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Research article

Cost of organic waste technologies: A case study for New Jersey

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Abstract: This paper evaluates the benefits of converting food waste and manure to biogas and/or fertilizer, while focusing on four available waste treatment technologies: direct combustion, landfilling, composting, and anaerobic digestion. These four alternative technologies were simulated using municipal-level data on food waste and manure in New Jersey. The criteria used to assess the four technologies include technological productivity, economic benefits, and impact on land scarcity. Anaerobic digestion with gas collection has the highest technological productivity; using anaerobic digesters would supply electricity to nearly ten thousand families in New Jersey. In terms of economic benefits, the landfill to gas method is the least costly method of treating waste. In comparison, direct combustion is by far the most costly method of all four waste-to-energy technologies.

Keywords: Organic waste; manure; combustion; land-fill gas; aerobic composting; anaerobic digestion

1. Introduction

Population growth and urbanization yield an increase in the generation and disposal of waste. On average, each person in the U.S. produces 1.5 kilograms of municipal solid waste (MSW) per day. Food waste is the largest single waste stream component of MSW: an average U.S. family of 2.63 people generates about 100 kilograms of wet food waste annually [1].[1] This amounts to about 340,000

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[1] Food waste includes waste from food processing factories, as well as pre- and post-consumption leftovers from both residences and commercial establishments (e.g., retail stores, restaurants and school cafeterias). Food waste contains large amounts of rapidly degradable components such as protein, carbohydrates, and short chain fats.

tons of wet food waste in New Jersey annually, and more than 12 million for the United States as a whole.

The rapid increase in the generation of MSW led to the proliferation of landfills. Originally designed to promote recycling of nutrients back into the ecosystem, landfills were located in open areas. However, landfills have been unable to adequately recycle materials to the soil due to limited space and the high volume of MSW generated. In addition, the gasses released by landfills (landfill gas) include about 40% to 50% methane (CH_4), a potent greenhouse gas (GHG) with the global warming potential 23 times that of CO_2 [3]. The U.S. Environmental Protection Agency [4] projects worldwide methane emissions from landfills to be 800 million metric tons by 2020. Landfills also negatively impact other environmental amenities and health.[2] Other than CH_4, gasses emitted by landfills can pose health risks to surrounding communities directly exposed to the site. Moreover, certain landfills produce leachate—a potentially polluting liquid that contains dissolved substances from water percolating through the landfill. This leachate may then enter the surrounding environment, threatening underground aquifers and other water supplies, resulting in a health risk to both surrounding ecosystems and human populations. New landfills (Sub-Title D) have a protective barrier and leachate recovery system that should stop leachate from getting to the aquifer.

Industrialization and economic growth have resulted in a rapid increase of meat consumption [5] and thus animal manure generation. The waste productivity of animals is significantly higher than that of humans. A dairy farm with 2500 head of cattle can produce the same amount of waste as a city with 411,000 people [6]. The most common method for manure disposal in the U.S. is application to farmland as bio-fertilizer. However, manure's odor and contamination potential of surface and groundwater [7] weaken the benefits from using it as a bio-fertilizer. In addition, pathogens in manure may cause human illness and disease [8].

Thus, current demographic and economic trends have generated demand for management practices that divert waste away from landfills,[3] and encourage manure collection and consumption systems. In this paper we investigate the benefits of four alternative technologies that meet this demand. The goal is to understand food waste/manure management technologies, and to assess their potential in generating energy. We compare energy generation, total net income, and demand for land for each of four waste management technologies.

2. Materials and Methods

2.1. The conceptual framework

In this paper, four technologies for treating food waste and manure are explained. These technologies are direct combustion, landfill to gas, aerobic composting, and anaerobic digestion. To simplify the evaluation process, we assume the following:

1. The combined waste stream is constant across geographic locations.

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[2] See the Environmental Victoria website, available at http://environmentvictoria.org.au/content/problem-landfill

[3] Food wastes containing approximately 1400 kilocalories are generated by one person per day in the U.S., adding up to 150 trillion kilocalories per year [2]. To produce 1 kilocalorie of food requires 3 kilocalories of fossil fuel on average [2]. Therefore, annual food waste accounts for approximately 300 million barrels of oil or about 4% of U.S. oil consumption in 2013.

2. In landfill to gas and anaerobic digester scenarios, biogas is consumed on-site for power generation with the residual electricity sold to the grid. Gross energy generated (P, measured in kJ/yr.) can be calculated based on the volume of methane generated ($V_{CH_{4,yr}}$) using the following equation:

$$P = V_{CH_{4,yr}} * 35{,}846 * \theta_p \tag{1}$$

Where $V_{CH_{4,yr}}$ is the volume of methane generated from combined waste in a whole year. The net heating energy of methane (35,846 KJ/m^3) was obtained from EIA report (i.e., [9]). With 50–60% methane content in biogas (in the analysis, we assumed 50%), the net heating energy of biogas is approximate 23 MJ per cubic meters. The total efficiency of power generation (θ_p)—i.e., the sum of electrical and thermal efficiencies – ranges from 70% to 80% (here we assume 75%) [10]. This yields the following equation:

$$P = V_{CH_{4,yr}} * 35{,}846 * 0.75 \tag{1'}$$

3. We assume that the efficiency of the internal combustion engine (θ_e) is 35% [10]. Thus, the final electricity generation (kWh) can be expressed as following:

$$Electricity = P * 0.35 * (1/3600) \tag{2}$$

4. The methane concentration in biogas is considered to be stable during any process at 50%.[4] In addition, we do not include in the calculations greenhouse gas emission from transportation to the processing facilities.[5] For simplicity and brevity, we assume that the location of the landfills and power generation facilities are the same.[6] This simplification tends to underestimate emissions from the various scenarios. But we do not think it will affect the comparison, since transportation emissions are similar for each of the waste/manure management facilities.

2.2. The waste/manure management technologies

The theoretical methane content was calculated using the Bushwell equation [11], assuming all elemental composition is known and reaction is fully completed [12,13]. The chemical composition of food waste and manure and the molecular weights that will be used in the Bushwell equation are from [14].

The methane potential calculated from this stoichiometric analysis leads to high yield values because of the assumption that carbon component is converted into methane and carbon dioxide with

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[4] Fifty percent is the average amount of methane commonly reported in the literature.

[5] This study aims to compare four different conversion technologies and it ignores transportation emissions because we do not predict large differences between the transportation emissions of the various technologies because of similar distance and volume of organic waste (see page 2). Having said that, our calculations suggest that transportation of food waste to landfills resulted in emissions of 195 metric tons of CO_2 on average per landfill.

[6] We thank the referee for pointing out that the location of landfills and power generation facilities can be the same.

no loss. It gives the maximum amount of methane that can be produced in theory, free from any technological limits (in practice, however, this number varies from 40% to 90%).

We assume food waste is 25% total solid and manure is 15% total solid, with the percent of volatile solids out of total solids 93% and 85%, respectively, for food waste and manure [10]. We also assume that 67% of the waste is food waste, and that total food waste in New Jersey is 1.37 billion tons.

2.2.1. Direct combustion (DC)

Direct combustion or incineration, is the most conventional thermochemical conversion technology to generate electricity from biomass on a large scale. The feedstock is not processed before incineration, and it is popular in countries where land is scare. In 2005, combustion combined with energy recovery supplied 4.8% of electricity consumption and 13.7% of total domestic heat consumption in Denmark [15].

The main stages of the combustion process include drying, degassing, pyrolysis, gasification and oxidation [16]. Waste is combusted at a temperature of 850 ℃ and transformed to carbon dioxide, vapor, and non-combustible incinerator bottom ash. The power plant performance depends on the type of incinerator and the waste composition as well as its moisture content [10]. Since combustion is normally applied to mechanically dewatered wastes, the high moisture content in food waste and manure makes them less attractive feedstocks for incineration [17]. But other suggests that high evaporation efficiency (up to 80%) can make the net energy benefits viable [18]. The work reported here assumes the same waste stream for all four technologies, and does not investigate the implications of different moisture contents.

Food waste and manure are combined before being transferred and treated in the combustion chamber. The mixed waste is then combusted at high temperatures, and we assume heat is recovered in the form of steam that drives a turbine to produce electricity. The bottom ash, a non-combustible part of the waste stream, is stored in a stack and will be separated as recyclable and non-recyclable. Because of data limitations we assume all the bottom ash is to be used for road construction at a price of \$3 US/ton.[7]

The combustion model is based on the calculation of Higher Heating Value (HHV) and Lower Heating Value (LHV). Equation (3) calculates the HHV (MJ/kg) based on dry basis [19]. The potential heating value or LHV (MJ/kg) is evaluated by Equation (4), after evaporating the water content:

$$HHV = 0.3491 \cdot C + 1.1783 \cdot H + 0.1 \cdot S - 0.1034 \cdot O - 0.0151 \cdot N - 0.0211 \cdot Ash \tag{3}$$

$$LHV = HHV - 2.766 \cdot wt \tag{4}$$

Where *wt* represents the moisture content in the inflow waste stream. The C, H, S, O, N, Ash represent the contents of carbon, hydrogen, sulfur, oxygen, nitrogen and ash, respectively. In addition, we chose the coefficient of heat required to evaporate water to be 2.766. Since food waste and manure have high moisture content, it is more realistic to estimate the potential power after the drying process.

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[7] The market value of coal combustion bottom ash is determined by several factors, including the uses that are dictated by the ash properties, distance, and regulations. An estimate of bottom ash cost for snow and ice control is between \$3-6 per ton, while bottom ash used for road base costs approximately \$4-8 per ton. See http://rmrc.wisc.edu/ug-mat-coal-bottom-ashboiler-slag/

2.2.2. Landfill-to-Gas (LtG)

There is a growing interest in upgrading traditional landfills with gas recovery facilities. Landfills are the most commonly used method to dispose of solid waste globally, and the landfill gas recovery technology is becoming more economically viable [20]. In the United States there are about 3581 municipal solid waste landfills. These are the third-largest source of human-related methane emission, accounting for 16.4% of total methane emission in 2012 [21]. From 1990 to 2011, a 27% decrease in the net methane emission from landfills has been observed, while landfills with methane recovery almost doubled from 1999 to 2010 producing approximately 14 TWh of electricity [22]. The reason for this reduction in net methane emission is better design of new landfills and the closing of old ones.

Landfill gas is a mixture of methane (45–60%), carbon dioxide (40–55%) and a trace amount of other components that gives landfill gas its characteristic smells [10]. Trace amounts of non-methane organic compounds and volatile organic compounds may result from the decomposition of by-products or the evaporation of biodegradable solid wastes.

In the LtG scenario, the final products are electricity and digestate. For this scenario, we use the first-order decay model that builds on the Landfill Gas Emission Model (LandGEM) developed by U.S. EPA, and follow the assumptions made by U.S. EPA [22] as well as the California Air Resource Board’s Implementation of IPCC’s Mathematically Exact First-order decay model.

2.2.3. Aerobic composting (COMP)

Aerobic composting, or aerobic digestion, is a bio-oxidative process. During the process, a large portion of the degradable organic carbon is converted into carbon dioxide and water [23]. A certain amount of methane emission can be generated in composting piles when there is excessive moisture or not enough ventilation [24]. Compared to other processes, composting produces a considerable amount of heat, which brings the temperature of the pile to more than 60 ℃ and helps reduce concentration of pathogens inside the composter. Approximately 400 commercial-scale composting facilities are in operation around United States [25]. The amount of waste composted in the US almost quadrupled from 1990 to 2011 mainly due to the increase in population and legislation from the 1900s aimed at reducing the amount of yard trimming disposed of in landfills [17].

The chemical and physical parameters for both food waste and manure used in composting are listed in Table 1.

After the composting process, compost can be used as fertilizer or disposed of in landfills. Compost contains approximately 8.3 kilograms of nitrogen per dry ton waste and 2.0 kilograms of phosphorus per dry ton waste [26]. For farmlands that are depleted through agricultural practice over multiple years, compost with a large amount of organic matter is an ideal soil amendment.

Table 1. Chemical and physical parameters for organic materials used for composting.

Parameter	Food Waste	Dairy Manure
Moisture %	75%	85%
% N (dry weight)	1.9–2.9	2.4
C:N ratio	14–16	18–20
Bulk density (kg/m^3)	497	637

With lower initial investment and regular operating costs, large-scale composting is the most widely accepted organic solids recovery option in the U.S. Most degradable organic matter is bio-oxidized in the composter during the first few days, when the greatest amount of heat is produced. Heat can be recovered to generate electricity, which can be used on-site or sold to local grid. The average amount of heat calculated by Guljajew and Szapiro was 961 kJ/kg with compost moisture content of 52.7% [27]. Collecting the waste heat through a heat exchanger system is able to provide domestic hot water supply and spatial heating at very competitive prices, where the unit cost is 0.4994 and 0.097 £per kWh, respectively [28].

The major drawback of using composts/digestates as fertilizer is that large amount of nitrogen is in the form of ammonia/ammonium, which is prone to be released to the atmosphere after surface land application. More expensive land application methods, such as shallow injection, are therefore recommended to reduce ammonia loss to air. However, some research suggests that ammonium is a more preferred form of nitrogen for plants and soil microbes [29], which is an advantage of using fertilizer with high ammonium concentration.

In the COMP scenario, we assume organic waste is oxidized and completely converted to carbon dioxide. Following [30], a linear relationship between the digestion time and logarithmic form of total residual efficiency is assumed (Equation (5)).

$$log(1 - VS_d) = -0.0114 \cdot t + 4.368 \qquad (5)$$

Where VS_d is the volatile solids destruction (in percent) and 17.6×10^3 kJ kg^{-1} is the amount of heat produced during carbohydrate oxidation (kJ/kg). [31] Proposed that on average, 37.4% of heat is recovered from a composting process, which is proportional to degradable volatile organic solids removal rate. Thus, the COMP facility produces organic fertilizer based on Equation (5), and produces $6.5824 \times 10^3 (= 17.6 \times 10^3 \times 0.374)$ kJ kg^{-1} of recoverable heat for heating water and space.

2.2.4. Anaerobic Digestion (AD)

Anaerobic digestion is a fermentation process that breaks down organic matter in the absence of oxygen to produce biogas and a digestate. Based on a lifecycle analysis, compared to landfilling without energy recovery, anaerobic digestion results in less energy consumption, fewer GHG emissions, and fewer pollutants released. Moreover, the process results in sterilization, as certain pathogenic bacteria present in the feedstock are eliminated. The process also reduces existing waste in landfills and results in a by-product that can be used as an organic fertilizer.

Compared to other waste management methods, anaerobic digestion has several merits: First, the emission of CO_2 from anaerobic digestion tends to be 25% to 67% less than that from composting [32]. Second, anaerobic digestion is better at treating waste with high moisture content than direct combustion and landfilling. Similarly, cooking oil is better treated in an anaerobic digestion process than through composting. Third, anaerobic digestion requires less space than aerobic composting.

At the same time, there are several drawbacks: first, a well-controlled and operated digester may have higher cost. Second, anaerobic digestion may have lower organic removal rate than aerobic composting. Third, the digestate from anaerobic digestion contains about 7.6 kg/ton nitrogen and 1.1 kg/ton phosphorus (dry weight), which are not as effective fertilizer as compost residues [33].

The anaerobic digestion process is composed of three processes, including hydrolysis, fermentation, and methanogensis. At the first hydrolysis stage, the degradable organic solids are broken down into monosaccharides, amino acids, and fatty acids. The product is converted into short chain fatty acids in the fermentation phase. Then with the activity of methanogens, methane and carbon dioxide are produced in the final methanogensis stage. Studies show the carbon/nitrogen/phosphorous (C/N/P) ratio to be 100–128/4/1 or C/N of 25–32:1 [34].

Mathematical models to describe anaerobic digestion of organic waste have been built since the 1960s [35]. This study employs an anaerobic digestion model built on the first-order kinetics model [20].

Table 2 summarizes the various outputs produced using the four aforementioned technologies:

Table 2. Waste management facilities and outputs.

Technology of facility	Output
Direct Combustion	Electricity; bottom ash used for road construction
Landfill	Electricity; digestate
Composting	Digestate
Anaerobic Digesting	Electricity; digestate

2.3. Data

We chose eighteen operating landfills in New Jersey for the simulation. Information on a candidate plant is summarized from a variety of databases. The primary source of data comes from EPA's LMOP database, which provides information about landfills with Landfill-to-Gas projects. However, the accuracy of these data is limited due to the voluntary data submission process. Therefore, we also sought plants with supplementary information from FRS Facility Detail Report (EPA) and New Jersey Landfill Database (NJDEP). The information of these eighteen plants is presented in [14]. Although in 2013 about 37% of New Jersey solid waste was transported out of state for disposal, in our analysis we assume no import or export of waste from or to New Jersey. All food waste and manure are collected and transported to the landfill, which is located in New Jersey. Data on population and land area of all municipalities in New Jersey is from US Census Bureau's FactFinder, while livestock and manure data was supplemented by survey data provided by Rutgers' EcoComplex. The calculations suggest that the volatile solid (VS) to total solids (TS) ratio are 93% and 85% for food waste and manure, respectively. The biodegradable COD concentration is approximately 238 $\mathrm{kg/m^3}$ when food waste density is chosen to be 496.57 $\mathrm{kg/m^3}$. In comparison, the biodegradable COD concentration for manure is less (130.8 $\mathrm{kg/m^3}$), with density of 637.4 $\mathrm{kg/m^3}$.

Table 3 below shows the average capital cost in four scenarios and the corresponding data source. The levelized cost of the conventional coal-based plant is about \$50/MWh, while the levelized cost associated with biogas power is projected to be \$70/MWh[8]. The literature suggests the largest capital costs are for DC and AD facilities, but the lowest are for COMP. However, the COMP capital costs do not include heat-capturing technologies.

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[8] http://en.openei.org/apps/TCDB/

Table 3 also depicts the O&M costs for the four scenarios investigated. In the following economic analysis, we take the mean value of each range as the unit cost. Largest O&M costs are present in DC, while the smallest are for COMP.

Table 3. WTE facilities with average capital costs.

Technology of WTE facility	**Capital Cost ($/ton)**	**O&M Cost ($/ton)**$^{+}$
Direct Combustion	49.01*	80–120
Landfill	24.36$^{\&}$	10–30
Composting	13.6$^{\&\&}$	30–60
Anaerobic Digesting	50$^{@}$	60–100

Source: (*) [36]; ($^{\&}$) [36]; ($^{\&\&}$)[37]; ($^{@}$) [38]; ($^{+}$) [39]

Waste management facilities charge a “tipping fee” to dispose waste in their facility. It is common that different tipping fees exist at a facility for distinct types of waste material. We use the average fee charged by New Jersey landfills to dispose of Type 10 waste.[9]

We assume that the residue solids (compost or digestate) have a resale value of $80/ton based on the average mixed fertilizer retail price in northeast United States. We also assume that waste facilities in New Jersey could earn $0.15/kWh from the sale of electricity to the local grid and pay $0.0998/kWh to purchase electricity from the local power utilities [40].

2.4. Economic analysis

The economic analysis is done using the following assumptions:

For a given scenario, the design specifications are identical for each plant regardless of the location. Technically, each plant consumes 1/18th of total available food waste and manure in New Jersey. In addition, the unit cost (fixed and O&M) only differs across different scenarios, not across plants.

1. All cost and benefits are scaled on a one-year basis, without considering inflation and money value across plant’s life span. The cost unit and sale price are drawn from actual market information and prior studies.
2. There is no difference in transportation cost among all four scenarios. Without enough data to estimate the cost of maintaining transportation vehicles and salary paid to truck drivers, the total transportation cost is only calculated as a portion of O&M cost.[10]

3. Results

3.1. The Supply of Energy

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[9] We also simulated the four different facilities using actual values from the various counties; but because qualitatively results do not change, we do not report those results in the paper.

[10] We also computed an alternative simulation, whereby the transportation cost was assumed to be part of the tipping fees. However, because there are no qualitative differences between that analysis and the one presented in the paper, we do not report the results of that analysis in this paper.

Table 4 depicts amount of electricity that *potentially* can be supplied if the selected 18 plants were employing a given technology. Although the total number of household supplied represent less than 1% of New Jersey population, the amount of electricity generated from biomass resources could serve 10% of total electricity needs statewide. We also believe that total electricity generation and sales revenue are underestimated, since food waste data used in this study doesn't include waste from the food industry (e.g., food manufactures and restaurants).

Table 4. Summary of electricity sales revenue.

Technology	Total electricity generation (MWh)	Total electricity sales revenue (million $)	Annual number of household supplied
Direct Combustion	7719.41	1.157	867
Landfill	12,764.26	1.914	1435
Anaerobic Digestion	82,479.77	12.37	9265

In 2013, the amount of methane produced by the simulated LtG and AD facilities could have been sold at an annual Citygate Price in New Jersey of 6.21 US$/thousand cubic feet, adding 1.286 million US$ to the LtG plant revenues, but 4.223 million US$ to the AD plant. AD is much more efficient at producing methane.

3.2. Economic Analysis

Although the heat generated during the aerobic composting process can be partly harnessed to heat water and space, the gross energy content recoverable in the COMP process is 20% of that produced in AD. However, revenue from selling upgraded compost or digestate as fertilizer does bring in a significant amount of income. The COMP is the most cost-efficient technology to produce digestate, with 3.9 billion US$ annually (assuming a price of 80 US$/ton). However, AD also results in revenues from selling digestate—a total of 3.2 billion US$ of revenues for the 18 waste facilities (Table 5).

Table 5. Digestate production.

Technology of facility	**Digestate (million tones)**	**Total digestate sales (billion of US$)**
Landfill	37.977	3.0381
Aerobic composting	49.297	3.9437
Anaerobic Digesting	39.953	3.1962

Because there is minimum nitrogen loss in AD and COMP, we can also do a mass-balance, assuming that all the N in the raw material goes to the end product and is sold for the same price as inorganic fertilizer (price of Urea 44–46% in 2013 was 526 US$/ton). This alternative resulted in sales of Urea 44–46% nitrogen of 5487 million US$. Table 6 presents the main advantages and disadvantages of the various technologies. Whereas anaerobic is best at generating electricity, aerobic composting technologies are the most efficient at the production of organic fertilizers. However, the least costly technology to manage municipal waste is LtG.

Table 6. Main advantage/drawback of technology.

Technology of facility	Advantage	Disadvantage
Direct Combustion (DC)	Burns the waste, hence reduces demand for land	Lowest net income, and does not produce digestate
Landfill to Gas (LtG)	Least costly technology to manage municipal waste	Not as productive as AD in generating electricity or as productive as COMP in producing digestate. Consumes land.[11]
Aerobic Composting (COMP)	Most efficient in production of digestate	Does not generate electricity
Anaerobic Digesting (AD)	Most efficient in generation of electricity	High upfront costs

4. Discussion and Conclusion

In sum, the landfill-to-gas method produced a positive income stream and is the least costly technology used to manage municipal waste, because it has low initial investment requirement (Table 3). Direct combustion is the most expensive method to operate, because of high investment costs and high O&M costs (Table 3). Because of the high moisture content in combined wastes, a significant amount of fossil fuel is needed to dewater the feedstock and maintain a high burning temperature. Mixing waste with solids containing low moisture content, such as paper and yard waste, can improve its income stream. Compost produces a stream of net income and is a viable way of reutilizing organic wastes in New Jersey, especially if high fertilizer prices are a concern. However, anaerobic digestion is the most cost-efficient way of producing electricity and methane. The significant capital investment and utility expense are the barriers to AD becoming a much more lucrative waste conversion alternative.

The NJ Solid Waste Management Plan, released in 2006, affirmed that more food waste has been generated than the combined wastes of old newspapers, glass containers and aluminum cans in New

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[11] Data from the 2012 Census of Agriculture, National Agriculture Statistics Service, USDA, suggests average market value of farm per acre in New Jersey of US$12,792, where total landfill area in New Jersey in 2010 was 7,417 Square Miles. For comparison, average market value of farm per acre in Pennsylvania, New York, and Iowa were US$5,425, US$2,600, and US$6,389, respectively, and the average in the United States was US$2,481. Note that although Technically these figures include the value of farm structures. Because buildings are a small portion of the real estate value of farms, these numbers are commonly used to give rough estimates of land value on farms across states. Then, because landfills, different from DC, COMP, and AD, do not convert waste (other than the collection of biogas) to an input used by the agriculture or energy sectors, land is a concern. Landfills have been unable to adequately recycle materials to the soil due to limited space and the high volume of MSW generated [2].

Jersey. The productivity analysis presented in this paper outlines different options to reduce waste volume and utilize the potential energy stored in waste.

This work shows that anaerobic digestion is generally better than other technologies with regard to total and net energy generation. The less net income value, on the other hand, suggests that there are cost barriers to its adoption (although when natural gas prices are high enough, this technology becomes more attractive). Landfill-to-gas has a great advantage in operating cost and reducing volume of food waste. Compost is the most cost-efficient way of converting waste to fertilizers.

With the increasing production of organic wastes and reduced landfill capacity, various waste management technologies should be studied and improved. Anaerobic digestion is a promising option to produce energy and reduce organic wastes, while its high capital investment and utility expense prevent it from becoming the most cost-effective waste management method. Further research can be conducted to reduce the capital cost of anaerobic digestion by reducing the complexity of the system and improving management practices to reduce operation and maintenance costs. On the other hand, selecting high yield substrates and co-substrates can increase the yield of the system. More research is required to improve substrate utilization efficiency.

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Conflict of interest

The authors have no conflict of interest.

References

1. Diggelman C, Ham RK (2003) Household food waste to wastewater or to solid waste? That is the question. *Waste manag res* 21: 501–514.
2. Hall KD, Guo J, Dore M, et al. (2009) The progressive increase of food waste in America and its environmental impact. *PLoS One* 4: 1–6.
3. IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
4. U.S. Environmental Protection Agency (1999) U.S. Methane Emissions 1990–2020: Inventories, Projections, and Opportunities for Reductions. available from: www.calystaenergy.com/pdfs/EPA Methane Emissions 1990-2020.pdf .
5. Delgado CL (2003) Rising Consumption of Meat and Milk in Developing Countries Has Created a New Food Revolution. *J Nutr* 133: 3907S–3910S.
6. Manale A (2006) Agriculture and the Developing World: Intensive Animal Production, a Growing Environmental Problem. *Geo Int Envtl L Rev* 19: 809.
7. Krapac IG, Dey WS, Roy WR, et al. (2002) Impacts of swine manure pits on groundwater quality. *Environl Pollut* 120: 475–492.
8. Altekruse SF, Cohen ML, Swerdlow DL (1997) Emerging foodborne diseases. *Emerg Infect Dis* 3: 285–293.

9. U.S. Energy Information Administration (2010) State Profile and Energy Estimates, New Jersey, available from: www.eia.gov/state/data.cfm?sid=NJ.
10. Deublein D, Steinhausser A (2011) *Biogas from Waste and Renewable Resources*. 2nd Ed. WILEY-VCH Verlag GmbH & CO. KGaA.
11. Buswell AM, Mueller HF (1952) Mechanism of methane fermentation. *Ind Eng Chem res* 44: 550–552.
12. Eleazer WE, Barlaz MA, Wang YS, et al. (1997) Methane Potential of food waste end anaerobic toxicity of leachate produced during food waste decomposition. *Waste Manage Res* 15: 149–167.
13. Engler C, Capereda S, Mukhtar S (2010) Assembly and Testing of an On-Farm Manure to Energy Conversion BMP for Animal Waste Pollution Control. *Texas Water Resources Institute.*
14. Shishi W (2014) Modeling and analysis of utilizing food waste and manure in New Jersey. *Thesis*, Rutgers University.
15. Kleis H, Dalager S (2004) 100 years of waste incineration in Denmark. Heron Kleis and Soren Dalager, Denmark.
16. Bosmans A, Vanderreydt I, Geysen D, et al. (2013) The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. *J Clean Prod* 55: 10–23.
17. Centore M, Hochman G, Ziberman D (2013) Worldwide Survey of Biodegradable Feedstocks, Waste-to-Energy Technologies, and Adoption of Technologies. *In* Modeling, Optimization and Bioeconomy.
18. Bernstad A, la Cour Jansen J (2011) A life cycle approach to the management of household food waste–a Swedish full-scale case study. *Waste manage* 31:1879–1896.
19. Channiwala SA, Parikh PP (2002) A unified correlation for estimating HHV of solid, liquid and gaseous fuels. *Fuel* 81: 1051–1063.
20. Zhang R, El-Mashad HM, Karl Hartman, et al. (2007) Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technol* 98: 929–935.
21. Lamb D, Venkatraman K, Bolan N, et al. (2012) An Alternative Technology for the Sustainable Management of Landfill Sites. *Environ Sci Technol* 44: 561–637.
22. U.S. Environmental Protection Agency (2011) An overview of Landfill Gas Energy in the United States, Landfill Methane Outreach Program (LMOP).
23. Berger J, Fornés LV, Ott C, et al. (2005) Methane oxidation in a landfill cover with capillary barrier. *Waste Manage* 25: 369–373.
24. Thompson AG, Wagner-Riddle C, Fleming R (2004) Emissions of N_2O and CH_4 during the composting of liquid swine manure. *Environ monit assess* 91 (1–3): 87–104.
25. U.S. Environmental Protection Agency (2013) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011.
26. Finnveden G, Moberg Å, Johansson J, et al. (2005) Life cycle assessment of energy from solid waste—part 2: landfilling compared to other treatment methods. *J Clean Prod* 13: 231–240.
27. Guljajew N, Szapiro M (1962) Determining of heat energy volume released by waste during biothermal disposal. *Sbornik Naucznych Robot*: 135–141.
28. Irvine G, Lamont ER, Antizar-Ladislao B (2010) Energy from waste: reuse of compost heat as a source of renewable energy. *International Journal of Chemical Engineering* 2010: 1–10.
29. Jackson LE, Schimel JP, Firestone MK (1989) Short-term partitioning of ammonium and nitrate between plants and microbes in an annual grassland. *Soil Biol Biochem* 21: 409–415

30. Shao L, Wang T, Li T, et al. (2013) Comparison of sludge digestion under aerobic and anaerobic conditions with a focus on the degradation of proteins at mesophilic temperature. *Bioresource technol* 140: 131–137.
31. Klejment E, Rosiński M (2008) Testing of thermal properties of compost from municipal waste with a view to using it as a renewable, low temperature heat source. *Bioresource Technol* 99: 8850–8855.
32. Mata-Alvarez J, Mace S, Llabres P (2000) Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource technol* 74: 3–16.
33. Finnveden G, Johansson J, Lind P, et al. (2005) Life cycle assessment of energy from solid waste—part 1: general methodology and results. *J Clean Prod* 13: 213–229.
34. Speece RE (1996) Anaerobic biotechnology for industrial wastewaters. Archae Press, USA. *Environ Sci Technol* 01/1996; 17.
35. Karim K, Klasson KT, Drescher SR, et al. (2007) Mesophilic digestion kinetics of manure slurry. *Appl biochem biotech* 142: 231–242.
36. van Haaren R, Themelis NJ, Barlaz M (2010) LCA comparison of windrow composting of yard wastes with use as alternative daily cover (ADC). *Waste manage* 30: 2649–2656.
37. Steuteville R (1996) How much does it cost to compost yard trimmings? *BioCycle* 37: 39–46.
38. EIA, US. 2010a. Annual energy outlook 2010.
39. Zafar S (2011) Analyzing Different Waste-to-Energy Technology. BioCycle Magazine.
40. EIA, US. 2010b. State Profile and Energy Estimates, New Jersey, Data.