Solid Waste Characterization and Recycling Potential in University of Phayao, Northern Thailand

Sarawut Sangkham[1]* and Chaiwat Sangsrichan[2]

[1]Department of Environmental Health, School of Medicine, University of Phayao, Phayao 56000, Thailand

[2]Department of Civil Engineering, School of Engineering, University of Phayao, Phayao 56000, Thailand

* Corresponding author. E-mail address: sarawut.sa@up.ac.th

Received: 21 January 2020; Revised: 27 April 2020; Accepted: 14 May 2020; Available online: 11 June 2020

Abstract

The objective of this study is to determine solid waste generation and waste composition, and its physical and chemical characteristics. Surveys were conducted in both 2018 and 2019, the dry seasons, to evaluate the types of composition, its quantity, its physical and chemical characteristics, and solid waste generation. The sampling was collected on weekdays and was analyzed using the ASTM standard methods. The total solid waste collected in the university area averaged to 750 kg/day. The solid waste generation rate was approximately 0.32 kg/capita/day, with food wastes representing the largest portion of waste at 33.65%, followed by plastic and papers at 32.96% and 18.82%, respectively. The results show that in the physical characteristics, combustibles were the highest with 92.71%, followed by non-combustibles and other wastes were 3.61% and 3.68%, respectively. The results show that the average chemical characteristics: moisture content, total solids, volatile solid, carbon fixed, hydrogen, and ash content from the solid waste in this study was 21.67%, 78.33%, 47.94%, 26.63%, 31.96%, and 38.34%, respectively. This paper focused on determining the physical composition and chemical characteristics of solid waste. These characteristics proved that the high amount of combustibles in University of Phayao can be potentially used as solid waste through waste compacting refuse-derived fuel (RDF) which would be an appropriate option of solid waste management in University of Phayao. Hence, to achieve sustainable waste management, it is essential to start formulating environmental policies continuously together with campaigns raising awareness among the students and staff within the university, such as solid waste separation and reduction of single-use plastic bags. Also, consumers should receive reward points for not accepting plastic bags and there should be a recyclable solid waste bank.

Keywords: wastes compositions, solid waste management, solid waste characteristics, University of Phayao

Introduction

In today's world, rapid urbanization, population growth, migration to the urban areas, and lack of sufficient funds and affordable services often force city authorities to offer unreliable and insufficient waste management services. University communities can be regarded as "mini-cities" with large territorial coverage and diverse human life activities, which have different degrees of effect on the environment (Adeniran, Nubi, & Adelopo, 2017; Alshuwaikhat & Abubakar, 2008; Iresha & Prasojo, 2018). Solid waste is one of the most visible environmental health problems in Thailand. Solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden posed on the municipal budget as a result of the high costs associated with its management, the lack of understanding over a diversity of factors that affect the different stages of waste management, and the linkages necessary to enable the functioning of the entire handling system (Guerrero, Maas, & Hogland, 2013). Waste production has increased due to the increase in population, technological development, industrialization, and urbanization. Furthermore, it has become an important issue nowadays due to its hazards to the environment as well as human health (Boysan, Özer, Has, & Murat, 2015). The first step to implement a waste management plan at a university is getting information on the composition and the amount and distribution of the waste generated in its facilities. As the waste composition and generation depends, among other things, on the climate, these variables should be analyzed every year (Gallardo, Edo-Alcón, Carlos, & Renau, 2016). Also, the waste composition is particularly important to determine the management of waste because successful solid waste management requires a complete understanding of the flow stream of waste generated as well as the activities that determine the first place it was generated. In this paper, we will identify the types, quantity, composition, physical and chemical characteristics of solid waste in the University of Phayao. The findings will provide an understanding of solid waste recycling and propose alternative waste management at the university.

Methods and Materials

1. Study area

The University of Phayao is located in the Northern part of Thailand. It is one of the major universities in the Phayao Province with approximately 916 hectares of land area hosting 16 faculties, 2 colleges, the students' hostels, and several administrative and academic buildings. It has estimated that there were over 20,000 student enrollments and around 1,799 academic and service staff in 2018 (University of Phayao, 2018a). The major activities in the institution focus on teaching, research, and community services. For carrying out these functions, academic, administrative, residential, and commercial spaces are provided. Most of the areas have permanent structures that are often built intentionally for a specific activity. A cross-sectional descriptive study was done on the solid waste generation rate at the University of Phayao.

2. Solid waste sampling and laboratory analyses

In this procedure, samples are taken directly from the source of solid wastes, namely from faculties and cafeteria. The procedure followed by solid waste the separation process by sample preparation techniques grain mixed and coned, cone flattened for quartering or spread out sample, and then the segregation by first division, second division 4 quartered and opposite quarters taken discard and save for reduced sample. Next, the samples of solid waste were weighed on a weighing machine and the data were recorded. These samples were analyzed both by their weight as well as the percentage composition as described by Pichtel and ASTM D5231-92 (ASTM , 2008; Miezah, Obiri-Danso, Kádár, Fei-Baffoe, & Mensah, 2015; Pichtel, 2005). The solid waste collected was an average of 750 kg from the buildings in the University of Phayao. The data collection was done on weekdays during an open semester and in the dry season (Jan – May) in 2018 and 2019. The moisture content of typical solid waste determined, by drying using hot air oven set at 105 °C, for 24 hours. (Model No: SMO14-2, Serial No: 03001314, USA). These samples of solid waste (3.00 g) were added into a muffle furnace combustion at 750 °C (Serial No. S/N. 0402144118N003, made by DAIHAN scientific Co., Ltd., Korea) to conduct volatile solids and ash content analysis. In this study, we applied equation to calculate to chemical characteristics including, moisture content, total solids, volatile solids, carbon fixed, hydrogen, and ash (Komilis, Evangelou, Giannakis, & Lymperis, 2012; Srisatit, 2015). Data were analyzed using STATA, version 14.0. The descriptive statistics, that is the percentage, mean, standard deviation, and minimum and maximum values, were used to summarize and describe the data by figure and tables.

Figure 1 The figure shown represents the solid waste separated by using the quartering method

2.1 Physical properties

The per capita generation was determined as per the mixed or the total waste collected in a day and also the separated fractions, using the following formula:

Equation no.1 Capita waste generation (kg/capita/day) = $\frac{\text{Weight of solid waste generated at university per day (kg/day)}}{\text{Total number of persons in the university (person)}}$

Equation no.2 The usual expression for calculating density is

$$D = \frac{(W_1 - W_2)}{V}$$

Where D = Density (kg/m^3)

W_1 = Weight of fresh solid waste and waste measuring container

W_2 = Weight of solid waste measuring container

V = Volume of solid waste measuring container

Equation no.3 The percentage composition of each of the components was calculated by the formula:

$$\text{Composition of each solid waste component (\% by weight)} = \frac{\text{(Weight of each separated waste)}}{\text{(The total weight of mixed waste sampled)}} \times 100$$

2.2 Chemical properties

The chemical solid waste characteristics were analyzed using the following formula:

$$\text{Moisture content (\%)} = \frac{\text{initial (wet) weight of sample} - \text{final (dry) weight of sample}}{\text{initial (wet) weight of sample}} \times 100 \quad \text{(Equation no.4)}$$

Total solids (%) = 100 – Moisture content (%) (Equation no.5)

$$\text{Volatile solids (\%)} = \frac{\text{weight of sample before combustion (g)} - \text{weight of sample after combustion (g)}}{\text{weight of sample before combustion (g)}} \times 100$$

(Equation no.6)

Ash content (A) = T – V (Equation no.7)

Where A = Ash content (%)

T = Total solids (%)

V = Volatile solids (%)

Results

1. Generation and composition of solid waste

The composition analysis revealed that the total solid waste collected from the university area averaged to 750 kg/day, and the rate of waste generation averaged to 0.32 kg/capita/day. From these data, it can be concluded that in 2018 plastics formed the majority of the solid waste at 39.36%, followed by food wastes (27.60%), papers (16.79%), glass (5.12%), and hazardous wastes (4.65%). In 2019, the highest solid waste composition was found in food wastes (39.69%), followed by plastic (26.55%), papers (20.85%), and leaf/trimming wastes (5.57%). The average highest of the solid composition during 2018 - 2019, a dry season, was food wastes at 33.65%, followed by plastic (32.96%) and papers (18.82%). The types of solid waste compositions are shown in (**Table 1**).

Table 1 Composition of solid wastes with a dry season during 2018 – 2019.

Composition of solid wastes	Year		Average (% by weight)
	2018	2019	
	% by weight	% by weight	
Food waste	27.60	39.69	33.65
Papers	16.79	20.85	18.82
Plastics	39.36	26.55	32.96
Bamboo stick (like a needle)	0.31	1.81	1.06
Ceramics/tile	0.00	1.20	0.60
Rubber	0.67	1.76	1.22
Metal and aluminums	0.55	0.36	0.45
Glass	5.12	0.00	2.56
Leaf and trimming	2.12	5.57	3.84
Foam	1.11	1.22	1.16
Hazardous wastes	4.65	0.03	2.34
Other (soil particles/or not identified)	1.72	0.96	1.34
Total	100.00	100.00	100.00

Table 2 Physical solid waste characterization % by weight in a dry season during 2018 – 2019

Solid waste characterization	Year		Average (% by weight)
	2018	2019	
	(% by weight)	(% by weight)	
Combustibles	87.96	97.45	92.71
Non-combustibles	5.67	1.56	3.61
Other	6.37	0.99	3.68
Total	100.00	100.00	100.00

This study grouped the physical solid waste into three types, combustibles (e.g. food waste, paper, plastic, rubber, leather, textile, grass leaves/leaf, bamboo stick and timber), non-combustibles (e.g. metal, glass, rock, and ceramic), and other wastes, and these were found both in 2018 and 2019. While conducting solid waste characterization in 2018, it was found that 87.96% of the solid wastes were combustibles while 5.67% and 6.37% were non-combustibles and other wastes, respectively. While, in 2019, the results showed that 97.45% were combustible wastes followed by non-combustibles and other wastes at 1.56% and 0.99%, respectively. The average (92.71%) in terms of solid waste characterization were combustibles, followed by non-combustibles and other wastes at 3.61% and 3.68%, respectively, as demonstrated in (**Figure 2**) and (**Table 2**).

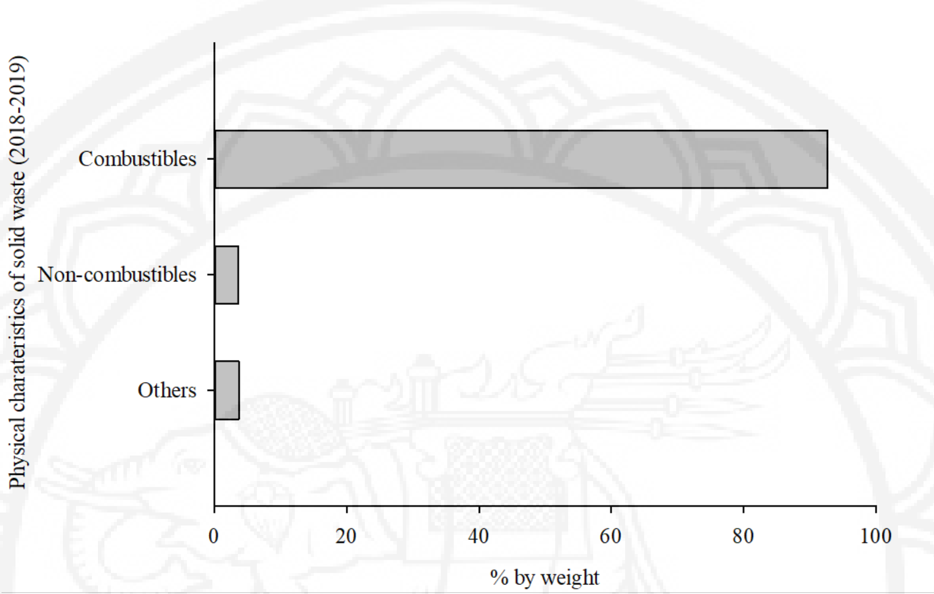


Figure 2 Physical characteristic of solid waste (% by weight) in 2018 – 2019

2. **Chemical properties of solid waste**

The results show that the chemical study of solid waste samples in 2018 found that the moisture content was 20.82%, total solids was 79.18%, volatile solids was 34.01%, carbon fixed was 18.89%, hydrogen was 22.68%, and ash was 45.17%. In 2019, it was found that the moisture content was 22.52%, total solids was 77.48%, volatile solids was 61.87%, carbon fixed was 34.38%, hydrogen was 41.25%, and ash was 31.51% are shown in (**Table 3**).

The total average percentage of the chemical characteristics of solid wastes from 2018 to 2019 was at follows: moisture content at 21.67%, total solids at 78.33%, volatile solids at 47.94%, carbon fixed at 26.63%, hydrogen at 31.96%, and ash content at 38.34% as exhibited in **Table 4**.

Table 3 Chemical solid waste characteristics in the dry season, 2018 – 2019

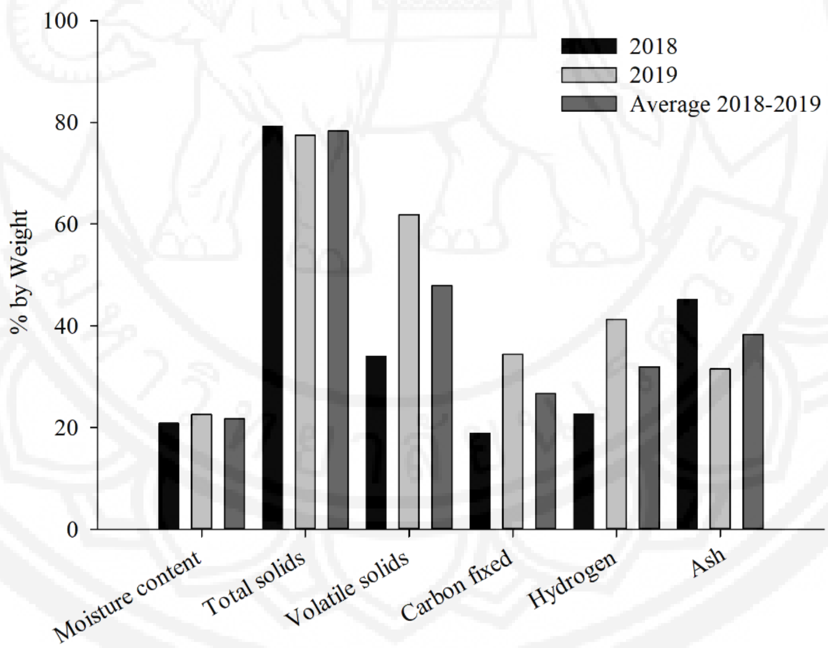
Dry Season, 2018	Chemical solid waste characteristics (% w/w)			
(n = 7 locations)	Mean	S.D.	Min.	Max.
Moisture content	20.82	2.35	19.21	25.87
Total solids	79.18	2.35	74.13	80.79
Volatile solids	34.01	13.78	15.00	50.87
Carbon Fixed	18.89	7.66	8.33	28.26
Hydrogen	22.68	9.19	10.00	33.91
Ash	45.17	14.24	28.22	64.61

Table 3 (Cont.)

Dry Season, 2019 (n = 6 locations)	Chemical solid waste characteristics (% w/w)			
	Mean	S.D.	Min.	Max.
Moisture content	22.52	4.82	14.79	29.55
Total solids	77.48	4.82	70.45	85.21
Volatile solids	61.87	30.45	4.96	97.33
Carbon Fixed	34.38	16.91	2.76	54.07
Hydrogen	41.25	20.30	3.31	64.89
Ash	31.51	32.82	0.24	73.62

Table 4 Chemical solid waste characteristics (% average by weight) in the dry Season of 2018 – 2019

Chemical solid waste characteristics	(% average by weight)
Moisture content	21.67
Total solids	78.33
Volatile solids	47.94
Carbon fixed	26.63
Hydrogen	31.96
Ash	38.34



Chemicals solid waste characteristics in the dry Season of 2018-2019

Figure 3 Chemicals solid waste characteristics in 2018 – 2019 and the total average (moisture content, total solids, volatile solids, carbon fixed, hydrogen, and ash content).

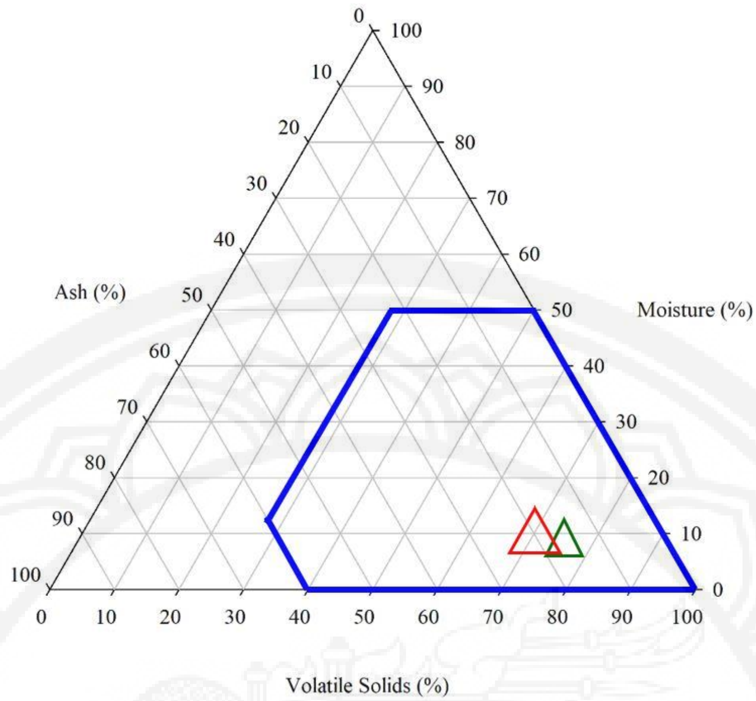


Figure 4 Tanner chart on the chemical parameters. The blue line depicts the self-suitable combustion area, the green line depicts SRF, and the red line depicts RDF (Antonopoulos, Karagiannidis, & Kalogirou, 2010)

Discussion

According to the study of the environmental section, division of building and facilities, University of Phayao (2018) the most common types of wastes are plastic/plastic bags of the total wastes (University of Phayao, 2018b). The high composition of food wastes is influenced by the students' lifestyle of buying packaged food instead of having their meals at the food center and restaurants that are present in each faculty or department in a university. The consumer buying behavior was influenced by factors such as cultural, social, personal, and psychological features. Personal factors include age, occupation, and economic status (Ishak, Mahayuddin, & Mohamed, 2015; Sriwongchai, Setthee, & Prasongsook, 2017; Viriya, 2015). During the same period, however, the quantities of food wastes increased from 27.60% in 2018 to 39.69% in 2019. The reason being the lifestyle of students, who purchased more food, which also accounted for the increase in the quantities of paper wastes from 16.79% in 2018 to 20.85% in 2019. The quantities of plastic wastes decreased from 39.36% in 2018 to 26.55% in 2019 because the university and society started raising awareness and conducting campaigns to reduce wastes in the university. Thus, there were policies put in place and measures taken to ensure shops reduced the use of plastic bags when the students purchased food and other items within the university. All the solid wastes are a result of the daily life patterns and purchasing behaviors on the university. The given value of moisture content in the municipal solid waste of developing countries can be explained by the specific food consumption, which largely consists of fresh fruits and vegetables (Chamem & Zairi, 2019; Zairi, Aydi, & Dhia, 2014).

In addition to the aforementioned results, a supplementary valorization of the solid waste was evaluated by applying the Tanner graphic method (Antonopoulos et al., 2010; Chamem & Zairi, 2019; Gillet, 1985,) which used the following three parameters: moisture content (%), ash (%), and volatile solids (%) (according to the reference data from this study, the moisture content was 22%, volatile solid was 48%, and ash was 38% of the solid waste). The results of this analysis show that the physical characteristics of solid waste are within blue line depicts the self- suitable combustion area (see **Figure 4**). Thus, considering the value of solid waste in the Phayao University from 2018 – 2019, this study concludes that solid waste is not suitable for composting because of the design of the aerobic composting system, moisture content ranging from near 50% - 60% on a wet basis. (Odomsinrot, 1994; Ussawarujikulchai, Hansuk, & Peerakiatkhajohn, 2011).

The characterization of solid waste as highlighted in this paper provided a better understanding of the waste generation pattern in the university and how it should stimulate the basis for a better decision on sustainable policies in the management of solid waste at the university. It is a way of managing waste by adding value and income to the university. However, it must be done in conjunction with the campaign to reduce the source reduction by decreasing the use of plastic bags in the university to make it into a "Zero Waste University" in the future. It is recommended that the university raises awareness of waste management among its students and personnel and also focuses more on recycling. Hopefully, the findings from this study would be beneficial to the University.

Implementing the guidelines for solid waste management in the university would require cooperation from all departments, personnel, and students, including all those who come to do activities in the university. With the management of solid wastes, the managers must begin to clearly define the environmental policies in order to have a concrete policy implementation. The Environmental Infrastructure Division, responsible for physical and environmental work initiates the project by proposing to the boards and the university committees, in order to approve the project to support the budget, campaign and promote the public relations project to the people involved in the university to be informed. The waste management project plan in that university may start with a campaign to separate, reuse, and recycle waste and increase the usage of cloth bags by refusing to accept plastic bags. Value management approaches in waste management such as establishing a recycling bank as a means of generating income for students should be promoted. The solid waste management project plan can be applied to make the university a "Zero Waste University". Hence, source separation and recycling systems are best suited for the university as shown in **Figure 5**.

Thus, appropriate waste management guidelines, which focus on systematically and efficiently managing solid waste management and also waste segregation everywhere, including cafeterias, shops, offices on campus, need to be in place in the university. There also need to be enough waste containers to support each type of wastes. This can help in recycling waste easily and reducing contamination while collecting solid waste. It is also a way to appropriately reduce volume before final disposal.

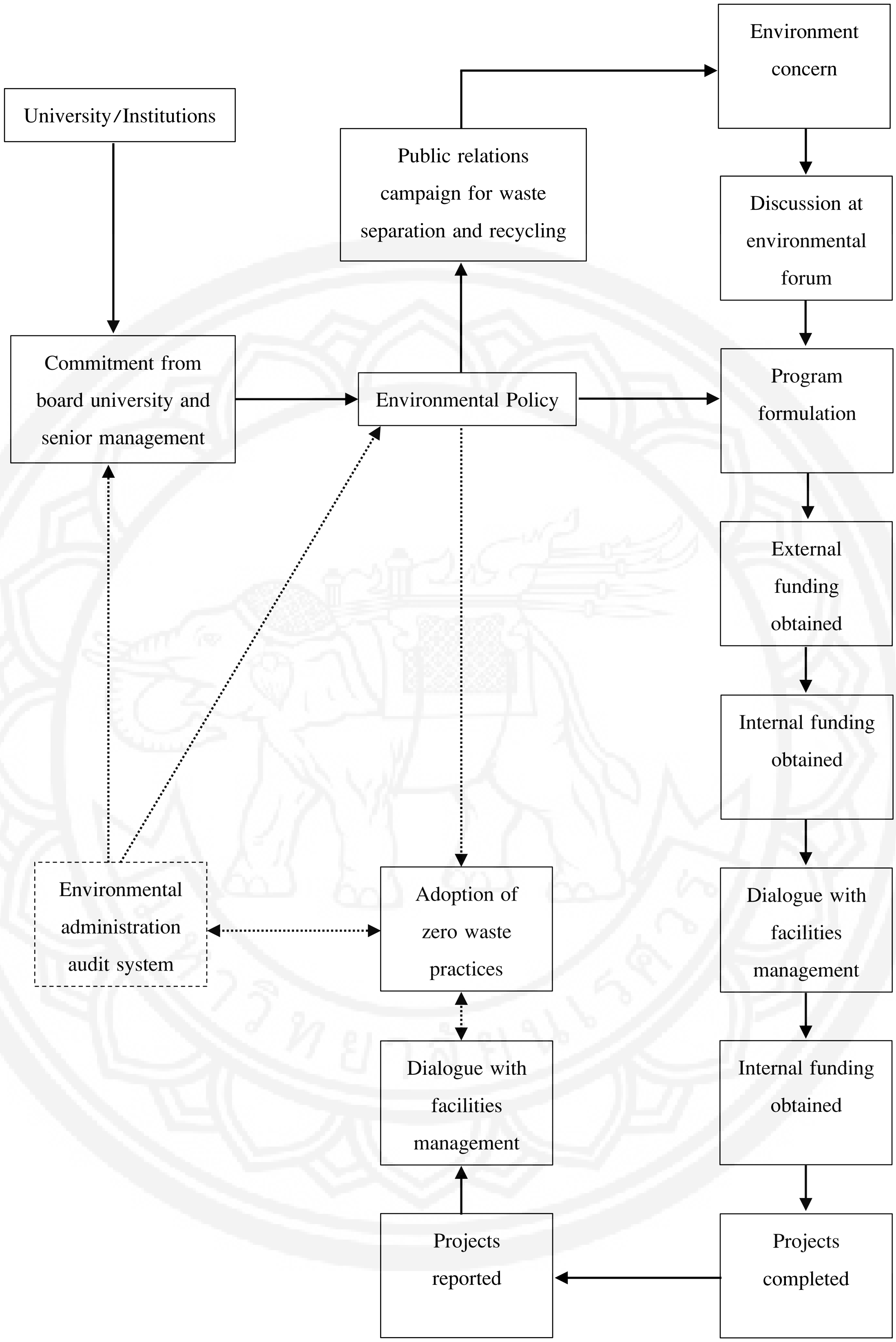


Figure 5 Implementation procedure for the zero-waste plan adopted from Mason, Brooking, Oberender, Harford, and Horsley (2003)

Conclusion and Suggestions

This study focused on waste generation and determined the physical and chemical characteristics of the solid wastes in the University of Phayao. The average waste generation rate was 0.32 kg/capita/day at the time of the study, with food wastes representing the largest portion of waste at 33.65%, followed by plastic and papers at 32.96% and 18.82%, respectively. In the University of Phayao, most of the wastes were combustibles at 92.71%, followed by non-combustibles and others at 3.61% and 3.68%, respectively. These chemical characteristics indicated that solid waste is depicted the suitable combustion. Thus, the solid waste generated could be managed via refuse-derived fuel (RDF), which would be an appropriate method and an alternative composting management option. Strategic policies and community participation are needed for the solid waste hierarchy such as source reduction and improved recycling of waste. Appropriate alternative technologies for converting waste to energy such as refuse-derived fuel (RDF), mechanical biological treatment facilities (MBT), and composting, need to be implemented to reduce the solid waste that is dumped or open burned. The results depend on every case, but it is clear that MBT alone is not the solution. Integrated technology as the usage of the solid waste management hierarchy:

- The retailers should prefer to get supplies for their food centers and shops from environmentally-friendly producers.
- The consumers, as well as universities, should seek all avenues to generate less solid waste and separate their solid waste at source, that is classrooms, dormitories, faculties, and pubic areas, for easy recycling, thereby reducing the adverse impact on environmental health.
- The university should provide the students and staff with adequate education on how to reduce solid waste and provide convenient and sustainable solid waste management options.

Acknowledgments

The authors would like to thank the students for helping in the data collection and the environmental health laboratory and school of medicine for conducting analysis during the study and providing secondary data from the University of Phayao.

References

Adeniran, A. E., Nubi, A. T., & Adelopo, A. O. (2017). Solid waste generation and characterization in the University of Lagos for a sustainable waste management. *Waste Management, 67,* 3-10. http://doi:10.1016/j.wasman.2017.05.002.

Alshuwaikhat, H. M., & Abubakar, I. (2008). An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices. *Journal of Cleaner Production, 16*(16), 1777-1785. https://doi.org/10.1016/j.jclepro.2007.12.002.

Antonopoulos, I. S., Karagiannidis, A., & Kalogirou, E. (2010). Estimation of municipal solid waste heating value in Greece in the frame of formulating appropriate scenarios on waste treatment. In *Proceedings of the 3rd International Symposium on Energy from Biomass and Waste 8-10 November 2010.* Italy; Venice.

ASTM (2008). *ASTM D5231-92 Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Wastes.* United States: American Society for Testing and Materials.

Boysan, F., Özer, Ç., Has, M., & Murat, M. (2015). Project on solid waste recycling plant in Sakarya University Campus. *Procedia Earth and Planetary Science, 15,* 590-595. http://doi:10.1016/j.proeps.2015.08.108.

Chamem, O., & Zairi, M. (2019). *Physical and chemical characteristics of municipal solid waste in Gabes: IEREK Interdisciplinary Series for Sustainable Development.* Retrieved from https://www.researchgate.net/publication/330024105_Physical_and_Chemical_Characteristics_of_Municipal_Solid_Waste_in_Gabes_IEREK_Interdisciplinary_Series_for_Sustainable_Development

University of Phayao. (2018a). *Business Intelligence.* Retrieved from http://dev.citcoms.up.ac.th/bi/Main/HR/Default.aspx

University of Phayao. (2018b). *UP Waste management policy.* Retrieved from http://www.sustainability.up.ac.th/WM01.aspx

Gallardo, A., Edo-Alcón, N., Carlos, M., & Renau, M. (2016). The determination of waste generation and composition as an essential tool to improve the waste management plan of a university. *Waste Management, 53,* 3-11. https://doi.org/10.1016/j.wasman.2016.04.013.

Guerrero, L. A., Maas, G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management, 33*(1), 220-232. https://doi.org/10.1016/j.wasman.2012.09.008.

Ishak, N. R., Mahayuddin, S. A., & Mohamed, M. R. (2015). *Generation and composition of solid waste in university campus.* Retrieved from https://link.springer.com/book/10.1007/978-981-4585-45-3

Iresha, F. M., & Prasojo, S. A. (2018). *Evaluation of solid waste management at campus using the "Zero Waste Index": The case on campus of Islamic University of Indonesia.* Retrieved from https://www.matec-conferences.org/articles/matecconf/pdf/2018/13/matecconf_icet4sd2018_02004.pdf

Komilis, D., Evangelou, A., Giannakis, G., & Lymperis, C. (2012). Revisiting the elemental composition and the calorific value of the organic fraction of municipal solid wastes. *Waste Management, 32*(3), 372-381. http://doi:10.1016/j.wasman.2011.10.034.

Mason, I. G., Brooking, A. K., Oberender, A., Harford, J. M., & Horsley, P. G. (2003). Implementation of a zero waste program at a university campus. *Resources, Conservation and Recycling, 38*(4), 257-269. https://doi.org/10.1016/S0921-3449(02)00147-7.

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management, 46,* 15-27. https://doi.org/10.1016/j.wasman.2015.09.009.

Odomsinrot, K. (1994). *Environmental engineering.* Bangkok: Mitnara Printing

Pichtel, J. (2014). *Waste Management Practices.* Boca Raton: CRC Press.

Gillet, R. (1985). *MSW Management and its Application in Developing Countries.* Copenhagen, Denmark: OMS Publisher.

Sriwongchai, S., Setthee, P., & Prasongsook, S. (2017). Study on behavior of participation in solid waste management of Burapha University Sakaeo campus's students and personnel. *Burapha Science Journal, 22*(2), 288-299.

Ussawarujikulchai, A., Hansuk, P., & Peerakiatkhajohn, P. (2011). Zero waste management in Mahidol Uiniversity Salaya Campus. *Journal of Environmental Management, 7*(1), 17-29.

Viriya, H. (2015). Comparison of solid waste composition between regular and weekend programs at Nakhon Ratchasima Rajabhat University. *Asia-Pacific Journal of Science and Technology, 20*(1), 34-41.

Zairi, M., Aydi, A., & Dhia, H. B. (2014). Leachate generation and biogas energy recovery in the Jebel Chakir municipal solid waste landfill, Tunisia. *Journal of Material Cycles and Waste Management, 16*(1), 141-150. http://doi:10.1007/s10163-013-0164-3.