Selection of Anaerobic Digestion System over Composting Technologies: Decision Support Tool Case Study

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Abstract

This paper describes the application of a dashboard tool incorporating multi-criteria decision analysis (MCDA) that was developed for the evaluation and selection of sustainability technologies, in the context of food waste management for U.S. Army Installations. The main driver for this work was the U.S. Army's progressive sustainability goals, specifically the Army's Net Zero Initiative, and concurrent reductions in financial and labor resources. The dashboard addresses a the problem in waste management of implementing a technology that is simultaneously appropriate for a specific site's capabilities and available resources, and which also meets the high-level priorities and goals set by the site's overarching organization. In previous applications of the dashboard, the dashboard was demonstrated to suggest technologies for selection for differently constrained installations. In the presented case study, installation capabilities were systematically adjusted to determine the suite of factors that would return the most positive evaluation of an anaerobic digestion (AD) system relative to forced-air, windrow, or containerized composting technologies. The AD systems outperformance of the composting technologies was then analyzed by metric, number of units required, annual cost of electricity, and degree of acceptability to an installation, while acreage available to and volume of food waste processed by the installation varied. The performance of AD relative to the composting technologies and the necessary capabilities to favor AD selection are then discussed.

Keywords: Multi-Criteria Decision Analysis, Food waste, Net zero, U.S. Army, Technology selection

1. Introduction

In 2011, the U.S. Army launched its Net Zero Initiative, aiming for all Army installations to be net zero in water, energy, and waste by 2050 (Foster, 2011; Lopez, 2012). To help achieve this goal by aiding in the selection of sustainability technologies at Army installations for on-post use, the authors developed a Macros-embedded excel-based decision support tool, herein referred to as the dashboard, for U.S. Army Installation Management Command (IMCOM). IMCOM is in charge of the day to day operations at army installations domestically and abroad, including that of dining facilities.

Typically technology selection at Army installations is performed by installation personnel without much guidance. Unstructured decision making such as this often unintentionally includes cognitive biases (e.g., confirmation bias, repetition bias), and can result in an overemphasis on one or more selection elements such as cost (Oswald et al., 2004; Kahneman, 2011). The dashboard uses multi-criteria decision analysis (MCDA) to quantitatively evaluate different technologies over a range of objectives, criteria, and metrics identified by IMCOM and weighed to reflect their importance relative to IMCOM's Net Zero goals (Belton and Stewart, 2002; Foster, 2011). The dashboard's initial application was for food waste management technology selection for on-post use. 14 different technology makes and models were selected by IMCOM for analysis including dehydrators, pulpers, garbage disposals, containerized in-vessel composting, windrow composting, forced-air static composting, and a containerized anaerobic digestion system (AD). For installations and sites that have limited land resources or are otherwise severely constrained there exist other models and resources for food waste management guidance which consider off-post alternatives, such as the U.S. Army ERDC technical report *Organic Waste Diversion Guidance for U.S. Army Installations* (Fey, 2016).

Unlike other MCDA tools, the dashboard also uses these same metrics to capture the capabilities and limitations of a specific installation to implement a technology. For each metric there exist different levels of resource requirement or associated consequences. Installation personnel are interviewed to elicit the installations ability to accommodate these consequences or levels of resource requirement. The installation's ability to accommodate these consequences and levels of resource requirement are reflected by the development of green, yellow, and red range for each metric. Respectively, the green, yellow, and red ranges signify a certain level of resource or associated consequence is acceptable, acceptable with some difficulty, or unacceptable. The dashboard calculates an MCDA score for each technology using the technology performance evaluations and weightings, and determines the percentage of the score that falls into each color range. The dashboard can be easily re-run to reveal the effect of changes to an installation's capabilities and limitations, the priorities of the overarching organization, or the performance of a technology.

The dashboard's creation and application to Fort Hood, TX is outlined in *Decision Support for Selection of Food Waste Technologies at Military Installations*, which is under review in the Journal of Cleaner Production (Chadderton et al. 2016). In its previous application at Fort Hood and on three scenario installations used as a sensitivity analysis of the dashboard's weights, the dashboard's results had AD performing poorly relative to the windrow composting, forced-air composting, and containerized composting technologies in terms of their appropriateness for the installation. Since AD like composting offers the ability to reuse and transform organic waste into a new product for beneficial use in addition to diverting it from a landfill, the difference in performance of these technologies came as a surprise. The results of this previous dashboard application inspired the experimental research question at the center of this report: under what circumstances would AD be the optimal choice for an installation?

2. Methods

2.1 Case study

The selection of an AD technology for an installation was illustrated by comparing one model of an AD technology against one model each of a containerized composting technology, a windrow composting technology, and a forced-air static composting technology.

2.1.1 Weights

The weights for the dashboard used for this case study were set the same as for the previous application of the dashboard at Fort Hood, TX. The weights were set by the authors to reflect the Army's Net Zero goals using a modified "SMARTER" (Simple Multi-Attribute Rating Technique Exploiting Ranks) approach (Edwards and Barron, 1994), which is a swing weighting approach that maintains the ratios of importance between metrics. Equal weighting among metrics is allowed, as are weights of zero, as weights are normalized to sum to 100%. Of the 55 metrics used to evaluate each technology, 13 each individually accounted for four percent or more of the total score and thus "drive" the model. Collectively these 13 metrics account for almost 70 percent of the total score.

2.1.2 Capabilities and limitations of hypothetical installation

To answer the research question of this case study and determine the factors that would lead to AD being the most optimal technology for an installation a hypothetical "Pro-AD" installation was developed where AD was set to be the most preferred technology. To create this scenario, the installations capabilities and limitations were set so zero percent of the AD technology's MCDA score fell into the red range, and that for every metric any performance by the composting technologies worse than that of the AD technology was deemed unacceptable and fell into the red range. As an example, the model of AD system evaluated for this experiment requires 1.5 full time equivalents (FTE) to operate the technology, and so 1.5 FTE is listed for AD under the *Personnel Requirement (FTE)* metric. Therefore the Pro-AD installation can accommodate a technology that requires up to 1.5 FTE for its operation, and the percentage of the total score for this metric would fall into the green range as long as the FTE required is less than or equal to 1.5. For any technology with a higher FTE requirement, e.g., 2 FTE, the installation would not be able to accommodate that FTE requirement and the percentage of the total score for this metric for that technology would fall into the red range.

2.1.3 Variation of land availability and food waste processing volume parameters

AD's performance against composting was additionally observed while simultaneously varying two parameters: acreage availability and the volume of food waste processed. The acreage parameter compared an installation's ability process food waste with 1 acre and 10 acres, reflecting a land constrained and non-land constrained installation. The second parameter allowed for the analysis of each technology's suitability to the installation depending on the installation’s need to process 25 percent, 50 percent, 75 percent, or 100 percent of the 1500 tons of food waste it generated annually.

2.2 Analyzing AD’s outperformance of composting technologies

AD’s outperformance of the composting technologies was analyzed in four ways. The first analysis determined the metrics where AD outperformed at least one of the composting technologies. The second analysis evaluated the number of units of each technology required by an installation per percentage of food waste processed and acreage available. The third analysis examined the installations annual electricity cost for operating the technologies per percentage of food waste processed and acreage available. The fourth analysis scrutinized the percentage each technology’s score that fell into the red range and how that percentage changed as the percentage of food waste processed and acreage availability varied.

3. Results and Discussion

3.1 Where does AD outperform composting?

The first analysis of AD versus the composting technologies determined the metrics where AD outperformed at least one of the composting technologies; meaning, AD provided to the installation a benefit greater than or burden less than, at least one composting technology. As shown in Table 1 below, AD outperforms at least one of the three composting technologies on ten of the 55 metrics evaluated in the Dashboard. Two of these metrics, *Land Resources* and *Potential for Recoverable Energy*, each individually account for 6.5% of the Dashboards total score, and collectively the 10 metrics account for 22.5% of the Dashboards total score. These ten metrics were used in part to determine the capabilities for the Pro-AD installation.

Type of Metric	Number of Metrics	Percentage of Total Score
AD outperforms at least one composting technology	10	
AD performs equal to all the composting technologies	9	
AD performs equal to at least one composting technology (worse to the others)	7	
AD performs worse than all the composting technologies	13	
Metrics that are weighted as zero	13	
Metrics that depend on land availability	3	

Table 1. Metrics for which AD outperforms at least one composting technology

	Personnel Requirement (FTE)	Land Resources*	Impact on Site (Land Clearing)	Pest/Vector Management (Risks)	Sensitivity to Weather Conditions	Potential for Recoverable Energy*	Mobile Infrastructure (Equipment)	Mobile Infrastructure (Non-Tactical Vehicle Use)	Building Construction	Computerized Capability (Capacity)
Windrow Composting										
Forced-Air Static Composting										
Containerized Composting										
Anaerobic Digestion										

*foot note to explain about the other 35 metrics

3.2 Number of units required as volume of food waste processed increases?

The second analysis of AD versus the composting technologies determined the number of units of each technology required to process the food waste generated annually by the installation. Table 2 shows the throughput per technology depending on the installations acreage availability.

Table 2. Throughput per Unit of Technology (Tons/Day)

	1 Acres	10 Acres
Windrow Composting (WR)*	2.19	21.92
Forced-Air Composting (FA)*	12.88	128.77
Containerized Composting (CC)	0.25	0.25
Anaerobic Digestion (AD)	13.70	13.70

*Throughput calculated using space efficiency value for windrow and trapezoidal piles (cubic yards per acre), residence and curing times, and 20% estimate for area of active composting (piles and curing area)from Allen & Bakx (2006) and food waste density from Dobles et al. (2014).

As shown in Table 2, the throughput for windrow composting and forced-air composting is a function of tons per acre per year. For these technologies, one unit would use all the land available to the installation. Contrarily, the containerized composting and AD technologies have a unit-based throughput of 500 pounds per day and 5000 tons per year respectively. The AD model used in this case study was selected by the author's client IMCOM for the previous dashboard application. Figure 1 shows the number of units of each technology required by an installation with 1 acre of land available as the percentage of food waste processed by the installation varies.

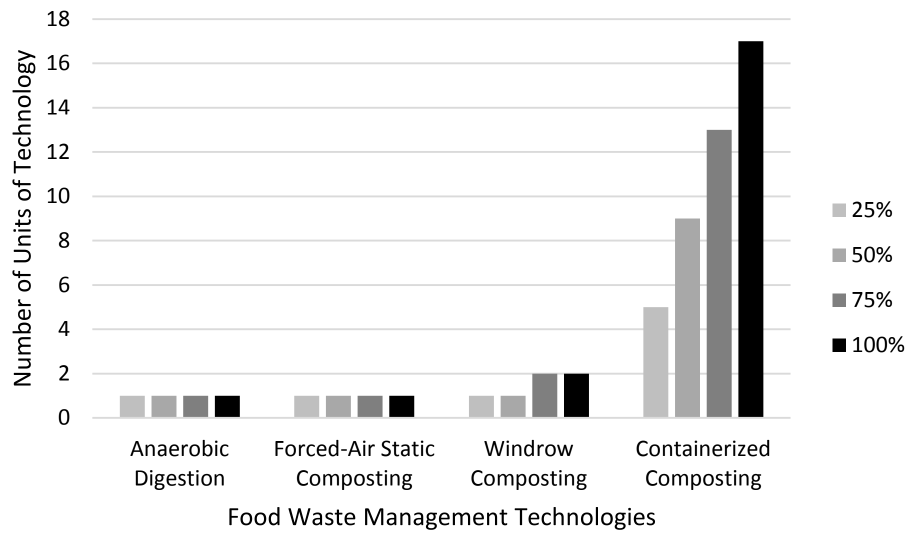

Figure 1. Required Number of Technology Units per Percentage of Food Waste Processed (11Acre Installation)

As shown in Figure 1, when processing 75 percent or more of the installation's 1500 tons of annual food waste, two units of the windrow composting technology would be required. Since one unit of windrow composting already uses all of an installation's available acreage, having a second unit of this technologies is not possible The dashboard assumes the dimensions of the windrow would be held constant, whereas in reality an installation would want to consider increasing the volume of its compost rows before looking for additional acreage to expand the composting site. As the percentage of food waste processed by the installation increases, the number of containerized composting units needed increases incrementally due to the small throughput of the model evaluated. The footprint of the containerized composting units are 100ft^2 per unit, so even 17 containerized composting units would fit within 1 acre with enough room for equipment such as a front loader to move around. The dashboard assumes that if an installation is processing a higher volume of waste, additional units of the same-sized containerized composter would be used to meet the increased demand, in reality an installation would likely use a larger capacity containerized composter and would therefore need a fewer units of the technology. The capacity of the AD model and forced-air static composting technology evaluated for this research can each accommodate 100 percent of the installation's annual food waste.

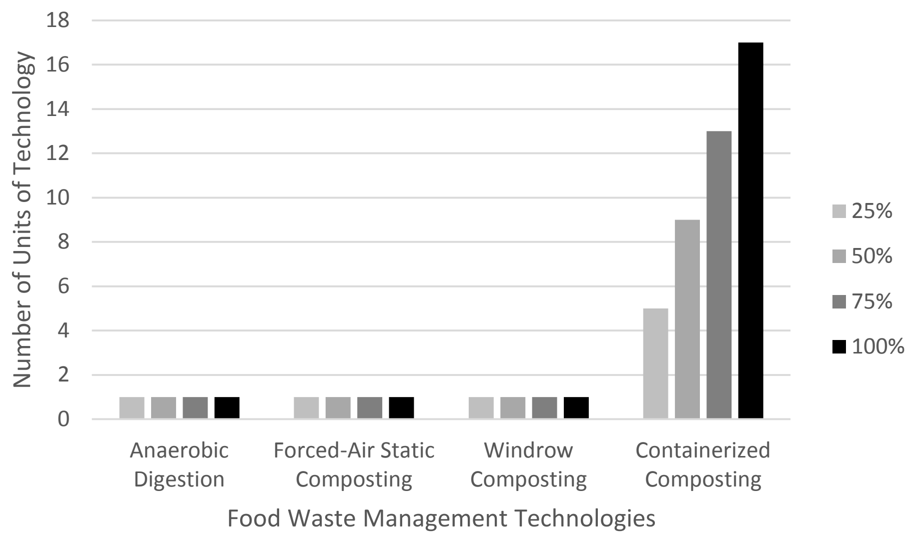

Figure 2. Required Number of Technology Units per Percentage of Food Waste Processed (10 Acre Installation)

Figure 2 shows the number of units of each technology required by an installation with 10 acres of land available as the percentage of food waste processed by the installation varies. With 10 acres of land, one unit of the windrow composting technology is capable of processing up to 100 percent of the installations annual food waste. Since the throughputs are unit-based for the containerized composting and AD technologies, the number of required units of these technologies is independent of acreage.

3.3 What's the energy situation as volume of food waste processed increases?

The third analysis of AD versus the composting technologies examined the annual cost of electricity required by the units each technology to operate. Figure 3 shows the annual electricity costs for the four technologies as the percentage of food waste that the installation is processing varies for an installation with 1 or 10 acres of land available. Annual electricity costs were calculated using the kilowatt-hours per ton processed for each technology listed by each technology manufacturer listed by and multiplying that by the number of tons processed by the installation and an estimated electricity price of $0.08 per kilowatt-hour.

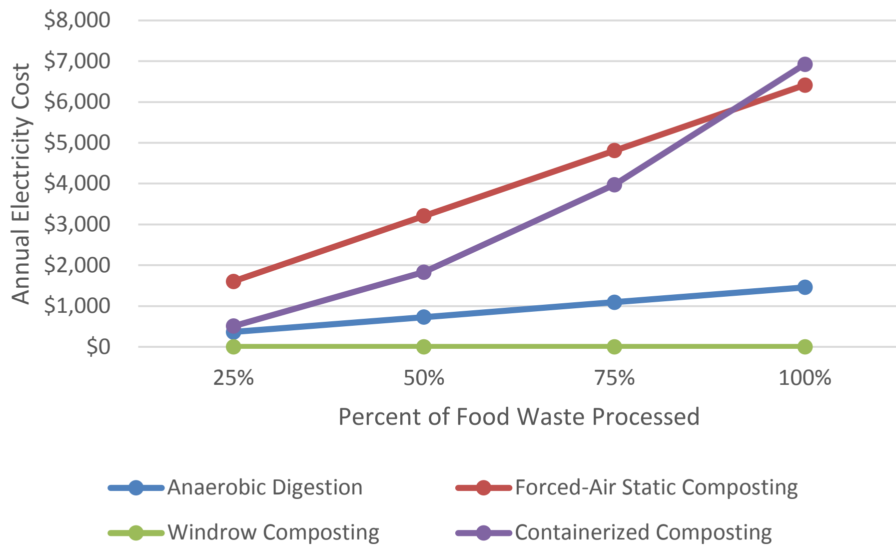

Figure 3. Annual Electricity Cost per Percentage of Food Waste Processed (1 Acre and 10 Acre Installations)

As Figure 3 shows, the annual electricity costs for the technologies are independent of acreage. The annual electricity costs for the AD and forced-air composting technologies increase linearly, with AD increasing more gradually than forced-air composting. Containerized composting's annual electricity costs increase incrementally as more units of the technology are required to process an increasing percentage of the installations food waste. The need for additional units of windrow composting cannot be visualized as windrow composting is assumed to not require electricity and instead to use gasoline powered windrow turners to mechanically turn the compost rows. At higher volumes of waste processing, it is clear that AD outperforms the forced-air static composting and containerized composting technologies in terms of annual electricity cost.

3.4 Percentage of score in Red Range

The fourth and final analysis of AD versus the composting technologies scrutinized the percentage each technology's MCDA score that fell into the red range. The red range signifies that a certain level of resource or consequence associated with a metric is unacceptable. The lower the percentage of a technology's MCDA score in the red range, the more likely an installation would be able to accommodate that technology. Figure 4 shows the percentage of the MCDA score in the red range for the four technologies as the percentage of food waste that the installation is processing varies for an installation with 1 or 10 acres of land available. The red range score for the composting technologies that comes from the 10 metrics where but does not consider the per10 metrics that where.

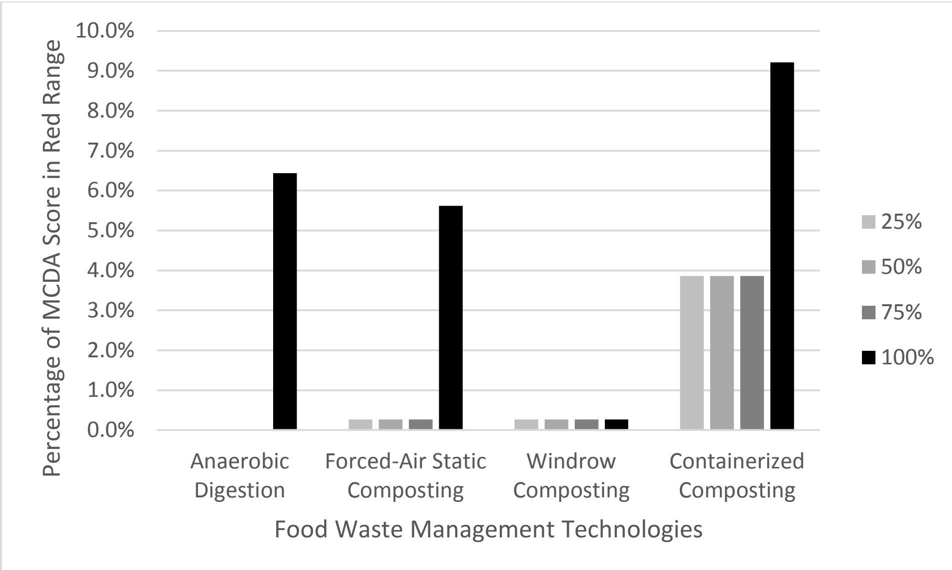

Figure 4. Percent of Score in Red Range per Percentage of Food Waste Processed (1 Acre and 10 Acre Installations)

The percentage of each technologies score in the red range is independent of acreage. At 100 percent processing of the installation's food waste the AD, forced-air static composting, and containerized composting technologies each have a higher percentage of their score in the red range. For the AD technology this is explained by the evaluated model's ability to reduce only 95 percent of waste, with the residual material still requiring disposal. At 100 percent processing of the installation's food waste the forced-air composting and containerized composting technologies the increased electricity costs that accompany processing an increased volume of waste exceeded the hypothetical installations set capability to accommodate costs between $2,000 and $5,000 if necessary (yellow range), so the percentage of the total MCDA score associated with this metric falls into the red range. For the forced-air static composting and windrow composting technologies the 0.3 percentage of MCDA score in the red range stems from the dashboard's *Building Construction* metric which assumes the composting site will require one or more buildings for miscellaneous composting activities and/or associated operations. The low throughput per unit of the containerized composting technology is responsible for the almost four percent of its MCDA score that is in the red range independent of the percent processing of the installation's food waste.

3.5 Discussion

While hypothetical, the Pro-AD installation in this case study demonstrated some of the more burdensome aspects of an AD system which an installation might need to accommodate, and some capability limitations it might need to possess for an AD system to be preferable over windrow composting, forced-air composting, or containerized composting. The aspects of an AD system which an installation might need to accommodate include: the hazards associated with produced biogas, high costs (e.g., capital, operations and maintenance), permits (e.g., air quality, environmental impact), food waste pre-processing, residual material post-processing (i.e., turning solid digestate into compost), some potable water requirement, and a moderate risk from effluent (i.e., liquid digestate with high concentrations of ammonia and salts). The capability limitations of an installation that would favor AD's selection over a composting technology include:

personnel hiring constraints of 1.5 FTE, limited land resources (i.e., less than ½ an acre), a need for a containerized technology (e.g., for pest management or climate reasons), and a limited budget for infrastructure purchases (e.g., annual electricity costs, equipment and vehicles, building construction). These burdensome aspects and capability limitations are embodied in the dashboard as metrics.

4. Conclusion

The case study presented in this article showed that while certain aspects of an AD system can hinder its implementation and reduce its performance relative to composting technologies, AD nonetheless also possesses distinct benefits over composting and that under the right circumstances an installation can be "Pro-AD." The strengths of AD and the obstacles it faces in its implementation at Army installations hold true for other potential implementation sites such as at Universities. AD can become more desirable for a site if the benefits of AD became more desirable, thereby changing the weighting of the Dashboards metrics, or if AD technology performance advances such that some of its more burdensome aspects are more readily accommodated by the installation. The authors foresee opportunities for future research in evaluating different kinds of AD systems with the Dashboard, and uncovering the reasons for the selection of AD over composting technology alternatives at sites where AD has already been implemented.

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