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Assessment of Municipal Solid Waste Generation in Universiti Putra Malaysia and Its Potential for Green Energy Production

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Abstract: The global waste generation keeps increasing over the years and it requires innovative solutions to minimize its impacts on environmental quality and public health. A strategic plan must be ascertained to overcome the future challenges of Municipal solid waste (MSW) locally and globally. Universiti Putra Malaysia (UPM) coined an initiative to demonstrate a showcase pilot plant for green energy production from MSW. The data was obtained from the survey and actual sampling within the UPM compound shows that UPM has generated 5.0–7.0 t/d of MSW generated consist of 30–35% organic fraction. Restaurants are the main source of the organic fraction. Upon separation, the organic fractions were digested into biogas. At a maximum conversion of the organic fraction, 715 kWh of electricity might be generated from the 2.2 t/d of organic waste generated in UPM. In this study, organic components from UPM were proposed to be subsequently used as a substrate via anaerobic digestion to produce green energy in the form of electricity or flammable fuels.

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

1. Introduction

Municipal solid waste (MSW) is a solid waste that is commonly described as trash or garbage that is generated daily by household, commercial establishment, industries, and others. 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]. Food waste is the major proportion of household waste in Malaysia when compared to an urban area in South-Eastern (40%) and Central Europe, which comprises about 24% of their MSW composition [2]. The food waste needs to be reduced by half, as stated in the United Nations sustainability development goals (SDGs) 12.3 [3]. The accumulation of food waste in MSW has created another burden to the society and urban setting [4]. The composition and amount of MSW that are generated vary from place to place due to geographical regions urbanisation, degree of industrialisation, socioeconomic [5], lifestyle, education, and family composition [6]. The growth in urban population contributes to the increasing food consumption, which leads to the increasing MSW generation in Asian countries [6]. In Medan, Indonesia, the urban population generates about 0.295 kg/person/d of MSW as compared to the suburb population with 0.18 kg/person/d [7]. Developed countries usually produce higher MSW (522–759 kg/person/y) when compared to the developing countries 110–525 kg/person/y. The MSW may become potential threats to the environment, as it is estimated to exceed two-billion t/y globally [8]. In Asia, more than one-million/d of MSW generated and expected to hit 1.8 million tons by 2025 [6]. Malaysia is one of the Asian countries that has consistently recorded a remarkable economic development. Malaysia's is about $10,570/capita with a population of about 30 million in 2016 [9]. As a developing country, Malaysia is experiencing an increase of urban population growth, leading to the development, rapid urbanisation and industrialisation, and finally contributes to the increment of MSW generation [10]. In 2007, 17,000 t/d [11] of household waste has been generated in Malaysia, which then doubled in 2012 from 1.00 to 1.33 kg/capita/d on average. This number is expected to increase by 49,670 t/d in the year 2020 [12].

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 to be discussed in universities in the form of research, teaching, and outreach activities [13]. In Malaysia, some public and private universities have studied solid waste management, such as waste management [14], from cafeteria [15] and office building [16], producing a final report as an output. However, the data obtained from these studies still require lab study. The lack of comprehensive collaboration, on-site experience and understanding, and networking between the government agencies and universities are among the barriers suppressing the cradle-to-cradle strategies [17]. Filling a gap of the MSW management is crucial to foresee the potential solution that may be provided by the university in the specific scope and its capability [13]. As reported, the financial abilities and inadequate infrastructure are the most challenging factors in waste management due to the large amount of MSW generated [18]. The option of appropriate treatment technology, such as biological approach, could be the best answer, as it will take care of the solid waste treatment and able to produce by-products as for green energy [19].

Anaerobic digestion (AD) is likely to be one of the most promising technologies for converting organic waste into bioenergy, including methane-rich biogas [20] and fertilizer products [21]. In New Zealand, AD is considered to be the most attractive solution for waste management, as it is environmentally friendly, economical, and consistent with the country's existing waste management strategy [22]. AD is a complex biochemical process that combines chemical and physicochemical reactions in series, involves different microbial species that potentially treat organic waste, and produces renewable energy [23]. AD using food waste as feedstock to produce bioenergy, such as biomethane [23], biohydrogen [24], and bioethanol [25]. However, biogas production in Malaysia mainly focused on the palm oil industry, as it is estimated that 80% of biomass energy potential was from the palm oil industry [26]. The energy generated is considered to be green energy, since it is produced from renewable sources that are less harmful to the environment than fossil fuels [27]. The biogas (CH_4) is a feed-stock for electricity generation and could be used as flammable fuel for cooking and heating purposes [28]. Capturing and utilizing methane is important in contributing to CH_4 emission reduction and as a renewable energy source [29].

The anaerobic digestion process consists of hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The hydrolysis is known as a rate-limiting step in the process and it will determine the duration of the digestion process. The efficiency of the AD commonly evaluated according to the COD that was 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). A 1 kg COD is needed to produce 0.25 kg of methane that may generate electricity about 1.29 kWh/kg $COD_{removed}$ [28]. Universiti Putra Malaysia (UPM), which is one of the leading research universities in Malaysia, has committed to look out over the issues of environment and sustainability as well as to support the Malaysia National Renewable Energy Policy and Action Plan. An appropriate setting of waste management is tremendously crucial for the best practices in MSW management for green energy production. 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 organic waste for the waste-to-wealth projects in Malaysia.

2. Materials and Methods

2.1. Field Survey Activity

UPM is a world-renowned centre of learning and it is one of the leading research universities in Malaysia. Its main campus is in Serdang, Selangor next to Malaysia's administrative capital city, Putrajaya. In 2018, UPM was ranked at 202 of world university ranking and 34 of Asian university rankings by Quacquarelli Symonds (QS) World University Rankings 2018/2019 [30]. In general, UPM consists of 19,000 students and 2,274 academies staff, with another 1,000 supporting staff making up to 23,000 people at one time [30]. UPM is predicted to receive a tonnage amount of MSW generated daily from the students and staffs through their administrative activities and daily life due to the huge population in the campus [13]. 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 is used to pay the contractor and local municipalities and the rest of the allocation is 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, are separately handled by Occupational Safety and Health Management Office UPM.

The survey involved in three major groups: (1) residential and colleges, (2) administrative offices, and (3) restaurant premises. The administrative offices include department offices, faculty offices, and centres in UPM compound (Table S1 and S2). 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 of the data obtained were evaluated and quantified to represent the statistical acceptance for assessment.

The study of MSW generation in UPM campus consists 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

Different sets of questions were prepared and disseminated via face-to-face interview or an online survey to the targeted respondent. The questionnaires comprised three parts; general info, waste management, and awareness programme. The questions were mainly based on the MSW composition and management, on-going awareness program, future and budget allocation. The questions to the restaurant representatives were mainly focused on the operation handling and the amount of organic fraction generated from their premises. Independent experts from a different background validated all of the questions (refer to the acknowledgement section).

2.3. Statistical Analysis of the Questionnaires

IBM SPSS Statistics software was used to validate the survey questions by conducting a reliability test to obtain the α-value [31]. This α-value will determine whether or not the questions will produce a stable and consistent answer to avoid the respondents from giving a random answer. Referring to Krejcie and Morgan [32], the sample size for survey distribution should be between 377–379, since the UPM population is 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, at 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 stages. During the fasting month, most of the restaurants are closed in the daytime and are open from 4.00 pm until midnight. The sampling was done for each consecutive day for each restaurant. The MSW was collected from the restaurant premises then segregated, according to an organic fraction (left-over food, kitchen refuse, including vegetables and meat) and an inorganic fraction (plastic, paper, glass, fabric, metal, and tetra pak). During the survey activities, the MSW was quantified and segregated daily for one week for each restaurant. The data that are presented are the daily average of each premise. For the anaerobic digestion process, the collection and segregation process was every 2 d prior to use in anaerobic digestion for biogas production.

2.5. Physical and Chemical Analysis of Organic MSW

The organic fraction was characterized based on its physical and chemical properties, such as total solids (TS), volatile solid (VS), moisture content, chemical oxygen demand (COD), and total Kjeldahl nitrogen (TKN). For the moisture content, TS and vs. the analyses were immediately done after the segregation completed. However, the COD and TKN were done after the grinding process (Section 2.7). All of the analysis was referred to the Standard Methods for the Examination of Water and Wastewater, American Public Health Association APHA [33]. For the COD analysis, a 2 mL of a slurry sample of the organic fraction (Section 2.7) was added in COD digestion vials (HACH) and digested at 150 °C and measured with spectrophotometer DR3900. The TKN was measured while using 4500-Norg B test kit (HACH), according to the manufacturer protocol. All of the analysis was done in triplicate from independent samples to represent average data.

2.6. Biogas Production Potential

The number of organic wastes that were generated from the restaurants was used as an indicator to evaluate biogas generation through anaerobic digestion. The COD and total organic (VS) fed into the anaerobic digester were measured daily based on the amount in kg of organic waste fed daily to the anaerobic digester. From the amount of COD and total organic (VS) measured, the potential methane and green energy generation were quantified, based on stoichiometry [28].

2.7. Biogas Pilot Plant Set-up

The pilot plant consists of three main sections, which are a food grinder, 15 m^3 anaerobic digester, and 10m^3 gas storage balloon. The pilot plant was built in the Biorefinery complex located inside UPM. Figure 1 shows the flow of the process for the conversion of organic waste to biogas. The cow dung was used as a starter (inoculum) for the anaerobic digester process. Approximately 50% of the reactor was filled with the inoculum and water (1:1 ratio). The biogas generated was flushed out for three cycles in order to acclimatize the inoculum to ensure the anaerobic condition in the digester. After the acclimatization process completed, the reactor was fed with organic waste as the main substrate. The collected MSW was segregated into organic and inorganic fractions. Subsequently, organic fraction ground into slurry form by mixing with water (1:1 ratio). The slurry organic fraction then fed into the anaerobic digester for the anaerobic fermentation process. The biogas was channelled through a piping system into the flow gas meter to measure the volume generated. The biogas was stored in a gas storage balloon for further application.

2.8. Start-up Biogas Production

The reactor was gradually fed with organic slurry until reaching the maximum capacity of 15 m^3. A fed-batch strategy was applied to avoid any shock to the digester. The initial feeding rate was 50 kg/d and gradually increase to 25 kg/d. To determine the organic loading rate, COD and vs. were measured to monitor the digester progress. The other parameters, such as pH and temperature, were measured daily for monitoring purpose.

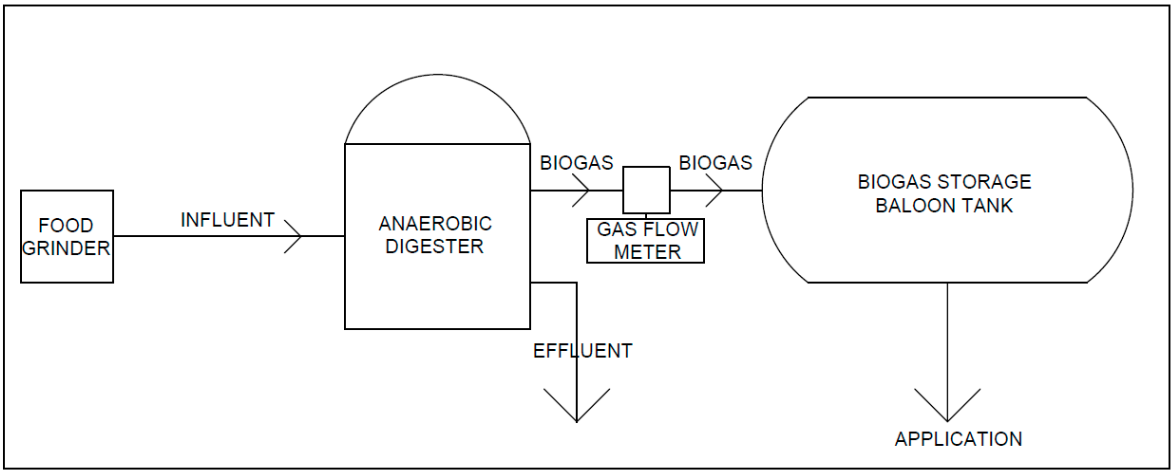

Figure 1. Process flow of food waste for the biogas production via anaerobic digestion process.

3. Result and Discussion

3.1. Solid Waste Management in UPM

A specific contractor appointed by University through the division name Development Office and Asset Management, UPM collected the MSW generated in UPM daily (PPPA UPM). The MSW is transported to the landfills at Tanjung 12, Putrajaya for final disposal twice a day. The MSW generated are pooled together without any segregation practice performed at the point of waste generated. Another private company for disposal at Dengkil inert landfills separately collected the landscaping and street cleansing waste from the MSW. The appointed contractor collects MSW twice daily and they do not practice a selective collection of the MSW. To date, no data on solid waste that is generated within the UPM campus has 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 was observed during the semester break when compared to the normal semester, June–September 2018, and October to December 2018. The maximum MSW collected was on December (240 t) and the lowest on June (118 t). On average, about 170–230 t of MSW is generated in UPM campus monthly and around 5.0–7.0 t/d.

Table 1. Municipal solid waste (MSW) collected by a private company in Universiti Putra Malaysia (UPM) compound from May to December 2018.

Month	Weight (t)	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 is self-management, whereas the staff members, except for sweeping and cleaning, do MSW disposal and collection in the offices compound. From the survey data, most of the offices do not have specific information on the budget for MSW management and choose to not answer the question that represents 39% of respondents (Table 2). However, certain offices that deal with e-waste, chemical, and clinical waste, such as medical, veterinary, and a few other faculties have spent between USD 1,200–USD, 2,400, and up to USD 4,800 per month, which represent 23% of the respondents (Table 2). For several, including the engineering faculty, the budget allocation is quite high due to a huge population and bigger land area for cleaning and maintenance, which is allocated more than USD 7,200/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	0 *	39
for municipal solid waste management includes:	0	4
Cleaning services	Less than 1,200	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 is disposed in bulk collection bins and a contractor appointed by PPPA UPM collects it. Figure 2a depicts the MSW generation and composition from an administrative office based on the survey. The estimated amount is the total amount that is generated from the point if generated without any segregation. However, improper segregation is partially done by the cleaner, where some of the recycled materials were put aside to be sold to the third party. Most of the offices produce MSW between 70–200 kg/w (65%). The amount of waste produced corresponds to their population size, for instance, the Faculty of Engineering and Library cater to 5000/person/d, which gave between 751–1000 kg/w. Another office entity reported less than 100 kg/w, which consists 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, named Equine unit, produces horse manure (animal waste), which are internally disposed of to oil palm plantation in UPM. The amount of MSW that is generated from the administrative office depends on their routine activities and the size of the population (staff and student) of the specific office compound. Various types of waste are generated from the office (Figure 2b). Out of 23 offices in UPM surveyed, papers, plastics (packaging and pet bottles), and kitchen waste are available in all of the offices, followed by 20 offices producing e-waste and tetra pak. Only one office in the survey produces used cooking oil as waste. Kitchen waste is mainly generated from their staffs and some of the faculties have their own pantries and restaurants that are placed within the building. Most of the recyclable papers and plastics are 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 that is 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 the source, but the level of implementation dependent on each office administration.

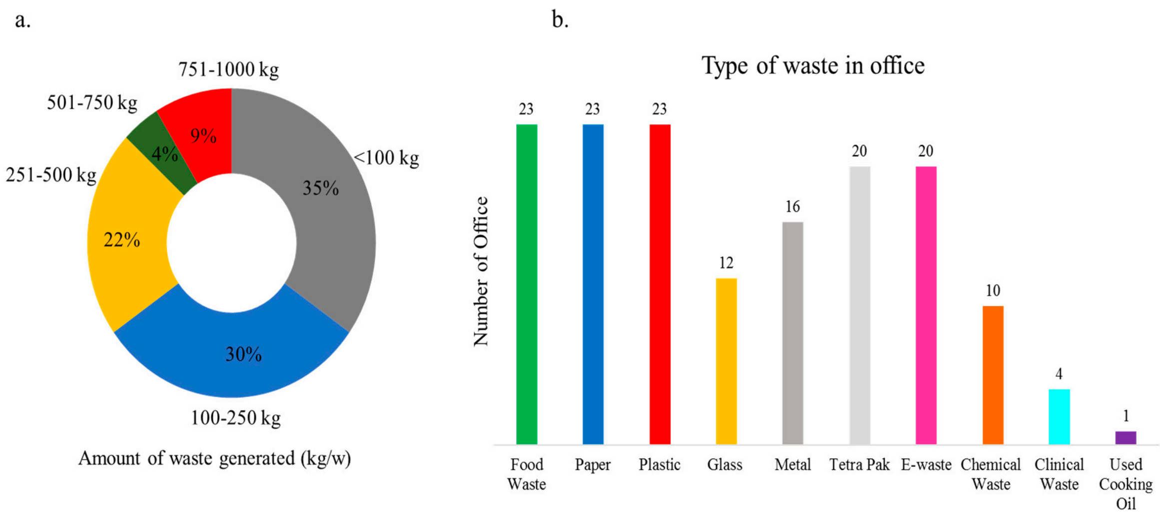

Figure 2. The estimated amount and MSW composition obtained from Administrative offices in UPM over the week without any segregation process at the source. (**a**) Estimated weight range of MSW generated (kg/w) and percentage (%) of total MSW generated. Grey (<100 kg, ~35%), Blue (100–250 kg, ~30%), Yellow (251–500 kg, ~22%), Red (751–1000 kg, ~9%) and Green (501–750 kg, ~4%). (**b**) The number of Administrative offices that generating the specific MSW with the total number of Administrative offices = 20 offices. (Green—Food waste, Blue—Paper, Red—Plastics, Yellow—Glass, Grey—Metal, Light grey—Tetra pak, Pink—E-waste, Orange—Chemical waste, Turquoise—Clinical waste and Purple—Used cooking oil.

3.3. Waste Generation from Residentials

UPM Serdang consists of 17 residential colleges that accommodate more than 5000 students at a time. In some of the colleges, the MSW management is handled by UPM and a few of them are handled by a private entity. A group of 600 respondents answered the survey via an interview and online form (Figure 3a). In the residential college, the students dispose of their waste into small bins in the front of their room and it is collected daily by cleaners before being dumped into curbside bin prepared by the contractor. Based on the result, less than 2 kg and 2–3 kg/w of waste generated per student, which represents 45.2% and 21.1% of the respondent. The other answers are scattered differently, since they just estimated the amount of waste without any proper measurement. In average, UPM student generates about 2.7 kg/w. In term of composition, food waste, plastic, and paper were the main compositions in the MSW that was generated from residential college (less than 1 kg/w for each component). Glass is the lowest, with 20% of respondents answering producing 0.1–1.0 kg/w (Figure 3b). It is indicated that most of the MSW from residential college consists of food waste, plastic and paper only. Subsequently, most of the paper will be collected for recycling purpose. However, from house residential, 28% of respondents produced within 9–10 kg/w and 18% of the respondents generated 7–8 kg/w (Figure 3d). One household in UPM produces an average of 7.6 kg/w. This showed that a group of the family consists of around 3–5 people/house generate more waste when compared to what the student residential suggested due to the cooking activities occurring 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 is one of the dominant components in their MSW, but in terms of the amount, house residential generate more food waste, as they may produce kitchen refuse rather than just left-over waste. Tetra pak, metal, and glass were the other components (Figure 3e). As similar practice from the offices, recyclables paper was collected by a 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 that was generated was higher from house mainly inorganic fractions (Figure 2). As stated earlier, it was due to cooking activities and the number of family members per house. When comparing the average composition of MSW between residential college and house, the food waste fraction is higher (20%) in college compared to house (16%) due to high inorganic fractions being generated from house residential and the addition of used cooking oil fraction to the house residential MSW composition (Figure 3c,f).

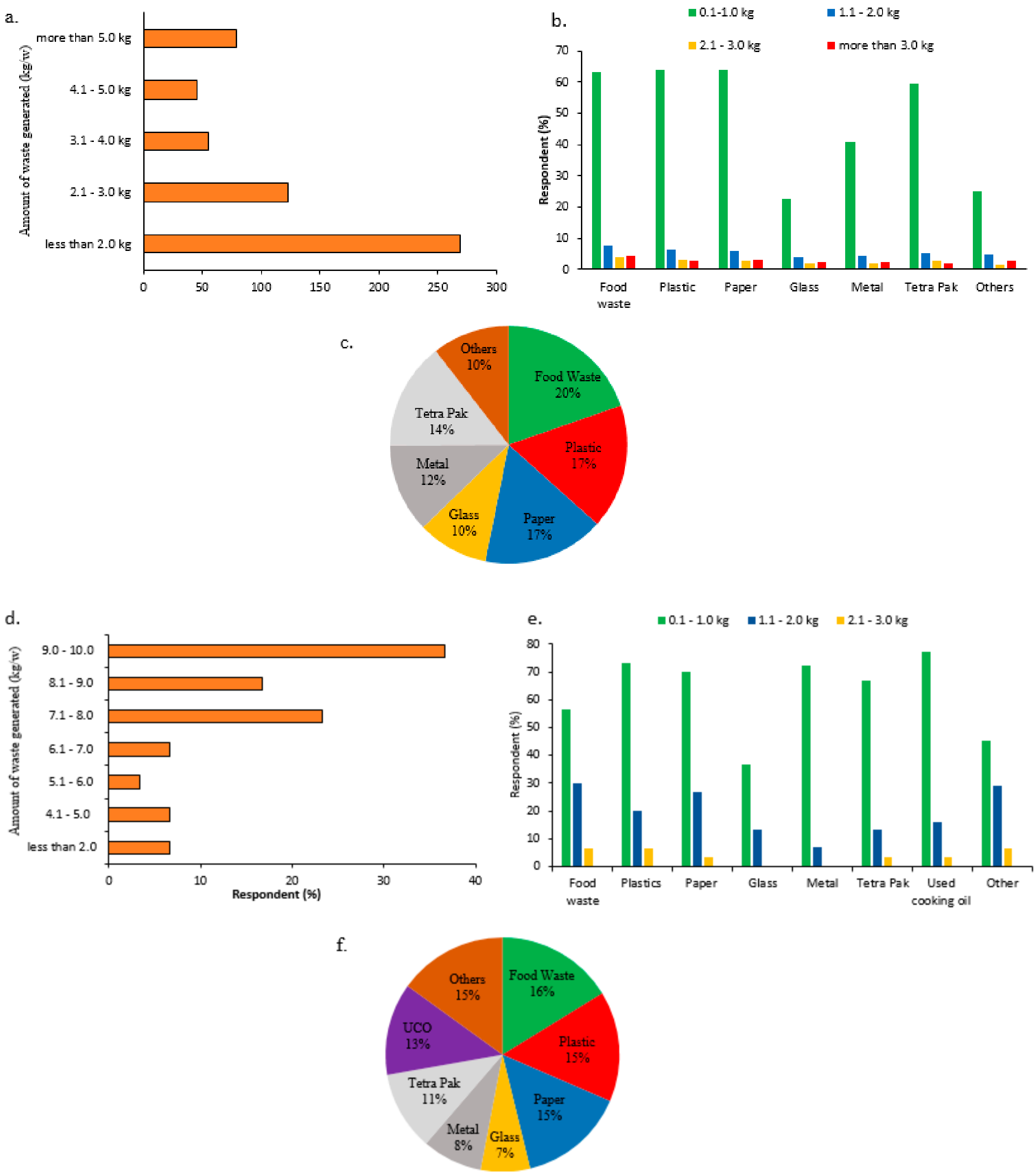

Figure 3. Amount of municipal solid waste and specific waste generated from residential college and house in UPM over the week. (**a**) The total amount of waste generated from the residential college in a week. (**b**) The range amount of different types of waste generated from residential college. (**c**) The average composition of MSW in a residential college. (**d**) The total amount of waste generated from the residential house. (**e**) The range amount of different types of waste generated from a residential house. (**f**) The average composition of MSW in a residential house.

3.4. A Survey from Restaurant and Cafeteria

According to the survey, most of the restaurants discard their waste into the curbside bin twice a day, which is before lunchtime and before closing time around midnight. It was hard to find a restaurant practicing waste segregation at the source due to awareness with 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 are about 10–15 kg/d, which represent 45% respondents followed by 5–10 kg/d (27% respondent). About 18% respondent generate 15–20 kg/d (Figure 4a). The amount is that is quite discordant depends on its customers. The type of restaurant that generates plenty amount of kitchen waste usually from the stall that offers a buffet menu as compared to the à la carte menu. The amount from the meals prepared and left-over meals from the buffet menu.

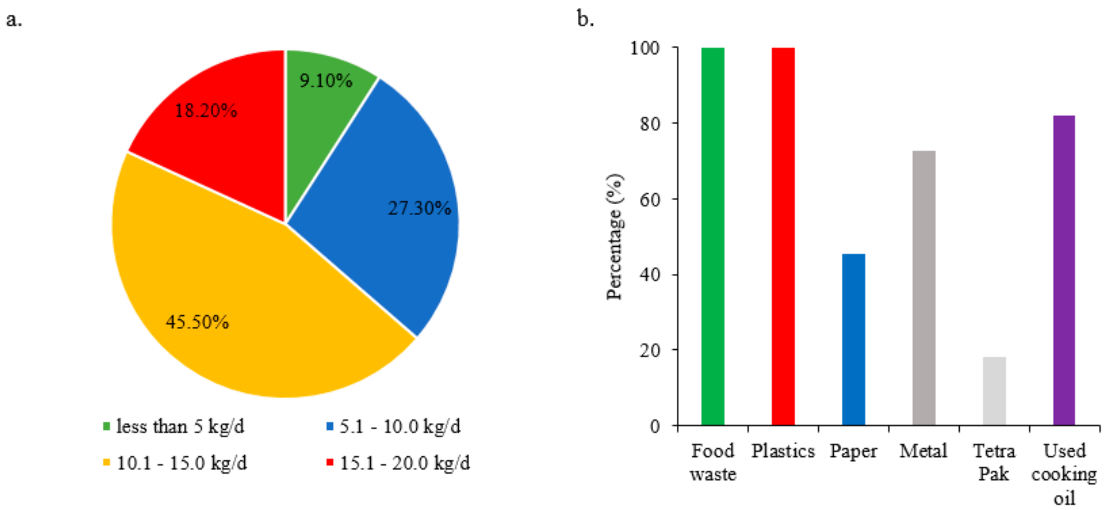

Figure 4. Estimated amount and types of municipal solid waste (MSW) generated from selected restaurant premises in UPM. (**a**) Estimated weight range of the MSW generated in the restaurants (kg/w) in the percentage of total restaurant involved in the survey activities. (**b**) The percentage composition of specific waste posed in the MSW (Green—Food waste, Red—Plastics, Blue—Paper, Yellow—Glass, Grey—Metal, Light grey—Tetra pak, Pink—E-waste, Orange—Chemical waste, Turquoise—Clinical waste and Purple—Used cooking oil.

From the survey, all of the restaurants mainly produce food waste, plastic packaging, used cooking oil, and the lowest is tetra pak. It shows that all of the MSW obtained from restaurant premise consists of food waste and plastics, followed by used cooking oil and some of the restaurants did not produce any paper or tetra pak, which gave less percentage of the total number of restaurants that are involved in the survey activities (Figure 4b). The food waste and plastic are contributed by kitchen refuse and left-over food and plastic mainly from packaging materials. Third parties usually collect the used cooking oil that is generated from the kitchen for further process. The other waste includes metal and tetra pak from canned food and drinks. 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.

3.5. Amount of Organic and Inorganic Waste Generated from the Restaurant

The restaurants were grouped into three different categories; Group 1 involved restaurants that only offer a buffet menu. Group 2 is the restaurants that offer only à la carte menu, whereas the restaurants that offer both menus were named Group 3. The categories were formed to understand the relationship between their nature of business and waste generation. The demerit factor was seen from Group 2, where the amount of waste really depends on the walk-in customers (Figure 4a). Less customer will devote less amount of waste generated. In contrast, a large amount of MSW was 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 that is generated from the restaurant was around 18–23 kg/d/premise, which was higher than the data that were obtained from the interview (5–10 kg/d/premise) (Figures 4a and 5a). The main component of the MSW generated is the organic waste that represents 80–85% from the total amount. The other 15–20% involves miscellaneous items, such as straw, plastic and paper packaging, canes, and glass bottles.

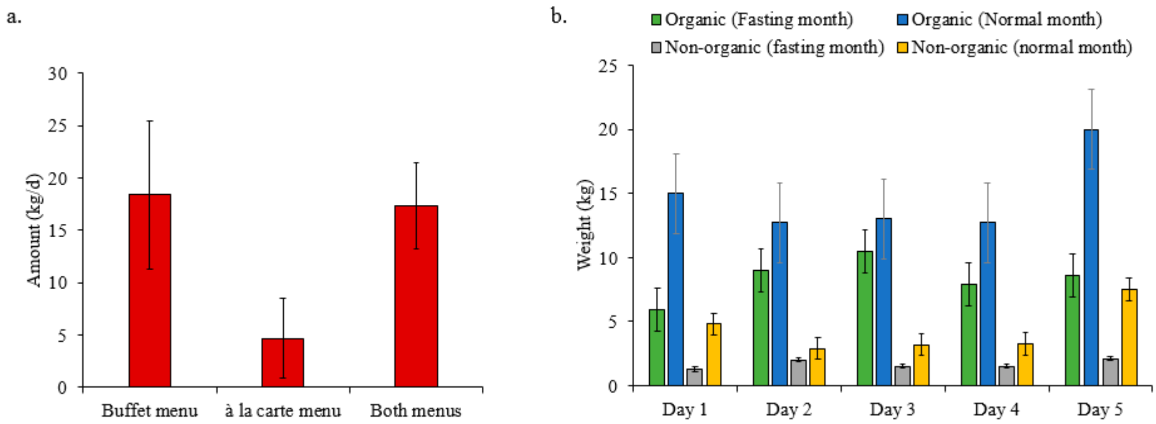

Figure 5. Amount of municipal solid waste generated from premises. (**a**) The average amount of organic waste from three different categories of the restaurant (Buffet menu and a la carte). (**b**) A comparison of the MSW generated between normal semester and fasting month. (Green and blue—Organic, Grey, and yellow—Non-organic).

The data that were obtained during fasting month delivered a different situation. About half of the waste generated was reduced during the period as compared to the normal period (Figure 5b). The amount of waste reduced was because many students buy their meals from independent stalls in the market rather than from restaurants inside UPM provided that the restaurant only opens from late afternoon until midnight. The operation time and fasting period became a bottleneck for the waste generation during fasting month in UPM. The data from this period is important to estimate the minimum organic waste available in the campus, even during normal semester running. It is necessary to seek further application of organic waste. It may indicate fewer substrates being available for the anaerobic digestion for the green energy production.

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

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

Day	Types of waste (kg/d)									
	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—Semester running 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 potential of the material to be used as raw material for further application. The food waste generally consists of carbon that can become an important precursor for bioenergy production and composed a wide economy prospect in industries. The detailed characterisation of the organic fraction generated in MSW from the restaurant demonstrated in Table 4. The moisture content between 50–70% with TS and vs. in a range of 30–50% and 20–35%. Malaysia's climate with heavy rainfall has tremendously influenced the moisture content. Usually, the curbside bin and garbage bin are exposed to the open sky without any lid. The most important criteria were obtained from COD and total nitrogen (TKN). Indirectly, COD exhibit the potential component to be utilized a by microorganism, especially in the application of anaerobic digestion [34]. The higher amount of COD predicts the potential of biodegradable components that are present in the organic fraction.

Table 4. The chemical and physical characteristic of organic waste obtained from the restaurant in UPM.

Parameter	This study	Reference	
Moisture Content	50%–70%	70%	[25]
Total Solid	30%–50%	17%	[35]
Volatile Solid	20%–35%	16%	[35]
Ash	3%–8%	13%	[25]
Chemical oxygen demand (COD)	200–600 g/L	190–346 g/L	[24]
Total Kjeldahl nitrogen (TKN)	0.1–0.3 g/L	0.50 g/L	[36]

Table 5 shows the summary of MSW generation from a different waste generator in UPM compound. The 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/d). Less amount of organic fraction was observed from the administrative office (10%), residential house, and college (40% and 20%). The office mainly generates inorganic fraction, such as paper. In college, the students are not allowed to cook, resulting in the organic fraction was only from the left-over food. It is understood that the main cooking activities only happened during the weekend in a residential house. The rest of the days involves only left-over food and simple cooking activities that contribute to the huge number of organic fractions. This important data shifted our understanding of organic source for anaerobic digestion. As the main organic source should be obtained from cooking activities is preferable than left-over food. Another important issue was related to awareness practice. The organic waste that was obtained from the restaurant was still contaminated with 20% inorganic materials, such as straw, small plastic packaging, labelling, etc. The 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-terms of amount and composition. The logistic is 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. The estimated amount of organic waste generated from different waste generators in UPM compound during this study.

Group	Waste Generation (kg/d/premise)	Total Amount (kg/d)	Organic Amount (kg/d)
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 biogas that 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. The effluent produced could be expended as a liquid fertilizer for fertigation, as it is still rich in nutrients, such as nitrogen and phosphorus [37]. It is computed that, with the current MSW generation, UPM could potentially generate about 715 kWh of electricity daily at the maximum conversion of organic waste to COD, as calculated based on estimation in Figure S1. 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 0–15 kg of food waste was added on a daily basis into the digester. Figure 6 shows biogas production from start-up operation. For the first 15 d, no additional food waste was added into the seeding inoculum and the biogas was released to ensure an anaerobic condition in the bioreactor. The slurry food waste was fed at 5 kg/d until stable biogas production observed. At the current feeding, 15 kg/d of food waste was operated and projected to increase until 50 kg/d of food waste. At current stable biogas production, an additional 5 kg/d of food waste was added Under certain condition, the system produces an average of 1.5–2.15 m^3 of biogas generated daily consists of CH_4 (55–60%), CO_2 (30–35%), N_2 (4–5%), and a trace amount of H_2S. during start-up operation, the HRT at 172 days, and the temperature fluctuated between 25 °C–35 °C due to weather and ambient condition. The average COD of the influent is 204 g/L. This gave the average of COD feed into the anaerobic digester about 3–4 kg/d. The COD removal efficiency remained between 80–85% as the COD was measured from the influent and effluent. At the current biogas generation rate, we manage to utilize cooking activities for 3–5 h/d while using a normal kitchen stove without any modification. The other application of biogas generation will be further quantified in the steady-state condition at the maximum feeding rate. The biogas was projected to purify and supply into the gas engine for the electricity generation and the application of the bottling system is in our current research progress for green energy production as an alternative energy source

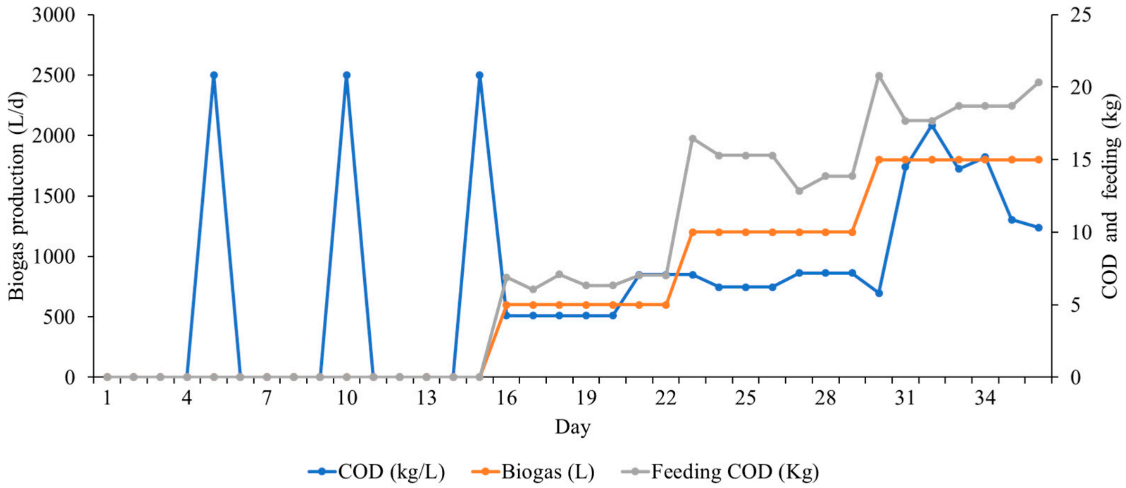

Figure 6. Start-up operation of biogas production from food waste in 15 m^3 anaerobic digester at a feeding rate between 0–15 kg/d of slurry food waste.

4. Conclusions

UPM has been estimated to generate 20,000–27,000 t of MSW annually, which consists of 30–35% of organic fraction and various amount of inorganic fraction, such as paper, plastics, glass, and metal. The appropriate premise and MSW composition are the crucial factors in determining the success of up-scaling activities of green energy production. The complete utilization of organic fraction via anaerobic digestion has been projected to generate 715 kWh of electricity based on the balanced stoichiometrically conversion. The actual biogas production from organic waste while using 15 m^3 biodigester would give insight projection for the utilization of MSW to green energy in UPM. The data obtained is important to estimate the size of the digester and to proof the feasibility of AD as a tool for solid waste treatment and management on a bigger scale. With on-going biogas production, the biogas will be further purified and utilized as the green energy either using the gas engine for electricity generation or direct usage as cooking fuel. On top of that, we are currently developing a bottling system for the low-pressure biogas bottle.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/14/3909/s1, Figure S1: Calculation of potential electricity generation from methane produce from the anaerobic digestion of organic waste in UPM, Table S1: Selected Administrative Office, restaurant premises and residential area for the survey of MSW generated in UPM, Table S2: Sample question used during the survey activities of MSW generation index and its composition in UPM.

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Abbreviations

AD	Anaerobic Digestion
APHA	American Public Health Association
COD	Chemical Oxygen Demand
d	Days
GDP	Gross Domestic Product
h	hour

MSW	Municipal solid waste
SDGs	Sustainability development goals
TKN	Total Kjeldahl Nitrogen
t	Tone
UPM	Universiti Putra Malaysia
UCO	Used Cooking Oil
HRT	Hydraulic Retention Time
OLR	Organic Loading Rate
TS	Total Solid
VS	Volatile Solid
w	week

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