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Quantifying Food Waste Produced in Dormitories: A Case Study from a University in New York, USA

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Abstract

Globally, 30-50% of food produced, approximately 1.3 billion tons, is wasted prior to consumption [1–4]. Food waste at colleges and universities poses a serious concern, as its impact can be compared to that of mini-cities or large corporations. Identifying an institution's capacity to reduce and redistribute food waste is critical to decreasing its carbon footprint and maintaining sustainability. Understanding the nature of waste produced at a university's buildings is the first step in establishing effective waste management plans; however, campus cafeterias, being the primary source of food waste, are typically the focus. Limited research emphasis has been placed on assessing food waste generated in campus dormitories. This project tests the hypothesis that food waste generated from dormitories at the main campus of Adelphi University, a private liberal arts institution in New York, is a significant component of waste. To analyze post-consumer trash disposal patterns, garbology methods were utilized [5–7]. Trash collected at dormitories between 2022 and 2024 was sorted and weighed. This mixed methods analysis included student interviews of waste perceptions. Food waste was the primary waste type generated in the halls, followed by food and beverage packaging, including containers, napkins, and utensils. In particular, food waste comprised 32.3% of sampled dormitory waste. Interview results integrated with these quantitative results demonstrated student perceptions of food led to food waste, such as perceived level of cooking, portion sizes, and home context. These results suggest that any efforts to improve campus sustainability through management of food waste–such as composting or anaerobic digestion–must encompass dormitories as well as cafeterias.

Keywords: food waste; garbology; university dormitories

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1. Introduction

Food waste encompasses items that are meant for human consumption but are discarded, contaminated, or degraded throughout all stages of the food supply chain, including pre-packaged food thrown away because of expiration dates or best used by date labels [2,8–14]. The majority of food waste is generated during the post-consumer stage [4]. Food waste is becoming increasingly recognized as a global issue that contributes to unsustainable utilization of natural resources [2,15,16], food insecurity [3] and its related health consequences including diabetes, obesity, heart disease, and mental health disorders [17–19]. Decomposition of food waste that is disposed of in landfills also contributes significantly to global greenhouse gas emissions [20–32].

In 2017 total global waste was estimated to be 20 billion tons, or 2.63 tons of total waste per capita per year, and it is expected to be 46 billion tons by 2050 [33]. Globally 30-50% of food produced (1.3 billion tons) is wasted [1,3,4,34]. According to the United Nations, individuals waste enough food to feed every hungry person on the planet more than once a day [35]. For food industry enterprises food waste is effectively an economic loss, estimated to be worth USD 1 trillion globally [36,37]. Americans could feed 870 million hungry people by saving one-fourth of the food that is wasted [16].

In the United States food waste encompasses the largest percentage of waste at 21% [23]. Regional food waste volumes are also immense. For example, food waste in New York State, the location of this case study, is estimated to be 4 million tons annually, representing 17% of the state's solid waste, yet over 2.5 million New Yorkers are food insecure [38]. Additionally, there is an ongoing waste management crisis within the local study area where Long Island's 2.9 million residents produce over 14 million pounds of solid waste daily, with another 29.1 million daily pounds of trash produced by construction and demolition [39]. Most municipal solid waste is routed to one of four waste-to-energy plants on the island. Unburned waste is transported off of Long Island to distant landfills [39]. Only the Brookhaven Landfill still operates on Long Island. It has closed except for Cell 6, which accepts only construction and demolition debris, along with incineration ash from the waste-to-energy plants [39,40]. The current operating permit for the landfill is scheduled to expire in 2026, although an application for renewal is being considered [40]. With the future closure of the Brookhaven landfill, the question of how to manage waste on Long Island in the future is open.

Removing the food waste component from municipal solid waste is one way to reduce the volume of trash being incinerated or transported off of the island. Universities can be part of this solution as their food waste volumes may be similar to those produced by small cities or large corporations [41–45]. Additionally, young people (ages 18-34) are a key demographic for addressing the adverse impacts of food waste because they are more susceptible to wasting food [4,46–50], while also being the most likely to engage in food waste reduction behaviors [42,51]. While university cafeterias and kitchens are recognized as the primary food waste producers on campus [52], only a few peer-reviewed studies have focused on other campus locations, such as dormitories [15,53–55]. Furthermore, these studies all take place outside of the USA. In the U.S., the New York State Pollution Prevention Institute has included dormitory studies in reports [56], but sources for generator estimates do not include waste categories from university settings. Thus, the reliance on interviews and site visits demonstrates a gap in data from waste sorts or garbology specific to university dormitory settings, In this study we utilize garbology methods to test the hypothesis that food waste is a significant component of trash in the dormitories of Adelphi University in New York State, USA because garbology is the only way to quantify food waste while comparing with behavioral and interview analyses [5,17]. We also compare these data to food waste estimators to facilitate accurate estimation for future endeavors.

1.1. Food Wastage in Institutions of Higher Education

The food service sector is extremely complex, as are educational food service settings, which include catering, restaurants, cafés, and school dormitories [34]. Food waste comprises 33% of the overall waste in higher education institutions amounting to 22 million pounds of food annually across the United States [16,45,57]. Primary causes of food waste at universities include excessive cooking, overspending, inefficient food planning, and management such as ineffective inventory, storage, and preservation [43]. Food quality, portion size, satiety, time, and consumer habits also contribute to food waste on campuses [15,58,59]. These studies demonstrate food waste occurs throughout the entire food production and consumption process on campuses.

In a large-scale study of 78 primary schools in Italy including 11,000 students where approximately 110,000 school meals were monitored, the amount of food waste produced during lunch accounted for 21.7% of the food prepared on a daily basis, or roughly 90g/day/capita while unserved food resulted in 117g/day/capita [60]. For comparison, a waste coefficient of 158.8 g of food waste was estimated per meal for New York university settings [56]. Research that focuses specifically on food waste production in dormitories is relatively limited, but several studies in countries outside of the United States have taken place (15, 53-55). However, each of these studies developed distinct hypotheses, used different methodologies, and were conducted at dormitories with different characteristics from those in this study (e.g. total population, on-site refrigerators, or cafeterias in the dormitory).

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1.2. Garbology

Professor William Rathje (1945-2012), an American archaeologist at the University of Arizona, established the area of contemporary refuse studies in 1973. Garbology is the study of contemporary trash generated by a population to reconstruct that population's activities and behavior based on the premise that behavior and material culture are related 5, 61-63] . Methodologically, garbology involves collecting trash, sorting, counting, weighing, and cataloguing trash types to document human behavior, from the individual trash can level to municipal landfills [61]. Date of collection, census tract, and any information from packaging are also recorded [61].

The analysis of physical garbage remains often provides a more accurate and quantified assessment of waste components compared with interviews and questionnaires [61]. For instance, interviews and questionnaires regarding alcohol consumption show that people consistently underestimate their alcohol consumption on the order of 40 to 60% [61]. Garbology research also quantified that the rate of biodegradation in landfills was slower than assumed, thus providing data for more effective design of municipal landfills including ventilation and composting facilities [47,61,62]. The U.S. EPA [23] specifically applies the garbology technique in its guide to conducting food waste assessments, and it has been applied to characterize and quantify university solid waste [64]. Additionally, direct weighing has a high accuracy of measurement, is low cost, and suitable for solid and liquid waste [34]. It focuses on segregated streams of waste [34], and when combined with participant observation and interviews allows for detailed information to assess contributing behavior.

2. Materials and Methods

2.1. Study Location

This mixed-methods study took place at the Adelphi University Garden City campus, a private institution located 25 miles east of New York City on western Long Island, several miles from Queens, NY, one of the boroughs of New York City. During the 2022-2023 academic year, the University enrolled a population of 7,252 students, including 5,055 undergraduates and 2,197 graduate students [65, Table 1]. According to the University, approximately 20% of the undergraduate population and 1% of the graduate population reside in dormitories each year [55,66]. Adelphi University has seven dormitories on campus, each of which has a unique layout with respect to room capacity, common areas, and amenities. The largest hall, Earle Hall, has a capacity for 309 students, while the smallest hall, Chapman Hall, houses 116 students. In total, dormitory capacity is 1,263 students. The dormitories are all housed in buildings that are separate from campus cafeterias, so students must exit their buildings to access cafeterias.

Table 1. Adelphi University Enrollment During Study Period [65].

	Year	Full Time	Part Time	Sum
Undergraduate	2022-2023	4780	275	5055
Graduate	2022-2023	1103	1094	2197
Total	**2022-2023**	**5883**	**1369**	7252
Undergraduate	2023-2024	4891	233	5124
Graduate	2023-2024	1173	1109	2282
Total	**2023-2024**	**6064**	**1342**	7406

In terms of campus eateries, the university has two large cafeterias, one with a centralized kitchen, and the other with smaller vendors such as Back Bar Grill, Asian Fusion, 500 Degrees (Pizza), and Carved and Crafted. There are also several cafes and vending machines around campus. Dining Services at Adelphi is currently contracted to Chartwells®, a member of the Compass Group. Adelphi is committed to decreasing reliance on fossil fuels, decreasing the production of emissions that contribute to climate change, pesticide-free grounds, greener construction, and recycling efforts [67].

One such initiative has been the installation of a geothermal heating and cooling system, the first higher education institution to do so in the region. This case study addresses Adelphi's commitment to decreasing the production of emissions that contribute to climate change and recycling efforts. Our Sustainability Commitment website [68] notes:

"We offer ingredients sourced from local and regional suppliers. Our food is produced with minimal or no chemicals and antibiotics. We provide meat and eggs from vendors committed to the humane treatment of farm animals, and our seafood is sourced sustainably."

Sustainability is also addressed by incorporating perfectly imperfect produce into recipes [69]. The Adelphi website states it contracts with HowGood® to measure the sustainability of recipes with reference to eight variables: greenhouse gas emissions, processing, water usage, biodiversity, animal welfare, soil health, land use, and labor risk [68]. The website addresses food waste directly in that it states that Compass® participates in the WasteNot 2.0® program to measure and reduce kitchen waste in campus facilities. It employs an ORCA® machine which liquifies food waste for sewer disposal where it may be utilized to generate renewable energy. At Starbucks® facilities on campus, food products are no longer displayed as it contributes to display waste, a form of food waste that would be thrown out at the end of the day if unsold [16,68]. Straws are also no longer offered unless requested. Used cooking oil is collected by FiltaFry for recycling into biodiesel. The website also states sustainable and compostable packaging at The Market and Back Bar Grill are produced from a sugar cane, bamboo, and wood blend [68]; although, there are no composting containers available on campus. Additionally, there are several options for plating meals for dining-in to reduce container trash.

Finally, one of the goals of the university's strategic plan relates to "Smart Growth and Infrastructure," which includes completing a 'Sustainability Tracking, Assessment, and Rating System (STARS) survey' to identify sustainability metrics to monitor [70]. STARS is a framework developed by the Association for the Advancement of Sustainability in Higher Education (AASHE) for universities to measure and self-report their sustainability goals and performance to achieve various ratings. One of the metrics to pursue relates to operations, which includes food and dining [71].

2.2. Interviews and Observations

Prior to the quantitative phase of this study, an IRB approved ethnographic study (Adelphi University 2021, #120820) was conducted to identify individuals' food waste knowledge, concern, and practices at Adelphi University that contribute to the overall accumulation of food waste on campus. Observations at dining halls and open campus spaces were made focusing on individual interaction with the structure of the food service and social environment, and methods of food waste dispersal. Then, twenty individual interviews were conducted, focusing on personal food waste habits and perspectives. Interviews were semi-structured where questions followed a basic outline of topics: (1) individual morals, lifestyle practices, and sociocultural upbringings that have shaped their views on food waste, (2) individual eating practices on campus, (3) motives behind food waste at home and on campus, (4) individual awareness and concerns about the amount of attention addressed about food waste on campus, (5) knowledge and opinions on food waste and sustainability, (6) perspectives on effective food waste collection at Adelphi, and (7) willingness to participate in, and cooperate with, systemic changes within waste and dining hall practices, with and without the accompaniment of Covid-19 [69]. Two group interviews focused on cooperative views and willingness for the university to be more environmentally conscious in the area of food waste to improve food waste practice on campus. Although a modest sample size, and likely biased toward students who were active in carbon emission reduction, these are students navigating the food landscape on campus. Interview data were not directly correlated with particular dormitories, but

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were integrated with quantitative findings as elements of rationale that contribute to food waste on Adelphi's campus.

2.3. Sampling

For this study, we collected and analyzed refuse at each of Adelphi's seven dormitories by following Rathje's [17] garbology methodology to test the hypothesis that food waste is a significant component of trash in university dormitories on campus [61,62]. Collection involved removing trash bags from receptacles located on one floor's trash room, as well as from trash receptacles in the communal dormitory kitchens on the first floor adjacent to the kitchen. For this pilot study we prioritized obtaining samples from all of the dormitories throughout three consecutive fall and spring semesters spanning from November 2022 to October 2023 (Figure 1). However, samples were not collected during the summer due to the low number of residential students. Sampling was always conducted around 8 am before the overnight trash cans were emptied. This ensured discard patterns reflected evening and night activities but were too early to reflect breakfast for the majority of students. Trash sample collection on different days (Monday, Tuesday, Wednesday, and Friday) was randomized throughout the sampling period to address questions of food waste consistency throughout the week. Access was facilitated by student researchers who lived in these buildings. Additionally, the number of samples from each hall varied, ranging from four to six samples. In total, trash was collected 33 times (Table 2). A more detailed seasonal and temporal analysis including exam periods and academic breaks was not included because of the high percentage of local students living in dormitories. Students typically return home for these periods and are not allowed to remain in dormitories during breaks. Although the sample size was small for this pilot study, statistical analyses were conducted for preliminary comparisons.

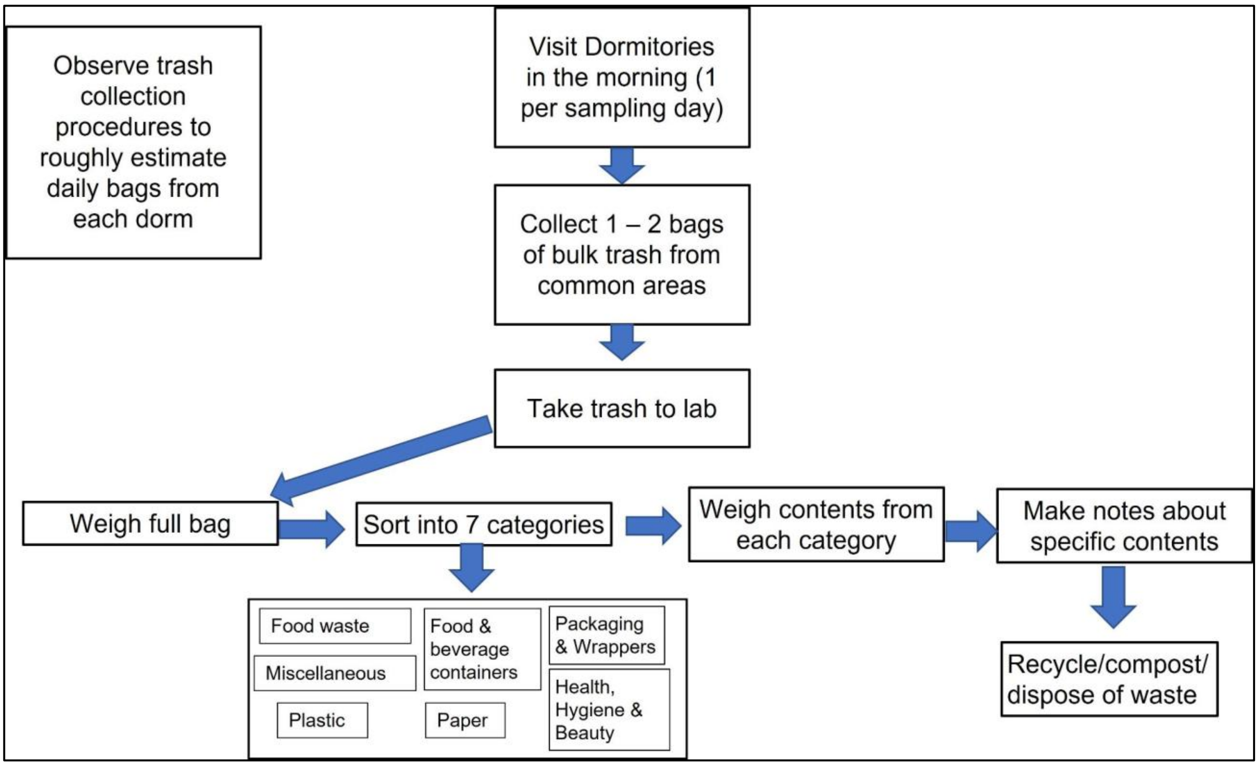

Figure 1. Schematic diagram showing waste sampling procedures for dormitories. Trash-collection observations were conducted separately from sampling.

Contents of the trash bags were sorted into seven categories: food waste; food & beverage containers (including takeout containers and glass and plastic bottles); paper; remaining plastics not related to food/beverage (such as laundry detergent containers); other non-food packaging &

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wrappers; health, hygiene & beauty; and miscellaneous. The miscellaneous category included items that did not fit easily into other categories, such as tape cartridges, face masks, or bubble wrap (Figure 2**)**. Once sorted, the contents of each category were weighed in a 3-gallon bucket using an Asani® hanging electronic weighing scale (Figure 3). Initial weights were measured to the nearest pound for comparison to American literature and converted to kilograms (kg) for broader global comparison. Liquids were dumped from beverage containers prior to weighing. General notes about food waste composition were also catalogued. Food waste was composted off-site, recyclable materials were placed into recyclable trash bins on campus, and the remaining trash was bagged and disposed of in campus dumpsters.

Figure 2. Trash sample from Residence Hall A showing a variety of food waste, food and beverage containers, and paper products.

Figure 3. Weighing food waste after sorting it from the remaining trash.

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Data collected during this study were recorded in Microsoft Excel®. Statistical analyses were conducted using SPSS©. Kolmogorov-Smirnov tests were conducted to assess whether data were normally distributed. Kruskal-Wallis nonparametric tests were performed to test the null hypothesis that food waste weight medians were statistically equivalent between refuse types, collection days, and dormitories, while Mann-Whitney nonparametric tests were utilized for selective post hoc comparisons for significant Kruskal-Wallis test results and for comparisons between two groups. Effect sizes were calculated for statistically significant results of Mann-Whitney two-way comparisons. These tests were performed on total waste weights as well as standardized to per capita waste weights based on dormitory capacities. Although small, the sample size of 33 is sufficient to detect a large effect size which is important for preliminary examination of relationships that can be used to formulate future research questions [72:34].

Per capita calculations of dorm capacity were determined by maximum capacity to ensure comparability between semesters because actual occupancy rates vary between, and throughout, semesters. Thus this method provides minimum per capita waste values because it assumes the dormitories are at capacity rather than over-estimating. Sampled waste values were examined based on total waste for all dormitories, as well as by comparing production between halls. Because halls were not sampled equally, cross-hall analysis was completed by examining average waste per collection as well as waste per capita. The total capacity values for each hall were used to assess per capita ratios of waste production.

To examine sampled trash on a larger scale, and for comparison with published estimators, data were extrapolated. It should be noted that these extrapolations are based on rough estimates, so results are meant to be examined only for informational/comparative purposes to illustrate potential food waste production if a large-scale food waste audit was conducted. During the study, students observed trash pickup by custodians to roughly estimate the number of bags collected each day per hall. These daily values were integrated with the data collected in the study to estimate waste values on daily, weekly, and semester bases. The base value used for calculations was the average trash bag weight for each hall, determined by dividing the total weight sampled per hall throughout the study period by the total number of bags sampled per dormitory. To estimate the total waste produced daily per dormitory, the average bag weight was multiplied by the estimated number of daily trash bags. This value was multiplied by 5 to estimate total weekly trash. Five-day weeks were used because many students travel home for the weekend, and to account for the fact that samples were not collected on the weekends. To estimate semester-wide waste, the daily values were multiplied by the number of instructional days not including make-up days and the winter intersession, but including final exam week (103 days). Total daily, weekly, and semester-wide food waste amounts were also calculated using the same formulae, but by multiplying the total waste by the proportion that constituted food waste. Additionally, daily, weekly and semester estimates for total waste and food waste were divided by the dormitory capacity value (1,263 students) to estimate per capita production.

Extrapolated food waste values were compared with two estimators, the New York State Pollution Prevention Institute's (NYSPPI) Food Waste Estimator [73], and the RecyclingWorks Massachusetts Food Waste Estimation Guide [74]. Both estimators use a food generation factor of 0.35 pounds (0.159 kg) of food waste per meal, but the two estimators vary in output. The New York estimator provides results in pounds per week, and the Massachusetts estimator uses pounds per student per year as the base value. These base values were used to calculate ratios that could be directly compared to the estimated data for this study.

3. Results

During the study period a total of 239.5 kg of trash was collected during 33 samplings. This amounts to an average of 7.3 kg of trash collected per sampling. Food waste accounted for 77.31 kg., or 32.3% of all waste sampled from the dormitories–the largest proportion of total waste sampled (Table 2; Figure 4). Results of a Mann-Whitney test comparing total food waste weights to all non-

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food waste weights as well as per capita food waste were statistically significant, larger than all other waste categories, thus supporting this study's hypothesis where the effect size for total food waste compared to non-food waste was a moderate effect (*r*= -.39) (Table 3). The most common food items were leftovers from prepared meals, while bread, pizza, fruits, and potato products (e.g. chips) were the next most frequently discarded food types. Of the seven categories, food and beverage containers were the second largest component, accounting for 59.9 kg, or 25% of the total waste sampled. Miscellaneous materials were the third largest component, with a total of 42.6 kg sampled, amounting to 17.8% of the total (Table 2; Figure 4).Throughout the study period, an average of 2.34 kg of food waste and 1.81 kg of food and beverage containers were collected per sampling.

Table 2. Total categorized waste (in kilograms) sampled throughout the study period for 33 samplings.

	Food Waste	Food and beverage containers	Misc.	Paper	Packaging and Wrappers	Plastic	Health, hygiene & beauty	Total
Total per category (kg)	77.315	59.888	42.601	28.477	13.984	8.727	8.541	239.533
Avg. per sampling (kg) (n=33)	2.343	1.815	1.291	0.863	0.424	0.264	0.259	7.259
Proportion of total from each category (%)	32.277	25.002	17.785	11.888	5.838	3.643	3.566	100.00

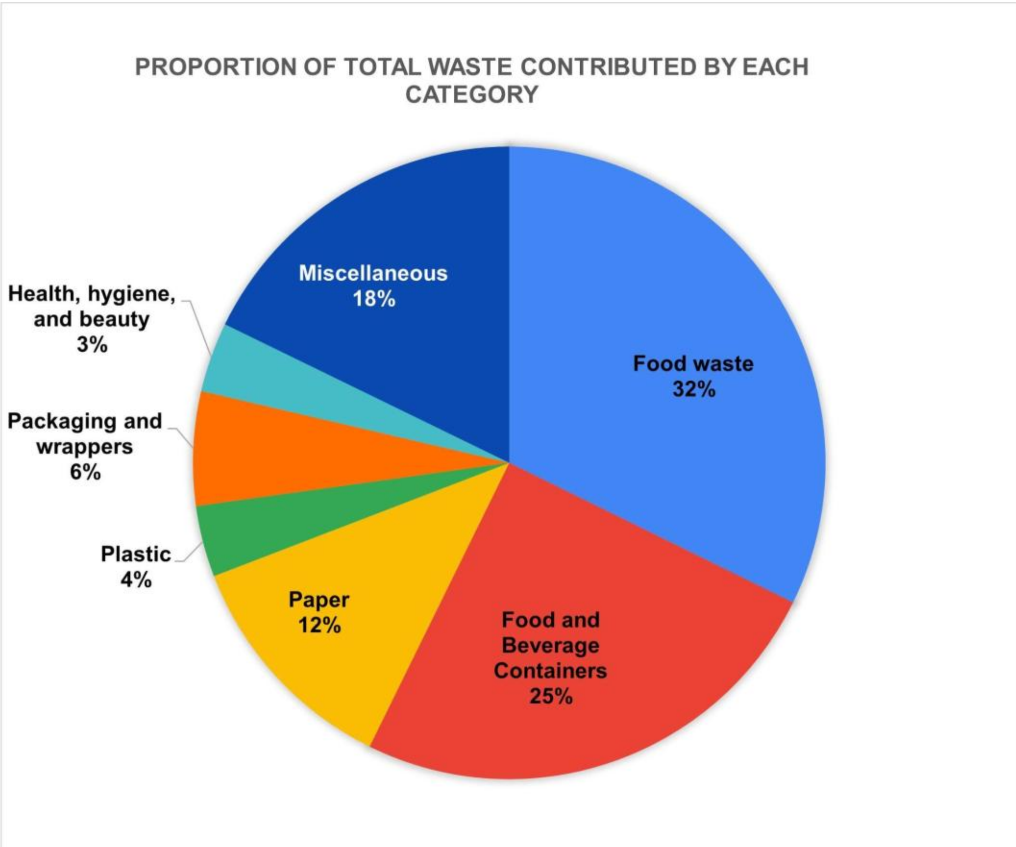

Figure 4. Pie chart showing the proportion each waste category contributed to the sampled waste total of 239.5 kilograms collected over 33 samples.

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3.1. Weekly Waste Patterns

When comparing waste totals and food waste totals for the different collection days (Monday, Tuesday, Wednesday and Friday) and collection periods (each of the three semesters), each day indicated a normal distribution except Mondays (Figure 5; Table 3). However, Kruskal-Wallis tests revealed no statistically significant differences in daily waste weights per capita, nor between semesters when waste was collected (Table 3). Friday may have a higher variance because students' departure for home may have a smaller food waste footprint, while some who are staying for Friday classes or the weekend may engage in end of the week celebrations including food.

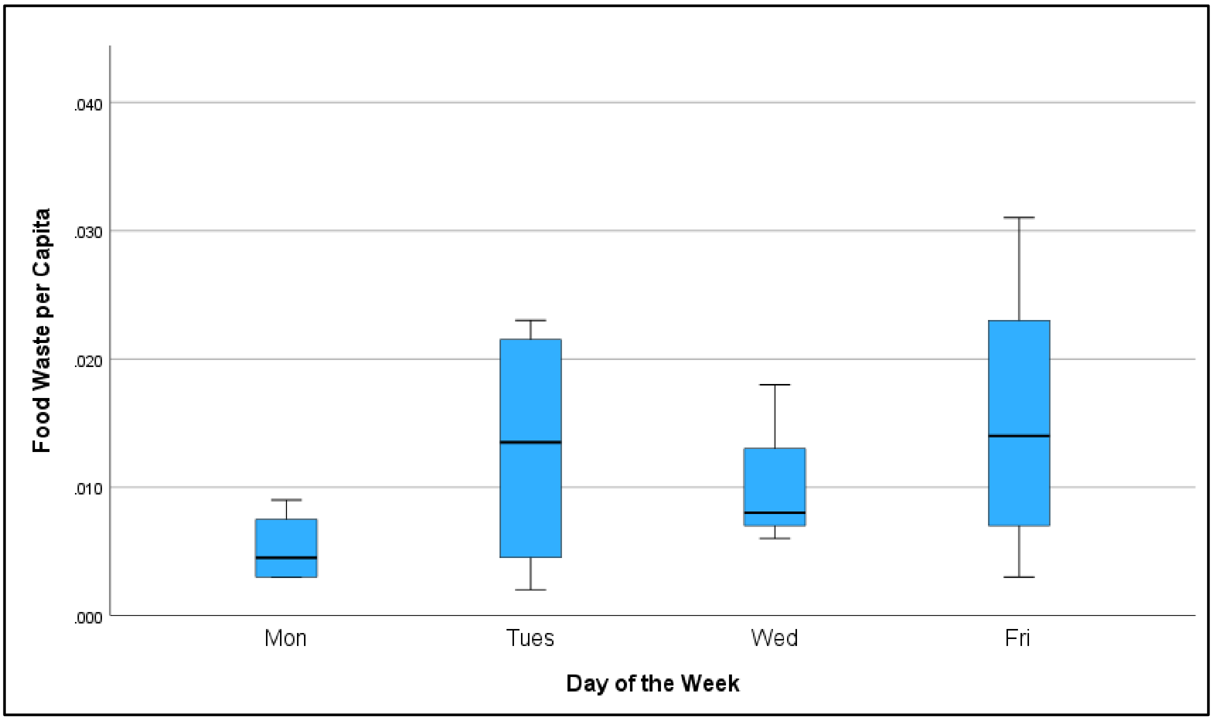

Figure 5. Box plot of food waste distribution by collection day. Per capita values are provided in kilograms.

Table 3. Summary of statistical tests conducted on food waste at Adelphi. For tests of normality, only statistically significant results are included. * denotes a statistically significant result. *r*=effect size.

Statistical Test	Variables	Statistic	df	p Value	Details
K-S test of normality	total food waste x all non-food waste	0.224 0.236	32 198	<0.001* <0.001*	food waste non-food waste
K-S test of normality	waste total x collection day	0.352	5	0.042*	Mondays
Mann-Whitney	total food waste x all non-food waste	1129.000	--	<0.001*, n=230, *r*= -.39	
K-S test of normality	total waste x semester	0.224 0.141 0.280 0.275 0.319 0.283 0.116	32 33 33 33 33 33 33	<0.001* 0.094 <0.001* <0.001* <0.001* <0.001* 0.200	food waste food containers paper other plastic wrappers health, hygiene misc.
Kruskal-Wallis	total waste x semester	0.093	2	0.954	

K-S test of normality	total food waste per capita x all non-food waste per capita	0.224 0.0275	33 231	<0.001* <0.001*	food waste per capita non-food per capita
Mann-Whitney	total food waste per capita x all non-food waste per capita	2301.5	--	<0.001*, n=264, *r*= -.23*	
Kruskal-Wallis	daily total waste per capita	1.859	3	0.602	
Kruskal-Wallis	daily food waste per capita	1.977	3	0.577	
K-S test of normality	food waste per capita x dormitory	0.296 0.266 0.277	4 4 4	0.00* 0.00* 0.00*	Chapman Linen Waldo
K-S test of normality	all non-food waste per capita x dormitory	0.256 0.254 0.268 0.263 0.276 0.293 0.247	28 42 35 28 35 35 28	<0.001* <0.001* <0.001* <0.001* <0.001* <0.001* <0.001*	Chapman Earle Eddy Linen ResA ResB Waldo
Kruskal-Wallis	food waste per capita x dormitory	12.728	6	0.048*	
Mann-Whitney	food waste per capita x dormitory	0.500 1.000	-- --	0.013*, n=9, *r=-.789* 0.027*, n=9 *r=-.738*	Chap. x Earle Chap. x Eddy
Kruskal-Wallis	all non-food waste per capita x dormitory	12.042	6	0.061	

3.2. Dormitory Comparison Results

For all dormitories, either food waste or food and beverage takeout containers were the top contributing category to the sampled waste total. For all but two halls either food waste or food and beverage takeout containers were the second contributing category to the sampled waste total (Tables 4 and 5; Figure 6). Miscellaneous waste was the second highest contributor for Residence Hall B and Waldo Hall (Tables 4 and 5; Figure 6). With respect to average waste per sampling, Waldo Hall produced the highest average total waste, with 10.28 kg per sampling (n=4; capacity=153), and Residence Hall A produced the highest average food waste, with 3.18 kg per sampling (n=5; capacity=205) (Table 5). Sample sizes were too small to test the hypothesis that dormitory capacity correlates to food waste production. However, this sample does not appear to show a relationship between dormitory capacity and food waste. Earle Hall, with the largest capacity (309 students), produced the lowest average food waste and the third lowest average total waste; while Chapman Hall, the smallest dormitory (116 students) produced the second highest total waste and food waste averages per sampling (Tables 4 and 5).

Per capita total and food waste averages were highest for Chapman Hall, with an average of 0.078 kg per person total waste and 0.024 kg per person per sampling (n=4) (Table 5). A Kruskal-Wallis test indicated statistically significant differences for per capita food waste by dormitory. Post-hoc Mann-Whitney tests demonstrated per capita food waste from Chapman was larger than that of Eddy and Earle Halls with a large effect size (Table 3). Further, although data were not normally distributed for per capita non-food waste totals for each of the seven dormitories (Figures 7 and 8), there were no statistical differences between dormitories for all combined categories of non-food waste (Table 3, Figures 6 and 9).

Table 4. Total categorized waste collected from all dormitories (in kilograms). Individual numbers of samples per dorm are provided after the location. .

Location	Food Waste	Food and beverage containers	Misc.	Paper	Packaging and Wrappers	Plastic	Health, hygiene & beauty	Total sampled waste
Chapman (n=4)	11.254	8.541	11.220	6.672	4.340	1.569	0.998	**36.092**
Earle (n=6)	10.160	10.328	5.679	6.314	1.597	1.066	2.055	**37.199**
Eddy (n=5)	10.401	5.847	4.804	3.502	0	1.048	1.524	**27.125**
Linen (n=4)	8.047	6.228	3.429	3.856	5.126	0	0.281	**26.966**
Res. Hall A (n=5)	15.885	10.795	5.715	1.846	3.797	0.794	2.073	**40.905**
Res. Hall B (n=5)	11.848	5.407	6.114	2.749	0.798	2.486	0.717	**30.119**
Waldo (n=4)	9.720	12.741	11.771	3.538	0.699	1.764	0.894	**41.127**

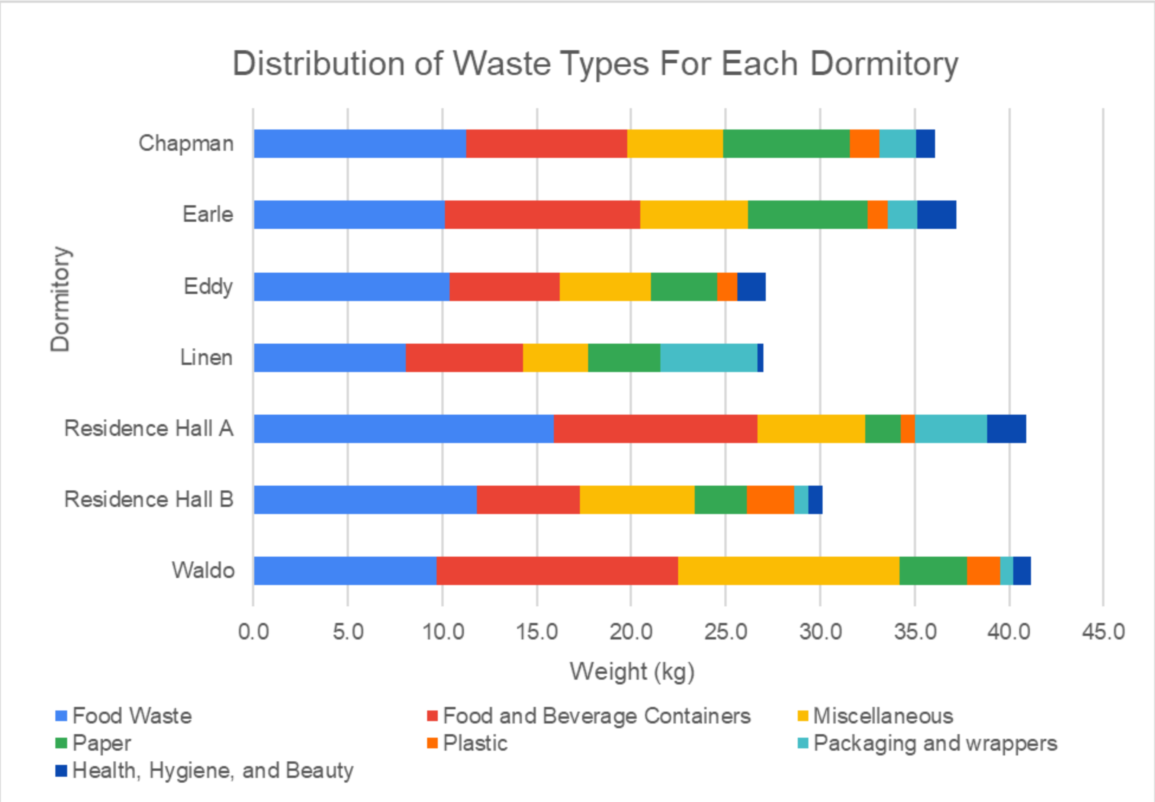

Figure 6. Distribution and total weight (in kilograms) of waste types for sampled waste in all dormitories for 33 samples.

Table 5. Dormitory Food Waste Descriptive Statistics, Total Building and Per Capita Values (in kilograms).

Location	Sample Size	Total per building (kg)	Min. (kg)	Max. (kg)	Mean (kg)	St. Deviation
Chapman	4	11.254	1.60	3.65	2.81	1.015
Earle	6	10.160	0.848	4.196	1.693	1.283

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Eddy	5	10.401	0.948	3.797	2.080	1.220
Linen	4	8.047	0.998	3.084	2.012	1.066
Res. Hall A	5	15.885	1.451	4.967	3.177	1.561
Res. Hall B	5	11.878	0.549	4.899	2.370	1.947
Waldo	4	9.720	0.744	4.350	2.430	1.785
Total	**33**	**77.315**	**---**	**---**	**2.343**	**---**

Location	**Sample Size/Capacity**	**Total per Capita**	**Min. (kg)**	**Max. (kg)**	**Mean (kg)**	**St. Deviation**
Chapman	4/116	0.097	0.014	0.032	0.024	0.009
Earle	6/309	0.033	0.003	0.014	0.006	0.004
Eddy	5/172	0.061	0.006	0.022	0.012	0.007
Linen	4/136	0.059	0.007	0.023	0.015	0.008
Res. Hall A	5/205	0.078	0.007	0.024	0.016	0.008
Res. Hall B	5/172	0.069	0.003	0.029	0.014	0.011
Waldo	4/153	0.064	0.005	0.028	0.016	0.012
Total (per capita)	**33/1263**	**0.061**	**---**	**---**	**0.212**	**---**

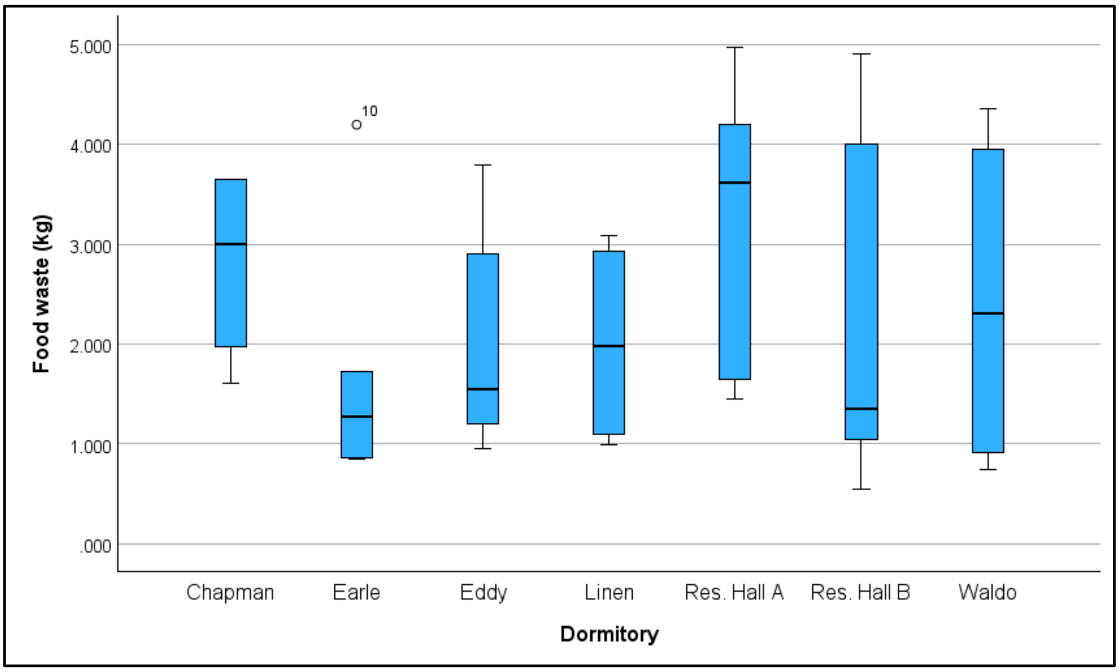

Figure 7. Total food waste by dormitory. Outliers are noted as individual sample points that were numbered for analysis. Per capita values are provided in kilograms.

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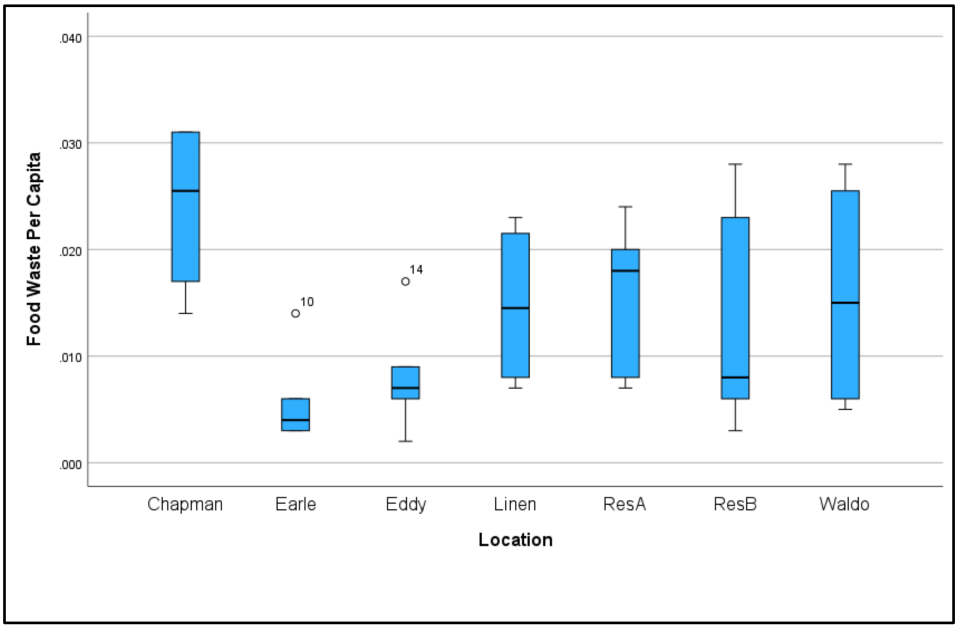

Figure 8. Per capita total food waste by dormitory. Outliers are noted as individual sample points that were numbered for analysis. Per capita values are provided in kilograms.

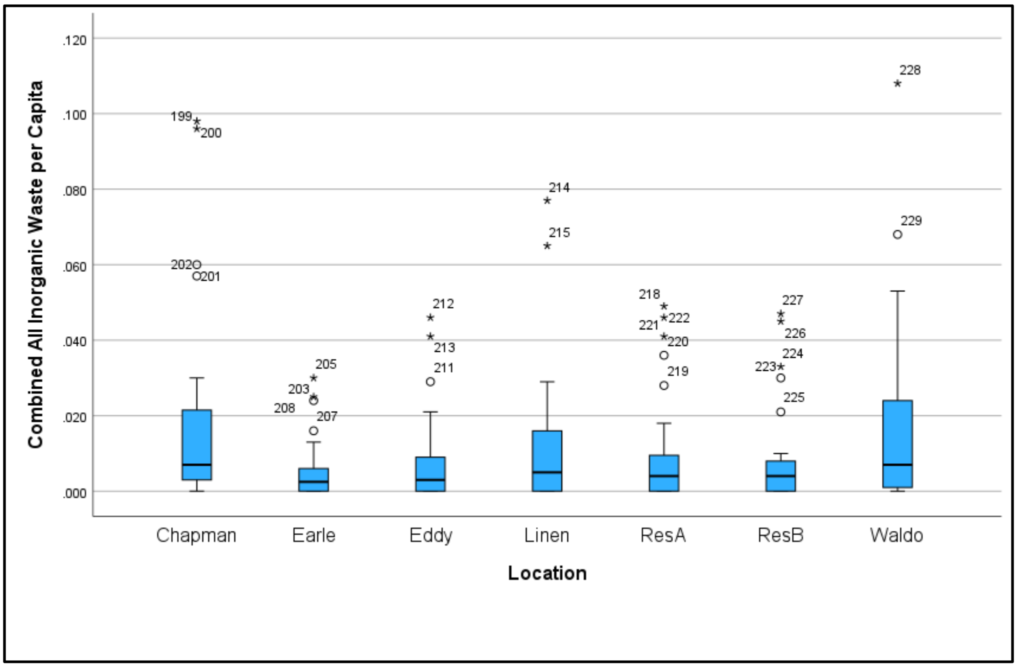

Figure 9. Box plot of all combined inorganic waste per capita by dormitory. Outliers are noted by their catalog numbers for specific waste type categorization rather than sample number. Per capita values are provided in kilograms.

3.3. Waste Extrapolations

Results of extrapolation calculations for total and per capita food waste showed that the seven dormitories combined produce an estimated 1,137.35 kg of total waste and 374.74 kg of food waste per day. This amounts to an estimated 0.9 kg of total waste and 0.3 kg of food waste produced per student resident per day (Table 6). Total weekly (5-day week) and semester-wide waste is estimated at 5,686.8 kg per week and 117,147.2 kg for each semester. This amounts to approximately 4.5 kg of waste generated per person each week, and 92.8 kg generated each semester per person (Table 6).

When considering weekly and semester-wide food waste production in the dormitories, an estimated 1,873.7 kg is produced each week, with 38,598.6 kg produced each semester, meaning that student residents produce approximately 1.5 kg of food waste per capita each week and 30.6 kg per person every semester (Table 6). In comparison, the New York State Prevention Institute Food Waste calculator [73], estimates 1,558 kg of food waste produced per week for the 1,263 residents, and 24,932 kg produced per semester, much lower than our estimates based on trash sampling.

Table 6. Estimated values for total waste and food waste based on estimated daily trash bags collected for all dormitories (272 bags per day) and values based on food waste calculators [73,74] in kilograms. Per capita values are based on dormitory capacity of 1,263 students.

Extrapolated Results (kg)	**Daily**	**Per Capita Daily**	**Weekly (5-day week)**	**Per Capita Weekly**	**Per Semester (103 days)**	**Per Capita Per Semester**
Total Estimated Waste	1137.35	0.90	5686.76	4.50	117147.20	92.75
Estimated Food Waste	374.74	0.30	1873.72	1.48	38598.64	30.56
Food waste estimator results (kg)	**Daily**	**Per Capita Daily**	**Weekly (assumes 7-day week)**	**Per Capita Weekly**	**Per Semester (15 weeks)**	**Per Capita Per Semester**
NYSPPI estimator (residential students)	222.61	0.17	1558.25	1.23	23373.80	18.51
RecyclingWorks MA estimator (residential students)	386.70	0.31	2706.89	2.14	40603.38	32.15

3.4. Qualitative Interview Results

Several themes emerged during observations and interviews with students on campus. These interviews relate to garbology results in that they provide initial glimpses into the range of student motivations driving food waste behaviors. Many students indicated in interviews they tossed food because of sanitary concerns assessed through their visual inspection of chicken, for example. Each of the students interviewed were in support of using food scrap bins if they were to be offered in campus dining halls. Concerns for their efficacy included Covid-19, sanitary conditions, misuse of bins, and lack of direction and information. They also noted during vacation breaks, less campus food was prepared as cafeteria capacities reduced hours of operation. Pre-packaged food also resulted in greater food waste as best-used-by dates were passed. The following quotes exemplify individual approaches to food and food waste:

"With my family, we have five people so usually we don't eat at the same time, because we have different schedules between work and classes. Oftentimes, food is left over and no one will finish that so I think it will actually end up in the garbage"

"I live alone in New York and would always finish my food because, like I'm on my own so I'm more aware of when and how I buy the food. I can finish this portion on my own."

Second, there were cultural motivations to prevent food waste, particularly as it relates to family size and prior family experiences before emigrating to the United States. Students whose family members emigrated from less affluent countries were more hesitant to throw away food. Family and culture tended to be a more powerful predictor of food waste patterns than environmental incentives. The following quotes were particularly salient:

"I would say it's a cultural thing like we come from like a family, a lot of people so basically whatever portion you're eating is someone's portion."

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"I'm first generation American, my parents came from South America, they came from Ecuador… There's poverty and hunger that they have experienced first hand. I feel like because of them experiencing that, they pass it down to us."

"I come from an Asian home, like the mom would always buy more than what we need to because she thinks we should rather have more than have less. So yeah, so well at home, I can say that we usually waste a lot of food."

Third, students that engaged in other daily sustainability practices, such as purchasing organic produce, composting, carpooling/biking/public transportation, plant-based diets, reducing single-use plastics, recycling, and sustainable and ethical fashion were more likely to be food waste conscious. Meal preparation was associated with lower amounts of food waste.

"When shopping, we definitely try to say we are going to start with the list to differentiate what we need, what we still have, and what we need more of at home, and say 'we should definitely use all of it before we start to buy more of this.'"

Food packaging was also a common concern where one student noted:

"Bring the compostable containers back, like all the prepackaged stuff is packaged in plastic, so I feel like I'm always like consuming plastic it's like the sushi bar and then it's like the sandwiches and like little like snack boxes, that they have in the market."

4. Discussion and Recommendations

The results of this study show that waste produced on the Adelphi University campus dormitories is heavily skewed toward food (32.3%) and food-related waste (25%)(Figure 4). This compares well with the national average of 33% [45]. While most food waste garbology research on university campuses has focused on cafeterias [43,57,75], our results illustrate that dormitories are also a significant source of food waste, and that more focus should be placed on dormitories to determine the source of the food, as well as behaviors that influence the production of food waste in buildings that do not serve food directly. The most wasted food items were prepared carbohydrates, especially fries, pasta, pizza, and bread. This compares well with Molander and Lenihan's [75] garbology analysis of post-consumer refuse at the UBC Okanagan cafeteria where fries, pasta, and bread were most wasted foods. Similarly, food waste from a Georgia Gwinnett College dining hall consisted of over 60% mixed food, followed by fruits and vegetables [52]. The nature of the waste also indicates that student residents remove a considerable amount of food from the dining centers, which may result in underestimation of food waste production from cafeterias. This pattern is reflected in interview results when students shared family values of having more food than they need, rather than less, as part of family backgrounds where elders experienced periods of food insecurity.

Results from this study demonstrate there was not a strong correlation between dorm capacity and food waste amounts. This indicates that population density alone is insufficient to account for all food waste patterns. Although it is not possible to identify or quantify the extent off-campus food consumption and food delivery services contribute to the food waste observed in dormitories in this study, future research on undergraduate consumption behaviors driving food waste may provide insight. For instance, one Adelphi student who resides in the dormitories mentioned that Earle Hall has a very high population of student athletes, and that the athletes tend to eat together in the cafeterias for meals. This could partially explain why the per capita and average food waste volumes in Earle were the lowest despite the hall having the largest total population (Table 5).

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4.1. Non-Food Waste

With respect to non-food waste, 67.7% of sampled waste was non-food when including food and beverage packaging. This compares closely with a study of food waste produced at a dormitory at Slovak University of Agriculture in Nitra, Slovakia, which found that the average annual dormitory waste was comprised of 28% organic waste, and 72% non-organic waste, categorized as glass (26%), other waste (24%), plastic (9%), paper (6%), metal (4%), tetrapak cardboard beverage packaging (2%), and e-waste (1%) [53]. In studies that focused on cafeterias, disposable cutlery [52], napkins, and disposable cups [75] accounted for the largest proportion of non-food waste. Therefore, the fact that food and beverage containers made up the second largest proportion of waste produced in the dormitories for this study suggests that students are purchasing a large portion of their food in disposable containers, possibly from the campus dining centers. This is reflected in student interviews by concerns for best-used-by dates on pre-packaged food.

Qualitative observations in the dining center revealed that most students consumed their food and drink purchases on site and discarded their waste into the trash receptacles within the dining center. This could imply that a majority of foods in dormitory waste receptacles may not be derived from university dining centers, but a more detailed analysis would be needed; in particular, to determine whether the observed students are primarily residential or non-residential students, or whether food waste in dormitories comes from other sources (e.g. from vending machines, food trucks, or off-campus locations).

4.2. Food Waste Estimation

The daily, weekly, and semester estimates of total waste and food waste were based on extrapolations from rough estimates of daily trash bags collected at the seven dormitories, so these data are not statistically valid. However, the estimated values, while observed with caution, show that dormitories may be a ‘hidden’ source of food waste that should be considered for universities that aim to decrease their total waste production through food waste management efforts. Our estimates suggest that dormitories at Adelphi University may produce as much as 117 metric tons of waste, and 38.6 metric tons of food waste every semester (Table 6). When comparing the estimated food waste results to publicly available food waste estimators, this study’s results were similar to those of the Massachusetts-based ‘RecyclingWorks’ estimator, with estimates of 40.6 metric tons of food waste produced every semester [74]. However, The NYSPPI estimator only calculated 23.4 metric tons of food waste production each semester [73]. This discrepancy between the two estimators is, in part, due to assumptions built into the algorithms. The constant for food waste weights in each calculator is 0.1587kg (0.35 lbs.), but the RecyclingWorks calculator bases its calculation on 405 meals per residential student per year, assuming a 30-week school year, which is equal to 13.5 meals per student per week [74]. However, the NYSPPI calculator bases its calculation on a generation factor of 1.23kg (2.72lbs)/student/week , which equates to only 7.8 meals per student per week [73].

While estimates from this study compare relatively well with the RecyclingWorks calculator, they could be inflated because they were exclusive to residence hall waste, in contrast to university-wide waste, which is assumed by the estimators. Nevertheless, these comparisons show that dormitories are a significant source of food waste. Additionally, the comparisons demonstrate the importance of scrutinizing the algorithms underlying each estimator, and using multiple estimators when predicting food waste.

4.3. Factors Contributing to Food Waste

A survey of U.S. consumers indicated the primary motivations for food wastage were concerns for foodborne illness, and a desire to eat the freshest food [76]. This compares well with the ethnographic results from the Adelphi study. In a Thailand university dormitory context, food waste resulted from over purchasing of food, lack of awareness of the seriousness of food waste, and a lack of association between saving money and avoidable food waste [54]. Most food waste was from pre-packaged items, and half of the food waste had not been opened or eaten but remained edible [54]. Similarly, a New Zealand study [4] assessed practices leading to food waste among university students ages 20-25 through social practice theory (SPT), which emphasizes practices over individual behavior. Their study demonstrated over-purchasing of food during shopping, absence of formal meal planning and lists, limited cooking experience, and assessing edibility based on passing peak ripeness resulted in food waste [43,77]. Further, food quality, portion size, satiety, time, and attitudes contribute to food waste at campus cafes [57]. Although participants did not specify these points, they may be relevant to the Adelphi context where freshness and foodborne illness may relate to food over purchasing and/or lack of planning as well as focus on satiety rather than having too little food.

4.4. Food Waste Comparisons

While food waste research including garbology has increased globally [4,26,41–47,52–54] there are no directly comparable American studies of dormitory food waste. However, there are some similarities between the results of this study and previous research in international settings. For example, at the Slovak University of Agriculture the average annual dormitory waste generated per student was 38 kg, where organics comprised 28% of the waste [53]. While this weight is lower than the estimated yearly value of 61.7 kg per student per year in this study, the proportion of organic waste is similar (Table 6). However, there are notable differences in study design, namely that an individual room trash was sampled and that a dining area was associated with the dorm [53]. In the Thai dormitory study [54] students largely ate at the university canteen, similar to the Adelphi dormitory design. However, there were refrigerators on each dorm floor [54]. Their results indicated half of the avoidable food waste had not even begun to be eaten, and was generated by female students, as a result of motivation, opportunity, and ability [54]. In a Shanghai dormitory where questionnaires and garbology were conducted, household food waste accounted for 29% of the residential waste [15]. This study randomly sampled 112 dorm rooms rather than communal refuse bins, and found lower educational level and better financial condition were associated with more waste generation [15]. The association of gender and food waste varied for waste types. Social science and natural science students created waste in similar volumes [15]. These trends are not likely reflected in dorms since they are mixed by gender, major, and educational level. In a Swiss company cafeteria unserved prepared buffet foods constituted the highest percentage of losses by weight (38.21%) whereas uneaten food on plates contributed a quarter of all food waste (25.16%) [78]. If the Adelphi dormitory food waste was exclusively uneaten food from plates, this is slightly lower than this study's results (32.3%).

4.5. Limitations and Future Research Directions

The initial results presented in this pilot study serve as preliminary data to develop avenues for future research. The modest sample size limits the statistical power of the data, but the results serve as a baseline for the proportions of different waste categories found in dormitory trash. The extrapolated data based on estimated bags is approximate, but shows that dormitories, specifically, are major contributors of food waste on campus. To more fully test this hypothesis, future research could involve recording the number of daily trash bags that are collected by staff each day. Additional trash surveys to increase the number of waste samples per dormitory would also account for variations in the number of samples per dormitory, differences in the days of the week on which samples were collected, and collections primarily from a common area on only one floor. Collecting a consistent number of samples each day of the week, including on weekends, would allow for more detailed comparisons of waste production variations throughout the week, which could, in turn, be related to student behaviors such as leaving campus on the weekends. This study utilized dormitory capacity to assess per capita waste production, due to the fact that occupancy varies from semester-to-semester, or even within semesters. However, future surveys could utilize actual occupancy numbers at the time of sampling. Future work could also involve interviews and surveys to determine demographics, occupancy by different groups (e.g. athletes, honors students) and dormitory layout (e.g. refrigerators in rooms vs. in common areas). Additional questions relating to the number of meals residents eat on campus, how often they eat in the dining halls compared to their dorms, and how often they bring meals from cafeterias back to their dormitories versus food from off-campus establishments would allow for a more comprehensive understanding of variation between dormitories. Future analyses could incorporate quantitative analyses of cultural and socio-economic differences among students to provide additional insight as to food waste behaviors.

4.6. Solutions and Recommendations

As the world's population continues to rise at a rapid pace, primarily in metropolitan areas, the volume of waste generated by this growth must be addressed [79]. Reducing food waste is a social obligation of universities, and a means for building a positive public image [37,80]. Food wastes have a high organic content that can be recycled into forms that can be repurposed into soil, fertilizers, and other products [25]. According to the New York State Department of Environmental Conservation, in 2023, 35% of New York State's greenhouse gas emissions were from methane, with over 34% of that methane coming from the waste sector [81]. As methane is a particularly potent greenhouse gas, diverting organic wastes from landfills could lower New York State's methane emissions significantly [80]. Characterizing and quantifying waste is a critical first step for waste management planning designed to advance sustainability at institutions of higher education [82].

Given their semi-autonomous nature , universities are well-positioned to serve as testing grounds for potential solutions to the problems of food waste. Colleges and universities are uniquely positioned to integrate sustainability-focused coursework linking food systems, environmental impacts, and everyday decision-making. The University of California, Los Angeles, introduced a freshman course named "Food: A Lens for Environment and Sustainability." As a result of learning about the carbon emissions associated with a meat-heavy diet, students drastically cut back on their meat intake, which helped them lower their dietary carbon footprint [26]. Adelphi University's Food Studies minor program offers several courses such as "Society and the Environment" and "Urban Environments," which address the relationship between food and environmental sustainability. Courses such as these can also act to improve knowledge on food preparation and storage that is critical for reducing food waste [21].

Institutions may also involve students in their sustainability actions, which not only improves student awareness of methods to reach sustainability goals, but also offers students experience working with university administration and staff. Ithaca College, in New York, launched its Resource and Environmental Management Program (REMP) in 1991 to support individual departmental waste reduction plans through guidelines, regulations, and deadlines [83]. They recruit student 'Eco-Reps' in every dormitory to educate residents on waste separation, holding educational programs, and collecting recycling [83]. At nearby Cornell University (Ithaca, NY), student volunteers are in charge of transporting their dorm kitchen's organic waste to a collection site where it is then collected and composted on-site by Farm Services [84].

Other institutions such as Bard College, Skidmore College, and New York University have also initiated composting projects to reduce food waste in landfills [84]. Composting is not always appropriate for organic waste when contaminated with non-compostable materials such as plastics, bones, and meat [53]. Further, composting requires infrastructural inputs and frequent monitoring [85]. Yet, composting remains a potential option, especially as technological advances, such as developments in vermicomposting, improve the quality and efficiency of composting, as well as its reduction of waste volume, methane emissions [85]. Trent University in Canada [86] and St. John's University in Queens, New York both participate in composting on campus, and all have created programs to deal with and promote sustainability on their campuses [86,87]. Adelphi has a small community garden, so developing a small-scale composting effort on campus, in which compost can be used in the garden, could serve as a pilot project to determine whether composting on a larger scale is feasible.

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Pending chemical and biological characterization of waste, anaerobic digestion is an alternative to composting. This process produces biogas by consuming organic material in the absence of oxygen, which can be utilized for renewable electricity, as well as a solid and liquid digestate which is appropriate for topsoil, compost, and animal bedding [88]. Because anaerobic digesters can accommodate fats, oils, greases, food processing waste, food scraps, manure, and biosolids, this technique may also be important for foods and organic wastes that cannot be composted [89]. For larger institutions such as The University of California, Davis, anaerobic digestion, which converts organic food waste and sewage sludge into biogas, may be a sustainable waste management option [90–92]. Gasification and pyrolysis are two additional waste-to-energy procedures that can sustainably manage the impacts of food waste [88].

Universities can take many potential pathways to reduce food waste. For example, universities could re-design dormitory rooms and suites with kitchenettes to reduce the number of students who share a single refrigerator. Modifying food service strategies can also reduce food waste. For instance, trayless dining service at two U.S. universities is associated with decreased volumes of food selected and consumed [93,94] as well as overall reduced food waste [94]. Limiting portion sizes could also prevent overeating in addition to reducing food waste. Institutions can also reduce food waste by collaborating with local food banks to donate extra food following the Bill Emerson Good Samaritan Food Donation Act (42USC § 1791). The Food Recovery Network is one such nationwide group that works with colleges and other institutions to gather leftover food and donate it to those in need. The nonprofit has retrieved nearly 11,000 metric tons (24 million pounds) of food since it was founded in 2011 [95].

Reducing food waste is becoming a circular economic strategy within universities which eschew the take-make-waste economic model in favor of a regenerative one to minimize waste while restoring, renewing, or revitalizing energy and material sources [16,44]. Future university-based food waste studies may test hypotheses about the most effective education awareness programs.

5. Conclusion

Waste characterization is an effective method for determining the amount and pattern of waste production. It can be a decision-making tool when implementing efforts for institutions to manage their garbage sustainably. Previous food waste on university campuses focuses on dining halls [52], with few studies of food waste from dormitories, especially, especially in American contexts [53]. This pilot study demonstrated that food waste and food containers comprise a significant percentage of overall waste in university dormitory settings. Extrapolated values, while not statistically valid, demonstrate that dormitories are likely a significant source of food waste at colleges and universities–even at institutions in which a majority of students live off-campus. In the future, a more detailed and precise analysis could be completed by collecting more samples over a longer time period, interviewing residents about their dining and consumption habits, and collecting demographic data for residents of dormitories throughout the study period. Any future sustainability efforts that focus on reducing food waste should include dormitories in both food waste audits and food waste reduction efforts.

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