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Review Article

Composting and Anaerobic Digestion of Food Waste and Sewage Sludge for Campus Sustainability: A Review

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Composting and anaerobic digestion have emerged as better options for managing food waste and sewage sludge at the campus level. This review highlights the characteristics of food waste and sewage sludge from various global higher education institutions. The composting and anaerobic digestion processes of food waste and sewage sludge will be reviewed and evaluated. Also, the adoption of composting and anaerobic digestion at various campus levels has been reviewed. The challenges and future direction, focusing on managing university campus composting and anaerobic digestion, are discussed as well. This review paper will significantly contribute to the understanding of the potential for managing and handling campus waste in a natural-friendly manner.

1. Introduction

As the growing population increased yearly with rapid development that mostly took place in urban areas, the volume of waste generated from this development needed to be addressed. It was reported that the world creates 2.01 billion tons of municipal solid waste every year, with the East Asia and Pacific regions contributing 23% of it, and it is expected to grow to 3.40 billion tons by 2050 [1]. Kaza et al. [2] found that an average of 0.74 kilograms was produced per person per day, but it varied greatly, varying from 0.11 to 4.54 kilograms. In Malaysia, the daily solid waste generation has exceeded 38,427 metric tons per day in 2021 (1.17 kg/capita/day), with 82.5% of this waste being disposed of in landfills. The solid waste generated including food waste (FW), sewage sludge (SS), and household sludge and even from the industries is in tandem with the increased population of 32.8 million people [3].

Every year, about a third of 1.3 billion tons of food are predicted to be discarded [4]. In 2017, there were 38.1 million tons of food waste disposed of [5]. Therefore, to prevent serious health problems and environmental contamination, careful management of food waste is essential [6, 7]. In Malaysia alone, the average household consumes around 0.5 kg to 0.8 kg of FW per day, with FW accounting for almost 63.1% of solid waste components per day [8]. Higher education institutes are one of the major generators of food waste. As reported by Torrijos et al. [9], 33% of total waste in higher education institutes consisted of food waste. Usually, all the waste generated at a university will be disposed of at a landfill.

Sewage sludge is the largest waste generated during the sewage treatment process, contains high organic content, and is considered organic municipal solid waste. The generation of sewage sludge has increased throughout the year. For example, in the 27 European Union countries, the dry mass of sewage sludge has increased annually from 10 million tons in 2010 to 13.5 million tons in 2020 [10]. Composting and anaerobic digestion is favored since it can process the waste into a safer product such as organic fertilizers and soil improvers [11]. Sewage sludge enriched in nutrients and trace minerals can be used as fertilizer for crops if pollutant levels are within acceptable values. At present, SS is applied on land for agricultural purposes or disposed of in landfills.

Landfilling food waste and sewage sludge will cause environmental pollution such as greenhouse gas emissions and leachate generation [12, 13]. The food waste and sewage sludge, mainly from the cafeteria, residential colleges, and buildings on campus, can be processed so that it can be used either in the form of compost and/or biogas. Compared to the traditional disposal methods of landfills, composting and the anaerobic digestion (AD) method are promising alternatives and nature-friendly technologies to be applied to biodegradable waste on the campus [14, 15]. However, understanding the process and the strategic plan needs to be envisaged for a proper demonstration, design, and criteria before adopting the disposal method mentioned. Employing composting to manage food wastes [16] and sewage [17] can reduce the cost and pollution as well as turning them into valuable products.

Implementing composting and anaerobic digestion of food waste and sewage sludge (SS) is still in its infancy on university and college campuses, especially in Malaysia. Increasing numbers of students lead to increasing waste generation and encourage universities to find a solution to manage their waste. Learning from and setting an example for the public is a good way to accomplish this, as the public has higher expectations and looks up to higher institutions. Higher education institutions serve as a place to foster idealism and creativity, as well as a means of providing and creating a scholar and intelligence community. The growth mindset of improving environmental sustainability through the action of solving environmental conditions with profit-making through compost or energy resources should be implemented in the campus community [18]. With this mindset, the campus community can work together to carry out the agenda of environmental sustainability by incorporating the latest knowledge and technologies. Therefore, this review aims to provide a greater understanding and an idea of implementing composting and anaerobic digestion on campus for sewage sludge and food waste. The main goal of this review is, therefore, to assess the potential of treating sewage sludge and food waste on campus through composting and anaerobic digestion by providing a basic understanding of the method. The characteristics of food waste and sewage sludge were reviewed for their suitability for composting and anaerobic digestion processes. The adoption of composting and anaerobic digestion by various global higher education institutes was also reviewed. This review will also highlight some trends, future opportunities, challenges, and tasks faced when adopting composting and anaerobic digestion on campus.

2. Characteristics of Food Waste and Sewage Sludge

For the past decades, food waste has become a significant component of municipal solid waste (MSW) globally. Food waste is recognized as a pollutant because, in natural environments, it quickly decomposes, produces odors, and can often cause illness owing to its high decomposable organic compounds and moisture content. FW contains food waste from households, businesses, institutions, and other locations like factory cafeterias, canteens, and lunchrooms, as well as FW from preparing food, food from poor handling (under and overcooked), and food from the refrigerator [19]. The food waste composition in higher education institutions includes vegetable and fruit waste, meat, oil and fats, fish, and staple foods (noodles, bread, and rice). FW contains micronutrients such as phosphorus (P), calcium (Ca), potassium (P), and magnesium (Mg) [20].

Table 1 shows the physicochemical characteristics, nutritional elements, and heavy metals of food waste from some higher institutions. Food waste on campus had a C/N ratio of between 14 and 27, while municipal food waste had a wider range of C/N ratios of 14 to 40. The organic matter (OM) of food waste on campus was higher than in municipal waste, which ranged from 22% to 45%. Food wastes have a moisture content (MC) of between 70% and 80%, indicating a readily biodegradable organic substrate. In the municipal sector, the MC of food waste ranges between 36% and 75%. Most of the food waste was acidic in a pH range of 4.1 to 7.4, while a higher pH (7.5–7.8) of food waste was found in municipal waste.

The EC of food waste was higher than that of municipal waste which was 1.7–8.9 dS/m and 0.52–1.59 dS/m, respectively. Food waste on campus has higher N, P, and K content (N: 0.8%–5.7%, P: 0.2%–0.4%, K: 0.6%–0.8%) compared to municipal food waste (N: 0.1%–1.2%, P: 0.002%–0.5%, K: 0.1%–0.4%). A study by Browne and Murphy [35] found that food waste from the main university campus canteen in University College Cork consists of 18.1% proteins, 59.0% carbohydrates, 19.0% lipids, 49.6% carbon, 7.3% hydrogen, 34.9% oxygen, and 3.5% nitrogen.

The chemical properties of municipal food waste were based on a few studies [40–42]. There was not enough data for the physical and microbiological properties of food waste on campus. The bulk density was in the range of 760–980 kg/m^3, as reported by Donahue et al. [39]. Fei-Baffoe et al. [22] mentioned that the total coliform and fecal coliforms found in food waste were 7.5×10^{10} MPN/g and 2.4×10^{8} MPN/g, respectively. These data variations have demonstrated that each food waste has varying characteristics and needs to be determined beforehand since the process mechanism may be affected.

The compositions of sewage sludge vary greatly and are affected by a variety of factors, including the seasons, the technology used in sewage treatment, and the specificity of the influent's source area [43]. Campus sewage sludge (CSS) contains high organic matter, ranging from 32% to 70%, as shown in Table 1 [21, 22]. It has the same characteristics as municipal sewage sludge, in which the predominant fractions of organic substances in the CSS are lignin, cellulose, glucose, and protein [44]. However, the concentration of organic substances in municipal sewage sludge may be varied as compared to campus sewage sludge [45].

Municipal sewage sludge contains organic matter, such as extracellular polymeric substances (EPSs), recalcitrant cell

Table 1: Characteristics of food waste and sewage sludge on campus.

	Water	C/N	OM (%)	TS (%)	VS (%)	MC (%)	pH	EC (dS/m)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Pb (mg/g)	Zn (mg/g)	Ref.
Sewage sludge	São Paulo State University (UNESP)	9	34	NA	NA	NA	5.9	NA	2.1	2.9	NA	1.4	0.3	2.0	NA	0.3	[21]
	Kwame Nkrumah University of Science and Technology (KNUST)	10	70	27	NA	73	6.3	NA	3.9	0.8	0.8	0.8	1.0	NA	0.03	NA	[22]
	Kwame Nkrumah University of Science and Technology (KNUST), Kumasi	22	32	NA	NA	15	5.4	0.9	0.8	0.8	1.6	0.3	0.4	NA	NA	NA	[23]
	University of British Columbia, Vancouver	NA	NA	0.5	0.4	NA	6.9	NA	NA	NA	NA	NA	NA	NA	NA	1.6	[24]
	University of British Columbia (UBC)	NA	NA	0.4	NA	NA	6.6	NA	NA	133 mg/L	NA	NA	NA	NA	NA	NA	[25]
	Chulalongkorn, University	NA	NA	39.1 g/L	39 g/L	NA	6.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	[26]
	Indian Institute of Technology Guwahati (IITG)	11	NA	NA	34	82	7	NA	2.1	NA	NA	NA	NA	NA	NA	NA	[27]
Food waste	Universiti Malaysia Sabah (UMS), Malaysia	NA	NA	NA	NA	76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	[28]
	Universiti Sains Malaysia (USM), Malaysia	10	NA	NA	NA	NA	6.2	NA	3.9	NA	NA	NA	NA	NA	NA	NA	[29]
	University of Nottingham, Malaysia	20	96	NA	NA	NA	5.4	NA	NA	0.2	0.63	NA	NA	NA	NA	NA	[30]
	University of a Coruña (UDC), Spain	17	NA	NA	NA	NA	NA	NA	2.6	0.4	1.2	2.5	0.1	NA	<0.00008	00.02	[31]
	King Abdul-Aziz University, Saudi Arabia	NA	92	NA	NA	84	6.4	1.7	NA	NA	NA	NA	NA	NA	NA	NA	[32]
	Indian Institute of Technology (IIT), India	25	95	NA	NA	79	4.7	2.1	NA	0.2	0.6	0.3	0.1	0.2	0.001%	0.002%	[33]
	Kwame Nkrumah University of Science and Technology (KNUST), Ghana	27	85	NA.	NA.	NA	7.4	NA	1.8	0.3	0.8	0.6	0.4	NA	0.005	NA	[22]
	University of Science and Technology Beijing, China	17	91	NA	NA	74	6.1	8.9	2.7	NA	NA	NA	NA	NA	NA	NA	[34]
	University College Cork (UCC), Ireland	14	NA	29	95.3	NA	4.1	NA	3.5	NA	NA	NA	NA	NA	NA	NA	[35]
	Zhejiang University, China	NA	NA	28	25.9	NA	4.5	NA	2.2	NA	NA	NA	NA	NA	NA	NA	[36]
	University Putra Malaysia (UPM), Malaysia	NA	NA	256 g/L	NA	72	6.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	[37]
	Pennsylvania State University, USA	15	NA	25	92.3	NA	4.6	NA	0.8	NA	NA	NA	NA	NA	NA	NA	[38]
	University of Maine, Maine	NA	NA	31	95.9	NA	4.5	7.8	NA	0.4	0.7	NA	NA	NA	NA	NA	[39]

C/N: carbon to nitrogen ratio, OM: organic matter, TS: total solid, VS: volatile solid, MC: moisture content, BD: bulk density; EC: electrical conductivity, N: nitrogen, P: phosphorus, K: potassium, Ca: calcium, Mg: magnesium, S: sulfur (%), Pb: lead, and Zn: zinc. Note: the unit follows the abbreviation unless stated otherwise in the table.

walls, and other high molecular weight organic matter, which can also be found in the complex floc structure but not reported in CSS [46]. Moreover, hazardous organic matter such as organic halogens, linear alkylbenzene sulfonates, and polyaromatic hydrocarbons may be present in municipal sewage sludge [47]. Therefore, identifying the hazardous organic matter in the CSS should be done before application since it may contain various types of organic matter that could be hazardous, as in municipal sewage sludge.

As reported in Table 1, the C/N ratio of CSS ranges from 9 to 23. The C/N ratio is almost similar to that of municipal sewage sludge, which is within 10 to 20, which is considered low, and higher C/N ratio materials should be added to improve the composting process. Major nutrients were detected, including nitrogen (N), phosphorus (P), and potassium (K) in the municipal sewage sludge. The percentage of N in CSS is 0.8% to 3.9% lower than municipal sewage sludge (~ 6.5–7%) [48, 49]. P concentrations in sewage sludge range up to 2.9%, with K fractions ranging from 0.8% to 1.6%.

According to Table 1, the composition of volatile solids (VS) and total solids (TS) in CSS is approximately 0.4–34% and 0.4–27.4%, respectively. VS in municipal sewage sludge comprises polysaccharides, lipids, and humic substances [50, 51].

As shown in Table 1, the most common heavy metals in CSS are lead (Pb) and zinc (Zn). Other heavy metals were also detected, such as copper (Cu) (0.1%) and iron (Fe) (24.3 mg/g) [21], nickel (Ni) (0.03 mg/g) [24], manganese (Mn) (0.3 mg/g) [21], boron (B) (0.1 mg/g), aluminum (Al) (4.7 mg/g), and chromium (Cr) (0.4 mg/g) in CSS. It also has magnesium (Mg) and calcium (Ca) in it, which make up about 0.3–1.0% and 0.3–1.4%, respectively. Still, only a few authors investigated these heavy metals, so they are not listed in Table 1.

Zn, Cu, Ni, Pb, Cd, Cr, and Hg are the common heavy metals in municipal sewage sludge (Zhang et al., 2017). Zn has the highest concentration in CSS and is typically contained in most municipal sewage sludge. The electrical conductivity (EC) of CSS ranges from 0.3 dS/m to 1.6 dS/m. The pH is in the range of 5.4 to 7.0, which is slightly acidic to neutral. The presence of coliform was reported as 2.4×10^{14} MPN/g [22]. The bulk density of the reported CSS in Table 1 is between 0.27 g/cm^3 and 0.53 g/cm^3.

3. Composting and Anaerobic Digestion

Composting is a biological and aerobic process that stabilizes organic materials through biological degradation and the efficacy is directly reliant on microorganism activity [53]. In organic waste, there are microbial communities that play an important role during the composting process. A microbial community is made up of different types of organisms that can interact with each other in the environment in which they coexist. The microorganisms break down the organic waste into its simplest components, and the simplest components are then formed into compost, a humus-like structure in a reasonably short period of time which is four to six weeks [54]. Figure 1 displays a simple conversion of the aerobic and anaerobic processes.

Composting methods include windrows, aerated static piles, and in-vessel systems. Large-scale composting (>100 kg/day) methods are normally employed at the composting facilities to cater to the high volume of wastes, but the characterization of the compost can be conducted at research facilities. In small-scale composting, the process can be controlled, and the results are usually consistent. To ensure composting efficiency, proper composting conditions such as moisture content, carbon to nitrogen ratio, particle size, and aeration must be met. Bulking agents like sawdust, yard waste, and animal manures can be added to keep the mixture moist, give structure and porosity to the mixture for proper aeration, sustain an active microbial activity, and absorb part of the leachate produced during the decomposition process [12]. Although high-quality compost can be obtained through large-scale composting, the products generated are not consistent in terms of composition and characteristics. The use of simple tools such as germination index (GI) for monitoring process performance and compost quality in large-scale composting facilities would help to address operational weaknesses and improve waste processing to produce quality compost [53].

Anaerobic digestion (AD) is a specific biological reaction that only uses microorganisms to degrade organic waste in the absence of oxygen yielding biogas that comprised 60%–70% methane and 30%–40% carbon dioxide and other trace gasses [55–57]. The degradation and conversion process occurs in four steps (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) with different classes of bacteria responsible for each phase where the first two steps are facultative and the latter two are strictly anaerobic. In AD, hydrolysis is the process of decomposing complex organic matters such as carbohydrates, polysaccharides, proteins, and lipids into the simpler organic matter [58, 59]. In the treatment plant, the sewage undergoes a process called sludge thickening before undergoing the mechanical drying process and exits with 80% moisture and 20% dry matter [60, 61]. Although the characteristics of campus sewage sludge are less complicated than those of municipal sewage, they apply similar AD processes as shown in Figure 1.

3.1. Food Waste Composting. Composting food waste might be challenging due to its inconsistent characteristics, as it depends on its sources and the eating habits of the consumer. Besides, different types of waste have different amounts of degradable carbon. Samah et al. [62] mentioned that the Islamic International University Malaysia Kuantan campus initiated a system to manage solid waste generated from its cafeteria where the recyclable waste is sent to the recycle center and the food waste will be transported to the composting area. By implementing this system, they found that composting is an environmentally friendly, cost-effective, sustainable, and wealth-creating approach to waste management. Meanwhile, the food waste generated at the University of Malaya was treated either by composting or anaerobic digestion [63].

Among the earliest publications, in-campus composting of food waste was done at the University of Wisconsin-River

A) Aerobic

Organic matter + O_2 + Nutrient → New cells + compost + CO_2+ H_2O + NH_3 + SO_2^{2-} + heat

B) Anaerobic

Organic matter + H_2O + Nutrient → New cells + compost/digested sludge + CO_2 + CH_4 + NH_3 + H_2S + heat

Figure 1: Conversion of organic waste in aerobic composting and anaerobic digestion.

Falls [64]. They found that composting reduces significant dormitory waste with minimum capital and supervision. The Penn State University in-state college uses food residuals and soiled napkins from facilities with foodservice operations on campus for composting [65]. They can be used in landscape applications like flower beds, potted plants, turf top-dressing, building site reconstruction, and research projects. Table 2 tabulates a list of higher education institutions that conducted food waste composting.

Most of the studies cited were still on a research scale, but there were also some universities that had already implemented the composting system. Food waste is widely available in universities. The high amount of food waste generated in institutions where 350 kg of food waste per day was generated at Anna University, 125 kg/day at Kean University (KU), 25.5 kg/day at one of the Universiti Malaysia Sabah cafeterias, 130 kg/day at University of Nottingham, and 378 kg/day at Virginia Military Institute. Bakri et al. [73] carried out a preliminary study to practice buffet-style food serving during the orientation week. They found that buffet-style dining generated low food waste compared to take-away methods.

A variety of bulking agents were used in food waste composting, and most of the studies used landscape waste as it is readily available on the campus. Sangamithirai et al. [67] studied composting and cocomposting yard waste at Anna University's university campuses and successfully turned food waste, yard waste, and paper waste into compost using a cylindrical in-vessel composter for 105 days. The majority of the C: N ratios in the various composts satisfy the basic compost requirements of less than 30 : 1. At Kean University, a rotary in-vessel with a capacity of 450 kg of food waste/day and 125 kg of wood chips/day was used to produce compost [68]. KU successfully created compost of 13, 377 kg/year. Bhave and Kulkarni [69] conducted a lab-scale study for in-vessel composting using food waste from VJ Technological Institute's canteen as feedstock. They found that the active aerated reactor's compost was better than the passive aerated reactor's compost in terms of germination index (GI) and NPK value.

Food waste and dry leaves were composted using in-vessel composting for 55 days at the Universiti Malaysia Sabah (UMS). Meanwhile, Universiti Malaya (UM) developed a composting center in 2011 called Universiti Malaya Zero Waste Campaign Center (UMZWC). Most of their food waste and green waste are diverted from landfills through composting. UM used the Takakura composting and aerated pile composting methods for food waste and green waste [70, 74]. From the composting process, about 0.15 kg of compost was produced from 1 kg of food waste after 60 days [75]. Alerding et al. [71] also used aerated static piles for food waste composting at the Virginia Military Institute.

The University of Nottingham, Malaysia Campus, built a composting site at the campus where 550 kg of compost is produced per month. According to Keng et al. [30], food waste and leaves were composted using the windrow method for 7.5 months per cycle. Windrow food waste composting was employed at the University of Minnesota, Morris, and Kwame Nkrumah University of Science and Technology in Ghana [22, 72]. Windrow and vermicomposting of food waste, dry leaves, and paper were conducted at Universiti Malaysia Sabah. It was found that the quality of compost concerning physicochemical properties and crop growth was better in vermicomposting than in windrow composting [76]. The selection of the method of composting depends on several factors, such as cost and available space.

At the University of New Hampshire, food waste is obtained from the dining hall and other facilities [77]. The university used a mechanized system to manage the food waste to the dishing area, where it was turned into a dry oatmeal-like material that composted easily owing to its increasing surface area. The compost was then poured into a hole in a windrow and covered to be screened each spring for retail sale to area farmers and gardeners. Meanwhile, at Ohio University, food waste was gathered from 82 food courts as part of their assignment in a sustainable agriculture class. Of that 355.5 pounds, 50% was deposited into the compost bin. It is estimated that the university is expected to allocate 2.5 to 3 tons of food waste each day to composting based on the size of the population, the size of the dining hall, and a third party evaluation [78].

Kamyab et al. [79] calculated greenhouse gas emissions from the compost processed from 5 to 10 tons of food and green waste, respectively, at the Universiti Teknologi Malaysia. Total GHG emissions, including emissions from the compost, transportation, and processing, were at 0.111 MTCO2E/ton of feedstock. These values enable further calculation of GHG emissions related to waste transportation to different locations. Bolong and Saad [76] found that compost produced by different residential colleges and a canteen at Universiti Malaysia Sabah, Malaysia, had different pH values of around 6 and 7.5, which are acceptable for plant growth. The EC value was acceptable for the plant growth (<2 mS/cm).

Table 2: Sewage sludge and food waste composting of some higher education institutions.

Campus	Waste generated	Feedstock for composting	Composting methods	Compost characteristics	References
		Sewage sludge			
Kwame Nkrumah University of Science and Technology, Ghana	NA	Sewage sludge: organic waste solid (food leftover, fruit waste, vegetable waste)	Open windrow pile (Dimension: 1 m height × 1.5 m wide) (Manual turning)	C/N: 9.1–10.2 pH: 5.2–8.0 OM (%): 46.7–56.7 Ash (%): 43.3–57.0 N (%): 2.7–3.5 P (%): 0.7–1.7 K (%):0.2–0.8	[22]
Indian Institute of Technology Guwahati, India	150 kg	Sewage sludge, cattle manure, sawdust	Rotary drum composter (550 L capacity, batch mode) (Manual turning)	M/C (%): 43.2–55.2 C/N: 8.5–11.9 pH: 7.4–7.6 OM (%): NA Ash (%): NA N (%): 1.5–2.1 P (%): 3.2–4.4 K (%):8.3–9.9	[66]
		Food waste			
Anna University, Chennai, India	350 kg/day	Food waste, yard waste, paper waste	In-vessel	MC: 49.8–63.1% C/N: 9.1–47.2 pH: 6.1–7.6 N: 0.4–2.9% P: 0.1–0.3% K: 0.1% GI: 45.0–120.0%	[67]
Kean University (KU) Union Campus, United States	125 kg/day	Food waste: wood chips	In-vessel	NA	[68]
V J Technological Institute, India	NA	Food waste, vegetable waste, fruit waste	In-vessel	MC: 32.2–33.4% C/N: 36.0–45.0 pH: 6.5–7.5 N: 0.9–1.0% P: 0.9–1.0% K: 0.7–0.9% GI: 71.1–81.7%	[69]
Universiti Malaysia Sabah (UMS), Malaysia	25.5 kg/day for one cafeteria	Food waste, dry leaves	In-vessel	NA	[28]
University Malaya, Malaysia	200 kg/day	Food waste, yard waste	Aerated static pile	MC:29.54% pH:6.6 N: 2.39% P: 2.82% K:0.21%	[70]
Virginia Military Institute (VMI)	378 kg/day	Food waste, bark leaves, paper	Aerated static pile	MC: 67.4–70.4% C/N: NA pH: NA N: NA P: NA K: NA	[71]
University of Nottingham, Malaysia	130 kg/day	Food waste, leaves	Windrow	C/N: 12 pH: 7.3	[30]

Table 2: Continued.

Campus	Waste generated	Feedstock for composting	Composting methods	Compost characteristics	References
				N: 2.62% P: 3.39% K: 0.58%	
University of Minnesota, Morris (UMM)	NA	Food waste, food-spoiled paper	Windrow	NA	[72]
Kwame Nkrumah University of Science and Technology (KNUST), Ghana	NA	Food waste, sewage sludge, fruit waste, and vegetable waste	Windrow	MC: NA C/N: 9.4–11.6 pH: NA N: 2.2–3.5% P: 0.5–1.7% K: 0.2–1.1%	[22]

MC: moisture content, C/N: carbon to nitrogen ratio, N: nitrogen, P: phosphorus, K: potassium, GI: germination index, and NA: not available.

Vázquez et al. [31] use decentralized composting to make high-quality fertilizer for university-urban gardens, utilizing the waste of faculty canteens (BWUC) in the University of Coruña by using gardening waste (GrW) as bulking material. Composters of 20 (SCH) and 40 kg BWUC/day were used, and the first stage was performed in a dynamic composter (DC) from January to July 2011, involving 3000 kg of waste. Complete maturation was achieved after four and two months in SHC and DC-SC systems, respectively. The C/N ratio obtained ranged from 9 to 15, which was influenced by BWUC: GrW.

The composting program has provided economic, environmental, and educational benefits to the campus. The compost produced at KU was either used at the farm at KU or sold to the KU cafeteria and the surrounding community. The sale of the vegetables grown with compost produced at KU could generate revenue of $13,200 per year [68]. The University of Nottingham, Malaysia, saved RM 12,600/year (from tipping fees and waste collection fees from landfilling) and RM 2,000/year from buying chemical fertilizer. Keng et al. [30] reported that the cost of landfilling is lower (RM12,600 per year) than composting (labor, machinery maintenance, and fuel consumption for grinder and wood chipper), which costs RM19,618 per year. The deficit is due to low-cost landfilling in Malaysia. UMZWCTeam [75] stated that total chemical fertilizer consumption was reduced due to compost production from food waste.

Mu et al. [68] also studied the differences between composting and landfilling food waste for their environmental impacts. They found that the greenhouse gas emissions for composting were lower than those for landfilling, at 448 kg CO_2 eq and 648 kg CO_2 eq, respectively. Composting is in accordance with some European Green Deal Goals, which are improving waste management, moving toward a circular economy, and a healthy food system for people and the planet [80]. Implementing composting in institutions indicates that a high amount of organic waste could be diverted from landfills or incinerators, thus, reducing GHG emissions. Composting on campus can also be a learning tool for students and bring those lessons to the community. In conclusion, this shows that composting is an effective way to manage food waste in universities as it reduces waste from landfilling, reduces the dependency on chemical fertilizer, lowers the cost of waste management, and increases awareness of composting.

3.2. Sewage Sludge Composting. There have been few reports on sewage sludge composting on campus, and the research has been limited to small-scale systems as shown in Table 2. Previous studies carried out in Ghana by Fei-Baffoe and his team at Kwame Nkrumah University of Science and Technology show that composting sewage sludge alone fails to produce good compost quality [22]. They have made a reasonable effort by cocomposting sewage sludge and natural waste products collected from the campus to produce compost with physicochemical properties suitable for organic fertilizer. Organic waste includes food scraps as well as fruit and vegetable waste. Cocomposting sewage sludge and natural waste products in the ratios of 1 : 2 and 1 : 3 reported achieving a temperature of 55°C in just 8 days, which is necessary for pathogenic destruction. The compost produced is considered safe to be used as fertilizer due to its deficiency of heavy metals, fecal coliforms, and elevated levels of nutrients to promote plant growth. This work will benefit the university in waste management and produce fertilizer for agricultural activities. Unfortunately, the scale of the composting system was not reported.

Nayak and Kalamdhad [66] conducted composting of sewage sludge using a rotary drum composter at the Indian Institute of Technology, Guwahati, India. Sewage sludge was blended with sawdust and livestock manure over 20 days of composting, with a C/N ratio varying from 0 to 30. The total weight of the mixture for each composition is 150 kg.

A sample with a C/N ratio of 30, which consists of 87 g of sewage sludge, 45 g of cattle manure, and 18 kg of sawdust, shows a significant reduction in CO_2 evolution (94.7%), OUR (94.9%), and C/N ratio (60.5%), indicating that biodegradable ingredients were stabilized. A temperature above 50°C was achieved on day 2 for samples with a C/N ratio of 25 and 30, while sewage samples with a C/N ratio of 15 and 20 showed a lower temperature profile. Because of its low porosity, sewage sludge can only reach a maximum temperature of 35°C on its own.

Herrera-Melián et al. [81] studied removing hormones from the wastewater of a university campus. The content of hormones could affect the metabolism of aquatic animals. Composting is able to release hormones from steroids in cattle manure. A vertical reactor is better at removing biochemical oxygen demand (BOD) and ammonia because it has better air circulation. This makes it easier for hormones to be released.

3.3. Anaerobic Digestion for Food Waste. Previous research has shown that AD can reduce waste volume while also reducing greenhouse gas emissions (GHGs) [82] and can help to reduce odor and pathogens before being disposed of in a landfill [83]. The main goal of the AD is to treat and turn waste into valuable products, as well as to make waste management more environmentally friendly. Anaerobic digestion is considered an attractive method for food waste treatment due to its ability to capture and recycle energy and nutrients. Food waste makes excellent anaerobic digestion substrates. Academic institutions provide a perfect opportunity for anaerobic digestion projects due to their high populations, which leads to large waste generation and high energy consumption [84]. However, implementing anaerobic digestion inside the campus to treat waste and produce energy has not been much reported.

A case study of the potential for biogas development and implementation at the Broward Dining Hall at the University of Florida has been reported. The study used a 136.4 L daily-fed anaerobic digester built from recycled polyethylene drums as a biogas reactor. According to the report, turning food waste into biogas could provide a substantial additional energy source for the dining room. At the same time, it eliminates solid waste and generates carbon-neutral renewable energy. It is also expected to decrease the energy footprint and carbon emissions associated with existing methods of disposal. It was reported that human habits are one of the challenges in preparing the substrate for anaerobic digestion, as it depends on the routine of employees to separate kitchen waste [85]. This problem might be solved by using a smart advanced electronic system to classify the university waste according to the categories and allow the identification of the type of waste and its weight [86]. However, due to safety concerns and budget limitations, most universities opted to send their waste to authorized waste management companies.

Thammachataree and Abdul Salam [87] researched the effectiveness of producing biogas using the food waste available at the Asian Institute of Technology (AIT), Thailand. The researchers also aim to use biogas to substitute for the LPG used on campus. A total of 1,383 kg per day is collected at AIT from residential units and restaurants. Installing seven food waste bins at different residential units was carried out to encourage the campus community to separate their waste. According to the study, current food waste can generate around 85–123 m^3 of biogas per day. Three small-scale digester concepts of one-stage wet digestion, two-stage wet digestion, and dry digestion were investigated. From the study, the one-stage wet digester is described as the most promising, with a 7-year payback period of 718 tCO_2e/year net greenhouse gas (GHG) emission and the expectation that about 60% of the food waste could be fed into the digester. However, through the Clean Development Mechanism (CDM), the installation is not doable because its anticipated cash benefit seems to be smaller than the investment cost.

At Clarkson University, the USA, a digester comprising three 5 m^3 reactors operated in a single and two-phase system was installed for treating food waste produced regularly inside the university campus kitchens, as stated by Grimberg et al. [88]. During the academic year, this university has 3000 students who serve 3700 meals a day and approximately 500 meals during the summer months. The digester was initially run as a single-stage system before being upgraded to a two-stage system. It was found that biogas yield was greater in the two-stage system. A significant reduction in food waste was caused by campus holidays during the summer months. However, it was found that the two-stage system could effectively handle short loading times, as reflected by the pH of 5.2.

It is also reported that the University of California, Davis, has developed an anaerobic digestion facility called the Renewable Energy Anaerobic Digester (READ) at the campus' former landfill. The university's invented technology has been successfully commercialized and patented. It can transform 50 tons of food waste from campuses and restaurants into 12,000 kWh of electricity, diverting 20,000 tons of waste from local landfills annually [89].

In Indonesia, the Institut Teknologi Bandung (Jatinangor Campus) has developed an anaerobic digestion system to manage biodegradable waste obtained on campus and at a nearby traditional market. The anaerobic digester consists of a single stage, and wet fermentation is constructed on an area of 200 m^2. The amount of biogas generated was found to be about 2 m^3 per day. The proportion of methane reduced could be 40%–60% by implementing a simple biogas purification unit. As a result of the waste reduction at the source, the various possible negative consequences of open dumping at the Indonesian landfill site could be avoided [90].

4. Technology Selection for Campus-Scope Composting and AD

There are concerns about the type of technology suitable for campus-scope composting as opposed to general municipal or industrial-waste composting. However, before the type of technology is selected, there are a few considerations to be made. These include managing the volume of feedstocks, climate and seasonal change, space, availability of resources, and managing odors, animals, and insects. Therefore, a significant difference between the scales of campus-level composting, as opposed to general municipal or industrial-waste composting, is in the perspective of the scale. In this context, the scale of campus-scope composting is much lower in comparison to general municipal or industrial-waste composting. Other concerns are discussed in the following discussion.

4.1. Consideration of the Type of Waste Production. Based on the early discussion, the type of waste production from a university campus is comparable to the waste production from general municipal waste in terms of organic matter [21, 22], and similarly has a low C/N ratio [91]. However, for a university campus, the content of hazardous matter [46], major nutrients such as nitrogen (N), phosphorus (P), and potassium (K) [48, 49] and heavy metals in terms of type and concentration are reduced [21]. This could be due to the variation of the waste produced, such as location related to dietary customs that may affect the quality of the waste. The waste stream is a function of the activities. In this case, the types of permitted activities on a university campus are not as liberal as when compared to domestic or industrial activities. Therefore, the discharge is predictable in comparison to general municipal households or industrial discharge.

4.2. Consideration of the Amount of Discharge Based on Activities. According to Metcalf and Eddy [92], wastewater flow rates vary depending on the nature of the discharges to the collection system, i.e., during the time of day, day of the week, and season of the year. A university campus setting falls under the seasonal variation, where activities are seasonal. The magnitude of the variation is expected to depend on the size of the community, which will be largely influenced by the number of students and the activity. The activity on campus is largely dependent on the academic calendar. The activities include study weeks, revision weeks, final examination weeks, and middle and end of semester breaks. Because the number of students decreased during the semester break, the estimated discharge was reduced. Hypothetically, the campus composting activities will be reduced when the discharge is reduced. Therefore, proper planning must be conducted to suit the overall activities of the composing initiatives and the community of the university campus.

4.3. Consideration of the Design of the Composting and AD Facilities. The design for a university campus and general municipal composting may differ in terms of the scale of input. For university composting, since its discharge flow rate is a seasonal variation, it may not require a design with a scale of continuous input requirement such as for general municipal composting. In the scope of composting, there are a few well-applied techniques that are being used. The type of selection of technique will have an effect on the duration of the process or maturity requirement, which can be taken up from a few weeks to months. This includes long-duration processes such as vermicomposting, static piles, and windrows and also controlled processes that have a short maturity duration, usually measured in weeks, such as anaerobic digesters and vessels.

4.4. Use of Campus-Scope Composting and AD as a Living Laboratory. Sustainability development is a key strategy for ensuring that humans and the environment are in good health. Having an on-campus university composting facility opens the door to generating and modeling solutions for new discoveries and innovations for emission reduction strategies, therefore spurring sustainable innovation for the Earth. This finding of this continuous effort can be replicated and cascaded across local, regional, and global levels. Therefore, based on the discussion, necessary consideration needs to be given in the process of creating the product of composting activities to follow the required standard.

Based on the research presented, installing an anaerobic digester on campus will allow for the sustainable management of food waste while also producing renewable energy. However, there are very few digesters currently existing on campus sites all over the world. The reason might be the high capital investment required to develop the system. Therefore, feasibility studies are required, particularly on the feedstock's characterization, designing the system, and selecting technology.

5. The Challenge and Future Remarks

Adopting composting and AD for sewage sludge and food waste on campus will face many challenges from economic, political, or even environmental aspects (Figure 2). A strategic plan needs to be envisaged for full implementation and a good response from all participant parties. Najafian and Karamidehkordi [93] discuss sustainability efforts at the University of Zanjan, Iran, where a sustainable waste management agenda is part of the university's strategic plan and policies. The sewage disposal management uses water for landscape management while its sludge is treated through composting for farms.

Ayilara et al. [94] have discussed the challenges of waste management by composting. For sewage sludge or term as activators, high content of microorganisms and low C : N ratio affect the composting process. Therefore, cocomposting sewage sludge with organic materials with a high C : N ratio helps achieve the optimum ratio. Additionally, the biogas generated from organic waste composting can be quite low (estimated at 0.01 m^3/kg) [90] and can be improved through cocomposting, adding new microorganisms, or introducing new pretreatment to generate more biogas. Pathogenic organisms such as *E. coli* and *Salmonella* spp. are expected to be present in composts [95, 96]. Therefore, the safety of compost should be evaluated according to the microbial constituents of plants, soil organisms, animals, and humans.

Awasthi et al. [97] have discussed in detail the opportunities and risks of food waste composting. They stated that the lack of a simultaneous maturity index system could make cocomposting difficult. Maturity could also be described as the degree to which the digestive process has progressed. It can be used to measure the amount of humification in compost. As a result, respiration rates, which imply the conversion of organic substances, may be used to assess this process [97, 98].

Another challenge for composting is odor and gas emissions because of the content of CH_4, N_2O, and NH_3, which create environmental pollution [99]. Furthermore, Wang et al. [100] pointed out that there are difficulties in food waste selection and unsatisfactory grading, which affect

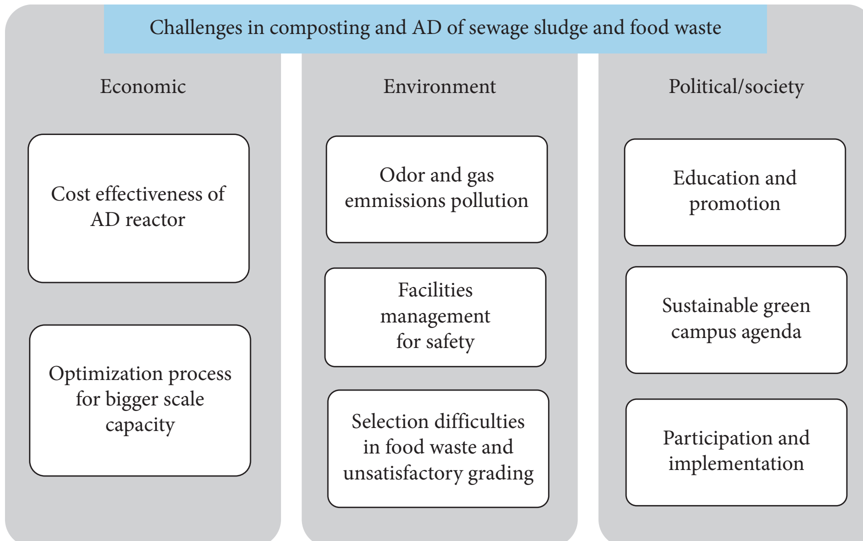

Figure 2: Challenges in the adaptation of composting and AD in universities.

the physical and chemical degradation of the waste during composting. If the waste is not well managed and shows an increase in volume, it can cause harm to humans and their surroundings, with problems such as flooding, air pollution, and vector disease. Moreover, if the sewage is not treated appropriately, it will create a smelly odor on the campus (Yaser et al., 2029).

One of the challenges faced by universities in implementing a composting system is the segregation of waste. Composting on campus faces some difficulties compared to industrial composting, such as inconsistency in the quantity of food waste. Low food waste generated during semester breaks may affect the feasibility of the composting program. Other than that, the constraints can be limited space and human resources. In terms of quality, composting on campus can produce acceptable compost as most of the compost produced meets the standards. Furthermore, the difference between campus composting and large-scale composting is scale. Thus, there are less energy use, less methane gas production, and less environmental impact [63].

Since university composting is done to serve only the community on the campus, the cost of the methods is much lower and limited. In most of the composting methods mentioned in this review, most universities opted for windrow composting, which is much cheaper than reactors. Most of the campuses process their waste at full-scale capacity (>100 kg/day) for either composting or anaerobic digestion. Moving forward, with the problem arising due to the open-space methods in terms of odor that attracts animals (rats, monitor lizards, birds, etc.) and vector diseases, anaerobic digestion integrated with composting in a reactor can be considered to minimize the odor. Composting can also be carried out through a centralized or decentralized system. For the decentralized system, each building that has a cafeteria will do its own compost. Nonetheless, further research needs to be carried out to optimize the parameters that lower the composting cost without affecting the quality of the end products. Additionally, compostable products can be used as compost for landscaping.

At a university with a composting program, awareness of composting participation and student attitude toward composting efforts were found to be positive at a university with a composting program [102]. A university's strategic plan and policies must be integrated into education and research activities aligned with the United Nations' sustainable development goals, such as climate change initiatives. The infrastructure to build composting facilities should also be appropriately managed and ensured safe due to microorganisms' involvement. Educating the communities through on-site demonstrations, campaigns, and workshops can be a collaborative move that the university can apply. Continuous monitoring and knowledge sharing in conjunction with ongoing composting, whether on campus or in communities, can not only benefit both universities and communities but can also attract participation from higher levels of governance and people.

Sustaining the green campus agenda is the role of all people at the university, from the top management, academic staff, management personnel, and also students. A proper plan for the handling of campus waste and sewage should be envisaged and carried out. Working hand in hand with the implementation and promotion of a sustainable green campus agenda, supporting an effective policy backed by the university's top management, and maintaining good monitoring not only pave the way for achieving the goals but also provide a conducive knowledge transfer medium on the campus. From these reviews, we can observe that a trial by global institutes has been carried out on the sewage and waste management of their waste, with different results. Assuring the campus community handles their waste safely and efficiently will have hiccups, but as modern technology advances, it will provide an improved solution to solve the problem that arises.

To our knowledge, studies that adopt anaerobic digestion using campus sewage sludge are not widely reported or very limited. Future research should focus on the application of anaerobic digestion using sewage sludge generated by universities or campuses. Exploring a wider range of technology and testing new feedstocks in composting and anaerobic digestion can also be implemented. A recent and notable trend in the development of anaerobic digestion technology is to codigest two or more substrates together. Investigating the synergistic effect of using a combination of both feedstocks (food waste and sewage sludge) that are generated on campus to be used in cocomposting or in anaerobic codigestion is a lucrative move that can be thought of. Also, using codigestion can solve some problems like a lack of micronutrients, an unbalanced C/N ratio, and unfavorable organic loading rates, as well as reduce the cost of money that needs to be spent on building new waste management facilities [103, 104]. Adopting codigestion of food waste and sewage sludge followed by digestate composting is also an interesting method in the future.

Data Availability

All the data have been included in the text.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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