Economic Feasibility of Anaerobic Digesters with Swine Operations

Abstract:

In the U.S., anaerobic digestion systems are rarely adopted because large construction costs make them economically infeasible for most animal feeding operations. However, limited research is available on the application of these technologies on swine farms. Net present values were calculated to compare the economic feasibility of anaerobic digestion systems and covered lagoons under different output, co-product, and government policy scenarios. Results seem to indicate that with no government intervention, the lower-cost covered lagoon systems were more economically feasible than the complete mix and plug flow anaerobic digestion systems.

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1. Introduction

An increasing population requires more food and more intensive agricultural operations. However, as animal production facilities become larger and more concentrated, the risk of environmental and social externalities increases (Centner 2003). Environmental degradation from nutrient pollution, specifically phosphorus, consistently ranks as one of the top water quality issues in the U.S. (Carpenter et al. 1998). Excess phosphorus loading can lead to water quality problems such as hypoxia and eutrophication. Carpenter et al. (1998) argue that eutrophication is a widespread problem, and phosphorus pollution results primarily from agricultural and urban activities and is directly related to livestock stocking rates upstream.

In addition to water quality impairments, the livestock industry in the U.S. is often blamed for atmospheric environmental problems, including the discharge of methane into the atmosphere (Zaks et al. 2011). Methane is a potent greenhouse gas that could contribute to global warming (Lashof and Ahuja 1990). While livestock are not a net source of carbon dioxide, Steinfeld et al. (2006) argue that livestock are the most important source of anthropogenic methane on the planet, and methane released from enteric fermentation may total 86 million tons per year. The production of livestock also requires large amounts of human and fossil fuel energy. The agricultural sector accounts for approximately 19% of the energy use in the U.S., and these food production, processing, packaging, transportation, and preparation activities are driven almost entirely by non-renewable energy sources (Canning et al. 2010; Pimentel et al. 1973; Pimentel and Pimentel 1996; Pimentel et al. 2008).

Anaerobic digestion could be a viable solution to the environmental and resource concerns identified for confined animal agriculture. An anaerobic digester is a system that stores and processes manure under anaerobic conditions (without oxygen). Anaerobic digestion systems can alleviate greenhouse gas emissions by capturing and combusting methane. These systems can also precipitate and divert mineral phosphorus (as struvite, or magnesium ammonium phosphate, $NH_4MgPO_4 \cdot 6H_20$) in a more concentrated form (Burns, Moody, and Shepherd 2006; Çelen et al. 2007; Shu et al. 2006; Uysal, Yilmazel, and Demirer 2010; Yilmazel and Demirer 2011). By doing this, phosphorus is not as likely to be over-applied, and fertilizer transportation costs are reduced. Anaerobic digesters also have the potential to produce value-added coproducts on the back end that could include soil amendments, livestock bedding, and liquid that can be used as fertilizer (Zaks et al. 2011; Bishop and Shumway 2009). However, despite the potential environmental and economic benefits, anaerobic digestion systems are not yet common in the United States. Currently only 239 of the almost 20,000 (~1%) confined animal feeding operations in the United States have anaerobic digestion systems, and the swine industry accounts for only 29 of these systems (USEPA 2012; USEPA 2014).

The potential environmental and economic benefits of anaerobic digestion systems are only one side of a very complex *economic* issue. The economics, and more specifically the capital costs, of these systems are often blamed for their limited adoption (Lazarus and Rudstrom 2007; Kruger et al. 2008; Stokes, Rajagopalan, and Stefanou 2008; Bishop and Shumway 2009; Wang et al. 2010). Most of the current literature on the economic feasibility of anaerobic digestion systems has focused on site-specific case studies in the *dairy* industry. Bishop and Shumway (2009) and Kruger et al. (2008) describe financial analyses of anaerobic digesters on two dairy farms in the Pacific Northwest. Both found that, for these digesters, reduced capital costs from government grants, additional revenue streams from co-products like electricity, fiber, and nutrients, and co-digestion of food waste are important for obtaining sufficient return on investment. Lazarus and Rudstrom (2007) studied the economic feasibility of an anaerobic digestion system on a Minnesota dairy farm. They used a ten-year capital budgeting analysis and found that the profitability of the digester was primarily due to favorable pricing by the local electrical utility and financial assistance from various government agencies. Wang et al. (2010) aggregated cost and returns data from six dairy farms in the state of Vermont to study the economics of converting manure to electricity and also found that economic returns for digesters primarily depend on electricity premium price, government grants and/or subsidies, and selling value-added co-products. Stokes, Rajagopalan, and Stefanou (2008) used capital budgeting and a real option framework to determine why dairy producers in Pennsylvania adopt methane digester technology. They determined that the initial investment of a digester is so great that "significant grant funding is required to induce methane digester investment since the option to delay the investment has value" (Stokes, Rajagopalan, and Stefanou 2008, p. 675).

While most previous research on anaerobic digestion has focused on the dairy industry, it is also important to understand the potential for these systems on *swine* operations and also to determine the type of digester that is the most economically feasible. Anaerobic digestion systems and/or covered lagoons could help swine operations avoid the environmental and resource concerns identified for confined animal agriculture while providing the protein needed to feed the world. Digesters produce methane at a higher and more constant rate, whereas covered lagoons require lower maintenance, materials, and construction costs. Therefore, understanding the tradeoff between better performance and lower costs associated with digesters and covered lagoons, respectively, could help producers who are interested in implementing this technology. Therefore, the primary objective of this study is to determine the economic feasibility of anaerobic digesters and covered lagoons on swine operations. The second objective is to determine the physical parameters, co-products, and/or government policies that it would take to make anaerobic digesters or covered lagoons the optimal method of handling swine manure. To accomplish these objectives, net present values were calculated to gauge the economic performance of anaerobic digester and covered lagoons. Co-product marketing scenarios were formulated, and sensitivity analyses were used to determine how the economic feasibility of the digesters and covered lagoons are affected under different economic, co-product, and policy scenarios.

2. Theory

A discrete-choice optimization problem for a risk neutral producer that wants to determine the economic feasibility of extracting methane and other co-products from manure produced at a swine animal feeding operation (AFO) can be defined as

$$\max_{i,d} NPV = \sum_{t}^{T} \left[\frac{1}{(1+r)^t}\right] \left[p_{it}E(y_{itd}) - w_{itd}x_{itd} - C_{id}\right] \quad (1)$$

$$\text{s.t. } NPV > 0$$

where i is a choice variable for the output that the producer wishes to produce, where $i = 1, \dots, n$, n is the number of coproducts extracted from the digester, $i = 1$ is recovered methane, $i = 2, \dots n$ are any additional value-added products, d is the method used for handling swine manure, where $d = 1, 2$ (1 = anaerobic digester, 2 = covered lagoon), r is the discount rate for the t^{th} year, $E(y_{itd})$ is the amount of the co-product that is extracted in units/year, p_{it} is the price of each output in \$/unit, w_{itd} is the variable cost of the inputs required to produce each output in \$/unit, x_{itd} is the input, or physical parameter, required to achieve the i^{th} output, and C_{id} is the fixed cost of producing each output (\$).

4. Data

A survey instrument was used to collect primary data for this study. The survey was distributed to the major hog-producing states across the U.S. with the help of the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). Swine operations that currently use anaerobic digestion technology on their farms were asked to answer five sections of the survey. The five sections included 1) Introductory Questions, 2) Physical Parameters and Digester Design, 3) Economic Considerations, 4) Policy Implications, and 5) Demographics. Survey participants were asked to share cost, revenue, and production data from their anaerobic digester. Qualtrics Survey Software was used to create and administer the survey online and a paper version of the survey was also sent in an attempt to generate additional responses.

On December 20, 2013, a postcard was sent to all swine animal feeding operations. The postcard described and requested help with this study and provided a link to the online survey platform. Since the response rate was not adequate after sending the first postcard, a survey packet was distributed on January 24, 2013. The survey packet included a cover letter, a paper version of the survey, and a business reply envelope. While the response generated from the paper survey was better than with the postcard, a second postcard reminder was sent on February 12, 2014. The final paper survey was returned on May 9, 2014, and the online survey was deactivated on May 16, 2014.

Of the 29 swine operations that operate anaerobic digesters in the United States, as identified by the USEPA AgSTAR Program, eight responded to the survey (USEPA 2014b). Two respondents operated covered lagoons, while the other six operated complete mix (n = 1) or plug flow (n = 5) anaerobic digesters. For the purposes of this study and in order to protect the confidentiality of the survey respondents, the two covered lagoons will be grouped together, representing the "low rate, low cost" digesters, and the complete mix and plug flow digesters will be grouped together, representing the "high rate, high cost" digesters. Table 1 includes a summary of selected respondent, farm, and digester characteristics.

Table 1. Mean Respondent Farm and Digester Demographics

Digester Type	Years Operating Digester	Farm Size (# of swine)	Diversified Livestock Production	Manure Input (%)
Complete mix/plug Flow	8	6,825	Yes	75
Covered lagoon	9	5,045	No	100

The mean number of years that the digesters or covered lagoons were operational was similar for both groups. Some of the swine farms included in this study reported that they also raise dairy cattle and that manure was not the only material entering the digestion system. The complete mix and plug flow anaerobic digesters had an average of 25 percent food production or processing waste in the digester input stream. Both covered lagoons only processed swine manure. Dairy manure and food waste have higher volatile solids (VS) content than swine manure. Volatile solids are the portion of the total solids that the microorganisms consume and convert into methane (Tchobanoglous, Burton, and Stensel 2003). The average loading rate for the anaerobic digesters was approximately 9,750 lb VS/ft^3/day, while the average loading rate for the two covered lagoons was close to 1,250 lb VS/ft^3/day. While this is partially due to the fact that swine manure slurry typically contains higher water content, the addition of dairy manure and food production or processing waste could allow the anaerobic digesters to produce methane at an even higher rate than the covered lagoons. To give some perspective, a lactating dairy cow will produce an average of 17 lb VS/day, and a dry cow and dairy heifer will excrete 9.3 and 7.1 lb VS/day, respectively (USDA 2008). In contrast, the average lactating sow will emit 2.3 lb VS/day, and a gestating sow will produce only 1.0 lb VS/day (USDA 2008). Nursery and grow-to-finish pigs generate approximately 0.24 and 0.83 lb VS/day, respectively (USDA 2008). Food processing wastes that have similar characteristics as livestock manure, in terms of moisture, total solids, and volatile solids content and chemical/biological oxygen demand, can improve the methane output of an anaerobic digester (Scott and Ma 2004). Food wastes have twice the methane yield per pound of volatile solids when compared to manure (15 ft^3/lb VS vs. 7 ft^3/lb VS) (Goldstein 2012). However, since most anaerobic digesters and covered lagoons in the U.S. are designed to treat animal wastes, the addition of food or other organic wastes that do not have similar physical, biological, and chemical compositions could disrupt the system, so careful consideration must be taken when adding food waste to an anaerobic digestion apparatus.

5. Procedure

Net present value (NPV), as specified in equation 1, was used to gauge and compare the economic performance of digesters and covered lagoons. Since all anaerobic digesters produce methane, NPV was calculated for the average anaerobic digester and covered lagoon on the basis of only methane production for comparison purposes. Additional co-products, such as electricity generation and soil amendments, were added to the analysis for those operations that reported co-product marketing. Methane can be injected into an internal combustion engine/generator to produce electricity used on-farm, offsetting the cost (retail price) a producer must pay for electricity (Zaks et al. 2011). Any electricity not consumed on the farm can be sold back to the utility (or back “on the grid”) for a whole sale price. All of the anaerobic digesters in this study produce methane that is injected into an electric generator, and one of the covered lagoons reported electricity generation as a part of the anaerobic digestion system. All of the operations that produce electricity from methane either sell the electricity off the farm at a wholesale price or use it to offset their own (retail) costs of electricity. The average price that this electricity was sold by each respondent is included in Table 2 as wholesale electricity. The average price paid by each respondent for their electricity is included in Table 2 as retail electricity. The anaerobic digesters and covered lagoons also reported revenue and/or cost savings from the production of solid and/or liquid fertilizer (NPK) and compost soil amendments. The price for soil amendments was based on national averages for similar products. However, survey respondents were asked to report revenue and cost-savings information, and these values are included in Table 4.

Table 2. Potential Anaerobic Digester Co-products

Source	Units	Price $/unit
Wholesale electricity[a]	kWh	0.043
Retail electricity[a]	kWh	0.075
Carbon trading on CCX[b]	ton	0.10
Carbon trading on ECX[c]	tonne	5.12
Social cost of carbon[d]	tonne	33
Bulk soil amendment[e]	cu yd	25
Renewable energy tax credit[e]	kWh	0.02

[a] Mean prices, as reported by survey respondents
[b] Chicago Climate Exchange (2012)
[c] European Climate Exchange (2014)
[d] For regulatory analysis – under Executive Order 12866, $r = 3\%$ (2013)
[e] All other prices estimated from various sources

The agricultural operations included in this study also reported benefiting from carbon trading on the Chicago Climate Exchange (CCX), carbon offsets, renewable energy tax credits, and state or federal government grants (Tables 2 and 4). Therefore, any benefits from government policies were also added to the analysis as co-products. Table 2 includes two additional, hypothetical variables to determine how the price of carbon credits could affect the economic feasibility of anaerobic digesters and covered lagoons. Farms and businesses in the U.S. cannot trade on the European Climate Exchange (ECX) at this time, but it presents an interesting scenario to explore. Under Executive Order 12866, the social cost of carbon was determined “to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analysis or regulatory actions that impact cumulative global emissions” (US Government 2013). While the social cost of carbon is not currently an actual price obtained on the market for offsetting carbon emissions, it does pose an interesting question. Can we accurately “estimate the monetized damages associated with an incremental increase in carbon emissions in a given year” (U.S. Government 2013)? If so, what are the cost savings associated with offsetting those damages? It is important to note the significant difference between the actual price obtained for carbon credits on the CCX (from 2003 to 2010, when it operated as a comprehensive cap and trade program with an offsets componenet) and the government-specified social cost of carbon (SCC). The U.S. Government (2013) used three integrated assessment models that included changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change, among other parameters, to estimate an average SCC at discount rates of 2.5, 3, and 5 percent. The SCC of $33/tonne (Table 2) is estimated at a discount rate of 3 percent. According to Ackerman and Stanton (2012), the SCC has widely acknowledged limitations and is not an observable price in any actual market. It is rather a shadow price that measures the marginal benefit of emissions reductions and is deduced from an analysis of climate dynamics and economic impacts. Under the current administration, the higher the SCC is set, the more stringent the regulatory standards on greenhouse gas emissions (Ackerman and Stanton 2010). To determine the potential effects of the SCC on the swine operations included in this study, the amount of methane captured and combusted, resulting in offset carbon emissions, was calculated.

While the survey instrument did not obtain information on methane production rates, enough information was generated from respondents in order to calculate the potential carbon offset for each swine operation. Tchobanoglous, Burton, and Stensel (2003) derived an equation for methane yield, which is specified as

$$E(y_{1d}) = 5.65\eta F\left[1 - 4.2\left(\frac{Y}{1 + b\theta_c}\right)\right] \tag{2}$$

where $E(y_{1d})$ is the expected amount of methane produced from an anaerobic digester or covered lagoon in ft^3/day, η is the conversion efficiency of the system (typically about 0.6-0.9), F is the applied biological oxygen demand (BOD) in lb/day, Y is the effective yield of the microorganisms in lb cells/lb BOD, b is the decay rate (typically about 0.03 d^{-1}), and θ_c is the mean cell residence time in days. Conversion efficiencies of 0.9, 0.8, and 0.7 were used for the complete mix, plug flow, and covered lagoon systems, respectively. USDA (2008) provided per-animal applied biological oxygen demand data for sows, nursery pigs, grow-to-finish hogs, dairy cows, and dairy heifers. These values were multiplied by the survey-provided number of animals contributing manure to the anaerobic digester or covered lagoon. Applied biological oxygen demand for each animal group were added together to obtain a total value for each system. The effective yield was determined based on the kinetics of the system and the composition of the material entering the digester. Organic decomposition, and hence methane production, depends on the percent distribution (by weight) of carbohydrates, proteins, and fatty acids in the material entering the digester. For example, livestock manure is made up of 60 percent protein and 40 percent carbohydrates, while food waste is made up of 50 percent protein, 40 percent carbohydrates, and 10 percent fatty acids. Each of these organic materials is assigned a stoichiometric equation coefficient for conversion into methane via the anaerobic digestion process, and the weighted average is taken to determine the effective yield for each material. The effective yields for livestock manure and food waste are added together to determine the total effective yield for the material entering the anaerobic digester or covered lagoon.

After the amount of methane in ft^3/day was determined by Equation 2, conversion factors were used to obtain methane yield in tons/year and tonnes/year. Methane tons (or tonnes) can then be converted into carbon dioxide tons (or tonnes) using the carbon dioxide equivalent for methane. The Intergovernmental Panel on Climate Change (1996) determined that the global warming potential of methane is equivalent to 21 times that of carbon dioxide. Therefore, avoiding the emission of one metric ton of methane gas via anaerobic digestion or a covered lagoon has the effect of reducing the amount of greenhouse gas emission equivalent to 21 metric tons of carbon dioxide. Multiplying the resulting average amount of offset carbon dioxide equivalent for each type of digester by the price provided for trading carbon credits on the European Climate Exchange (ECX) yields estimated revenues, which are shown in Table 3. The value of the carbon offsets according to the current federal administration can also be calculated in a similar fashion by using the *social* cost per ton or carbon provided in Table 2.

Table 3. Mean Fixed and Annual Benefits

	Sources of Revenue/Cost Savings					
Digester Type	Gov't Grants[a] (% capital cost)	Methane[a] ($/yr)	Electricity[a] ($/yr)	Co-products[a] ($/yr)	ECX ($/yr)	SCC ($/yr)
Complete mix /plug flow	49	10,500	131,400	39,167	8,706	61,853
Covered lagoon	13.5	13,750	78,840	50,000	4,230	30,051

[a] Mean benefits, as reported by survey respondents

Only one anaerobic digester operator and one covered lagoon operator reported no help in the form of government grants when paying for their system. The average of those reporting assistance through government grants is included in Table 3 and was included in the NPV analysis. According to the survey results, the methane generated by the anaerobic digesters and covered lagoons was flared, used for furnace fuel, injected into an internal combustion engine for electricity generation, and/or compressed and used for vehicle fuel (compressed natural gas, CNG). The resulting annual revenue and/or cost savings resulting from all of these practices, with the exception of electricity generation, is included in Table 4. If the electricity generated from the anaerobic digester or covered lagoon was used on the farm and sold off of the farm (or "back on the grid"), the difference between the wholesale price paid for electricity ($/kWh) and the retail cost of electricity on the farm ($/kWh) was multiplied by the installed capacity (kW) and the number of hours in a year to get the total revenue generated by electricity production ($/yr). If the electricity was not sold off of the farm, but instead used on the farm to offset costs, the retail price per kWh (Table 2) was multiplied by the installed capacity and the number of hours in a year to get the total cost savings. Respondents were asked the percent of the electricity that they used on and off of the farm to improve the accuracy of these calculations. The average annual revenue and cost savings for the anaerobic digesters and covered lagoons are included in Table 4. In addition to electricity, anaerobic digesters benefitted from marketing solid and/or liquid fertilizer (NPK), compost soil amendment, animal bedding (for dairy cows), and government incentive programs. Aside from electricity, the covered lagoons only benefitted from government programs, such as incentives for capturing and combusting methane.

Table 4. Mean Digester Size and Digester Fixed and Variable Costs

Digester Type	Size (ft^3)	Capital Cost (2014 $)	Variable Cost ($/yr)
Complete mix/plug flow	335,433	2,130,000	60,000
Covered lagoon	240,400	1,010,000	55,000

In the survey instrument, respondents were asked to identify all components included in their covered lagoon or anaerobic digestion system. All operations had to pay for the anaerobic digester or covered lagoon. Some systems also included one or more of the following: solids separator/sludge thickener, electricity generator, boiler/furnace, post treatment apparatus, gas conditioning/processing unit, flare, external heater, gas storage unit, manure storage unit, an/or agitator (or stirrer). Survey respondents were asked to provide a capital investment cost that included the cost of all components in the system. After converting all capital cost values to 2014 dollars, the mean size, capital costs, and variable costs were calculated for the anaerobic digesters and covered lagoons. As expected, the average cost for the anaerobic digesters was larger than the average costs for the covered lagoons. Variable costs include the average annual costs associated with the operation, labor, maintenance, and repairs of each system.

Sensitivity analyses were used to determine how the economic feasibility of the digester is affected by including each of the co-products, government incentive programs, and hypothetical carbon trading (or carbon offset) scenarios. As stated previously, the NPV was first calculated for the average anaerobic digester and covered lagoon on the basis of only methane production for comparison purposes. Therefore, costs had to be adjusted. The total cost of the system was reduced for only methane production because the system would not include an electricity generator set. The estimated fixed and variable costs for electric generator sets, given the desired installed capacity, were obtained from RSMeans (2014). Installed capacities for each anaerobic digester and covered lagoon were provided by the survey respondent. The cost estimates for the electricity generator set were subtracted from the cost values provided by the survey respondents, and the resulting costs estimates used for scenarios that excluded electricity generation are provided in Table 5.

Table 5. Mean Fixed and Variable Costs, without Electric Generator Sets

Digester Type	Capital Cost (2014 $)	Variable Cost ($/yr)
Complete mix/plug flow	2,024,142	46,679
Covered lagoon	995,188	52,863

Costs were then assumed to remain unchanged for all other co-product marketing and government policy scenarios. The only source of change was whether or not electricity was generated. After calculating average costs and revenues, Equation 1 was used to determine the net present value (NPV) of the digester under the different scenarios. A discount rate of 4.0% and a project life span of 25 years were used, which are consistent with previous literature (Bishop and Shumway 2009; Tchobanoglous, Burton, and Stensel 2003; USACE 2011).

6. Results

Due to the large capital investment required to purchase an anaerobic digestion or covered lagoon system, net present values (NPVs) for the production of only methane are negative (Table 6). Therefore, it is not likely that a hog farm would adopt an anaerobic digester or covered lagoon for manure management if it could produce only methane. These results correspond with similar studies carried out in the dairy industry (Bishop and Shumway 2009; Wang et al. 2011).

Table 6. NPVs for Anaerobic Digesters and Covered Lagoons on Swine Farms

Revenue Source Scenarios	Anaerobic Digester	Covered Lagoon
1. Methane only	-$2,589,333	-$1,606,214
2. Methane + co-porducts	-$1,977,463	-$825,110
3. Methane + co-products + electricity	-$238,682	$358,338
4. Methane + co-products + gov't grants	-$985,634	-$690,760
5. Methane + co-products + electricity + gov't grants	$805,018	$494,688
6. Methane + ECX	-$2,453,327	-$1,540,133
7. Methane + co-porducts + ECX	-$1,841,457	-$759,029
8. Methane + co-products + electricity + ECX	-$102,676	$424,419
9. Methane + co-products + gov't grants + ECX	-$849,628	-$624,679
10. Methane + co-products + electricity + gov't grants + ECX	$941,024	$560,769
11. Methane + SCC	-$1,623,061	-$1,136,755
12. Methane + co-porducts + SCC	-1,1011,191	-$355,651
13. Methane + co-products + electricity + SCC	$727,591	$827,797
14. Methane + co-products + gov't grants + SCC	-$19,361	-$221,301
15. Methane + co-products + electricity + gov't grants + SCC	$1,771,291	$964,147

Net present values remained negative for all scenarios that did not include electricity generation (2 and 3). The addition of co-product markets, such as solid and/or liquid fertilizer, compost soil amendments, and carbon trading on the CCX were not enough to overcome the large capital costs of digester/lagoon installation. On average, carbon trading on the Chicago Climate Exchange (CCX) only generated approximately $187 revenue per year for anaerobic digesters and about $91 revenue per year for covered lagoons. While some of the survey respondents reported trading carbon credits on the CCX, all trading would have occurred prior to December 2010, when all trading of carbon credits on the Climate Exchange ceased. Electricity generation was added in Scenario 4, but still did not produce a positive NPV for the complete mix and plug flow anaerobic digestion systems. The capital costs for these systems still remained too high. Most economic feasibility analyses of anaerobic digestion systems on dairy farms have included the production of methane and electricity and have also found that anaerobic digesters are not economically feasible (Bishop and Shumway 2009; Garrison et al. 2003), and the results of this study, applied to swine operations, agree with the previous literature. However, when looking at the net present value of producing methane and electricity along with other co-products on a swine operation using a *covered lagoon*, the results seem to disagree with previous literature. Even without the assistance of government grants, the net present value for the covered lagoon that produces methane, electricity, and soil amendments is positive. The addition of government grants made little difference in the NPV of the covered lagoon system because the initial costs and the percent paid by the government were smaller than the corresponding values for the anaerobic digestion systems. However, the addition of government grants resulted in a positive NPV for the complete mix and plug flow anaerobic digestion systems, which was larger than the NPV for the covered lagoon.

Carbon trading on the ECX increased the net present values for all scenarios, but this increase was not enough to make the NPV for anaerobic digestions systems positive without government assistance. Similar results were obtained when adding the SCC. A positive NPV resulted for the anaerobic digester, but the NPV was still smaller than the NPV for the covered lagoon.

7. Summary and Conclusions

Results from this study seem to indicate that there *is* a trade-off between better performance and lower costs. However, the results of this trade-off differ depending on the co-products and government policies available. In the absence of government grants for capital investment, the covered lagoon was able to achieve a positive net present value and was therefore economically feasible without government assistance. For all scenarios, the large capital investment required for the higher rate anaerobic digestion systems were not economically feasible without the support of government grants.

While having the ability to trade on the ECX did not change the results of this study, valuing carbon offsets with the government-specified “Social Cost of Carbon”, along with methane, co-product, and electricity markets, did result in positive NPVs for anaerobic digesters and covered lagoons. While these scenarios are only theoretical, it is important to understand how international carbon trade policy and/or government mandates on the cost of carbon could affect the economic feasibility of renewable energy systems on swine farms.

In summary, co-products, such as soil amendments and electricity generation are required to make covered lagoons the optimal method of handling swine manure. When co-product markets, electricity generation, and government grants are available, anaerobic digesters and covered lagoons both resulted in positive NPVs. Since carbon trading does not currently exist in the U.S. and government grants for renewable energy technologies may not always be readily available via federal or state government agencies, covered lagoons, when compared to anaerobic digesters, could be considered the optimal method for handling manure on swine animal feeding operations. While covered lagoons may produce methane, co-products, and electricity as a slower and more inconsistent rate than anaerobic digesters, the benefits of the system are enough to cover the lower costs of construction and maintenance.

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