ECONOMIC ANALYSIS OF ANEROBIC CO-DIGESTION USING DAIRY MANURE AND BYPRODUCT FEEDSTOCKS

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Abstract

There is increasing interest in the United States to expand the use of anaerobic digestion (AD) as a means to generate renewable energy and reduce greenhouse gas emissions from dairy operations. Economic feasibility is the primary constraint facing farmers and investors considering an AD capital investment. The purpose of this paper is to develop an economic optimization model of an AD system using co-digestion of dairy manure and byproduct feedstocks. This model uses a daily time step to specifically model the operating parameters and AD technical design and capacity constraints. The end of system digestate is applied to farm land subject to agronomic application rates and timings. The model is applied to an existing AD system producing electricity in Washington State. The paper reports the technical aspects and operating parameters of the modeled AD system. The economic results conclude a positive economic feasibility but a low rate of return for the modeled system. The conclusions suggest evaluate alternative AD design options and AD evaluation methods to increase the economic feasibility of AD systems for dairies.

Keywords: anaerobic digestion, co-digestion, linear programming, economic feasibility

1. Introduction

Anaerobic digesters (AD) are fixed capital assets that have been constructed to improve the environmental sustainability of dairy farm nutrient management systems, and are now receiving increasing interest for their potential to generate additional revenues. Previous economic analyses of AD, have applied annual capital budgeting to evaluate economic feasibility. Annual budget estimates may oversimplify the AD management on a day to day basis when considering manure inflow rates and delivery of co-digestion feedstocks with respect to the AD design capacities and regulatory constraints. There is a need for a model that evaluates within year AD management strategies that maximizes an anaerobic digester's economic sustainability. The Anaerobic Digester OPTimizer (ADOPT) programming model simulates daily AD management to optimize the annual net economic return of an anaerobic digester utilizing dairy manure with co-digested pre-consumer food-waste feedstocks. The feedstocks have variable value in terms of tipping fees, volumes delivered, nutrient composition and bio-gas electricity producing potential. Anaerobic digestion is receiving increased attention in the United States due to increasing interest in generating renewable energy and reducing greenhouse gas emissions. The USDA has introduced initiatives to promote agriculture based biogas energy development. The USDA signed a memorandum of understand with dairy producers through the Innovation Center for U.S. Dairy to accelerate the adoption of dairy based biogas installations with a goal of 25 percent reduction in greenhouse gas emissions from manure by the year 2020 (USDA News Release, 2011).

Technical feasibility is not the primary hurdle to successful implementation of AD at dairies provided the AD is planned, designed, constructed and operated properly. Anaerobic digestion of dairy manure technology is available for farm applications through a number of commercial vendors. Although AD technology has waste management, environmental and potential economic benefits, it has not been widely adopted in the United States. The number of new farms adopting AD has grown annually since 2000, and there are now over 100 dairy digesters in operation in the U.S., servicing approximately 150,000 cow equivalents Frear and Yorgey (2010). Although the number of ADs is increasing, the present digesters service only small fraction of the potential farms and cows. Barriers to adoption include the intensive capital cost of the existing commercial systems, with typical systems costing as much as $1,500/cow for a 500-2,000 cow operation Frear and Yorgey (2010).

The limited adoption of AD could be due to financial infeasibility or lack of information regarding AD profitability management. Previous economic studies of an AD apply a capital budgeting methodology using AD construction cost estimates and annual projections of AD net revenues to determine the net present value of AD scenarios under consideration. Bishop and Shumway (2009) used a capital budget case study of a Washington AD. Leuer, Hyde and Richard (2008) used a capital budget approach and introduced stochastic parameters on AD revenue factors and life expectancy to analyze AD economics on three different sized dairy farms in Pennsylvania. In each of these and other capital budget AD feasibility studies the capital budget net economic return results are very sensitive to the modeling input parameters associated with the scenario with results ranging from large losses to large net gains. This indicates that AD design and management are critical to AD success.

2. ADOPT model

The ADOPT model was designed to simulate the daily management of an AD. ADOPT is a linear programming model that maximizes the annual net revenue of the AD using a daily time step subject to the AD design capacity and operating constraints. The ADOPT model's objective function is represented in the following equation.

$$Maximize \sum_{t}^{T}\sum_{i}^{n} R_{it}\, P_{it} - \sum_{j}^{m} VC_{jt} - FC$$

The equation is simply the AD profit function that the model maximizes the difference between daily revenues produced minus the daily operating variable costs and the annual fixed costs. Where t represents a day summed over the year T = 365. The variable i represents each revenue source, i = 1 to n, multiplied by the price received for each revenue source, P_{it}. The daily variable cost is VC_{jt} for each variable cost factor j and FC is the annual fixed cost FC. Figure 1 shows the inflows into the AD and the n revenue sources for the ADOPT model. The following sections describe the project site, revenue sources and costs modeled in ADOPT.

2.1. Project site

The base modeling parameters were obtained through a collaborative research project at the Qualco Energy Anaerobic Digester in Monroe, Washington. The project involves an intensive data collection on the AD inflows, bio-gas production, electricity generation, solids, and effluent. The Qualco digester was developed in 2008, and is a public-private partnership between Northwest Chinook Recovery, the Tulalip Tribe, and the Snohomish / Skykomish Agricultural Alliance. Although the digester currently receives manure from only one dairy, the digester was designed with the capacity to receive manure from several nearby dairies through a gravity fed sewer pipe system to the digester that avoids trucking transportation costs. After flowing through the AD the effluent is stored in a lagoon at the AD site. Effluent is pumped back to the dairy farm for agricultural field applications. The dairy is about 1 mile away from the digester, has about 1,100 cows, beds with sand and has a flush manure management system.

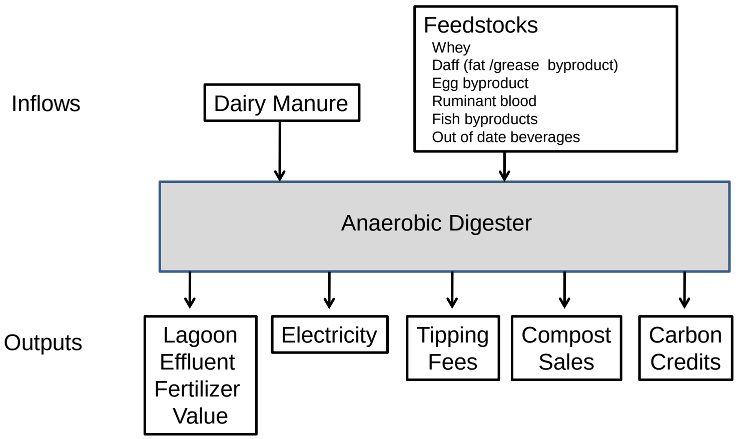

Figure 1. ADOPT Model AD Inflows and Revenue Sources

2.2. Tipping fees

Anaerobic digestion is not limited to manure. Dairy anaerobic digesters can also accept non-manure organic wastes co-digestion feedstocks that can be digested by bacteria to produce methane. Accepting co-digestion feedstocks generates revenue through tipping fees and can also increase the amount of bio-gas produced to increase electricity sales. Bio-gas production from other organic wastes can produce more methane than from manure alone. In dairy digesters, the large feedstock of animal manure helps stabilize the digestion process by providing a high buffering capacity Murto, Bjornsson, and Mattiasson (2004).

ADOPT simulates the daily inflow of manure and co-digestion feestocks using daily data collected at the Qualco project site. Over the time frame modeled the following co-digestion feedstocks were added to the AD: whey, daff which is fat/grease by-product, ruminant blood from a beef packing plant, processed frozen fish byproducts, and out of date beverages which are high in sugar content. Each of these feedstocks were analyzed for nutrient composition and bio-gas production potential. The associated revenue from the feedstocks are called tipping fees to reflect a load of feedstock being tipped into the digester receiving tank. The tipping fee revenue for each feedstock is an individually negotiated contractual rate. The individual contractual tipping fee rates are confidential and are not disclosed in this report. The cumulative tipping fee revenue is reported in the results section.

2.3. Electricity

The Qualco AD is designed to capture the bio-gas and burn the methane to produce electricity. Qualco sells all of the power generated and is not designed as a net metering system. The electricity sales are the megawatt hours generated per day sold to Puget Sound Energy transferred through Snohomish PUD. The electricity revenue is the price per megawatt sold net of the wheeling fee plus Washington's renewable energy credit. The renewable energy credit is $5 per megawatt hour. The net revenue generated is $74 per megawatt hour in the base case analysis. Due to the availability of hydro-electric power in Washington the electricity sale rates are lower in comparison to other regions. The generator is a 450 KW Gauscor system.

2.4. Compost

Most AD use solid separators to reduce the amount of solids stored in their lagoons. The separated solids can be composted and then reused as bedding, sold off site commonly for nursery applications, or applied as a soil amendment. The compost is high in fiber and has some nutrients. The project site AD has a screw press solids separator that is composted using a Daritech Inc. Bedding Master composting system. Presently there are no contracts for continued sales of the compost. Some of the compost is used as bedding and the extra is used as an agriculture field soil amendment. In the base case of the ADOPT model there is no revenue from compost that reflects the current situation that there are no compost sale contracts.

2.5. Carbon Trading Credits

For digester owners, carbon trading is a potential source of revenue because methane emissions are reduced and that can be converted into a carbon credit. However due to the failure to enact federal legislation to establish a carbon cap and trade system, the carbon market has largely collapsed with the exception of regional efforts to establish carbon emission caps. Some dairies have carbon sale contracts that continue to generate revenue. The project site has a small carbon trading contract that generates revenue.

2.6. Other potential revenue co-products

Adding other organic waste feedstocks to dairy digesters can increase biogas production but they can also increase nitrogen and phosphorus nutrients when compared to manure only. Under the dairies nutrient management plan, the increased nutrients for additional feedstocks need to be quantified and incorporated into the nutrient management plan so that the field applications of effluent nutrients are balanced with crop production. There are cases where dairies receiving liquid effluent from digesters have had to obtain additional land and adjust cropping to make use of the increased nutrients. Phosphorus recovery from livestock wastewater in the form of struvite has been demonstrated in other parts of the country. A pilot-scale test at the Qualco Energy digester project site has demonstrated successful struvite recovery from dairy digester effluent, reducing total phosphorus in the effluent by 60-80% (Mena, N. 2011). Another potential revenue source is collect and clean the bio-gas to extract methane. Clean methane can then be sold to natural gas providers. These potential revenues are not included in the base run of the ADOPT model.

2.7. Costs

Table 1 presents the annual digester operating and fixed expenses. The construction cost for the Qualco Energy digester was $3.4 million dollars with a projected economic life of twenty years. The annual straight

Table 1. Digester annual operating and fixed expenses used in the base ADOPT economic analysis

Operating Expenses	
Labor	$ 39,420
Professional Fees	5,500
Shavings	4,000
Supplies	1,000
Repairs	
Composter	35,500
Digester	75,000
Separator	21,000
Site Maintenance	15,000
Interest	15,000
Utilities	70,000
Total Operating	281,420
Fixed Expenses	
Insurance	$ 28,000
Taxes	7,000
Depreciation	170,000
Total Fixed Expenses	205,000
Total Expenses	$ 486,420

line economic depreciation cost over this investment is $170,000. The annual interest expense on debt used to construct the digester is $15,000. The annual operating costs are primarily repair expenses, utilities and labor. The total annual operating expenses are $281,420 and fixed costs are $205,000. The total annual expense is $486,420.

3. Adopt analysis and discussion

The ADOPT model is programmed using GAMS mathematical programming software. The Qualco Energy digester serves to calibrate the model parameters and mimics the actual revenue and cost streams of the digester. The AD lagoon effluent is not assigned a revenue value in the modeling results, because the lagoon effluent does not generate revenue. It does have value as fertilizer nutrients in the cropping system, but it does not generate revenue. Figure 2 provides the daily revenue.

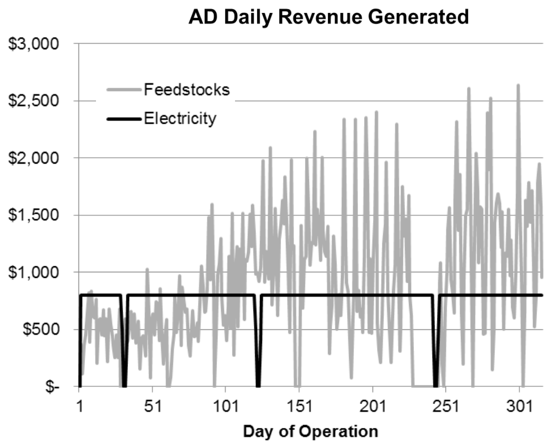

Figure 2. ADOPT model daily revenue

The feedstock revenue is the light grey line in Figure 2 that exhibits high daily variability. The variability is from differences in the volume of co-digestion feedstocks delivered. The contractual tipping fees differ between feedstocks, but the tipping fee of a feedstock remained fixed over the time period modeled. The electricity revenue is the relatively constant black line. The variation in the electricity revenue is when the electrical generator shut down four times for maintenance and electricity revenue went to zero. The electricity generated is fixed to the level constrained by the generator. Presently the more bio-gas is produced than the generator can use and the excess is flared. Additional analysis and data collection on the amount of bio-gas flared is ongoing to determine if a larger generator should be installed, or if adding a second generator to the system would be better economically.

The total annual revenue under the base analysis is presented in Figure 3. The annual electricity revenue is $244,696, for tipping fees the annual revenue is $278,818, and the existing carbon credit contracts provide $22,000. The cumulative annual revenue is $545,514. The annual total costs previously reported in Table 1 are $486,420, which results in an annual positive net return of $59,094. On a capital investment of $3.4 million, the construction cost of the digester, the annual return on investment is only about 2 percent.

The low annual return on investment found in this particular case and reported in other AD economic studies, is an explanatory factor to the low adoption rates of AD across the country. However in this case there is a high potential to increase revenue by improving the digesters electrical generating capacity through capturing the existing bio-gas that is currently being flared off. Also compost sales are a promising potential revenue that currently is receiving no economic value. Work on developing this market potential is ongoing.

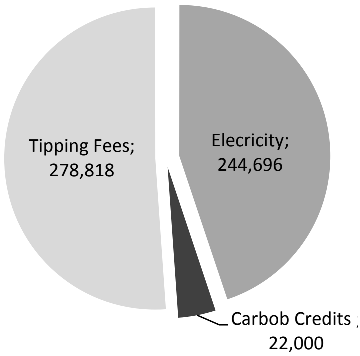

Figure 3. ADOPT model annual revenue from electricity, tipping fees and carbon credits [USD]

The tipping fee revenue cannot be increased by much. Presently in this base case the volume of co-digestion feedstocks in nearly a maximum. The volume currently being received is close to the maximum allowed by state regulations and the dairy farm's nutrient management plan for the application of the AD effluent. The only way to increase tipping fee revenue is to renegotiate the tipping fee contract. That will not be easy as additional AD are constructed and the market becomes increasingly competitive for co-digestion feedstocks. One alternative that is currently being investigated is to evaluate the co-digestion feedstocks for their ability to generate bio-gas and increase electricity revenue. This will provide AD managers information to evaluate tipping fee contractual rates. Co-digestion feedstocks with low electricity potential should require higher tipping fees. Of course this requires that the AD have sufficient electricity generating capacity to effectively convert the bio-gas potential of co-digestion feedstocks to electricity revenue.

Another factor that is often overlooked in the economic analysis of AD is the marginal comparison of a traditional nutrient management system to an AD system. The traditional lagoon – land management system is a sunk cost to the dairy farm that has no potential to generate revenue or a return on investment. The AD return may be low, but as long as it is positive it represents a better capital investment than a traditional system. Even if the AD system has a negative return it still may be a better economic investment than a traditional system when evaluated on a minimum cost basis. Also additional work is needed to evaluate the marginal value difference of the nutrient profile between traditional and AD effluent. The higher nutrient profile of AD effluent is not being captured by current economic models. There are several other potentially positive future developments that may improve AD economics. Increasing electricity costs in the future could have a positive effect on AD economic return. Developing a market for the AD compost should become a primary effort as this is a large volume of product. Also developing analysis on the scale economics of digesters could identify more economically sustainable AD systems.

4. References

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