2 ± 3.3	8.34 ±2.0	3.0 ± 0.8	1.9 ± 0.4	1.04 ± 0.3	0.9 ± 0.36	0.15 ± 0.06	0.12 ± 0.04	0.24 ± 0.16	0.3 ± 0.13

Normal – Normal semester running with a full student capacity
Fasting – An organic waste generated from the restaurant during fasting month (once a year)

3.6. Physical and chemical analysis of the MSW generated

The physical and chemical properties of the organic fraction are important to evaluate the quality and the potential of the material to be used as raw material for further application. The food waste generally consists of carbon that can be an important precursor for bioenergy production and composed a wide economy prospect in industries [24]. Malaysia one of the countries that blessed with the multi-racial community that given a variety of food as an option. According to a report, 45% of the MSW generated in Malaysia is a food waste [1]. Which could give a good indicator to be utilized as a feedstock for bioenergy such as biomethane [16], biohydrogen [25, 26] and bioethanol [24]. The details characteristic of the organic fraction generated in MSW from the restaurant demonstrated in table 4. The moisture content between 50-70% with total solid and volatile solid in a range of 30-50% and 20 – 35%, respectively. Malaysia's climate that has heavy rain will tremendously influence the moisture content. Usually, the curbside bin and garbage bin are exposed to the open sky without any lid. On the other hand, the most important criteria were obtained from chemical oxygen demand (COD) and total nitrogen (TKN). Indirectly COD and TKN exhibit the potential component to be utilized by microorganism especially in the application of anaerobic digestion [27, 28]. The higher amount of COD predicting potential biodegradable component posed in the organic fraction.

Table 4: Chemical and physical characteristic of organic waste obtained from the restaurant in UPM

Parameter	This study	Reference	
Moisture Content	50% -70%	70%	[29]
Total Solid	30% - 50%	17%	[30]
Volatile Solid	20% - 35%	16%	[30]
Ash	3% - 8%	13%	[29]
Chemical oxygen demand (COD)	200-600 g/L	190 - 346 g/L	[24]
Total Kjeldahl nitrogen (TKN)	100-300 mg/L	505 mg/L	[22]

Table 5 shows the summary of MSW generation from a different waste generator in UPM compound. Highest MSW generation was obtained from the administrative office followed by restaurant premise. However, the highest organic fraction (80%) was obtained from a restaurant (850 – 960 kg/day). Less amount of organic fraction observed from administrative office (10%), residential house and college (40% and 20%), respectively. The office mainly generates inorganic fraction such as paper. In college, the students are not allowed to have cooking activities, hence, the organic fraction was only from the left-over food. Meanwhile, it is understood that the main cooking activities happened only during the weekend in a residential house. The rest of the days just a left-over food and simple cooking activities that contribute to the huge number of organic fractions. This important data that shift our understanding of organic source for anaerobic digestion. The main organic source should obtain from cooking activities rather than left-over food. Another important issue is related to awareness practice. The organic waste obtained from restaurant still contaminated with 20% inorganic such as straw, small plastic packaging, labelling etc. Thus, post-segregation is essential prior to be used as raw material for anaerobic digestion. These two criteria are crucial in our study and it could be a reference for the scale-up activities. The source of the raw material should be precisely identified and evaluated on its consistent supply and accessibility. Based on our survey, sometimes the organic waste is available but very fluctuate in-term of amount and composition. The logistic also one of the barriers to scale-up activities. The full cooperation between the restaurant owner and waste manager is a key factor to see the smooth activities for the utilization of MSW for green energy production.

Table 5: Estimated amount of organic waste generated from a different waste generator in UPM compound during this study

Group	Waste generation (kg/ day/premise)	Total amount (kg/day)	Organic amount (kg/day)
Administrative offices	40 – 50	1040 – 1300	104 – 130
House residentials	2 – 3	160 – 240	64 – 100
colleges	0.2 – 0.3	2720 – 4080	500 – 820
Restaurant premises	20 – 22	1060 – 1200	850 – 960
Total waste generation		4900 - 6800	1500 – 2200

3.7. Potential biogas generation from the organic fraction

The anaerobic digestion process consists of hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The hydrolysis is known as a rate-limiting step in the process and will determine the duration of the digestion process. The efficiency of the AD commonly evaluated according to the COD released from the organic fraction (biodegradable). Stoichiometrically, 1 kg of COD releases about 15.625 mol of methane gas (CH_4) at standard temperature and pressure (STP). Hence, 1 kg COD is needed to produce 0.25 kg of methane that may generate electricity about 1.29 kWh/kg $COD_{removed}$ [18]. The biogas generated from the digestion of organic waste could be used to produce electricity by using a gas engine or as an alternative to substitute liquefied petroleum gas for household cooking. On the other hand, the effluent produced could be expended as a liquid fertilizer for fertigation as it is still rich in nutrients such as nitrogen and phosphorus [28]. It is computed that with the current MSW generation, UPM potentially to generate about 775 kWh at maximum conversion. Therefore, currently, we are performing a start-up operation of biogas production using 15 m^3 anaerobic digester from kitchen waste as a substrate. Under start-operation at the feeding of 20 kg of food waste per day, about 2.0 – 2.5 m^3 biogas generated from the system. The biogas consists of CH_4 (55-60%), CO_2 (30 – 35%), N_2, and a trace amount of H_2S. The biogas generated was used for the cooking activities about 3 – 5 hour per day. The actual biogas generation will be further quantified at the steady state condition and the biogas will be used to produce green energy as an alternative energy source.

4. Conclusion

UPM is estimated to generate at about 20000 – 27000 tonnes of MSW annually that consists of 30 - 35% of organic fraction and various amount of inorganic fraction such as paper, plastics, glass, metal and others. The appropriate premise and MSW composition are the crucial factors to determine the success of up-scaling activities of green energy production. The complete utilization of organic fraction via anaerobic digestion projected to generate about 775 kWh of electricity based on the balanced stoichiometrically conversion. The actual biogas production from organic waste using 15 m^3 biodigester would give an insight projection for the utilization of MSW to green energy in UPM.

Supplementary Materials: Table S1: Selected Administrative Office, restaurant premises and residential area for the survey of MSW generated in UPM

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviation

AD	Anaerobic Digestion
APHA	American Public Health Association
COD	Chemical Oxygen Demand
GDP	Gross Domestic Product
MSW	Municipal solid wastes
SDGs	Sustainability development goals
TKN	Total Kjeldahl Nitrogen
UPM	Universiti Putra Malaysia

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