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Evaluating Biogas Potential for U.S. Army Installations

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Abstract: Sustainability challenges are particularly complex on military installations, where security and environmental objectives are often tense. Currently, wastewater treatment facilities on Department of Defense (DoD) installations are a source of greenhouse gas emissions (GHG) and contribute waste to landfills at the installations' expense. The beneficial use of biogas produced using anaerobic digestion offers a means to reduce emissions and landfill contributions, decrease energy costs and reliance on fossil fuels, and improve energy security. This study models the economic and environmental implications of utilizing anaerobic co-digestion to produce electricity from wastewater and food waste across U.S. Army installations. Given the characteristics of each installation, we calculate energy production, waste disposal savings, environmental benefits, and additional infrastructure costs. We conclude with a sensitivity analysis that quantifies the financial and environmental benefits over a range of uncertain parameters, thereby illuminating installation-specific characteristics most appropriate for the near-term beneficial use of biogas.

Keywords: Anaerobic Digestion, Biogas, Optimization, Sustainability

1. Introduction

The US Department of Defense (DoD) is the world's largest institutional emitter of greenhouse gases (GHGs), emitting an estimated 55.4 million metric tons of CO_2 in 2018 (Crawford, 2019). Most DoD GHG emissions stem from the use of fossil fuels, which power vehicles and generate electricity. Less than 1% of the estimated 900,000 tJ energy consumption included renewable sources in 2018 (Crawford, 2019). The DoD continues to recognize climate change as an urgent national security threat and has issued relevant policies and strategies. In 2022, the US Army released the "Army Climate Strategy" and an implementation plan to attain net-zero emissions by 2050 (Office of the Assistant Secretary of the Army for Installations, Energy and Environment, 2022). Intermediate objectives include a 50% reduction in Army net greenhouse gas (GHG) emissions by 2030 and the capacity to generate carbon pollution-free power on all installations by 2040. The US Army plans to implement numerous changes to installations and the deployable fleet, including transitioning to carbon-free electricity and constructing more efficient structures (Office of the Assistant Secretary of the Army for Installations, Energy and Environment, 2022).

Military installations also produce large quantities of organic waste, such as food scrap, fats, oils, and grease (FOG), and wastewater sludge, usually disposed of in landfills. Food scrap waste is the most significant component of municipal solid waste in the U.S. (US EPA, 2017). Food scraps contain substantial chemical energy that can be converted to other forms of usable energy (Breunig, Jin, Robinson, & Scown, 2017; Sarpong & Gude, 2021). FOG generated at dining facilities and restaurants has a higher chemical energy density than food scrap. Sludge generated from wastewater treatment processes is also rich in chemical energy. The chemical energy in these organic wastes can be recovered through anaerobic digestion, using the metabolism of anaerobic microbiota to convert organics to biogas, which contains the gaseous end-products of methane (CH_4) and carbon dioxide (CO_2) (EPA, 2018). Anaerobic co-digestion, or the simultaneous digestion of several organic wastes, can increase biogas production relative to digesting one organic substrate, e.g., wastewater sludge (Cheong et al., 2022; Azarmanesh, Zarghami Qaretapeh, Hasani Zonoozi, Ghiasinejad, & Zhang, 2023). A significant obstacle to the widespread adoption of anaerobic digestion is cost. Typically, anaerobic digestion at larger installations is more economically viable due to increased food scrap and wastewater sludge production rates (Pfluger et al., 2019).

Combined heat and power (CHP) generation microturbines can achieve approximately 70% efficiency when burning biogas, which typically contains 60-70% (CH_4) (Adnan, Ong, Nomanbhay, Chew, & Show, 2019). The few military installations that produce biogas as part of their wastewater treatment process either burn it via flaring it or release it to the environment. When biogas is not burned, the methane that is released into the environment has a negative effect on greenhouse gas emissions.

Several models have been used to evaluate GHG emission reductions, energy cost savings, and economic impacts of different waste management practices, including the EPA's Waste Reduction Model (WARM) and financial feasibility models that use various approaches to assess new technologies and practices (EPA, 2018; Moriarty, 2013; Morrison, Petri, Guy, & Gilbert, n.d.). This study investigates the economic feasibility, environmental impact, and security benefits of displacing some of the energy requirements of Army installations with anaerobic digestion and CHP technology to offset energy and waste disposal costs. Figure 1 displays the anaerobic digestion process which begins with the installation population and data as inputs.

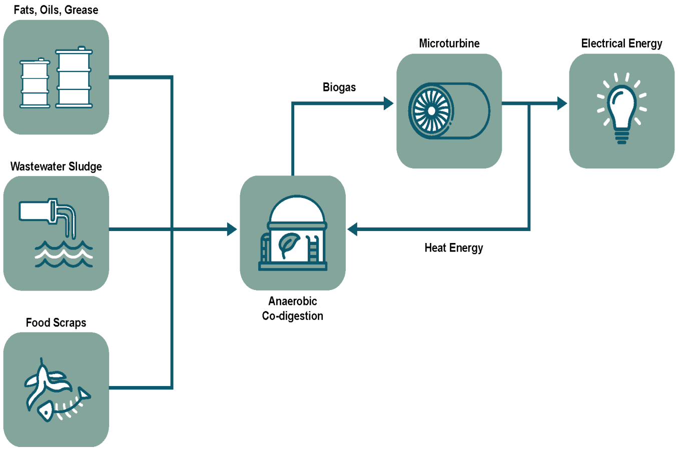

Figure 1: Diagram of Anaerobic Digestion process. Inputs of AD are fats oils and grease, wastewater sludge, and food scraps. The inputs go through anaerobic co-digestion, produce biogas, and then biogas goes into the microturbine which outputs electrical energy.

2. Modeling

A 2023 survey issued by the U.S. Army Installation Management Command (IMCOM) was used to collect data on characteristics from active facilities, including influent wastewater flow rates, wastewater sludge volumes, sludge treatment and disposal methods, anaerobic digestion (if present), biogas beneficial use, and planned facility upgrades. Data was collected for 89 WWTFs on 37 U.S. Army installations were surveyed. The analysis did not include installations that transport wastewater off-installation for treatment (e.g., Fort Bragg, Fort Lee, Fort Drum, and Fort Leavenworth). The Headquarters Installation Information System (HQIIS) for property reporting was used to verify data accuracy and survey completion. Six installations reported that they already have an anaerobic digester (Aberdeen Proving Ground, Ft. Sill, JBLM, Presidio of Monterey, Schofield Barracks, West Point, and USAG DAEGU). Installation population data was derived from the Army Stationing and Installation Plan (ASIP) and used to estimate food waste, FOG generation, and collection rates. According to the U.S. Department of Housing and Urban Development, roughly 33% of DoD service members reside on the installations. In order to report those living off post, the model discounts population by 67% to account for those that only contribute one meal to food waste and fog per day. (HUD, 2015).

To model electricity production, organic production rates were first determined. Each installation's influent wastewater flow rates and typical characteristics for medium-strength domestic wastewater were derived using (Metcalf, Billy, & Billy, 2014). These were used to estimate the wastewater sludge generation rate. Anaerobic digester volumes were calculated from daily total organic production rates. Volatile solid destruction and methane production rates were determined using methods described in (Metcalf et al., 2014). (2014). Typical microturbine characteristics, i.e., a 33% electrical energy conversion efficiency and 42% heat energy conversion efficiency (from (US EPA, 2015)), were used to model electrical energy production.

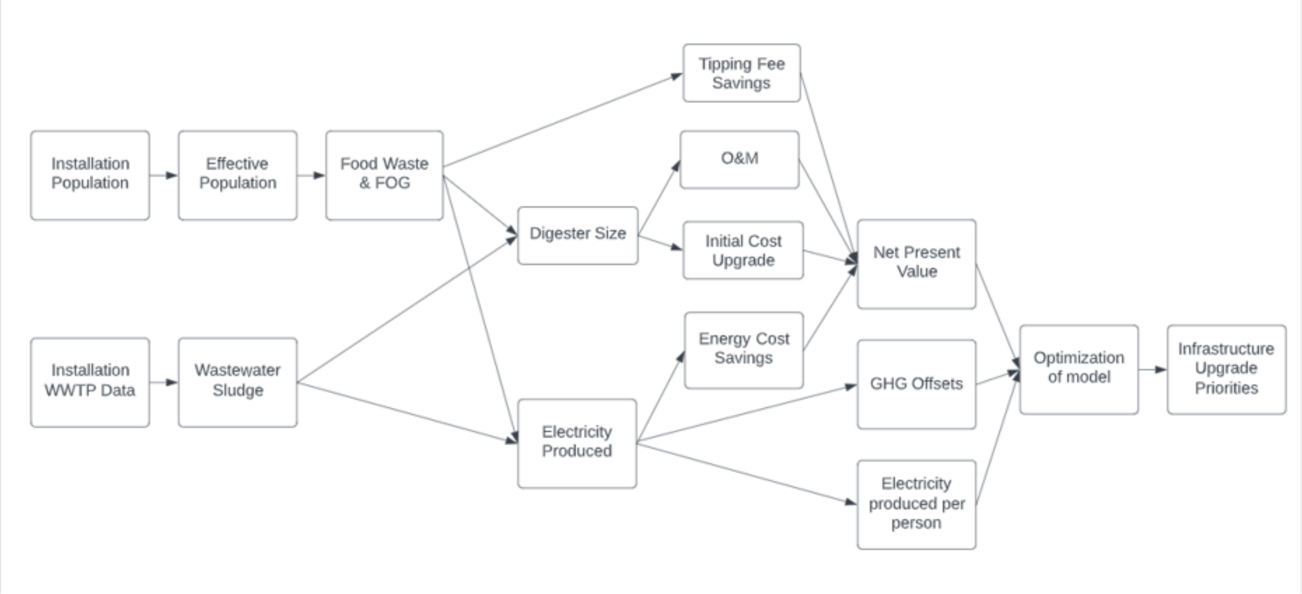

Figure 2: Diagram of Modeling framework beginning with inputs installation population and data, ending with output infrastructure upgrade schedule.

The model uses installation population and WWTP data along with state-specific data to calculate costs, waste disposal savings, and GHG offsets. The modeling framework is displayed in figure 2. GHG offsets were calculated by multiplying the potential amount of electricity produced by the average carbon emissions of electricity produced in the state of the installation. The Nuclear Energy Institute (NEI) provides values on each state's electricity generation fuel mix (Institute, n.d.). The EIA provides specific values for the average amount of coal, oil, and natural gas CO^2 emissions offset per kWh (EIA, 2021). The EIA also publishes the average retail price for electricity ($/kWh), which was used to estimate cost offsets of producing electricity through microturbines. An installation's ability to produce their own electricity also adds a security benefit since it allows the installation to be less reliant on outside sources of energy.

Initial capital costs of upgrading existing WWTFs were determined by summing the costs of the anaerobic digester and the microturbine. The cost of the digester was determined through the regression of proprietary data on digester costs and sizes recently constructed in the US. The capital cost of the microturbine varied based on the potential electrical energy production of the installation. Installations with pre-existing digesters had lower capital costs as they only required a microturbine addition. Annual operations and maintenance (O&M) costs for anaerobic digesters were determined based on digester characteristics, including volume and initial cost. Microturbine O&M costs were scaled based on the power production capacity of the microturbine.

Installation annual revenue was determined as a function of electrical production and the amount of food waste digested. To calculate the potential energy cost savings, annual electrical production was multiplied by the cost of electricity for the US state where the installation was located. The amount of food waste produced on each installation was multiplied by the tipping fees for the installation's location to determine cost avoidance for food waste diverted from landfills.

Net Present Value (NPV) provides a measure to compare projects with different timelines by discounting the value of present or future revenues and expenditures to the present day based on a fixed discount rate. Once energy cost savings, tipping fee savings, and O&M costs are calculated for each installation, as displayed in Figure 2, the model takes all three as inputs into the annual cash flow which are equal for 25 years. The NPV calculation uses a real discount rate of 7% as specified by the US Office of Management and Budget Circular A-94.

3. Optimization

Results from anaerobic digestion, biogas production, and electrical energy generation modeling are used to select which installation's WWTP should upgrade to a CHP system. Two primary inputs, (i) installation WWTF characteristics and (ii) installation population data, are used to prioritize WWTF infrastructure. The analysis used a tri-objective optimization that selected financial, environmental, and security objectives to maximize resiliency at installations. The financial objective is to maximize the NPV. The environmental objective is to maximize the annual GHG offsets produced by an installation if upgraded. The security objective is the annual electrical production per person for each installation since it would allow an installation to be less reliant on outside sources of energy. The objectives were normalized prior to optimization and weighed equally, and installations were ranked in order from highest to lowest values of total benefit.

4. Results

4.1. Main Results

Table 1: Top Ten Installations for Upgrading to CHP

Installation	Initial Cost (MM \$)	Elect. Prod. (kWh/person/year)	NPV (MM \$)	GHG Savings (MM kg CO_2/year)	Biogas Production (KK $m^3/year$)
Fort Campbell, KY	5.41	143.2	-4.99	2.31	.152
Fort Stewart, GA	6.98	285.6	-4.63	1.68	.237
Schofield Barracks, HI	.394	91.6	2.86	.730	.049
Joint Base, WA	1.75	162.6	3.39	.457	.261
Fort Knox, KY	2.78	57.3	-3.36	.571	.044
Fort Leonard Wood, MO	2.75	34.1	-2.95	.528	.048
Fort Carson, CO	3.25	50.4	-3.40	.517	.062
Fort Sill, OK	.444	72.9	.545	.320	.059
West Point, NY	.455	129.9	1.49	.213	.056
Fort Polk, LA	2.90	69.3	-3.47	.315	.046

Table 1 shows the main results with key metrics reported for each installation. The installations are ordered in terms of prioritization by the tri-objective optimization. Generally, installations with higher populations and pre-existing anaerobic digesters are the most economically feasible and provide the highest environmental and security benefits. JBLM, Schofield Barracks, and Ft. Sill have the highest NPV due to their pre-existing anaerobic digesters, which significantly lower the initial cost of the upgrades. These installations would be the most convenient to upgrade and

Installations with the highest GHG offsets were Ft. Campbell, Ft. Stewart, and Schofield Barracks. These installations reside in states with a high fossil fuel energy mix, leading to higher GHG offsets per kWh of carbon-neutral power. If installations had higher populations and wastewater flow rates, they could produce more biogas and offset greenhouse gases to a higher degree.

The installations that were selected for the highest energy production were Fort Stewart, JBLM, and Fort Campbell. The installations had higher energy production since they had high wastewater flow rates and large populations. High wastewater flow rates and population allow more waste to be used in anaerobic digestion and CHP and produce more electricity.

4.2. Sensitivity Analysis

Through analysis of the initial results, it was determined that initial costs had the greatest impact on NPV (Figure 3). As a result, to test how sensitive initial costs were to the total NPV, initial costs were increased and decreased by 50%. If initial costs were increased by 50%, the range of total NPV cost ranged from negative eight million to positive two million dollars. The significant change in the NPV from the initial cost indicated that NPV was extremely sensitive to changes of the initial costs. If initial costs were reduced, the range of NPV values became more compressed. This is due to the fact that Operations and Maintenance cost of all installations were of similar value, which contributed to similar NPV values. The positive outliers in the graph were due to installations having pre-existing infrastructure (such as anaerobic digesters) which help contribute to the reduction of their initial cost.

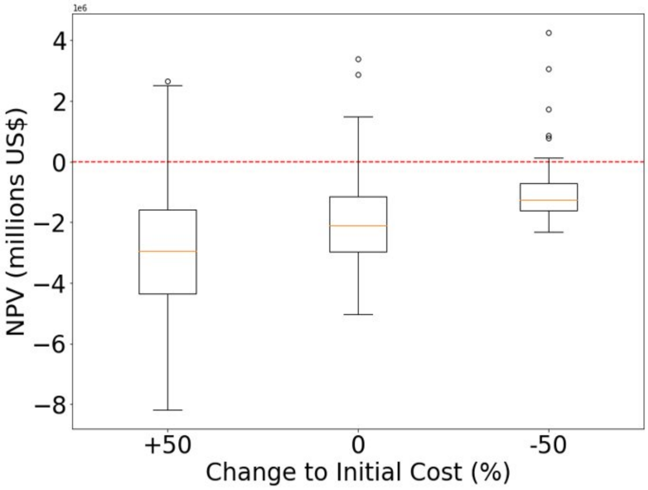

Figure 3: Sensitivity Analysis on the Initial Cost of AD and CHP.

5. Conclusion

The DoD recognizes climate change as a threat to our national security and that it must achieve mission success while reducing emissions and environmental impact. The production of biogas-derived electricity using anaerobic co-digestion of wastewater sludge and food waste provides a means to reduce emissions and landfill contributions while simultaneously improving energy security. This study provides vital insights demonstrating the potential biogas production on U.S. Army installations. The five installations with pre-existing digesters (JBLM, Schofield, Aberdeen, West Point, and Ft. Sill), can attain a positive NPV from energy savings by producing biogas from internal sources. NPV is generally negative for the remaining installations due to the high up-front cost of the anaerobic digester.

Nevertheless, two installations (Ft. Campbell and Ft. Stewart) can cover their anaerobic digester O&M costs with the resulting energy cost savings, with annual savings ranging from US$ 36,000 to 201,000. If ten installations (Ft. Campbell, Ft. Stewart, Schofield, JBLM, Ft. Knox, Ft. Leonard Wood, Ft. Carson, Ft. Sill, West Point, and Ft. Polk) are selected for these upgrades, they could collectively offset approximately 7.65 million kg CO_2 per year. Finally, in terms of an energy security perspective, the top five installations (Schofield, West Point, Ft. Campbell, JBLM, and Ft. Stewart) could use the proposed method to produce 92 to 285 kWh of electricity.

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