Poo Power: Revisiting Energy Generation from Biogas on Dairies in Texas

Authors:

Justin Benavidez

AgriLife Fellow, Department of Agricultural Economics

Texas A&M University

2124 TAMU, College Station, TX 77843-2124.

benavidezjustin@tamu.edu

Anastasia W. Thayer

Research Assistant, Department of Agricultural Economics

Texas A&M University

2124 TAMU, College Station, TX 77843-2124.

athayer@tamu.edu

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Introduction

Manure generated on dairy and swine farms across the United States is an underutilized resource with the potential to generate 13,144,441 MWh/year through biogas recovery systems (AgSTAR Market Opportunities Report, 2011). Biogas recovery systems collect the animal waste and capture methane and other gases that are released through the process of anaerobic digestion. Captured methane can then be used to create electricity to be used on the farm or sold in local markets. Coproducts of anaerobic digesters also include heat, fertilizer, animal bedding and compost (AgSTAR Market Opportunities Report, 2011). Environmental benefits from biogas recovery systems include reduced odor, greenhouse gas emission reduction, fewer pathogens and decreased weed seed germination (Yiridoe, Gordon, and Brown, 2009). Despite these benefits, high initial costs to invest in technology, barriers to local energy markets, knowledge of the technology, and necessary economies of scale have slowed nationwide adoption (Lazarus and Rudstrom, 2007).

California, Idaho, New Mexico, Texas, and Wisconsin were identified as the states with the greatest potential for electricity generation on dairy farms, with 155 farms identified in Texas alone and the potential to generate 429,000 MWh/year (AgSTAR Market Opportunities Report, 2011). This estimate of suitable farms and the subsequent potential energy estimate is overly optimistic as it relies solely the number of farms that meet minimum total head requirements. Success of a biogas recovery system relies on the size of the operation (Klavon et al., 2013), the available subsidies and support for investment (Key and Sneeringer, 2012), as well as the availability of electricity markets (Camarillo et al., 2012). All of these factors were ignored in the initial estimation of viable farms in Texas and associated electricity estimates. Given the interest in biogas generation in Texas (Texas Bioenergy report, 2010), an accurate estimate of the number of farms and electricity potential is needed to inform policy, future government initiatives and producers when considering biogas recovery systems.

Objective

The success of biogas recovery in other regions suggests potential benefits for producers in Texas. The objective of this paper will be to provide an accurate, region-specific estimate of the capacity for biogas recovery for Texas dairy producers. A quantitative analysis of financial statements will test the viability of digester adoption and maintenance under risk using data from representative farms at 2 locations in Texas and industry assumptions for biogas digesters. Only after analysis of regional farms will the results be aggregated to the state level with the goal of informing farmers and policy makers on the viability of biogas as an alternative source of fuel for Texas producers. This research is the first to simulate the financial viability of anaerobic digesters and consider risk or other potential sources of input variability.

Review of literature.

Biogas Generation from Anaerobic Digesters

Biogas technology is any manure collection facility that can be adapted to collect biogas, which primarily consists of methane. (Roos, Martin and Moser, 2004) Additionally, producers utilize digester byproduct in the form of fertilizer or bedding for livestock. The key components in a typical biogas system consist of manure collection, anaerobic digestion, effluent storage, gas handling, and gas use.

Different types of manure are created by diluting or drying raw manure. Dairy cattle produce a mean of 86 kg., (189 lbs.) of fresh excrement per 1,000 kg., (2204 lbs.) of live animal mass per day. (Steele, 1995) The fresh excrement consists of approximately 12 kg., or 13% of total solids. (Steele, 1995) The AgStar Manual for Developing Biogas Systems classifies manure with solids content of 13% as semi-solid manure, which, once scraped and deposited into a digester, can be used for biogas and energy production. Table 1. details different types of manure and its viability for biogas.

Table 1. Types of Manure and Uses

Manure Type	*Solid Content*	*Viable for Biogas*
Raw	8-25%	Typically not used
Liquid	<5%	Typically viable in "warm" climates
Slurry	5-10%	Viable for biogas, typically diluted
Semi-Solid	10-20%	Viable for biogas when fresh (less than one week old)
Solid	>20%	Typically not used

Source: Animal Waste and the Land-Water Interface

The type of manure available for biogas generation varies from dairy to dairy, and is largely dependent on the least cost option available for manure collection. The type of manure available determines the choice of digester. Manure content can vary based on the feed ration the animals are consuming and the breed of animal.

A digester consists of an airtight impermeable cover to trap biogas generated from naturally occurring anaerobic bacterial processes that occur during the decomposition of manure. (Roos, Martin and Moser, 2004) Dairy producers have the option of any of three types of digesters; covered lagoons, complete mix digesters, or plug flow digesters. The type of digester chosen is dependent on the needs of the facility, climate at the digester location, and the financial viability of each option.

Covered lagoons are reservoirs with gas-tight covers used to capture the biogas generated by bacterial processes. Production of biogas in covered lagoons varies seasonally because of their exposure to temperature fluctuations. (Giesy et al., 2005) Fixed-film digesters immobilize bacteria on packing material within the retaining vessel, which prevents washout of bacterial biomass. The retention of bacteria offsets the lower rate of metabolism that occurs in fixed-film digesters. (Giesy et al., 2005) Complete-mix digesters utilize mechanical agitation or recirculation of effluent or biogas. Complete-mix digesters are typically constructed of coated steel or concrete and, despite the name, mix manure intermittently.(Giesy et al., 2005) The final type, plug-flow digesters, do not utilize mixing and instead flow semi-continuously as a plug through a reactor.(Giesy et al., 2005) Swine manure cannot be treated with a plug flow digester due to its lack of fiber. (Roos, Martin and Moser, 2004) Table 2. provides details of different types of digesters.

Table 2. Summary Characteristics of Digester Technologies viable for Dairies

Characteristics	*Covered Lagoon*	*Complete Mix Digester*	*Plug Flow Digester*	*Fixed Film*
Digestion Vessel	Deep Lagoon	Round/Square in/Above-Ground Tank	Rectangular In-Ground Tank	Above Ground Tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	0.5-3%	3-10%	11-13%	3%
Solids Characteristics	Fine	Coarse	Coarse	Very Fine
HRT* (days)	40-60	15+	15+	2-3
Optimum Location	Temperate and Warm Climates	All Climates	All Climates	Temperate and Warm
*Hydraulic Retention Time (HRT) is the average number of days a volume of manure remains in the digester				

Source: A Manual for Developing Biogas Systems at Commercial Farms in the United States

An advantage of the covered lagoon system is the option to retrofit an existing manure collection system, i.e. an existing lagoon, into a digester. The remaining options require investment in new technology. When the primary goal is odor reduction, covered lagoons are a viable option as they produce relatively little gas. (Lazarus and Rudstrom, 2007)When energy production is the main goal, the primary choices are complete mix digesters and plug flow digesters.

While the type of technology varies for each type of digester, the basic process of energy generation is the same. Gas handling systems collect the biogas generated from the natural bacterial processes that occur inside the digester via a collection pipe that employs a slight vacuum. As the biogas moves away from the digester origination point it cools. Water vapor in the gas condenses and is drained from the mixture. Collected biogas is used to generate electricity for on-farm use or sale to the local power grid. The primary uses of biogas retained on-farm are for equipment that normally operates on propane or natural gas, including boilers, heaters, and chillers. (Roos, Martin and Moser, 2004)

AgSTAR Findings

AgSTAR is a program of the Environmental Protection Agency (EPA) that, “promotes the use of biogas recovery systems to reduce methane emissions from livestock waste.” (AgSTAR, 2017) AgSTAR provides producers with financing options and planning assistance to encourage the implementation of biogas technology for its substantial environmental benefits and the economic benefits of producers. The primary candidates for biogas generation technology are confined livestock production systems, in particular swine and dairy facilities. The top ten dairy producing states represent 82 percent of the total electricity production potential from dairies. (Market Opportunities, 2011) As of November 2011, AgSTAR reported that Texas was 4th in total potential electricity generation from dairies behind California, Idaho and New Mexico with the potential to generate 429 thousand MWh/year. (Market Opportunities, 2011) Table 3. is the State Profile of Texas' biogas energy generation potential.

Table 3. Market Opportunities to Generate Electricity with Anaerobic Digestion (2007)

Total number of dairy operations	1,293
Total number of mature dairy cows (000 head)	404
Number of feasible dairy cow operations	155
Number of mature dairy cows at feasible operations (000 head)	266
Methane emissions reduction potential (000 tons/year)	66
Methane production potential (billion ft^3/year)	5.0
Electricity generation potential (000 MWh/yr)	429

Source: Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities

Case Studies

A number of case studies have estimated the economic feasibility of installing anaerobic digester technology on dairy farms in the United States. A point of evaluation for all the literature reviewed was the number of head on any dairy farm analyzed. The number of head evaluated ranged from 500 to 2000. In general, larger dairy operations typically netted higher profits after installing biogas generation systems which is consistent with economy of scale principles. The number of head also dictated digester choice due to the cost and investment of management's time.

In all case studies, net present value was used to evaluate digester system investment while other outputs were also considered. Other key measures were the probability of a positive NPV and the expectation of NPV at the end of the digester's useful life. Additional variables used for evaluation included, but were not limited to, the change in milk cost, payback period, the internal rate of return on the digester and the electricity price required to achieve breakeven. (Lazarus and Rudstrom, 2007)

Giesy et al. (2005) evaluated the economic feasibility of digesters on Florida dairy farms. Two consulting firms developed input cost estimates and capital costs of digester instillation, which Giesy et al. used in a simulation to obtain an estimate of NPV. The simulation evaluated three herds ranging in size from 600 – 2000 head and found that the owner's share of capital proved a significant factor when choosing whether to install a digester.(Giesy et al., 2005) A key assumption was the use of a 25% efficiency rate of biogas conversion.

Lazarus and Rudstrom (2007) conducted a case study in Minnesota on a successful biogas generation system that had been in place for 5 years. They found that a key to the profitability of digesters was the ability of a manager to maintain detailed records and a high electricity cost.

In Pennsylvania Leur, Hyde and Richard (2008) utilized stochastic capital budgeting model to seek the probability of a NPV that was greater than zero and the end of the installed digester's useful life. They found that economies of scale were key when making the decision on whether to install an anaerobic digester system. Additionally, the way the separated solids were marketed was important to determining if NPV was positive or negative. When separated solids were marketed or retained as livestock bedding, the larger farms in the evaluation obtained a positive NPV and the probability of a dairy with greater than 2000 head being greater than zero was approximately 66%. (Leuer, Hyde and Richard, 2008) When separated solids were marketed or retained as compost the probability of NPV being greater than zero was only 33% and the expected NPV for all dairy sizes in the evaluation was negative. Again, electricity price was a significant factor in the final NPV determination, along with the estimated useful life of the digester. (Leuer, Hyde and Richard, 2008)

Cost Benefit Analysis

As stated in the previous section, a standard investment evaluation output is NPV found using capital budgeting. Bishop and Shumway (2009) established example capital budgets for component costs and annual net income using an example digester system in Washington. Table 4. and Table 5. are adapted examples of the budgets by Bishop and Shumway which detail the component costs and annual net incomes from an operational digester.

Table 4. Initial Capital Outlay, Including Financing Cost

Component	Cost*
Pit	$19,435
Digester	498,913
Gas mixing	27,777
Co-generator	282,087
Building	95,637
Total Capital Cost	$923,849
Other Cost	212,515
Present Value of Financing Cost**	--
Total Cost	$1,136,364

Adapted from: The Economics of Dairy Anaerobic Digestion with Coproduct Marketing
*Not to be used without updating – examples from Bishop and Shumway
**Not included in Bishop and Shumway original budget

Table 5. Yearly net income

Source	Year 1
*Revenue**	
Electricity Sales	$97,088
Tax credit	38,835
Avoided bedding cost	18000
Digested fiber	10265
Other income	4306
Income from government programs	
Total Revenue	$168,494

*Operating Costs**	
Building repairs	$7088
Engine repairs	11569
Equipment repairs	27199
Oil	24187
Utilities	30139
Professional service	11212
Miscellaneous	11898
Total operating Expenses	123292
Income above operating costs	$45,202

Adapted from: The Economics of Dairy Anaerobic Digestion with Coproduct Marketing
*Not to be used without updating – examples from Bishop and Shumway

Table 4. and Table 5. Demonstrate capital budget used to calculate NPV at the end of the useful life of a proposed digester system. The key steps are to: 1. Calculate the initial capital outlay required to install a digester system and; 2. To calculate annual net income from the digester after installation discounted over the estimated useful life of the digester. Multiple line-items in each budget can be expanded or condensed based on their viability to a regional system. Additionally, the operating costs and revenues can be treated as a distribution rather than a point estimate.

Methodology and Data

Following, Richardson and Mapp (1976) and Richardson and Condra (1981), models of potential investments and farm production decisions should integrate uncertainty and risk. A simulation model can inform future decisions and demonstrate the long-term viability of projects. This study uses a simulation model to evaluate farm-level investment in a lagoon biogas recovery system for two farm sizes in Texas.

In order to determine the feasibility of biogas recovery systems on dairy farms in Texas, resulting savings to the farm, and potential production of electricity, farm-level data was gathered for two representative dairy farms in Texas. Representative farm data was provided by the AFPC at Texas A&M University. One simulation represented a dairy farm in east Texas with 1500 head of milking-age cows while another represented a farm in west Texas with 3800 milking-age cows. These milking age cows are split into lactating cows and dry cows for analysis, as the same cow produces different amounts of manure when lactating versus when they're dry. Dairy farms in east Texas tend to be smaller operations than those in west Texas which impacted the success and viability of the biogas recovery systems. Results were aggregated to the state level to determine state-level viability of the systems and associated potential electricity and energy generation. Aggregate state-level data will be gathered from United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). Key output variables simulated on the farm level were: net present value, ending cash flow, and probability of negative ending cash flow. These variables determined the profitability of the investment and if the investment was sustainable for each farm over the simulated period.

Results were compared to estimates provided by AgSTAR on the potential number of farms and electricity output. Each simulation consisted of 1000 iterations.

Distributions

The enterprise analysis utilizes three types of distributions to create stochastic values for certain components. A small amount of variability was introduced into the recovery system's efficiency by multiplying a uniform standard deviate (USD), bounded at a 10% increase in efficiency and 10% decrease in efficiency, by the percent of solid conversion to biogas and the cubic feet of biogas per pound of volatile solids converted. The inclusion of an USD allows equally weighted draws from 10% above and 10% below the expected values of both figures which are important in determining the amount of electricity generated by the system.

The normal distribution is utilized in calculating the kilowatt hour per cow (kwh/cow) of electricity needed on each dairy, the stochastic wholesale purchase price of electricity from the dairy, the stochastic price of electricity purchased by each dairy and the amount of manure produced by each farm's cows. The amount of manure produced is an important component when determining whether or not the biogas generation project generate excess energy for sales and whether or not the biogas generation project is a financial success. The normal distribution was appropriate for each of the variables discussed as the mean and standard deviation were available from easily accessible data. Further, normality is assumed as we have no reason to believe that the distributions of the underlying variables are not normal and lack sufficient data to test other distributions.

The final type of distribution used in the biogas generation project enterprise analysis was the GRKS distribution, which simulates a subjective probability distribution based on minimal input data. The GRKS distribution accounts for the fact that managers or modelers may not account for situations that are 'worse' or 'better' than expected and so allows for around five percent of the values to occur outside of the minimum and maximum values provided. The rest of the distribution is split into eight intervals, four below the mid-point and above the minimum of equal size and four above the mid-point and below the maximum of equal size. The GRKS was applied to the initial capital outlay required to construct a lagoon pit biogas generator. Few observations were readily available and varied widely, making the GRKS the ideal distribution.

Scenarios

The model evaluates each farm under a set of four different scenarios. Each scenario introduces an additional enterprise (called co-product by the literature) or financial support in an attempt to make the investment in biogas energy generation systems more profitable. The base scenario evaluates the investment under the assumption that the dairy does not sell energy back to the grid, has no gains from deferred bedding costs and does not obtain any grants.

The second scenario assumes that the dairy does possess the capability to sell excess power generated back to the grid and can secure a contract with the utility. The costs of equipment required to sell excess power is not included in the estimate and is therefore considered negligible or already encompassed in the construction costs.

The third scenario assumes the dairy possesses the ability to sell excess power back to the grid and can use dried refuse as bedding, which defers a standard cost of certain types of dairies. The large dairy the model evaluates does not have an initial bedding cost and so the results of the second and third scenarios are the same for the large dairy. The final scenario assumes that the dairy possesses the ability to sell excess power back to the grid, can use dried refuse as bedding and qualifies for grant support.

Model and Assumptions

The first stage of the model requires inputs from each dairy. The herd information is composed of the number of lactating and dry cows. The herd is split into these categories as the two categories produce a different amount of manure. The number of different types was provided by the AFPC representative farm data.

Capital costs were based on a GRKS distribution of cost ($/cow) taken from AgSTAR's database of dairies utilizing lagoon pit digesters. Unlike other industries or investments, projects to date did not exhibit increasing returns to scale. The minimum, middle and maximum costs, the parameters for the GRKS distribution, were $274.55/cow, $931.77/cow and $2000/cow, respectively. The stochastic value calculated using the GRKS distribution was multiplied by the number of cows on the given dairy to calculate the total capital cost for the project. The generator, boiler, pumps and controls have a depreciable life of seven years while the remainder of the components have a depreciable life of 20 years. The model assumes a working capital contribution of 10% of the overall farm's cash receipts for the year.

In order to introduce variability into the biogas system's output amount, a stochastic element was added to the amount of solid conversion to biogas as a percent and the cubic feet of biogas per pound of volatile solids converted. The model assumes a uniform distribution from 10% above and 10% below the expected values of both figures which are important in determining the amount of electricity generated by the system and reflect real-life variability in system output.

Data from the University of Vermont Extension service indicates that dairy cows in the United States require between 800 and 1,200 kWh of electricity annually (Energy Analysis, 2009). When modeling the dairies in Texas the kWh requirements were adjusted to reflect the lower power needed for Texas dairies compared to, for example, Vermont dairies which require heating and additional lighting due to decreased daylight in the winter. Higher average temperatures and longer daylight hours in Texas compared to the rest of the U.S. mean that dairies in Texas require less heating and lighting. Splitting kWh usage into two categories from 800-1000 kWh/cow and 1000-1200 kWh/cow allowed the model to account for Texas' lower energy usage.

A normal distribution was developed using the mean and standard deviation of each category. The stochastic value obtained from the normal distribution was multiplied by a weighted average of the lower half of the kWh usage (800-1000 kWh) and the upper half of kWh usage (1000-1200 kWh) provided an estimate of the average kWh/cow used on each dairy. The lower kWh usage category carried an 80% weight with the higher kWh usage category weighted 20%. The weight was chosen to represent Texas dairies typically lower use of electricity than other dairies around the country.

A normal distribution was also used to obtain stochastic values of the cost of power purchased by each dairy and the wholesale price paid for power generated by the dairy sold back to the grid, assuming the scenario allows for sales back to the grid. Using annual average energy price in cents from the U.S. Energy Information Administration from 1990 to 2016 the model calculates a stochastic purchase price from the grid using a mean of 7.84 cents and standard deviation of 1.22 cents (Detailed State Data, 2016). The model assumes a normally distributed stochastic wholesale price (cents/kWh) with a mean of 3.4 cents and standard deviation of 1 cent using annual price from the 2016 State of the Market Report for the ERCOT Electricity Markets (ERCOT, 2016).

The body of literature surrounding biogas generation from manure on dairies overwhelmingly supports the necessity of grants. The Rural Energy for America Program (REAP) provides loan assistance and grants for producers seeking to install a biogas collection and electricity generation system. Grant assistance is capped at 25% of the total capital costs of the project and the total amount funded cannot exceed $500,000. One of the four scenarios evaluated in the model incorporates grant assistance and assumes that the amount received is 25% of total capital costs or at most $500,000.

The model assumes two categories of materials in the initial capital costs, both with a different depreciable life. The first category includes the generator, boiler, pumps and controls with a depreciable life of seven years. The second category includes the cost of a building, site work, power wiring, manure piping and the digester tank itself with a depreciable life of 20 years. The Program on Agriculture and Small Business Finance at Cornell University provides estimated depreciation rates for both categories, which the model uses to calculate the accumulated depreciation and book value of the two categories for use in the financial statements. Using the percentage allocated to each material category from the Cornell Decision aides, the model allocates the stochastic total amount to each material category to the dairy that is being evaluated.

The model takes into account a stochastic value of manure produced by individual cows. Steele (1995) provides a mean and standard deviation of the amount of manure produced by different livestock species and the components of each species' manure. Using the data from Steele (1995) the model constructs a normally distributed stochastic value of manure per head ($\bar{x}$=190 lbs., σ=37 lbs. for lactating animals, $\bar{x}$=104 lbs., σ=20 lbs. for dry), which is multiplied by the number of cows in each of the lactating and dry cow categories to obtain the total pounds of manure produced on each dairy.

In order to value the amount of electricity generated by the biogas generation system in kWh/year the model begins with calculating millions of British Thermal Units (MMBTUs) per year and converts them kWh. Kilowatt hours are multiplied by the stochastic thermal conversion efficiency and daily online percentage of the system to obtain the final value of kWh/year generated. The daily online percentage decreases by a percent each year to account for increasing risk of breakdowns leading to lower use not accounted for by depreciation of the asset.

Total farm energy requirements (kWh/year) are the sum of the power use of the biogas generation system and the pre-system farm requirements. The amount of electricity sold back to the dairy by the biogas generation enterprise is equal to the total farm energy requirements (kWh/year). The value of the electricity sold back to the farm is equal to the benefit of the defrayed electricity cost from installation of the biogas system. Any excess electricity can be sold back to the grid, depending on the scenario evaluated. The value of on-farm electricity generated is equal to the stochastic purchase price from the grid (cents/kWh) multiplied by the stochastic real electricity savings in kWh per year. The value of excess electricity generated by multiplying the excess generation in kWh by the stochastic sale price to the grid (cents/kWh).

The key evaluation points of the model are the final net present value of the investment in a biogas energy generation system and the ending net worth of the enterprise. Additionally, the model calculates a probability of an annual negative ending cash value.

Results

Analysis of the two farms reveals that both dairies under all four scenarios are expected to have a negative net present value (NPV) of investment for an anaerobic digester (Table 1). This suggests that installing an anaerobic digester is not profitable for farms of similar size in Texas. The NPV is less negative for the small dairy compared to the large dairy. In both farms, the NPV is the most negative for investments in the base scenario which does not allow for bedding offsets, electricity to be sold back to the grid, or include grants. As expected, each addition to the analysis which allows the farm to recoup part of the initial cost such as offsetting production expenses, selling excess electricity, or taking advantage of governmental programs increases the NPV of the investment. The standard deviation is smaller in the small dairy ($608,242 averaged across all scenarios) compared to the larger dairy ($1,569,087 averaged across all scenarios).

Table 1: NPV of Anaerobic Digester Investment

	Small Dairy	Large Dairy
Base	-$1,028,416	-$2,678,677
	$617,739	$1,569,359
B+ES	-$973,497	-$2,541,771
	$619,325	$1,572,630
B+ES + BG	-$705,298	-$2,541,771
	$619,325	$1,572,630
B+ES+BG+G	-$568,817	-$2,355,292
	$576,581	$1,561,729

The cumulative distribution of the NPV of AD investment shows greater differences between scenarios' outcomes for the smaller dairy than the larger dairy (Figure 1). The smaller dairy also has a smaller range of NPV (-$3,284,503 to $907,894) compared to the larger dairy where values range from -$8,532,437 to $2,220,931). However, while the average NPV for both farms under all scenarios is less than zero, the upper quartile for the smaller dairy is always positive whereas the base scenario for the larger dairy does not have a positive upper quartile.

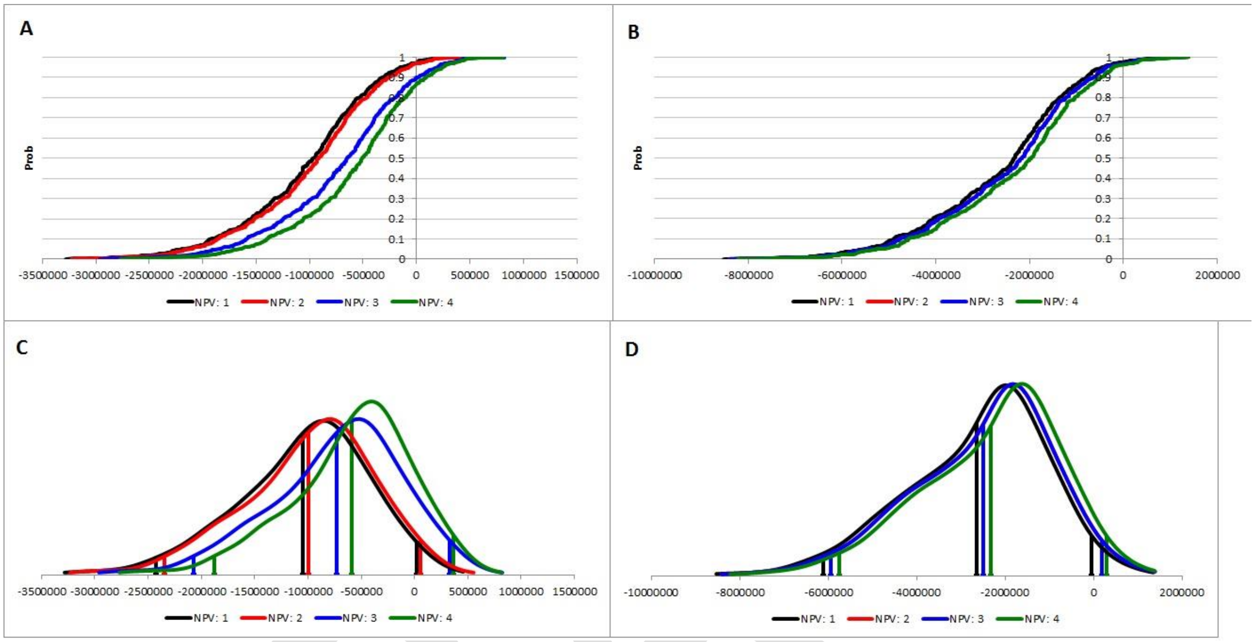

Figure 1: Comparison of CDF and PDF of net present value (NPV) of anaerobic digester (AD) investment on two dairy farm sizes in Texas. A) CDF of the NPV of AD investment in a small dairy (~1500 head). B) CDF of the NPV of AD investment in a large dairy (~3500 head). C) PDF of the NPV of AD investment in a small dairy (~1500 head). D) PDF of the NPV of AD investment in a large dairy (~3500 head).

Ending net worth for both dairies considered in this analysis was negative for all scenarios after the investment in an AD (Table 2). Ending net worth was lower for the large dairy compared to the small dairy. Similar to the NPV analysis, scenarios which included more offsets for the initial investment have a higher ending net worth. The standard deviation was lower for the smaller dairy ($1,577,624 average across scenarios) compared to the larger dairy ($4,069,807 average across scenarios).

Table 2: Ending Net Worth

	Small Dairy	Large Dairy
Base	-$2,667,445	-$6,947,798
	$1,602,257	$4,070,512

B+ES	-$2,525,001	-$6,592,701
	$1,606,368	$4,078,997
B+ES + BG	-$1,829,361	-$6,592,701
	$1,606,368	$4,078,997
B+ES+BG+G	-$1,475,366	-$6,109,021
	$1,495,502	$4,050,722

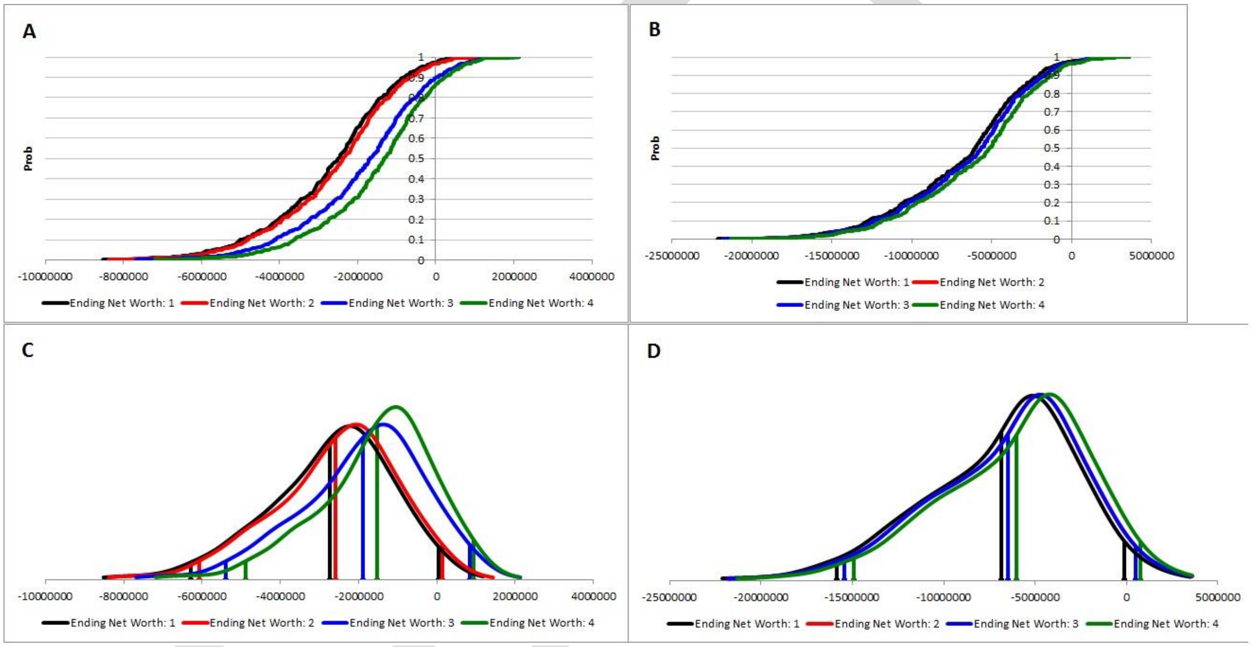

Figure 2: Comparison of CDF and PDF for ending net worth after investment in an anaerobic digester (AD) on two dairy farm sizes in Texas. A) CDF of the ending net worth after AD investment in a small dairy (~1500 head). B) CDF of the ending net worth after AD investment in a large dairy (~3500 head). C) PDF of the ending net worth after AD investment in a small dairy (~1500 head). D) PDF of the ending net worth after AD investment in a large dairy (~3500 head).

The cumulative and probability distributions for each dairy's ending net worth after investment in the AD suggest that the smaller dairy has greater differences in ending net worth between scenarios than the larger dairy (Figure 2). The base and base plus energy sales group similarly and the other scenarios that also include offset bedding and the inclusion of grants group similarly. The range of ending net worth is larger for the large dairy (-$22,130,945 to $5,760,522.80) compared to the smaller dairy which has a range of -$8,519,155 to $2,396,383.

The average value of ending net worth under all four scenarios for both farms is negative but for the small farm, all values of the upper quartile are positive and for the large farm, all scenarios except for the base have a positive upper quartile value.

Table 3: Probabilities of Ending Cash Below Zero

	Small		Large	
	No Sales	Sales	No Sales	Sales
Year 1	0.0010	0.0010	0.0030	0.0020
	0.0316	0.0316	0.0547	0.0447
Year 2	0.9940	0.9890	0.9960	0.9960
	0.0773	0.1044	0.0632	0.0632
Year 3	0.9890	0.9870	0.9950	0.9890
	0.1044	0.1133	0.0706	0.1044
Year 4	0.9870	0.9840	0.9890	0.9870
	0.1133	0.1255	0.1044	0.1133
Year 5	0.9840	0.9780	0.9870	0.9860
	0.1255	0.1468	0.1133	0.1175

The probability of ending cash below zero varies widely when comparing results after year 1 compared to all other years (Table 3). The probability of ending cash below zero is close to zero for the first year for both farms and close to one for all remaining years. There appears to be little difference in the probabilities even if the farm sells electricity back to the grid. This is likely because the cost of selling electricity to the grid is low compared to the investment costs.

Analysis of the NPV of investment, ending cash flow, and probability of negative returns suggests that farms in Texas should not consider installing anaerobic digesters; however, installing an AD is potentially more profitable for a smaller dairy compared to a larger dairy in Texas. This result supports our hypothesis that original estimates of digester potential in Texas were overestimated. It appears to not be profitable for most farms to install AD. Counterintuitively, these results do not support increasing returns to scale.

Digesters are likely not profitable in Texas for the following reasons: 1) low cost of selling electricity to the grid, 2) highly variable costs of investment based on available budgets of similar projects, 3) few government incentives or grant support. Differences between scenarios suggest that adding additional components such as offsetting bedding costs, selling electricity back to the grid, and finding grants to support the project may offset some of the initial costs but it may not be enough to make the project financially feasible. Further, limits on grant support or caps to government incentives favor smaller dairies which have a lower grant to capital investment ratio. For this reason, it may be more profitable for smaller dairy to invest in an AD but not profitable for a larger dairy given that larger farms do not benefit from economies of scale.

Finally, if results from the small and large farm were aggregated across similar farms in the state, results show that in total 5,478,618 MMBTU/year or 361,280,481 kWh/year could be produced on dairy farms in Texas using AD (Table 4). Note that only 89,993,981 kWh/year would be excess generation and available for sale to the grid. This number is considerably lower than the estimate given by AgSTAR. As predicted, local financial and energy estimates suggest that potential energy production is much lower and the choice of investing in an AD is not feasible for many producers. Further, based on the low price of electricity due to a deregulated market, the price to sell to the grid is lower than in other areas of the country which leads to a total value of excess generation of only $3,113,792/year.

Table 4: Aggregated Environmental and Energy Data

	Small	Large	Total for Texas
Number of Similar Farms	52	53	105
MMBTU/year	29648	74281	5478618
Total kWh Produced in Year 1	1955125	4898377	361280481
Electricity Savings ($)	1410000	280071	88163763
Excess Generation (kWh)	490375	1216877	89993981
Price to Sell to Grid	0.035	0.035	0.035
Value of Excess Generation ($)	16967	42104	3113792

Conclusion

This analysis demonstrates that the potential energy generation and carbon equivalent emission offsets from investment in AD on dairies in Texas is considerably lower than previous estimates from AgSTAR. The introduction of financial and production information from farms in Texas as well as the introduction of risk into decision models decreases the financial viability of AD investment and the projected electricity generated. Further, this study is the first to show the importance of including risk and variability into models specific to the decision of whether or not to install biogas collection and electricity generation equipment on dairies.

Not only is the estimate of potential energy generation provided by AgSTAR overstated, the likelihood financial viability of installing digesters, described in an overarching fashion by the program, is misleading. While government support makes the ending NPV of any capital expenditure more feasible, the amount of support necessary for a profitable investment in Texas does not exist under current programs. Low electricity prices in Texas make it very unlikely that a dairy will recoup its investment in the first ten years after installation. Additionally, this analysis assumed that the initial capital cost included the price of equipment required to connect to the grid. That cost could vary widely based on distance to a viable collection point for excess power generation, and an increased cost would decrease the final NPV.

Future work includes evaluating the decision to install different types of digesters and their potential for profitability in the Texas electricity market. Finding a breakeven in order to determine the necessary government support to make biogas generation on Texas dairies feasible is also a natural extension of this work. Extensions to this work would show the support or additional requirements necessary for AD on dairies to become a reality in Texas.

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