A Model for Estimating Revenue from Avoided Demand Charges for Agricultural Operations Utilizing Anaerobic Digesters

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Abstract: This paper investigates how to estimate revenue from avoided demand charges that are part of a net-metering time-of-use contract that is seen in California. Utilizing fifteen minute kW data regarding supply and demand of electricity for a digester operator, simulation modeling was used to investigate electricity bills, specifically demand charges. Findings show that demand charges are an important component for a digester operator to be mindful of when selecting the individual's initial engine configuration and maintenance scheduling.

Key Words: anaerobic digesters, time-of-use, net metering, dairy, best management practices, electricity generation, differential pricing

Introduction

Anaerobic digester (AD) technology used on US farms has been around since the early 1970's (Lusk, 1998). In a database dated May 2015, the United States EPA AgStar program reported that there were 247 operational digesters across the United States with an additional 13 in various points of construction. They also reported that 53 digesters have shutdown operation since they have kept records.[1]

AD are systems that utilize bacteria in a non-oxygenated environment to convert organic material, such as manure, into a biogas that is primarily made up of methane. Ruminant animals (cattle, goats, sheep, etc.) are natural digesters that release methane into the atmosphere, but there are manufactured systems like dairy lagoons that also release methane into the atmosphere. Agricultural engineers in the last fifteen to twenty-five years have developed mechanical improvements in the methane digestion process that have allowed them to boost methane production beyond what would naturally occur.

Government entities are concerned with methane gas because it is considered a greenhouse gas that is **21 times** more potent than carbon dioxide (Stocker et al., 2013). While methane gas from anaerobic digesters may be considered a negative externality, the gas produced from an AD can be used to fuel an engine that can produce electricity and heat. This gas can also be "scrubbed" and be converted into a biogas that can be injected into a utility pipeline. These two end products, electricity and heat, from an AD were seen to have an economic value. Unfortunately, many of the AD that were built in the seventies failed to be economically profitable. Some of

[1] The AgStar program indicates that these reported values are from multiple different sources and have not been validated for accuracy

the reasons for these failures were due to unsuitable design of the digester, improper installation, and/or poor management of the systems once they were operational (Binkley et al., 2013).

A fundamental basis for a profitable digester is the on-going operation and initial design of the system. When initially designing these systems, agricultural engineers need to take into account many factors including herd size, engine size, digester type, revenue generation components, etc. Once operational the digester operator has to carefully manage the system ensuring that maintenance occurs at proper intervals. All of these factors lead into the feasibility of the system. There have been several articles in the literature that have reported on the operational and economic characteristics of functioning digesters (Bishop and Shumway, 2009; Lazarus and Rudstrom; 2007; Morris, Jorgenson, and Snellings, 2010).

To understand how to properly design and operate a methane digester, it is important to understand how the digester receives its revenue. The literature has identified many different sources of revenue including electricity production, natural gas production, heat production, tipping fees, digested fiber that can be used for bedding, renewable energy credits, carbon credits, etc. While the researchers in the digester arena have done an excellent job identifying different sources of revenue, there is still work to be done on understanding the main revenue generator, electricity production.

The typical avenue that researchers have used to calculate revenue for a methane digester is to take the retail or wholesale rate that is received by the utility and multiply that by the energy production in terms of kWh of the digester. Unfortunately, this is a strong assumption to make and can be quite misleading especially for digester operators who utilize a net metering time-of-use contract which is utilized in California.

The Energy Policy Act of 2005 discussed and defined the idea of net-metering (US GPO, 2005). Guerrero et al. (2010) has summarized net metering as a way for electric consumers to bank excess electricity that they have produced above their needs so that they can utilize it during other times of need. Hence a net-metering contract in the context of a dairy producer that has methane digester is way for the producer to store excess electricity production so it can be used at other times when demand for power exceeds the ability of the digester to supply the demand.

In California, time-of-use contracts are utilized by the two main electricity suppliers in the state. A time-of-use contract applies a different cost to electricity during different parts of the day and year. This pricing is utilized to charge higher rates during the peak demand for electricity in the state allowing the utility companies to better manage electricity generation and distribution.

Having an understanding of how net-metering time-of-use contracts affect the design and operation of a methane digester is important in order for building and running a digester in an economically efficient manner. One important component in a time-of-use contract that are seen in California is demand charges which can make-up a substantial part of the rate. If the digester operator cannot capture the savings related to demand charges, then the actual rate that he receives will be less than the reported retail and/or wholesale rate making the widespread usage of a retail or wholesale rate inappropriate for model analysis.

The purpose of this paper is to focus on developing a model for contracts that account for net-metering and time-of-use charging where demand charges are involved. This paper is meant to provide a deeper understanding of how demand charges work in California and how they can affect the design and operation of a methane digester. Specifically this paper utilizing supply and demand data from a digester operator in California simulates a digester running multiple engines in order to minimize demand charges.

The rest of the paper is broken up into the following. The next section provides a brief overview of the literature in terms of methane digestion. The third section discusses a theoretical model for examining net-metering contracts with time-of-use pricing specifically for one major California utility. The fourth section talks about the data that was collected and the methodology used for analyzing the data. Section five of the paper will provide results regarding the examination of how demand charges affect a particular dairy in the Central Valley of California. The final section presents a brief set of summary and conclusion.

Literature Review

The initial set of anaerobic digesters developed in the seventies never really caught on as a technology adopted by many agricultural producers. Since that time, much research has improved the design of AD. In the agricultural engineering literature, Lusk (1998), Martin et al. (2003), and Wilkie (2005), have discussed the technical nature of designing a methane digester. Others in the agricultural engineering area (Martin, 2008; Bailey et al., 2008; Yiridoe, Gordon, and Brown, 2009) have examined the economic feasibility of certain types of anaerobic digestion systems.

Over the last ten years, there has been an increase in the interest of anaerobic digesters (AD) in the economics literature. Studies have examined different revenue generation sources, general feasibility studies, and policy questions including papers discussing what sorts of policies can induce animal operators to adopt methane digestion.

Lazarus and Rudstrom reported on the economics of an operational anaerobic digester in Minnesota (2007). This AD was built to process manure from 800 dairy cows utilizing 130 kW engine. The dairy that was analyzed initially received a rate of between $0.0725 to $0.073 per kWh. This price represents the retail rate the dairy is paying. Once this contract was up, the dairy is expecting to get a renewed contract that will pay $0.0365 per kWh. They found that the amount of biogas produced by the cows and the chosen engine produced more electricity than the farm needed. They also discovered that the farm would not receive a retail rate for its power production. The authors acknowledge that the utility company offered a multitude of different contracts for purchasing the electricity.

Bishop and Shumway (2009) reported on an operational AD in the state of Washington. Their study focused on understanding the different revenue sources that could be associated with the digester including: "electricity, digested fiber, tipping fees, and carbon credits" (p. 394). The digester they examined was a plug-flow system that initially was set-up for 500 cows. Utilizing the first two years of operation data, Bishop and Shumway estimate the effects of the four different revenue sources. For electricity, they assumed that the digester owner would receive $0.05 per kWh. They found that if the digester had to rely on power generation as its sole source of income, then it would be economically infeasible.

Leuer, Hyde, and Richard (2008) investigated how net-metering policies and carbon credits can affect the profitability of anaerobic digesters for dairy farms in Pennsylvania by utilizing a stochastic capital budgeting model and simulation methods. Three different farm sizes in terms of cow numbers were investigated in their models—500, 1,000, and 2,000 cows. They examined how different sources of revenue affected the net present value of the digester. These revenue sources included electricity, sales of composted separated solids, offsets to the purchase of bedding, renewable energy credits, and carbon credits.[2] The researchers used a base price for the

[2] Separated solids represent an interesting issue when examining the revenue generation of a digester. Since solids separation can be conducted without having a digester, a question arises as to whether it should be accounted for as a revenue source attributable to the digester.

electricity sold of \$0.03 per kWh, while also examining \$0.01, \$0.05, and \$0.10 per kWh. Their key finding was that dairies needed to be larger to be able to operate a profitable digester.

Outside of feasibility studies, there have been articles related to investment decisions, policy issues, and environmental concerns. Stokes, Rajagopalan, and Stefanou (2008) utilize a real options approach combined with a capital budgeting model since they view a digester as an investment with a large upfront capital cost and a stream of unknown revenue. Gloy and Dressler (2010) research investigates the top reasons why lenders/investors may be reluctant to finance anaerobic digesters. Gebrezgabher, Meuwissen, and Oude Lansink (2010) examined the cost of energy neutrality for the dairy industry by utilizing biogas. Gloy (2010) estimated a supply curve for carbon dioxide offsets coming from anaerobic digester operations. Key and Sneeringer (2011) investigated how various different policies, e.g., cost sharing, electricity pricing, and carbon offsets, affect the profitability of anaerobic digesters in terms of meeting certain policy goals. Morris, Jorgenson, and Snellings (2010) examine in their study the usage of food waste in an anaerobic digester system and its effects on the environment.

Theoretical Model

A digester operator can be viewed as a multiproduct firm where a single production process produces multiple co-products such as electricity, heat, separated solids, carbon credits, etc. It can be argued that a typical digester owner focuses their decision on the amount of electricity to produce where the rest of the co-products from production our byproducts that have positive economic value. The ability to capture these byproducts for revenue generation is based on whether their net present value exceeds the net present cost of building the system to capture the costs. For example, a digester generates a large amount of heat that can be utilized for cleaning facilities which would offset potentially propane costs. The digester owner will only add this ability to the digester system if there is an expected net benefit. While this decision is made at the inception of the digester, it is argued in this paper that production decisions for the digester owner comes from the generation of electricity only and that the adoption of selling a co-product is based on the initial digester design decision.

Given the assumption that the AD operator's decision is based primarily on the production of electricity, it is important to understand how the decision is made in a net metering time-of-use environment when there are demand charges. In a typical net metering situation, the digester owner can offset other electricity demand from other parts of the individual's operation up to the total amount of electricity used by the AD operator over some contracted period of time, e.g., a year. For a typical dairy producer, this electricity demand would come from a milking parlor, water pumps for irrigation, and other miscellaneous demands for electricity on the operation.

To understand the dairy producer's decision regarding operating a digester, it is helpful to break-up the life of the digester, which will be defined as T_L, into discrete subparts. These subparts could be considered the billing cycle for the dairy which will be designated as T_B. For purposes of this paper, it will be useful to aggregate a set of T_B in terms of a defined period which will be denoted as T_Y. It is helpful to think of T_Y as the time period of the contract where power can be net metered from one billing cycle to the next. This billing cycle can be further categorized as t_b which represents discrete times within a billing cycle. The purpose of breaking up the billing cycle into these discrete units is because the utility company takes a measurement of the demand in kW at each of these time periods in order to calculate the utility bill. To summarize $t_b \subseteq T_B \subseteq T_Y \subseteq T_L$.

Following the Duthu et al. (2014) model, the main objective of a digester operator utilizing a methane digester can be represented as minimizing the cost of the dairy's electrical bill. This bill is broken up into three main components: the meter rate, the demand rate, and the energy rate. The meter rate represents a fixed cost to the dairy for being a part of the electrical grid. The only way that the dairy can avoid this charge is for the dairy to be completely off the grid which is a very unrealistic assumption for the modern dairy. Since this is a fixed charge, it does not enter into the digester operator's decision. The second portion of the bill represents a charge for the amount of kW that is demanded at any given interval by the dairy where this interval is set by the utility. In the case of the digester operator for this study, the time interval is every fifteen minutes. The dairy operator is charged a flat rate times the largest amount of kW demanded during a billing cycle and this rate can be different during different parts of the day and different parts of the year. The third cost in a billing cycle is the energy cost. The energy cost is based on the total kWh that is demanded by the dairy during the billing cycle. Similar to the demand rates, these rates can be different during different parts of the day and the year.

Given this set-up the goal of a digester operator is the following:

$$Min \sum_{T_Y \in T_L} \sum_{T_B \in T_Y} \left(\sum_{t_b \in p \in T_B} EC_P\left(D_{t_b} - L_{t_b}\right) \right) + DC_P ArgMax\left(D_{t_b} - L_{t_b}\right) + OMC(I_{t_b}) + MC$$

$$s.t. \sum_{T_B \in T_Y} \sum_{t_b \in T_B} EC_P\left(D_{t_b} - L_{t_b}\right) \geq 0$$

where L_{t_b} is the amount of kW that the digester producer produces in any time interval t_b and can be considered the operators key decision variable. MC represents the meter charge and is not reliant upon the decision variable. DC_p is the demand charge for any period p where p is categorized based on the time of day and the time of year to represent time-of use charging. D_{t_b} is the amount of kW that are demanded by the operation at any specific time t_b. EC_p is the energy charge which is also based upon period p. Period p is a function of the time t_b in the billing cycle. The constraint represents that at the end of the contract allowing for net metering, that the amount paid on energy charges are non-negative, i.e., the dairy operation cannot sell excess power to the grid and can only bank it for the contracted time period. OMC is the operational and maintenance cost which is a function of the other main decision variable for the digester operator, I_{t_b}, which is the interval length between maintenance cycles.

Methodology and Data

Electricity data was acquired from a 5,000 cow dairy located in the Central Valley of California operating a covered lagoon methane digester.[3] The digester has been in operation since 2004. During the time of data collection, the digester operator was utilizing up to three engines to produce electricity.[4] The dairy has an industrial level on-site cheese plant that absorbs the excess capacity from the digester that goes beyond the amount to run the dairy. This electrical supply and demand data for the operation spans from 2009 to 2012 and covers the kilowatts demanded and produced by the dairy in fifteen minute increments.

Electricity rate schedules were acquired on-line from one of the major utility companies in this state that is utilized by the dairy. The digester operates under a net-metering contract with a western utility. It faces the E-20 electric schedule from the utility utilizing the primary voltage rates. This rate schedule has five different time periods and associated rates. These include the Peak Summer, Partial-Peak Summer, Off-Peak Summer, Partial-Peak Winter, and Off-Peak

[3] This dairy is a bit unique in the sense that it has an industrial sized cheese plant and pays industrial rates for the power it consumes.

[4] When the digester system was first developed, a single engine was part of the initial design. This engine had the ability to produce approximately 300 kW. Over time, the digester operator found that the gas production from the system far exceeded the ability of the single engine. The operator decided that it would be worthwhile to purchase a second engine that produced roughly 400 kW. These two engines were still not enough to handle the gas production, so the digester operator decided to add a third engine in 2012 that had a nearly 800 kW capacity.

Winter. Since the digester operator has the ability to net-meter its power, it faces another five rates associated with these time periods. This implies that dairy potentially faces ten different prices for the power that it produces.

The associated summer rates run from May 1 through October 31, while the winter rates run from November 1 to April 30. Summer Peak hours are defined from 12:00 pm to 6:00 pm. Partial-Peak hours run from 8:30 am to 12:00 pm and 6:00 pm to 9:30 pm. Both of these sets of hours are valid for Monday through Friday except for eight designated holidays. Holidays and all other times and days are considered Off-Peak during the summer months. In the winter season, Partial-Peak runs from 8:30 am to 9:30 pm Monday through Friday except for holidays. All other days and times are classified as Off-Peak hours. Table 1 presents the cost per kW that the utility charged for each period for the four years under investigation, while Table 2 provides the charge per kWh for each period.

Table 1: Utility Rate per kW Faced by Dairy Digester Operator

Beginning Date	Ending Date	Summer Max Peak	Summer Partial Peak	Summer Off-Peak	Summer Maximum	Winter Partial Peak	Winter Off-Peak	Winter Maximum
1/1/2009	2/28/2009	$ 11.86	$ 2.73	-	$ 6.18	$ 0.67	-	$ 6.18
3/1/2009	9/30/2009	$ 12.62	$ 2.90	-	$ 6.60	$ 0.67	-	$ 6.60
10/1/2009	12/31/2009	$ 12.62	$ 2.90	-	$ 6.60	$ 0.67	-	$ 6.60
1/1/2010	2/28/2010	$ 12.10	$ 2.80	-	$ 6.68	$ 0.74	-	$ 6.68
3/1/2010	4/30/2010	$ 12.10	$ 2.80	-	$ 7.52	$ 0.74	-	$ 7.52
5/1/2010	5/31/2010	$ 12.10	$ 2.80	-	$ 7.52	$ 0.74	-	$ 7.52
6/1/2010	12/31/2010	$ 12.02	$ 2.78	-	$ 7.12	$ 0.72	-	$ 7.12
1/1/2011	2/28/2011	$ 11.04	$ 2.59	-	$ 7.45	$ 0.82	-	$ 7.45
3/1/2011	12/31/2011	$ 10.98	$ 2.57	-	$ 7.95	$ 0.80	-	$ 7.95
1/1/2012	2/29/2012	$ 14.03	$ 2.99	-	$ 9.36	$ 0.25	-	$ 9.36
3/1/2012	6/30/2012	$ 14.03	$ 2.99	-	$ 9.36	$ 0.25	-	$ 9.36
7/1/2012	12/31/2012	$ 13.93	$ 2.97	-	$ 9.36	$ 0.25	-	$ 9.36

Table 2: Utility Rate per kWh Faced by Dairy Digester Operator

Beginning Date	Ending Date	Summer Max Peak	Summer Partial Peak	Summer Off-Peak	Summer Maximum	Winter Partial Peak	Winter Off-Peak	Winter Maximum
1/1/2009	2/28/2009	$ 0.1403	$ 0.0930	$ 0.0726	-	$ 0.0790	$ 0.0687	-
3/1/2009	9/30/2009	$ 0.1537	$ 0.1030	$ 0.0810	-	$ 0.0879	$ 0.0768	-
10/1/2009	12/31/2009	$ 0.1541	$ 0.1033	$ 0.0814	-	$ 0.0883	$ 0.0771	-
1/1/2010	2/28/2010	$ 0.1512	$ 0.1035	$ 0.0829	-	$ 0.0894	$ 0.0790	-
3/1/2010	4/30/2010	$ 0.1523	$ 0.1045	$ 0.0839	-	$ 0.0905	$ 0.0800	-
5/1/2010	5/31/2010	$ 0.1523	$ 0.1045	$ 0.0839	-	$ 0.0905	$ 0.0800	-
6/1/2010	12/31/2010	$ 0.1496	$ 0.1020	$ 0.0814	-	$ 0.0879	$ 0.0775	-
1/1/2011	2/28/2011	$ 0.1404	$ 0.0981	$ 0.0799	-	$ 0.0859	$ 0.0766	-
3/1/2011	12/31/2011	$ 0.1416	$ 0.0994	$ 0.0813	-	$ 0.0872	$ 0.0780	-
1/1/2012	2/29/2012	$ 0.1229	$ 0.0895	$ 0.0699	-	$ 0.0857	$ 0.0730	-
3/1/2012	6/30/2012	$ 0.1235	$ 0.0901	$ 0.0706	-	$ 0.0863	$ 0.0736	-
7/1/2012	12/31/2012	$ 0.1224	$ 0.0894	$ 0.0701	-	$ 0.0857	$ 0.0731	-

Using Excel, the dairies utility bill was simulated over the four year period to develop an understanding of how much cost is being avoided through electrical output by operating the digester. This represented the first scenario where the dairy is being considered to not have a digester. This is meant to provide a baseline for understanding how much value is generated by the digester and how it affects the demand charges. To develop this model, maximum kW were calculated for each season, winter and summer, and for each time-of-use billing period (Max Peak, Partial Peak, and Off-Peak). To get kWh for each time period, the kW were added together and divided by four since the data is in 15 minute increments. The billing table presented above was used to multiply the corresponding prices to the corresponding cost components.[5]

The second scenario examined was the actual electricity generation data from the digester that was provided by the dairy. A difference was taken between the actual demand for kW and the

[5] The only other cost not showing in the two tables are the meter costs. These charges were $32.854 per day from January 1, 2009 through December 31, 2011. After this period, the meter charge increased to $49.281 per day.

supply of kW from the electrical generation process for every fifteen minute period of data collection. These values were used to find the new billing cost components mentioned in scenario one above. Once these values were found, the cost of each monthly bill was estimated utilizing the prices in Tables 1 and 2 above.

The second scenario represents the actual results of operating the digester in a real world setting. In this scenario, the digester operator had two engines producing power for all four years. These engines were the 300kW and 400 kW systems. In 2012, the digester acquired a third engine that was capable of producing 800 kW of power.

Given that the digester operator could have purchased the 800 kW system at the beginning of the whole project, a third scenario was investigated where the digester had all three engines completely operational during the beginning of the data collection process. It will be assumed under this scenario that each engine will be brought down for service every three weeks for general maintenance.[6] In order to minimize demand charges, it is assumed that only one engine is brought down at a time and that each engine is brought down every third Sunday from 1:00 am to 6:00 am.[7]

Since conducting maintenance on a Sunday from 1:00 am to 6:00 am may be difficult to do as a digester operator, a set of more realistic scenarios are investigated. These scenarios can be labeled 4 through 8 where the fourth scenario will examine doing the maintenance schedules on Monday, fifth represents Tuesday, sixth represent Wednesday, etc. Under each of these

[6] A three week interval for engine maintenance might be considered a bit of an extreme value on the low side. The researcher of this study has seen maintenance cycles as low as two weeks and as long as four weeks.
[7] The purpose of choosing a five hour maintenance interval is because the average downtime for the digester in this study was estimated to be five hours. Sunday was chosen as the day to bring down the digester because it represented the lowest average demand for the digester operator.

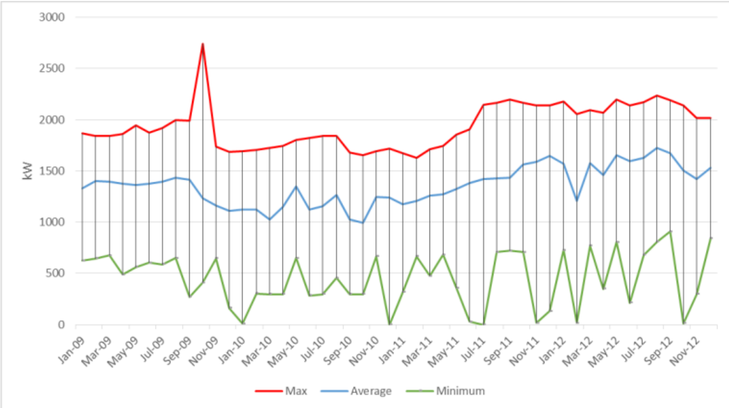
scenarios, it will be assumed that the maintenance schedule will occur from 8:00 am to 1:00 pm. As with the previous scenarios, the maintenance will be done every third week.

A final two scenario were examined. The ninth scenario will consider the usage of a single engine. Under this scenario, it is assumed that the digester operator has only one engine that produces 1,500 kW. This scenario will again assume that maintenance occurs on Sunday from 1:00 am to 6:00 am every three weeks. A tenth scenario investigated is looking at two engines that are rated at 750 kW each utilizing the same maintenance schedule as scenario nine.

Results

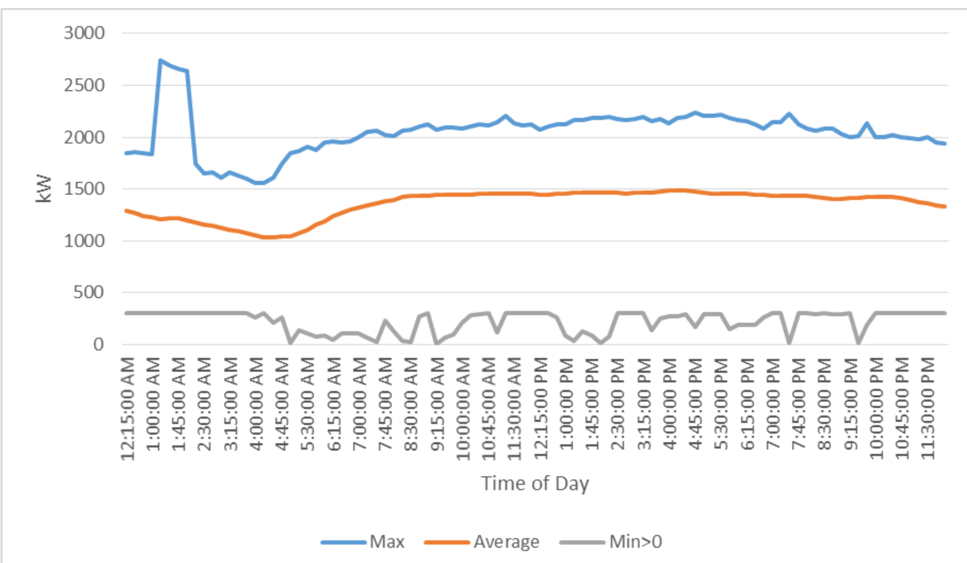
There is much information that can be gleaned from examining the demand and operation data of the digester examined in this study. Figure 1 below shows the maximum, average, and minimum kW demanded or each month over the four years that data was collected for the digester operator. Some of the minimums are related to power outages that occurred and represent an unusual and unpredictable extreme. The dairy has the opportunity to bring down its digester at any time during the day and the the month. The difference in the maximum and minimum represents the potential for the digester to strategically conduct its maintenance at lower demand parts of the month. It should be noted that the spike of the maximum that occurred in 2009 represents daylight savings which was better accounted for in 2010-2012 by smoothing.

Figure 1: Electrical Demand Data by Month for Digester Operation



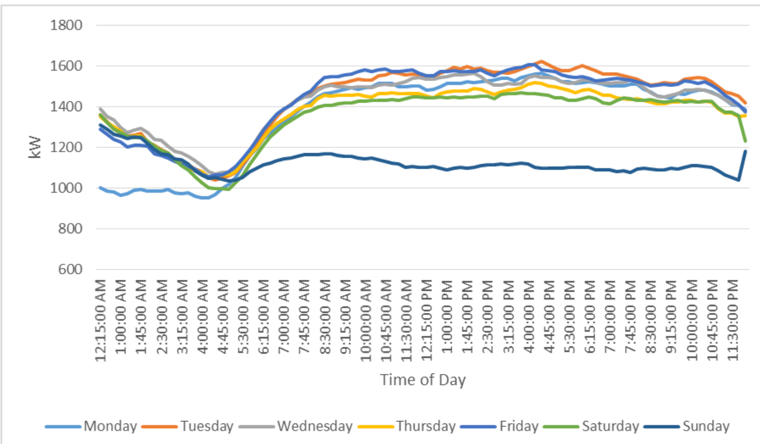
When trying to establish the best time for maintenance taking into account demand charges, it is important to understand what the demand is per kW at different times of the day. Figure 2 shows the maximum, average, and minimum demands by the dairy digester operator. Since there were times when the power was out and demand was not recorded, the minimum represent the lowest positive value recorded. If a naïve approach was used and the average was utilized to make the decision on when it may be the best time to do maintenance on the digester from the perspective of demand charges, the time between 2:30 am and 4:45 am appears to be ideal.

Figure 2: Maximum, Minimum, and Average kW Demanded During Different Times of the Day for the Digester Operator



By focusing on the average, it can be seen in Figure 3 that it is best in terms of demand charges to bring down the digester on Sundays for maintenance. While all the weekdays take a dip between 2:30 am and 4:45 am, Sunday by far has consistently the lowest average demand in comparison to other times during the week.

Figure 3: Average kW Demanded During Different Times of the Day and Week for the Digester Operator



The first scenario examined was the no digester scenario. This scenario examined what the dairy operators electricity bill would have been if the dairy did not have the methane digester. Over the four year period, the digester required 47,576,157.80 kWh of power for its dairy and cheese plant. It would have paid $5,726,405.41 over the four year period. This equates to an average electrical rate of $0.1204 per kWh. The average monthly rate paid per kWh ranged from a high of $0.1521 to a low of $0.081. The average portion of this rate that was attributed to demand charges was 24.06% equating to $1,474,253.34. Demand charges ranged from 13.54% to 36.71% with a standard deviation of 7.96%.

Under the second scenario, the digester was factored into the operation of scenario 1. The dairy's digester had 127 days where the digester engines were down for some portion of the day. This equates to the digester producing electricity 91% of the days under analysis utilizing between two and three engines. It would be expected that if maintenance occurred on a monthly basis and all engines were brought down simultaneously, then the digester should only be down for 48 days. If the maintenance schedule was every three weeks, the digester engines should be down for approximately 70 days. When the digester was down, it was off-line for approximately 4.80 hours on average. Table 3 provides the number of days and average hours the digester was not producing electricity. This table shows that Saturday had the lowest number of days that the digester was not operational, while Thursdays had the highest. Even though Thursdays had the highest non-operational days, it also had the lowest average downtime.

Table 3: Non-Operational Days and Average Hours by Day of the Week for the Digester

Day of the Week	Number of Days Non-operational	Average Number of Hours Non-operational
Monday	22	4.98
Tuesday	18	6.57
Wednesday	20	4.75
Thursday	23	3.52
Friday	16	4.39
Saturday	10	4.83
Sunday	18	4.85

Focusing on the revenue generated by the digester through avoided cost due to electricity production, i.e., Scenario 2, the digester is paying $3,150,153.48 to the utility company for power. This represents a savings of $2,576,153.93 over the four year time period, or an annual savings of $644,062.98. The demand charges for the four year period was 1,109,437.76. Hence by utilizing the digester the dairy and cheese producer was able to save $364,815.58 over the four year period. These demand charges represented an average of 33.32% of the total electrical bill with a high of 60.55% to a low of 20.49%. The standard deviation was 9.21%.

The third scenario was meant to investigate what would have happened to the digester operator's utility bill, if he had all three digesters operational at the beginning of the data collection period. Because this scenario is based on doing an "optimal and conservative" maintenance plan and conducts the maintenance at nearly the ideal time based on looking at the demand data ex post, this scenario could be viewed as an ideal state for the digester operator. Based on these ideal settings, it is estimated that the four year electricity cost for the operator is $165,343.03 which equates to a yearly bill of $41,335.76. In this ideal state, the digester operator could save $2,984,810.45 over the four year period being studied in comparison to what actually occurred over the last four years, i.e., scenario 2. Demand charges in this ideal state were $454,307.58 which were $655,130.18 less than what the digester operator actually had to pay over the four year period. This scenario demonstrates that the digester operator was astute to purchase this third engine. It should be pointed out that an interesting finding is that the demand charges are larger than the actual bill. If the net metering contract called for energy charges not offsetting demand charges, then the digesters utility bill would be $508,319.90.

The results from Scenarios 4 through 8 are presented in Table 4 below. There are a couple of interesting results seen in the table. First, while it was expected from examining the average demand data that the best time to conduct the maintenance was during Sundays from 1:00 am to 6:00 am, the table demonstrates that a lower utility bill can be realized by conducting the maintenance on Monday from 8:00 am to 1:00 pm which could be considered normal business hours. Tuesday, Wednesday, and Friday have very similar electricity bill costs that are close to $500,000. Similar to scenario 3, the demand charges exceed the actual bill implying the energy charges were negative due to producing more than was needed. If the net metering contract did not allow for this, then the bill of digester would be $781,957.79.

Table 4: Estimated Electricity Bill and Savings for Different Maintenance Schedules

Scenario	Day of the Week	Total Bill	Savings over Scenario 2	Demand Charges
4	Monday	$448,686.84	$ 2,701,466.64	$ 727,945.47
5	Tuesday	$498,984.35	$ 2,651,169.12	$ 778,625.81
6	Wednesday	$497,371.47	$ 2,652,782.01	$ 777,012.93
7	Thursday	$475,874.75	$ 2,674,278.73	$ 755,430.50
8	Friday	$495,791.56	$ 2,654,361.92	$ 775,247.27

The ninth scenario examined looked at what the utility bill would have looked like if the digester had only a single engine rated at 1,500 kW. Under this scenario, it was assumed that maintenance would occur on Sundays from 1:00 am to 6:00 am every third week. Based on these assumptions, the digester would have achieved the lowest utility bill yet at a cost of $416,497.76. This result shows that the dairy could save approximately $8,000 by having a single engine. This provides an interesting dilemma for a digester operator. While there is a small savings by having a single engine, this simulation did not take into account the possibility that the engine may unexpectedly go down. Under the three engine scenario, if one of the engines unexpectedly goes down, the other two will still be operating keeping the demand charges down. In the single engine scenario, it would be expected that the demand charges would spike for the month.

While the ninth scenario provided evidence that a single engine may be the right choice for the given digester operator studied, scenario ten provides a different result. Utilizing to 750 kW engines would allow the digester operator to have an electrical bill of $160,817.86 over the four year period. This is over a $50,000 savings per year in comparison to the single engine decisions. This is when it would be very important to take into consideration the initial costs of the single and double engines and the maintenance cost for each.

Summary and Conclusions

The purpose of this paper was to gain an understanding of how demand charges affect the electricity bill of a digester operator. It should be kept in mind that a digester operator typically is gaining its main source of revenue through avoided utility bills. It is argued that having an understanding of the demand charges portion of the bill can allow a digester operator to make better decisions on the size and or number of engines to get for the digester system, as well as, allowing the individual to develop an optimal maintenance schedule.

Utilizing a four year electricity supply and demand data set that has 15 minute incremental data from a digester operator in the Central Valley, this paper analyzed ten different scenarios and their effects on the overall utility bill and specifically demand charges. It was found that a single engine rated at 1,500 kW saved slightly more than having three engines that produced this same amount of power. Counter to this finding, it was found that two engines rated at 750 kW each would provide sizable savings in comparison to the single engine digester. This emphasizes the importance of completely understanding the digester operator's revenue source, in this case, their utility bill and its components. If a per kW cost of an engine is lower for a larger engine as would be expected, it would make sense for the digester to get a single engine in comparison to having several smaller engines. On the other hand, two smaller engines has been shown to save more on the utility bill than a single engine. It was also found that in very ideal states, it was possible for the digester to produce enough power to avoid energy charges and yet still have large demand charges.

There is a couple of big caveat to the results of this study. First, he dairy that was used for this study was very large and operated an industrial scale cheese plant. Hence, the utility rates are not necessarily typical of your typical digester operator. This allowed it to absorb all the power that it produces gaining full market rate for its electricity generation. It should be noted that this paper focused specifically on revenue generation from electricity production and did not take into consideration costs in order to better understand demand charges. The initial costs and costs of maintenance could tip any of the results in this study.

There are two areas that could be explored from here. Since this study focused on an ideal situation, it would be informative if research examined the stochastic nature of engine operation. It was shown in this study that the digester operator had the engines down for more than what would be expected as a maintenance cycle implying that engines unexpectedly break. This situation could easily make it possible that a multiple engine system could pay for itself. Obviously, the other natural area to explore is the costs related different single and multiple engine scenarios for the digester. While cost is an important characteristic to consider, the focus of this paper was meant to understand what kind of savings could occur from demand charges.

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