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Estimation of the Solid Waste Generation and Recycling Potential of the Hotel Sector: A Case Study in Hue City, Vietnam

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Abstract

This study examined the solid waste generation and recycling potential of the hotel sector in Hue City, Vietnam. The authors conducted waste measurement, waste composition, and questionnaire surveys for 45 target hotels over ten consecutive days. The waste generation rates (WGRs) by rooms, beds, guests, and workers were assessed by hotel class using the following three waste categories, considering informal waste collection: general waste (GW), separated recyclables (SRe), and separated food residue (SFR). The 5-star hotels exhibited the highest WGR per room at 1.61 kg/room/day, while 1-star hotels exhibited the lowest per-room WGR (0.39 kg/room/day). Spearman Rank correlation test revealed that hotel class and per-room, per-bed, and per-guest WGRs were significantly positively correlated ($p < 0.01$). The major components of GW were food waste (40.9% to 57.4%), paper (10.1% to 20.3%), and plastic (10.7% to 15.5%). The recycling and composting potentials remaining in the GW were 19.3% to 38.5% and 38.0% to 57.9%, respectively. Based on the WGRs and waste composition determined in this study, the estimated total amount of waste generated was 6.88 tons/day (6.26 to 7.62 tons/day, 95% CI), of which 4.37 (64%), 2.13 (31%), and 0.38 tons/day (6%) were GW, SFR, and SRe, respectively. The recycling and composting potentials remaining in GW were 0.94 (13%) and 2.57 tons/day (37%), respectively. High-class hotels should be considered as the highest priority targets for a "reduce, reuse, recycle" (3R) promotion campaign in the future, with estimated recycling and composting potentials of 0.27 (4%) and 1.10 tons/day

(16%), respectively.

Keywords

Waste Generation, Recycling Potential, Hotel Sector, Confidence Interval Estimation

1. Introduction

Rapid urbanization, economic growth, and changing lifestyles have drastically increased the amount and variety of municipal solid waste (MSW) in developing countries [1]. Over 15 million tons of MSW are collected and treated annually by Vietnam's formal sector, of which 71% is directly filled in land [2]. Sanitary problems affecting public health and ecosystems have become an emerging environmental issue for Vietnamese authorities [3] [4] [5]. Furthermore, according to Vietnam's national strategy on the management of waste and discarded material issued in 2015 (Decree no. 38/2015/NĐ-CP), domestic solid waste must be classified and stored according to the following three groups: biodegradable organics, reusable and recyclables, and other wastes [6]. Currently, there are few official waste separation practices in Vietnam, and recycling activities are mainly conducted by the informal sector, for example, food waste collection by livestock breeders or recyclable material collection by waste pickers and junk-buyers [7] [8] [9].

Municipalities in Vietnam need to establish a MSW management system that considers public health, the efficient use of organic and recyclable waste, and recycling activities by the informal sector. Williams (2005) suggested that accurate data concerning estimated present and future production and composition of different types of waste were essential for efficient and economical long-term waste management planning [10]. It is important to understand the amount of waste generated; the waste composition, including the recycling potential of organic and recyclable materials; the waste stream, including informal sectors; and the contribution by each source as a scientific basis to establish a MSW management system and advance towards a sustainable society [11] [12].

The hotel sector is a primary source of MSW [9] [13] [14] [15] [16], and a major contributor of organic/wet waste in landfills, which is a major source of greenhouse gas emissions [17]. Otoma *et al.* (2013) suggested that the hotel sector contributed 9% of the total municipal solid waste in Danang, Vietnam [3].

Several studies have reported on the solid waste generation by Vietnam's hotel sector, and two approaches have been adopted for estimating waste quantity and composition. One distributes a questionnaire survey to the waste generators, and the other directly measures waste at the point at which it is generated or at the treatment facility [18]. Following the questionnaire survey method, Trung and Kumar (2005) surveyed 37 hotels in nine major Vietnamese tourist provinces, and reported the waste generation rate (WGR) per guest for different hotel classes in different areas [19]. However, the data regarding the amount of waste

obtained by the questionnaire survey were not validated by comparing them with actual WGRs obtained by direct measurement. Following the direct measurement method, Byer *et al.* (2006) surveyed three hotels in Halong, Vietnam for one week, including 2-, 3-, and 4-star hotels. They measured WGRs per room and guest, and determined the physical composition of waste based on nine categories that included organic, inorganic, and recyclable waste [9]. Giang *et al.* (2017) surveyed nine hotels in Hoi An, Vietnam, and reported a per-room WGR that ranged from 0.35 kg/room/day for a small hotel to 4 kg/room/day for a 4-star hotel [20]. Otoma *et al.* (2013) surveyed 10 hotels in Danang, Vietnam, and reported average WGRs of 89.72 kg/hotel/day and 0.95 kg/room/day [3]. However, these studies did not consider the influence factor of waste generation by the hotel sector, or the amounts of recyclable material and food residue collected by the informal sector.

Hue City is a major tourism city in Vietnam and houses a UNESCO World Heritage Site, the Complex of Hue Monuments, inscribed in 1993. The authors selected Hue City as a study area to determine waste generation by the hotel sector. To provide scientific information for promoting the 3Rs (reduce, reuse, recycle) in the hotel sector, this study aims to determine the WGRs of hotel sector in Hue City by 3 categories: compostable, recyclable, and other materials; identify the factors influencing WGRs; and describe the waste flow in detail. To consider the amount of waste collected by the informal sector and determine differences between hotel classes, the authors determined the amount of waste, including recyclables and food residues, collected by the informal sector and surveyed 45 accommodation facilities covering all hotel classes. This study also presents an interval estimation of the total amount of waste and its' components by Monte Carlo simulation. Uncertainty analysis was also conducted to understand the impact of the reliability of each waste flow component on the confidence interval of the total amount of waste.

2. Methodology

2.1. Research Area and the Target Sample

Hue City, the capital city of Thua Thien Hue Province located in central Vietnam, was selected as the study area (**Figure 1**). Hue City contains 27 wards with 354,124 people at a population density of 4779 persons per km^2 as of 2015 [21]. In 2014, the Vietnamese government approved "Decision No. 649/QD-TTg—Approval for Adjustments to General Planning for Hue City to 2030 and a Vision to 2050", which called for Hue City to become environmentally sustainable [22]. Approximately 210 tons/day of waste is collected in Hue City and the general collection rates for the whole city and urban areas are approximately 89 and 90% - 95%, respectively [23].

As a city with a UNESCO World Heritage Site, the number of tourists visiting Hue City rapidly increased at an annual growth rate of 10%, reaching 2.5 million in 2012. To fulfill the demands of the visitors, the number of accommodation

Figure 1. Location and boundary of the research area. Source: Google Maps and Hue's People Committee website.

facilities also continually increased, reaching 402 facilities with 7762 rooms and 13,660 beds in 2012 [24]. Based on the guest house and hotel classification standards, the 402 facilities in Hue City are categorized into six classes: guest house (GH), 1-star hotel, 2-star hotel, 3-star hotel, 4-star hotel, and 5-star hotel [25] [26].

To acquire representative samples of the hotel sector, the authors applied systematic sampling based on lists of hotels sorted by the number of beds. The lists were prepared separately for the abovementioned six classes, and the number of samples by hotel class is shown in **Table 1**.

2.2. Outline of Survey

The survey procedure followed the methodology presented by Matsui *et al.* (2015) [13]. The authors conducted three surveys for all target samples from June 2nd to 11th, 2012: actual waste measurement, waste composition and questionnaire surveys.

The authors requested the target facilities to keep their waste into the following three categories based on their typical separation manner:

- Separated recyclables (SRe): waste items separately kept for recycling, selling to the informal sector, or transferred to somewhere/someone else by the owners;
- Separated food residue (SFR): edible leftover food separately kept for feeding, collected by livestock breeders;
- General waste (GW): all remaining waste items collected daily by the formal waste collection sector, the Hue Urban Environment and Public Works State Company (HEPCO).

Table 1. Numbers of hotels in Hue City and target samples by hotel class.

Hotel class	Facility	Room	Bed	Target sample
Guest house	289	2511	4071	10
1-star hotel	55	1071	2008	10
2-star hotel	31	1156	2226	7
3-star hotel	12	868	1615	8
4-star hotel	11	1509	2750	7
5-star hotel	4	648	990	3
Total	402	7763	13,660	45

Source: General statistics office, 2015.

The authors assessed the waste separation rate at the target facilities based on their usual separation behavior, which was categorized into the following four patterns: 1) recyclables and food residue separation, 2) recyclables separation only, 3) food residue separation only, and 4) no separation.

Regarding the actual waste measurement survey, the surveyors daily visited all the target facilities and directly measured the amount of waste generated over 10 consecutive days. The first three days were spent preparing the surveyors and target facilities, and data from the following seven days were used for the analysis.

The waste composition survey was conducted to evaluate the recycling and composting potentials of GW. The authors selected 21 target facilities with recyclables and food residue separation. (The sample size by hotel class is shown in Table 6) GW was classified based on materials (plastic, paper, kitchen waste, rubber and leather, grass, textile, metal, glass, ceramic, and miscellaneous), types (container/packaging, product, and other), and their potentials for recycling and composting. The authors sorted GW into 10 physical categories and 77 detailed sub-categories as shown in Table 2, and regrouped GW into the following three sub-categories:

- Recycling potential (Re): the recyclable portion of the discharged GW, defined based on Hue City's current informal sector trading market in 2012;
- Composting potential (Co): the compostable portion of the discharged GW, referred from the acceptable items established by Vietnamese composting facilities;
- Non-recyclable (NRe): The remaining portions of GW after the abovementioned recycling and composting potentials were considered.

The authors also conducted a questionnaire survey at the target facilities. The attributes and influencing factors on waste generation and recycling activities were collected and used for further analytical procedures.

2.3. Analytical Procedure

The WGRs were calculated by dividing the daily amount of waste generation by four business scale indicators: number of rooms, number of beds, number of

Table 2. Categorization of waste from hotel sector.

Category	Code	Details	Recycling potential
1. Plastic			
Container & Packaging	101	PET bottles	Re
	102	Other plastic bottles	Re
	103	Tray	Re
	103*	Tray	NRe
	104	Tube	Re
	104*	Tube	NRe
	105	Other shapes	Re
	105*	Other shapes	NRe
	106	Shopping plastic bags	Re
	107	Other plastic packaging	Re
Product	108	Other C&P	Re
	108*	Other C&P	NRe
	109	Plastic products	Re
	109*	Plastic products	NRe
Other plastics	110	Other plastics	Re
	110*	Other plastics	NRe
2. Paper			
Container & Packaging	201	Carton	Re
	202	Containers	Re
	203	Cardboard	Re
	204	Packaging	Re
	205	Other C&P	Re
	206	Newspaper/poster	Re
Product	207	Books	Re
	208	Notebooks	Re
	209	Photocopy	Re
	210	Disposal paper products	NRe
	210*	Nappies/Diapers	NRe
	211	Other paper product	Re
	211*	Other paper products	NRe
Other Paper	212	Other Paper	Re
	212*	Other Paper	NRe
5. Grass and wood			
Container & Packaging	503	Containers & packaging	Co
	503*	Containers & packaging	NRe
Product & Others	504	Grass and wood products	Co
	504*	Grass and wood products	NRe
6. Textile			
	601	Clothes	Re
	602	Daily commodities	NRe
	603	Disposed commodities	NRe
	604	Other product	Re
7. Metal			
Aluminum	701	Containers	Re
	702	Other containers and packaging	Re
	702*	Other containers and packaging	NRe
	703	Products and others	Re
	703*	Products and others	NRe
Steel	704	Containers	Re
	704*	Containers	NRe
	705	Other containers and packaging	Re
	706	Products and others	Re
Stainless	707	Products and others	Re
Lead	707*	Products and others	NRe
Other metals	708	Other metals	Re
	708*	Other metals	NRe
8. Glass			
Container	801	Returnable bottle	Re
	802	Disposal bottle	Re
	803	Other containers	Re
Products and others	804	Thermometers, fluorescent lamp	NRe
	805	Products and others	NRe
9. Ceramic			
	901	Containers	NRe
	902	Products and others	NRe

Continued

3. Kitchen waste				**10. Miscellaneous**			
Compostable	301	Kitchen waste	Co		1001	Combustibles	NRe
Non-compostable	301*	Coconut/Durian shells	NRe		1002	Liquids_edible	Co
	302	Hard animal bones	NRe		1002*	Liquids_inedible	NRe
4. Rubber and leather					1003	Incombustibles (no ash)	NRe
	401	Rubber and leather	NRe		1004	Ash	NRe
5. Grass and wood					1005	Medical care	NRe
Garden waste	501	Garden waste	Co		1006	Batteries	NRe
	501*	Garden waste	NRe		1007	E-waste	NRe
	502	Flower	Co		1008	Others	NRe

*: Non-recyclable waste.

workers (including managers and serving workers), and number of guests as follows:

$$WGR_i = \frac{DWA}{TN_i} \quad (1)$$

where:

WGR_i: Waste generation rate of each target hotel by four indicators: waste generation amount per room, that per bed, that per worker, and that per guest;

DWA: Daily amount of waste generation of each target hotel;

TN_i: Total number of unit of each target hotel by four indicators: number of rooms, number of beds, number of workers, and number of guests.

To determine whether the WGRs followed a normal/Gaussian distribution, the authors applied a Shapiro-Wilk test [27] [28] and found that the WGR distributions were significantly different from a normal distribution ($p < 0.001$). Therefore, the authors employed non-parametric tests for further analysis.

In this study, the WGRs are reported as the mean with the 95% confidence interval (95% CI). Non-parametric bootstrap with replacement sampling method was applied to determine the 95% CI [12]. The authors assessed the difference in WGRs between hotel classes using a Kruskal-Wallis H test. And, a Mann-Whitney U test was used to identify significant differences between hotel classes by comparing all the pairs [28].

The composition of GW was analyzed using the categories and sub-categories listed in **Table 2**, and the recycling and composting potentials were aggregated based on this table.

To establish the solid waste stream from the hotel sector in Hue City, the authors estimated the total amount of generated waste, as well as its components by hotel class based on the WGR, waste separation rate, and waste composition survey results collected in this study. The detailed procedure is introduced in Section 3 after these results are elaborated.

3. Results and Discussion

3.1. Waste Separation Rate

The waste separation rates of the target samples are summarized in Table 3 by the following 4 separation patterns: 1) recyclables and food residue separation, 2) recyclables separation only, 3) food residue separation only, and 4) no separation. The waste separation rates were calculated by dividing the number of targets applying specific waste separation activities by the total number of observed facilities by each hotel class.

$$WSR_{ij} = \frac{NHS_{ij}}{TNH_j} \quad (2)$$

where:

WSR_{ij}: waste separation rate of separation pattern i of hotel class j;

NHS_{ij}: number of facilities with separation of separation pattern i of hotel class j;

TNH_j: total number of facilities of hotel class j.

The results show that most of the target hotels (43 of 45 facilities) separated their waste. All 3- to 5-star hotels separated recyclables and food residue, while the waste separation rates of GH and 1-star hotels were lower. This tendency seems to be consistent with that found in a study on the hotel sector in Cairo, Egypt, which reported that high-class hotels successfully sorted waste at its source [29]. A study on hotels in India by Malik, S.M. and Kumar (2012) also suggested that small hotels have not paid attention to solid waste management practices due to a lack of funds and knowledge, which may be a reason for the difference in the waste separation rate between hotel classes [30].

3.2. Waste Generation Rate and Influence Factors

WGRs are reported to differ between hotel classes, services, and regions [31] [32] [33]. A similar tendency was observed in a study on the hotel sector in Halong, Vietnam (Byer *et al*., 2006), which reported daily waste generation rates of 203.3, 114.3, and 89 kg/day at 4-, 3-, and 2-star hotels, respectively [9].

Table 4 presents the total daily amounts of waste generated and WGRs (mean and 95% confidence interval) in three categories based on the hotel's typical separation manner, calculated by the following four denominators: room, bed,

Table 3. Waste separation status by hotel class.

Waste separation activity	GH	1-star	2-star	3-star	4-star	5-star
Sample size (n)	10	10	7	8	7	3
Recyclables and food residue	10%	40%	86%	100%	100%	100%
Recyclables only	70%	30%	14%	0%	0%	0%
Food residue only	10%	20%	0%	0%	0%	0%
No separation	10%	10%	0%	0%	0%	0%

Table 4. Waste generation rates by hotel class.

Category	n	Total waste		GW		SRe		SFR	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Total daily waste generation amount (kg/day)									
Guest house	10	5.3	3.8 - 7.0	4.2	2.8 - 5.9	0.5	0.3 - 0.7	0.6	0 - 1.4
1-star hotel	10	7.8	6.0 - 9.8	5.5	4.3 - 6.8	0.7	0.3 - 1.0	1.6	0.6 - 2.7
2-star hotel	7	30.1	21.7 - 38.4	15.5	12.4 - 18.6	1.8	1.4 - 2.4	12.8	7.2 - 18.9
3-star hotel	8	68.8	58.8 - 179.0	36.3	33.9 - 86.6	2.5	4.3 - 11.8	29.9	19.3 - 83.9
4-star hotel	7	190.5	151.9 - 231.7	102.1	81.4 - 126.9	10.8	7.0 - 14.9	77.6	58.5 - 97.2
5-star hotel	3	271.8	223.1 - 490.6	162.8	146.5 - 220.8	14.9	9.1 - 42.1	94.0	55.4 - 234.5
K-W test (H value)		38.058***		37.321***		31.669***		37.046***	
Spearman's ρ		0.917**		0.906**		0.813**		0.899**	
WGRs per room (g/room/day)									
Guest house	10	534	382 - 708	400	272 - 567	42	24 - 61	95	0 - 224
1-star hotel	10	387	300 - 488	294	226 - 363	34	18 - 52	59	22 - 99
2-star hotel	7	779	562 - 993	415	332 - 498	51	39 - 68	313	175 - 460
3-star hotel	8	1155	987 - 3007	606	565 - 1443	42	71 - 196	507	328 - 1423
4-star hotel	7	1455	1160 - 1770	769	613 - 956	86	56 - 119	600	452 - 751
5-star hotel	3	1607	1319 - 2901	995	895 - 1349	85	52 - 240	526	310 - 1312
K-W test (H value)		27.97***		22.31***		11.81***		27.49***	
Spearman's ρ		0.807**		0.708**		0.453**		0.793**	
WGRs per bed (g/bed/day)									
Guest house	10	487	333 - 668	369	234 - 548	42	24 - 61	75	0 - 187
1-star hotel	10	265	194 - 339	206	144 - 273	21	11 - 32	38	14 - 61
2-star hotel	7	379	315 - 444	211	178 - 245	27	20 - 34	142	82 - 199
3-star hotel	8	613	711 - 2263	323	399 - 1110	22	48 - 150	268	254 - 1048
4-star hotel	7	821	632 - 1007	431	337 - 535	49	31 - 69	341	246 - 431
5-star hotel	3	1208	702 - 1528	757	445 - 710	63	28 - 126	388	165 - 691
K-W test (H value)		24.31***		17.22**		10.80*		27.73***	
Spearman's ρ		0.779**		0.573**		0.291		0.833**	
WGRs per guest (g/guest/day)									
Guest house	5	604	424 - 785	432	237 - 629	30	4 - 56	141	8 - 303
1-star hotel	4	603	483 - 724	466	313 - 641	30	0 - 64	107	29 - 184
2-star hotel	4	481	383 - 610	300	233 - 381	26	18 - 40	155	59 - 244
3-star hotel	7	1706	1347 - 2136	963	754 - 1169	65	38 - 91	717	516 - 993
4-star hotel	6	2322	1705 - 3112	1175	855 - 1504	147	107 - 192	1001	697 - 1456
5-star hotel	3	6568	2583 - 10061	4162	1175 - 6148	301	223 - 409	2104	1185 - 3504
K-W test (H value)		24.056***		20.108***		19.117**		22.746***	
Spearman's ρ		0.747**		0.645**		0.746**		0.809**	

Continued

WGRs per worker (g/worker/day)									
Guest house	10	2144	1455 - 3170	1756	1057 - 2706	216	107 - 357	172	0 - 411
1-star hotel	10	786	635 - 941	604	466 - 751	65	33 - 97	117	37 - 215
2-star hotel	7	1431	904 - 2002	756	536 - 1016	88	68 - 111	587	247 - 934
3-star hotel	7	1403	1075 - 6289	738	605 - 2957	53	15 - 338	611	576 - 3092
4-star hotel	7	1151	892 - 1413	606	470 - 758	68	43 - 94	476	351 - 600
5-star hotel	3	1263	949 - 2498	757	588 - 1161	70	38 - 206	436	249 - 1130
K-W test (H value)		18.87**		13.87*		9.12		18.05**	
Spearman's ρ		−0.049		−0.353		−0.297		0.638**	

K-W test: H value by Kruskal-Wallis test by ranks; Spearman's ρ: Rank correlation coefficient by Spearman method; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

guest, and worker. Table 4 also shows the results of the Kruskal-Wallis H tests and Spearman's rank correlation analyses.

Regarding the difference between hotel classes, the rank correlations between total daily amounts of waste generated and WGRs and room, bed, and guest were significantly positive (excluding the WGR of SRe per bed). The 5-star hotels exhibited the highest total daily waste generation (271.8 kg/day), followed by 4-star hotels (190.5 kg/day), 3-star hotels (68.8 kg/day), 2-star hotels (30.1 kg/day), 1-star hotels (7.8 kg/day), and GHs (5.3 kg/day). The daily waste generation and WGRs increased as the hotel increased. The results were consistent with those in past studies on the hotel sector [17] [31] [34].

For the per-guest WGRs, 5-star hotels generated an average of 6.57 kg/guest/day, followed by 4-star hotels (2.32 kg/guest/day), 3-star hotels (1.71 kg/guest/day), 2-star hotels (0.48 kg/guest/day), 1-star hotels (0.60 kg/guest/day), and GHs (0.60 kg/guest/day).

According to some previous studies on the WGRs of the hotel sector in Asia [17] [35] [36], the per-guest WGRs range from 0.8 to 3.33 kg/guest/day, which overlaps the range of 0.60 to 6.57 kg/guest/day presented in this study.

The per-worker WGRs of GW and SRe were not significantly rank correlated with hotel class, and those by GHs were highest. The number of workers employed by GH was generally much smaller than that employed by higher-class hotels, which could have caused the increased per-worker WGRs at GHs. The GW and SRe WGRs of 2- to 5-star hotels were similar, despite higher-class hotels employing greater numbers of workers. This could be attributed to the higher WGRs per room, bed, and guest exhibited by higher-class hotels.

The SFR WGRs was significantly rank correlated with hotel class. Most 3-5-star some 2-star, and a few 1-star hotels and GHs provide food and beverage services, such as restaurants and coffee shops/bars, which could be a possible reason for the higher SFR WGRs of higher-class hotels.

Based on the results of the Kruskal-Wallis H test, there were significant differences in the total per-room WGRs between hotel classes $\left(\chi^2(5) = 27.97, p < 0.001\right)$,

and significant differences were also detected for other WGRs per bed, guest, and worker. To clarify the significant differences between hotel classes, a Mann-Whitney U test was conducted by comparing all WGR pairs. The results suggested that hotel classes could be re-grouped into: 1) Low (guest house and 1-star hotel); 2) Middle (2- and 3-star hotels); and 3) High (4- and 5-star hotels) classes. The WGRs were recalculated by these three hotel classes and presented in Table 5.

The authors also examined the influences of factors such as food service (breakfast, dining) and events (wedding party, conference) on WGRs. The Mann Whitney U test for each class indicated that there was no significant difference ($p > 0.05$) between hotels with and without food services/events.

3.3. Waste Composition and Recycling Potential

Table 6 presents the physical composition (in percentage) of GW by hotel class. Food waste accounted for the largest proportion of GW for all hotel classes, and was highest for GHs (57.4%), followed by 5- (56.6%), 1- (51.0%), 3- (48.4%), 4- (44.1%), and 2-star hotels (40.9%). These results are similar to those from a study on ten hotels in Danang, Vietnam, by Otoma *et al.* (2013), who reported that food waste accounted for 65.5% of waste. Paper accounted for the second largest proportion, ranging from 10.1% (5-star hotel) to 23.9% (1-star hotel), followed by plastic, ranging from 10.7% (2-star hotel) to 15.5% (GH).

Table 6 also presents the waste composting and recycling potentials from GW. The composting potential was highest for most hotel classes, especially low-class hotels (53.2%). The recycling potential was highest for 2-star hotels, at 38.5%, followed by 4-star hotels (35.1%) and GHs (33.5%).

Plastic containers and packaging, paper containers and packaging, and paper products were the major three components that could be recycled, accounting for over half of the recycling potential for most hotel classes (excluding 2-star hotels). Plastic containers and packaging accounted for a major proportion of the recycling potential at low-class hotels (10.2%). In contrast, paper products

Table 5. Waste generation rates by three hotel classes.

Category	n	Total waste		GW		SRe		SFR	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
WGRs per room (g/room/day)									
Low-class hotels[1]	20	461	371 - 585	347	295 - 486	38	30 - 55	77	9 - 104
Middle-class hotels[2]	15	980	769 - 1205	517	413 - 621	46	34 - 59	417	299 - 544
High-class hotels[3]	10	1501	1251 - 1772	837	666 - 1048	86	61 - 111	578	470 - 689
K-W test (H value)		25.582***		19.075***		10.304***		26.138***	
Spearman's ρ		0.843**		0.764**		0.493**		0.824**	

[1]Low-class hotels: Guesthouse and 1 star hotels; [2]Middle-class hotels: 2 and 3 star hotels; [3]High-class hotels: 4 and 5 star hotels. K-W test: H value by Kruskal-Wallis test by ranks; Spearman's ρ: Rank correlation coefficient by Spearman method; **: $p < 0.01$; ***: $p < 0.001$.

Table 6. Physical composition of GW from the hotel sector by hotel class (%).

Component	Hotel class								
	GH	1-star	2-star	3-star	4-star	5-star	Low[1]	Middle[2]	High[3]
Sample size (n)	8	4	3	3	2	1	12	6	3
Plastic	15.5	12.0	10.7	11.8	11.5	12.5	14.4	11.2	11.9
Paper	13.5	23.9	16.7	14.8	20.3	10.1	17.0	15.8	16.9
Food waste	57.4	51.0	40.9	48.4	44.1	56.6	55.2	44.7	48.3
Rubber & leather	0.3	0.2	2.8	0.7	0.2	0.0	0.2	1.8	0.2
Grass & wood	2.0	7.2	10.7	8.5	6.4	7.0	3.7	9.6	6.6
Textile	2.4	2.2	7.7	1.6	4.0	0.9	2.3	4.7	3.0
Metal	1.3	0.2	1.7	0.7	0.4	0.3	1.0	1.2	0.3
Glass	3.8	1.0	3.3	0.3	1.4	1.1	2.9	1.8	1.3
Ceramic	0.6	0.0	0.0	0.3	0.6	7.4	0.4	0.1	2.9
Miscellaneous	3.2	2.4	5.5	12.9	11.0	4.2	2.9	9.2	8.7
Composting potential	57.9	43.9	38.0	52.4	48.7	48.8	53.2	45.2	48.7
Food waste	56.0	41.0	27.9	44.8	42.5	45.7	51.0	36.3	43.6
Garden waste	1.9	2.9	10.2	7.6	6.2	3.0	2.2	8.9	5.2
Recycling potential	33.5	31.5	38.5	28.6	35.1	19.3	32.8	33.6	29.8
Plastic—C&P [a]	11.1	8.6	6.9	8.1	7.1	4.5	10.2	7.5	6.2
Plastic—Product	2.7	1.1	1.5	2.3	1.4	1.1	2.1	1.9	1.3
Plastic—Other	0.0	0.6	0.9	0.0	0.6	0.0	0.2	0.5	0.4
Paper—C&P [a]	4.6	7.4	4.1	5.1	4.1	3.3	5.5	4.6	3.8
Paper—Product	7.4	8.4	7.2	8.2	14.3	5.7	7.7	7.7	11.5
Paper—Other	1.6	1.0	1.8	0.5	0.8	1.0	1.4	1.1	0.9
Other material	6.0	4.3	16.1	4.4	6.8	3.7	5.6	10.2	5.7
Non-recyclable	8.6	24.6	23.5	19.0	16.2	31.9	13.9	21.2	21.4

[a]C & P: containers and packaging. [1]Low-class hotels: Guesthouse and 1 star hotels; [2]Middle-class hotels: 2 and 3 star hotels; [3]High-class hotels: 4 and 5 star hotels.

dominated the recycling potential at high-class hotels (11.5%). Although the hotel sector in Hue City conducts recycling using informal sectors such as junk-buyers and livestock breeders, substantial amounts of compostable and recyclable waste still remain in GW. Recycling activities tend to focus on materials that are easily separated and high value, such as beverage containers, while items that are not easily separated, such as a small amount of recyclables and smelly organic waste, are often put into GW without separation.

3.4. Estimation of Waste Generation

The estimation procedure followed the methodology reported by Matsui *et al.* (2018) [12]. To depict the solid waste stream from the hotel sector in Hue City,

the authors estimated the total waste generation and its components by hotel class based on the per-room WGRs (Table 6), waste composition (Table 6), waste separation rates (Table 7), and total number of rooms (Table 7) by hotel class, as follows.

For the facilities separating both recyclables and food residue, the total waste generation could be divided into the following five components based on the waste's composition and waste measurement survey data: recycling potential, composting potential, non-recoverable, separated recyclables, and separated food residue. For the facilities with other types of separation procedures, such as "recyclables only", "food residue only", and "no separation", the authors estimated the amounts of waste generated for the five components using the waste composition data of facilities conducting "recyclables and food residue separation" according to assumed component allocations, as shown in Table 8. The authors assumed that the unseparated recyclables and food residue were discharged as a part of the recycling and composting potentials in GW at these facilities.

Based on the waste composition data of facilities separating "recyclables and food residue", the total waste generation and its five components for each hotel class was calculated using the following equations:

Table 7. Waste separation status and number of rooms in Hue City by hotel class.

	Low-class[a]	Middle-class[b]	High-class[c]
Waste separation status			
Sample size (n)	20	15	10
Recyclables and food residue	25%	93.5%	100%
Recyclables only	50%	6.5%	0%
Food residue only	15%	0%	0%
No separation	10%	0%	0%
Number of hotels in Hue City			
Facilities	344	43	15
Rooms	3582	2024	2157

[a]Low-class hotel: Guesthouse and 1 star hotels; [b]Middle-class hotel: 2 and 3 star hotels; [c]High-class hotel: 4 and 5 star hotels. Source: General statistics office, 2015.

Table 8. Assumed component allocations by waste separation status.

Separation status	Rate	General waste			Separated recyclables	Separated food residue
		Recycling potential	Composting potential	Non-recoverable		
Recyclables and food residue separation	a_1	Re	Co	NRe	SRe	SFR
Recyclables separation only	a_2	Re	Co + SFR	NRe	SRe	-
Food residue separation only	a_3	Re + SRe	Co	NRe	-	SFR
No separation	a_4	Re + SRe	Co + SFR	NRe	-	-

$$\text{Recycling potential} = n_i * \left[\left(a_1 + a_2 \right) * \text{Re} + \left(a_3 + a_4 \right) * \left(\text{Re} + \text{SRe} \right) \right]$$

$$\text{Composting potential} = n_i * \left[\left(a_1 + a_3 \right) * \text{Co} + \left(a_2 + a_4 \right) * \left(\text{Co} + \text{SFR} \right) \right]$$

$$\text{Non-recyclable} = n_i * \left(a_1 + a_2 + a_3 + a_4 \right) * \text{NRe}$$

$$\text{Separated recyclables} = n_i * \left(a_1 + a_2 \right) * \text{SRe}$$

$$\text{Separated food residue} = n_i * \left(a_1 + a_3 \right) * \text{SFR}$$

Total waste generation I = Recycling potential + Composting potential + Non-recyclable + Separated recyclables + Separated food residue.

Where n_i is the total number of rooms in Hue City by each hotel class (Low-class, Middle-class, High-class).

To estimate the 95% CI of the total waste generation and its five components from the hotel sector in Hue City, the Monte Carlo simulation by non-parametric bootstrap method with return was applied [12] [37].

The results of the total waste generation and its components by the Hue hotel sector are shown in **Figure 2**. The figure shows both the results of point estimation by the average value of each parameter and those of the 95% CI. From the point estimation results, the total waste generation of the hotel sector in Hue City was estimated to be 6.88 tons/day, 4.37 tons/day (64%) of which was GW, 2.13 tons/day (30%) was SFR, and 0.38 tons/day (6%) was SRe. The estimated composting and recycling potentials remaining in the GW were 2.57 (37%) and 0.87 tons/day (13%), respectively. The results show that the amount of waste treated at the landfill site could be reduced by 78%, from 4.37 to 0.94 tons/day, by improving waste separation at source.

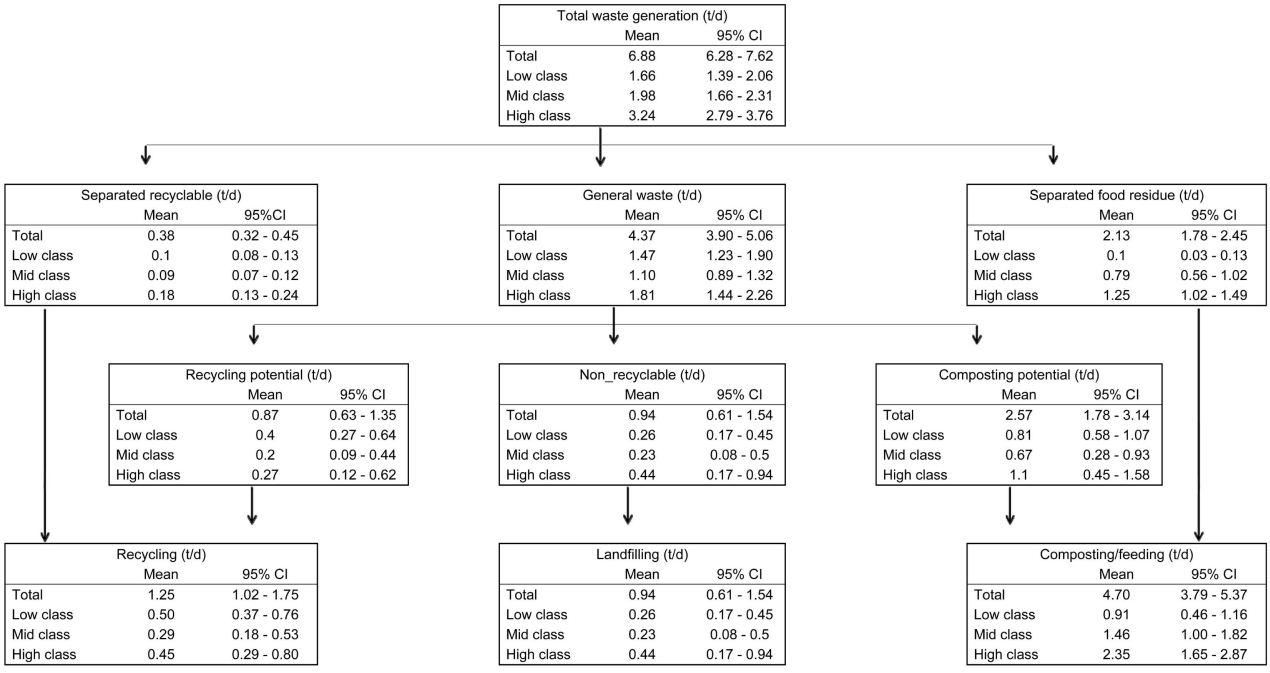

Figure 2. Estimated waste stream of the hotel sector in Hue City.

High-class hotels contributed the highest amount of waste to the total amount generated by the hotel sector, at 3.24 tons/day (47%), followed by middle-class hotels at 1.98 tons/day (29%), and low-class hotels at 1.66 tons/day (24%). The recycling potential was highest for low-class hotels at 0.4 tons/day (6%), and the composting potential was highest for high-class hotels at 1.10 tons/day (16%).

The 95% CI of the total waste generation by the hotel sector was 6.28 - 7.62 tons/day, and the 95% CIs of the separated recyclable and separated food residue were 0.32 - 0.45 and 1.78 - 2.45 tons/day, respectively.

To estimate the impact of each parameter used for the confidence interval estimation of total waste generation, the authors also conducted sensitivity analysis by squaring the Spearman's Rank Coefficients of each parameter, summing the results, and adjusting them to 100% [12] [38] [39]. The results presented in **Figure 3** show that GW produced by high-class hotels contributed the most to sensitivity (38.2%), followed by GW produced by low-class hotels (22.3%), SFR produced by middle-class hotels (12.4%), and SFR produced by high-class hotels (11.7%). The GW produced by high-class hotels was the largest contributor, constituting 26% of the total waste generation. Therefore, it contributed the most to the sensitivity analysis result. To improve the reliability of the estimated total waste generation, the parameters with greater impacts on uncertainty require additional data collection and/or modeling by influence factors, which would reduce the overall uncertainty of the results.

4. Conclusions

This study assessed the solid waste generation and recycling potential of the hotel sector in Hue City, Vietnam. The authors analyzed waste generation rates (WGRs) and composition in detail for 45 targeted establishments. The WGRs were also categorized considering the amount of waste collected by informal

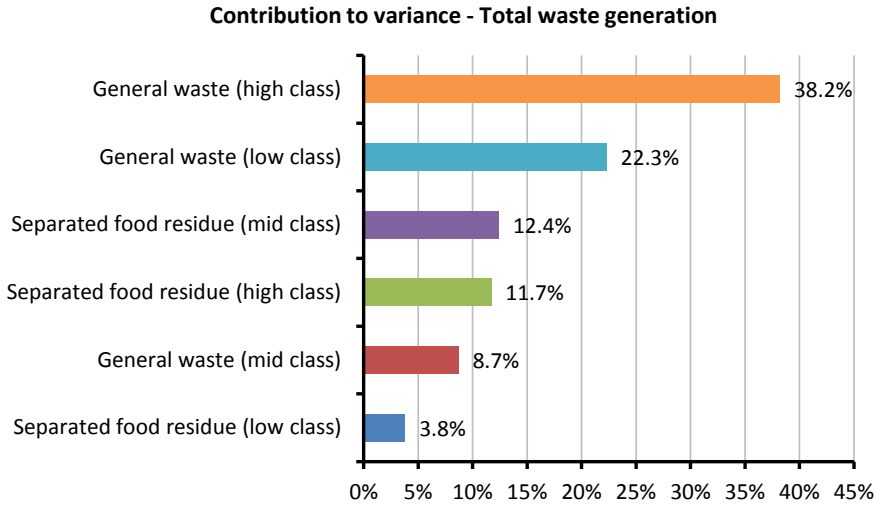

Figure 3. Sensitivity analysis of the total waste generation of the hotel sector.

sectors: general waste (GW), separated recyclables (SRe), and separated food residue (SFR). Some key findings of this study are outlined below.

1) Participation in waste separation by the hotel sector in Hue City was very high; 95.56% of the target establishments separated waste at its source. Food waste separation was common among middle- and high-class hotels (from 2- to 5-stars) where food and beverage services (such as restaurants or café bars) were provided.

2) The average total daily waste generation per facility was highest at 5-star hotels (271.8 kg/day), followed by 4- (190.5 kg/day), 3- (68.8 kg/day), 2- (30.1 kg/day), and 1-star hotels (7.8 kg/day), and guest houses (5.3 kg/day).

3) The total per-room WGRs were highest for 5-star hotels at 1.61 kg/room/day, and lowest for 1-star hotels (0.39 kg/room/day). In addition, the total per-guest WGRs were highest for 5-star hotels at 6.57 kg/guest/day, and lowest for 1-star hotels and guest houses (0.6 kg/guest/day). The rank correlations between the hotel classes and WGRs per room, bed, and guest (excluding the WGR of SRe per bed) were significantly positive.

4) Food waste constituted the largest proportion of GW within a range of 40.9% -57.4%. The composting and recycling potentials were within ranges of 38.0% - 57.9% and 19.3% - 38.5%, respectively. Plastic containers and packaging, paper containers and packaging, and paper products were the three major components, accounting for over half of the recycling potential of most hotel classes. Plastic containers and packaging accounted for a major proportion of the recycling potential at low-class hotels (10.2%), while paper products were dominant at high-class hotels (11.5%).

5) The total waste generation of the hotel sector in Hue City was estimated to be 6.88 tons/day (6.28 - 7.62 tons/day, 95% CI). The remaining recycling and compostable potentials of GW accounted for 0.87 tons/day (0.63 - 1.35 tons/day, 95% CI) and 2.57 tons/day (1.78 - 3.14, 95% CI), respectively. Therefore, the total amount of non-recyclable waste delivered to landfill sites can be reduced from the current 4.37 tons/day (3.90 - 5.06 tons/day, 95% CI) to 0.94 tons/day (0.61 - 1.54 tons/day, 95% CI).

6) The recycling potential of GW was highest for low-class hotels at 0.4 tons/day (0.27 - 0.64 tons/day, 95% CI), and the composting potential of GW was highest for high-class hotels at 1.10 tons/day (0.45 - 1.58 tons/day, 95% CI). High-class hotels should be considered as priority targets for a 3R promotion campaign in the future.

7) Based on the sensitivity analysis, the GW produced by high-class hotels had the highest influence (38.2%) on the estimated total waste generation, followed by GW produced by low-class hotels (22.3%), SFR from middle-class hotels (12.4%), and SFR from high-class hotels (11.7%). To improve the reliability of the estimated total waste generation, the parameters with greater impacts on uncertainty require additional data collection and/or modeling by influence factors to reduce the overall uncertainty of the results.

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