Journal of
Environmental and Social Sciences

Open Science Publications

Volume 3, Issue 1 - 2016

www.opensciencepublications.com

An Estimation of Solid Waste Generation and Recycling and Composting Potential at Educational Facilities: A Case Study in Hue City, Vietnam

Research Article

Do Thi Thu Trang1, Nguyen Phuc Thanh[2], and Yasuhiro Matsui[1*]

[1]*Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushima-naka, Kita-ku, Okayama-shi, 700-8530 Japan*

[2]*Technology Research Department, Engineering Business Division, Hitachi Zosen Corporation, 15th Floor, OMORI-BELLPORT D-wing, 26-3 MINAMI-OHI 6-Chome, Shinagawa-ku, Tokyo 140-0013, Japan*

***Corresponding author:** Yasuhiro Matsui, Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushima-naka, Kita-ku, Okayama-shi, 700-8530 Japan; E-mail: matsui@okayama-u.ac.jp

Article Information: **Submission:** 30/05/2016; **Accepted:** 23/06/2016; **Published:** 27/06/2016

Abstract

This study was undertaken to characterize the solid waste generation at educational facilities in Hue, Vietnam. The authors surveyed 35 educational facilities within six categories of schools for seven consecutive days. The waste generation rates by facility, student, classroom, staff member, and floor area were assessed by school category using the following three waste categories: general waste (GW), separated recyclables (SR), and separated food residue (SFR). To determine the potential for composting and recycling from the disposal amount, GW was classified and measured by 10 physical categories and 77 sub-categories. Plastic, paper, and food waste were dominant in most of the school categories. The total waste generated from educational facilities in Hue was determined by extrapolating the total number of facility/student in Hue and the waste generation rate by facility/student. The total waste generated was estimated to be 5.76 tons/day, of which 3.29 tons/day (57.2%) was GW, 0.15 tons/day (2.6%) was SR, and 2.33 tons/day (40.5%) was SFR. The authors also revealed a considerable potential to recycle and compost remaining in GW, at rates of 1.11 tons/day (19.3%) and 1.29 tons/day (22.4%), respectively. The total amount sent to a landfill could be reduced from 3.29 tons/day (57.2%) to 0.89 tons/day (15.5%). A detailed breakdown of the recycling and composting potential is also analyzed and discussed for use in policy making decisions. Through the Monte Carlo simulation, the 95% confidence interval of the total waste amount was estimated to be 4.85-7.71 tons/day.

Keywords: School waste; Recycling potential; Composting potential; Interval estimation

Introduction

The amount of municipal solid waste (MSW) generated in Vietnam has been increasing in recent years. The amount of MSW was approximately 19 million tons in 2008 [1] and increased to 23 million tons in 2014 [2]. The amount of waste is expected to increase to 61.6 million tons by 2020 [3]. The rapid increase in MSW has

ISSN: 2454-5953

Table 1: Total number of and samples from educational facilities in Hue by school category.

Category	Total number in Hue	Number of targets	Description[25]
Day-care center	126	6	Provides nurturing and caring for children from 3 months old to 3 years old.
Kindergarten	49	9	Accepts children from 3 to 6 years of age. This service is offered by both public and private sectors.
Primary school	37	7	Consists of five grades (Grades 1 to 5), starting with 6-year-old children. Children will complete primary schools at the age of 11.
Secondary school	35	9	Includes two levels: lower and upper secondary education. Lower secondary education consists of four grades (Grades 6 to 9). Upper secondary education comprises three grades (Grades 10 to 12).
College & University	11	2	Includes colleges, universities, and academic research institutes.
Private tutoring	55	2	Provides learning services to help students preparing for important examinations or to simply enhance their knowledge in specific subjects (e.g., English, mathematics, etc.)

Table 2:Classification of waste from educational facilities.

Category	Code	Details	Recyclable/ Compostable	Category	Code	Details	Recyclable/ Compostable
1. Plastic				**5. Grass and wood (continued)**			
Container & Packaging	*101*	PET bottle	Re	*Container& Packaging*	*503*	Containers & packaging	Co
	102	Other plastic bottle	Re		*503[a]*	Containers & packaging	NRe
	103	Tray	Re	*Product &Others*	*504*	Grass and wood products	Co
	103[a]	Tray	NRe		*504[a]*	Grass and wood products	NRe
	104	Tube	Re	**6. Textiles**			
	104[a]	Tube	NRe		*601*	Clothes	Re
	105	Other shape	Re		*602*	Daily commodities	NRe
	105[a]	Other shape	NRe		*603*	Disposed commodities	NRe
	106	Plastic shopping bags	Re		*604*	Other product	Re
	107	Other plastic packaging	Re	**7. Metal**			
	108	Other *C&P* (e.g., buffer)	Re	*Aluminum*	*701*	Containers	Re
	108[a]	Other *C&P*	NRe		*702*	Other containers and packaging	Re
Product	*109*	Plastic product	Re		*702[a]*	Other containers and packaging	NRe
	109[a]	Plastic product	NRe		*703*	Products and others	Re
Other plastics	*110*	Other plastics	Re		*703[a]*	Products and others	NRe
	110[a]	Other plastics	NRe	*Steel*	*704*	Containers	Re
2. Paper					*704[a]*	Containers	NRe
Container & Packaging	*201*	Carton	Re		*705*	Other containers and packaging	Re
	202	Containers	Re		*706*	Products and others	Re
	203	Cardboard	Re	*Stainless*	*707*	Products and others	Re
	204	Packaging	Re	*Lead*	*707[a]*	Products and others	NRe
	205	Other *C&P*	Re	*Other metals*	*708*	Other metals	Re
Product	*206*	Newspaper/poster	Re		*708[a]*	Other metals	NRe
	207	Books	Re	**8. Glass**			
	208	Notebooks	Re	*Container*	*801*	Returnable bottle	Re
	209	Photocopy	Re		*802*	Disposable bottle	Re
	210	Disposable paper products	NRe		*803*	Other containers	Re
	210[a]	Nappies/diapers	NRe	*Products &Others*	804	Thermometer lamps	NRe
	211	Other paper product	Re		*805*	Products and others	NRe
	211[a]	Other paperproduct	NRe	**9. Ceramic**			
Other paper	*212*	Other paper	Re		*901*	Containers	NRe
	212[a]	Other paper	NRe		*902*	Products and others	NRe

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3. Kitchen waste				**10. Miscellaneous**			
Compostable	*301*	Kitchen waste	Co		*1001*	Combustibles	NRe
Non-compostable	*301[a]*	Coconut/durian shells	NRe		*1002*	Liquids - edible	Re
	302	Hard bones of animals	NRe		*1002**	Liquids - inedible	NRe
4. Rubber and leather					*1003*	Incombustibles (excluding ash)	NRe
	401	Rubber and leather	NRe		*1004*	Ash	NRe
5. Grass and wood					*1005*	Medical care (syringe, needle, …)	NRe
Garden waste	*501*	Garden waste	Co		*1006*	Batteries	NRe
	501[a]	Garden waste	NRe		*1007*	E-waste	NRe
	502	Flower	Co		*1008*	Others	NRe

[a]Re = Recyclable; Co = Compostable; NRe = Non-recyclable and non-compostable item.The recycling potential of each item was defined based on reports from two junk-shop owners. The compostable item and non-compostable item were defined based on the acceptable items at some composting plants.

Table 3: Waste generation rates of educational facilities.

Category	N	General waste		Separated Recyclable		Separated Food residue		Total waste			
		Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	*CV*	ANOVA (F value)
By facility (kg/facility/day)											
Day-care center	30	2.1	2.3	0	0	0	0	**2.1**	2.3	1.1	27.39***
Kindergarten	43	15.5	13.0	0.1	0.5	23.8	19.3	**39.4**	31.1	0.8	
Primary school	35	26.1	22.9	0.8	1.2	24.9	22.7	**51.8**	42.8	0.8	
Secondary school	41	22.9	12.7	2.8	3.3	7.0	6.6	**32.7**	17.0	0.5	
College & University	9	93.9	55.5	4.9	2.7	18.5	5.5	**117.2**	48.6	0.4	
Private tutoring	9	0.8	0.4	0	0	0	0	**0.8**	0.4	0.5	
By student (g/person/day)											
Day-care center	30	81	40	0	0	0	0	**81**	40	0.5	67.67***
Kindergarten	43	54	17	0.5	2	87	30	**141**	33	0.2	
Primary school	35	40	18	1.0	2	35	27	**76**	37	0.5	
Secondary school	41	23	14	2.0	2	5	5	**29**	12	0.4	
College & University	9	19	6	1.0	1	5	3	**25**	2	0.1	
Private tutoring	9	34	33	0	0	0	0	**34**	33	1.0	
By classroom (g/classroom/day)											
Day-care center	30	1,205	646	0	0	0	0	**1,205**	646	0.5	53.41***
Kindergarten	43	1,947	852	14	62	2,974	1325	**4,934**	1885	0.4	
Primary school	35	1,533	619	58	93	1,346	992	**2,937**	1346	0.5	
Secondary school	41	1,064	447	129	136	309	284	**1,502**	625	0.4	
College & University	9	1,059	557	61	39	226	86	**1,346**	444	0.3	
Private tutoring	9	514	356	0	0	0	0	**514**	356	0.7	
By staff member (g/person/day)											
Day-care center	30	670	469	0	0	0	0	**670**	469	0.7	25.96***
Kindergarten	43	512	179	4	19	804	290	**1,321**	334	0.3	
Primary school	35	681	359	22	35	587	443	**1,290**	671	0.5	
Secondary school	28	324	152	35	37	48	44	**407**	167	0.4	
College & University	9	229	104	15	10	53	24	**296**	72	0.2	
Private tutoring	9	610	426	0	0	0	0	**610**	426	0.7	

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By area (g/m²/day)											
Day-care center	30	11.3	8.7	0	0	0	0	**11.3**	8.7	0.8	16.03***
Kindergarten	38	6.8	3.2	0.1	0.3	12	6.0	**18.8**	8.5	0.5	
Primary school	35	10.1	4.0	0.3	0.5	8.2	6.3	**18.5**	7.5	0.4	
Secondary school	41	4.0	3.4	0.3	0.4	1.7	3.1	**6.0**	6.2	1.0	
College & University	9	4.8	4.1	0.1	0.1	0.6	0.4	**5.6**	4.4	0.8	
Private tutoring	9	22.3	19.5	0	0	0	0	**22.3**	19.5	0.9	

*** *p<0.001*

posed significant challenges for Vietnamese solid waste management authorities. In addition, in 2015, the Vietnamese government issued a national strategy to manage waste and discarded material (Decree no.38/2015/NĐ-CP), which indicated that daily-life solid waste must be classified and stored according to the following three categories: biodegradable organic, reusable and recycled, and "other" [4]. Determining the recyclable and organic amounts is indispensable for Vietnam's handling of waste in the years to come.

It should also be noted that some categories of waste are collected by informal sectors in developing countries; these include recyclables for sale and leftover food waste for farmers to feed animals [5]. A survey in Hanoi showed that recyclable waste accounted for approximately 20% of MSW [6]. As for food residue, the estimated amount of recycled food residue was 4.1% of the domestic waste collected in Danang, Vietnam [7]. However, most previous studies in Vietnam mainly focused on MSW collected by formal sectors [8-11]. To design a comprehensive MSW plan, Vietnamese authorities need to determine the total material flow of MSW, including the waste recovered by informal sectors.

Currently, MSW management in Vietnam has been empirically planned without the use of reliable data, but it will include such data in the near future. Shortcomings in MSW data include inconsistencies in definitions and collecting data; lack of unification in reporting data among the municipalities; and differences in the amount of waste generated, which makes predicting trends difficult [1]. As some previous studies have mentioned, it is important to understand the amount of waste generated, the waste composition, and the waste stream as the first step in developing an effective MSW strategy that includes 3R promotion (reduce, reuse, recycle) [12,13].

MSW is generated and discharged from various sources: households; commercial sources like hotels, restaurants, and markets; and institutional sources like educational facilities, medical facilities, and offices. To promote the 3Rs, it is indispensable for all members of society to separate valuable items such as recyclables and food residue. In particular, the public sector is responsible for raising awareness and promoting waste separation. Educational facilities could assume a role in educating individuals, and take the lead in 3R promotion.

Previous studies have investigated the generation of waste from educational facilities, but some studies have focused only on universities [14-16], and other studies have surveyed waste from primary and secondary schools [17,18]. They did not cover all school categories from nursery school through university. One study in Vietnam surveyed waste from educational facilities, but the study did not provide details on waste composition, the potential for recycling and composting, or waste collected by informal sectors [19].

In order to provide the scientific information that can contribute to the promotion of the 3Rs at educational facilities, this study aimed to provide a detailed description of the solid waste generation and composition from educational facilities in Hue, Vietnam. The authors surveyed six school categories, ranging from "Day-care center" to "College & University, "including "Private tutoring," according to "The system of economic branches of Vietnam, 2007" [20], and analyzed differences by category. The authors conducted a survey on the waste collected by formal sectors, and also measured the amount of separated recyclables and food residue collected by informal sectors. The waste collected by formal sectors was classified into 10 physical categories and 77 sub-categories to identify the potential for recycling and composting the waste. This study also conducted an interval estimation of the total waste in Hue, and aimed to clarify the reliability of collected data and improve future tasks through uncertainty analysis.

Methodology

Research area and target educational facilities

Hue, the capital city of Thua Thien Hue province, located in the center of Vietnam, was selected as the study area. Hue is comprised of 27 wards with a total area of 71.7 km² and a population of 342,556 as of 2011 [21]. Hue is well known for its historical monuments, which were deemed World Cultural Heritage sites on December 11, 1993, by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) [22]. Regarding solid waste management, the amount of collected waste in Hue is reported to be approximately 210 tons/day. The collection rate in the entire city was about 89%, and 90-95% in urban areas, in 2011 [23].

There are a total of 402 educational facilities in Hue. The authors covered six school categories according to "The system of economic

Table 4: Waste generation of primary school by food service.

Category	Primary school with food service	Primary school without food service	ANOVA (F Value)
General waste	42±18	25±11	3.9
Separated recyclable	2±2	0	0
Separated Food residue	41±24	0	0
Total waste	85±33	25±11	15.7***

***p<0.001

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Table 5: Physical composition of GW at educational facilities (%).

Physical category	Day-care center	Kinder- garten	Primary school with service	Primary school without food service	Secondary school	College & University	Private tutoring
Plastic	16.3%	14.4%	25.5%	38.6%	35.1%	18.4%	21.7%
Paper	47.5%	18.9%	15.4%	12.3%	28.1%	22.6%	35.4%
Food waste	22.9%	54.8%	31.4%	20.7%	5.2%	45.6%	19.7%
Rubber & leather	0.1%	0.2%	0.2%	0.0%	0.1%	2.0%	0.0%
Grass & wood	3.0%	3.1%	15.2%	12.4%	14.5%	2.4%	5.1%
Textiles	1.7%	1.3%	1.4%	4.2%	1.4%	1.2%	0.0%
Metal	0.6%	0.3%	0.3%	0.6%	0.6%	0.6%	0.0%
Glass	0.0%	0.5%	0.0%	0.0%	0.0%	2.3%	0.0%
Ceramic	5.1%	0.7%	0.5%	0.2%	1.9%	0.0%	0.0%
Miscellaneous	2.8%	5.7%	10.1%	10.8%	13.1%	4.9%	18.2%

***p<0.001

Table 6: Estimation of total waste and the breakdown from educational facilities.

Physical category	Day-care center	Kinder- garten	Primary school withfood service	Primary school withoutfood service	Secondary school	College & University	Private tutoring
Composting potential	23.7%	57.2%	46.7%	35.5%	42.0%	39.2%	35.1%
Recycling potential	35.7%	28.2%	33.7%	43.0%	33.0%	27.8%	53.9%
Other residue	40.6%	14.6%	19.5%	22.0%	25.2%	33.0%	11.0%
Contribution of components in recycling potential							
Plastic C&P	32.8%	35.7%	43.6%	53.8%	42.3%	39.7%	24.5%
Plastic product	1.9%	4.3%	6.1%	3.9%	6.1%	2.1%	0.0%
Plastic other	0.0%	0.2%	0.1%	0.4%	0.0%	8.7%	0.0%
Paper C&P	47.9%	38.4%	15.4%	15.1%	24.8%	17.1%	35.2%
Paper product	6.5%	6.9%	21.1%	13.1%	25.1%	19.2%	15.0%
Paper other	0.4%	2.8%	2.4%	2.2%	3.1%	5.7%	2.4%
Other material	10.5%	11.7%	11.2%	11.4%	8.6%	7.6%	23.0%
Contribution of components in composting potential							
Kitchen waste	83.3%	92.6%	64.0%	54.0%	38.7%	98.8%	53.6%
Garden waste	8.7%	3.3%	30.6%	30.8%	51.0%	0.2%	0.7%
Other item	8.0%	4.1%	5.4%	15.2%	10.3%	0.9%	45.8%

branches of Vietnam, 2007": "Day-care center," "Kindergarten," "Primary school," "Secondary school," "College & University," and "Private tutoring." For the sample selection, the authors used the lists of schools by school category. For "Kindergarten," "Primary school," "Secondary school, "and "College & University, "the lists provided the number of students at each school. Thus, the authors sorted the lists by the number of students and chose target schools by systematic sampling. Regarding "Day-care center" and "Private tutoring," the lists did not include data on the number of students at each school. Therefore, the authors chose target schools from the original lists without sorting by systematic sampling. A total of 35 targets were selected. The total number of facilities in Hue, the number of targets, and the description by school category are shown in Table 1.

Outline of survey

This survey focused on MSW and did not include construction and demolition waste, medical waste, or hazardous waste. The procedure for the waste generation survey followed the methodology presented by

Matsui et al. [24]. The authors conducted three surveys for all target facilities: a waste generation survey by actual measurement, a waste composition survey, and a questionnaire survey.

A waste measurement survey was conducted to acquire data on the generation amount for seven consecutive days. Before the survey period, the authors spent three days to prepare and practice with surveyors and target facilities. The target facilities separated the waste into three categories according to their usual customs; waste collected by formal sectors (hereinafter referred to as "general waste (GW)"), recyclables sold to informal sectors (hereinafter referred to as "separated recyclables (SR)"), and food residue sold/given to pig farmers (hereinafter referred to as "separated food residue (SFR)").

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Table 7: Estimation of total waste and the breakdown from educational facilities.

Category	Unit	Total number in Hue	General waste			Separated recyclables	Separated food residue	Total amount
			Residual amount	*Recycling potential*	*Composting potential*			
Day-care center	Facility	126	*0.11*	*0.09*	*0.06*	0	0	0.26
Kindergarten	Student	14,114	*0.11*	*0.21*	*0.44*	0.01	1.22	1.99
Primary school with food service	Student	22,057	*0.13*	*0.22*	*0.34*	0.03	0.78	1.50
Primary school without food service	Student	4,037	*0.02*	*0.04*	*0.04*	0	0	0.10
Secondary school	Student	35,390	*0.31*	*0.34*	*0.16*	0.06	0.17	1.04
College & University	Student	32,579	*0.20*	*0.17*	*0.24*	0.05	0.16	0.83
Private tutoring	Facility	55	*0.01*	*0.02*	*0.02*	0	0	0.04
Total (tons/day)			**0.89**	**1.11**	**1.29**	**0.15**	**2.33**	**5.76**
%			*15.5%*	*19.3%*	*22.4%*	*2.6%*	*40.5%*	**100%**

The surveyors measured and recorded the amount of waste per category (GW, SR, SFR) daily. The separation rates for recyclables and food residue were as follows:

- Day-care center: 0% for recyclables; 0% for food residue
- Kindergarten: 33% for recyclables; 100% for food residue
- Primary school: 57% for recyclables; 86% for food residue
- Secondary school: 78% for recyclables; 67% for food residue
- College & University: 100% for recyclables; 100% for food residue
- Private tutoring: 0% for recyclables; 0% for food residue

The authors conducted a waste composition survey for GW during the survey period. To acquire the information relating to recycling and composting potential contained in GW, the authors classified GW into 10 physical categories and 77 sub-categories. This classification system was based on material (plastic, paper, kitchen waste, rubber &leather, grass, textiles, metal, glass, ceramic, and miscellaneous), type (container/packaging, product, and other), and potential to recycle and compost. The recycling potential was based on the practical trading status of the recycling market in Hue. Recyclable items contained plastic, paper, glass, metal, and textiles that can be bought and sold at a recycling market. The composting potential was based on the acceptable items as determined by some composting plants in Vietnam. Descriptions of waste classification categories are included in Table 2. The authors asked the persons in charge of facility management or waste handling to record the attributes and current status of target facilities by using the structured questionnaire and through interviews. The questionnaire was designed to obtain detailed information on relevant factors (business-scale indicators) influencing waste generation, recycling activities, and attitudes toward solid waste management at each facility.

Analytical procedure

The authors calculated basic statistics relating to waste generation rates (WGRs) by waste generation amount divided by five indicators: facility, classroom, baby/kid/student (hereinafter referred to as "Student"), staff members (including lecturers, managers, researchers, and other people who provide service at educational facilities), and area. The mean differences of WGRs of total waste among the six school categories were assessed by analysis of variance (ANOVA). The authors also calculated the coefficients of variations (CVs: standard deviations divided by means) of WGRs, and compared the CVs among five indicators. The CV was used as the indicator of reliability in this study. The authors chose WGRs with smaller CVs among five indicators for further analyses.

The waste composition of GW by percentage was calculated according to the 10 physical categories by school category. In addition, based on 77 sub-categories, the authors assessed the recycling and composting potential in GW. The total waste generated from educational facilities in Hue was determined through extrapolating by the total number of facility/student in Hue and the waste generation rate by facility/student. ("Day-care center" and "Private tutoring" were estimated by facility. "Kindergarten," "Primary school," "Secondary school," and "College & University" were estimated by student). The authors also calculated the 95% confidence interval (CI) of the total waste generated by a Monte Carlo simulation (100,000 times) based on the mean and standard error of the WGR by student/facility per educational category. Monte Carlo simulations are used widely to assess error propagation for model parameters [26]. The uncertainty of the result is affected by the uncertainty of the input data [27]. The authors intended to estimate the sensitivity as a percentage of the contribution from each parameter to the variance of the final result [28].

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Results and discussion

Waste generation rates of educational facilities

Table 3 presents the means and standard deviations (Mean ± SD) of WGRs of GW, SR, SFR, and total waste per school category according to the following indicators: daily amount at the facility (kg/facility/day), daily amount by student (g/student/day), daily amount by classroom (g/classroom/day), daily amount by staff member (g/person/day), and daily amount by area (g/m^2/day). The authors also indicated the result of ANOVA on the mean difference among school categories, as seen in Table 3. The result indicated that there were significant differences in WGRs by all indicators ($p<0.001$) among school categories.

Regarding the total WGR by facility, "College and University" generated the largest amount (117.2kg/facility/day), followed by "Primary school" (51.8kg/facility/day), "Kindergarten" (39.4kg/facility/day), "Secondary school" (32.7kg/facility/day), and "Day-care center" (2.1kg/facility/day). "Private tutoring" generated the smallest amount (0.8kg/facility/day). Regarding the total WGR by student, "Kindergarten" was the category with the highest WGR (141g/student/day), followed by "Day-care center" (81g/student/day) and "Primary school" (76g/student/day). The higher WGRs from "Kindergarten" and "Primary school" facilities were mainly attributable to the large amount of SFR. The higher WGR at "Day-care center" facilities was considered to be due to the waste generated in infant care, such as disposal diapers.

The total WGRs were smaller at "Secondary school" (29g/student/day), "College & University" (25g/student/day), and "Private tutoring" (34g/student/day). The total WGRs in these categories were close to the reported value (21g/student/day) in a 2010 study in Cambodia [18]. Table 3 also shows the CVs of WGRs for total waste. The WGRs by student had the smallest CVs in most of the school categories. Therefore, the authors chose the WGR by student as the representative indicator for waste generation, which was used for further analyses.

Mean difference in waste generation rates by food service provided

At "Primary schools," some schools provided food service at their own canteens, and others did not. The authors analyzed the mean difference of the WGR by food service provided by ANOVA, as shown in Table 4. The WGR for total waste differed significantly between "Primary school with food service" (85g/student/day) and "Primary school without food service" (25g/student/day). The difference was considered to be due to the large contribution of SFR at "Primary school with food service" (41g/student/day). "Primary school without food service" did not separate recyclables and food residue.

Waste composition at educational facilities

Physical composition

Table 5 presents the composition of GW by 10 physical categories per school category. It was revealed that plastic, paper, and food waste were dominant in most school categories. The results in this study were in line with the following reported values on waste from schools in Ho Chi Minh City [19]: food residue ranged from 23.5% to 75.8%, followed by plastic, which ranged from 8.5% to 34.4%, and paper, which ranged from 1.5% to 27.5%. Food waste accounted for the highest portion at "Kindergarten" facilities (54.8%), whereas it was lowest at "Secondary school" facilities (5.2%). This difference could be explained by the fact that the entire "Kindergarten" category provided food service, and some inedible cooking residue is discharged as GW. At the "Secondary school" facilities, the students rarely ate inside the buildings. Paper accounted for a larger portion at "Day-care center" facilities (47.5%), followed by "Private tutoring" (35.4%). Paper at "Day-care center" facilities was mainly baby diapers. This resulted in the lower recycling potential at "Day-care center" facilities. Grass and wood accounted for a large portion at "Primary school with food service" (15.2%), "Secondary school" (14.5%), and "Primary school without food service" (12.4%).

Recycling and composting potential of general waste at educational facilities

Although the educational facilities in Hue separated some recyclables and food residue collected by informal sectors, some recyclable and compostable portions were discharged as GW. The authors categorized each component of GW according to the potential shown in Table 2, and aggregated the data by the following components: "Recycling potential in GW," "Composting potential in GW," and "Other residue in GW."

Table 6 presents the potential to compost and recycle and provides a detailed breakdown from GW by school category. "Composting potential in GW" accounted for a large portion, from 23.7% at "Day-care center" to 57.2% at "Kindergarten."Table 6 also shows that "Recycling potential in GW" accounted for a large portion among educational facilities, which ranged from 28.2% at "Kindergarten" to 53.9% at "Private tutoring." These results were similar toa 2009 study at the University of Northern British Columbia, which indicated that the recyclable materials made up more than 37% of waste in most of the activity areas on campus [29]. "Plastic C&P," "Paper C&P," and "Paperproduct" showed higher contributions in recycling potential. "Kitchen waste" accounted for the highest portion in all school categories, and "Garden waste" showed a higher contribution at "Primary school without food service," "Primary school with food service," and "Secondary school" in composting potential. To promote recycling and composting at educational facilities, these five

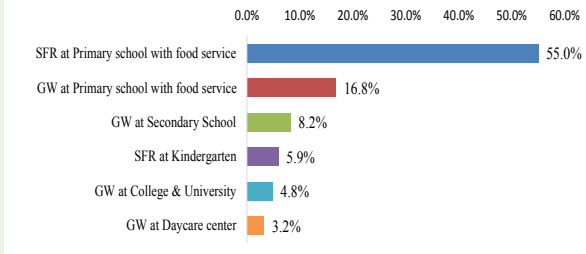

Figure 1: Result of sensitivity analysis of total waste generation from educational facilities in Hue

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items should be considered as major target items for initial separation.

Estimation of total waste generated from the educational sector

To draw the total waste flow diagram of solid waste generated from educational facilities in Hue, the authors estimated the total amount of three components (GW, SR, SFR) from the educational facilities in Hue by each category. Additionally, the authors estimated the total recycling potential, composting potential, and residual food amount in GW by the contribution of each component presented in Table 6 multiplied by the total amount of estimated GW amount

Table 7 presents the estimation of total waste and the breakdown of the waste generated from educational facilities. The total waste generated from educational facilities in Hue was 5.76 tons/day, of which 3.29 tons (57.2%) was GW, 0.15 tons (2.6%) was SR, and 2.33 tons (40.5%) was SFR. The high percentage of SFR revealed that pig farmers played an important role in MSW systems, recovering 40.5% of the total waste from educational facilities. Although the educational facilities achieved a certain level of recycling and separating of food residue, the GW still contained 19.3% that could be recycled and 22.4% that could be composted. Based on the comparison of the SR amount and the recycling potential by school category, it was suggested that the separated portion of recyclables was quite low, especially at "Kindergarten" and "Primary school" facilities; the amount of SR was only 0.01 tons (4.5%) in 0.22 tons of total recyclables and 0.03 tons (12.0%) in 0.25 tons of total recyclables, respectively. The composting potential was more than one-third the GW amount. Some past studies have mentioned that organic waste is typically the heaviest component of a waste stream and has the highest potential to emit greenhouse gases once buried in a landfill [30]. The result of this study suggested that the total disposal amount sent to a landfill could be reduced from 3.29 tons (57.2%) to 0.89 tons (15.5%) by recovering the recyclables and compostable parts within GW.

Regarding the contribution from each school category, "Kindergarten" was identified as the largest generation source with 1.99 tons/day, followed by "Primary school with food service" (1.5 tons/day), "Secondary school" (1.04 tons/day), "College & University" (0.83 tons/day), and "Day-care center" (0.26 tons/day). The "Private tutoring" category generated the smallest amount, with 0.04 tons/day. It is clear that the GW from "Secondary school," "Primary school with food service," "Kindergarten," and "College & University" categories contained larger recycling and composting potential. To promote recycling and composting at educational facilities, these four school categories should be considered as major targets to make separation an initial priority.

Interval estimation and uncertainty analysis of total waste generation from educational facilities in Hue

The 95% CI of the total waste amount from 402 educational facilities was also estimated by Monte Carlo simulation (100,000 times) assuming normal distributions based on the means and standard errors of the WGRs shown in Table 3. The results showed that the range for a 95% CI was 4.85-7.71 tons/day.

The authors also examined the sensitivity as a percentage of the contribution from the WGR of each school category to the variance of the total waste amount. Figure 1 presents the results of sensitivity analysis on the total waste generated at schools. "SFA at primary school with food service" was identified as the category with the largest impact on the CI of the total waste amount (55%), followed by "GW at primary school with food service" (16.8%), "GW at the secondary school" (8.2%), and "SFR at kindergarten" (5.9%). To improve the reliability of the total estimation, the authors should start by improving the data reliability at "Primary school with food service" by a further survey to increase the sample size and clarify the influencing factors on WGRs of SFR and GW.

Conclusions

1) This study aimed to provide a detailed description of the solid waste generation and composition from educational facilities in Hue, Vietnam. The authors surveyed 35 educational facilities for six school categories over seven consecutive days.

2) The WGRs by facility, student, classroom, staff member, and floor area were assessed by school category by three waste categories: general waste (GW), separated recyclables (SR), and separated food residue (SFR).

3) The mean differences of WGRs of the total waste among the school categories were assessed by ANOVA. There were significant differences in WGRs by all indicators among the six school categories.

4) GW was classified and measured by 10 physical categories and 77 sub-categories. Plastic, paper, and food waste were the dominant forms of waste in most school categories. "Composting potential in GW" accounted for 23.7%–57.2% and "Recycling potential in GW" accounted for 28.2%–53.9%.

5) The total waste generated from educational facilities in Hue was estimated to be 5.76 tons/day, of which 3.29 tons (57.2%) was GW, 0.15 tons (2.6%) was SR, and 2.33 tons (40.5%) was SFR. GW still contained 19.3% that could potentially be recycled and 22.4% that could potentially be composted in the total waste amount. The total disposal amount sent to the landfill could be reduced from 3.29 tons (57.2%) to 0.89 tons (15.5%).

6) To promote recycling and composting at educational facilities, the key findings can be summarized as follows:

- Target waste items: According to the detailed breakdown of recycling and composting potential, plastic containers & packaging, paper containers & packaging, paper products, kitchen waste, and garden waste showed the highest contributions.
- Target school categories: According to the estimated recycling and composting potential, "Secondary school," "Primary school with food service," "Kindergarten," and "College & University" contained the largest potential to recycle and compost within GW.

The above mentioned items and school categories should be considered as the major policy targets for separation with the

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highest priority.

7) The 95% CI of the total waste amount was estimated to be 4.85-7.71 tons/day. According to the sensitivity analysis, the WGRs of the "Primary school with food service" category were identified as having the largest impact on the CI of the total waste amount.

Acknowledgements

The authors sincerely thank the staff and students at Hue University for their assistance in this study. Special thanks to Dr. Pham Khac Lieu and Mr. Tran Ngoc Tuan who enthusiastically supported our survey. The authors also express their appreciation to the statistical office in Hue as well as all target schools for their collaboration.

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