RSF Conference Proceeding Series: Engineering and Technology Vol. 4 No. 1 (2025) https://doi.org/10.31098/cset.v4i1.1058

Research Paper

Anaerobic Digestion Versus Composting: A Comprehensive Review on Waste Stabilization, Resource Recovery, and Sustainability

Nina Anggita Wardani*, Muhammad Redo Ramadhan, Nuha Amiratul 'Afifah
Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia

Received : Sept 16, 2025	Revised : Oct 1, 2025	Accepted : Oct 6, 2025	Online : October 14, 2025

Abstract

The rapid growth of organic waste from agricultural, industrial, and municipal activities has raised serious environmental concerns. Anaerobic digestion (AD) and composting (COM) are two widely applied biological technologies developed to stabilize organic waste and recover valuable resources. This review compares their performance, products, environmental impacts, and operational challenges, and discusses the potential benefits of integrating both processes. AD degrades organic matter under anaerobic conditions into biogas and digestate, which can be used as an organic fertilizer due to its high nutrient content. COM is an aerobic self-heating process that transforms organic residues into stable compost suitable for soil improvement. Comparative data show that AD achieves higher degradation rates in shorter residence times, while COM produces a stable product with lower investment and operational complexity. Life cycle assessments indicate that COM has higher energy-related environmental burdens, whereas AD offers better energy recovery but requires higher capital costs and post-treatment of digestate. The integration of AD and COM enables the complementary use of both processes, where AD contributes to methane generation and nutrient retention. At the same time, COM enhances pathogen inactivation and moisture reduction, thereby improving the overall efficiency and sustainability of organic waste management.

Keywords *fertilizer, nutrient, greenhouse gas, digestate, compost*

INTRODUCTION

The rapid increase in organic waste generation from agricultural, industrial, and municipal sources has raised serious environmental concerns, including greenhouse gas (GHG) emissions, soil and water pollution, and nutrient losses. To address these challenges, biological waste treatment technologies have been widely developed to recover valuable resources while reducing environmental impacts. Among these technologies, anaerobic digestion (AD) and composting (COM) are two of the most commonly applied and well-established methods (Cucina, 2023; Li et al., 2025; Sadh et al., 2018).

AD is an oxygen-free process that breaks down organic matter into biogas and digestate, allowing simultaneous energy recovery and nutrient recycling. Meanwhile, COM is an aerobic and self-heating process that transforms organic residues into stable, nutrient-rich compost suitable for soil improvement (Sorino et al., 2024). Both processes are environmentally attractive and contribute to circular bioeconomy strategies by converting waste into valuable products (Subbarao et al., 2023; Wainaina et al., 2020).

Despite their shared goal of organic waste stabilization, AD and COM differ significantly in terms of operating conditions, product characteristics, environmental performance, and economic feasibility (Eftaxias et al., 2024; Katada et al., 2021; Porterfield et al., 2023; Yaser et al., 2022). Understanding these differences is crucial for selecting the most suitable treatment technology or designing integrated systems that are tailored to specific needs. Therefore, this review compares the performance, products, environmental impacts, and practical challenges of AD and COM, and

Corresponding author's email: nina.anggita@upnyk.ac.id

discusses the potential benefits of integrating both processes to improve overall efficiency and sustainability.

LITERATURE REVIEW

Anaerobic Digestion and Composting

AD involves breaking down complex organic materials without the existence of oxygen. Operating regimes include mesophilic (35-40 °C) and thermophilic (55-60 °C) digestion (Wardani et al., 2020). During AD, acidogenesis and acetogenesis are most active under slightly acidic conditions, typically around pH 6, where fermentative and acetogenic bacteria convert hydrolysis products into volatile fatty acids, hydrogen, and CO_2. In contrast, methanogenesis requires neutral conditions (pH 7–7.5), as methanogenic archaea are highly sensitive to acidic environments. Operating the system so that acidogenesis/acetogenesis occur at pH 6 and methanogenesis at pH 7 is therefore a key strategy to enhance methane production (Wardani & Budhijanto, 2023).

Under these optimized conditions, methanogenesis produces methane (CH_4) as the primary energy carrier in biogas, with CO_2 as the main co-product. Besides biogas, AD also generates digestate, a nutrient-rich by-product that can be used as organic fertilizer after quality assurance and, if necessary, post-treatment (Lamolinara et al., 2022). Digestate is recognized for its ability to recycle nitrogen, phosphorus, potassium, and organic carbon, thereby enhancing soil fertility and reducing the reliance on synthetic fertilizers (Reuland et al., 2021). This dual function, energy recovery via methane and nutrient recycling via digestate, positions AD as a core technology for advancing the circular bioeconomy (Bayu et al., 2022).

COM is a self-heating biological treatment widely applied to organic waste, proceeding through three main phases: mesophilic, thermophilic, and maturation (Cucina et al., 2022). It provides a natural stabilization method, where microorganisms degrade organic matter and generate stable, nutrient-rich, and pathogen-free fertilizers. Throughout the process, microorganisms metabolize compounds such as polysaccharides and proteins, which increases the temperature of the COM mass and promotes the formation of humic substances (Zheng et al., 2022).

The process relies on aerobic metabolism (with oxygen concentrations above 6% v/v) by diverse microbial communities that utilize organic waste as a source of carbon and energy. Their activity transforms the waste primarily into CO_2, water, stabilized compost, and heat. Achieving thermophilic conditions (temperatures above 55 °C) during the active stage is essential for inactivating pathogens and weed seeds. The resulting compost is enriched with stable and recalcitrant organic compounds, making it a valuable soil conditioner. Typically, the process takes around 90 days and must be carefully managed under controlled parameters, including moisture content (50–60% on a weight basis), oxygen availability (>5–6% v/v), a C/N ratio less than 20:1, and appropriate temperature ranges (Cucina et al., 2022).

Product of Anaerobic Digestion and Composting

Both AD and COM have waste treatment as their primary purpose, but they also produce byproducts that may add additional value. As previously mentioned, AD degrades organic material into biogas and digestate as its products, while COM produces compost. Both digestate and compost can be used as organic fertilizer (Kakadellis et al., 2025; Liu et al., 2022; Wang et al., 2025).

Several studies have found that mass degradation in AD is less significant than in COM (Cucina et al., 2022). The data shown in Table 1 indicate that, on a wet basis, the mass degradation in AD is significantly higher than in COM. This may be caused by no leachate production in AD. If we examine the dry basis, the mass degradation in AD is significantly higher than in COM, indicating that organic material degradation is actually higher in AD than in COM. This is linear to the value of

VS in digestate, which is 30% of the initial VS of the waste, which is much lower than the recovery of VS in the COM process (67%).

Although the nutrient content in digestate is generally higher than that in compost, further processing, such as drying or fractionation, is required to comply with the EU 2019/1009 regulation, which stipulates that an organic soil improver must contain at least 7.5% organic carbon (OC) and a minimum of 20% dry matter. The carbon present in digestate is considered more readily available for microbial uptake, as approximately 61% of it is found in the liquid phase, which contains higher concentrations of organic acids compared to the liquid after fermentation (LAF). Most of the phosphorus and carbon fibers are typically retained in the solid fraction of the digestate, providing both short-term and long-term carbon sources. This solid fraction constitutes only about 11% of the digestate, the lowest among all treatments. However, it can still be separated and applied to soil as an amendment due to its relatively high carbon content, which is 46% higher than the total carbon content of compost, even without considering the carbon present in the liquid phase (Chavez-Rico et al., 2022).

Table 1. Percentage of Some Parameters Mass Recovered in The Product Relative To Its Initial Amount in The Biomass

No.	Parameter	Compost	Digestate
1	Mass in wet basis	37%	88%
2	Mass in dry basis	80%	53%
3	C	39%	64%
4	N	53%	100%
5	P	1%	100%
6	VS	67%	30%
7	Soluble C	16%	957%
8	Soluble N	14%	517%
9	Soluble P	18%	714%
10	Ca	18%	124%
11	K	29%	263%
12	Mg	1%	74%

Source: Chavez-Rico et al. (2022)

Environmental Impacts

A study by Estévez et al. (2023) benchmarked the environmental impact of AD and COM. Table 2 presents the relative environmental contributions of COM and AD across seven environmental impact categories. The contributions are further subdivided by their primary sources, namely energy use, chemical inputs, emissions, and others.

For COM, energy use was the dominant contributor to most impact categories, particularly Freshwater Eutrophication (99%), Marine Eutrophication (94.5%), Land Use (99.5%), and Fossil Resource Scarcity (99.5%). Emissions also played a significant role in Global Warming Potential (99%) and Terrestrial Acidification (91%). In contrast, the contribution of chemicals remained minor (<3%) across all categories.

For AD, energy contributed substantially to several categories, including Freshwater Eutrophication (16%), Marine Eutrophication (16%), Land Use (15.5%), and Fossil Resource Scarcity (16%). In comparison, emissions had a more significant influence on Global Warming Potential (0.4%) and Terrestrial Acidification (1.92%). Notably, water consumption under AD showed a more diverse distribution, with contributions from energy (8%), chemicals (8%), emissions (53%), and others (17.6%). Overall, COM showed a strong dominance of energy-related impacts in almost all categories. In contrast, AD demonstrated a more balanced distribution among different sources, particularly showing higher shares from emissions and others in water consumption.

Table 2. Relative Environmental Impact of Digestion to Several Environmental Aspect

Aspect	Energy		Chemical		Emission		Others	
	C	**D**	**C**	**D**	**C**	**D**	**C**	**D**
Global Warming Potential	1%				99%	0.4%		0.49%
Terrestrial Acidification	9%	1%		1.9%	91%	1.92%		
Fresh Water Eutrophication	99%	16%		1.6%		1.5%		
Marine Eutrophication	94.5%	16%		1.2%		44.5%		5.5%
Land Use	99.5%	15.5%		2.3%				0.5%
Fossil Resource Scarcity	99.5%	16%		31.4%				0.5%
Water Consumption	47%	8%					53%	17.6%

C = composting; D = anaerobic
Source: Estévez et al. (2023)

RESEARCH METHOD

This paper adopts a narrative review approach to synthesize and compare the performance of anaerobic digestion (AD) and composting (COM) in waste stabilization, resource recovery, and sustainability. Relevant literature was collected from major scientific databases, including Scopus, Web of Science, and ScienceDirect. The primary focus was on peer-reviewed journal articles published between 2018 and 2025, although earlier seminal works were also included to provide conceptual and historical context.

Studies were included if they contained quantitative or qualitative data related to the performance, products, environmental impacts, or integration of AD and COM. The selected articles were systematically analyzed and categorized based on four key aspects: (i) process mechanisms and operating conditions, (ii) products and nutrient recovery, (iii) environmental impacts, and (iv) challenges and recommendations. Comparative data from various studies were summarized in a tabular form to highlight similarities, differences, and potential integration opportunities between AD and COM.

FINDINGS AND DISCUSSION

Several studies comparing AD and COM in processing various wastes are shown in Table 3. Table 3 compares the performance of COM, AD, and integrated AD-COM treatments in terms of operating conditions, types of waste treated, duration, degradation efficiency, and biogas production.

Overall, AD showed higher degradation rates and biogas yields compared to COM under similar or shorter treatment periods. For example, cardboard-based wastes showed degradation levels of 76–92% under AD, accompanied by biogas production of 338–395 mL CH_4/g VS, while

COM under similar conditions achieved slightly lower degradation (83–88%) without producing biogas. In the case of thermoplastic cellulose acetate, COM achieved low degradation (17.7–18.9%) despite operating at high temperatures (45–78 °C), whereas AD reached 36.8–50.3% degradation with measurable methane production (up to 115.27 mL CH_4). All of those degradation levels were achieved in AD, even at lower temperatures and shorter residence times than in COM. Those findings contradict the findings of Cucina (2023), who reported that the degradation of AD is lower than that of COM.

Table 4 summarizes the main advantages (A) and disadvantages (D) of AD and COM, considering their product characteristics, area requirements, capital investment, operational aspects, and environmental and safety impacts (Lamolinara et al., 2022). In terms of products, AD generates both biomethane and digestate, offering an energy recovery benefit; however, it produces a large volume of digestate that requires post-treatment and may contain pathogens, despite being rich in nutrients. In contrast, COM produces only compost with a smaller volume and requires no pretreatment, but results in some nutrient losses (O'Connor et al., 2024).

Since AD operates in closed reactors, it requires only a small area and minimizes odor emissions, leachate formation, and nutrient losses. However, the resulting digestate often needs post-treatment to remove pathogens, stabilize organic matter, and degrade organic contaminants (Martín-Sanz-Garrido et al., 2025). Regarding this aspect, it is important to note that well-optimized AD systems, particularly those running under thermophilic conditions with appropriate retention time and organic loading rates, can produce high-quality digestate that can be directly applied in agriculture to restore organic matter and supply plant nutrients (Hu & Shen, 2024; Pigoli et al., 2021; Wardani et al., 2020; Zilio et al., 2021).

Overall, AD offers advantages in energy recovery, space efficiency, and environmental safety, but it involves higher costs and operational complexity. In contrast, COM is more straightforward and less expensive, but less efficient in resource recovery, and poses higher environmental risks.

The integrated AD–COM approach further improved overall degradation compared to either method alone. For instance, thermoplastic cellulose acetate with layered double hydroxide achieved 57.8% degradation under the combined process, which was higher than that of AD or COM alone (50.3% and 17.7%, respectively). The integration of AD and COM can be an optimal technology integration because an effective AD occurred when the C/N ratio was between 20 and 30, while adequate COM maturation occurred when the C/N ratio fell below 20 (Wardani et al., 2025; Chan et al., 2021; Suksong et al., 2020; Wardani et al., 2020).

Table 3. Comparison of Composting (COM), Anaerobic Digestion (AD), and Integrated Anaerobic Digestion-Composting. Symbols: (-) "not applicable" for treatment type; (n/a) "data not available"

Treatment	Temperature	Waste	Duration	Degradation	Biogas Production	References
COM	50 °C (1st 30 days) and 30 °C (2nd 30 days)	premium-meadow hay and dog food	60 days	20%	-	(Chavez-Rico et al., 2022)
AD	30 °C		135 days	47%	n/a	
COM	60 °C (55-70 °C)	cartonboard laminated with a PLA film	12 weeks	88%	-	(Dolci et al., 2024)
AD	55 °C		24 days	76%	338 (mL CH_4/g VS)	

COM	60 °C (55-70 °C)	corrugated cardboard (bleached)	12 weeks	83%	-	
AD	55 °C		21 days	92%	395 (mL CH_4/g VS)	
COM	45-78 °C	Thermoplastic cellulose acetate	21 days	18.92%	-	(Gadaleta et al., 2022, 2023)
AD	40 °C		14 days	36.82%	115.27 mL CH_4	
AD (1st); COM (2nd)	40 °C; 45-78 °C		35 days	39.49%	n/a	
COM	45-78 °C	thermoplastic cellulose acetate + layered double hydroxide	21 days	17.71%	-	
AD	40 °C		14 days	50.25%	93.82 mL CH_4	
AD (1st); COM (2nd)	40 °C; 45-78 °C		35 days	57.82%	n/a	

Table 4. Advantages (A) and Disadvantages (D) of Anaerobic Digestion and Composting

Aspect	Anaerobic Digestion	Composting
Product	• Produce biomethane and digestate (A) • Large volume of digestate (D) • Digestate needs post-treatment (D) • Digestate has high nutrient (A) • Digestate may contain pathogens (D)	• Produce only compost (D) • Small volume of compost (A) • Compost needs no pretreatment (A) • Nutrient loss (D) • Compost doesn't contain pathogens (A)
Area	• Small area requirement (A)	• Wide area requirements (D)
Capital Investment	• High Investment (D)	• Low investment (A)
Operational	• Complex operation (D) • Need special skilled workers (D)	• Simple operation (A) • Need workers with no special skill (A)
Environmental and Safety	• Reduce odour emission (A) • Release no GHG (A) • No leachate (A)	• Odour emission (D) • Release GHG (D) • Leachate production (D)

CONCLUSIONS

AD offers several advantages over COM in terms of performance. It achieves a higher degradation rate and does not release greenhouse gases (GHGs). Regarding the digestate, AD preserves more nutrients, although it requires post-treatment to remove pathogens and reduce water content. Integrating AD with COM can be an efficient technological approach. Through AD, biomethane can be produced while nutrients are preserved, and subsequent COM can then remove pathogens and reduce the water content of the digestate, eliminating the need for separate post-treatment. While this review primarily focuses on recent studies of commonly reported substrates and laboratory-to-pilot scale findings, a broader exploration of diverse feedstocks and full-scale implementation remains a promising direction for future research.

LIMITATIONS & FURTHER RESEARCH

This narrative review synthesizes recent evidence but may underrepresent studies outside selected databases and uses that vary in keywords and reporting units, limiting strict cross-study comparability, such as wet vs. dry basis, versus basis, and differing OLR/HRT, inoculum, and temperatures. Environmental conclusions remain sensitive to LCA boundaries, allocation choices, and local energy mixes. At the same time, many performance data derive from lab pilot settings that may not fully capture the realities of scale-up, such as heat or mass transfer, odour, dewatering, and downtime. Regulatory nuances for digestate and compost quality, such as pathogens, ARGs, microplastics, and persistent organics, also vary by jurisdiction. Future work should prioritize standardized reporting checklists and PRISMA-guided meta-analyses, longitudinal full-scale monitoring with coupled TEA-LCA under policy scenarios, targeted risk and quality assessments, and design of experiments to optimize integrated AD and COM sequences for nutrient retention, emissions control, and operational robustness.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided by the Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM) of Universitas Pembangunan Nasional Veteran Yogyakarta under Grant No. 800/UN62.21/PG.00.00/2025, which enabled the implementation of this review.

REFERENCES

Anggita Wardani, N., Amalia, D., Redo Ramadhan, M., Jaya, D., Wahyu Widayati, T., Nursubiyantoro, E., Amanda Putra, R., Athaya Khaliq, M., Shofia Najla, Q., & Raffa Syailendra, N. (2025). Evaluating the influence of transition metal oxides on anaerobic digestion performance. *ASEAN Journal of Science and Technology Report, 2025*(4), 257685. https://doi.org/10.55164/ajstr.v28i4.257685

Bayu, A. I., Lestary, R. A., Dewayanto, N., Mellyanawaty, M., Wicaksono, A., Alvania Kartika, R. W., Sakka, D. F., Azis, M. M., & Budhijanto, W. (2022). Kinetic study of thermophilic anaerobic digestion of sugarcane vinasse in a single-stage continuous stirred tank reactor. *Results in Engineering, 14,* 100432. https://doi.org/10.1016/j.rineng.2022.100432

Chan, Y. J., Lee, H. W., & Selvarajoo, A. (2021). Comparative study of the synergistic effect of decanter cake (DC) and empty fruit bunch (EFB) as the co-substrates in the anaerobic co-digestion (ACD) of palm oil mill effluent (POME). *Environmental Challenges, 5,* 100257. https://doi.org/10.1016/j.envc.2021.100257

Chavez-Rico, V. S., Bodelier, P. L. E., van Eekert, M., Sechi, V., Veeken, A., & Buisman, C. (2022). Producing organic amendments: Physicochemical changes in biowaste used in anaerobic digestion, composting, and fermentation. *Waste Management, 149,* 177–185. https://doi.org/10.1016/j.wasman.2022.06.005

Cucina, M. (2023). Integrating anaerobic digestion and composting to boost energy and material recovery from organic wastes in the circular economy framework in Europe: A review. *Bioresource Technology Reports, 24,* 101642. https://doi.org/10.1016/j.biteb.2023.101642

Cucina, M., Tacconi, C., Gigliotti, G., & Zadra, C. (2022). Integration of anaerobic digestion and composting allows safe recovery of energy and nutrients from AFB1-contaminated corn. *Journal of Environmental Chemical Engineering, 10*(5), 108356. https://doi.org/10.1016/j.jece.2022.108356

Dolci, G., Intilisano, M., Fava, F., Venturelli, V., Malpei, F., & Grosso, M. (2024). Degradation of paper-based boxes for food delivery in composting and anaerobic digestion tests. *Bioresource Technology, 408,* 131212. https://doi.org/10.1016/j.biortech.2024.131212

Eftaxias, A., Kolokotroni, I., Michailidis, C., Charitidis, P., & Diamantis, V. (2024). Techno-economic assessment of anaerobic digestion technology for small- and medium-sized animal husbandry enterprises. *Applied Sciences, 14*(11), 4957. https://doi.org/10.3390/app14114957

Estévez, S., Rebolledo-Leiva, R., Hernández, D., González-García, S., Feijoo, G., & Moreira, M. T. (2023). Benchmarking composting, anaerobic digestion and dark fermentation for apple vinasse management as a strategy for sustainable energy production. *Energy, 274,* 127319. https://doi.org/10.1016/j.energy.2023.127319

Gadaleta, G., De Gisi, S., Chong, Z. K., Heerenklage, J., Notarnicola, M., Kuchta, K., Cafiero, L., Oliviero, M., Sorrentino, A., & Picuno, C. (2023). Degradation of thermoplastic cellulose acetate-based bioplastics by full-scale experimentation of industrial anaerobic digestion and composting. *Chemical Engineering Journal, 462,* 142301. https://doi.org/10.1016/j.cej.2023.142301

Gadaleta, G., De Gisi, S., Picuno, C., Heerenklage, J., Cafiero, L., Oliviero, M., Notarnicola, M., Kuchta, K., & Sorrentino, A. (2022). The influence of bio-plastics for food packaging on combined anaerobic digestion and composting treatment of organic municipal waste. *Waste Management, 144,* 87–97. https://doi.org/10.1016/j.wasman.2022.03.014

Hu, Y., & Shen, C. (2024). Thermophilic-mesophilic temperature phase anaerobic co-digestion compared with single-phase co-digestion of sewage sludge and food waste. *Scientific Reports, 14*(1), 62998. https://doi.org/10.1038/s41598-024-62998-w

Kakadellis, S., Delgado, H. D., Teall, R., Leon, R., Simmons, C. W., & Spang, E. S. (2025). Circular urban agriculture: Food waste-derived fertilizers lead to comparable yields in a tomato greenhouse experiment. *Journal of Agriculture and Food Research, 24,* 102286. https://doi.org/10.1016/j.jafr.2025.102286

Katada, S., Fukuda, A., Nakajima, C., Suzuki, Y., Azuma, T., Takei, A., Takada, H., Okamoto, E., Kato, T., Tamura, Y., & Usui, M. (2021). Aerobic composting and anaerobic digestion decrease the copy numbers of antibiotic-resistant genes and the levels of lactose-degrading Enterobacteriaceae in dairy farms in Hokkaido, Japan. *Frontiers in Microbiology, 12,* 737420. https://doi.org/10.3389/fmicb.2021.737420

Lamolinara, B., Pérez-Martínez, A., Guardado-Yordi, E., Guillén Fiallos, C., Diéguez-Santana, K., & Ruiz-Mercado, G. J. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. *Waste Management, 140,* 14–30. https://doi.org/10.1016/j.wasman.2021.12.035

Li, Z., Fan, T. W., Lun, M. S., Li, Q., Hong, Q., Chen, H., Ma, L., & Yu, J. (2025). Study on implementation of anaerobic digestion and composting technologies for kitchen waste management: A case study in Macau. *Heliyon, 11*(10), e42778. https://doi.org/10.1016/j.heliyon.2025.e42778

Liu, Y., Wang, T., Xing, Z., Ma, Y., Nan, F., Pan, L., & Chen, J. (2022). Anaerobic co-digestion of Chinese cabbage waste and cow manure at mesophilic and thermophilic temperatures: Digestion performance, microbial community, and biogas slurry fertility. *Bioresource Technology, 363,* 127976. https://doi.org/10.1016/j.biortech.2022.127976

Martín-Sanz-Garrido, C., Revuelta-Aramburu, M., Santos-Montes, A. M., & Morales-Polo, C. (2025). A review on anaerobic digestate as a biofertilizer: Characteristics, production, and environmental impacts from a life cycle assessment perspective. *Applied Sciences, 15*(15), 8635. https://doi.org/10.3390/app15158635

O'Connor, J., Mickan, B. S., Gurung, S. K., Siddique, K. H. M., Leopold, M., Bühlmann, C. H., & Bolan, N. S. (2024). Transforming waste to wealth: Impact of food waste-derived soil amendments and synthetic nitrogen fertilizer on soil dynamics. *Soil Use and Management, 40*(3), 13093. https://doi.org/10.1111/sum.13093

Pigoli, A., Zilio, M., Tambone, F., Mazzini, S., Schepis, M., Meers, E., Schoumans, O., Giordano, A., & Adani, F. (2021). Thermophilic anaerobic digestion as suitable bioprocess producing organic and chemical renewable fertilizers: A full-scale approach. *Waste Management, 124,* 356–367. https://doi.org/10.1016/j.wasman.2021.02.028

Porterfield, K. K., Hobson, S. A., Neher, D. A., Niles, M. T., & Roy, E. D. (2023). Microplastics in composts, digestates, and food wastes: A review. *Journal of Environmental Quality, 52*(2), 225–240. https://doi.org/10.1002/jeq2.20450

Reuland, G., Sigurnjak, I., Dekker, H., Michels, E., & Meers, E. (2021). The potential of digestate and the liquid fraction of digestate as chemical fertiliser substitutes under the RENURE criteria. *Agronomy, 11*(7), 1374. https://doi.org/10.3390/agronomy11071374

Sadh, P. K., Duhan, S., & Duhan, J. S. (2018). Agro-industrial wastes and their utilization using solid state fermentation: A review. *Bioresources and Bioprocessing, 5*(1), 18. https://doi.org/10.1186/s40643-017-0187-z

Sorino, D., Bartolucci, L., Cordiner, S., Costa, G., Lombardi, F., & Mulone, V. (2024). Numerical framework for anaerobic digestion and/or composting of bioplastics and organic waste performance evaluation under real-like large-scale operating conditions. *Sustainable Chemistry and Pharmacy, 37,* 101418. https://doi.org/10.1016/j.scp.2023.101418

Subbarao, P. M. V., D'Silva, T. C., Adlak, K., Kumar, S., Chandra, R., & Vijay, V. K. (2023). Anaerobic digestion as a sustainable technology for efficiently utilizing biomass in the context of carbon neutrality and circular economy. *Environmental Research, 234,* 118512.

Suksong, W., Tukanghan, W., Promnuan, K., Kongjan, P., Reungsang, A., Insam, H., & O-Thong, S. (2020). Biogas production from palm oil mill effluent and empty fruit bunches by coupled liquid and solid-state anaerobic digestion. *Bioresource Technology, 296,* 122304. https://doi.org/10.1016/j.biortech.2019.122304

Wainaina, S., Awasthi, M. K., Sarsaiya, S., Chen, H., Singh, E., Kumar, A., Ravindran, B., Awasthi, S. K., Liu, T., Duan, Y., Kumar, S., Zhang, Z., & Taherzadeh, M. J. (2020). Resource recovery and circular economy from organic solid waste using aerobic and anaerobic digestion technologies. *Bioresource Technology, 301,* 122778. https://doi.org/10.1016/j.biortech.2020.122778

Wang, X., You, G., Liu, C., & Sun, Y. (2025). Bioaugmentation strategies in co-composting anaerobically digested food waste with agricultural by-products: Enhancing fertilizer quality and microbial communities. *Ecotoxicology and Environmental Safety, 290,* 117539. https://doi.org/10.1016/j.ecoenv.2024.117539

Wardani, N. A., Afiqah, N., Azis, M. M., & Budhijanto, W. (2020). Comparison of biogas productivity in thermophilic and mesophilic anaerobic digestion of bioethanol liquid waste. *IOP Conference Series: Earth and Environmental Science, 448*(1), 012002. https://doi.org/10.1088/1755-1315/448/1/012002

Wardani, N. A., & Budhijanto, W. (2023). Mendukung pengembangan biofuel generasi kedua: Peruraian anaerob termofilik vinasse untuk berselaras dengan kapasitas pabrik bioetanol berbahan dasar molase. *Journal of Bioenergy Research, 20*(1), 1–10.*

Yaser, A. Z., Lamaming, J., Suali, E., Rajin, M., Saalah, S., Kamin, Z., Safie, N. N., Aji, N. A. S., & Wid, N. (2022). Composting and anaerobic digestion of food waste and sewage sludge for campus sustainability: A review. *International Journal of Chemical Engineering, 2022,* 6455889. https://doi.org/10.1155/2022/6455889

Zheng, X., Zou, D., Wu, Q., Wang, H., Li, S., Liu, F., & Xiao, Z. (2022). Review on fate and bioavailability of heavy metals during anaerobic digestion and composting of animal manure. *Waste Management, 150,* 75–89. https://doi.org/10.1016/j.wasman.2022.06.033

Zilio, M., Pigoli, A., Rizzi, B., Geromel, G., Meers, E., Schoumans, O., Giordano, A., & Adani, F. (2021). Measuring ammonia and odours emissions during full field digestate use in agriculture. *Science of the Total Environment, 782,*146882. https://doi.org/10.1016/j.scitotenv.2021.146882