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West Central Research and Outreach Center

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Contents

1 Abstract

The goal of this project was to determine if the West Central Research and Outreach Center (WCROC) dairy production could achieve a net zero energy status, meaning that the dairy operation uses as much as energy on-site as the amount of energy that is produced on-site for the dairy operation. There are several ways to accomplish this goal, principally through energy conservation, by means of installing more energy efficient technologies, as well as the installation of on-site renewable energy. At the WCROC dairy, a new utility room has been installed to introduce energy efficient technologies to the dairy operation, as well as 54 kilowatts of solar photovoltaic (PV), and 20 kilowatts of wind energy to power the dairy operation. Through these installments, the WCROC dairy has reduced energy consumption and operational costs. On-site energy coming from the solar PV and wind turbines has been able to successfully power the dairy operation to create a net zero energy dairy production facility. It is important to explore the reasons why making these updates are important, and how saving energy honors the values and purpose of the rural farmer. To examine several of these reasons, an environmental ethics analysis was completed. This analysis provides insights as to why, morally and ethically, it is important to recognize and execute best practices on the farm with regard to energy and the environment. Economic analysis was key to this success at the WCROC dairy, and it is critical that economic viability analysis of energy efficiency upgrades and renewable energy systems are completed to ensure the best value for any farm. At WCROC, economic viability included comparing costs of the baseline energy system to costs of the new energy system as well as the amount of money that renewable energy systems are offsetting in fossil fuel costs. The Net Present Value and the Internal Rate of Return were calculated for the renewable energy systems and energy efficiency upgrades on the WCROC dairy farm to determine if they were viable economic investments for the farm.

2 Net Zero Energy Dairy Production at West Central Research and Outreach Center

2.1 Net Zero Energy Dairy Production Overview

Dairy production systems are energy intensive, and with many American dairy farms using fossil fuels to power their farms, they also create emissions, including methane and carbon dioxide. To avoid these emissions, cut costs of production, and invest in long-term infrastructure, WCROC is working on establishing a net zero energy dairy production, meaning that the dairy farm consumes as much energy as the amount of energy that is produced on the dairy farm. The energy produced on site comes from solar photovoltaic and wind power systems, as well as heat waste-product recovery from the milking process. The reason for this is to establish a model that other dairy farms in Minnesota can follow, as large-scale dairy farms become a dangerous competitor. For small- and medium-sized dairy productions, reducing energy-related operational costs and emissions can greatly help keep family farms up and running (Houston, et.al). By overall reducing energy consumption and searching for areas that can be improved upon in terms of energy efficiency, WCROC continues to take steps toward becoming a net zero energy dairy production by installing energy efficient technologies and on-site renewable energy systems.

2.2 Energy Efficiency Upgrade Opportunities in Dairy Production

To accommodate an increase in demand for dairy products (80% increase by 2050 (Steinfeld et.al., 2006)), it is important to study the energy intensity aspects of dairy farming including feed supply and diet composition, machines and technical facilities, livestock operations, and the milking (Kraatz, et.al., 2012). The process of milking a cow is energy intensive, and when there are around 250 cows to milk twice per day at WCROC, the price of this process quickly accumulates. The amount of electricity used on the WCROC dairy farm equates to 440 kWh per cow per year (3.5 kWh per hundred weight of milk produced) costing around $30 each day ($10,950 yearly, per cow), and the amount of natural gas used is 21 therms per cow per year, costing around $11 each day ($4,015 yearly, per cow). At the WCROC dairy, before implementing energy efficient technologies, it was important to understand where energy was being used and where energy consumption could be reduced. For example, there are many electricity loads on the dairy farm. Milk cooling accounts for 26% of the WCROC dairy electrical load, as can be seen in figure 1 (WCROC Dairy Guidebook, 2017). For comparison, on a dairy farm in Ireland, the main energy consuming aspects of dairy production are milk cooling (31%), water heating (23%), milking (20%), pumping water (5%), and lighting (3%) (Upton, et.al., 2013).

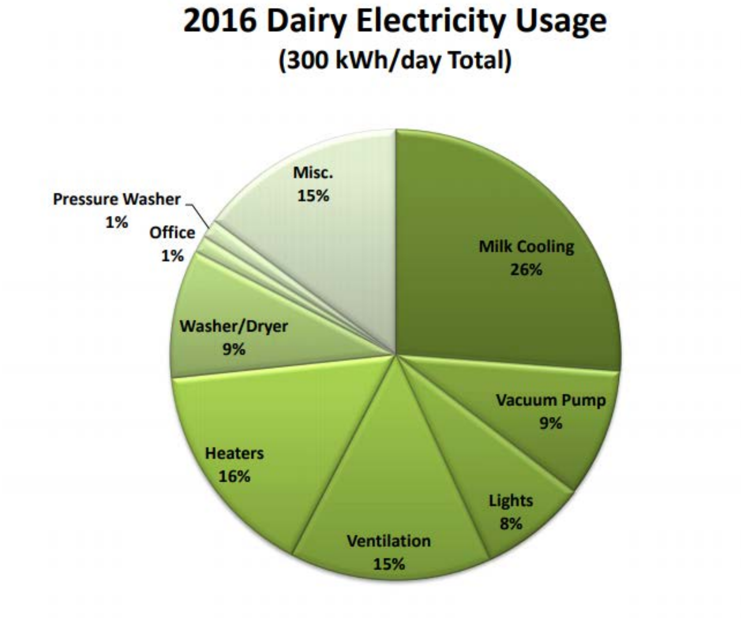

Figure 1: 2016 Dairy electricity usage from WCROC.

To reduce the large electricity demand of milk cooling, a plate cooler or heat exchanger is used. The heat exchanger works by running cool well water past tubes carrying warm milk which comes out of the cow at around 100 degrees Fahrenheit. A variable frequency drive is also installed to help reduce energy in the milk pumping process by slowing the flow of milk past the cool well water pipes in order to maximize heat transfer. This way, the originally 100-degree milk is cooled to within 5-10 degrees of the well water (which enters the plate cooler at about 40 degrees) reducing the load on bulk tank compressors. Another opportunity for a variable frequency drive (VFD) to be installed is the vacuum pump used for milking. The milk pump VFD installed in the WCROC dairy lead to a 75% reduction in electricity usage for that load, and saved the farm $4 per day in operating costs. Another important but very simple and easy efficiency upgrade to make is lighting. LED light bulbs are the most efficient lighting option. Not only are LED light bulbs more efficient, providing more light and emitting less heat, but they last substantially longer than many fluorescent bulbs, meaning less maintenance on the fixtures and reduced replacement costs. A fluorescent bulb will last an average of 8,000 hours, whereas an LED will last around 25,000 hours. Additionally, because LEDs emit little to no heat compared to fluorescent lighting, less money will have to be spent on cooling the barn during warm months. Upgrading lighting is one of the easiest ways to reduce energy consumption and costs, as LEDs are 31% more efficient than T8 lighting. Even the switch from incandescent lighting to T8 lighting reduces energy consumption by 68% (Houston, et.al, 2013).

Figure 2: Left: A dairy barn with incandescent lighting. Right: A dairy barn with LED high efficiency lighting (Carrie Houston, et.al, 2013).

Energy demand regarding lighting in dairy barns can also be significantly decreased depending on the amount of time the cows spend outside, when the barn lights do not have to be on at all. A study examining energy intensity in livestock operations found that whole-year confinement in a free-stall barn was the most energy intensive way to raise dairy cows compared to half-time summer grazing or full-time summer grazing. Additionally, including pasture feeding in the diet of young cattle reduces energy inputs for machines by 46% (Kraatz, et.al., 2012). The cows at the WCROC dairy are year-round pasture grazing cows, and they do not spend any time in the barn. This is due to the fact the the WCROC dairy farm owns plenty of pasture land that is not used to produce agricultural crops, and instead is used solely for grazing the cows. Some dairy farms do not have this extra land, and so cows spend most of the time inside a barn. Other reasons for keeping cows inside might be to better control their diet and feed composition.

2.3 Use of Renewable Energy Systems in Dairy Production

One option for implementing renewable energy systems on dairy farms is solar energy. There are two options for collecting solar energy, the first being solar thermal (collection as heat), and the second being solar photovoltaic (collection as electricity). Both systems can be implemented in dairy production to provide on-site electricity as well as instant water heating and preheating.

I. For solar photovoltaic (solar PV), net metering systems are used to connect to the grid so that excess electricity can be sold to the utility company or exchanged for fossil fuel credit. PV panels will collect energy as direct current electricity, which must be converted to alternating current electricity before use by going through an inverter.

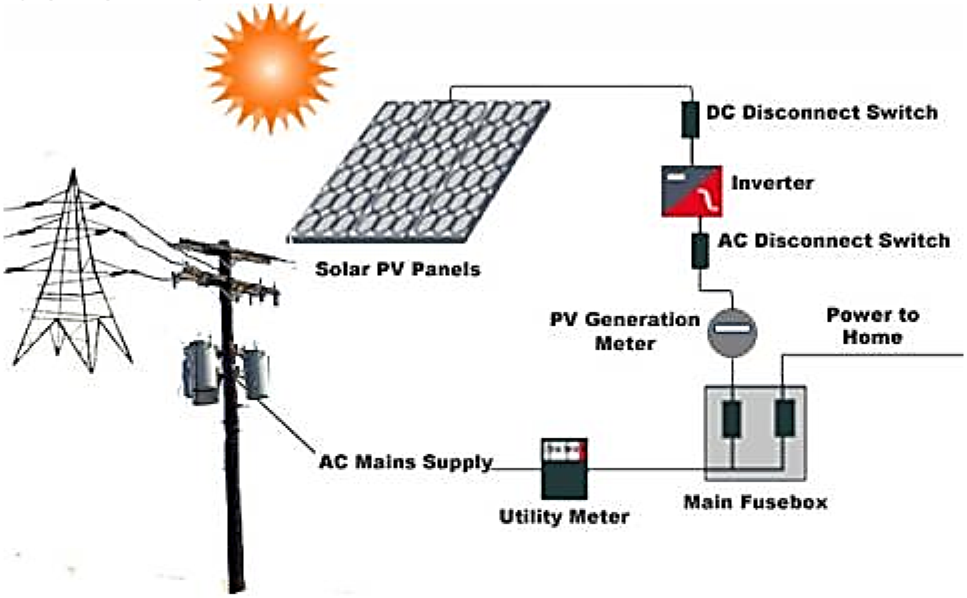

Figure 3: A solar PV system diagram. Energy from the sun is collected by the solar PV panel, which is then converted to alternating current energy from direct current energy. From the inverter, the energy powers the home through the main fuse box, and energy consumption is measured by the utility meter. Any excess energy not used by the home unit is transferred to the utility grid and the homeowner is credited for that excess generated power.

II. Solar thermal is one of the best ways to offset costs of heating water on the farm. This can be done by using either flat plate or evacuated tube systems. Flat plate systems consist of an insulated panel with a glass front. Evacuated tube systems are similar, but contain two nested glass tubes that create a vacuum around a copper tube with water inside of it that boils, from which heat is collected.

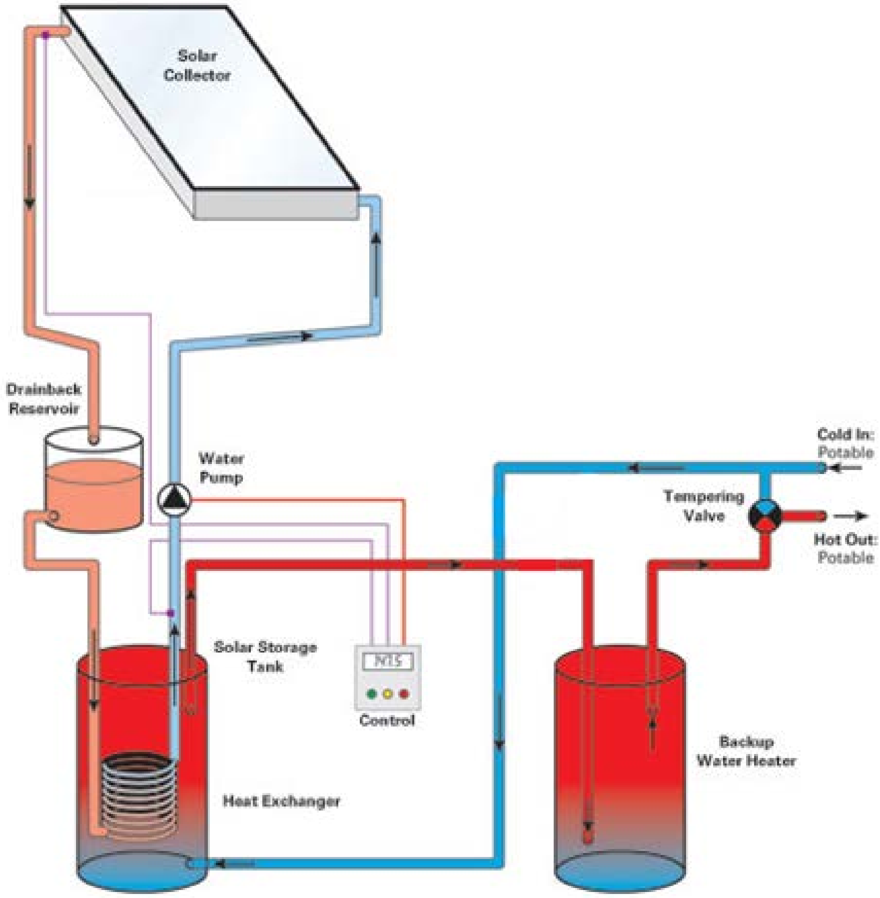

Figure 4: A solar thermal system diagram. Water is supplied to the solar thermal collector, which is heated by the energy of the sun. This water is heated to boiling, causing it to condense at the top of the panel and travel into the drain back reservoir and into the original tank. The hot water rises to the top, and is transferred to a water heater, which can be used for potable purposes.

III. In rural Minnesota, there is often a great amount of wind, which can be utilized on the farm by installing small-scale wind turbines (less than 100 kW) to reduce emissions and reduce operating costs. Ideally these turbines are mounted on towers 100 feet off the ground to maximize energy generation at higher altitudes. At WCROC (a medium-sized dairy farm of 250 dairy cows), two 10 kW wind turbines have been installed, and projected to produce about 40% of the farm’s energy needs. For comparison, 82% of energy needs on a small dairy farm in Prince Edward Island, Canada, was produced by a 25 kW wind turbine (Houston, et.al., 2013).

2.4 Overview of the Energy System at the WCROC Dairy

At the WCROC dairy, energy consumption of the dairy operation is measured separately from the rest of the farm. Total energy consumed by the dairy is measured using the electric company meter, from which the dairy operation is billed each month. The total of this bill is energy consumed by the dairy, minus the amount of energy produced on-site for the dairy, for a total amount that represents nonrenewable energy consumed by the dairy. An eGauge (an energy measuring device) records real time energy usage by the dairy each day, every minute. Whereas the bill from the electric company just explains how much energy was consumed and how much it costs, the eGauge provides minute-by-minute data of energy consumption that can be used to determine during what time of day energy consumption is high or low. This allows WCROC to determine during what time of day energy consumption can be reduced to save energy and money for the dairy production. As previously stated, there is energy produced on-site for the dairy operation. There are three main energy-producing entities for the dairy: a 4 kW solar array, a 50 kW solar array, and two 10 kW wind turbines. The energy from these systems account for the renewable energy used for the dairy operation. The energy production from the 4 kW solar array is measured using an online program, called Solar Web, which provides real time production data, to identify when the solar system is producing the most energy. The energy production from the 50 kW solar array is measured using an eGauge, which also provides real time production data. The energy production from the two 10 kW wind turbines is also obtained online, through the Bergey Monitoring System, which, again, provides real time production data.

3 Materials and Methods

3.1 4 kW Pole-Mounted Solar Array

A 4 kW solar photovoltaic array was installed at the base of one of the 10 kW wind turbines on June 6, 2017. The pole-mounted system is stationary and provides electricity for the dairy barn.

Figure 5: The 4 kW solar array installed at the WCROC dairy farm.

3.2 50 kW Ground-Mounted Solar Array

Also with the goal to offset expensive energy needs, a 50 kW direct current solar photovoltaic system was installed on October 4, 2016. This is a ground-mounted array near the calf hutches at the WCROC dairy farm. This system is projected to produce 70,000 kWh each year.

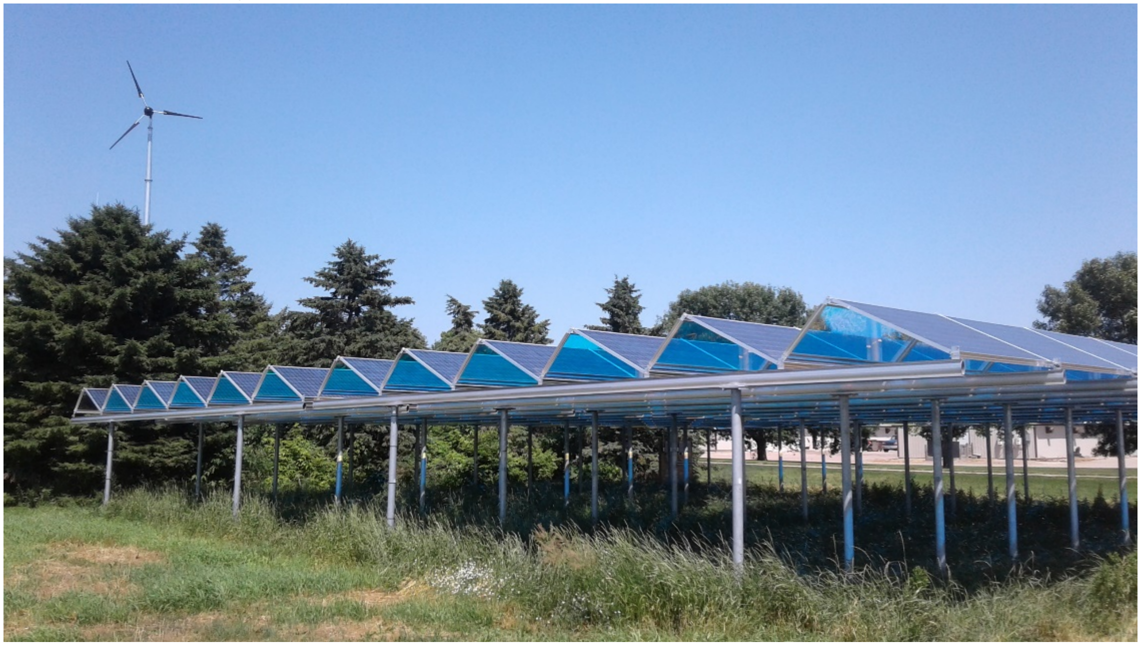

Figure 6: The 50 kW solar array installed at the WCROC dairy farm.

3.3 Two 70 Feet Tall, 10 kW Wind Turbines

For wind energy production, the taller the tower and the longer the blades means more power will be generated. To offset energy needs on the WCROC dairy farm, two 10 kW VT10 Ventera wind turbines were installed at the farm on June 6, 2017. At the base of one of these turbines is a 4 kW pole-mounted solar photovoltaic system. The predicted generation for each of these turbines is 22,400 kWh per year, per turbine.

Figure 7: One of the two 10 kW Ventera wind turbines installed at the WCROC dairy farm.

3.4 eGauge

The eGauge is used to measure the loads in the new utility room for the new energy system. There are two eGauges installed, one of which is on the outside of the barn and measures three loads using nine sensors. The three loads measured on this eGauge are the amount of electricity that goes to the baseline energy system in the old utility room, the amount of electricity going to the new energy system in the new utility room, and both of these measurements combined with the entire amount of electricity being used in the barn (figure 8).

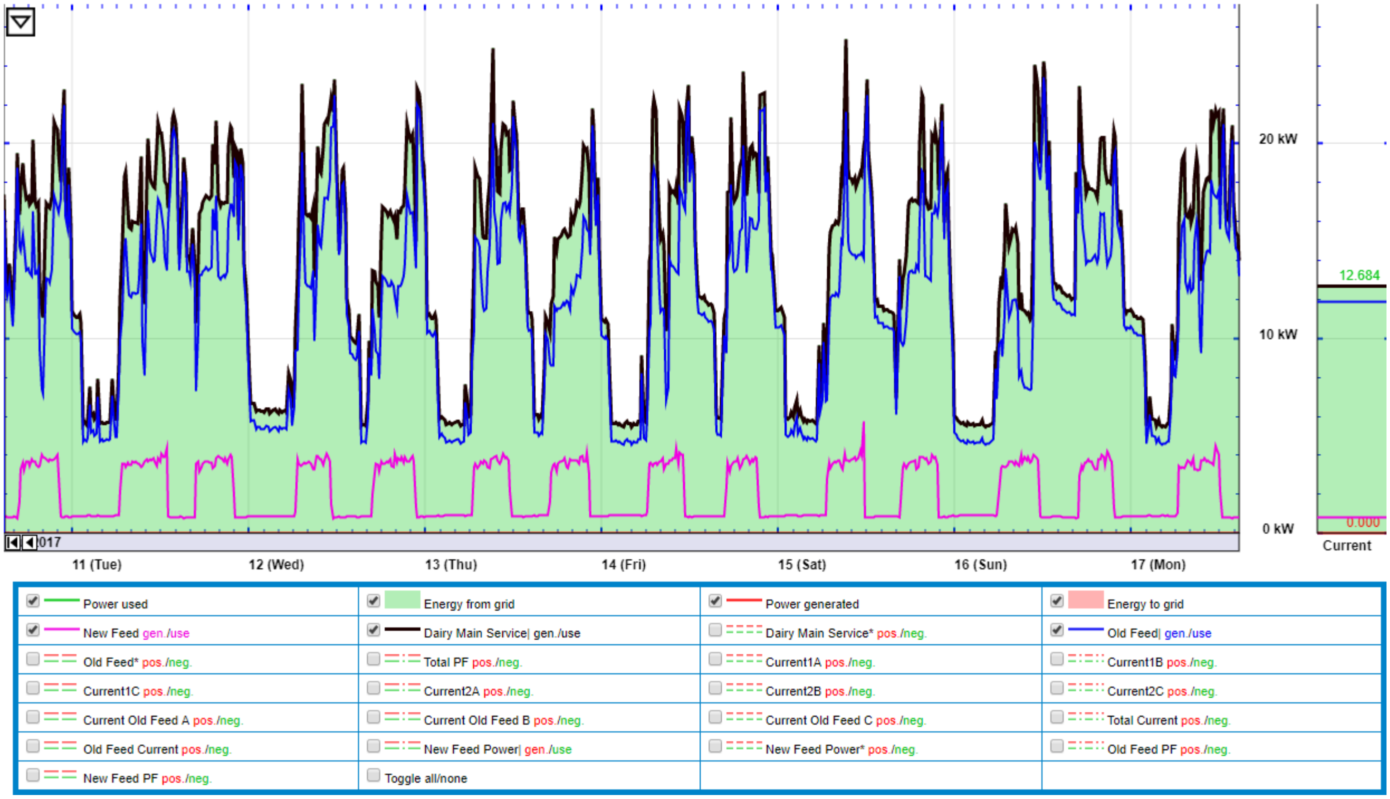

Figure 8: An example of what the eGauge monitoring system looks like for measuring the total electrical loads in the old utility room, the new utility room, and the load for the entire barn. The green solid color is showing the amount of energy used from the grid, which includes the amount of energy that has been generated using WCROC renewable energy systems on the farm. The pink line shows the amount of energy that the new utility room is using, with the energy efficiency upgrades. The blue line shows the energy use of the baseline utility room system. The black line, "dairy main service", is the same as the green solid color, which defines the amount of total energy use, including both the new and baseline energy systems, as well as lighting and other current loads (for example, receptacles, office energy use, etc.) in the dairy barn. The red "power generated" line is not shown, because this energy is directly integrated with energy from the grid. Power generation from the dairy solar and wind systems are measured with separate eGauges and other power generation software. This figure emphasizes the energy savings between the baseline energy system and the new energy system.

The second eGauge measures only the amount of energy that the new utility room energy system is using so that this amount can be easily compared to the amount of energy the baseline energy system is using (figure 9).

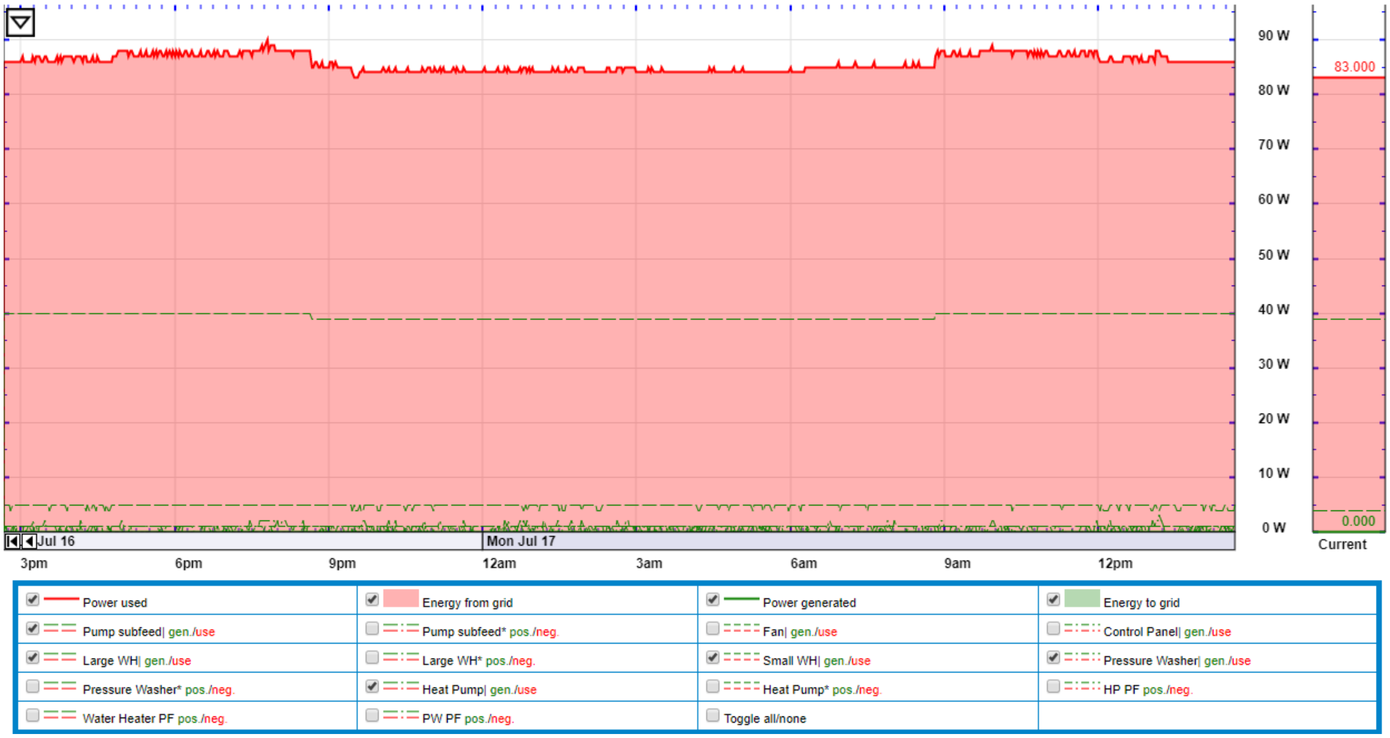

Figure 9: An example of what the eGauge monitoring system looks like for measuring the total electricity usage in the new utility room. This figure is a more concise visual of the pink line in figure 8 showing the total energy use for the new utility room in the dairy barn. Again, power generated is not shown in this figure.

3.5 Campbell Scientific Data Logger CR3000

A Campbell Scientific Data Logger (located in the old utility room for the baseline energy system) is used to measure 36 loads in the dairy barn. These loads include eleven temperature and flow loads, four temperature loads, one pressure load, and twenty current loads. Initially there were some sensor changes at the beginning of the trial in order to determine which loads are most significant to measure in the dairy barn, but no sensors have been moved since May of 2015. This data logger records data on each sensor every 10 seconds. These 10 second measurements are averaged into 10 minute intervals, and these 10 minute averages are recorded and analyzed. For each day, the 10 minute averages are then summed to average daily totals, which are then averaged for each month. Once several years of this data are collected, yearly comparisons can be made.

Sensor Code	Description	Type	Max Range	Model
T1F1	Mains inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T2F2	Water heater inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T3F3	Water heater outlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T4F4	Pressure washer inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40

T5F5	Milk sink hot water inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T6F6	Milk sink cold water inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T7F7	Tankwash hot water inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T8F8	Wash. machine hot inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T9F9	Wash. machine cold inlet temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T10F10	Bathroom cold temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T11F11	Bathroom hot temp & flow	temp/flow	100C/10 gpm	Grundfos VFS 2-40
T13	Milk sink water temp	temp	200F	CS 109-L40
T14	Parlor air temp	temp	200F	CS 110PV-L
T15	Outdoor temp	temp	-20 - 100F	CS 109-L40
T16	Utility room air temp	temp	-20 - 100F	CS 109-L40
P1	Pressure washer outlet pressure	Pressure	3000 psi	Digikey 480-2541-ND
C1	Furnace	current	20A	CR Magnetics CR9580-20
C2	Conventional tank chiller	current	50A	CR Magnetics CR9580-50
C3	Organic tank chiller	current	50A	CR Magnetics CR9580-50
C4	Vacuum pump	current	50A	CR Magnetics CR9580-50
C5	Pressure washer	current	50A	CR Magnetics CR9580-50
C6	Pressure washer exhaust fan	current	20A	CR Magnetics CR9580-20
C7	Milking parlor fans	current	20A	CR Magnetics CR9580-20
C8	Milk line cleaning machine	current	20A	CR Magnetics CR9580-20
C9	East side lights	current	20A	CR Magnetics CR9580-20
C10	Cow stall receptacles	current	20A	CR Magnetics CR9580-20
C11	Org. wash controller & agitator	current	20A	CR Magnetics CR9580-20
C12	Tank room lights	current	20A	CR Magnetics CR9580-20
C13	Parlor, UR, bathrm, office lights	current	20A	CR Magnetics CR9580-20
C14	Washing machine	current	20A	CR Magnetics CR9580-20
C15	Dryer	current	50A	CR Magnetics CR9580-50
C16	Portable heaters	current	50A	CR Magnetics CR9580-50
C17	Utility room fan	current	20A	CR Magnetics CR9580-20
C18	Parlor fans NW	current	20A	CR Magnetics CR9580-20
C19	East fans	current	20A	CR Magnetics CR9580-20
C20	Office receptacles	current	20A	CR Magnetics CR9580-20

Table 1: Dairy barn sensors: CR3000 Data Logger.

3.6 Methods: How to Analyze the Data

Several things were considered for this project. First, the Dairy Energy Report examines WCROC dairy production energy usage from 2013 through 2016. The data examined for this project is the accumulating data for 2017, which is under the new thermal energy system, with data being recorded by the Campbell Scientific CR3000 Data Logger, as well as data being recorded by the new eGauges. The new energy system in the new utility room is still under commission, and on any given day, some aspects of the system are working, and others are not. To estimate and predict future use, several example days of when different aspects of the new energy system were identified and analyzed to best give a representation of how the system runs. The new system was compared to the baseline system on a daily basis, and projected averages were determined based on milk production and total energy use. An estimate of electric, gas, and diesel use was also made based on the new system. Once this was completed, a comparison was made between energy usage on the WCROC dairy farm and energy usage on other Minnesota dairy farms. Regarding renewable energy production on the WCROC dairy farm, energy production from a 4 kW solar photovoltaic system, 50 kW solar photovoltaic system, and two 10 kW wind turbines was measured and compared to the total energy usage of the WCROC dairy to determine if the farm was a net zero energy production.

It is not enough to simply introduce energy efficient technologies and renewable energy. The farmer must recognize the farm as an entity that needs to be cared for by the farmer, who acts as the steward of the land. Identifying the areas of ethics and values that are important to a farmer, the ecosystem, and the farm itself is vital in making energy reduction changes and supporting the local environment. Some of these values, including the practical benefits of local economics and family heritage are upheld as high standards by rural farmers, and it is important to recognize these values and how they point to the necessity of environmental ethics and stewardship. The value of local economics and caring for the farm in a way that reduces the need to support industry and instead support local business keeps money in the community, which benefits the farmer.

Further, by reducing energy consumption on the farm and meeting energy demands with renewable energy, the farmer saves money each year that they can instead spend on the future of their farm and its livelihood for generations to come.

4 Environmental Ethics and their Value in Agriculture

4.1 What is Stewardship?

There is the idea in environmental ethics that farmers are the original natural stewards of the land, and practice good farming techniques, which include care for the soil, water, plants, and animals. This is the environmentalist idea of farming, something that most farmers would probably identify with (Thompson, 1995. Pg. 73). However, there is also the productionist idea of farming, which includes the exploitation of nature for the self-interested gains of humans, without regard or care for the environment. It has been argued in environmental ethics that stewardship requires conservation and avoidance of abusing the land and water, which does not fit into the productionist ideals of modern agriculture (Thompson, 1995. Pg. 77). Wise use of resources is seemingly abandoned when it comes to profits, and that appears to be the key in production of modern agricultural products, as industrialized farming practices become more common, and "agribusiness" dominates a monopoly of seeds, feeds, and technology.

Moreover, the core of environmental ethics presumes the farmer to be the natural steward of the land. Agricultural ethicists suggest that stewardship is an ethical virtue, which farmers should strive for, as this virtue will help them to better provide for their families and community, as well as the land itself and the ecosystem of the farm. This virtue is often understood by many small-town farmers as being essential to their work on the farm. In this context, small-town farmers and small farms is referring to those farms in which the owner is the primary caretaker of the land and animals that make up the farm (in economic terms, a farm is considered small if it produces less than $250,000 per year in agricultural products (USDA, 2013)). Many of these ideals come from values instilled from religion, as the agrarian stewardship of being the caretakers of the earth that God created for humans is a major theme of Christianity (Thompson, 1995. Pg. 74). Stewardship of the land requires supporting healthy soil, clean water, and ethically-raised animals, as humans are one with nature. Thus, in their role as stewards, it is the duty of the farmer to consider the potential consequences when it comes to best farming practices, and the stewardship and values those practices hold.

Best practices of agriculture have been changing over the past few decades. In modern industrial agriculture, practices of farming are directly opposite those outlined by the good, natural steward farmer. Immense amounts of pesticides and fertilizer directly pollute and degrade the soil, water, and plants that farmers are ethically responsible for. Therefore, the common practices of modern industrial agriculture; chemical pesticide and fertilizer use, and the exploitation of non-renewable energies which severely degrade water and soil all over the world, are not the "best" practices that could be used in accordance with environmental stewardship. It seems that there has been a deviation from the best practices with the aim to increase profits and shape to the mold of productionist agriculture (Thompson, 1995. Pg. 83). Although this form of "agribusiness" makes money, there is a question in the environmental and agricultural ethic sector: If productionist agriculture makes money, why should we change, and instead use environmentally friendly practices?

4.2 Why Prioritize Environmental Ethics on the Farm?

I. Reasons for Adopting Environmentally Focused Initiatives

There are many reasons to adopt practices on the farm that lead to environmental longevity, far too many to list here. Several of these reasons draw upon core principles of economics, which provides the farmer not only with an economic incentive to conserve the land on which they grow their livelihood, but also with moral incentives. These reasons include the intrinsic value of nature, the ecological balance on which farmers desperately rely, and the preservation of the land for future generations of farmers.

According to Thomas Jefferson, and many other modern political philosophers, certain claimable rights, for example "life, liberty, and the pursuit of happiness", are the gift of nature, rather than the production of democratic society. Nature has given us these rights as humans, and this is a generally accepted concept by many environmental ethicists. For this reason, it can be said that nature is intrinsically valuable to humans by providing these rights. It is widely accepted that nature has been exploited in past societies, but never to the extent that it has in the current time of the 20th and 21st centuries, and that this environmental degradation must be overcome by realizing that humans are not dominant over all of nature, but rather nature is something we should value and reconnect with (Worster, Pg. 45). The instrumentalist view of nature and the environment, that it is here solely for the domination and use of humankind, has justified industrialism since the beginning of the industrial revolution.

However, due to the fact that humans are fulfilling the destiny of industrialism, using the earth to the fullest extent for the furthering of human society, the environment is becoming exhausted; oceans are filled with plastic and oil, freshwater contaminated with agricultural runoff and the feces of livestock, and air quality continues to cause increases in respiratory disease (Worster, Pg. 46). As nature collapses as a result of these anthropogenic stresses, it is very possible that humans will no longer be able to rely on nature to provide us with the clean, uncontaminated resources we need to survive, including the land on which we farm. Healthy soil and clean water once readily available are becoming scarcer, and this once valuable aspect of nature has been taken advantage of, and the intrinsic value of nature has been lost and forgotten. If humans are able to again realize the value, both to humans and intrinsic, of clean, healthy, and wild nature, we will be able to effectively manage our resource intake, and avoid over-depletion of the environment, which has occurred ever since the beginning of the industrial revolution.

Wendell Berry describes "good farming", a term analogous with stewardship, as farming in which the farmer respects nature and harmonizes their farming with the ecology of the water, soil, and environment as a whole to produce an ecological balance between the economical farmer and nature (Thompson, Pg. 78). As stated above, farmers are environmental stewards for the land on which they grow their crop and make their living. However, when farming practices degrade the soil and water, ecological balance is thrown off, and can be detrimental to crop yields and success of the farm. According to studies done on agricultural soils, yearly tilling and distribution of pesticides and fertilizers has a negative impact on the quality of soil, including increases in soil salinization and acidification, making it difficult to grow a successful crop (Guangyong, et.al., 2011).

Part of finding balance with the natural surroundings of the farm is done by using those natural surroundings to the advantage of the farmer, but in a way that is reciprocal in nature, and gives back to the environment. In this way, nature is an economical ally, and the farmer, when well informed, can use the surroundings to foster growth on the farm and preserve it for years to come. By using natural fertilizer rather than chemically produced fertilizer, the farmer not only reduces farm waste, but increases the farm's profit by decreasing the need to purchase fertilizer from a supplier. By keeping livestock outside instead of in barns, energy from the sun supplies plants for the animals, which saves money on feed and energy costs to keep barns lighted and ventilated. By relying less on "purchased inputs" and instead on finding a more sustainable, economical balance with the environment, a farmer finds themselves in a much more beneficial relationship: with nature, rather than industry (Berry, Pg. 10).

As Aldo Leopold states, the balance of nature has a merit to humanity, which is that it provides utility to all species, by simply providing nourishment, home, and resources (Leopold, 1949.). This is true, as when nature is in balance, our food systems are in balance, meaning that humans have things to eat, and our land is in balance, meaning that we likely have water and a place to grow that food, and we have resources to build our homes and cultivate the land on which we grow our food. However, ecological balance is destroyed when pollutants are introduced, erosion dominated the soil, or climate suffers. When these balances are destroyed, humans struggle to find a route to survival. As described by Paul Thompson, when a thermostat's parts begin to wear out after use (especially improper use), the thermostat system fails, and can no longer function to maintain temperature in the home, for example, and loses all functionality to humans. Proper maintenance and sustainable use of the thermostat, however, prevents this failure, and it will continue to warm the home for years to come (Thompson, Pg.150). This is analogous to the current issue of climate change and agriculture. Climate change, caused by the extensive burning of fossil fuels, will have the most severe effects on farm land, including decreased crop yields, drought or increased floods (depending on the geographical location), pest swarms, and many others. In order to prevent this ecological destruction (the failure of the thermostat due to lack of maintenance), the farmer must prepare for climate change and take steps to combat its negative effects on the farm. One way to combat these effects is to decrease energy use (energy provided by fossil fuel burning which causes climate change), or to do away with fossil fuels all together and instead invest in renewable energy infrastructure for today and for the future.

The value of a farm that has been in the family for generations is of great importance to many farmers. The farm is a place where nature meets human economy most vibrantly, and where conservation for future generations is needed the most (Berry, Pg. 8). Farmers have a love for what they do, and most farmers would probably agree that they desire to pass down that same love and appreciation they have for farming to their children. For this to occur, farmers must act as conservationists, taking special care for the land, water, and resources that support their livelihood, so that they can pass it down to their children in a better condition than what they received it in. Farmers are responsible for not only conserving their skills of farming, but also conserving the land on which they farm by implementing practices that allow them to improve the quality of their homeland, their profits, and the state in which they pass down their land, in honor and dignity, and with respect for the land.

Wendell Berry describes how, contrary to modern, urban families, farming families center their lives around the hard work that goes into producing the goods needed for survival. This is something each member of the family unit learns and participates in, fostering a strong relationship system, as well as a strong and productive farm. Children growing up on the farm learn to appreciate what their parents do for the land and for the animals that they care for, and grow up to have the same loves and appreciations for the land and animals as their parents did (Thompson, Pg. 81). The virtues associated with environmental stewardship are ontological, in the sense that they derive from learning and fostering relationships with others, as well as a relationship with nature. These virtues are passed from the farmer to the next generation farmer, leading to a cycle of stewardship that keeps farming families together and strong, as they pass down their sacred family land to each other.

II. Roots in the Environment are the Roots of Your Farm

The values associated with the environment are also the base of the values of the farm. These are the values of the rural community, and those of the family unit. To achieve and honor these values of the community and family is to honor the values of the environment that famers so deeply depend on.

Rural values of the farm most deeply have connection and meaning in the community. For many communities, agriculture is the root of rural and community values, providing the people with a sense of cohesiveness as a unit that works together toward common goals (Pat Crow, Rural Values). In farming communities, farmers provide an economy for the community to live on by selling agricultural products, and being the consumer of feed and farm supply products that help the community thrive. Rural values in the agricultural sense also include the willingness of farmers to help other farmers when they are sick, or need some additional assistance. This willingness is not forced, or even asked for, but rather understood that to help other farmers means to be a good steward in the community, and a role model for future generations who will someday take over the farms and community. These neighbors that help each other say that a good neighbor is someone is shares, and that when they cannot repay the favor, they are just asked to repay the favor to someone else in the future. This type of commitment to neighbors and fellow farmers is something that is deeply understood in the farming community. This responsibility to help others and being committed to the community is analogous to being committed to the land

and environment. Having a rural value and love for one’s neighbors immediately relates to the love for the land and responsibility to care for the environment. For if there was no healthy environment to grow crops on, there would be no rural community value in the first place.

The traditional family farm in the United States is commonly associated with the values of ingenuity, self-reliance, humility, stewardship, and family (Strange, 1988). By upholding these family values on the farm, and demonstrating them to the children on the farm, a society of responsible agricultural stewards is grown, one that can continue to pass on these values (John Ikerd, 2004). John Ikerd, an agricultural economist, states that family relationships are integral to the success of the farm, and that the strength of the family unit increases the strength of the profits and the strength of the farm. “The Golden Rule” applies to the farm and family in more ways than one, but most importantly, that by valuing the environment and valuing the family, the farm will be successful and represent a better way to live.

According to a study done on the values of rural agriculture, farmers expressed that an important part of their job as a farmer is that they get to work close to home and close to their families (Ilbery, 1983). This close proximity to the family demonstrates the ability of the farmer to engage their families in the work of the farm, encouraging younger family members to participate in events on the farm that they will someday manage themselves. The farm family is a regenerative organization, in which the ownership of the farm is transferred to the following generations, continuous through the family cycle. Living and working in close proximity can present challenges to the family, but it also teaches them how to resolve these challenges, something that urban families do not have the opportunity to learn in the way that farming families do. The farming families learn to gain an appreciation for each other, and the work they do to support the farm to see it flourish and succeed. These values are transferred from generation to generation, and promote a healthy family relationship, a thriving economy, and an appreciation for the land that provides them these opportunities to learn and work with each other (Colman, 1987).

4.3 Values in Environmentally Conscious Behavior

I. Practical Benefits of Environmental Stewardship

In order to encourage other farmers to invest in the future and in sustainable farming practices, it is important to complete an economic analysis and examine the cost benefits of increasing sustainability and environmentally friendly technologies on the farm. Environmental ethicists suggest that the best way to promote sustainable practices and technologies on farms is to examine the economic gains of the practice and how it will be overall beneficial for the farmer and the well-being of their livelihood and the future. Investing in sustainable technologies, such as solar panels or wind turbines to power the farm from renewable energy sources, improves the environmental stewardship of the farmer who completes these projects, and helps them to better care for the land and water that they work with on a daily basis. An economic analysis was completed for the renewable energy systems and energy efficiency upgrades at WCROC, including analysis of potential economic incentives that can be applied to decrease the initial cost of the system.

Primarily, resource exhaustion, soil erosion, deforestation, and water pollution have led agriculture to search for more sustainable practices that do not decrease their productivity or profits. Many of these practices have been found in renewable energy technologies, as they decrease the need for oil and gas excavation, help farmers to be more independent, and decrease operational costs on the farm. One study determined that precision technologies, or technologies that can reduce wastes and respond better to varying environmental conditions (in comparison to traditional technologies) provide higher revenues, lower input costs, and decrease the amount of environmental pollution produced by farms (Zilberman, et.al.).

When new technologies are able to reduce pollution and other negative environmental effects of agriculture, and maintain productivity and profitability of the farm, then it seems that upgrading farm technologies is the way to go. As can be seen from the upgrades completed at WCROC, simple technologies, such as a variable frequency drive, have small initial costs, which quickly pay back in the form of energy savings on the electricity bill (see figure 15).

Not only can investing in environmentally ethical practices bring extra profits to the farm and save money and energy, these investments can extend the life and productivity of the farm for future generations. Maintaining ecological balance and considering the value of nature in cooperation with the farm system is critical to maintaining a healthy farm, which can help to increase productivity both now and for many years in the future.

More and more people are choosing to buy local and support farmers that are near to their homes, with the hope of supporting the local economy and the environment (Barber, Pg. 210). However, this shifting need is not substantial enough to put money back into family farms rather than industrialized operations. Not only for the consumers, but also for the environment, there is a need to return to more sustainable modes of agriculture. Farmers might be skeptical about this idea, but producing a more varied crop, raising a variety of animals, and reducing the tendency to grow too much keep economics local and keeps profits in the community. By shifting the money in the agricultural industry away from government subsidies and seed controlled by large corporations, farmers will not only be more in control of their farms, but also have the opportunity to grow what the consumer wants, bringing in money to the farmer directly from their local economy. This makes the whole community stronger and happier. And, by introducing renewable energy technologies on their farms, farmers can put even more money into their homes and communities by providing energy that they can use onsite as well as distribute to their region, making money in the process. Oftentimes, values drive ethical behavior, and by recognizing how rural values align with environmental stewardship, money and energy can be saved on the farm. As John B. Cobb, Jr. said, "See the basic relation between economic growth and environmental protection as positive…and there are many communities that are, as far as the present economy allows, taking more responsibilities for their own lives (Cobb, 368)."

II. Community Values in Sustaining the Environment through Agriculture

Being a leader and trusted member of community through upholding values of a good, virtuous farmer in terms of environmental stewardship is a character trait that many farmers would argue is important to have (Berry, Pg. 9). Farmers live and work at the border between the human economy and nature, where sustainable practices are arguably most needed. Additionally, as stated by Wendell Berry, a conservationist and farmer, "Good farmers, who take seriously their duties as stewards of Creation and of their land's inheritors, contribute to the welfare of society in more ways than society usually acknowledges, or even knows". These "good" farmers produce products for their communities, conserve land, soil, and water, and are good examples of environmental stewards for their families, future generations, and society (Berry Pg. 9). Berry, as a farmer, says that farmers do what they do because they love it; they love the land they work on, they love working where they live, and they love seeing their work grow into something beautiful that they can use to support the community with food and nourishment (Berry, Pg. 10). This value in supporting the community through farming suggests that in order to farm and farm well, one must also love the land on which they grow their crops. In order to do this, farmers must realize that nature has value, too, and that by supporting and nurturing nature and the environment, they support and nurture their crops and animals, and in turn support and nurture their families and communities.

III. Promoting Future Welfare of the Farmer

The intrinsic value of nature, preserving ecological balance, and preserving the land for future generations are several reasons to farm sustainably and adopt better practices. Sustainable farm practices can include anything from upgrading to more energy efficient lighting fixtures, to reducing pesticide and herbicide spraying, moving animals outside to reduce energy use, or implementing renewable energy technologies on the farm. Any of these practices promote the integrity and stewardship of farmers and help to demonstrate how farmers are the responsible care-takers of nature and creation. In order to encourage other farmers to invest in the future and sustainable farming practices, it is important to complete an economic analysis and examine the cost benefits of increasing sustainability and environmentally friendly technologies on the farm. Investing in a more sustainable way of farming can not only help to reduce emissions and pollution, but also increase the productive lifetimes of the farm. Additionally, these upgrades and practices can save the farm thousands of dollars per year, giving farmers more economic control of their farms, as well as providing energy independence for the farmer. It is important to consider the reasons why investing in sustainable farming practices are important, and many of these reasons directly align with the values of many rural farmers and farming communities. Being a good farmer and a good steward of the environment means that the farmer is a well-respected and trusted member of the community, who cares for his land, the environment, and the well-being of their families and their communities.

5 Economic Analysis

5.1 Overview

To complete the economic analysis and determine economic viability of the renewable energy systems and energy efficiency upgrades installed at the WCROC dairy, an analysis of the energy load from the dairy barn was completed. The electricity loads in the dairy barn from 2013 through October of 2017 were analyzed to compare the amount of energy used by the baseline energy system (2013-2016) and the energy used by the new energy system (2017). As described in section three, several data monitoring systems, such as eGauges and the Campbell Scientific Data Logger were used to do this.

The efficiency upgrades analyzed for this project were the 2200-gallon hot water storage tank, two tankless hot water heaters, the solar drain back tank, the heat pump, and six total variable frequency drives, as well as the eGauges and other hardware. All of the upgrades in the new utility room came to a cost of $229,674, and maintenance costs per year total $1,150.

The renewable energy systems analyzed for this project include the 50 kW solar array, and two 10 kW wind turbines. The cost of the 50 kW solar array was $138,000, with maintenance costs per year of $690. The cost for both of the two 10 kW wind turbines was $156,800, with a maintenance cost $784 per year (total, for both turbines combined). The 4 kW solar array had no yearly maintenance costs, and the predictions of energy savings were included in the predicted production data of the 10 kW wind turbines. Because this was a fairly small and inexpensive system ($5,600), analysis of the 4 kW solar array will not be included.

The 50 kW solar is expected to save $7,000 in energy costs per year. The two 10 kW wind turbines are expected to save $2,240 in energy costs per year. The energy efficiency upgrades are expected to save $11,223 in energy costs per year.

5.2 Calculations of Net Present Value and Internal Rate of Return

The Net Present Value (NPV) and Internal Rate of Return (IRR) were calculated to assess the economic viability of the energy efficiency upgrades, the

50kW solar array, and the 10 kW wind turbines. Microsoft Excel was used to complete these calculations.

The NPV for the 50 kW solar array was calculated by first examining the energy savings of the system. The energy savings was calculated by multiplying the estimated yearly production (from PV Watts) of the system by the efficiency decline of the system, which accounts for wear and tear on the system that decreases efficiency over the life span of the system. For the first year of the system, this efficiency decline was 3%, and for the rest of the analyzed 24 years the efficiency decline was .5%. Next, the energy savings was calculated by multiplying the cost of electricity by the energy savings in kWh to determine the amount of money saved by having the system. The cost of electricity began at 10 cents, and then was increased over the 25 years at an inflation rate of 2.10%. To calculate the present value, the energy savings in dollars was then divided by (1+i) raised to the power of n, where 1 is years passed (since the present value is compounded each year, this number remained 1 for each year in the 25 year analysis), (i) is the discount rate (5%), and n is the year (at year 12, n=12). The present value for all 25 years was added together, and the cost of the system, including yearly maintenance, was subtracted, and the NPV was determined.

The NPV for the two 10 kW wind turbines was calculated in the same way as the NPV for the 50kW solar array, but using 1.5% as the efficiency decline for each year. The energy savings was calculated using the cost of electricity from the energy savings in kWh. The cost of electricity began at 10 cents, and then was increased over the 25 years at an inflation rate of 2.10%. To calculate the present value, the energy savings in dollars was then divided by (1+i) raised to the power of n, where 1 is years passed (since the present value is compounded each year, this number remained 1 for each year in the 25-year analysis), (i) is the discount rate (5%), and n is the year. The present value for all 25 years was added together, and the cost of the system, including yearly maintenance, was subtracted, and the NPV was determined. Next, the “What-if analysis” and “goal-seek” functions were used to determine the IRR by setting the NPV equal to 0.

The NPV for the energy efficiency upgrades was also calculated in the same way as the NPV for the 50 kW solar array and the 10 kW wind turbines. The efficiency decline was the only difference in calculations, and it was .5% for each year.

The IRR for all three systems was calculated using the “What-if analysis” and “goal-seek” functions by setting the NPV equal to 0. A visual of these calculations can be seen in Appendix 3.

5.3 Net Present Value

The net present value, or NPV, is the profitability of an investment, which examines cash inflows and outflows. When an NPV is calculated for a system to be positive, an indicated earnings and positive investment has resulted. When the NPV is negative, there is an indicated loss, and a negative investment has resulted.

I. Energy Efficiency Upgrades

With an initial cost of $103,350 with both the 30% Federal Tax Credit and the 25% REAP Grant incentives, the NPV of the energy efficiency upgrades was found to be -$94,702 The negative NPV indicates the WCROC dairy farm is not yet experiencing a net savings in energy costs from these upgrades. The WCROC is still paying for the initial cost of the upgrades.

II. 50 kW Solar

The initial cost of the 50 kW solar array, also with both incentives, was $62,100. The NPV of this system was found to be $30,044. The positive NPV indicates that the WCROC dairy farm is experiencing a net savings in energy costs, and is making money from this system.

III. Two 10 kW Wind Turbines

The initial cost of the two 10 kW wind turbines with both incentives was $70,560. The NPV for these turbines was calculated and found to be -$55,359. This negative NPV indicated that the WCROC dairy farm is not yet experiencing a net savings in energy costs from this system, and is still paying back money for the initial cost of the system.

5.4 Internal Rate of Return

The internal rate of return, or IRR, is the rate at which the net present value will approach zero, meaning that the investment “broke even”. An IRR equal to zero indicates monetary gains after the investment has been made, and the system is making money. The discount rate must also be considered for the IRR calculation. The discount rate is the interest rate used in cash flow analysis when determining the net present value. For this project, the discount rate was found to be 5%. When the IRR is greater than the discount rate (greater than 5%), then the system was a good investment. When the IRR is less than the discount rate, the system was not a good investment.

I. Energy Efficiency Upgrades

The IRR of the energy efficiency upgrades was calculated with both of the incentives in table two included. The IRR of the energy efficiency upgrades was found to be -6%, indicating that the value of the system is not enough to support the cost of the system.

II. 50 kW Solar

The IRR of the 50 kW solar was also calculated including both incentives in table two. The IRR of the 50 kW solar was found to be 8%, indicating that the value of the system is enough to support the cost of the system.

III. Two 10 kW Wind Turbines

The IRR of the two 10 kW wind turbines was also calculated including both incentives in table two. The IRR of the two 10 kW wind turbines was found to be -3%, indicating that the value of the system is not enough to support the cost of the system.

5.5 Economic Incentives for Minnesota Farms

On the WCROC dairy farm, incentives from, for example, the federal government, made these energy efficiency upgrades and renewable energy systems more affordable by decreasing their initial costs. The incentives included in a 30% federal tax credit and the Renewable Energy for America Program (REAP). The REAP program included a 25% grant from the United States Department of Agriculture, and covered 25% of the cost of each system. The savings from these incentives can be seen in table 2 below.

System	Initial Cost of System	REAP (25%)	Federal Tax Credit (30%)	Cost of system with Both Incentives
Energy Efficiency Upgrades	**$229,674**	-$57,418	-$68,902	**$103,350**
50 kW Solar	**$138,000**	-$34,500	-$41,400	**$62,100**
Two 10 kW Wind Turbines	**$156,800**	-$39,200	-$47,040	**$70,560**

Table 2: Cost of renewable energy systems and energy efficiency upgrades with the incentives

There are several tax credits and grants available to farmers in rural Minnesota that can make installing energy efficiency upgrades and renewable energy a viable option by reducing the startup costs of the systems. For example, one easy way to reduce the cost of wind energy systems on small farms is to fill out a simple form (see appendix 2, number 1) which exempts the purchaser of any size wind turbine in Minnesota from the sales tax on that wind system. For example, one 10 kW wind turbine on the WCROC dairy farm from Ventera Wind Inc. cost $78,400 (not including any other incentives). With the Minnesota sales tax rate at 6.875%, the sales tax on this wind turbine would cost a farmer an additional $5,390. With the sales tax exemption form from the state of Minnesota, this cost is completely waived, significantly reducing the startup costs of that particular system. Additionally, a property tax exemption can be applied to private property taxes. For this incentive, the land on which the solar or wind system is located is still subject to property tax, but if a farmer had their private home on a piece of land separate from the land on which the renewable energy system was located, a property tax exemption will be applied to the farmer’s private property. Also under this incentive, production taxes for solar PV systems 1 MW or less are waived. Wind systems 250 kW or less are also exempt from production taxes. The cost of these taxes can depend on which county the farm is located in. For context, the WCROC dairy currently uses 20 kW of wind energy and 54 kW of solar energy, and therefore would be exempt from production taxes (see Appendix 2, number 2).

In addition to these exemptions, there are several loans available to farmers which can be used to offset the initial startup costs of renewable energy systems or energy efficiency upgrades. For farmers living in West Central Minnesota who rely on Ottertail Power Company as the energy provider, up to $100,000 (or up to 80% of the project costs) can be loaned to a farmer for energy efficiency upgrades including water heaters, lighting, chillers, heat pumps, air conditioners, heat recovery systems, motors, motor variable frequency drives, agricultural equipment, and food service equipment. For loans of $5,000 or more, the loan can be paid back over the course of 12 to 60 months, at in interest rate of 1.9% (see Appendix 2, number 3). For example, the cost of a variable frequency drive and electric pressure washer for the WCROC dairy farm was $5,780. With a loan of that amount, paid back over 60 months, the monthly payment would be $101.24. If the monthly payment of these energy efficiency upgrades is less than the amount of money saved in energy savings per month, then this was a good investment and a good loan (see formula 3). Also, a $45,000 per farm family loan can be applied to solar thermal, solar photovoltaics, wind (all), biomass, hydroelectric (small), and anaerobic digestion systems. For up to 10 years, this loan can be paid back at a fixed interest rate, which is currently 3%, although it can fluctuate (see Appendix 2, number 4).

$$monthly\ loan\ payment = (\frac{loan\ amount\left(\frac{interest\ rate}{number\ of\ payments\ per\ year}\right)}{(1-(1+\left(\frac{interest\ rate}{number\ of\ payments\ per\ year}\right)^{(number\ of\ payments\ pery\ year\times number\ of\ years)})}$$

Formula 3: Where the loan amount is how much was loaned, the number of payments per year is how many times a payment is made each year (for monthly payment=12), and the number of years is how many years the loan is for.

Grants are an additional option for reducing initial costs of renewable energy systems on the farm. For example, the Xcel Renewable Development Fund provides grants for the installation of solar thermal electric, solar photovoltaics, wind (all), biomass, hydroelectric, hydrogen, combined heat and power, anaerobic digestion, and fuel cells using renewable fuels. The grants are provided through a Request for Proposal process, in which applications for the grants are written and money is awarded based on those applications (see Appendix 2, number 5). Also, the USDA Rural Energy for America Program (REAP) provides grants for solar water heat, solar space heat, geothermal electric, solar thermal electric, solar PV, wind (all), biomass, hydroelectric, hydrogen, geothermal heat pumps, combined heat and power, tidal power, anaerobic digestion, fuel cells using renewable fuels, and microturbines. Up to 25% of the cost of any of the above projects is covered by this grant. For this grant, there is also an opportunity to combine the grant and a loan, which can cover up to 75% of the project's total cost (see Appendix 2, number 6).

6 Results

The results of this study showed that the addition of energy efficient technologies in the new utility room, such as electric hot water heaters, variable frequency drives, and refrigeration heat recovery, contributed to about an 18% reduction in energy use for the dairy operation. Additionally, the introduction of scroll compressors rather than reciprocating compressors results in 20-30% reductions in energy usage for the milking process. In combination with renewable energy generation, the total amount of megawatts used per year on the WCROC dairy farm has decreased overall, providing the farm with a decrease in yearly operational costs.

6.1 Energy Consumption

IV. Comparison of WCROC Dairy to Other Minnesota Dairy Farms

There are 4,746 dairy farms in the state of Minnesota, housing 463,000 dairy cows combined. The WCROC dairy farm, like all other dairy farms across Minnesota and the Midwest, uses a great amount of energy to power the dairy operation, including processes associated with raising the animals, feeding the animals, milking the animals, and cooling the milk to be sent off for processing and consumption. For the purpose of this study, the amount of energy needed to produce one pound of milk only considers the amount of energy used on the farm leading up to the transportation of the finished product. All energy-intensive processes including and after the milk physically leaves the farm via truck is not incorporated in the WCROC data. According to a study done by the Division of Energy Resources of the Minnesota Department of Commerce across 30 farms in Minnesota, the most energy-intensive processes on a dairy farm are the following:

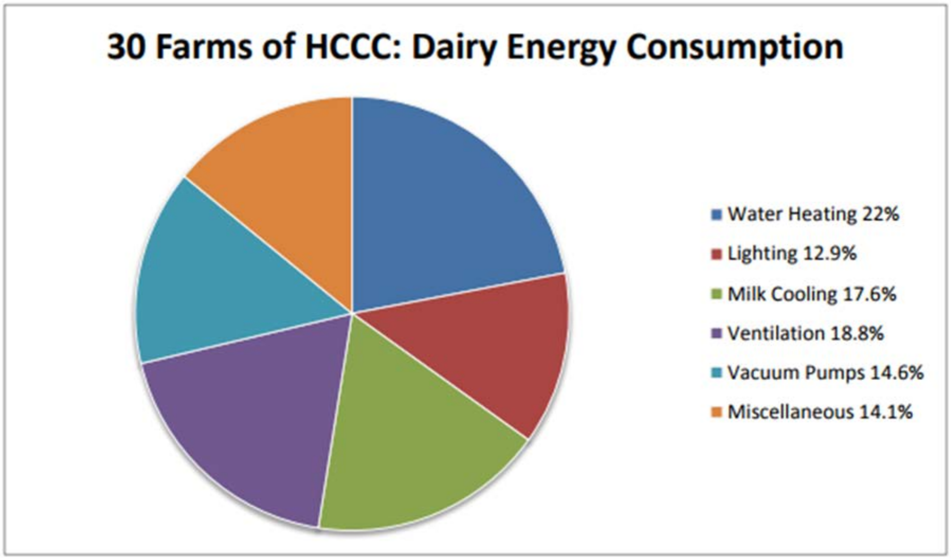

Figure 10: Analysis of energy consumption on 30 study farms. For these farms, the most energy-intensive process for dairy production is water heating, followed by ventilation, and milk cooling. This suggests that the water heating and milk cooling aspects of dairy production are some areas where energy efficient technologies can be introduced to reduce operational costs associated with energy.

For comparison, below is the summary of electric loads at the WCROC dairy, which shows that the most energy intensive process at the WCROC dairy is milk cooling, suggesting that the process of milk cooling is an area where energy efficient technologies can be employed to save money and energy in the dairy production process. Several different technologies have been integrated into the new utility room at the WCROC dairy to decrease these loads, described below.

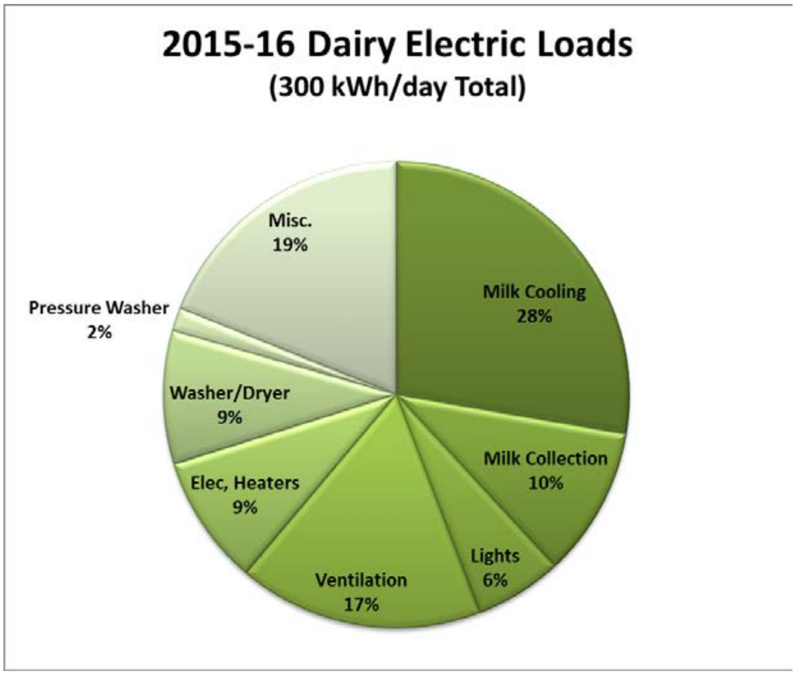

Figure 11: 2015-16 Dairy electric loads at WCROC.

a) Plate coolers have been installed to help cool the milk by running cool well water adjacent to a tube carrying the milk, which comes out of the cow at around 100 degrees Fahrenheit.

Figure 12: A plate cooler in the new utility room at WCROC.

The warm milk becomes cooled as the well water absorbs heat from the milk, cooling the milk to about 45 degrees Fahrenheit, significantly lowering the amount of work that needs to be done to lower the temperature of the milk to below 40 degrees Fahrenheit for sanitation reasons. Additionally, the water that has become warmer after the heat exchange with the milk is transported to a storage tank full of warm water that can reach temperatures high enough to sanitize the equipment after use, or high enough so that it does not require the amount of energy needed to heat room temperature water to over 160 degrees Fahrenheit for sanitation. Often called Refrigeration Heat Recovery (RHR), this process saves energy in the form of heat that can be repurposed instead of being expelled as a waste product as it would be if the milk went straight from the cow to the bulk tank where it would need to be cooled entirely by the compressors.

b) The type of compressor used also has an effect on the amount of energy needed to cool the milk to the proper temperature before distribution. At WCROC, there are two bulk tanks, one containing the organic milk, and one containing the conventional milk. The compressor for the bulk tank containing the conventional milk was an older reciprocating compressor (the reciprocating compressor was replaced with a new scroll compressor in summer of 2016 when the other energy efficiency upgrades were made), and the bulk tank containing the organic milk is a newer scroll compressor. As can be seen in figure 13, there is a large difference in the amount of energy used to power a reciprocating compressor and the amount of energy used to power a scroll compressor. From the below graph, one can see that the amount of energy consumed by a scroll compressor to keep milk cool while in the bulk tank is significantly lower than the energy consumed by the reciprocating compressor used for the same task. As farmers experience the need for a new compressor in their milk cooling system, many are making the choice to instead buy a new scroll compressor and save money and energy, rather than replacing their old reciprocating compressors with more reciprocating compressors.

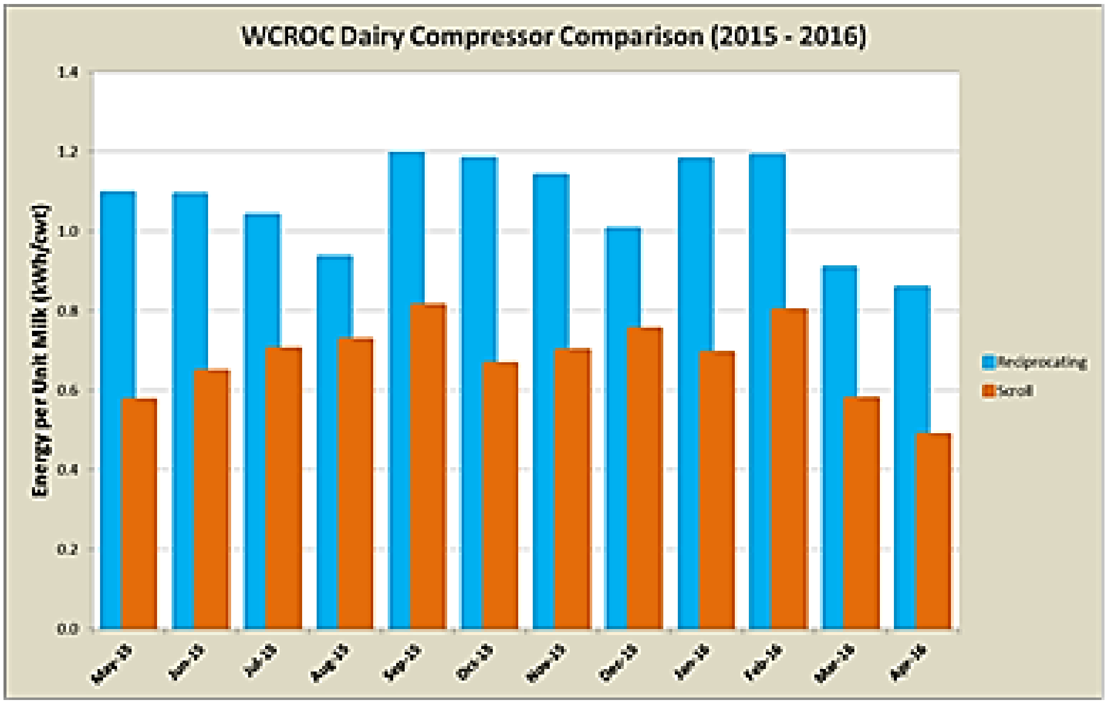

Figure 13: WCROC dairy comparison of scroll compressor and reciprocating compressor. This figure shows the 20-30% reduction in energy use of a scroll compressor (orange) compared to a reciprocating compressor (blue).

Figure 14: Bulk tanks for milk at WCROC. The bulk tanks store milk after it is extracted from the cow. The bulk tanks include circulation technology that stirs the milk, and uses a scroll compressor to keep the milk cool until it is picked up by the purchaser.

c) As stated previously, for sanitation reasons, water must be heated to 160 degrees Fahrenheit or above in order to kill bacteria and break up milk fats that come in contact with the tubes and other milking equipment after the milking process is complete. To do this, water is heated often using propane or natural gas. At the WCROC dairy farm, two tankless, electric water heaters have been installed with the idea of reducing the amount of fossil fuels that need to be used for water heating. Additionally, the water is instantly heated in these water heaters, helping to speed along the sanitation process.

d) In terms of the electrical load for lighting, from the study completed by the Division of Energy Resources, 12.9% of the total energy usage was used for lighting. At WCROC, the total amount of energy used for lighting is 8.3% as of 2017. The reason for this difference is that across these 30 Minnesota dairy farms, some of them may be tie stall barns, in which the dairy cows are kept inside either all year-round or for half of the year, usually during winter months. At WCROC, the dairy cows are kept outside all year round, and the only areas that are lighted are the milking parlor, the bulk tank room, the utility room, the office and bathroom, and occasionally the old tie stall barn that is no longer in use for cows, but used for storage. The types of lights at the WCROC dairy barn are T-12 fluorescent fixtures. Lighting is one of the most common and one of the easiest efficiency upgrades that a dairy farm can make, especially if the cows are inside year round and receive light in the barn 16-18 hours per day. For an average payback period of 2.2 years, according to the Division of Energy Resources, energy efficient light fixtures such as light-emitting diode bulbs (LEDs) or compact fluorescent bulbs (CFLs) are the best choice for lighting upgrades. These lights ultimately give off less heat, keeping the barn and the cows cooler and more comfortable, while giving the barn better lighting that will cost less in the long run. Additionally, more efficient lighting will last longer, usually two to three times longer than traditional fluorescent or incandescent bulbs (see section 2.2).

e) Another energy efficiency upgrade that can be made is the installation of a variable frequency drive (VFD). Instead of constantly running at full speed (resulting in high electricity use), a VFD matches the required load needed by varying a motor's speed. For example, these can be used for vacuum pumps or for fans. As can be seen in figure 15, when a VFD was installed at the WCROC dairy farm for a vacuum pump, the energy load decreased immediately by 75%, saving around $4 per day in energy savings from just one machine, with a short payback period of 2.5 years.

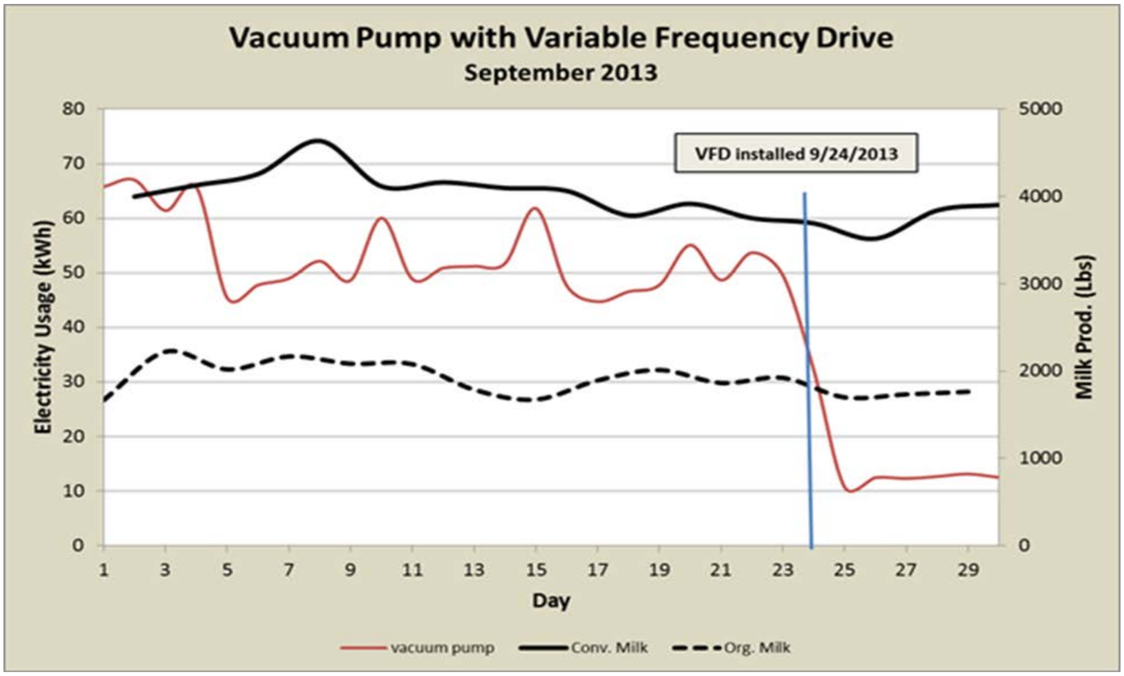

Figure 15: Visualization of how energy consumption decreased after a variable frequency drive was installed.

In the study completed by the Division of Energy Resources, the average payback period for a VFD was 14.2 years, depending on the size of the farm. For a 40-cow dairy farm, the payback was around 6.6 years, or 6.7 for a medium-sized dairy farm of 140 cows. The WCROC VFD payback period of only 2.5 years may be shorter compared to this study because there may have been additional funding through a research grant available for this particular drive.

In another study of Minnesota dairy farms and energy efficiency, the Jewison dairy farm of Janesville, Minnesota found an opportunity for 22% cost savings of their energy use after conducting a thorough energy audit. For example, it was found that installing a plate cooler to assist with cooling the milk before going into the bulk tank and then using the heated water from that process to preheat water for sanitation would save them a total of $513 per year, with a payback period of 3.8 years. According to the Minnesota Project HCCC report, the average payback period for a plate cooler is 9.5 years. The shorter payback period of the plate cooler at the Jewison farm, therefore, may be due to the fact that it is a small dairy farm with only 80 milking cows. The Jewison farm also installed a compressor heat recovery unit, energy efficient lighting, an engine block heat timer, and more efficient ventilation systems, for a total of $1,463 saved annually. These are just a few examples of how energy efficiency upgrades can be introduced in dairy farms across Minnesota to reduce energy consumption and energy-related operational costs.

II. Baseline Energy System Data Analysis

In this section, the baseline energy system data is analyzed and explained, using data from the eGauges in the baseline utility room, as well as natural gas bills for the dairy barn, and diesel data accumulated from the diesel-powered pressure washer. This data is later compared to the energy consumption of the barn with the utilization of the new utility room energy efficiency upgrades.

The data from the baseline energy system was recorded with the Campbell Scientific CR3000 data logger using the Logger Net program on a computer. Data measuring 36 energy loads, eleven temperature and flow loads, four temperature loads, one pressure load, and twenty electrical current loads, was collected every 10 seconds, then averaged per minute and then again averaged as 10-minute interval data, and was analyzed in this form. Each of these loads can be seen above in Table 1. These data were recorded beginning in August of 2013, and recorded through the rest of 2013, all of 2014, all of 2015, through April of 2016, some of June 2016, some of July 2016, and began again in April of 2017 after new energy efficiency upgrades were made.

Below are the averages of kWh used per month in all the months of data recorded as stated above, including the measured loads as well as all other loads in the barn as measured by the electricity meter:

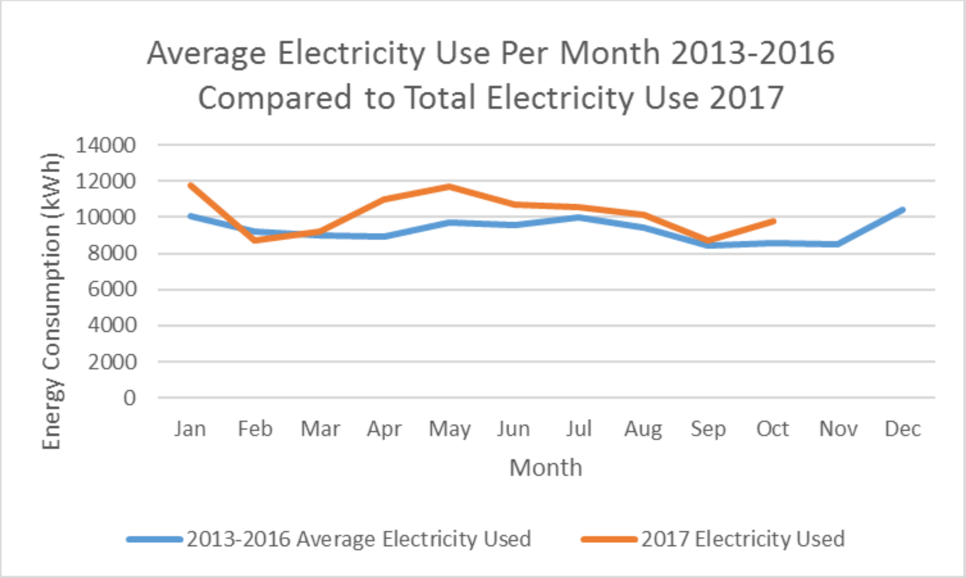

Figure 16: The total electricity consumption averaged per month from 2013 through 2016 compared to the total electricity consumption in 2017.

The total power consumed above does not include the amount of natural gas used to heat the water that is used in the dairy operation. The below graph (figure 27) includes all of the natural gas needed to heat the dairy barn, as well as for water heating purposes. It should be noted that in 2017, the new energy system was installed, including two tankless electric water heaters, significantly decreasing the need for natural gas-heated water, which is why there is a sharp decrease in monthly consumption around March of 2017.

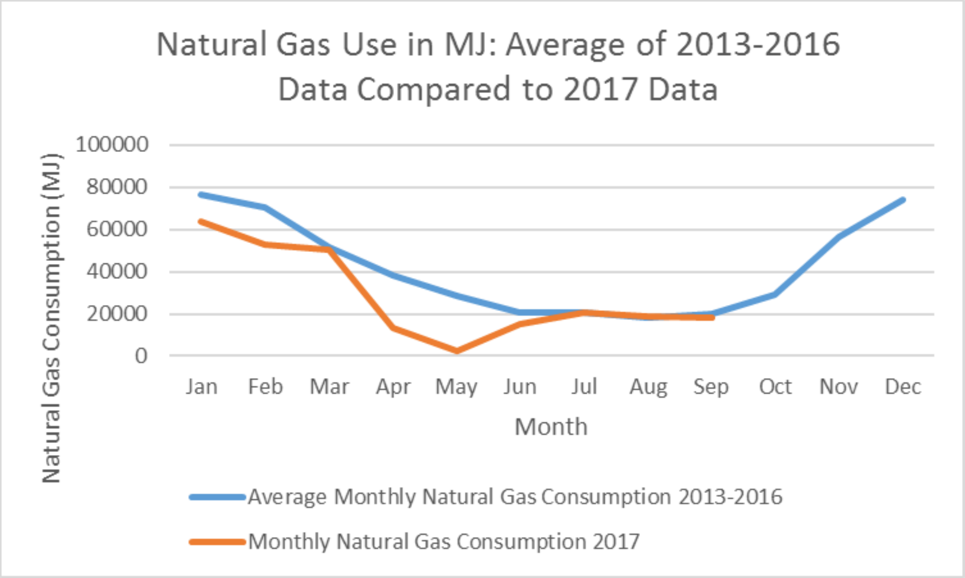

Figure 17: The total natural gas consumption averaged per month from 2013 through 2016 compared to the total natural gas consumption in 2017.

In the baseline energy system, a diesel-powered pressure washer was used. For the new energy system, an electric pressure washer was implemented, and diesel usage was no longer recorded, since it is assumed to be zero without the need for any diesel. It should be noted that the diesel pressure washer is still used as a backup when the electric pressure washer is not working properly, as the new system is still being commissioned. The total diesel consumption from 2013 to 2016 can be seen in the chart below. There is no line for 2017 because the diesel use for the new energy system is assumed to be zero.

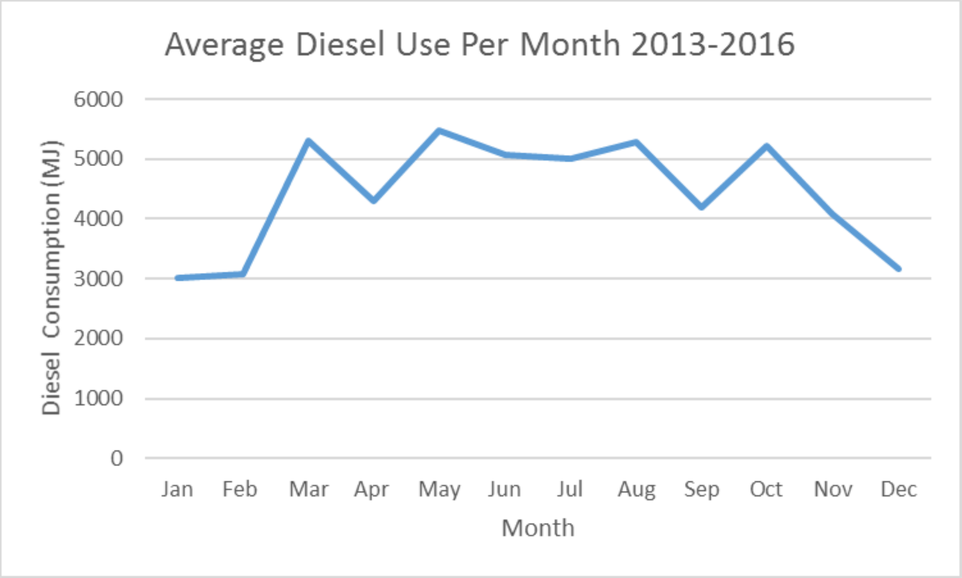

Figure 18: Total diesel consumption monthly averages from 2013 through 2016.

For the purposes of this study, the total electrical, natural gas, and diesel consumption were summed to find the total amount of energy used for the dairy production at WCROC. The results of this can be found in the following graph:

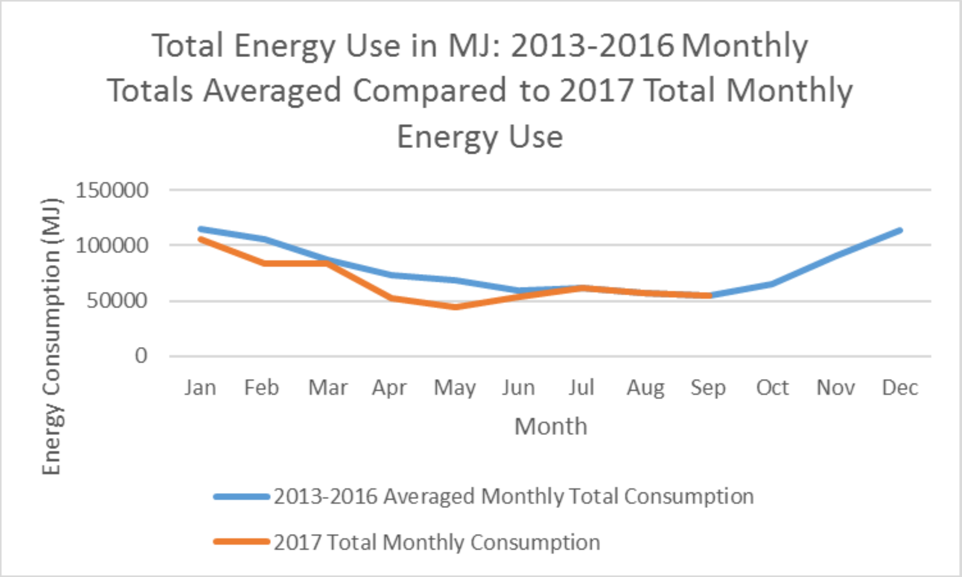

Figure 19: Total Energy Use in MJ: averages of combined totals each month from 2013 through 2016 compared to combined totals of electricity, natural gas, and diesel consumption in 2017.

III. New Energy System Data Analysis

The data for the new energy system was recorded with the eGauge in the dairy barn. The eGauge recorded data on eight loads of interest including total usage, the pump sub-feed, a fan, the control panel, the large tankless water heater, the small tankless water heater, the electric pressure washer, and the heat pump.

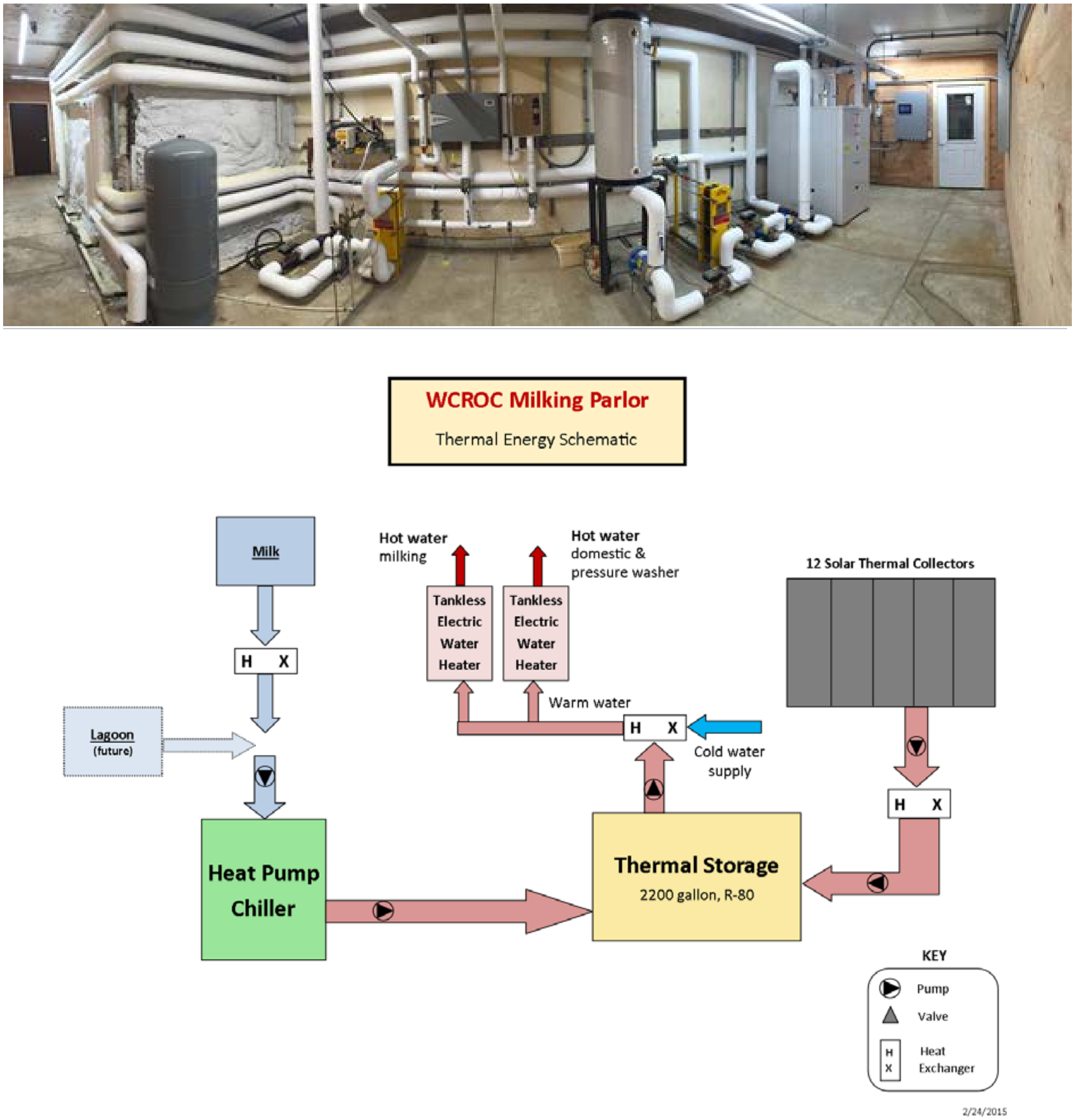

Figure 20: WCROC new utility room containing new energy system (top), and the schematic diagram of how the system flows (bottom).

The new energy system is still being commissioned, and on any given day, some aspects of the system are in use, and others are not. There currently has not yet been a day where the entire new system has been working and in use. Due to this fact, example days were observed when different aspects of the system were working, such as the electric pressure washer, the electric water heaters, and the heat pump along with the compressors of the old system for cooling the milk. On days when these components were working, averages of the kWh used per day by each component were taken, and modeled as a typical day of use. These typical days were then combined with total energy consumption of the new energy system, data received from the eGauge. The amount of energy that the electric pressure washer, electric water heaters, and heat pump/compressors combination used were totaled into a typical day with other miscellaneous loads that had not changed when the conversion from the baseline to the new energy system was made. This yielded the total amount of energy that the new energy system used, which could be compared to the amount of energy that the baseline energy system used on a typical day.

IV. Comparison of New Energy System and Baseline Energy System

In order to complete a comparison of the baseline energy system to the new energy system, some estimates of typical days when the new system was in use needed to be made. This was described in the above section. The baseline system energy use was then compared to these averages of a typical day when the new system would be fully functional. For this comparison, three main components of the energy system of the dairy barn were examined: the baseline diesel pressure washer compared to the new electric pressure washer, the baseline natural gas hot water heaters compared to the new electric hot water heaters, and finally the baseline cooling compressors compared to the new heat pump in combination with the same compressors. Average days for each of these components were observed when they were in use, and total kWh used per day for that component was recorded. Totals of kWh used per day were calculated for both the baseline energy system and the new energy system. After totals were computed, pie charts were created to determine what the percentage of total use was for each component in the dairy energy system. Results of these computations can be seen below. The “other” category consists of loads that did not change with the conversion from the baseline to the new energy system (lights, etc.).

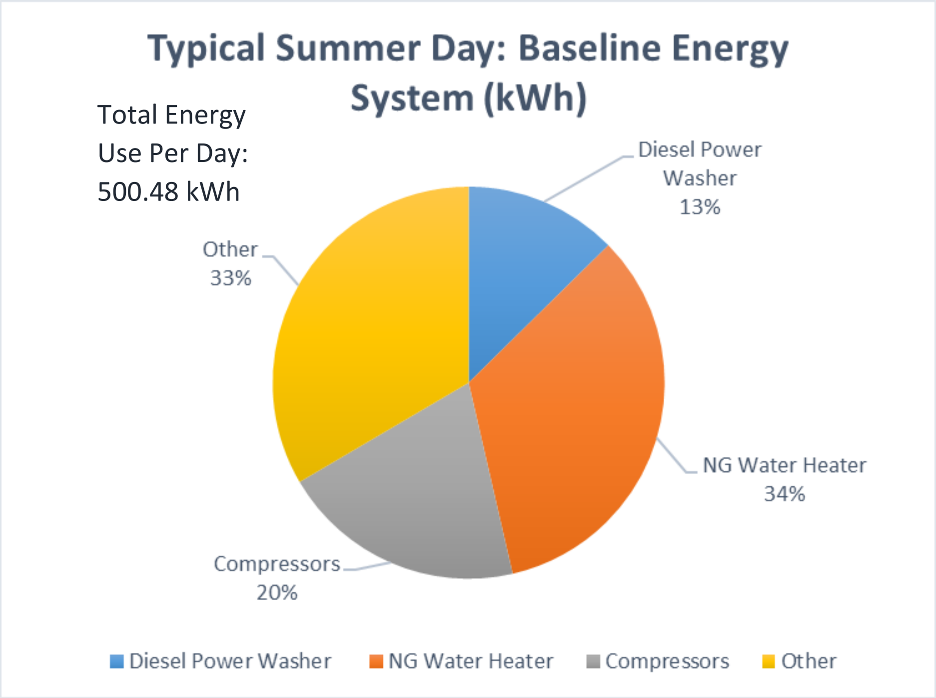

Figure 21: An example of a typical summer day when the baseline energy system is in use.

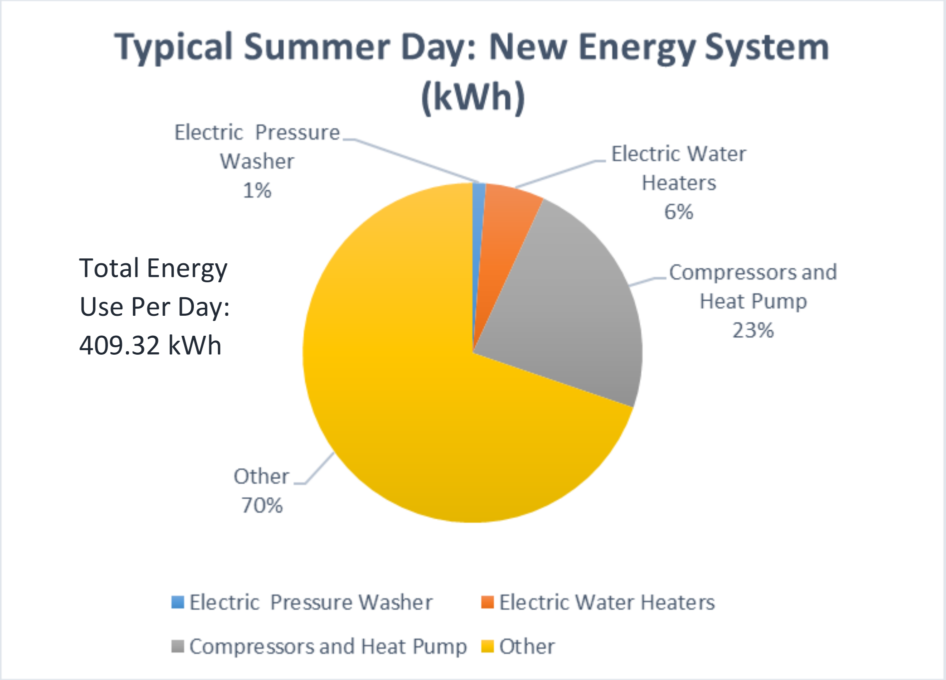

Figure 22: An example of a typical summer day when the new energy system is in use.

The total energy use for the baseline system in one day was 500.48 kWh. The total energy use for the new energy system in one day was 409.32 kWh. This is about an 18.2% reduction in total energy use from the baseline system to the new energy system. This reduction is even without the introduction of renewable energy systems, which will now be examined.

5.2 Energy Production

I. Pole Mounted 4 kW Solar

The data from the pole mounted 4 kW solar PV system was collected using the online Solar Web system from Fronius that monitors how much energy the PV system produces. The data were collected and analyzed in one day intervals, then totaled over each month. This was done in order to compare the projected energy production from this system to the actual energy production for this system. Also included in this graph is the average actual daily production to compare to the average predicted daily production. The results can be seen in the chart below.

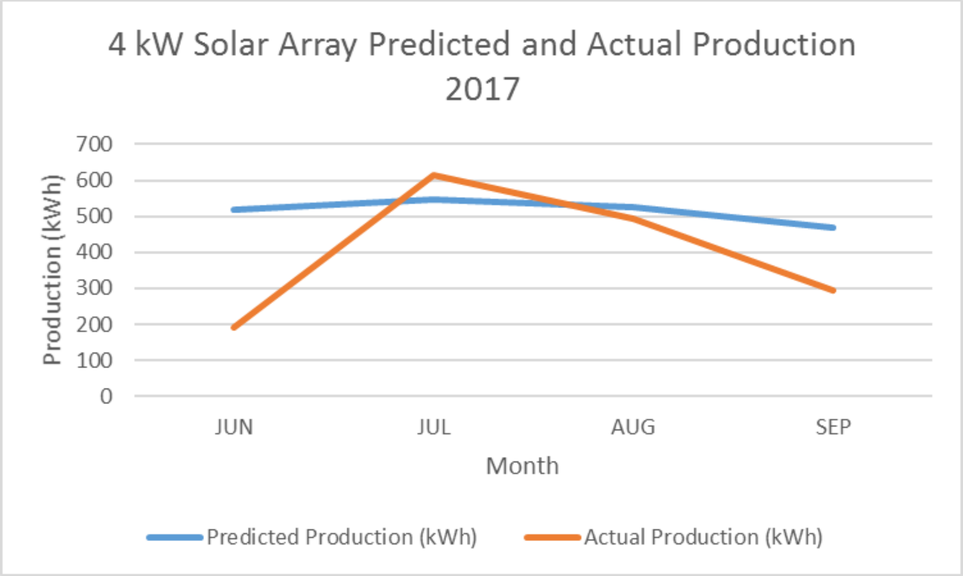

Figure 23: The predicted and actual production of the 4 kW solar system.

I. Ground Mounted 50 kW Solar

The data from the ground mounted 50 kW solar PV system was collected using an eGauge that monitors how much energy the PV system produces. The data was collected and analyzed in one hour intervals, then totaled for the day, and then totaled again for the month. This was done in order to compare the projected energy production from this system to the actual energy production for this system. The results can be seen in figure 24.

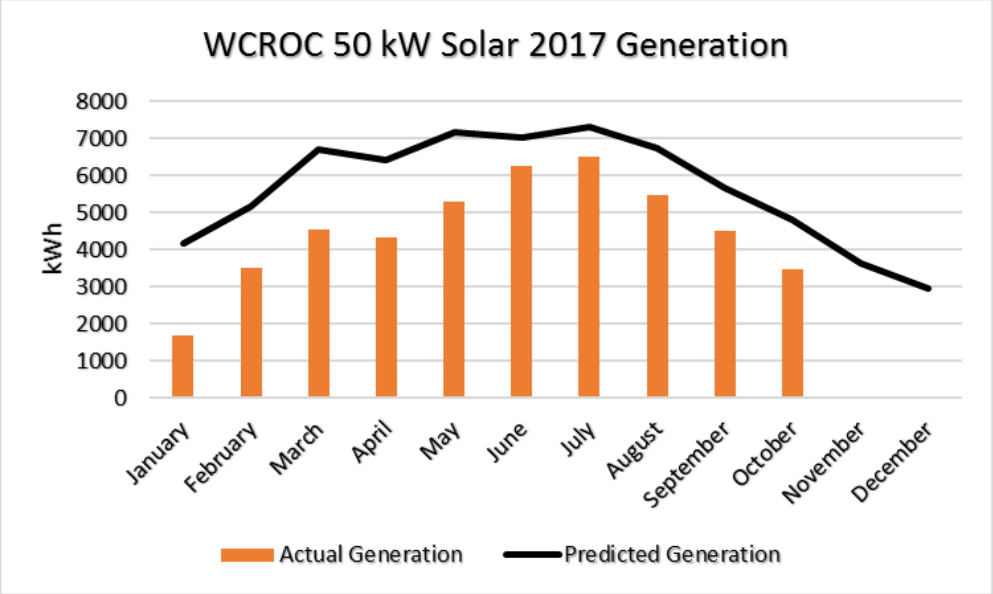

Figure 24: The predicted and actual energy production of the 50 kW solar array.

II. Two 10 kW Wind Turbines

The data from the 10 kW wind turbines was collected using the Bergey Online Wind Monitoring System to record how much energy the turbines produce. The data was collected and analyzed in one day intervals, then totaled over each month. This was done in order to compare the projected energy production from this system to the actual energy production for this system. The results can be seen in the charts below.

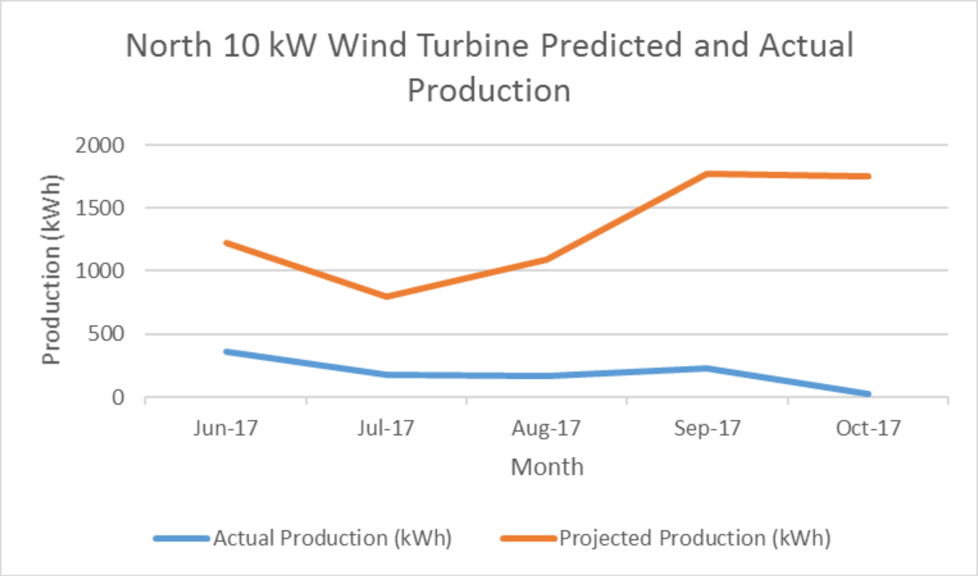

Figure 25: The predicted and actual energy production of the two 10 kW wind turbines.

III. Total Predicted Renewable Energy Production

Combining all of the predicted renewable energy production lines from figures 23, 24, and 25, the total renewable energy predicted production for an entire year can be calculated. This total energy production can then be compared to the total energy consumption of the WCROC dairy, and a net zero energy production analysis can be made. Below is a chart of the total predicted renewable energy production monthly for one year, including the 50 kW solar array, two 10 kW wind turbines, and the 4 kW solar array:

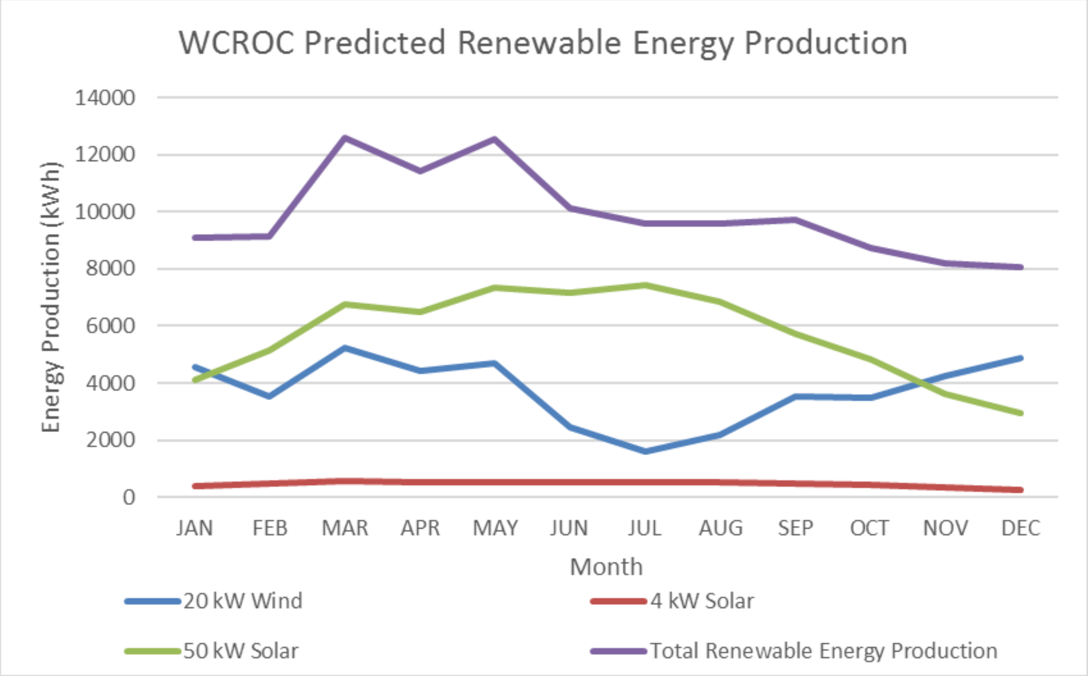

Figure 26: The total predicted renewable energy production over the course of one year.

7 Conclusion

7.1 Energy Use Compared to Energy Production: Net Zero?

In order to compare the total energy consumption to the total energy production, several calculations needed to be made. First, calculations of renewable energy production had to be made. These were based on the average insolation and wind speed in Morris that would cause energy production, then these were used to calculate an estimated amount of energy each renewable energy system would produce. Once an estimated monthly production was made for the 50 kW solar array, each 10 kW wind turbine, and the 4 kW solar array, the estimated monthly productions were added together to determine the total predicted renewable energy production each month for an entire year. This graph can be seen in figure 26. Next, the total amount of electricity, natural gas, and diesel consumption was calculated using data from the CR3000 data logger and the dairy barn eGauge to determine the amount of energy consumed each month. These totals can be seen for 2013 through 2017 in figure 19. Once all of these totals were calculated, the total amount of energy consumed and the amount of energy produced on-site were compared on the same graph. This can be seen in the graph below:

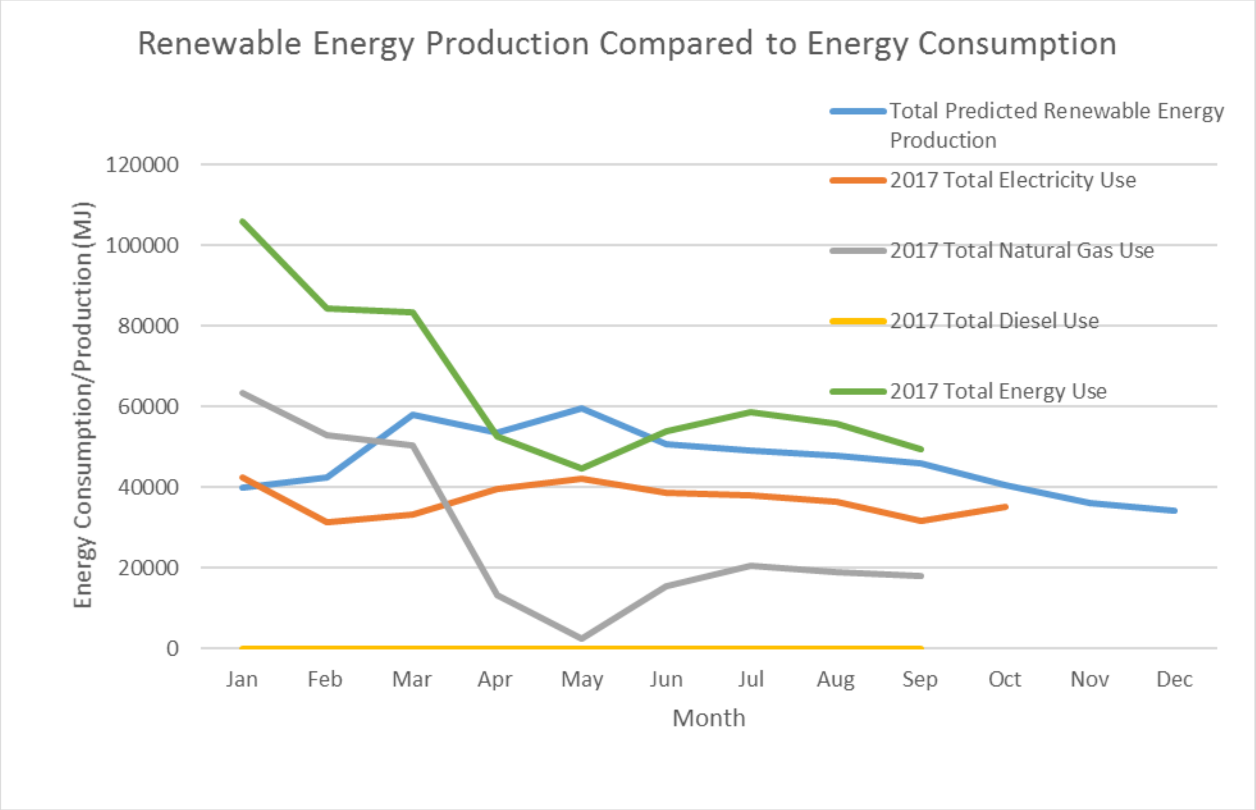

Figure 27: The total predicted renewable energy consumption for one year compared to the total energy consumption in 2017.

This graph represents 2017 data only with the new energy system in use. The red line represents the total electricity the barn used directly from the meter. This included any electricity going to the new utility room (new energy system) and the old utility room (baseline energy system), as well as any other electrical loads going into the dairy barn. The grey line represents the total natural gas use. As explained in figure 17, there is a sharp decrease in this line around March due to the use of the new electric water heaters instead of the natural gas water heaters. The yellow line is the total diesel use, which in 2017 is assumed to be zero due to the use of the electric pressure washer in place of the baseline diesel-powered pressure washer. The green line represents the total energy use, including electricity, natural gas, and diesel totals. Finally, the blue line represents the total predicted renewable energy production from the WCROC dairy farm renewable energy systems, a 50 kW solar array, two 10 kW wind turbines, and a 4 kW solar array. As can be seen from this graph, the total energy use in April is just slightly below the total predicted renewable energy production, suggesting that during this month, along with May, represents a net zero energy dairy production, as more energy was produced than was consumed during those months. Additionally, the amount of renewable energy produced in June is just slightly below the amount of total energy consumption, indicating that June 2017 was very close to being net zero energy. July and August show increases in natural gas usage, which indicated that the electric hot water heaters were probably out of commission during these months, causing the total energy consumption line to rise higher than the renewable energy production. From August to September, a decrease in energy use begins, as there is a decrease in natural gas use, indicating that now the electric hot water heaters are working again. The month of October is not included in the natural gas consumption line or the total energy consumption line because the bill for the natural gas will not arrive until mid-November.

Next, an environmental ethics analysis of increasing on farm sustainability was completed, in order to offer reasons and grounds for completing best practice updates on the farm. As claimed by most environmental ethicists, the best way to convince farmers to invest in the future of their farms is to explain the economic values and moral values associated with preserving the environment on the farm.

Finally, with respect to the economic analysis of the renewable energy systems and energy efficiency upgrades at the WCROC dairy farm, the economic viability of these investments was calculated. It was determined that the 50 kW solar array was the most successful investment, as within 25 years, the system will have paid for itself in energy savings, and will be returning money to the WCROC dairy with its energy savings.

7.2 Next Steps

The two main steps for achieving a net zero energy dairy production were, first, to identify energy inefficiencies in the system that can be replaced with newer, more efficient equipment to immediately reduce energy consumption. The next step was to install renewable energy components into the dairy, such as the heat pumps and heat exchangers that can capture heat previously ejected as waste product from milk when it comes out of the cow. The goal of this was to recycle heat that can be stored and used as “pre-heated” water for sanitation purposes after being brought to a high enough temperature using the high efficiency electric water heaters. After this step was completed, the next phase was installing renewable energy systems, including a 50 kW solar array, two 10 kW wind turbines, and a 4 kW solar array. The goal of this project is ultimately to create a net zero dairy production where the dairy barn uses as much energy as the amount of energy that is produced on-site for the dairy barn. Now that some data has been collected and some analysis of the system has been completed and explained through this paper, data collection must be continued to further assess the successes and areas of improvement of the dairy barn energy systems. Further analysis of the physical components of the new energy system, including the electric pressure washer, electric water heaters, and the heat pump must also be completed to ensure that they begin functioning normally every day so that the counterparts of these components in the baseline energy systems no longer need to be relied upon. A fully functioning new utility room is the next main goal for this project in order to continue towards the goal of a net zero energy dairy production.

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9 Appendices

Appendix 1: Figures and Tables

Figures:

original tank. The hot water rises to the top, and is transferred to a water heater, which can be used for potable purposes. (page 8)

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9. Figure 9: An example of what the eGauge monitoring system looks like for measuring the total electricity usage in the new utility room. This figure is a more concise visual of the pink line in figure 8 showing the total energy use for the new utility room in the dairy barn. Again, power generated is not shown in this figure. (page 13)
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11. Figure 11: 2015-16 Dairy electric loads at WCROC. (page 29)
12. Figure 12: A plate cooler in the new utility room at WCROC. (page 29)
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Tables:

Appendix 2: List of Renewable Energy and Energy Efficiency Upgrades Monetary Incentives

1. Wind Energy Sales Tax Exemption
   http://programs.dsireusa.org/system/program/detail/601
2. Wind and Solar-Electric (PV) Systems Exemption
   http://programs.dsireusa.org/system/program/detail/151
3. Ottertail Power Company- Dollar Smart Energy Efficiency Loan Program
   http://programs.dsireusa.org/system/program/detail/1530
4. Farm Opportunities Loan Program
   http://programs.dsireusa.org/system/program/detail/3395
5. Excel Energy Renewable Development Fund Grants
   http://programs.dsireusa.org/system/program/detail/1048
6. USDA Rural Energy for America Program Grants
   http://programs.dsireusa.org/system/program/detail/917
7. Energy Efficient Commercial Buildings Tax Deduction
   http://programs.dsireusa.org/system/program/detail/1271
8. Minnesota Power Solar Sense Rebate Program
   http://programs.dsireusa.org/system/program/detail/1092
9. FHA Power Saver Loan Program
   http://programs.dsireusa.org/system/program/detail/5631
10. Xcel Energy Solar Rewards Program
    http://programs.dsireusa.org/system/program/detail/5417

11. Renewable Energy Production Tax Credit
    http://programs.dsireusa.org/system/program/detail/734
12. Low Income Home Energy Assistance Program
    http://programs.dsireusa.org/system/program/detail/5712
13. USDA Repowering Assistance Biorefinery Program
    http://programs.dsireusa.org/system/program/detail/5316
14. Energy Incentive Programs, Minnesota
    https://energy.gov/eere/femp/energy-incentive-programs-minnesota
15. Minnesota Energy Tax Credit, Solar Rebates and Incentives
    https://www.dasolar.com/energytaxcredit-rebates-grants/minnesota
16. Made in Minnesota Solar Incentive Program
    https://mn.gov/commerce/industries/energy/solar/mim/

For more energy incentives in your region visit http://www.dsireusa.org/ and click on 'Minnesota' then search for your county, region, or energy provider.

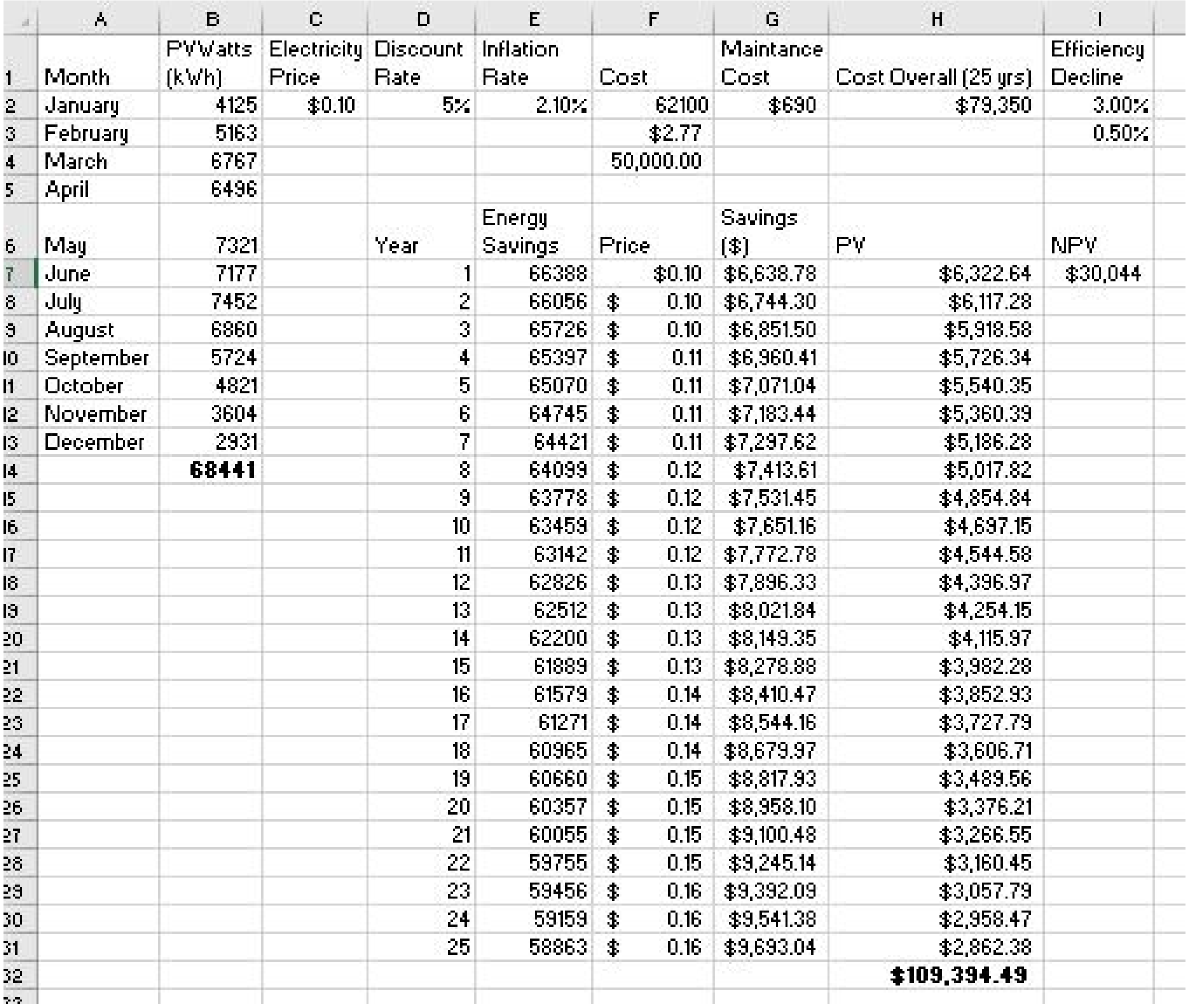
Appendix 3: Economic Analysis Spreadsheets

A	B	C	D	E	F	G	H	I	J
Month	VT10 Power	Electricity Price	Discount Rate	Inflation Rate	Efficiency Decline	Cost	Maintance Cost	Overall Cost (25	price per watt
January	2276	$0.10	5%	2.10%	1.50%	$78,400	$392	$88,200	$7.84
February	1756					$78,400			
March	2619		Year	Energy Savings	Price	Savings ($)	PV	NPV	
April	2210		1	$22,059.65	$0.10	2205.964577	2100.92	($55,359)	
May	2340		2	$21,728.75	$ 0.10	2218.505486	2012.25		
June	1224		3	$21,402.82	$ 0.10	2231.117689	1927.32		
July	800		4	$21,081.78	$ 0.11	2243.801594	1845.98		
August	1092		5	$20,765.55	$ 0.11	2256.557606	1768.07		
Septembe	1767		6	$20,454.07	$ 0.11	2269.386136	1693.45		
October	1751		7	$20,147.26	$ 0.11	2282.287596	1621.98		
November	2127		8	$19,845.05	$ 0.12	2295.262401	1553.52		
December	2433		9	$19,547.37	$ 0.12	2308.310967	1487.96		
	22396		10	$19,254.16	$ 0.12	2321.433715	1425.16		
			11	$18,965.35	$ 0.12	2334.631066	1365.01		
			12	$18,680.87	$ 0.13	2347.903444	1307.4		
			13	$18,400.66	$ 0.13	2361.251275	1252.22		
			14	$18,124.65	$ 0.13	2374.674988	1199.37		
			15	$17,852.78	$ 0.13	2388.175015	1148.75		
			16	$17,584.98	$ 0.14	2401.75179	1100.27		
			17	$17,321.21	$ 0.14	2415.405749	1053.83		
			18	$17,061.39	$ 0.14	2429.137331	1009.36		
			19	$16,805.47	$ 0.15	2442.946977	966.757		
			20	$16,553.39	$ 0.15	2456.83513	925.955		
			21	$16,305.09	$ 0.15	2470.802238	886.876		
			22	$16,060.51	$ 0.15	2484.848749	849.445		
			23	$15,819.60	$ 0.16	2498.975114	813.595		
			24	$15,582.31	$ 0.16	2513.181787	779.257		
			25	$15,348.58	$ 0.16	2527.469226	746.369		

Table 1 Energy Efficiency Upgrades Net Present Value Spreadsheet. The red NPV indicates that the value is negative.

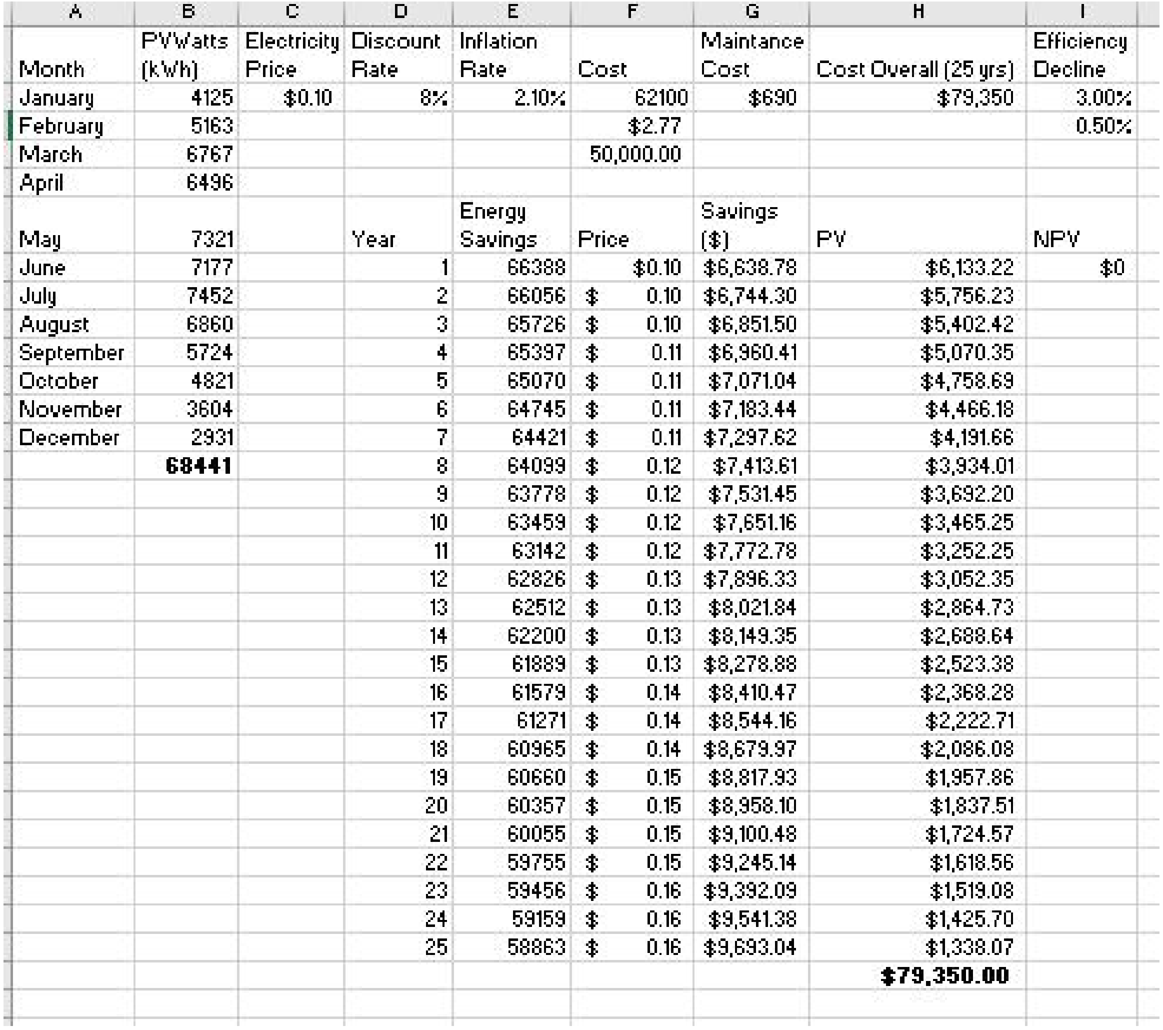
A	B	C	D	E	F	G	H	I	J
Energy Savings		Fuel Prices	Discount Rate	Cost	Maintanence Cost ($/yr)	Overall Cost (25	Inflation Rate		
	Electricity	$0.10	-6%	$103,350	$1,150	$132,100	3.50%		
$3,875.76	Natural Gas	$0.74							
	Diesel	$2.50							
$6,489.90	Propane	$1.20							
			Year	Energy Savings	Price	Savings ($)	PV		NPV
			1	$3,856.38		3725.972	3965.2	3846.2	$0
			2	$3,837.10		3581.973	4056.6	3934.9	
			3	$3,817.91		3443.54	4150.2	4025.7	
			4	$3,798.82		3310.456	4245.9	4118.5	
			5	$3,779.83		3182.516	4343.9	4213.5	
			6	$3,760.93		3059.52	4444.1	4310.7	
			7	$3,742.13		2941.277	4546.6	4410.2	
			8	$3,723.42		2827.605	4651.4	4511.9	
			9	$3,704.80		2718.325	4758.7	4616	
			10	$3,686.27		2613.269	4868.5	4722.4	
			11	$3,667.84		2512.273	4980.8	4831.4	
			12	$3,649.50		2415.181	5095.7	4942.8	
			13	$3,631.26		2321.84	5213.2	5056.8	
			14	$3,613.10		2232.108	5333.5	5173.5	
			15	$3,595.03		2145.842	5456.5	5292.8	
			16	$3,577.06		2062.911	5582.4	5414.9	
			17	$3,559.17		1983.185	5711.1	5539.8	
			18	$3,541.38		1906.54	5842.9	5667.6	
			19	$3,523.67		1832.858	5977.6	5798.3	
			20	$3,506.05		1762.023	6115.5	5932.1	
			21	$3,488.52		1693.925	6256.6	6068.9	
			22	$3,471.08		1628.459	6400.9	6208.9	
			23	$3,453.72		1565.524	6548.5	6352.1	
			24	$3,436.46		1505.021	6699.6	6498.6	
			25	$3,419.27		1446.855	6854.1	6648.5	

Table 2 Energy Efficiency Upgrades Internal Rate of Return Spreadsheet



	A	B	C	D	E	F	G	H	I
1	Month	PVWatts (kWh)	Electricity Price	Discount Rate	Inflation Rate	Cost	Maintance Cost	Cost Overall (25 yrs)	Efficiency Decline
2	January	4125	$0.10	5%	2.10%	62100	$690	$79,350	3.00%
3	February	5163				$2.77			0.50%
4	March	6767				50,000.00			
5	April	6496							
6	May	7321		Year	Energy Savings	Price	Savings ($)	PV	NPV
7	June	7177		1	66388	$0.10	$6,638.78	$6,322.64	$30,044
8	July	7452		2	66056	$ 0.10	$6,744.30	$6,117.28	
9	August	6860		3	65726	$ 0.10	$6,851.50	$5,918.58	
10	September	5724		4	65397	$ 0.11	$6,960.41	$5,726.34	
11	October	4821		5	65070	$ 0.11	$7,071.04	$5,540.35	
12	November	3604		6	64745	$ 0.11	$7,183.44	$5,360.39	
13	December	2931		7	64421	$ 0.11	$7,297.62	$5,186.28	
14		**68441**		8	64099	$ 0.12	$7,413.61	$5,017.82	
15				9	63778	$ 0.12	$7,531.45	$4,854.84	
16				10	63459	$ 0.12	$7,651.16	$4,697.15	
17				11	63142	$ 0.12	$7,772.78	$4,544.58	
18				12	62826	$ 0.13	$7,896.33	$4,396.97	
19				13	62512	$ 0.13	$8,021.84	$4,254.15	
20				14	62200	$ 0.13	$8,149.35	$4,115.97	
21				15	61889	$ 0.13	$8,278.88	$3,982.28	
22				16	61579	$ 0.14	$8,410.47	$3,852.93	
23				17	61271	$ 0.14	$8,544.16	$3,727.79	
24				18	60965	$ 0.14	$8,679.97	$3,606.71	
25				19	60660	$ 0.15	$8,817.93	$3,489.56	
26				20	60357	$ 0.15	$8,958.10	$3,376.21	
27				21	60055	$ 0.15	$9,100.48	$3,266.55	
28				22	59755	$ 0.15	$9,245.14	$3,160.45	
29				23	59456	$ 0.16	$9,392.09	$3,057.79	
30				24	59159	$ 0.16	$9,541.38	$2,958.47	
31				25	58863	$ 0.16	$9,693.04	$2,862.38	
32								**$109,394.49**	

Table 3 50 kW Solar Array Net Present Value Spreadsheet



A	B	C	D	E	F	G	H	I
Month	PVWatts (kWh)	Electricity Price	Discount Rate	Inflation Rate	Cost	Maintance Cost	Cost Overall (25 yrs)	Efficiency Decline
January	4125	$0.10	8%	2.10%	62100	$690	$79,350	3.00%
February	5163				$2.77			0.50%
March	6767				50,000.00			
April	6496							
May	7321		Year	Energy Savings	Price	Savings ($)	PV	NPV
June	7177		1	66388	$0.10	$6,638.78	$6,133.22	$0
July	7452		2	66056	$ 0.10	$6,744.30	$5,756.23	
August	6860		3	65726	$ 0.10	$6,851.50	$5,402.42	
September	5724		4	65397	$ 0.11	$6,960.41	$5,070.35	
October	4821		5	65070	$ 0.11	$7,071.04	$4,758.69	
November	3604		6	64745	$ 0.11	$7,183.44	$4,466.18	
December	2931		7	64421	$ 0.11	$7,297.62	$4,191.66	
	68441		8	64099	$ 0.12	$7,413.61	$3,934.01	
			9	63778	$ 0.12	$7,531.45	$3,692.20	
			10	63459	$ 0.12	$7,651.16	$3,465.25	
			11	63142	$ 0.12	$7,772.78	$3,252.25	
			12	62826	$ 0.13	$7,896.33	$3,052.35	
			13	62512	$ 0.13	$8,021.84	$2,864.73	
			14	62200	$ 0.13	$8,149.35	$2,688.64	
			15	61889	$ 0.13	$8,278.88	$2,523.38	
			16	61579	$ 0.14	$8,410.47	$2,368.28	
			17	61271	$ 0.14	$8,544.16	$2,222.71	
			18	60965	$ 0.14	$8,679.97	$2,086.08	
			19	60660	$ 0.15	$8,817.93	$1,957.86	
			20	60357	$ 0.15	$8,958.10	$1,837.51	
			21	60055	$ 0.15	$9,100.48	$1,724.57	
			22	59755	$ 0.15	$9,245.14	$1,618.56	
			23	59456	$ 0.16	$9,392.09	$1,519.08	
			24	59159	$ 0.16	$9,541.38	$1,425.70	
			25	58863	$ 0.16	$9,693.04	$1,338.07	
							$79,350.00	

Table 4 50 kw Solar Array Internal Rate of Return Spreadsheet

Month	VT10 Power	Electricity Price	Discount Rate	Inflation Rate	Efficiency Decline	Cost	Maintance Cost	Overall Cost (25	price per watt
January	2276	$0.10	5%	2.10%	1.50%	$78,400	$392	$88,200	$7.84
February	1756					$78,400			
March	2619		Year	Energy Savings	Price	Savings ($)	PV	NPV	
April	2210		1	$22,059.65	$0.10	2205.964577	2100.92	($55,359)	
May	2340		2	$21,728.75	$ 0.10	2218.505486	2012.25		
June	1224		3	$21,402.82	$ 0.10	2231.117689	1927.32		
July	800		4	$21,081.78	$ 0.11	2243.801594	1845.98		
August	1092		5	$20,765.55	$ 0.11	2256.557606	1768.07		
September	1767		6	$20,454.07	$ 0.11	2269.386136	1693.45		
October	1751		7	$20,147.26	$ 0.11	2282.287596	1621.98		
November	2127		8	$19,845.05	$ 0.12	2295.262401	1553.52		
December	2433		9	$19,547.37	$ 0.12	2308.310967	1487.96		
	22396		10	$19,254.16	$ 0.12	2321.433715	1425.16		
			11	$18,965.35	$ 0.12	2334.631066	1365.01		
			12	$18,680.87	$ 0.13	2347.903444	1307.4		
			13	$18,400.66	$ 0.13	2361.251275	1252.22		
			14	$18,124.65	$ 0.13	2374.674988	1199.37		
			15	$17,852.78	$ 0.13	2388.175015	1148.75		
			16	$17,584.98	$ 0.14	2401.75179	1100.27		
			17	$17,321.21	$ 0.14	2415.405749	1053.83		
			18	$17,061.39	$ 0.14	2429.137331	1009.36		
			19	$16,805.47	$ 0.15	2442.946977	966.757		
			20	$16,553.39	$ 0.15	2456.83513	925.955		
			21	$16,305.09	$ 0.15	2470.802238	886.876		
			22	$16,060.51	$ 0.15	2484.848749	849.445		
			23	$15,819.60	$ 0.16	2498.975114	813.595		
			24	$15,582.31	$ 0.16	2513.181787	779.257		
			25	$15,348.58	$ 0.16	2527.469226	746.369		

Table 5 10 kW Wind Turbines Net Present Value Spreadsheet

A	B	C	D	E	F	G	H	I	J
Month	VT10 Power	Electricity Price	Discount Rate	Inflation Rate	Efficiency Decline	Cost	Maintance Cost	Overall Cost (25	price per watt
January	2276	$0.10	-3%	2.10%	1.50%	$78,400	$392	$88,200	$7.84
February	1756					$78,400			
March	2619		Year	Energy Savings	Price	Savings ($)	PV	NPV	
April	2210		1	$22,059.65	$0.10	2205.964577	2269.87	$0	
May	2340		2	$21,728.75	$ 0.10	2218.505486	2348.91		
June	1224		3	$21,402.82	$ 0.10	2231.117689	2430.7		
July	800		4	$21,081.78	$ 0.11	2243.801594	2515.34		
August	1092		5	$20,765.55	$ 0.11	2256.557606	2602.92		
September	1767		6	$20,454.07	$ 0.11	2269.386136	2693.55		
October	1751		7	$20,147.26	$ 0.11	2282.287596	2787.34		
November	2127		8	$19,845.05	$ 0.12	2295.262401	2884.4		
December	2433		9	$19,547.37	$ 0.12	2308.310967	2984.84		
	22396		10	$19,254.16	$ 0.12	2321.433715	3088.77		
			11	$18,965.35	$ 0.12	2334.631066	3196.32		
			12	$18,680.87	$ 0.13	2347.903444	3307.62		
			13	$18,400.66	$ 0.13	2361.251275	3422.79		
			14	$18,124.65	$ 0.13	2374.674988	3541.97		
			15	$17,852.78	$ 0.13	2388.175015	3665.3		
			16	$17,584.98	$ 0.14	2401.75179	3792.93		
			17	$17,321.21	$ 0.14	2415.405749	3925		
			18	$17,061.39	$ 0.14	2429.137331	4061.67		
			19	$16,805.47	$ 0.15	2442.946977	4203.1		
			20	$16,553.39	$ 0.15	2456.83513	4349.45		
			21	$16,305.09	$ 0.15	2470.802238	4500.9		
			22	$16,060.51	$ 0.15	2484.848749	4657.62		
			23	$15,819.60	$ 0.16	2498.975114	4819.8		
			24	$15,582.31	$ 0.16	2513.181787	4987.62		
			25	$15,348.58	$ 0.16	2527.469226	5161.29		

Table 6 10 kW Internal Rate of Return Spreadsheet

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