A DECISION SUPPORT SYSTEM TO EVALUATE THE ECONOMIC FEASIBILITY OF SOLAR TECHNOLOGY ON DAIRY FARMS

By

Helen Miller

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Biosystems Engineering – Master of Science

2023

ABSTRACT

In 2020, the U.S. dairy industry launched its Net Zero Initiative (NZI) to encourage voluntary on-farm efforts to reduce the environmental impacts of dairy farming. Implementing energy efficient and renewable energy technologies on farms will play a critical role in reducing the greenhouse gas emissions of dairy farms in the United States. This research conducted a survey which found there is significant interest in installing solar panels on dairy farms. However, many farmers feel solar panels are too expensive and time consuming to install. Additionally, 51% of participants were not aware of government incentives related to on-farm renewable energy investments. The survey also found that many farmers rely on word of mouth, University Extension, and farm organization meetings as sources of information. A regression analysis was done on energy audit data from 132 dairy farms throughout Michigan. It was concluded that for every 1% increase in the number of milking cows, the annual electricity consumption will increase by 0.93%. Then, a case study was performed using the median subject from the energy audit data, consisting of 180 cows, to evaluate if solar panels would be a good investment for the subject farm. It was estimated that installing panels to produce their annual electricity consumption would cost $92,722 to install, have a net present value of $221,053, and have a payback period of 5.13 years. This suggests that installing solar panels would be economically beneficial for the subject dairy farm. A decision support system (DSS) was created to allow dairy farmers to enter pertinent data of their farm, then assess the economic feasibility of deploying the available solar technologies to power their farm operations. The DSS will advance the goal of the Net Zero Initiative by educating dairy farmers about the opportunities and challenges of using solar technologies on their farms including funding opportunities, Extension resources, and answers to frequently asked questions.

ACKNOWLEDGEMENTS

I am incredibly grateful to Dr. Ajit Srivastava for providing me guidance throughout the entirety of this thesis and academic program. I would like to thank Dr. Srivastava for his mentorship, wisdom, and endless opportunities to get involved in new projects. Working with Dr. Srivastava was the highlight of this process, his passion for bettering the world is something I hope to carry with me for the rest of my life. Additionally, I would like to thank my committee, Dr. Timothy Harrigan, Dr. Satish Joshi, and Mr. Aluel Go for their continual support throughout this project.

Many thanks to Mr. Jeffrey Siarto for his expertise in website development. The resources and coursework he provided was crucial for this project. I would also like to thank Mr. Dean Letter and the Michigan Milk Producers Association for providing me valuable feedback and a mode to connect with dairy farmers through a trusted organization. In addition, I am grateful to Mr. Tom Stanton for his consultation and feedback on the content of the website.

Finally, I am incredibly thankful for the support of my family, especially my sister. Phone calls with you were the best part of each day. I would also like to thank Ben for grounding me throughout this process, you remind me what matters most.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ASABE	American Society of Agricultural and Biological Engineers
CSS	Cascading Style Sheets
DSS	Decision Support System
EAW	Equivalent Annual Worth
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GHG	Greenhouse Gases
HTML	HyperText Markup Language
ITC	Investment Tax Credit
JS	JavaScript
KWH	Kilowatt-Hours
MFEP	Michigan Farm Energy Program
MMPA	Michigan Milk Producers Association
MSU	Michigan State University
NA	Not Available
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NZI	Net Zero Initiative
PV	Photovoltaic
Q-Q	Quantile-Quantile
REAP	Rural Energy for America Program

SAM	System Advisor Model
SRECs	Solar Renewable Energy Certificates
SSE	Sum of Squared Estimate of Errors
USDA	United States Department of Agriculture

1.0 INTRODUCTION

With the world's growing population comes the increased demand for food production (FAO, 2009). As more food is produced, agricultural production must become more sustainable to feed the growing population. While farms in the United States (U.S.) produce a significant amount of food, they are also responsible for the emission of greenhouse gasses, reduced biodiversity, and the degradation of natural resources (Reganold et al., 2011). The increase in greenhouse gasses in the atmosphere contributes to global warming, resulting in higher temperatures throughout the year. These higher temperatures during the growing season can have detrimental impacts on the productivity and profitability of farming, as well as food security (Battisti & Naylor, 2009). Therefore, agriculture in the United States must progress towards long-term sustainability while also maintaining its productivity and its profitability.

Dairy farms are a significant contributor to total greenhouse gas (GHG) emissions in the United States, with dairy cattle producing 1.3% of the U.S. total emissions (EPA, 2017). With the growing population, the global consumption of dairy products excluding butter is expected to increase by roughly 58% by 2050 (FAO, 2011). Given the increasing demand for dairy products, efforts must be made to counteract the greenhouse gas emissions that will ensue from the resulting increase in milk production.

In 2020, the U.S. dairy industry launched its Net Zero Initiative (NZI) with the goal of achieving carbon neutrality, optimized water usage, and improved water quality by 2050 (U.S. Dairy, 2021). Through the introduction of accessible and affordable sustainability practices, the initiative aims to encourage voluntary on-farm efforts to reduce the environmental impacts of dairy farming. The key areas of focus for NZI include feed production and practice changes, manure handling and nutrient management, cow care and efficiency, and on-farm energy efficiency and renewable energy usage (U.S. Dairy, 2021).

In the United States, 72% of the GHG emissions from dairy farms occur during on-farm processes (Thoma et al., 2013). Thus, implementing energy efficient and renewable energy technologies on farms will play a critical role in reducing the GHG emissions of dairy farms in the United States. Given the amount of electricity they consume, dairy farms are a crucial target for renewable energy implementation. With the cost of solar panels significantly decreasing, solar power is a more affordable option than other renewable energy sources (Louwen, 2020).

In Michigan, the cost of electricity increases by 2.96% annually (Solar Reviews, 2022). These prices are subject to market fluctuations caused by supply and demand shifts, availability, and pricing regulations. Due to the cost of delivering electricity, prices tend to be higher for residential and smaller corporate consumers as compared to large industrial consumers. Given the low selling price of milk produced, Michigan dairy farmers are vulnerable to the added cost of production caused by increasing electricity prices. The implementation of photovoltaic energy on dairy farms can protect farmers from fluctuating energy prices and reduce the cost of milk production, which can lead to greater profit.

A Decision Support System to Evaluate the Economic Feasibility of Solar Technology on Dairy Farms will provide an affordable and accessible source of information to help dairy farmers consider sustainable energy alternatives. The decision support system (DSS) will progress the NZI by educating dairy farmers about the opportunities and challenges of using solar technologies on their farms. With the existence of a decision support tool, farmers will be able to evaluate the economic feasibility of installing existing solar photovoltaic technology on their farms, allowing them to make informed decisions about on-farm changes.

The outcome of this project will be the creation of a computer program that allows dairy farmers to enter pertinent features of their farm, then assess the feasibility of deploying the available solar technologies to power their farm operations. Users of the program will be able to clearly recognize the economic and environmental impacts of adopting solar technologies. It is hypothesized that the use of solar energy on dairy farms will be economically beneficial, and dairy farmers will be more receptive to sustainable developments when presented with financial information that is relevant to their farm.

2.0 LITERATURE REVIEW

2.1 Energy Use in Agriculture

The agricultural industry is an energy intensive industry, often consumed in the form of fossil fuels and fertilizers (Schnepf, 2004). Fossil fuels were introduced to allow for greater and more consistent production on farms, however, the burning of fossil fuels releases greenhouse gasses that change climate patterns on a global scale (Cruse, 2009). In addition to GHG emissions, the use of fossil fuels also has adverse effects in broadband chemical application and in soil degradation. Furthermore, fossil fuel reliance makes farmers vulnerable to energy fluctuations, which is caused by crises in supply regions. With a growing population, dependence on fossil fuel by the agricultural industry poses major environmental, economic, and social risks for the world.

In the United States, roughly 15% of agricultural production expenses are energy related each year (NALC, 2004). Due to this reliance on energy, fluctuations in energy prices can have a major impact on farm revenues. With the upward trend of energy prices, agriculture will face reductions in profitability and scarcity of resources. Sustainable agriculture focuses on environmental health, economic profitability, and social and economic equity (SARE, n.d.). Farms need to start implementing sustainable agriculture practices that will be dependable for multiple years of operation.

In 2015, the United States Department of Agriculture (USDA) created the program Building Blocks for Climate Smart Agriculture and Forestry. This program was developed to help farmers counteract climate change through supporting efforts to reduce greenhouse gas emissions, increase carbon storage, and generate renewable energy (USDA, 2016). Various government programs such as this provide incentives for farmers to voluntarily move toward conservation strategies. There are multiple support systems in place such as the National Energy On-Farm

Initiative (NOFEI), Energy Efficiency and Conservation Loan Program, the High Energy Cost Grant Program, and many others to provide farmers with the funding necessary to use renewable energy on their land (USDA, n.d.).

While many governmental agencies provide incentives to farmers to switch to renewable energy, several factors prevent farmers from acting. Roughly 24% of agricultural employees reported working over 60 hours per week (Time Consuming Occupations, 2005). With the time-consuming nature of farming, there is little time for farmers to do needed research prior to making major farm decisions such as transitioning to solar energy. Additionally, farmers may not know where to search for information or what to look for. This hinders their ability to access information about the incentives to switch to renewable energy. The government programs also tend to require an official energy audit. With remote rural locations and little understanding of potential benefits, many farmers may not want to spend the time or money or to secure an auditor, especially when they are unsure whether solar energy is a viable option.

In 2011, a study was done with 53 Michigan farmers to evaluate their perspectives on climate change. It was determined that farmers were more focused on non-climate factors when making decisions about their farm, with the most common factor being economics (Doll et al., 2017). In addition, if farmers did take action to adapt to sustainable practices, that action must address the specific needs on their farm. In other words, generalized technology and initiatives may not be effective drivers of change, resulting in the need for customizable decision support tools that emphasize the economics of sustainability.

2.2 Solar Energy

In Michigan, the cost of solar energy has declined 45% in the last five years ("Michigan Solar," n.d.). With the cost of introducing solar panels to a farm significantly decreasing, it is quickly becoming a more affordable option. Solar power is also becoming more accessible. There are currently over one hundred solar power supply chain businesses that work to manufacture, install, and maintain photovoltaic operations in Michigan (Michigan Solar, n.d.).

There are several economic benefits to solar power. In addition to reducing or eliminating electricity bills, farmers can earn tax credits and other benefits. These benefits can include, but are not limited to, federal income tax credit, Solar Renewable Energy Credits (SRECs), and other local and state rebates (USGBC, 2017). Dairy farmers will also be eligible for incentives that are just for farmers, dairy farms, and other renewable energy specific farm initiatives.

Solar power is the best alternative to coal, natural gas, and nuclear power. Fossil fuel production requires a significant amount of water for cooling throughout its production, making it susceptible to negative impacts of droughts and heat waves (USGBC, 2017). Solar power will not rely on water to operate, nor will it pollute water resources. This makes it a reliable source of energy, thriving during heat waves and unaffected by drought. Wind and hydroelectric power are highly dependent on having wind and water sources available to capture energy, whereas farms in Michigan receive enough solar irradiation to create a substantial amount of power (NREL, 2018). On average, Michigan receives approximately 1600 $kWh/m^2/year$ solar irradiation, which is significantly more than Germany, the world leader in photovoltaic implementation, with 1200 $kWh/m^2/year$ (Wirth, 2023).

In addition to benefiting the planet, consuming renewable energy on farms will benefit farmers as well. High costs of energy create economic challenges for farmers, plus the declining supply of fossil fuels is raising concerns regarding how the world's growing population will be fed. Changes in the supply and demand of energy will have a major impact on the profitability of farming (Schnepf, 2004). As farmers produce their own energy and reduce their energy consumption overall, there will be reductions in expenses resulting in greater profits. Additionally, there is the possibility of selling excess energy for profit.

2.3 Energy Use on Dairy Farms

Dairy farms are a perfect target for renewable energy implementation given the energy intensive operations performed on these farms. These operations include milk cooling, lighting, vacuum pumps, electric space heating, water heating, and ventilation (Shine et al., 2020). Electricity consumed per gallon produced is dependent on a range of factors such as number of cows per farm, pasture versus confined management, and level of mechanization (Mohsenimanesh, 2021). For pasture-based dairies, irrigation of pasture is the primary use of electricity. In confined dairies, most of the consumed electricity is used to run the barn and the milking parlor (Belflower, 2009). While confined dairies tend to produce higher milk yields per cow than pasture-based dairies, they are less energy efficient as they require the use of energy-intensive technology such as lights, fans, and pumps (Mohsenimanesh, 2021). It was determined that farms saw as much as a 35% reduction in electricity consumption when using a pasture-based system as compared to a confined dairy (Shine et al., 2020).

Small scale upgrades such as lighting fixtures and higher efficiency motors are advertised to dairy farmers, but they lack the long-term energy security that solar energy can provide. It was determined that dairy operations can save between 10% and 40% of electricity through reliable energy efficient technology (Dairy Farm Energy Management Handbook, n.d.). With the combination of energy conservation practices and energy generation technology, it is possible for many dairy operations to achieve net-zero electricity (Mohsenimanesh, 2021).

Several models have been developed to analyze electricity consumption on dairy farms. Motivation for these models stems from rising electricity prices, increased production costs, and efforts to evaluate the impacts of managerial decisions on farmer electricity bills (Shine, et al., 2020). On a model created for dairy farms in Ireland, the business decision involved whether it was cheaper to operate the farm at night versus during the day, as Ireland tariffs on electricity vary based on flat versus day and night rates (Upton, et al., 2014). While dairy energy models do exist, they tend to be specific to a particular geographical region (e.g., Iran, Ireland, etc.) or business decision (e.g., pre-cooling milk on a plate cooler).

Even though existing energy models are not applicable to dairy farms in Michigan, they still provide useful information about energy consumption on dairy farms. Upton et al. developed a model of electricity consumption on dairy farms through conveying the inputs and processes that go into milk production (Upton, et al., 2014). The electricity consumption occurs during milk cooling, water heating, milking machines, lighting, pumps, and winter housing. For a given farm, these processes may differ from this model. Existing models like the one created by Upton et al. can be used as a foundation for developing the solar energy DSS. With the analysis of existing energy models, it can be ensured that the solar energy DSS will incorporate the many elements that contribute to energy consumption on dairy farms and use that information to create a more accurate economic model.

On a global scale, the consumption of milk and dairy products is expected to increase by 19% per person by 2050 (Alexandratos, 2012). As a result, an increase in the production of dairy products will need to occur to keep up with the growing demand. This indicates that with the growth in milk production, the demand for energy in the dairy industry will also escalate. For dairy farmers to find an alternative energy solution, there must be a program to help them determine if transitioning to solar energy is technically and economically feasible for their dairy operation.

2.4 History of Decision Making in Agriculture

For years farmers have had to rely solely on observation and recollection to make decisions about their farm (Pope, 2020). When farms were smaller and more closely managed, farmers could directly observe the factors that influenced their decision making, such as giving a cow a smaller portion of grain when it was no longer producing milk. With the introduction of Land Grant universities and the USDA, Extension services were able to get involved in farmer decision making, conducting research, and getting information directly from these farmers (NIFA, n.d.). In a study of nine hundred farmers in the United States, it was found that farmers trust other farmers and agribusiness for making production management decisions, and they trust university Extension for climate change information (Borrelli et al., 2018).

As technology makes data collection more efficient and farming decisions become more complex, there is a need for tools that can be used to assist farmers in making these decisions. While farmers may be hopeful about the potential benefits of technological tools, some may be skeptical due to a lack of experience. Although there is a lot of data available to them, that data and information does not directly appeal to the decisions that the farmer needs to make. Additionally, the provided data does not incorporate the specific constraints of their own farm operation.

2.5 Data Collection

To gain an understanding of decision making in agriculture, and to better inform the process of developing the decision support tool, data must be collected from farmers. Data collection can occur in the form of interviews, focus groups, phone calls, surveys, and many other options. In 2019, a comprehensive review was done focusing on quantitative studies of the adoption of agricultural conservation practices. It was found that a majority of data collected occurred through mail surveys, with interviews making up only 11.83% of data collected (Prokopy et.al, 2019). For this reason, surveys are considered the most effective method of collecting data from farmers. However, in a study spanning from 1971 to 2017, there was a significant decline in response rates in survey studies (Stedman et. al, 2019).

There are several methods to improve response rates such as contacting participants multiple times, and providing incentives for participation (Anseel et.al, 2010). Additionally, surveys sponsored by universities or trusted organizations have been found to have increased response rates compared to those held by private sponsors. One solution was to offer many choices in terms of response modes. It was determined that providing the choice of several modes sequentially is effective at improving response rates but offering many mode choices simultaneously does not improve response rates (Millar & Dillman, 2011).

In 2021, a review of multiple survey studies was published to examine the best practices for survey research involving agricultural producers in the Midwest. Based on this review, coupling a participation incentive with a follow-up email is an effective method of increasing survey participation (Avemegah et. al, 2020). Additionally, informing participants that the survey is from Michigan State University will increase the chance that farmers will be willing to participate.

2.6 Existing Solar Energy Models

In *Review: Dairy Farm Electricity Use, Conservation, and Renewable Production - A Global Perspective,* various decision support systems were listed that are meant to assist dairy farmers in modeling their electricity usage. Most of the sources listed do model energy use on dairy farms, but they do not directly address the implementation of solar energy on dairy farms (Mohsenimanesh, 2021). The National Renewable Energy Lab (NREL) created PVWatts, the leading program to help individuals make decisions regarding solar energy investment (PVWatts Calculator, n.d.). PVWatts is an online program that incorporates geographical weather data, solar panel specifications, and local energy costs to give an expected performance of how many kilowatt hours would be generated per year (Figure 1). The output also includes local irradiation data and the dollar value of the energy generated. While PVWatts provides useful information, it does not provide enough information to guide this major economic decision.

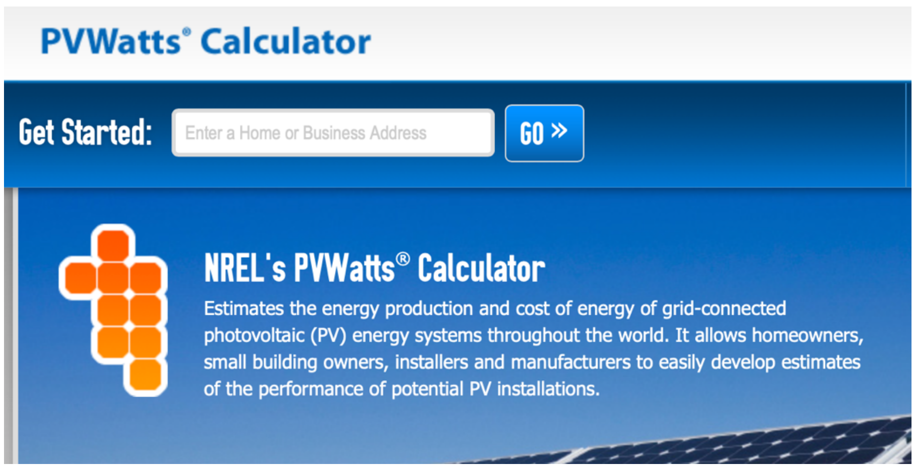


Figure 1. PVWatts online calculator (PVWatts Calculator, n.d.)

The NREL also created a downloadable application called the System Advisor Model (SAM). This model goes into much greater depth about system inputs, then produces a more comprehensive output that includes an energy loss diagram, analysis of cash flow, and other performance and financial metrics (Sam Help Manual, 2020). Inputs include items such as PV system specifications, economics, and performance adjustments. The output is a downloadable report that restates the inputs and then provides financial metrics to evaluate the profitability of the decision (Figures 2 & 3).

System Advisor Model Report

PVWatts	50.0 DC MW Nameplate	33.45, -111.98
Sale Leaseback	$1.03/W Installed Cost	UTC -7

Performance Model

PV System Specifications	
System nameplate size	50,000 kW
Module type	0
DC to AC ratio	1.2
Rated inverter size	41,666.67 kW
Inverter efficiency	96 %
Array type	fixed open rack
Array tilt	33 degrees
Array azimuth	180 degrees
Ground coverage ratio	N/A
Total system losses	14.08 %
Shading	no

Performance Adjustments	
Availability/Curtailment	none
Degradation	0.500000 %/yr
Hourly or custom losses	none

Results	Solar Radiation	AC Energy
	(kWh/m2/day)	(kWh)
Jan	5.4	6,594,735
Feb	6.04	6,619,296
Mar	6.87	8,050,990
Apr	7.28	8,096,188
May	7.31	8,148,920
Jun	7.23	7,617,144
Jul	6.61	7,312,741
Aug	6.66	7,396,352
Sep	6.93	7,442,034
Oct	6.6	7,542,902
Nov	5.93	6,911,413
Dec	5.04	6,233,334
Year	6.49	87,966,054

Financial Model

Project Costs	
Total installed cost	$51,382,248
Salvage value	$0

Analysis Parameters	
Project life	25 years
Inflation rate	2.5%
Real discount rate	6.4%

Financial Targets and Constraints	
Solution mode	Calculate PPA Price
Target IRR	9% in Year 20
PPA escalation rate	1%/year

Tax and Insurance Rates	
Federal income tax	21 %/year
State income tax	7 %/year
Sales tax (% of indirect cost basis)	5%
Insurance (% of installed cost)	0.5 %/year
Property tax (% of assessed val.)	0 %/year

Incentives	
Federal ITC	26%
Depreciation	Depreciation allocations defined with no bounus depreciation

Results	
Nominal LCOE	9.9 cents/kWh
PPA price (year one)	9.4 cents/kWh
Project IRR	9% in Year 20
Investor NPV	$2,477,200
Developer NPV	$3,486,300
Investor IRR	9.9%
Developer IRR	25.9%

Figure 2. System Advisor Model output report

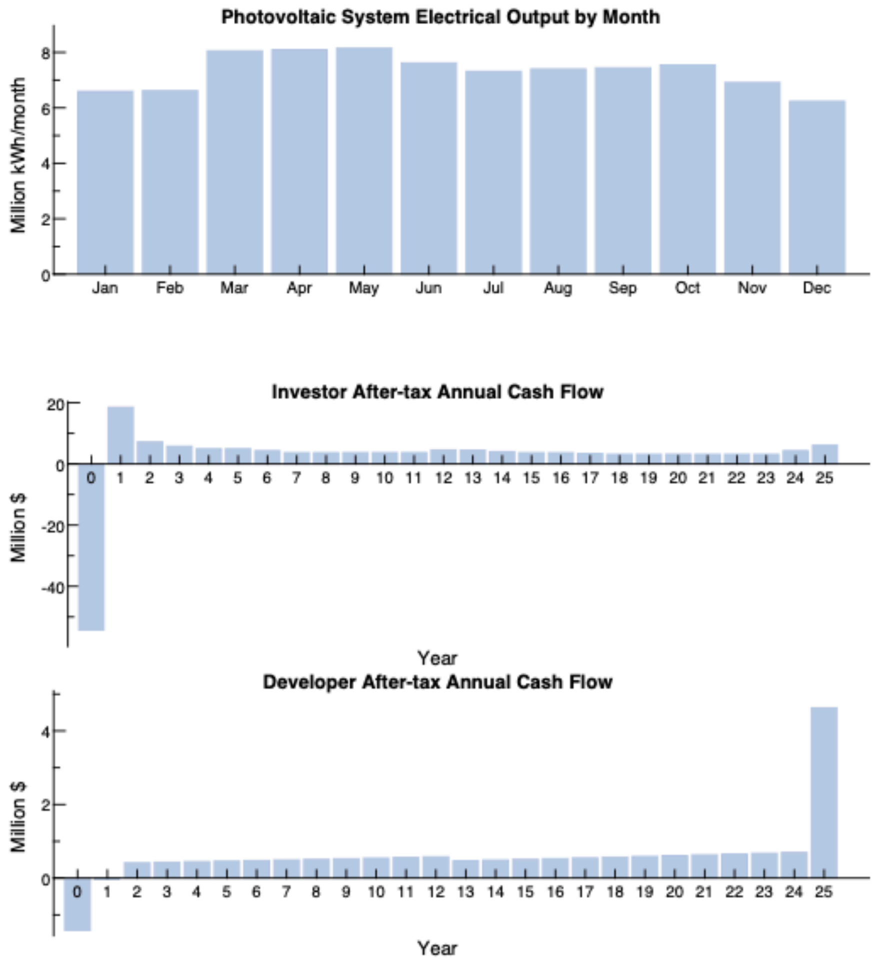


Figure 3. System Advisor Model graphical output

The SAM model gives a thorough analysis of the economics of solar installation, but it has a steep learning curve that farmers may not be willing or equipped to take on. These NREL models provide excellent information but are limited when it comes to the needs of farmers. They are not well advertised and are not easily accessible to farmers. The current models also cater to residential and commercial entities, not to the specific features of dairy operations.

The primary output of this project will be a computer program that dairy farmers can use to determine if incorporating solar energy on their farms is a feasible option for them. The computer program will provide an economic analysis of the specific dairy farm. This analysis will provide the user with information about the capital investment, payback period, and relevant government incentives that could benefit the farmer, and make clear recommendations to the farmer based on the data specific to their farm. There will also be data from the survey of farmers that determines different levels of interest in renewable energy technology, as well as their ability to invest in solar technology.

2.7 Impacts

Solar energy will provide long-term energy security for dairy farmers. Managing a dairy farm is a labor-intensive operation leaving little time to explore emerging technologies such as photovoltaic on their farms. Additionally, many farmers do not know where to search for information or what to look for in an objective and unbiased way. This hinders their ability to access reliable information about the incentives to switch to solar energy. The goal of this project is to improve the sustainability of Michigan's dairy industry by promoting the use of solar energy technologies. With an easy-to-use, accessible computer program to assist farmers in making this decision, it is expected that more dairy farmers will transition to renewable sources of energy, resulting in the reduction in the carbon footprint of dairy farms throughout Michigan and beyond.

Outcomes of this project include farmers gaining knowledge about government incentives, the cost and maintenance required of solar panels, and the economic feasibility of such a transition. Additionally, this project may improve farmers' perceptions toward sustainability and renewable energy. If the project is found to be successful, the scope of the project could be expanded to other states and other types of farm operations.

2.8 Objectives

To help dairy farmers evaluate whether the pursuit of solar energy is feasible for them, the following steps will be taken:

1. Evaluate the perspectives of dairy farmers on using solar technologies on dairy operations in Michigan.
   1.1. Conduct a survey to assess gaps in knowledge of farmers, evaluate what influences decision making, and determine what information should be included on the website.
2. Perform a case study from a farm management perspective.
   2.1. Start with a generic dairy farm, then based on the energy audits, document traditionally how much energy is used.
   2.2. Calculate how much of that electricity can be generated through solar.
   2.3. Perform an economic analysis including indicators such as net present value, benefit to cost ratio, payback period, and equivalent annual worth.
   2.4. Include what-if scenarios to simulate different tax credits available and loan options.
   2.5. Determine if installing solar technology on the subject farm will be economically beneficial.
3. Perform a regression analysis on the energy audit data provided from the Michigan Farm Energy Program.
   3.1. Use energy consumption data from 133 dairies across Michigan.
   3.2. Determine if there is a relationship between farm location and amount of electricity consumed.
   3.3. Find the relationship between number of cows and amount of electricity consumed per year (kWh).
4. Create a computer program that will perform the economic calculations for the farmer.
   4.1. The model will take data from the user to be plugged into the equation from the regression analysis.

4.2. The program will perform all the calculations outlined by the case study.

4.3. Results of the economic analysis will be displayed in words, tables, and graphs.

3.0 SURVEY OF DAIRY FARMERS IN MICHIGAN

3.1 Introduction

A survey was conducted featuring dairy farmers throughout Michigan. The data from the survey of farmers was used to evaluate different levels of interest in renewable energy technology, as well as the perceived barriers that prevent dairy farmers from investing in solar technology. Finally, the survey was meant to assess farmer willingness to use renewable energy assessment tools. The survey results were used in the development of the decision support system. The literature review resulted in the formulation of the following research questions about dairy farmers in Michigan:

1. Are Michigan dairy farmers interested in learning about installing solar technology on their farms?
2. What are the perceived barriers that prevent dairy farmers from installing solar panels on their farms?
3. What level of awareness do dairy farmers have regarding government incentives related to renewable energy investments?
4. Where do farmers seek information to aid in making decisions about their farms?
5. What is the level of willingness of farmers to use renewable energy assessment tools?

These questions were used to develop a survey that was distributed to dairy farmers through the Michigan Milk Producers Association.

3.2 Methods

3.2.1 Survey Distribution

In March of 2022, the Michigan Milk Producers Association (MMPA) included an excerpt in their newsletter to notify members that a survey would be sent to them. This excerpt assured farmers that the survey was legitimate and informed them of its purpose. Following the newsletter, the MMPA sent out the survey link to all members with emails on file. Three weeks into the survey, they sent a reminder email to all members to fill out the survey. The survey was made available from April 25th, 2022, until May 20, 2022. All survey responses were submitted electronically via Qualtrics software.

3.2.2 Formulation of Questions

The format and content of the survey were developed through several meetings between the committee members and through consultation with the Director of Member Services for the MMPA. The format of the survey prioritized efficiency and simplicity to encourage survey participation. This was done using multiple-choice questions that had an additional "Other" option where respondents could type in an answer that was not listed. The research questions had to appeal to farmers, so each question was simply worded using layman's terms wherever applicable. Finally, the original questions were synthesized to minimize the length of the survey and prevent incomplete responses. The resulting survey was comprised of the following sections: Farmer demographics, farm characteristics, level of interest in solar technology, perceived barriers to installing solar panels, awareness of government incentives, sources of information used when making farm decisions, and renewable energy assessment tools. Michigan State University's *Office of Regulatory Affairs: Human Research and Protection Program* approved this research study, study ID: STUDY 00007494, stating it to be exempt under 45 CFR 46.104(d) 2ii.

3.2.3 Data Analysis

The data evaluated in the results section of the paper excludes the responses that were deemed incomplete. The excluded responses include those that did not give consent to participate and those that did give consent to participate but did not answer any of the survey questions. Aside from demographic information, all survey questions were qualitative. Additionally, the quantitative demographic data was provided categorically (e.g., "0-99 cows", "100-499 cows") so descriptive statistics were not applicable. Therefore, no quantitative analysis was performed on the survey results aside from determining what percentage of the sample fell into a particular category.

3.3 Results/Discussion

3.3.1 Farmer Demographics

All survey respondents (n=35) were dairy farmers in the state of Michigan and members of the MMPA. Of the respondents, 14 percent were under 40 years of age, 49 percent were between 40 and 60 years of age, and 37 percent were above 60 years of age. The farm sizes were grouped into 0-99 cows (40 percent), 100-499 cows (49 percent), 500-1000 cows (3 percent), and more than one thousand cows (9 percent). Only one farm was pasture based, twenty-one farms were confined, and thirteen farms were a combination of pasture based and confined. None of the respondents had solar panels installed on their farms at the time of the survey.

The demographics of the survey participants are consistent with the distribution of farm sizes in Michigan. The number of milking cows per permitted dairy farm in Michigan averages out to just under 500 (Slawinski, 2022), which falls within the farm range that 49 percent of respondents were in. The survey had minimal input from medium sized farms (500-1000 cows) and large farms (more than one thousand cows). This suggests that the results of this survey cannot be used to generalize the population of dairy farmers whose farms have more than five hundred cows.

3.3.2 Research Question 1

Are Michigan dairy farmers interested in learning about installing solar technology on their farms?

To answer the first research question, the farmers were asked to report their level of interest in learning about solar energy for their personal dairy operation. Farmers could select "Very Interested," "Somewhat Interested," "Neutral," "Not Very Interested," and "Not Interested." Fifty one percent of participants stated that they were very interested in learning about solar technology, thirty seven percent stated they were somewhat interested, six percent stated they were neutral, and six percent stated they were not very interested.

3.3.3 Research Question 2

What are the perceived barriers that prevent dairy farmers from installing solar panels on their farms?

To evaluate the perceived barriers to solar panel installation, the survey participants were provided a list of potential barriers and then asked to select all items that they considered to apply (Figure 4). Economics and time management were perceived as the greatest barriers to installing solar panels on farms. Twenty-five farmers expressed uncertainty that installing solar panels is a good investment and twenty-three farmers thought the cost of the system was too high. Additionally, nine respondents felt they did not have the time to learn about solar technology, eleven thought they did not have time to install solar panels, and eleven thought they did not have time to manage or maintain solar panels. One participant said they did not have enough space for panels and one stated that they do not want to learn new technology.

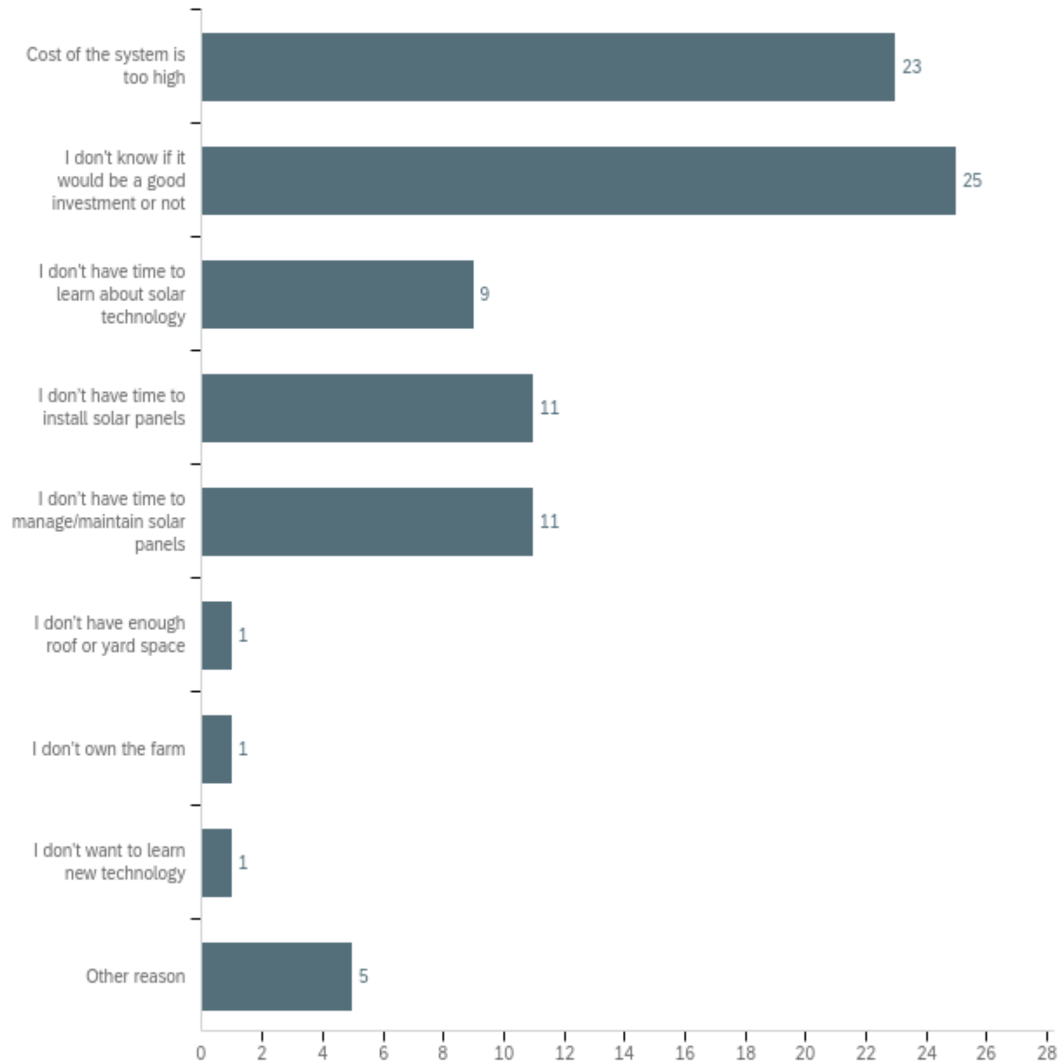


Figure 4. Farmers perspectives on the perceived barriers of installing solar panels

Participants were also able to select *Other* and include a personalized answer. For the option of *Other*, some participants included statements that were supportive of roof installations but expressed concern over "keeping [the solar panels] clean from bird droppings, dust, leaves, etc.." Other farmers felt unsure about the suitability of their barns to hold solar panels, due to "old barns" or barn orientation with respect to the sun. One other participant stated they were "concerned about cost and what happens when [the solar panels] live out their usefulness."

The participants' emphasis on finances was consistent with prior research done to assess the perspectives of farmers on climate change. As business owners, dairy farmers must prioritize maximizing their profits. However, the high level of concern suggests that sustainability initiatives are not doing enough to educate farmers about the economics of sustainable changes. Farmers may be viewing solar technology as an expense, without understanding the long-term economic benefits. The second major concern for dairy farmers is time. In order to encourage on-farm changes, dairy farmers must be made aware of the long-term economics of solar panels and the time required to own and operate them effectively.

3.3.4 Research Question 3

What level of awareness do dairy farmers have regarding government incentives related to renewable energy investments?

Each participant was asked if they were aware of government incentives related to renewable energy investments on farms. Eight farmers said they were aware of incentives, eighteen said they were not aware of incentives, and nine said they were somewhat aware of incentives. Overall, 51 percent of participants were not aware of government incentives related to on-farm renewable energy investments.

The lack of awareness of government incentives could be contributing to the farmers' perceptions that solar technology is too expensive to install and maintain. Without an understanding of grants, tax credits, and other incentives by the government, farmers may feel that they are solely responsible for the financial burden of making the on-farm change. When dairy farmers already face margin compression and increasing costs of inputs, it could be intimidating to consider a major on-farm investment. Sustainability initiatives must include a sector that educates farmers about government assistance, including instructions on how to apply for such incentives.

3.3.5 Research Question 4

Where do farmers seek information to aid in making decisions about their farms?

To gain an understanding of how dairy farmers make decisions, the survey participants were provided a list of resources and asked to state the likelihood that they would seek information from each one (Table 1). The sources were then ranked in order of farmer reliance by adding up the number of "Extremely Likely" and "Likely" selections. It was determined that participants were most reliant on consulting with business professionals and Extension educators when seeking information to aid in their decision making. The second most common source of information was word of mouth through friends, neighbors, and other farmers.

Table 1. Sources of information used by farmers to aid in decision making

#	Field	Extremely likely		Likely		Neutral		Not likely		I never use this source		Total
1	Word of mouth (friends, neighbors, other farmers, etc.)	25.71%	9	54.29%	19	20.00%	7	0.00%	0	0.00%	0	35
2	Consult with business professionals or Extension educators	20.59%	7	70.59%	24	5.88%	2	2.94%	1	0.00%	0	34
3	Extension bulletins and publications	8.57%	3	60.00%	21	22.86%	8	8.57%	3	0.00%	0	35
4	Look things up on the internet	29.41%	10	35.29%	12	20.59%	7	11.76%	4	2.94%	1	34
5	Conferences and farm organization meetings	8.82%	3	50.00%	17	23.53%	8	14.71%	5	2.94%	1	34
6	Other	9.09%	1	0.00%	0	54.55%	6	9.09%	1	27.27%	3	11

The implications of this data provide valuable information regarding where efforts should be directed to further engage farmers in sustainability initiatives. These results indicate that providing information solely on the internet will not be an effective way to influence farmer decision making. To be effective, sustainability initiatives should place an emphasis on University

Extension programs, farm organization meetings such as the MMPA or ASABE, and agricultural conferences. As farmers become more aware of initiatives through these sources, the information will continue to spread through word of mouth and reach a greater portion of the farming population.

3.3.6 Research Question 5

What is the level of willingness of farmers to use renewable energy assessment tools?

Participants were first asked if they had ever used any renewable energy assessment tools before. Zero farmers said they had used PVWatts, one farmer said they had used System Advisor Model (SAM), one farmer said "Other", and thirty-one farmers (94 percent) said they had never used any existing renewable energy assessment tools. Next, participants were asked, "If there was a website available that evaluates the potential of using solar energy customized to your farm, including a cost-benefit analysis and possible government incentives, how likely are you to use it?". Thirteen farmers said it was "highly likely," 17 said "somewhat likely", three said "neutral," and one said they would not use the website.

The responses from these questions emphasize the lack of utilization of existing decision support tools, such as PVWatts and SAM, by the dairy farming community. The reason for the lack of use was not directly addressed by this survey. However, 88 percent of respondents expressed a likelihood of using a website that evaluates the potential of solar energy on their farms. Based on this data and the results from Research Question 1, it is not due to a lack of interest in solar technology. This suggests that other factors such as tool complexity, accessibility, and lack of advertising could be responsible for these low numbers.

3.4 Conclusion

The primary limitations of this survey include sample size, sample distribution, and bias. Assuming one participant represents one dairy farm, then the sample size (n=35) represents less than 4% of the number of dairy farms in Michigan. Only four participants had more than five hundred cows, so differences between small and large farms cannot be analyzed. Additionally, farmers who are willing to participate in a sustainability-focused survey may be predisposed to be interested in renewable energy. These limitations indicate that this survey cannot be used to generalize the entire dairy population in Michigan. However, it can provide an understanding of what drives farmer decision making, and how that knowledge can be applied to result in more effective sustainability initiatives.

The results of the survey indicate there is a significant level of interest in installing solar technology on dairy farms. However, the implementation of solar technology is currently hindered by the pre-existing perceptions of dairy farmers. Many farmers believe that solar technology is too expensive and too time-consuming to be a feasible option for their farm. Additionally, many farmers rely on word of mouth, University Extension, business professionals, and farm organization meetings as sources of information. When sustainability initiatives place an emphasis on online advertising, they fail to reach a major subset of the farming community. For example, only one farmer said they have used SAM software and zero farmers had ever used PVWatts. If farmers are provided with relevant information from sources they rely on, they can better understand the feasibility of sustainable changes. As a result, sustainability initiatives can have a lasting impact on the farming community that reduces the effects of climate change for the entire world.

4.0 CASE STUDY

4.1 Introduction

A case study was performed to evaluate the economics of installing solar panels on a dairy farm. The goals of this case study were to gain an understanding of photovoltaic cost analysis, as well as to establish the flow of information through the decision support system. For this case study, the median of the MFEP energy audit data was used. The median farm had 180 milking cows and consumed 110,332 kilowatt hours (KWH) of electricity per year.

4.2 Methods: Establishing the Flow of Information

To establish the flow of calculations for the case study, it was determined which steps a farmer would have to take to plan a photovoltaic system on their farm. These steps were separated into system specifications, economic analysis, and financing.

4.2.1 System Specifications

1) First, the farmer must determine the amount of electricity they want to produce each year. This can be calculated by reviewing their annual electricity consumption, then determining what percentage of that they want to be generated via solar panels. The annual electricity consumption will be multiplied by the percent and divided by one hundred.
2) The next step is to determine what size solar array system is required to produce this amount of electricity. The size of the solar system depends on the local climate and sunlight emitted, as well as the physical size and efficiency of the panels.
    a) Hourly energy requirement will be the consumption divided by 365 days, divided by 24 hours.
    b) The number of solar panels will equal the hourly energy requirement times the peak sunlight hours, all divided by the panel wattage.

c) This calculation can be repeated for low wattage and high wattage panels to establish a range for the number of panels needed.

3) Next, the farmer must consider the potential locations that solar panels could be installed on their farm. These locations consist of south, east, or west-facing roofs, as well as on non-arable land. The amount of square footage available will then be used to decide how many panels will fit into that space, and what size (wattage) panels are compatible to generate the desired amount of electricity.

4) For the last step in determining the system specifications, the farmer needs to calculate the size of the total solar array. This can be done by multiplying the number of panels by the size (wattage) of each panel.

4.2.2 Economic Analysis

5) Once the size and number of panels have been determined an economic analysis can be performed. The economic analysis will be based on the 25-year lifespan of the solar panels.

6) Next, the farmer will need to determine the cost of installation. This can be done by multiplying the size of the solar array (Step 4) by the NREL installation cost estimate per kilowatt size system.

7) Next, benefits and costs must be evaluated to determine which year they apply to and how interest will affect them.

    a) Benefits

        i) Savings on annual electricity bill - Annual

        ii) Tax credit - Year 1

        iii) Salvage value - Year 25

    b) Costs

i) Cost of installation - Year 0

ii) Maintenance - Annual

iii) Depreciation - Annual

iv) Insurance - Annual

v) Degradation rate of panels - Annual

8) These benefit and cost values can be used to calculate the payback period (Equation 1), net present value (Equation 2), equivalent annual worth (Equation 3), and benefit to cost ratio (Equation 4) of this investment. These economic evaluation criteria can then be used to determine if this is a beneficial investment for the farmer. The equations are as follows in which t is the year, B_t is the benefit in year t, C_t is the cost in year t, i is the discount rate, and n is the life of the project in years.

$$Payback\ Period = \frac{Initial\ capital\ invesment}{Net\ annual\ benefits} \tag{1}$$

$$Net\ Present\ Value\ (NPV) = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{2}$$

$$Equivalent\ annual\ worth\ (EAW) = NPV[\frac{i}{1-(1+i)^{-n}}] \tag{3}$$

$$Benefit\ to\ cost\ ratio\ = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} \div \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{4}$$

4.2.3 Financing

9) If the farmer has determined that installing solar panels is a beneficial investment for their farm, they can consider financing options. There are typical loans available to farmers, as well as low-interest loans that are specific to agricultural producers and/or renewable energy investments. Additionally, farmers can consider grants from various government programs such as the Rural Energy for America Program (REAP) to help cover installation expenses.

10) Finally, the farmer should incorporate financing options into their economic analysis to gain an understanding of the cash flow throughout the lifetime of the solar panels. Viewing something such as a cash flow graph will help them to visualize the investment and determine if it is feasible for their farming operation.

4.3 Assumptions and Set Up

The case study followed the steps listed to simulate a farmer going through the decision-making process of installing solar panels. The chosen farm had 180 cows and used 110,332 kilowatt hours of electricity per year. Assumptions and givens of the case study are outlined in Table 2.

Table 2. Values and assumptions used in the case study

Variable	Value	Source
Number of cows	180 cows	MFEP
Electricity consumed per year	110,332 kWh/year	MFEP
Farm location	Michigan	Assumption
Percent consumed covered by solar generation	100 %	Assumption
Lifetime of project	25 years	NREL FAQ, 2023
Discount rate	3%	Average of past 25 years of discount rates (Federal Reserve Economic Data)
Salvage value	$0	Assumption

In order to determine the cost of the photovoltaic system, the calculated size of the system was multiplied by the NREL Modeled Mark Price estimate for 2022. The estimate includes the cost of modules, inverters, balancing systems, direct labor, indirect labor, permits, inspections, overhead, sales, and marketing costs (Ramasamy et al., 2022). This estimate is based on a national average of costs that assumes net metering at the same price and does not include the costs associated with storage or financing. Additionally, the NREL benchmark does not account for variability in the photovoltaic and storage markets.

The case study incorporated the federal tax credit in its present value, 30%, as well as if it were to be reduced to 20%, 10%, and 0% if it was not offered at all. This analysis was done to convey how an investment in solar panels would be affected by the federal tax credit. Additionally, the case study assessed the impact of fluctuating electricity prices on the investment. It estimated the effects of a 3% decrease, and 3%, 5%, and 7% increases in electricity rates per year.

Given that the NREL cost estimate did not include financing, the final component of the case study was to evaluate the impact of a loan on the economics of installing solar panels. Several farm loan interest rates were averaged out to a rate of 5.25%, with loan lifetime set to 25 years. Using this information, the cash flow was calculated based on the size of down payment made by the farmer, including 50%, 40%, 30%, 20%, 10% and 0% down payments. These loans were presented on a graph and compared to taking no loan at all.

4.4 Results and Discussion

For the system to generate 110,000 kilowatt hours per year, it was determined that 140 370-watt panels would be needed, resulting in a 52-kilowatt size system (Table 3). The cost of installation was calculated to be 92,722 dollars.

Table 3**.** Calculated photovoltaic system specifications

Specification	Value
Electricity generated per year	110,332 kWh
Number of panels	140

Table 3 (cont'd)

Size of panels	370 Watt
Size of solar array	51.8 kilowatt

The payback period was calculated to be just over 5 years and the net present value (NPV) was found to be over 200,000 dollars (Table 4). Since the NPV was positive, the net present value of benefits was far greater than the net present value of costs. The benefit to cost ratio was found to be 2.05, which indicates that the benefits are greater than the costs of the investment.

Table 4. Economic assessment criteria applied to the case study

Specification	Value	Assessment Criteria
Cost of installation	\$92,722	-
Payback period	5.13 years	-
Net present value (NPV)	\$221,053	> 0
Equivalent annual worth (EAW)	\$12,694	> 0
Benefit/cost ratio (B/C)	2.05	> 1

Figure 5 shows the cash flow of the subject dairy farm. This was based on the current tax credit, a 3% increase in electricity rates per year, straight line depreciation of the system, and fixed maintenance and insurance costs. The farmer would have a negative cash flow until 6 years after installation, then the savings would be much greater than installation costs resulting in a positive cash flow for the following 20 years.

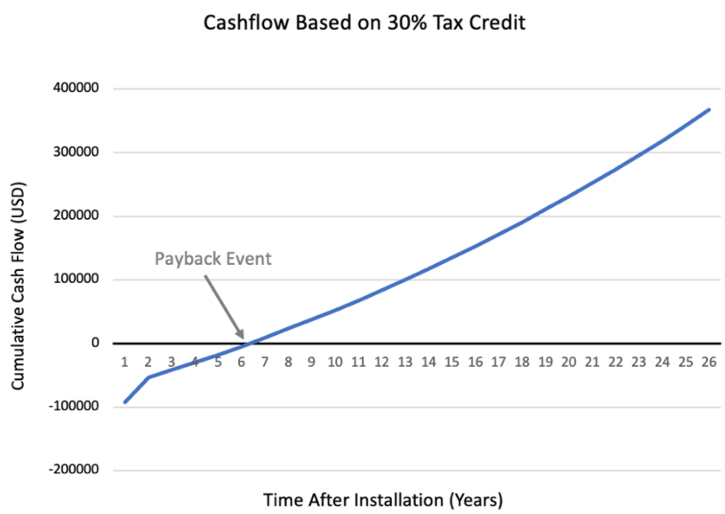


Figure 5. Cash flow and time of payback event based on standard conditions

At the time that this case study was performed, there was a federal tax credit offered as 30% of installation costs of photovoltaic projects. Figure 6 is meant to evaluate the impact that the tax credit would have on a farmer's solar technology investment. In the event of a reduced tax credit by the government, the program is eliminated, or the farm does not qualify, the payback event for this farm would still range between 5 and 8 years.

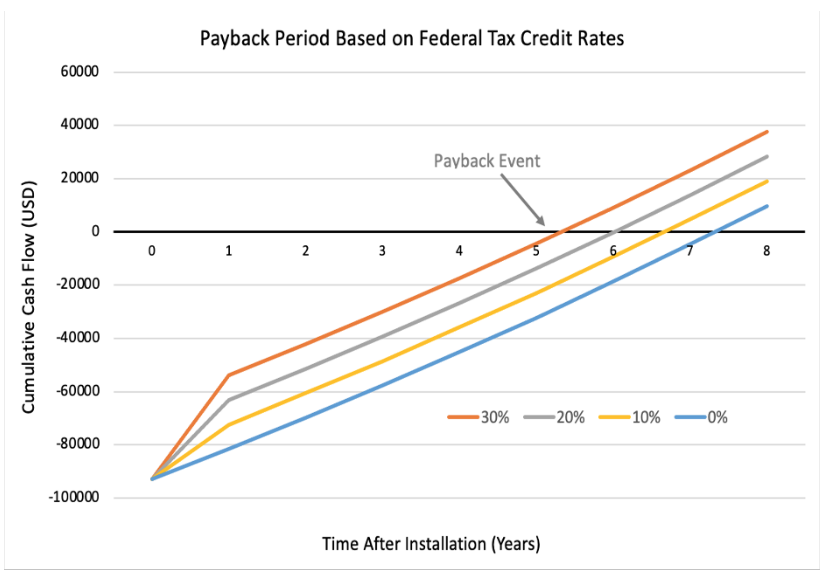


Figure 6. Time of payback event based on varying federal tax credit rates

As electricity rates increase, the yearly savings increase. Figure 7 depicts that regardless of which direction electricity rates fluctuate, the investment itself was not impacted greatly. The shift from negative to positive cashflow for this farmer would still occur between 4 and 6 years after installation.

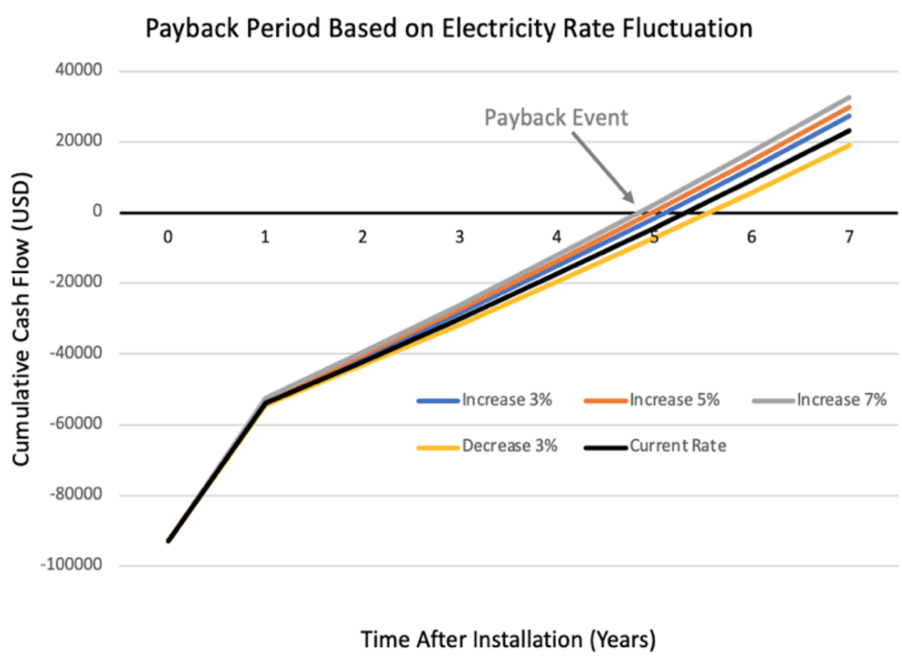


Figure 7. Time of payback event based on varying electricity rates

The final comparative analysis was focused on the timeline of different financing options. Several farm loan interest rates were averaged out to a rate of 5.34%, with loan lifetime set to 25 years. Using this information, the cash flow was calculated based on the size of down payment made by the farmer, ranging from 0% to 50% down. As depicted in Figure 8, the loan options have a higher cash flow for the first 14 years post-installation, and then the no-loan option exceeded the cash flow of the loans. With the use of a loan, this farmer would have a positive cash flow in the first three years following installation, whereas no loan would have a negative cash flow until five years after installation.

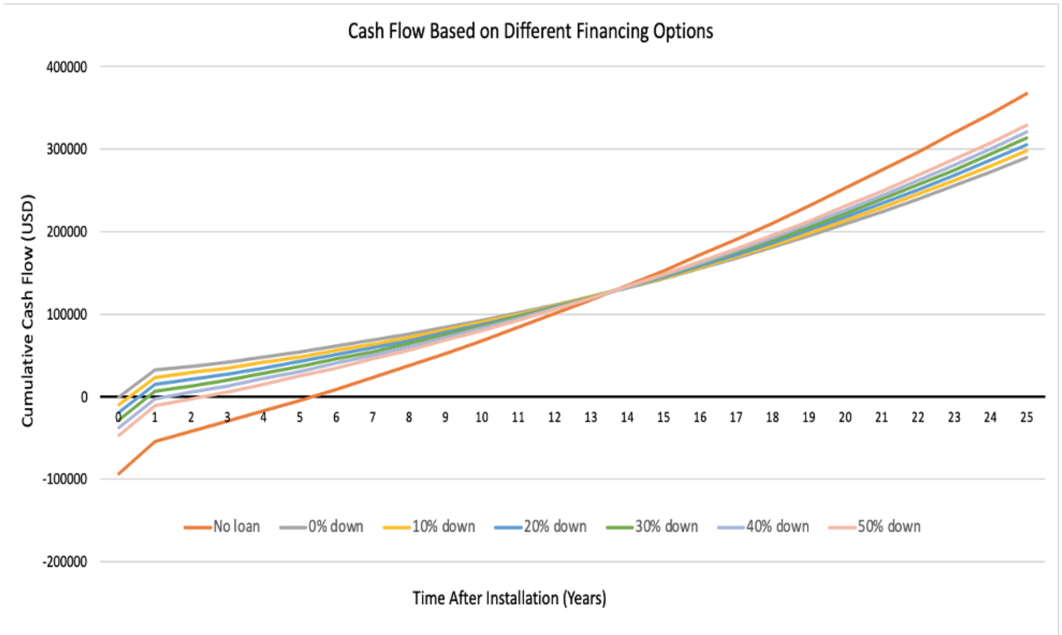


Figure 8. Comparison of loan payments based on percent down payment

4.5 Conclusion

Overall, the investment in solar technology would be beneficial for this mid-size dairy farm in Michigan. When using a 30% federal tax credit, the net present value and equivalent annual worth were positive values, with an NPV exceeding 200,000 dollars. The payback period was found to be just over five years and the benefit to cost ratio was over two. The economic evaluation criterion suggests that implementing solar technology on a dairy farm would be economically beneficial for farmers. Additionally, with the financing opportunities available, installing solar panels can be economically feasible for dairy farmers in Michigan. Finally, the complexity of the steps required in making this decision further emphasizes the need for a decision support system. These steps were used to create the solar calculator on the decision support website, which will be further discussed in Chapters 6 and 7.

5.0 REGRESSION ANALYSIS OF MICHIGAN FARM ENERGY PROGRAM DATA

5.1 Introduction

A regression analysis was performed on existing energy audit data of 132 dairy farms located in Michigan. The energy data was obtained from farm energy audits done by the Michigan Farm Energy Audit Program, with data collected from 2010 to 2016. The audited dairy operations were all confined, with some farms allowing pasture access for their cattle. The level of technology (e.g., robotic milkers) was low among this sample of dairies. The goal of the regression was to produce an equation that estimates the annual electricity usage (kWh/year) of a dairy operation based on its number of milking cows. This relationship was later used in the development of the decision support system.

5.2 Materials/Software

The farm energy audit data was originally contained in an Excel spreadsheet. This spreadsheet was converted to a comma-separated values file, which was then imported into RStudio software. RStudio was used for all statistical calculations, as well as for generating the figures that will be presented throughout this chapter.

5.3 Data Management/Cleaning

When reviewing the locations of the farm energy audits, one energy audit occurred in the state of Wisconsin. With only one subject, it was determined that there would not be enough data to accurately estimate the relationship between number of cows and electricity consumed for farms in the state of Wisconsin. Additionally, the decision support tool is advertised as being applicable to farms in the state of Michigan. For these reasons, the first step of data management was to exclude the data obtained from farms in Wisconsin. Once the Wisconsin farms were omitted, farm location had to be further considered. For each farm, the raw data included the area code in which the farm was located. In order to make location a continuous variable that could be regressed, each area code was replaced with its corresponding latitude, as latitude determines weather patterns that could affect electricity use (e.g., higher temperatures require more electric fans to be operated to keep cows cool).

The next step of data management was to convert "year" into a categorical variable. When importing data into RStudio, the software assumes all numerical data is continuous. However, for the purposes of this regression, "year" must be a categorical variable. The following image shows the summary of the data set after the "year" variable was converted to a categorical variable using a classification factor delineation.

```
  year         milk                cows          electricity         latitude
2010:48   Min.   :  158505   Min.   :  20.0   Min.   :  12782   Min.   :41.85
2011:24   1st Qu.: 2197054   1st Qu.: 110.0   1st Qu.:  68148   1st Qu.:42.48
2012:15   Median : 3743020   Median : 180.0   Median : 110332   Median :43.06
2013:14   Mean   : 7362938   Mean   : 289.2   Mean   : 221227   Mean   :43.27
2014:10   3rd Qu.: 6720000   3rd Qu.: 277.5   3rd Qu.: 199018   3rd Qu.:43.62
2015: 9   Max.   :89731571   Max.   :3200.0   Max.   :2450240   Max.   :46.38
2016: 7   NA's   :2                           NA's   :1
```

Figure 9. Summary statistics of energy audit data prior to cleaning

As depicted in Figure 9, the software indicated that there were multiple "NA" (Not Available) data points between milk and electricity. Using the *complete.cases()* function in Rstudio, it was determined that two data points, #63 and #92, were missing data regarding the number of cows and/or milk produced. This information coincided with the data contained in the Excel spreadsheet. The incomplete data was omitted from all subsequent steps of the regression analysis. In a summary of the newly cleaned data, it was confirmed that there were zero "NA" data points.

5.4 Variable Determination

5.4.1 Scatterplot Analysis

Once the dataset was cleaned, the regression analysis transpired. The first step was to visualize the data using scatterplots. Table 5 below states which scatterplot combinations were created, as well as the perceived relationship between variables when visually assessed. Based on the various scatter plots, there appeared to be a linear relationship between number of cows and electricity consumed, between amount of milk produced and electricity consumed, and between number of cows and amount of milk produced. The relationship between latitude and amount of electricity consumed did not appear to have a relationship of any kind.

Table 5. Visual analysis of initial scatterplots produced from energy audit data

X-Axis	Y-Axis	Perceived Relationship
Number of milking cows	Electricity consumed per year	Linear
Amount of milk produced per year	Electricity consumed per year	Linear
Latitude	Electricity consumed per year	N/A
Number of milking cows	Amount of milk produced per year	Linear

5.4.2 P-Value Comparison

The next step in variable determination was to run a regression for each variable with respect to electricity consumed per year (Table 6). For purposes of this regression, the null hypothesis states that there is no association between the independent variable and electricity consumed. The p-value indicates how probable the results are due to chance, as opposed to a relationship between the variables. When performing the regression, it was determined that location had a p-value of greater than 0.05, providing weak evidence against the null hypothesis.

This p-value indicates that the predictor of latitude is not meaningful for the model. The p-values for number of cows and amount of milk produced were significantly less than 0.001, which is highly statistically significant. In other words, there is very strong evidence against the null hypothesis and both the number of milking cows and amount of milk produced are excellent predictors of electricity consumption.

Table 6. Initial regression analyses on data after cleaning

Predictor Variable	Response Variable	P-Value
Number of milking cows	Electricity consumed per year	< 2E-16
Amount of milk produced per year	Electricity consumed per year	< 2E-16
Location (latitude)	Electricity consumed per year	0.0778

5.4.3 Multicollinearity

Multicollinearity is the occurrence of high intercorrelations between two or more independent variables in a regression model. Based on the plotted data, there was a linear relationship between the annual milk production and number of milking cows (Figure 10). This relationship suggested that a regression model involving both milk production and number of cows would have an issue of multicollinearity (i.e., the model would be "over-fitted"). If there is evidence of multicollinearity, the regression model must be altered to include just one of the independent variables to predict annual electricity consumption.

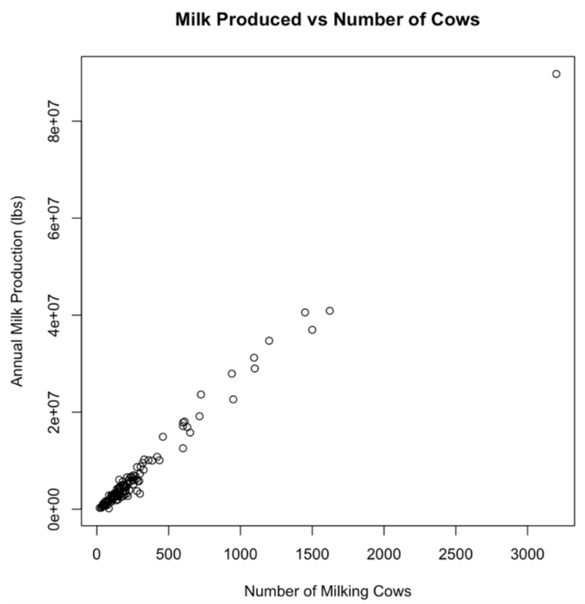


Figure 10. Correlation between number of milking cows and annual milk production (lbs.)

When running the correlation between milk production and the number of milking cows it was determined that the correlation was 0.993. Since a correlation of one indicates a perfectly linear relationship, this value of 0.993 suggested a strong positive correlation, and further expressed multicollinearity. Given that both the number of cows and milk produced had p-values of less than 2E-16, it was assumed that each variable would be equally appropriate in predicting electricity consumption. However, it was assumed that when using the decision support system, it will be easier for farmers to recall the number of cows on their farm than the amount of milk they produce per year. As a result, the number of milking cows was chosen as the sole independent variable which left the regression equation to be annual electricity consumed (kWh) as a function of number of milking cows.

5.5 Development of 3 Regression Models

5.5.1 Distributional Assumptions

Now that the number of milking cows was determined to be the independent variable, the data had to be analyzed to ensure the distributional assumptions are met. Linear regressions assume data is normally, identically, independently distributed. To have valid least squares estimate under the regression model, the data must meet these assumptions.

There must be constancy of variance across residuals to minimize error. Having a normal distribution is particularly an issue for prediction intervals as they are based on the normality of the raw data, whereas tests and confidence intervals are based on the normality of the sampling distribution of their estimates. Independence of residuals ensures there is only one measurement per test subject, and outliers must be removed to ensure accurate standard errors. Multiple models were considered to ensure the distributional assumptions were met, and to achieve the most accurate regression model possible. This section discusses the formulation of the following three models that were compared to determine the most accurate regression:

I. Model of full range of data: 0 - 3200 cows

II. Model of small to midsize farms: 0 - 500 cows

III. Model with logarithmically-transformed dependent and independent variables: Range from 0 – 3200 cows

5.5.2 Model II Formulation

Model I used the full range of the clean data with no transformations on either the independent or dependent variables. The relationship between number of cows and annual electricity consumption is displayed in Figure 11 below. The number of cows ranged from 20 to 3200, with a mean of 290.9 and median of 180 (Figure 12). This suggested there were far more data points from small to midsize farms (0-500 cows) than that of large farms, and more data analysis had to occur to ensure the full range of data met the distributional assumptions.

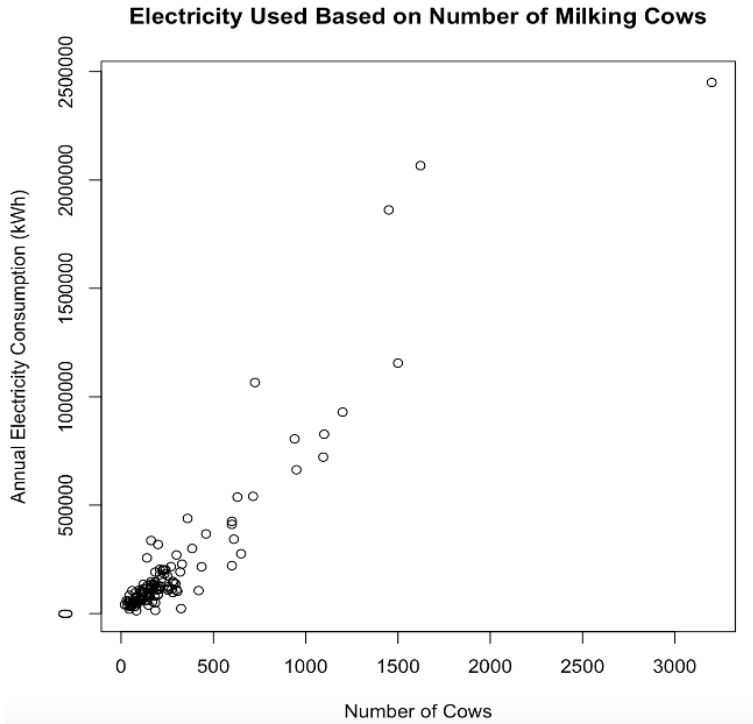


Figure 11. Scatterplot of electricity consumed based on farm size

```
      cows
Min.   :  20.0
1st Qu.: 110.0
Median : 180.0
Mean   : 290.9
3rd Qu.: 280.0
Max.   :3200.0
```

Figure 12. Basic statistics of the predictor variable *number of milking cows*

A box plot was created to help visualize the range of data and determine if range would present an issue in the analysis. As depicted in Figure 13, all subjects with more than five hundred cows existed outside of the upper quartile for the data. This indicated that all subjects exceeding five hundred cows are considered to be outliers. For this reason, Model II was created to exclude data outside of these upper and lower quartiles, with data ranging from 0 to 500 cows. While box plots provide useful information about outliers, they are limited in providing information about transformations. Therefore, more formal transformation testing had to be done.

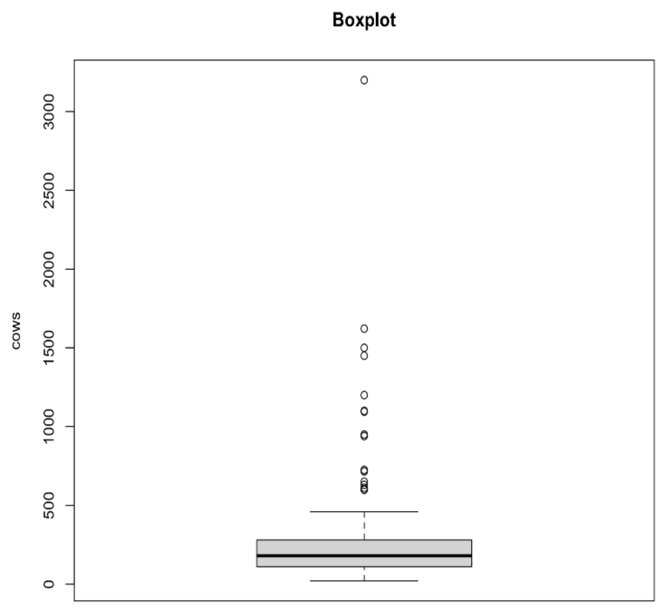


Figure 13. Boxplot of Model I

5.5.3 Model III Formulation

Box-cox transformations are used to formally determine an appropriate transformation on the dependent variable. The box-cox test transforms the dependent variable using a family of power transformations defined by lambda. Then, the test estimates what would be the "best" value of lambda to minimize error in the regression. On Figure 14 below, the x-axis has values of lambda, and the y-axis contains the maximum log likelihood for obtaining the minimum sum of squares error (SSE). The value of lambda and its 95% confidence interval, represented by the vertical dashed lines, correspond to an appropriate transformation. Since the 95% confidence interval for lambda did not include one, this implied a transformation would be necessary. Here, the 95%

confidence interval was close to zero in value, so a natural logarithmic transformation of Y was determined to be most appropriate (Table 7).

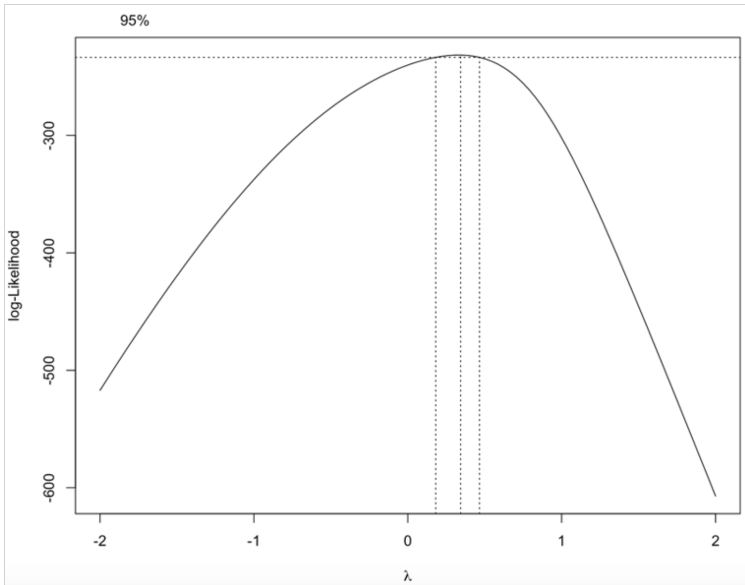


Figure 14. Box-cox transformation on full range of data

Table 7. Appropriate transformations based on lambda values

Lambda	Transformation
2	$Y' = Y^2$
1	$Y' = Y^1$ (no transformation)
0	$Y' = \log(Y^1)$
-1	$Y' = Y^{-1}$

In the formation of Model III, a logarithmic transformation on Y resulted in the data following a logarithmic curve instead of a linear line and a logarithmic transformation on X resulted in an exponential curve (Figures 15 and 16). However, performing a logarithmic transformation on both X and Y resulted in a function that was linear (Figure 17). Because of this, Model III was created with both the number of cows and the amount of electricity consumed logarithmically transformed.

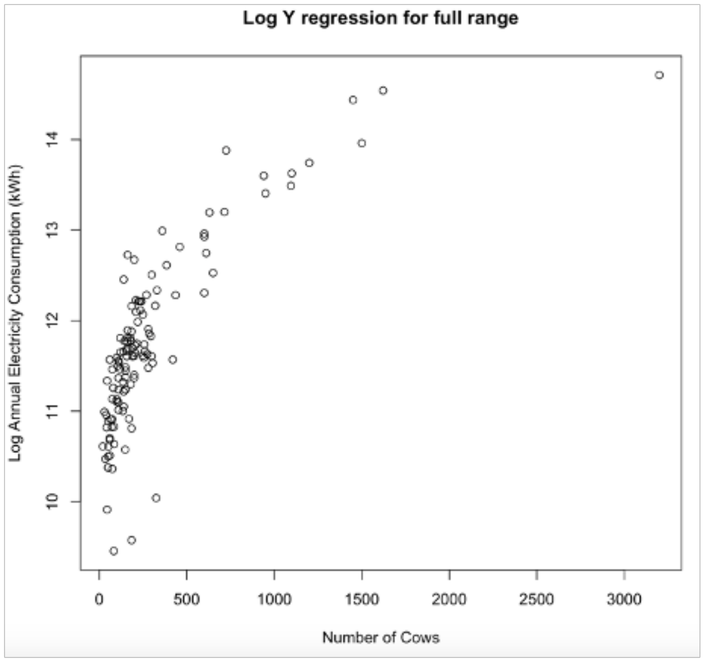


Figure 15. Scatterplot of logarithmic transformation on annual electricity consumption (Y)

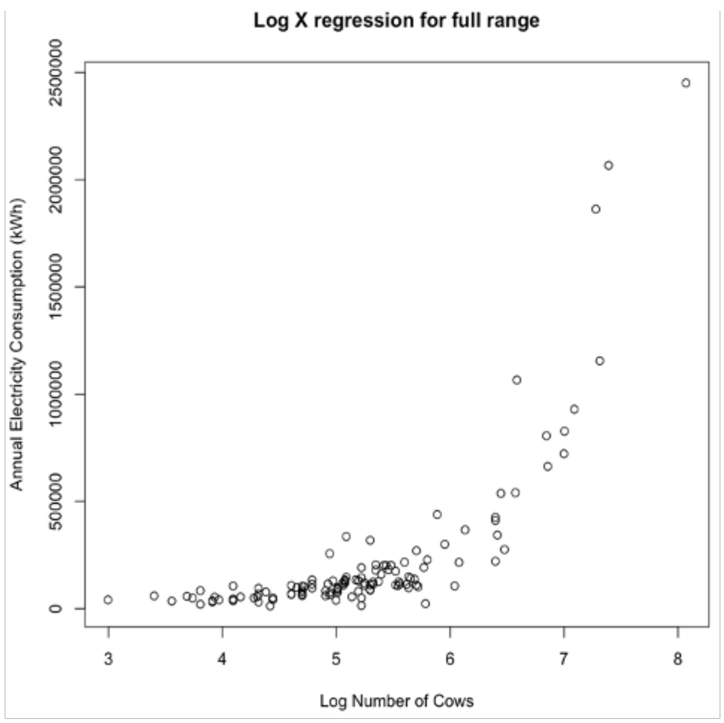


Figure 16. Scatterplot of logarithmic transformation on number of milking cows (X)

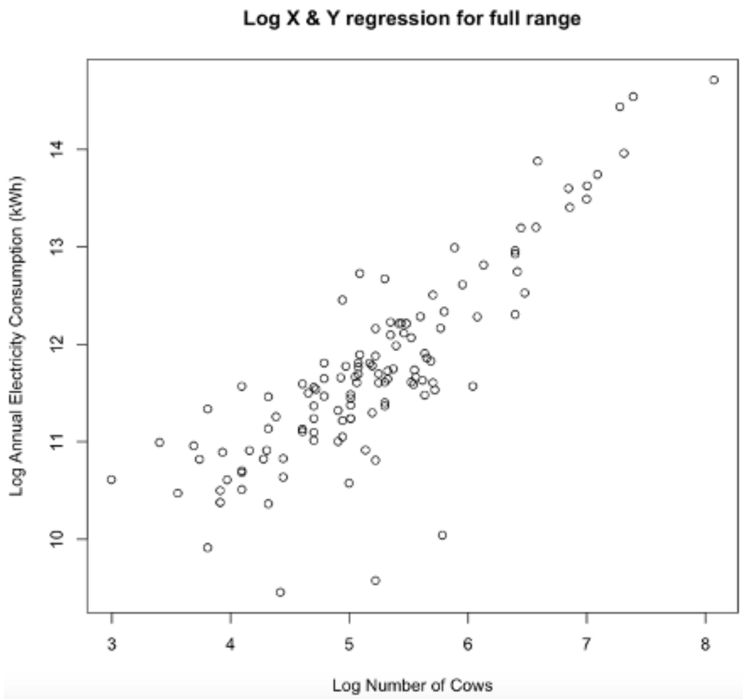


Figure 17. Logarithmic transformations on both number of cows (independent) and annual electricity consumption (dependent) variables

5.6 Model Comparison

5.6.1 Frequency Histograms

Histograms of data points were created to assess the normality of data among the three models. If the range of data forms a bell-shaped curve, the data is normally distributed. When including all data points, it was determined that the histogram of the full range of data did not portray a normal distribution (Figure 18). This suggested that there may not be enough subjects from large farms to accurately estimate their energy consumption. The histogram of the energy data for small to midsize farms (0-500 cows) indicated a much more normal distribution that is slightly skewed, lacking in subjects between 350 and 500 cows (Figure 19). The final histogram contains the data of the logarithmically transformed range, which resulted in a much more normal curve (Figure 20).

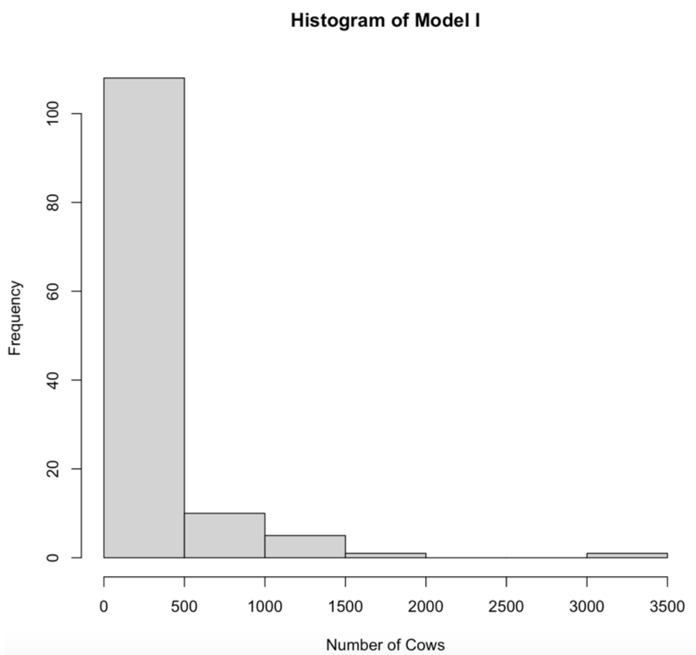


Figure 18. Histogram of number of cows for Model I

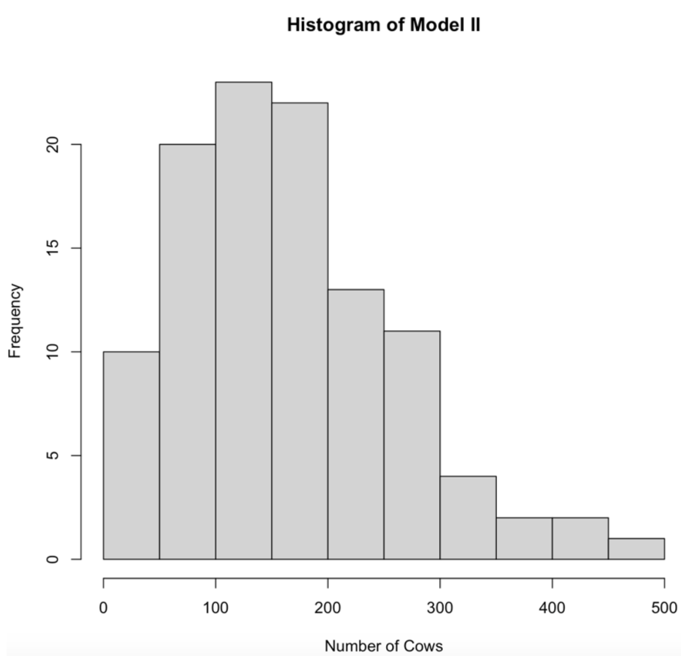


Figure 19. Histogram of number of cows for Model II

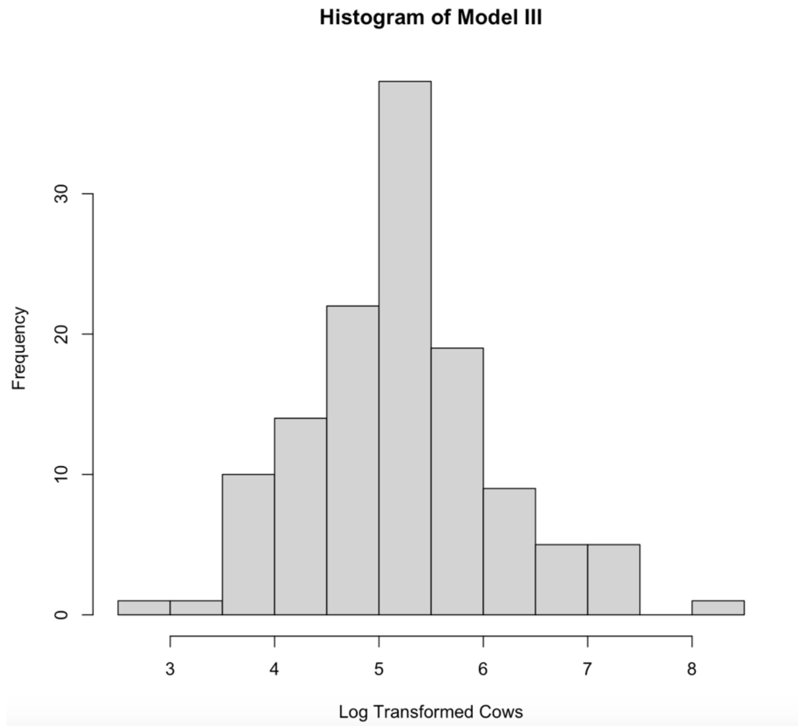


Figure 20. Histogram of number of cows for Model III

5.6.2 Residual diagnostics

Residual values of a linear regression are the difference between observed values and predicted values. The purpose of analyzing residual diagnostics is to minimize error, which is done through ensuring a constant variance of residuals across the range of data. Constant variance is represented by a symmetrical distribution above and below the center line at zero, as well as an even distribution from left to right. Additionally, the closer the points are to zero, the better the fit.

As depicted in Figure 21, Model I did not have an even distribution from top to bottom and had extreme clustering to the left. For Model II, there was a fairly symmetrical distribution from top to bottom, aside from the noted outliers. However, from left to right there was a higher density of points at lower values than on the right at higher values (Figure 22). For Model III, there was a low density of points on the outer edges but appeared to have an even distribution between 10.5

and 13. From top to bottom there were more points above 0.0, and a few outliers at residual values below negative one (Figure 23).

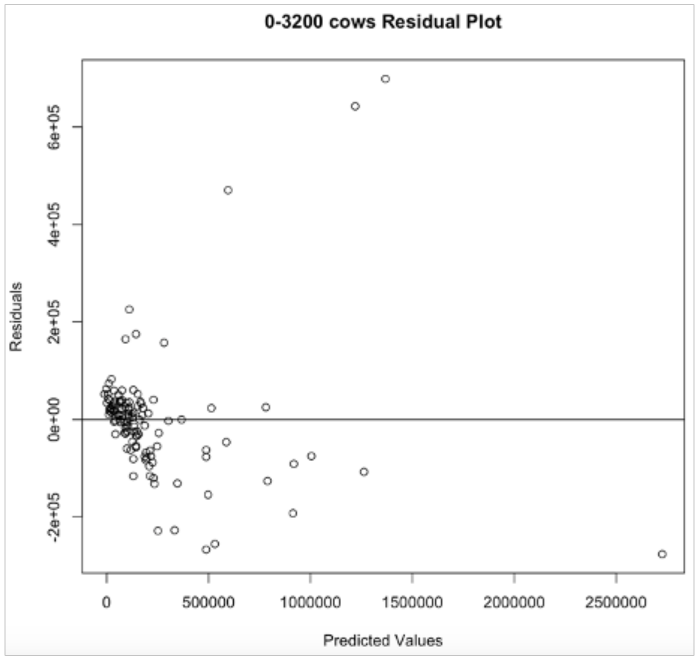


Figure 21. Plot of residuals for Model I

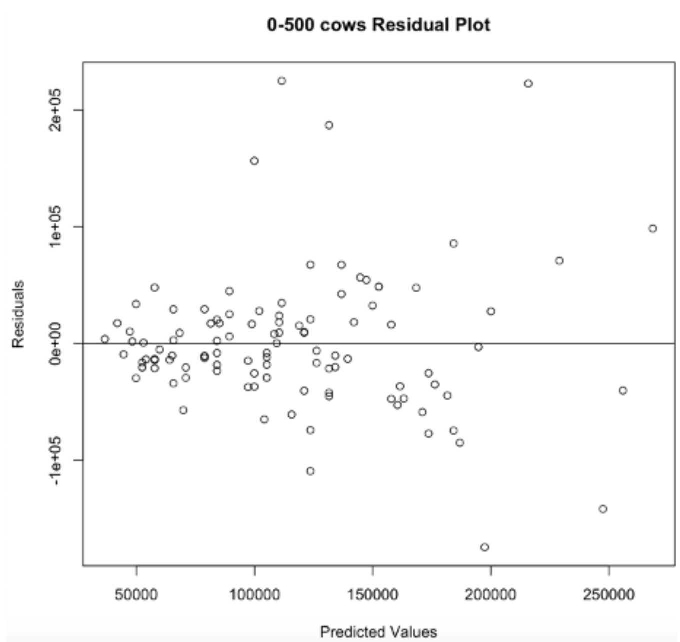


Figure 22. Plot of residuals for Model II

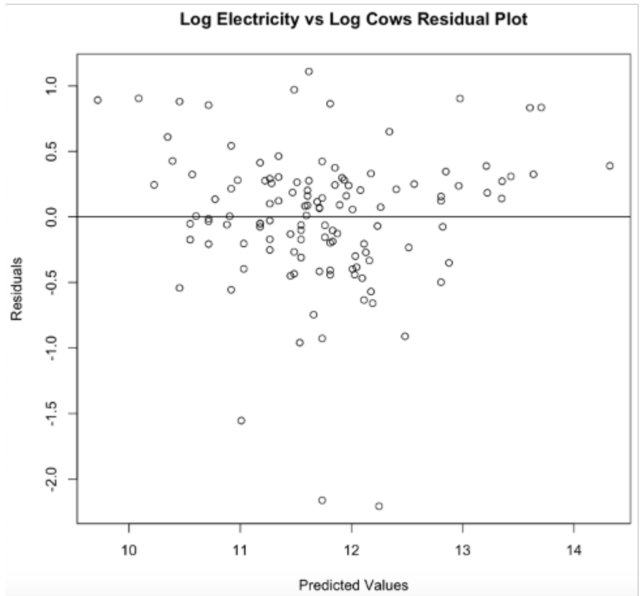


Figure 23. Plot of residuals for Model III

The second visual analysis of residual diagnostics includes Quantile-Quantile (Q-Q) plots to assess normality. The Q-Q plot displays standardized residuals on the y-axis and the theoretical quantiles on the x-axis. For these plots, points aligning closely to the linear dashed line indicates a perfectly normal distribution. For Model I, there appeared to be a normal curve in the central range but an extreme shift from the dashed line after quantile 2 (Figure 24). For Model II, the stray from the dashed line is not as extreme after quantile 2 but still indicates a non-normal distribution at the upper and lower ends of the range (Figure 25). For Model III, the data suggested a more normal distribution in the upper range, extremely normal in the central range, and then an extreme stray from normal in the -2 quantile (Figure 26). Model III has the potential to be most normal following the exclusion of outliers.

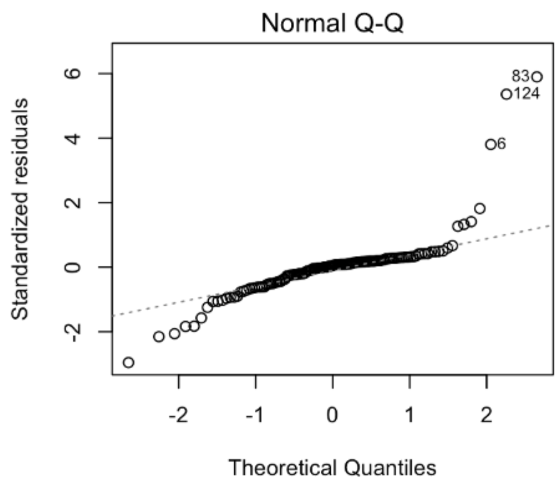


Figure 24. Quantile-quantile plot of Model I

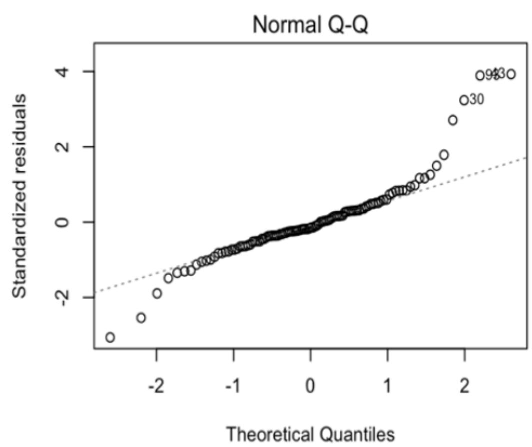


Figure 25. Quantile-quantile plot of Model II

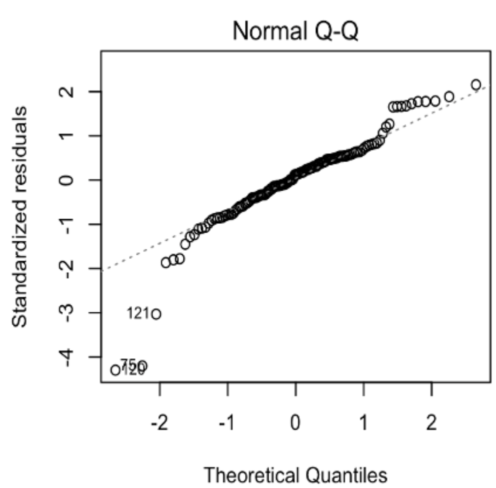


Figure 26. Quantile-quantile plot of Model III

5.6.3 Outlier identification and testing

As presented in 5.6.2, the residual plots conveyed the presence of outliers in each model. Therefore, testing was done to formally evaluate which subjects were outliers and determine how each outlier influenced its respective model. The first step was a Bonferroni outlier test. This test uses a t-distribution to test whether the model's largest studentized residual value is significantly different from the other observations in the model. If a certain subject has a significant p-value (less than 0.05) under the Bonferroni adjustment, the subject is considered an extreme outlier that requires further analysis.

To further the analysis, influence plots were created, which consist of the residuals on the y-axis and hat-values (leverage) on the x-axis. Influence measures how the parameter estimates would change if these points were excluded. The diameter of the circles shown in the image represent the square root of Cook's D statistic, which measures the influence of each point. The points farthest to the right, or those with the largest hat-values, are those with greatest leverage on the model which means they have the most potential to influence the model.

The final step in outlier testing was to plot Cook's distance for each subject. Cook's distance measures how much all the fitted values in the model change when the certain data point is deleted. Any distance greater than four divided by the sample size is considered to be an outlier. This 4/n value is the green dashed line in the center, with the blue lines representing 10th and 20th percentiles.

5.6.4 Outlier Trends

Based on the outlier analysis of each model, there were certain trends between outliers (Table 8). It was found that the four outliers from Model I all had more than five hundred cows. For Model II, four out of five of the outliers were subjects with more than 350 cows. These outlier trends indicated that these subjects fell outside of the useful range of their respective models. For Model III, two of the outliers were the maximum and the minimum of the data while the other two subjects had less than five hundred cows. This suggested that the outliers of the logarithmically transformed data do not have a trend associated with farm size.

Table 8. Trends in outliers among the regression models

Model Number	Outlier (Subject Number)	Trends in Outliers
I: 0 - 3200 cows	6, 19, 83, 124	4/4 subjects had more than 500 cows
II: 0 - 500 cows	43, 44, 57, 73, 93	4/5 subjects had more than 350 cows
III: Logarithmically transformed	19, 75, 80, 120	Outliers include the maximum and minimum of the data, there was no trend associated with farm size for the other subjects

5.6.5 Regression analysis

After the outlier testing, a linear regression was applied to each model. The null hypothesis for these linear models states that the coefficient is equal to zero, meaning it has no effect. The p-value of each model was significant, with values under 0.05. The p-value states how likely it is that the data could have occurred under the null hypothesis, so these low values indicated that the null hypothesis would be rejected. In other words, changes in the predictor variable, number of cows, were highly associated with changes in the response variable, electricity consumption.

R-squared is a measure of how close the data is fitted to the regression line. It is the explained variation divided by total variation and ranges from 0 to 100 percent. If R-squared was 100%, or a value of 1.0, this would mean that the model explains all the variability of the response data around its mean. Based on each regression, there was a high R-squared value for Model I, with a value of 0.88. The lowest R-squared was for Model II at 0.42, and Model III had an R-squared of 0.72 (Table 9).

Table 9. Comprehensive comparison of regression models

Model Number	Applicable Farm Size / Number of Cows	Degrees of Freedom	R^2	p-value	Residual Diagnostics
1	0 – 3600 cows	123	0.88	<2.2 E-16	Not NIID
2	0 – 500 cows	101	0.42	7.49 E-14	Somewhat NIID
3	0 – 3600 cows logarithmically transformed	123	0.72	<2.2 E-16	NIID

5.6.6 Fitted Line Comparison of Models

The final comparison between models was viewing the linear regression fitted line versus the subject data. For Model I, the points appeared close to the fitted line at lower ranges, however, this could have been due to the extreme zoomed out nature of the graph to include the large farms (Figure 27). The points strayed from the fitted line at farms with over five hundred cows, which indicated a poor fit or a lack of subjects from large farms. For Model II, the points followed a similar slope as the regression line, but they showed a widespread away from the fitted line, which was further reflected in the low R-squared value of 0.42 (Figure 28). In Model III, there was a fairly good fit throughout the entire range, aside from a few outliers, reflecting an R-squared of 0.72 (Figure 29).

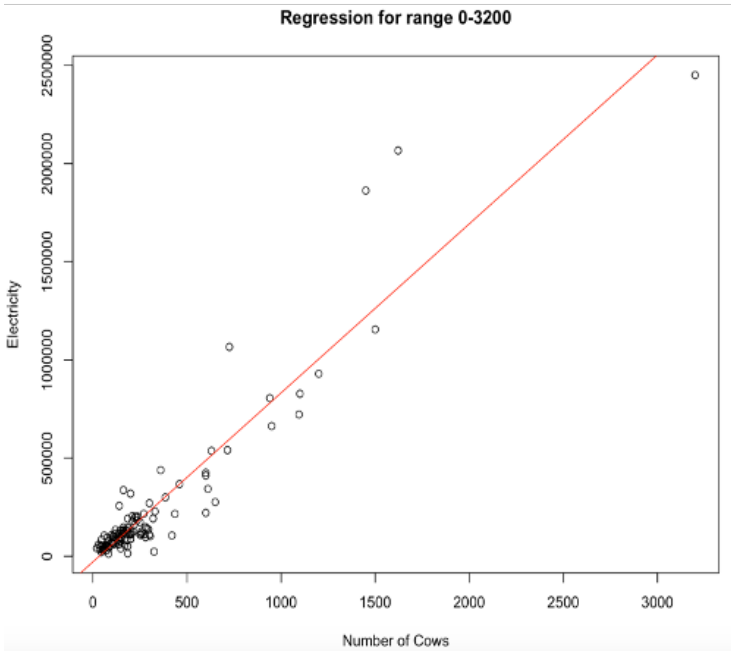


Figure 27. Fitted regression line (in red) for Model I

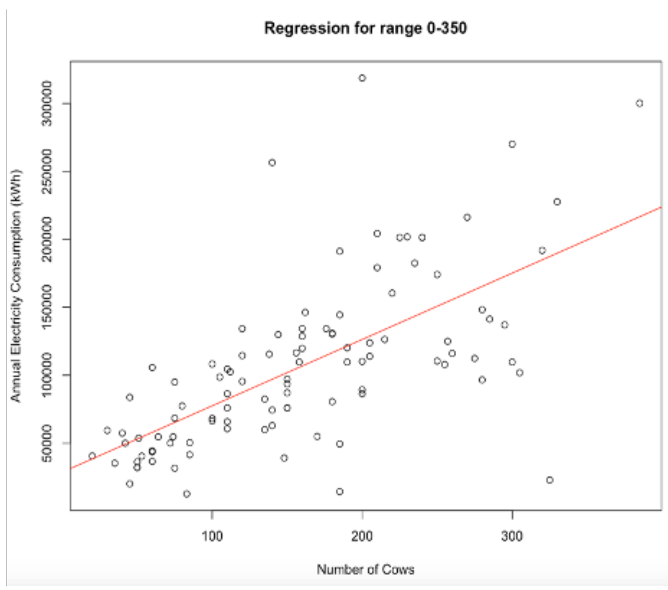


Figure 28. Fitted regression line (in red) for Model II

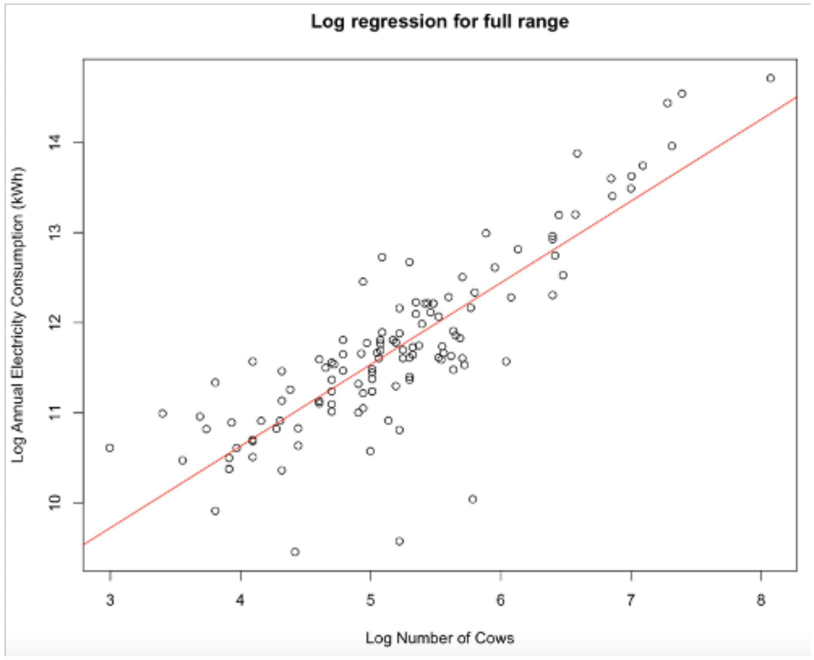


Figure 29. Fitted regression line (in red) for Model III

5.7 Results of Regression Model Comparison

Based on the residual diagnostics, outlier testing and trends, and regression analyses, it was evident that Model III was the most appropriate model for the purposes of the decision support tool. Normality issues stemming from the wide range of farm size were mitigated with the logarithmic transformation of variables. This led to better residual diagnostics, greater normality of data, and a regression line that fit well throughout the entire range of data. Additionally, using a regression model that includes medium to large farms ensured that a wider range of farmers can use the decision support tool.

5.7.1 Model III: Outlier testing and removal

Now that Model III was selected for the regression, the data were prepared for the final regression analysis. To do so, a series of outlier testing was performed on the model. The first outlier test done on Model III was a Bonferroni outlier test. Subject #75 and subject #120 had significant p-values under the Bonferroni adjustment, so they were considered extreme outliers that required further analysis. The next method of outlier identification was to create an influence plot, which included the residuals on the y-axis and hat-values (leverage) on the x-axis. Influence measures how much parameter estimates would be affected if these subjects were excluded from the regression. The diameter of the circles on the plot represents the square root of Cook's D statistic, which measures the influence of each point. As seen in Figure 30, it was clear that subjects 19, 75, 80, and 120 were the most influential points in the data set. Given that their residuals fell outside the range of +/- 2, it was further confirmed that points 75 and 120 were outliers. The points farthest to the right were those with the greatest leverage on the model. Subject #19 and subject #80 had the largest hat values (leverage), meaning they had the greatest potential to influence the model. Additionally, subject #80 had a relatively large diameter, which indicated it had high influence and may not have fit the overall model well.

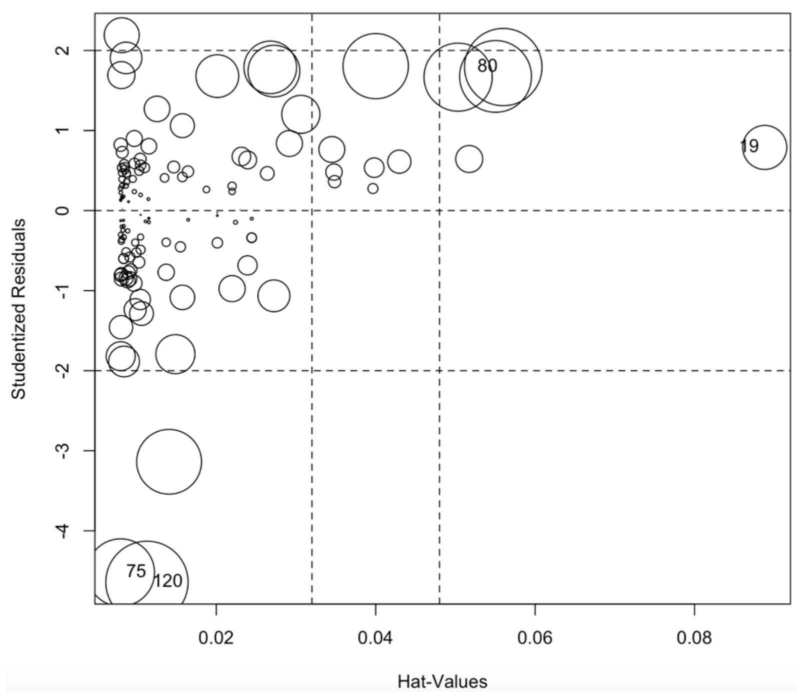


Figure 30. Influence plot of Model III

The final graph was a plot of Cook's distance for each subject (Figure 31). Cook's distance measures how much all the fitted values in the model change when the certain data point is deleted. Any distance greater than four divided by the sample size, which equaled 0.032 in this case, was an outlier. This value is the green dashed line in the center, with the blue lines representing 10th and 20th percentiles. As depicted in Figure 31, seven subjects have alarming Cook's distances greater than 0.06. These subjects are 71, 75, 80, 83, 120, 121, and 124. However, it must be noted that a subject that has a great influence on the regression is not considered an outlier unless it also strays from the fitted regression line. Therefore, the results of the three outlier tests were compared to formally declare which subjects would be excluded from the final regression.

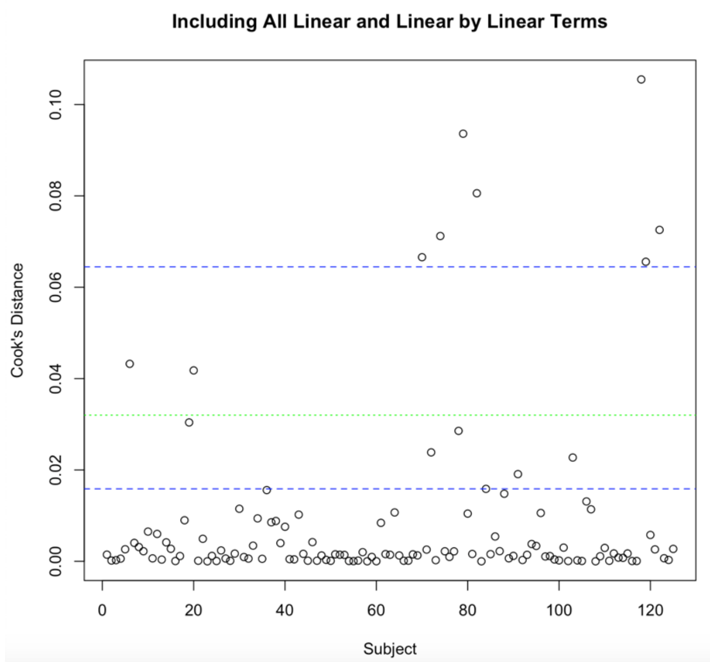


Figure 31. Cook's Distance

After all the outlier testing was completed, it was determined that there was sufficient evidence to exclude four subjects from the data before finalizing the regression. Table 10 shows which subjects were considered outliers, as well as which test result(s) indicated they were outliers as highlighted in red.

Table 10. Results of outlier testing for Model III

Subject	Number of Cows	Bonferroni p-value	Leverage (hat)	Cook's Distance
# 19	3200	> 0.05	0.08880	0.030398
# 75	185	0.001790	0.00800	0.071210
# 80	20	> 0.05	0.056000	0.093613
# 120	325	0.001096	0.011300	0.105495

After excluding four outliers, the histogram of data points looked sufficiently normally distributed (Figure 32). Additionally, excluding the outliers caused the R-squared value to increase from 0.72 to 0.77 and the standard error decreased from 0.051 to 0.046 (Table 11). This indicates that the data adhere more closely to the regression line, and the response variable can be more accurately predicted than before when outliers were included.

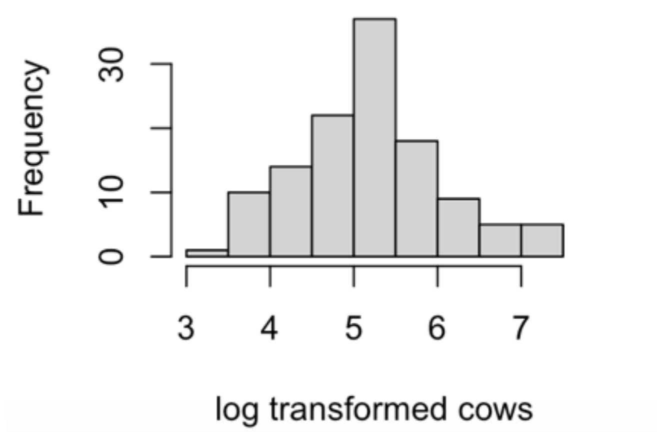


Figure 32. Histogram of Model III after excluding outliers

Table 11. Regression comparison of Model III with and without outliers

Model III	Degrees of freedom	Coefficient Estimate	Standard Error	p-value	R-squared
With outliers	123	0.907	0.051	<2E-16	0.72
Outliers excluded	119	0.932	0.046	<2E-16	0.77

As depicted in Figure 33, the residuals plot appeared to have a low density of points on the outer edges but an even distribution between 10.5 and 13. From top to bottom there was a fairly even distribution, with one subject at a residual value below negative one.

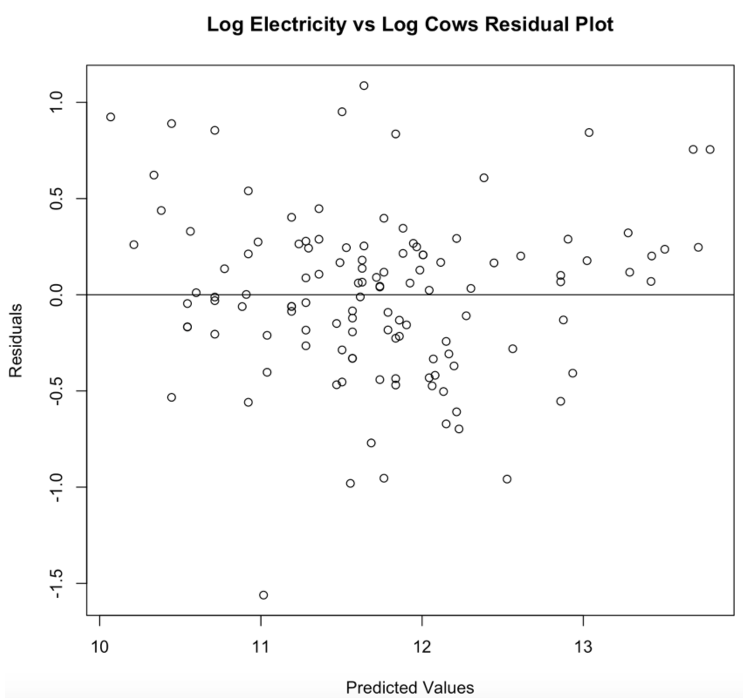


Figure 33. Residual plot after outliers were excluded from the data

5.7.2 Regression Equation

The final regression equation stated that for every 1% increase in the number of milking cows a farm has, their annual electricity consumption will increase by 0.93%. This is represented through the red line of best fit in Figure 34. Using the coefficient and the intercept, the regression equation was transformed into power law form in Equations 5 and 6, with y being the amount of electricity consumed per year (kWh) and x being the number of milking cows.

$$\log(y) = 0.932\log(x) + 6.899 \quad (5)$$

$$y = 991.283x^{0.932} \quad (6)$$

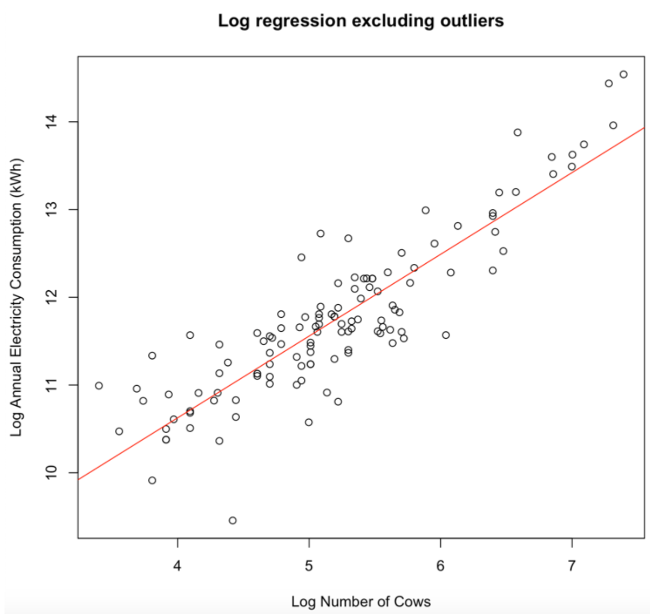


Figure 34. Line of best fit through Model III after outliers were excluded

5.8 Discussion

Once the four outliers were removed from the final model, the data ranged from 30 to 1622 milking cows. This means that the regression equation should only be used by dairy farms whose size are within this range. To avoid the risk of extrapolation, or prediction of points that exist outside the range of data, the decision support tool will advise farmers with less than 30 cows or more than 1600 cows to provide their own annual electricity consumption value.

R-squared is desired to be as close to 1 as possible, and for this regression it was found to be 0.77. R-squared values can be impacted by many factors, which could contribute to the error of this model. These factors may include but are not limited to differing management practices, inconsistency between auditors, and varying levels of mechanization. The energy audit data did not factor in energy efficiency on farms such as types of light bulbs used, and other factors that would vary from farm to farm. Additionally, this regression analysis did not account for number of times of milking per day, which could explain some of the variability between farms of the same size that consume considerably different amounts of electricity.

The data used in the regression analysis was collected from 2010 to 2016 which could also contribute to a lack of accuracy. Farms in that time may have been less efficient than farms in present day, which would result in an estimate that is too high. Alternatively, farms in present day may have more electrically powered mechanization than farms in that time did, which would result in the regression estimating a lower electricity consumption than present day. For the purpose of the computer model, farmers will be able to decide if they want to use the calculated electricity consumption based on their number of cows or if they want to input their own data from their electricity bills. Using a regression model that includes medium to large farms ensures the decision support tool applies to a wider range of dairy farmers in Michigan.

5.9 Other Implications / Future Work

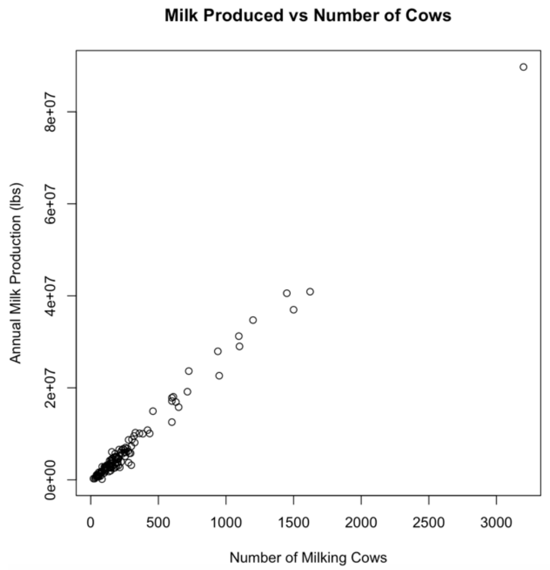


Figure 35. Relationship between annual milk production and number of milking cows

Based on the plotted data above, there is a linear relationship between the annual milk production and number of milking cows (Figure 35). From this figure, the larger dairy operations seem to be as efficient as smaller operations and vice versa. This has further implications that milk production per cow is consistent between large and small farms. The consistent slope indicates that healthcare and nutrition of large farms is just as good as those in smaller farms. Future analysis of this data could be used to analyze the effectiveness of extension services provided to farmers, farmer awareness of herd health, and other factors of farm productivity.

6.0 WEBSITE DEVELOPMENT

6.1 Introduction

A website was created to host the decision support system to assist dairy farmers with understanding the economics of installing solar panels. This website will provide them with an economic analysis that does not have the typical learning curve of other computer models. The website is composed of a *Solar Cost Calculator* for solar panel investments, *Sources of Funding*, and provides *Resources* that include Extension publications regarding solar power. In addition, the website includes a *Frequently Asked Question* section to ease uncertainty regarding solar panel maintenance, zoning laws, and other questions farmers might have.

6.2 Materials / Software

6.2.1 Software

Various software was used to design, develop, and implement this website. To start, Figma is an online design tool that assisted with pre-production processes. It was used to convey design ideas, prior to having to translate them into code. Next, a repository for the code was created on GitHub, which is a cloud-based hosting service for coding projects. Visual Studio Code was used as a source code editor, which allowed for any coding changes to be made from a desktop. As the code was developed on Visual Studio Code, it was saved, committed, and pushed to GitHub for storage. GitHub stored the code, as well as tracked any changes that were made throughout the process. GitHub can restore any previous version of code in the event of a major coding error. Finally, the GitHub repository was shared with Netlify, a website hosting platform. Netlify enabled the website to be viewed from a user's perspective and directed the efforts of how code had to be altered to achieve the final product.

6.2.2 Languages

Hyper-Text Markup Language (HTML) was used to arrange the website and carry its written content. HTML was essential in organizing the website into various pages, sections, and subsections. It allowed for the navigation between pages, as well as the embedding of hyperlinks to other pages and resources.

Cascading Style Sheets (CSS) was used to add stylistic elements to the website. The CSS code created stylistic rules that applied to the elements and organization established by HTML. CSS was responsible for font, margins, padding, colors, hover-colors, formatting, layout, and how elements are conveyed on a page. CSS was the mode for implementing the intended design of the website.

JavaScript (JS) was used to execute the functionality of the website. This included functions such as dropdown menus, responding to users "Clicking" on a button, storing user data, and performing calculations. Preliminary website development used very little JS, but the development of the *Solar Cost Calculator* was almost entirely done through JS. This will be described in greater detail in Chapter 7.

6.3 Methods

6.3.1 Website Design

In order to start the website design process, a pitch board was created to guide the focus of the website and ensure its final design appeals to its anticipated users (Figure 36). It was determined that the personas that are likely to use this website are dairy farmers, financial advisors, and solar installation companies. The next step was to consider comparable existing websites such as PVWatts and the System Advisor Model.

Dairytosolar.com

Short Pitch

Dairytosolar is a program designed to help dairy farmers explore the potential of installing solar energy on their non-arable farmland.

Long Pitch

Dairytosolar is a tool that aims to support dairy farmers through increasing production costs and stagnant milk prices. This program will provide them with farm-specific technology that does not have the typical learning curve of other computer models. Dairytosolar will include *How Photovoltaic Technology Works*, an *Economic Feasibility Analysis* of solar panel investment, *Sources of Funding*, and provide *Local Resources* of nearby vetted vendors and Extension programs. Dairytosolar aims to help the dairy industry achieve their goal of zero carbon emissions by 2050 and hopes to protect dairy farmers from the market volatility of increasing electricity prices.

Personas

Dairy Farmer: A dairy farmer in Michigan who is curious about the potential of solar technology on their farm but is unsure that it is financially feasible. This farmer is motivated by saving money but is discouraged by complicated technology and time-consuming decisions.

Financial Advisor: A financial advisor helping dairy farmers make informed business decisions regarding their farm. This user has a strong understanding of the financials of farming but is not well versed in photovoltaic technology or the economics of solar panel installation.

Solar Installation Company: A solar installation company that is curious what barriers prevent farmers from investing in their product. This company wants to gain customers in this market segment and will do so by determining how to optimize installation and maintenance for farmers.

Comps

NREL PVWatts Calculator https://pvwatts.nrel.gov

How Does Solar Work? https://www.energy.gov/eere/solar/how-does-solar-work

NREL System Advisor Model (SAM) https://sam.nrel.gov

Figure 36. Original pitch board of website goals and personas

Wireframes and compositions were created to visualize the layout of the site prior to its creation. The wireframes in Figures 37 and 38 depict the original idea for website design, which was based on the former Michigan Farm Energy Program (MFEP) website. The navigation bar was originally planned to be horizontal and under the solar panel image. Additionally, for smaller devices, the navigation bar would convert to a vertical menu on the left-hand side of the screen below the image.

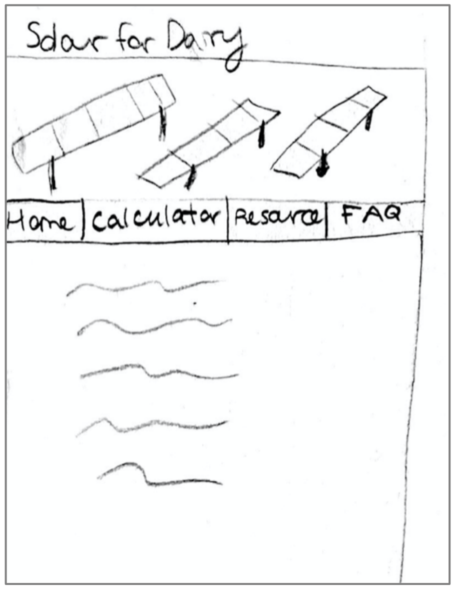


Figure 37. Wireframe of website desktop version

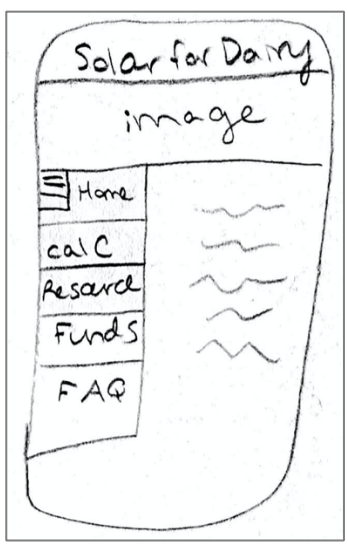


Figure 38. Wireframe of website mobile version

Figures 39 and 40 convey the more detailed design concept through a composition layout created with Figma software. These designs include a picture of solar panels and the use of green and gray to make the page easier to navigate. During the website development process, the MFEP updated their online platform. Since the website will be accessible through the MFEP website, certain design changes were made to add consistency between the two sites.

Figure 39. Draft of composition layout for desktop version

Figure 40. Draft of composition layout for mobile version

Once the design was established, Cascading Style Sheets (CSS) were used to implement stylistic choices on the HTML content. After several attempts to achieve these designs via code, it was determined that a toggle menu in the upper right-hand corner would be the most effective and feasible navigation design. Figures 41, 42, and 43 depict the final look of the navigation toolbar. For large screens, the navigation bar is displayed in a horizontal banner style (Figure 41). For smaller screens, the navigation is converted to a toggle menu in which users can leave it closed (Figure 42) or open it to view the menu options (Figure 43).

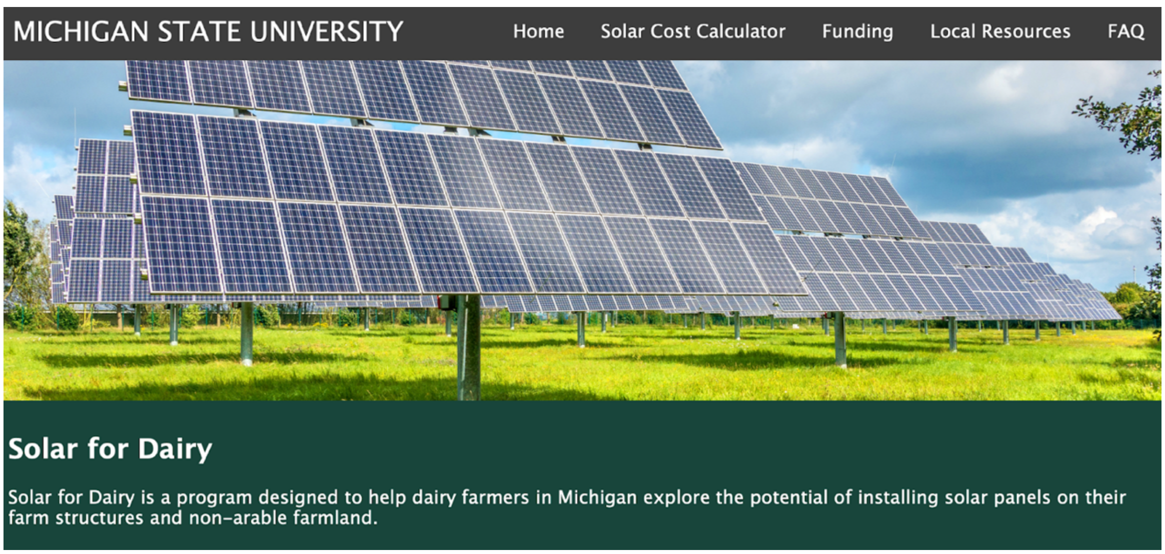


Figure 41. Website navigation bar for full display

Figure 42. Navigation bar for smaller display with toggle closed

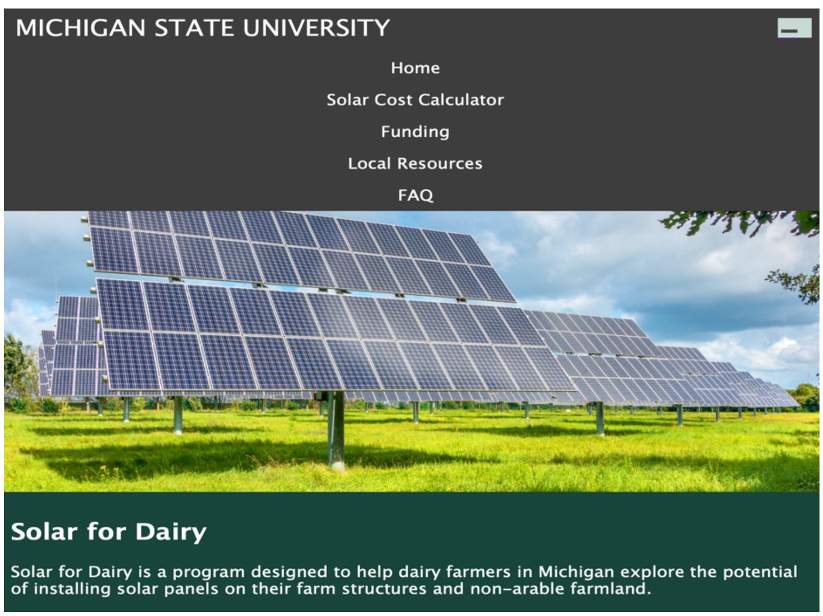


Figure 43. Navigation for smaller display with toggle open

Given that the website will be affiliated with Michigan State University (MSU), the website was designed to be a simplistic version of websites created by the university. It was determined which shade of green is considered "Spartan Green," which was then used as a background to highlight the central header. Additionally, the fonts commonly used by MSU were used throughout the website to maintain this sense of cohesiveness. To maintain the theme of the website, each tab of the site includes a different image pertaining to farming, solar energy, or cattle. These images were obtained from *rawpixel*, a website that enables the download of stock images that have creative commons licenses. Each image used has a Public Domain Dedication.

Finally, a shorthand workflow was written out to describe the function of the site, and further outline the user's experience. Figure 44 conveys the initial intended workflow of the website. From the Homepage, the navigation menu allows the user to visit the *Solar Cost Calculator*, *Funding, Resources*, and *Frequently Asked Questions*. From there, the workflow for each individual section moves downward and is organized by color.

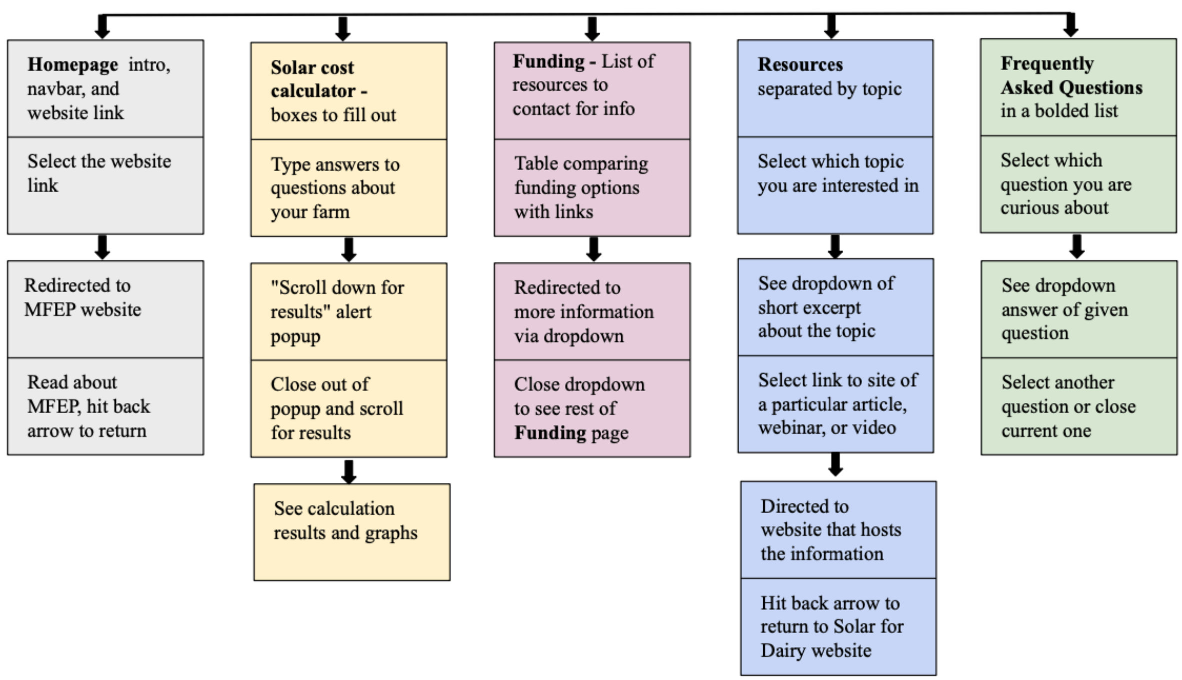


Figure 44. Shorthand workflow of website functionality

The website design closely followed this shorthand workflow of the website. To make the design more dynamic and easier to read, the structure of *Funding* was converted into a table that is responsive based on screen width. Additionally, both *Resources* and *Frequently Asked Questions* are composed of dropdowns that expand with more information. These design choices ensured the pages were well organized, easy to read, and visually appealing.

6.3.2 Website Content

Following the pre-production steps, the content for the website was planned in a separate document. The planning included content for the welcome page, as well as a few questions that were asked by dairy farmers during the *Perspectives of Michigan Dairy Farmers on Solar Technology* survey (Chapter 3). Content for *Resources* and *Funding* consists of websites and information available through MSU Extension and suggested by Tom Stanton. The final component of the website was the *Solar Cost Calculator.* This section houses the decision support tool, which uses JavaScript to perform calculations. Given the breadth of the decision support tool's development, the *Solar Cost Calculator* will be further discussed in Chapter 7. Each section of the website was contained in a separate HTML file, with the Homepage being the *index.html* file. The website aims to be accessible to dairy farmers, so the main content consideration was to avoid academic jargon and to keep the presentation of information simple. The written content for the website can be found the appendix.

6.4 Committee Input

In the quality control stage of the website development process, the site was presented to my graduate committee. Each member was given a questionnaire in which they were able to provide feedback. The opinions and questions presented by committee members were incorporated into the final design of the website.

6.5 Future of the Website

The SolarForDairy website will be housed in the Michigan Farm Energy Program's website. The MFEP has agreed to ensure its upkeep and maintenance following my graduation.

Throughout the coding process, notes and headers have been embedded throughout the code to keep it organized and readable. To ensure the website's longevity, all HTML, CSS, and JavaScript code will be provided to Mr. Aluel Go.

7.0 BUILDING THE DECISION SUPPORT SYSTEM

7.1 Introduction

The final step of completing the decision support system (DSS) was the coding of the *Solar Cost Calculator* for the website. The calculator was developed using the flow of information as outlined in the case study (Chapter 4). Calculations were taken directly from the case study, with a few logistical changes to account for user input and the use of default values.

7.2 Materials

The software and languages used for the calculator included all items described in Chapter 6, with a few additional details. Prior to transferring the JavaScript (JS) data to Visual Studio Code, the entire calculator was planned and troubleshooted using CodePen. CodePen is an online software that allows for code editing, design, and functionality to be output onto a website all in one location. It allowed for the user-interface to be updated in real time without having to commit and push code to the repository, resulting in more efficient development. The development of the *Solar Cost Calculator* was almost entirely done through JS. JS allowed data from user input to be taken from HTML code and stored in various functions. The use of if/then statements, default values, arrays, and iterative functions allowed for the necessary calculations to be done to perform the economic analysis.

7.3 Methods / Code Development

7.3.1 Pre-Production Phase

After the calculations were developed from the Case Study (Chapter 4), pre-production of the Solar Cost Calculator began. A spreadsheet was created to list all variables, their description, their units, and their variable names according to JS. The variables were organized by source as constants, results of equations, or data from user input. Another column was made which included the equation typed out in JS nomenclature and JS variable names. This approach ensured consistency between equations and prevented coding errors. A copy of this spreadsheet can be found in the appendix.

The second phase of pre-production was creating a flow chart to outline the flow of information in the computer program. The flow chart includes which variables were expected to be input by the user, the breakdown of energy consumption on dairy farms, and the order of operations in performing the calculations in JavaScript. Finally, the flow chart describes what the expected output of the program will be, organized by graphs and numerical financial output (Figure 45).

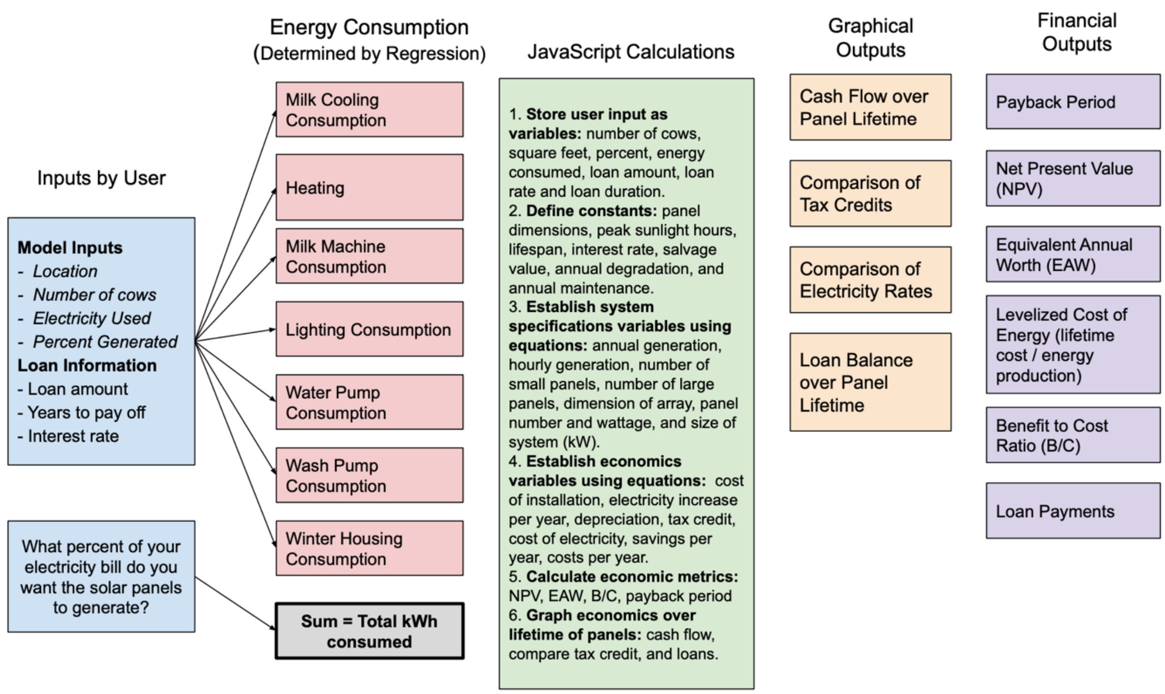


Figure 45. Flow chart of information through JavaScript calculations

7.3.2 User Input Form

The first element of coding the DSS was to create a method to obtain input from the user, which would then be stored as variables for the calculations. To start, a form was created in HTML that asked the user to input the number of cows they have, the square footage they have available to place solar panels, and what percentage of their electricity bill they wanted to be replaced with solar generated electricity. Each piece of data from the user was given a unique name using the *ID* HTML attribute. The initial form included simple input boxes, with the units placed to the right of each box. A "Submit" button was incorporated with an *OnClick* function to signal to the JS code that data was being inputted. Figure 46 below shows the original user input form, prior to adding style with CSS. Note that there was no border included on this input form at the time, the border shown below is for ease of reading.

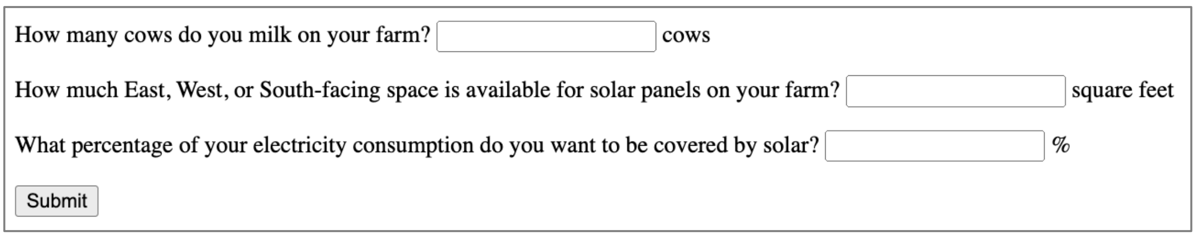


Figure 46. Original user input form without styling

After the form was created in HTML, a function was created in JS to store the user input as variables. Within the function, the *getElementById* method was used to call the data from the HTML code, then return the value of the element with the same ID (Figure 47). Variables were created with the *let* method and were named in accordance with the pre-production spreadsheet.

```
function returnText() {
  let numberCows =
document.getElementById('numberOfCows').value;
  let squareFeet =
document.getElementById('squareFeet').value;
 let percent =
document.getElementById('percent').value;
```

Figure 47. Stored data of user inputs using JS

To ensure the data was properly stored within the function, an *alert* was created with the JS variable names to report the user input with a pop-up window. Additionally, a few simple calculations were placed within the function to allow for troubleshooting of the code. If the calculations resulted in "NA", it was a signal that the data was not being properly stored. Finally, the values from the case study were used to verify the code was operating correctly. When the calculations turned out to be consistent with the results of the case study, it was time to move on toward designing the user interface of the form.

7.3.3 Design of the User Input Form

First it was decided that the submit button was too generic, small, and not synergistic with the overall website design. The black border was removed, padding was added around the button, and the background color was changed to "Spartan Green". The font was made bold, and a radius was added to the button's border to soften its appearance. Finally, the width was altered to extend the length of the entire form for ease of use (Figure 48).

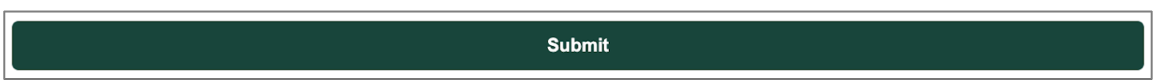


Figure 48. Submission button after styling

The next subject of styling was the input boxes. It was decided that moving the units inside of the textboxes would be more aesthetically pleasing than having them to the right of the textbox. This was done entirely in HTML, using a *span* tag to create an inline container. The *span* was placed within the overall *label* of the textbox and included the unit text (e.g., "sq feet"), as well as the styling necessary to align it appropriately within the box. A sample HTML code of the first textbox is provided below (Figure 49).

```
<p><label>How many cows do you milk on your farm?
      <input id="numberOfCows" type="text" style="padding-right:20px; text-
align:center;">   </input><span style="margin-left:-40px; color:
#5f5f5f">cows</span></label> </p>
```

Figure 49. HTML coding of input box including units

Padding was added around the input text and a solid black border with slight border radius was added around each input box. In order to help the user navigate the form, a *focus* selector was added to each of the input boxes. When a user clicks on a box to start typing, the border of the box becomes highlighted in blue (Figure 50). Note that the units are now located within the textbox.

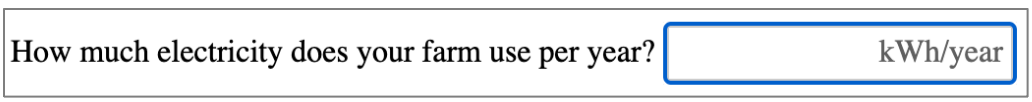


Figure 50. Use of a *focus* selector to highlight text boxes in use

Since the form itself was identified using a *div* in HTML, the *div* name could be called in the CSS code, and stylistic components were added to apply to the entire form. To help the user navigate the page, the form itself was styled to have a gray border. A border radius was added to have curved edges for a softer design. Figure 51 below is the final product of the user form with all the styling included.

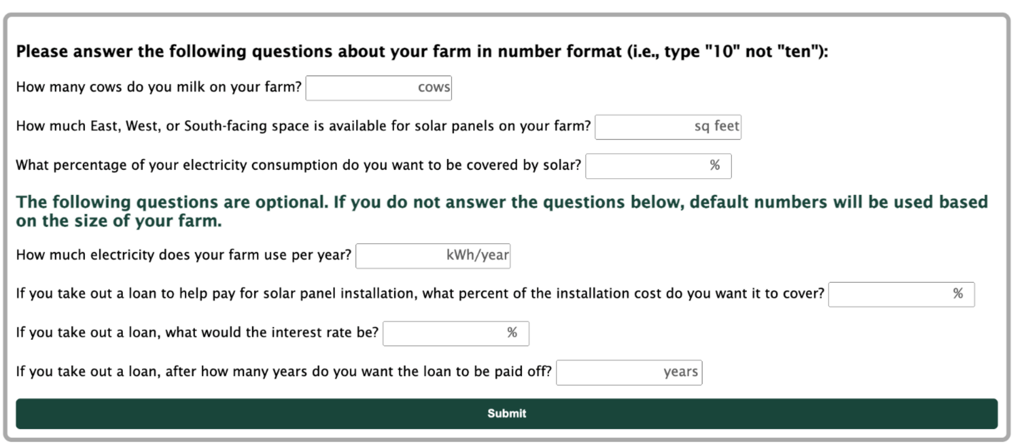


Figure 51. Final design of user input form with CSS styling

7.3.4 Equations / Calculations

All the calculations for the Solar Cost Calculator are based on the user's initial input. For this reason, all calculations occur within the primary user input function. For *annual electricity consumption* and information regarding loans, it is optional for the user to input data. If they do not input data, the code provides default values to run the calculations from (Table 12).

Table 12. Default values for user input into decision support system

Variable / Constant	Default Value	Source
Annual electricity consumption	991.28*(number milking cows)$^{0.932}$	Regression equation (Ch. 5)
Loan interest rate	5.34%	Average of multiple sources
Loan duration	25 years	Lifetime of panels
Loan percentage	100%	Assume loan will cover the entire cost of installation

The calculations were separated into four sections: Energy generation, system specifications, economic evaluation criteria, and loan information. After annual electricity consumption is determined, it is multiplied by percent generated to determine what the annual generation of the solar panels should be. From here, the program establishes the size of the system needed based on the number of peak sunlight hours and the amount of square footage available to house the panels. The program compares the number of panels needed if 150-Watt panels were used versus 370-Watt panels were used. The dimensions of the two configurations are then compared to determine which panel size is appropriate for the given amount of square footage available. The system size is then calculated to be the number of panels times the panel wattage, to result in a system sized by Watts.

After system size is determined, the size of the system is used to calculate how much the cost of installation will be, based on a cost per Watt value. The cost of installation is then used in all the economic equations. The next step was to establish the values that would be used in the economic analysis that were not based on user input (Table 13). After these values were established, iterative calculations were coded to account for the items that change on an annual basis. For example, electricity rates for each year of the 25-year lifespan were calculated based on the anticipated 2.96% rate of increase per year. Additionally, the yearly electricity generation was calculated for each of the 25 years based on the expected panel degradation of 0.5% per year. These pre-calculations allowed for later iterative calculations to be performed accurately.

Table 13. Values used in the economic analysis of the decision support system

Constant	Value	Source
Electricity rate	0.16	(Michigan.gov, 2022)
Lifespan	25 years	(NREL FAQ, 2023)
Annual inflation rate	3%	Average of past 20 years of inflation (U.S. Inflation Calculator)
MI electricity rate increase	2.96% per year	(Solar Reviews, 2022)
Salvage value	0 dollars	Assumption
Annual depreciation	Straight line	Assumption
Annual insurance	0.25% of installation cost per year	(Ramasamy et al., 2022)
Annual degradation	0.5%	(Jordan & Kurtz, 2021)
Annual maintenance	$17/kW per year	(Wiser, 2020)
Tax credit	30% of installation cost	(Department of Energy, 2023)

To continue following the order of calculations set forth by the case study (Chapter 4), the cumulative cash flow by year was calculated iteratively for both future and present value. This enabled a graph to be constructed which displayed the cumulative cash flow in present value and future value over the lifetime of the panels. The next graph was meant to evaluate the impact of the Investment Tax Credit (ITC) on the investment. The cashflow was calculated iteratively based on if the tax credit covers 30% of the installation cost, 15% of the installation cost, and if there was no tax credit at all.

These iterative results were used to perform the economic criteria calculations. Net present value, benefit to cost ratio, payback period, and equivalent annual worth were all calculated and presented to the user in table format. These calculations include the 30% tax credit applied one year after installation. The final component of the economic analysis was to incorporate loans into the calculations. User input or default values were used in a for-loop calculation to determine the loan balance each year and the expected annual payment. These values were determined for each year after installation, and subsequently graphed for the user's convenience (Figure 52).

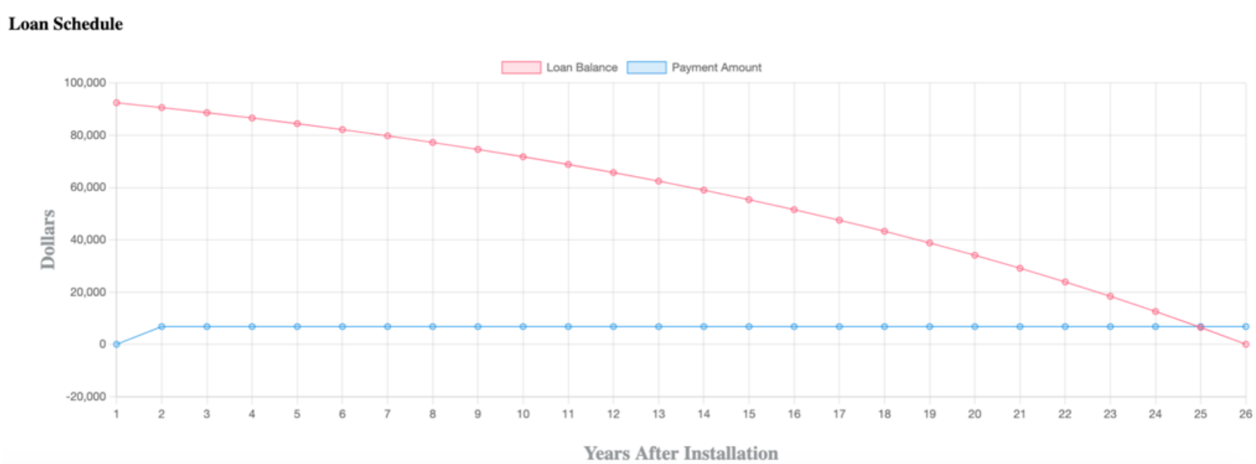


Figure 52. Example graph of loan balance and payment schedule

7.3.5 Presentation of Numerical Output

Originally, the numerical output was presented in a very simple list of results. The list was very long and required the user to scroll to see all the results because it was not responsive to screen width. It also had no contrast between variable name, value, and units which made the results difficult to read. As depicted in Figure 53, the list was unappealing, hard to follow, and not synergistic with the rest of the website. Additionally, it included information that was not necessary for the user to see and could potentially confuse farmers. For example, number of large and small panels, configuration dimensions, net present value of benefits, net present value of costs, etc. These results were removed from the numerical output.

Calculation Results

User Inputs

Number of Cows: 180 cows

Square Feet Available: 3000 square feet

Percent Generated: 100 %

Energy Generation

Annual Electricity Consumption: 110332 kWh

Annual Electricity Generated by Panels: 110332 kWh

Hourly Generation: 13 kWh

Number and Type of Panels

Peak Sunlight: 4.1 hours

Number of Small Panels: 344 150-Watt panels

Number of Large Panels: 140 370-Watt panels

Small Configuration: 3604 square feet

Large Configuration: 2597 square feet

Number of Panels: 140 panels

Panel Size (Wattage): 370 Watt panels

Cost of Installation

System Size: 51639 Watts

Cost of Installation: 92435 dollars

Economic Evaluation Equations

Payback Period: 8 years

Net Present Value: 190439 dollars

NPV total: 190207 dollars

Equivalent Annual Worth: 10923 dollars

Net Present Value of Benefits: 400037 dollars

Net Present Value of Costs: 209829 dollars

Benefit to Cost Ratio: 1.9064858814851717

Figure 53. Original presentation of decision support system numerical output

To keep the webpage both comprehensible and engaging, the style of the results was altered to be presented in table format. Results were clumped into their major categories, then placed into five separate tables. The use of multiple tables allowed for the information to be well organized, while also being responsive to varying screen widths. If the user has a screen/browser greater than nine hundred pixels wide, the results will be presented with two tables side-by-side. If the user has a screen under nine hundred pixels wide (i.e., accessing the site via mobile phone), the results will be displayed one table at a time scrolling down. Each table has separate columns for the name of the result, its numerical value, and its units. Padding and a thin 1-pixel border surrounds each textbox. The header of each table was given a vibrant green background and the text was centered, made white, and bolded to be more aesthetically pleasing (Figures 54 and 55).

Calculation Results

For more information about each value, hover over a row in the table!

User Input		
Number of Cows	180	cows
Square Feet Available	3000	square feet
Percent Generated	100	%

Energy Generation		
Annual Electricity Consumption	110332	kWh/year
Annual Electricity Generation	110332	kWh/year
Hourly Solar Panel Generation	13	kWh

System Specifications		
Total Panel Configuration	2597	square feet
Number of Panels	140	370 Watt panels
System Size	51639	Watts
Cost of Installation	92435	dollars

Economic Evaluation Criteria		
Payback Period	5	years
Net Present Value	190207	dollars
Equivalent Annual Worth	10923	dollars
Benefit to Cost Ratio	1.9064858814851717	-

Figure 54. Display of numerical results for screens more than 900 pixels in width

User Input		
Number of Cows	180	cows
Square Feet Available	3000	square feet
Percent Generated	100	%

Energy Generation		
Annual Electricity Consumption	110332	kWh/year
Annual Electricity Generation	110332	kWh/year
Hourly Solar Panel Generation	13	kWh

System Specifications		
Total Panel Configuration	2597	square feet
Number of Panels	140	370 Watt panels
System Size	51639	Watts
Cost of Installation	92435	dollars

Economic Evaluation Criteria		
Payback Period	5	years
Net Present Value	190207	dollars
Equivalent Annual Worth	10923	dollars
Benefit to Cost Ratio	1.9064858814851717	-

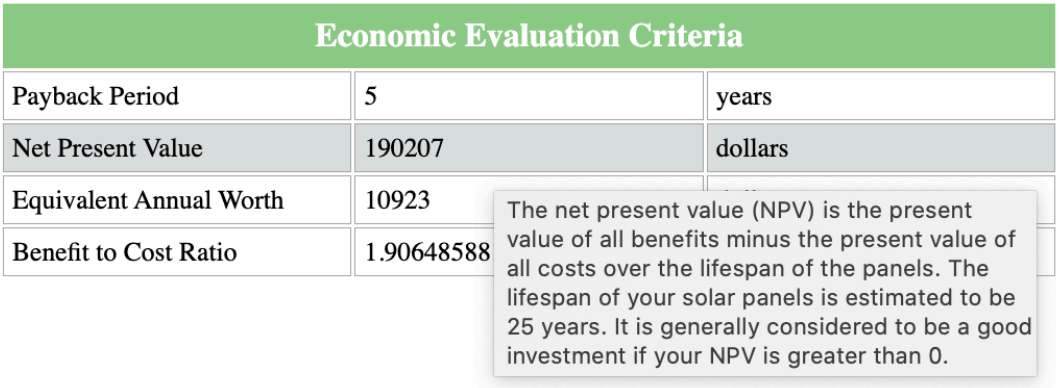
Figure 55. Display of numerical results for screens less than 900 pixels in width

As the functionality and look of the Solar Cost Calculator were finalized, it was crucial to consider the perspective of a farmer using the program. With a core objective of the website being its accessibility and applicability to farmers, it was determined that special features must be added to ensure farmers could understand the results. For this reason, the hover function in CSS was used to highlight a result in gray when the user hovers over it (Figure 56).

System Specifications		
Total Panel Configuration	2597	square feet
Number of Panels	140	370 Watt panels
System Size	51639	Watts
Cost of Installation	92435	dollars

Figure 56. Hover function in CSS

To communicate to the farmer what each result means, a written excerpt was created for each variable. Using the *title* attribute in HTML, these excerpts were translated to mouseover text that pops up when hovered over. As the user hovers over any variable, its row becomes shaded in gray, and the mouseover text provides information about the result. For the preliminary calculations, the text provides information on how the value was calculated, and what sources were used to obtain those values. For the economic evaluation criteria, the text includes information on what is considered a good investment based on the metric for each criterion (Figure 57). A comprehensive list of mouseover text is provided in the appendix.



Economic Evaluation Criteria		
Payback Period	5	years
Net Present Value	190207	dollars
Equivalent Annual Worth	10923	
Benefit to Cost Ratio	1.90648588	

Figure 57. Hover function plus mouseover text provided for NPV result

7.3.6 Graphical Output

After the economic analysis was performed, it was imperative to present this information in a way that the farmer can understand. For this reason, graphs were created to give the farmer a visual of what their financial position would be throughout the lifetime of the solar panels. To present graphical output, *Chart.js* was used to simplify the coding required for graphing the data. *Chart.js* is an open-source JS library and allows the program to produce to scatter plots, bar charts, line graphs, and many other options. For the purposes of this project, simple line plots were created to convey the economic information to the farmer.

After calculations were completed, a new variable was created to represent the line graph in question. The x-axis was labeled as the number of years after installation, and the y-axis varied based on what was being graphed. The font, size, and color of the labels were adjusted for aesthetic purposes throughout the coding process. When the chart was representing more than one dataset, each set was given a different color. For example, Figure 58 below depicts the cash flow over the lifetime of the panels in both future value and present value. The future value, unadjusted, is represented in blue, and the present value is represented in pink. When a user hovers over a data point, a text box appears that gives the numerical value for the given year. In the example shown below, the cumulative cash flow 25 years after installation is estimated to be $190,207.

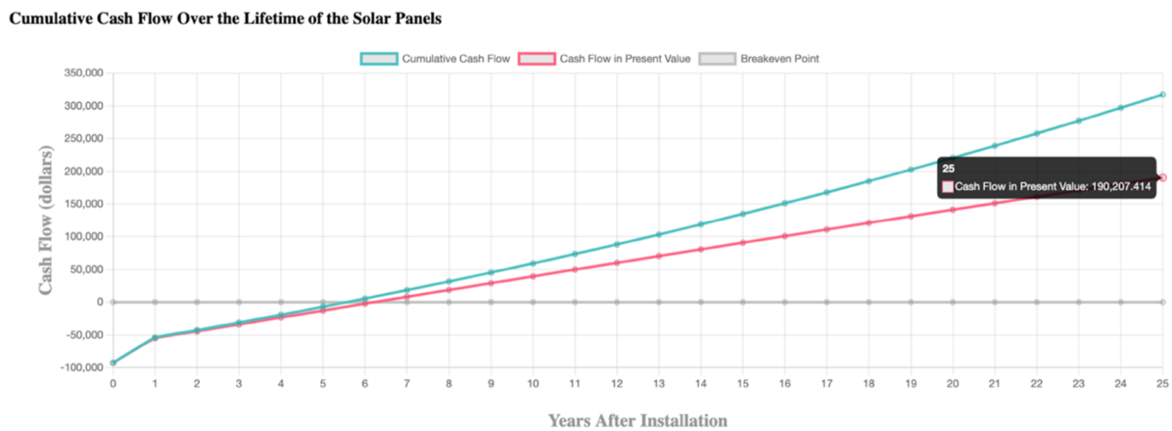


Figure 58. Cumulative cash flow over lifetime of panels

7.4 Results and Discussion

The development of this code produced a Solar Cost Calculator that is an interactive model for dairy farmers in Michigan. This online calculator incorporates the steps of the case study in Chapter 4 and the regression equation found in chapter 5 to form an interactive model for dairy farmers in Michigan. The results provide information to the user in the form of tables, graphs, and simple descriptions. The calculator allows farmers to decide what level of participation they want through the option of default values for several user input items. The option of default values will farmers feel less overwhelmed when researching solar panel installation.

The Solar Cost Calculator is not meant to replace the role of a solar installation consultant, but to provide an educational tool for farmers wishing to acquire more information on the topic. This website will help farmers explore the potential of solar technology on their farm without feeling pressure to commit, fear of personal information being stolen, and advertisements distracting them from the website’s content. The existence of the website will give dairy farmers a better understanding of the economics of this investment and better inform them as they consider making sustainable changes on their farm.

8.0 CONCLUSION

In 2020, the U.S. dairy industry announced their Net Zero Initiative, with a goal to achieve carbon neutrality by 2050. The U.S. dairy industry contributes to greenhouse gas emissions through cow digestion, agricultural practices done to grow feed crops, and the source of energy consumed on farms. As the world population continues to increase, there will be an increase in the demand for dairy products, furthering the dairy industry's impact on climate change. Therefore, there is a pressing need to support dairy farmers as they consider sustainable changes to their farms.

Given the energy intensive processes on dairy farms, implementing renewable energy technology is crucial in achieving carbon neutrality. In Michigan, the cost of electricity increases annually, while the cost of solar panels is significantly decreasing. Solar power provides an opportunity for farmers to reduce their cost of production and increase their profit. However, installing solar panels is a major investment that requires a thorough economic analysis. Therefore, a decision support tool was created to provide an economic analysis for the lifetime of solar panels, and help dairy farmers determine if it is economically feasible for their specific farm. This research included (1) a survey to understand the perspectives of Michigan dairy farmers on solar technology, (2) a case study to evaluate if solar panels would be a good investment for a subject dairy farm, (3) a regression analysis to determine the relationship between number of cows and the amount of electricity consumed, and (4) the development of a website to perform economic analyses for dairy farmers, as well as provide resources to further educate them on the decision. The findings from each of these chapters are presented below:

(1) The results of the survey indicate there is significant interest in installing solar technology on dairy farms. However, renewable energy implementation is hindered by pre-existing perceptions of farmers. Many participants felt solar panels were too

expensive and time-consuming to be a feasible option for their farm. Additionally, many farmers rely on word of mouth, University Extension, and farm organization meetings as sources of information. This indicates that sustainability initiatives will be most effective if they educate farmers through these means of communication.

(2) For the subject farm with 180 cows and 110,332 kilowatt-hours of electricity consumed per year, a 52-kilowatt solar array could produce their annual need for electricity. The system would cost $92,722 and when including the federal tax credit amounting in 30% of installation costs, have a net present value of $221,053, and have a payback period of 5.13 years. The benefit to cost ratio was found to be 2.05. The positive NPV and the B/C ratio greater than one indicate that installing solar panels would be economically beneficial for the subject dairy farm.

(3) When a regression analysis was performed on energy audit data of 132 dairy farms located in Michigan, a relationship between number of milking cows and amount of electricity consumed per year was found. The final regression equation states that for every 1% increase in the number of milking cows a farm has, their annual electricity consumption will increase by 0.93%.

(4) A website was created to help dairy farmers visualize the economics of installing solar panels on their farm. The website includes economic evaluation criteria, graphs that emphasize cash flow over the lifetime of the panels, and an option to include loan payments in the analysis. The website includes a frequently asked question section, a page of resources that include relevant MSU Extension publications, and a page that provides sources of funding. This website is meant to educate farmers about the investment and provide resources to aid their decision-making process.

9.0 FUTURE RESEARCH RECOMMENDATIONS

This research analyzed farmer decision making and aimed to help farmers make educated decisions about installing photovoltaic technology on their farms through a website. However, this website was limited by coding ability as well as efforts to keep it simple and understandable for dairy farmers. The primary limitation is having to use the NREL more generalized cost estimate based on residential projects, large commercial projects, and utility-scale projects. There is limited information regarding cost estimation for systems between ten kilowatts and two hundred kilowatts, which impacts the accuracy of the Solar Cost Calculator. Future work could be done to enhance the website in the following ways:

- Develop a model to better estimate the cost of solar between ten kilowatts and two hundred kilowatts. Provide a more specific installation cost breakdown of parts based on supply and demand for each part, as opposed to using broad estimates from NREL.
- Create an option to incorporate the *Sources of Funding* options with the actual calculations in the economic analysis, instead of solely including the federal tax credit. Allow the user to check a box for which funding source they would like to be included in the economic analysis to better inform their decision.
- Provide more information on battery storage options that account for seasonal fluctuation in energy production. Include a graph of anticipated production based on monthly irradiation data that is directly based on area code, as opposed to the general peak sunlight hours that were used for the state of Michigan.
- Develop a function that can seek out multiple quotes for local solar installation companies and then provide a comprehensive quote comparison for the dairy farmer.
- Expand the website to be applicable to the Midwest or even to the United States.

BIBLIOGRAPHY

Alexandratos, N. (2012). *World Agriculture towards 2030/2050: The 2012 revision*. 154.

Anseel, F., Lievens, F., Schollaert, E., & Choragwicka, B. (2010). Response Rates in Organizational Science, 1995–2008: A Meta-analytic Review and Guidelines for Survey Researchers. Journal of Business and Psychology. 25. 335-349. 10.1007/s10869-010-9157-6.

Avemegah, E., et al. (2020) An Examination of Best Practices for Survey Research with Agricultural Producers, Society & Natural Resources, DOI: 10.1080/08941920.2020.1804651

Battisti, D. S., & Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science (New York, N.Y.)*, *323*(5911), 240–244. https://doi.org/10.1126/science.1164363

Belflower, J. B. (2009). Environmental assessment of pasture-based and confined dairy farms in Georgia.

Borrelli, K. A., Roesch-McNally, G. E., Wulfhorst, J. D., Eigenbrode, S. D., Yorgey, G. G., Kruger, C. E., Houston, L. L., Bernacchi, L. A., & Mahler, R. L. (2018). Farmers' Trust in Sources of Production and Climate Information and Their Use of Technology. Journal of Extension, 56(3). Retrieved from https://tigerprints.clemson.edu/joe/vol56/iss3/21

Cruse, M. J. (2009). *Fossil energy use in conventional and low-external-input cropping systems* (Order No. 1465698). Available from ProQuest Dissertations & Theses Global. (304903654). Retrieved from http://ezproxy.msu.edu/login?url=https://www.proquest.com/dissertations-theses/fossil-energy-use-conventional-low-external-input/docview/304903654/se-2?accountid=12598

Current U.S. Inflation Rates: 2000-2023. US Inflation Calculator. Retrieved from https://www.usinflationcalculator.com/inflation/current-inflation-rates/.

Cut Costs and Energy Use Through Efficiency. (n.d.). SARE. Retrieved February 24, 2021, from https://www.sare.org/publications/clean-energy-farming/energy-efficiency/

DairyFarmEnergyManagementHandbook.pdf. (n.d.). Retrieved February 24, 2021, from https://datcp.wi.gov/Documents/DAD/DairyFarmEnergyManagementHandbook.pdf

Doll, J.E., Peterson, B., & Bode, C. (2017). Skeptical but Adapting: What Midwestern Farmers Say About Climate Change. *Weather, Climate, and Society,* 9(4), 739-751. Retrieved Dec 6, 2021, from https://journals.ametsoc.org/view/journals/wcas/9/4/wcas-d-16-0110_1.xml

Download—System Advisor Model (SAM). (n.d.). https://sam.nrel.gov/download.html

EPA. (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015. EPA 430-P-17–001. Environmental Protection Agency (EPA), Washington DC.

FAO. (2009). *Global Agriculture Towards 2050.* Retrieved from https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.

FAO. (2011). *World livestock 2011, livestock in food security. Rome, Italy: United Nations FAO.* Retrieved from http://www.fao.org/docrep/014/i2373e/i2373e00.htm

Homeowner's guide to the federal tax credit for solar photovoltaics. (2023). Department of Energy. Retrieved from https://www.energy.gov/eere/solar/homeowners-guide-federal-tax-credit-solar-photovoltaics

How much electricity prices increase per year in the U.S. (2022). Solar Reviews. Retrieved from https://www.solarreviews.com/blog/average-electricity-cost-increase-per-year

Interest Rates, Discount Rate for United States. Federal Reserve Economic Data. Retrieved from https://fred.stlouisfed.org/series/INTDSRUSM193N

Jordan, D., & Kurtz, S. (2021). *Overview of Field Experience - Degradation Rates & Lifetimes*. United States

Louwen, A., & van Sark, W. (2020). *Chapter 5 - Photovoltaic solar energy. In M. Junginger, & A. Louwen (Eds.), Technological learning in the transition to a low-carbon energy system (pp. 65-86). Academic Press.* https://doi.org/10.1016/B978-0-12-818762-3.00005-4

Michigan Solar. (n.d.). SEIA. Retrieved February 24, 2021, from https://www.seia.org/state-solar-policy/michigan-solar

Millar, M., & Dillman, D. , Improving Response to Web and Mixed-Mode Surveys, *Public Opinion Quarterly*, Volume 75, Issue 2, Summer 2011, Pages 249-269, https://doi.org/10.1093/poq/nfr003

Mohsenimanesh, et al. (2021). *Review: Dairy Farm Electricity Use, Conservation, and Renewable Production - A Global Perspective.* ASABE. *Applied Engineering in Agriculture.* Retrieved November 1, 2021, from https://elibrary.asabe.org/abstract.asp?aid=52779

NIFA. N.d. Extension. Retrieved from https://nifa.usda.gov/extension

NREL. (n.d.). Direct normal solar irradiance. Retrieved from https://www.nrel.gov/gis/assets/images/solar-annual-dni-2018-01.jpg.

Pope, M. and S. Sonka. *"Evidence, Data and Farmer Decision Making." farmdoc daily (10):45, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, March 11, 2020.*

Prokopy, L. et al. (2019). Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. Journal of Soil and Water Conservation. 74. 520-534. 10.2489/jswc.74.5.520.

PVWatts Calculator. (n.d.). Retrieved February 24, 2021, from https://pvwatts.nrel.gov/pvwatts.php

Ramasamy, V., Zuboy, J., O'Shaughnessy, E., Feldman, D., Desai, J., Woodhouse, M., Basore, P., and Margolis, R. 2022. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-83586. https://www.nrel.gov/docs/fy22osti/83586.pdf.

Reganold, J. P., Jackson-Smith, D., Batie, S. S., Harwood, R. R., Kornegay, J. L., Bucks, D., & Willis, P. (2011). Transforming U.S. agriculture. *Science*, *332*(6030), 670–671. doi:10.1126/science.1202462

Sam-help-2020-11-29.pdf. (n.d.). Retrieved February 24, 2021, from https://sam.nrel.gov/images/web_page_files/sam-help-2020-11-29.pdf

SARE. (n.d.). What is sustainable agriculture? UC Davis. Retrieved from https://sarep.ucdavis.edu/sustainable-ag

Salfer, J. (2017). UMN. Margin compression affects dairy producers. University of Minnesota Extension. Available online: https://extension.umn.edu/dairy-milking-cows/margin-compression-affects-dairy-producers (accessed on February 24, 2021).

Schnepf, R. (2004). *Energy Use in Agriculture: Background and Issues*. 44.

Shine, P., Upton, J., Sefeedpari, P., & Murphy, M. D. (2020, March 1). *Energy Consumption on Dairy Farms: A Review of Monitoring, Prediction Modelling, and Analyses*. Energies; MDPI AG. https://doi.org/10.3390/en13051288

Slawinski, T. (2022). *Fiscal Year 2022 Annual Report*. Michigan Department of Agriculture and Rural Development Food and Dairy Division. Retrieved from https://www.michigan.gov/mdard/-/media/Project/Websites/mdard/documents/annual-reports/fdd/2022_fdd_annual_report.pdf?rev=0c14bdbaea80481cb9ebc3c209a03f55&hash=30AF37BE5DA70EBF486AEA792C4528E0.

Stedman, R., Connelly, N., Heberlein, T., & Allred, S. (2019). The End of the (Research) World As We Know It? Understanding and Coping With Declining Response Rates to Mail Surveys. Society & Natural Resources. 32. 1139-1154. 10.1080/08941920.2019.1587127.

Thoma, G. J., J. S. Popp, D. W. Nutter, D. R. Shonnard, R. Ulrich, M. D. Matlock, D. Kim, Z. Neiderman, N. Kemper, C. East, and F. Adom. 2013. Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. Int. Dairy J. 31: S3–S14.

Time-consuming occupations and what they pay. (n.d.). Retrieved February 20, 2021, from https://www.bls.gov/careeroutlook/2005/summer/oochart.pdf.

Upton, J., Murphy, M., Shalloo, L., Groot Koerkamp, P. W. G, & De Boer, I.J. (2014). A mechanistic model for electricity consumption on dairy farms: Definition, validation, and demonstration. *Journal of Dairy Science, 97(8), 4973-4984. https://doi.org/10.3168/jds.2014-8015*

USDA. *(2016). Building Blocks for Climate Smart Agriculture and Forestry Implementation Plan and Progress Report May 2016*. (n.d.). 62. Retrieved February 25, 2021, from https://www.usda.gov/sites/default/files/documents/building-blocks-implementation-plan-progress-report.pdf.

USDA. (2023). *Dairy Data.* Economic Research Service. Retrieved from https://www.ers.usda.gov/data-products/dairy-data.aspx.

USDA. (n.d.). Federal funding opportunities. Retrieved December 10, 2021, from https://www.rd.usda.gov/newsroom/federal-funding-opportunities.

US Dairy. 2021. U.S. Dairy Net Zero Initiative. Retrieved from https://www.usdairy.com/getmedia/89d4ec9b-0944-4c1d-90d2-15e85ec75622/game-changer-net-zero-initiative.pdf?ext=.pdf

USGBC. (2017). Top four benefits of installing solar panels on your home. U.S. Green Building Council. Retrieved from https://www.usgbc.org/articles/top-four-benefits-installing-solar-panels-your-home

Wirth, H. (2023). *Recent Facts about Photovoltaics in Germany.* Fraunhofer Institute for Solar Energy Systems ISE. Retrieved from https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html

Wiser, R. H., Bolinger, M., & Seel, J. (2020). *Benchmarking utility-scale PV operational expenses and project lifetimes: results from a survey of US solar industry professionals*. Lawrence Berkeley National Lab (LBNL), Berkeley, CA (United States).

APPENDIX

System Advisor Model Report

PVWatts	50.0 DC MW Nameplate	33.45, -111.98
Sale Leaseback	$1.03/W Installed Cost	UTC -7

Performance Model

PV System Specifications	
System nameplate size	50,000 kW
Module type	0
DC to AC ratio	1.2
Rated inverter size	41,666.67 kW
Inverter efficiency	96 %
Array type	fixed open rack
Array tilt	33 degrees
Array azimuth	180 degrees
Ground coverage ratio	N/A
Total system losses	14.08 %
Shading	no

Performance Adjustments	
Availability/Curtailment	none
Degradation	0.500000 %/yr
Hourly or custom losses	none

Results	Solar Radiation (kWh/m2/day)	AC Energy (kWh)
Jan	5.4	6,594,735
Feb	6.04	6,619,296
Mar	6.87	8,050,990
Apr	7.28	8,096,188
May	7.31	8,148,920
Jun	7.23	7,617,144
Jul	6.61	7,312,741
Aug	6.66	7,396,352
Sep	6.93	7,442,034
Oct	6.6	7,542,902
Nov	5.93	6,911,413
Dec	5.04	6,233,334
Year	6.49	87,966,054

Financial Model

Project Costs	
Total installed cost	$51,382,248
Salvage value	$0

Analysis Parameters	
Project life	25 years
Inflation rate	2.5%
Real discount rate	6.4%

Financial Targets and Constraints	
Solution mode	Calculate PPA Price
Target IRR	9% in Year 20
PPA escalation rate	1%/year

Tax and Insurance Rates	
Federal income tax	21 %/year
State income tax	7 %/year
Sales tax (% of indirect cost basis)	5%
Insurance (% of installed cost)	0.5 %/year
Property tax (% of assessed val.)	0 %/year

Incentives	
Federal ITC	26%
Depreciation	Depreciation allocations defined with no bounus depreciation

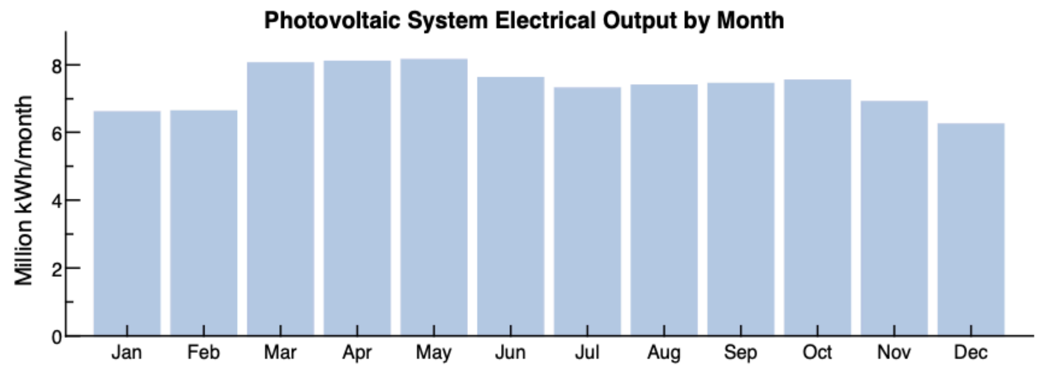
Results	
Nominal LCOE	9.9 cents/kWh
PPA price (year one)	9.4 cents/kWh
Project IRR	9% in Year 20
Investor NPV	$2,477,200
Developer NPV	$3,486,300
Investor IRR	9.9%
Developer IRR	25.9%

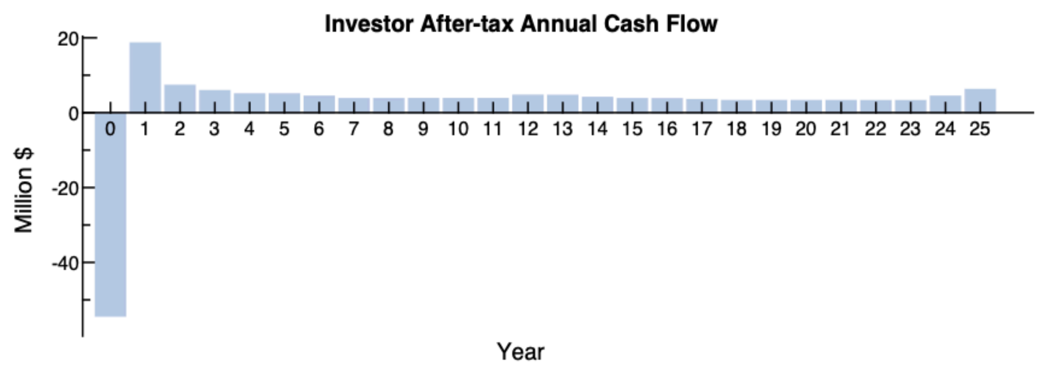
System Advisor Model Standard Report generated by SAM 2020.11.29 on Tue Aug 3 15:44:37 2021 1 / 3

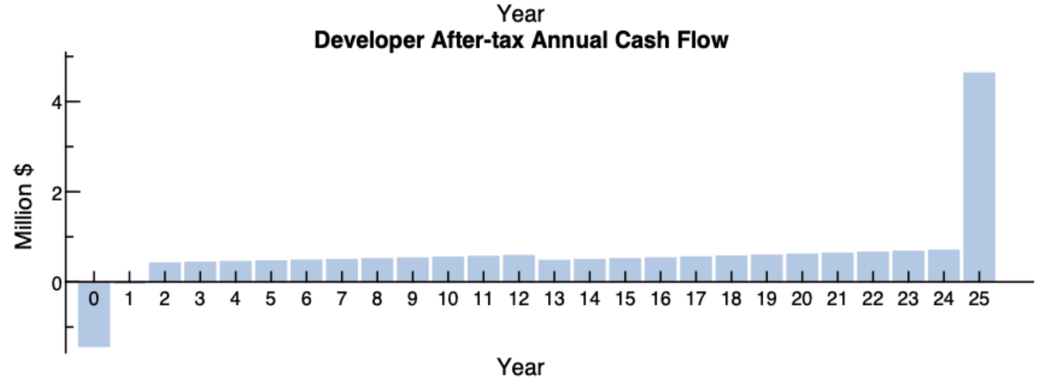
Figure A 1. System Advisor Model output report

Figure A 1 (cont'd)

PVWatts	50.0 DC MW Nameplate	33.45, -111.98
Sale Leaseback	$1.03/W Installed Cost	UTC -7







MICHIGAN STATE
UNIVERSITY

EXEMPT DETERMINATION
Revised Common Rule

March 30, 2022

To: Ajit Srivastava

Re: **MSU Study ID:** STUDY00007494
Principal Investigator: Ajit Srivastava
Category: Exempt 2ii
Exempt Determination Date: 3/30/2022
Limited IRB Review: Not Required.

Title: Dairy Farmer Perspectives Regarding On-Farm Solar Technology

This study has been determined to be exempt under 45 CFR 46.104(d) 2ii.

Principal Investigator (PI) Responsibilities: The PI assumes the responsibilities for the protection of human subjects in this study as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Continuing Review: Exempt studies do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the study is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Please contact the HRPP office if you have any questions about whether a change must be submitted for IRB review and approval.

New Funding: If new external funding is obtained for an active study that had been determined exempt, a new initial IRB submission will be required, with limited exceptions. If you are unsure if a new initial IRB submission is required, contact the HRPP office. IRB review of the new submission must be completed before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.

Reportable Events: If issues should arise during the conduct of the research, such as unanticipated problems that may involve risks to subjects or others, or any

Office of Regulatory Affairs
Human Research Protection Program

4000 Collins Road
Suite 136
Lansing, MI 48910

517-355-2180
Fax: 517-432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

Figure A 2. IRB Approval of the dairy farmer survey

MICHIGAN STATE UNIVERSITY

A Michigan State University (MSU) research team is working on a project to help Michigan dairy farmers improve the sustainability of their farm operations. They have created a survey that allows farmers to identify barriers preventing them from installing solar panels on their barns, on their non-arable land and in other use cases. This project builds on the highly popular Michigan Farm Energy Audit Program run by MSU.

This survey will take 5-10 minutes to complete. Up to 25 survey participants will have the opportunity to receive a free certified energy audit (worth $2,500) from the Michigan Farm Energy Audit Program.

The response of this survey will be anonymous and follow the MSU Human Research Protection Program guidelines for confidentiality. There are no foreseeable risks to participating in this study. You have the right to say no to participate in this research. You have the right to stop at any time after the survey has started.

By selecting "Yes," you consent to participate in this research study.

- ○ Yes
- ○ No

→

MICHIGAN STATE
UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility
Call MSU: (517) 355-1855 | Visit: msu.edu
MSU is an affirmative-action, equal-opportunity employer. |
Notice of Nondiscrimination
SPARTANS WILL. | © Michigan State University

Figure A 3. Dairy farmer survey distributed via Qualtrics

Figure A 3 (cont'd)

MICHIGAN STATE UNIVERSITY

What is your age?

- ○ Less than 40 years
- ○ 40 to 60 years
- ○ Over 60 years

How many cows do you milk on your farm?

- ○ 0 - 99
- ○ 100 - 499
- ○ 500 - 1000
- ○ More than 1000

How would you describe your farm?

- ○ Pasture based
- ○ Confined (i.e., housed year-round)
- ○ Combination of pasture based and confined
- ○ Other ________

Do you have any solar panels currently installed to produce energy for your dairy farm operation? (This does not include solar panels that are owned by a power/utility company)

- ○ Yes
- ○ No

Figure A 3 (cont'd)

How interested are you in learning more about solar energy for your dairy operation?

- ◯ Very interested
- ◯ Somewhat interested
- ◯ Neutral
- ◯ Not very interested
- ◯ Not interested

What do you think are the barriers to installing solar panels on your farm? Please select all that apply

- ☐ Cost of the system is too high
- ☐ I don't know if it would be a good investment or not
- ☐ I don't have time to learn about solar technology
- ☐ I don't have time to install solar panels
- ☐ I don't have time to manage/maintain solar panels
- ☐ I don't have enough roof or yard space
- ☐ I don't own the farm
- ☐ The farm has too much shade
- ☐ The panels don't look good
- ☐ I don't trust the technology
- ☐ I don't want to learn new technology
- ☐ Other reason __________
- ☐ None

Are you aware of government incentives related to renewable energy investments on farms?

- ◯ Yes
- ◯ No
- ◯ Somewhat

Figure A 3 (cont'd)

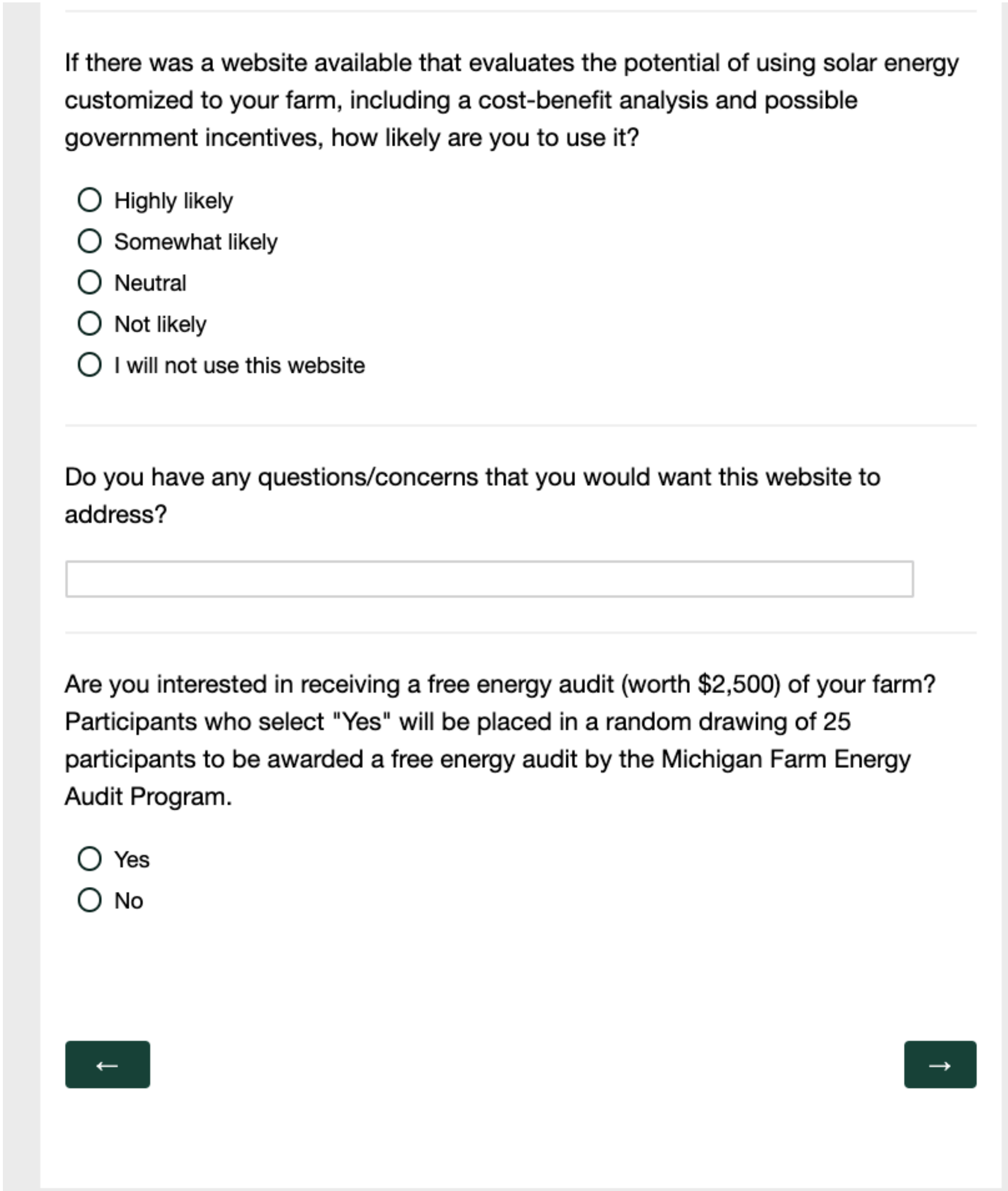
When making decisions about your farm operation, how likely are you to seek information from the following sources?

	Extremely likely	Likely	Neutral	Not likely	I never use this source
Word of mouth (friends, neighbors, other farmers, etc.)	○	○	○	○	○
Consult with business professionals or Extension educators	○	○	○	○	○
Extension bulletins and publications	○	○	○	○	○
Look things up on the internet	○	○	○	○	○
Conferences and farm organization meetings	○	○	○	○	○
Other ______	○	○	○	○	○

Have you used any renewable energy assessment tools or websites for your farm?
Please select all that apply.

- ☐ PVWatts
- ☐ System Advisor Model (SAM)
- ☐ Other ______
- ☐ I have not used any renewable energy assessment tools

Figure A 3 (cont’d)



If there was a website available that evaluates the potential of using solar energy customized to your farm, including a cost-benefit analysis and possible government incentives, how likely are you to use it?

- ○ Highly likely
- ○ Somewhat likely
- ○ Neutral
- ○ Not likely
- ○ I will not use this website

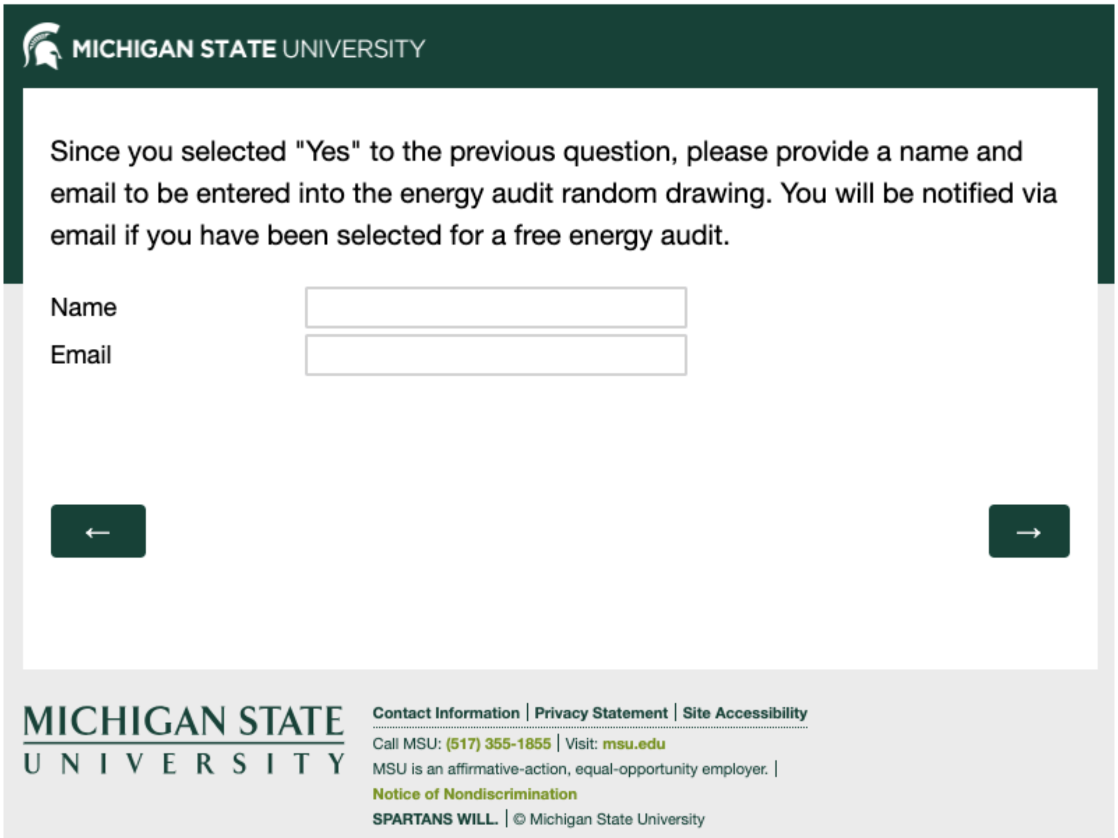
Do you have any questions/concerns that you would want this website to address?

Are you interested in receiving a free energy audit (worth $2,500) of your farm? Participants who select "Yes" will be placed in a random drawing of 25 participants to be awarded a free energy audit by the Michigan Farm Energy Audit Program.

- ○ Yes
- ○ No

←   →

Figure A 3 (cont'd)



MICHIGAN STATE UNIVERSITY

Since you selected "Yes" to the previous question, please provide a name and email to be entered into the energy audit random drawing. You will be notified via email if you have been selected for a free energy audit.

Name

Email

←

→

MICHIGAN STATE UNIVERSITY

Contact Information | Privacy Statement | Site Accessibility

Call MSU: (517) 355-1855 | Visit: msu.edu

MSU is an affirmative-action, equal-opportunity employer. |

Notice of Nondiscrimination

SPARTANS WILL. | © Michigan State University

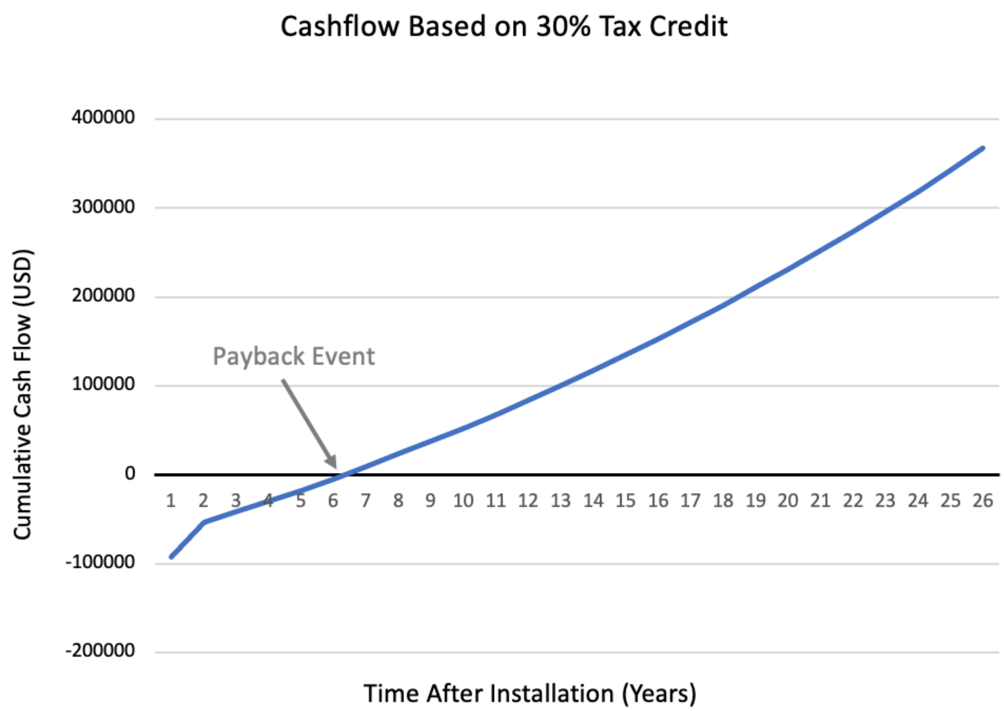


Figure A 4. Case Study: Cashflow based on 30 percent federal tax credit

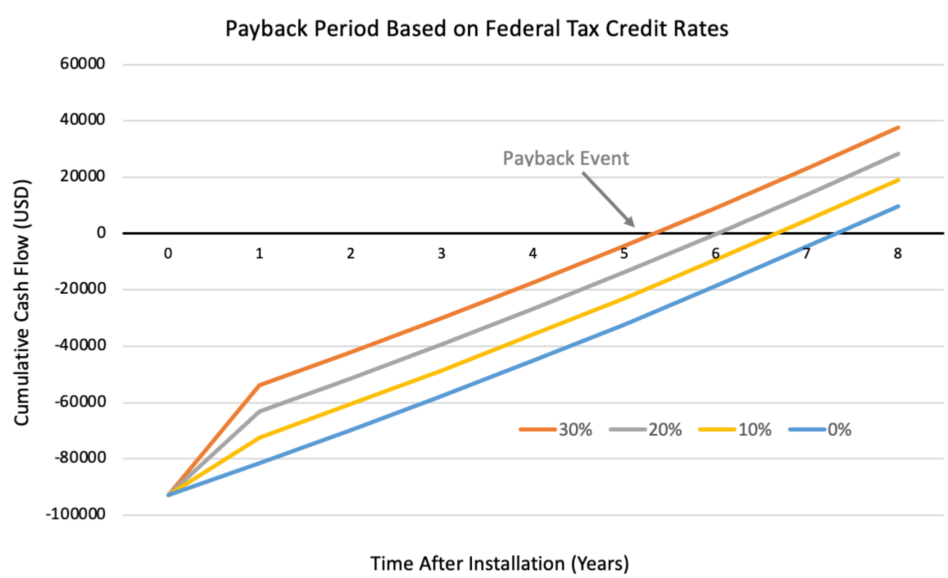


Figure A 5. Case Study: Payback periods based on differing tax credit rates

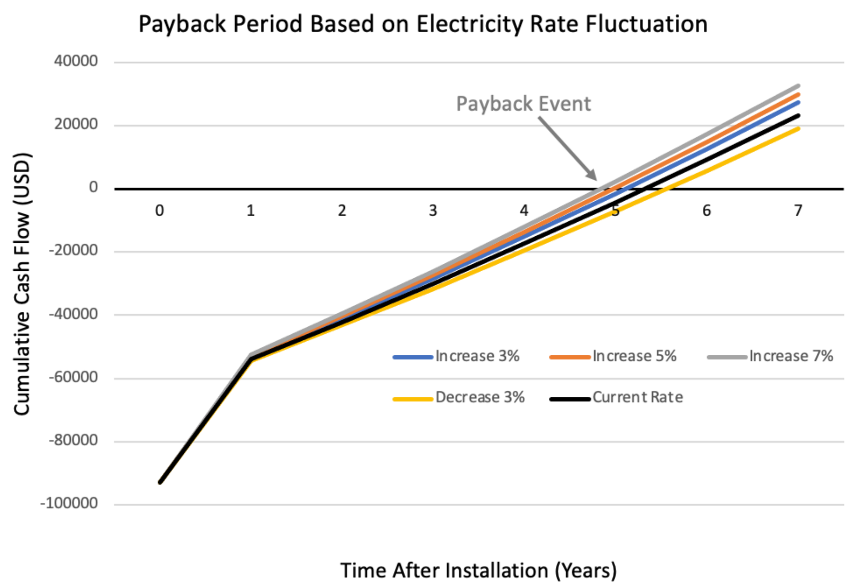


Figure A 6. Case Study: Payback periods based on electricity rate fluctuation

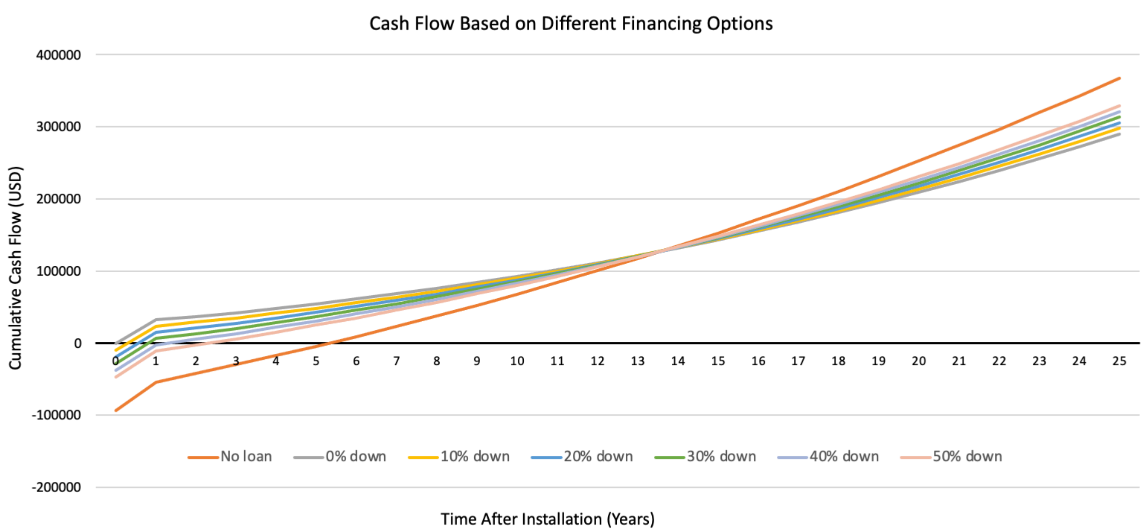


Figure A 7. Case Study: Down payments for a 25-year loan at 4.125% interest

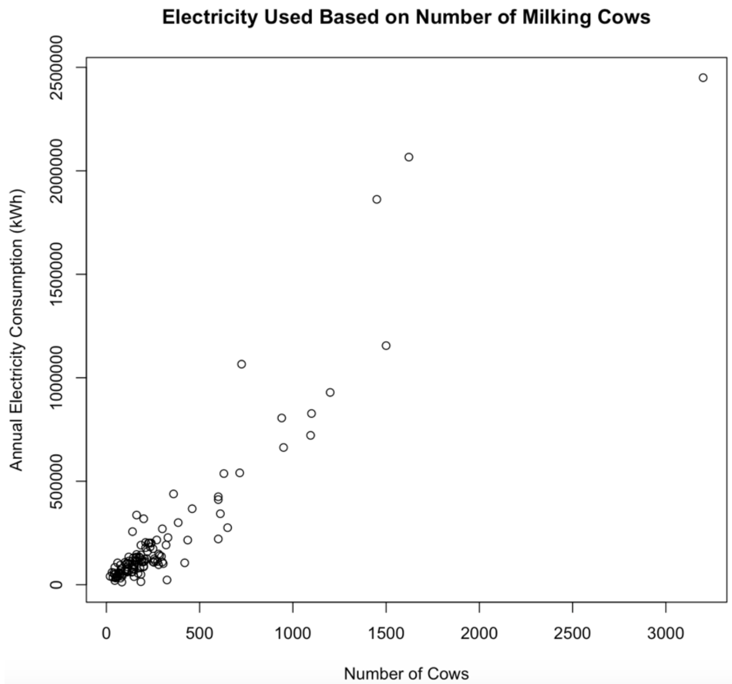


Figure A 8. Number of milking cows vs annual electricity consumption scatterplot

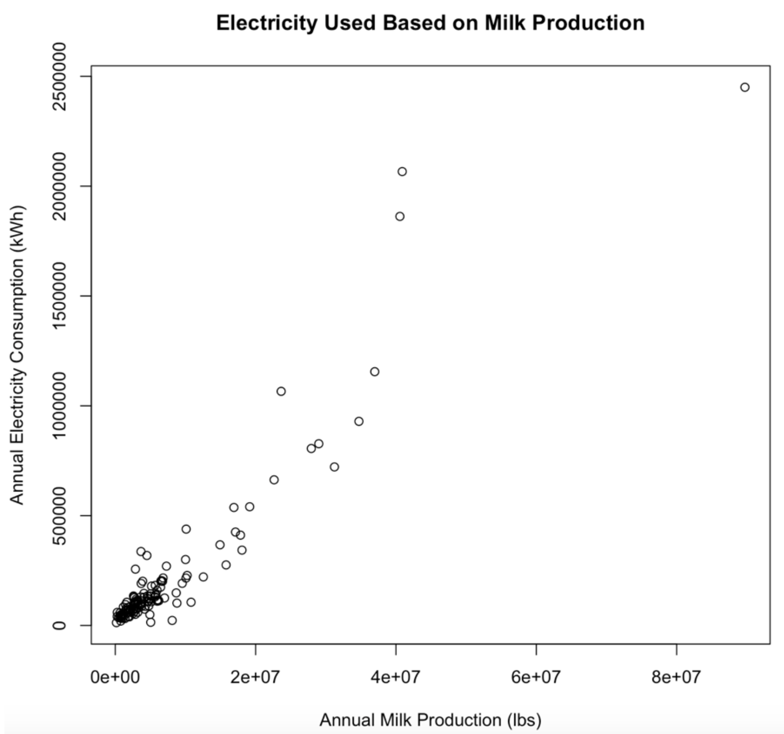


Figure A 9. Annual milk production vs annual electricity consumption scatterplot

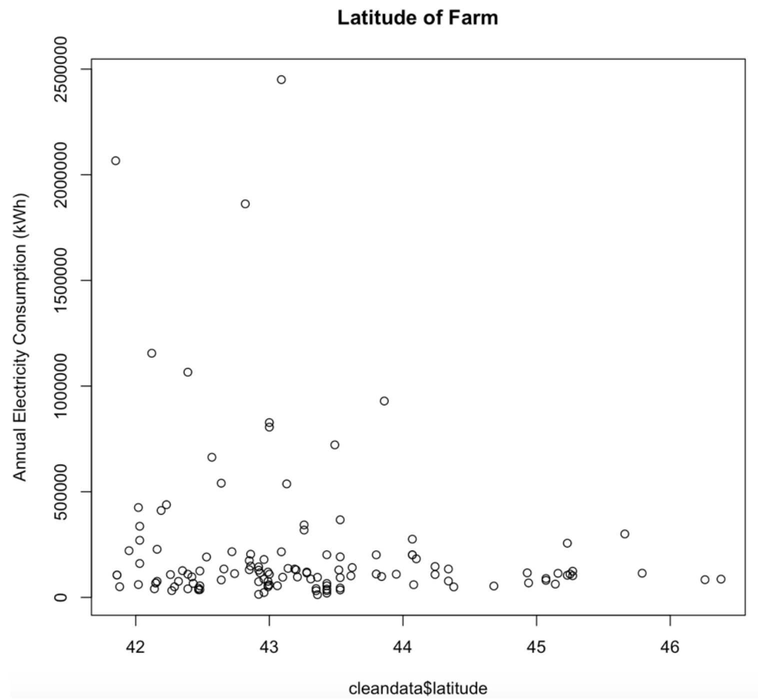


Figure A 10. Latitude vs electricity consumption scatterplot

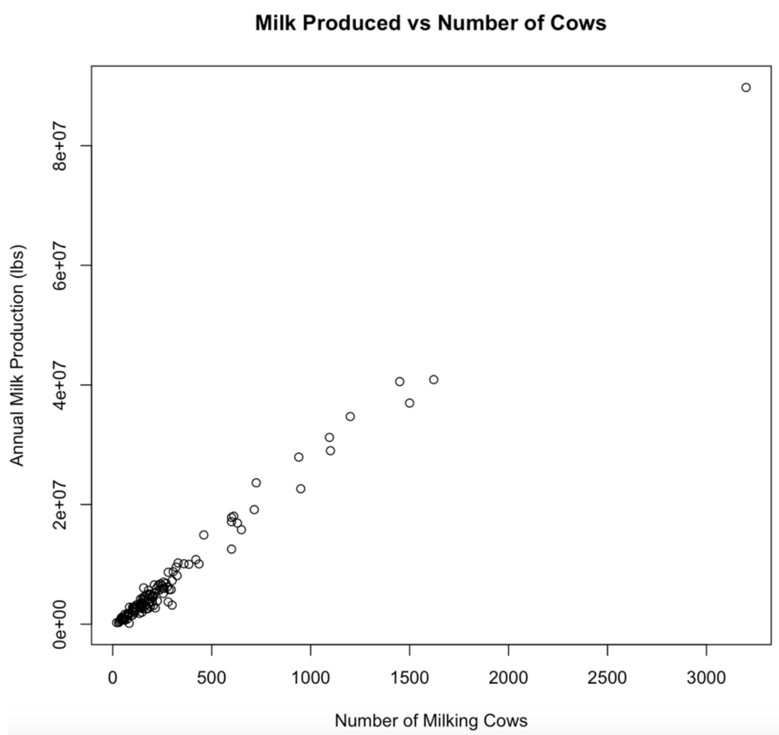


Figure A 11. Number of milking cows vs annual milk production scatterplot

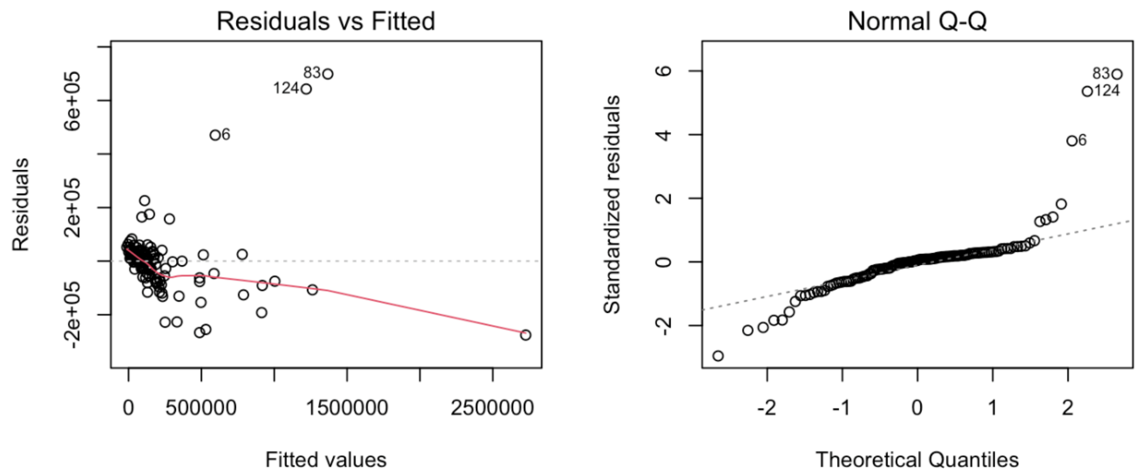


Figure A 12. Residuals and quantile-quantile plot for Model I

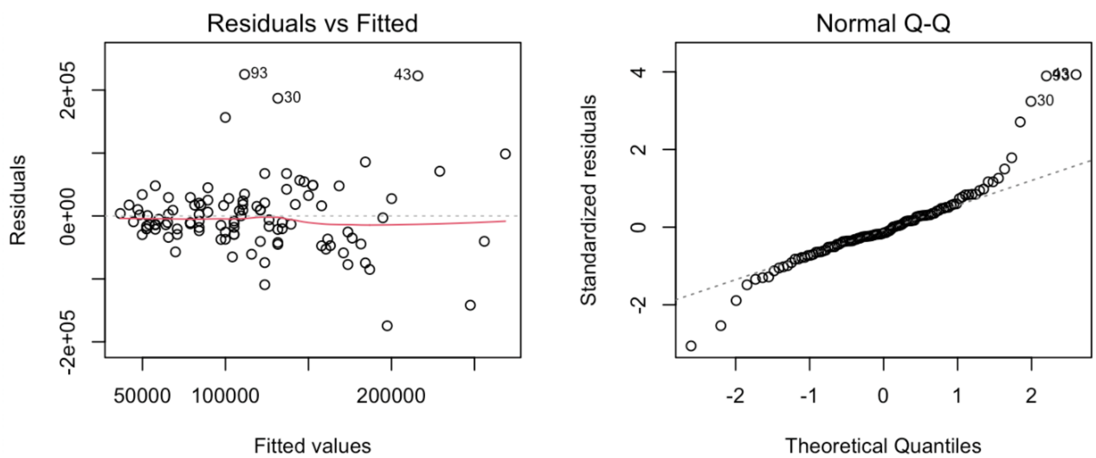


Figure A 13. Residuals and quantile-quantile plot for Model II

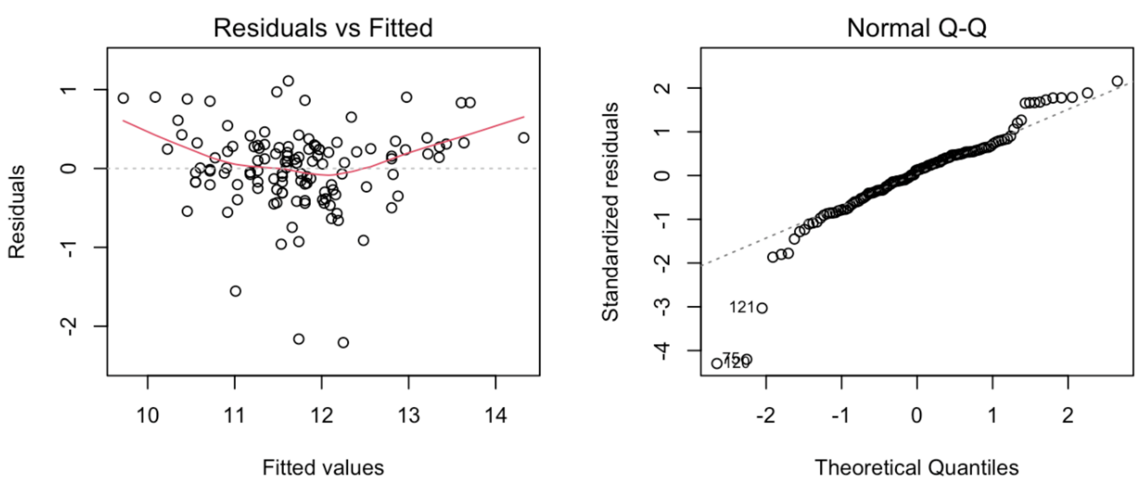


Figure A 14. Residuals and quantile-quantile plot for Model III

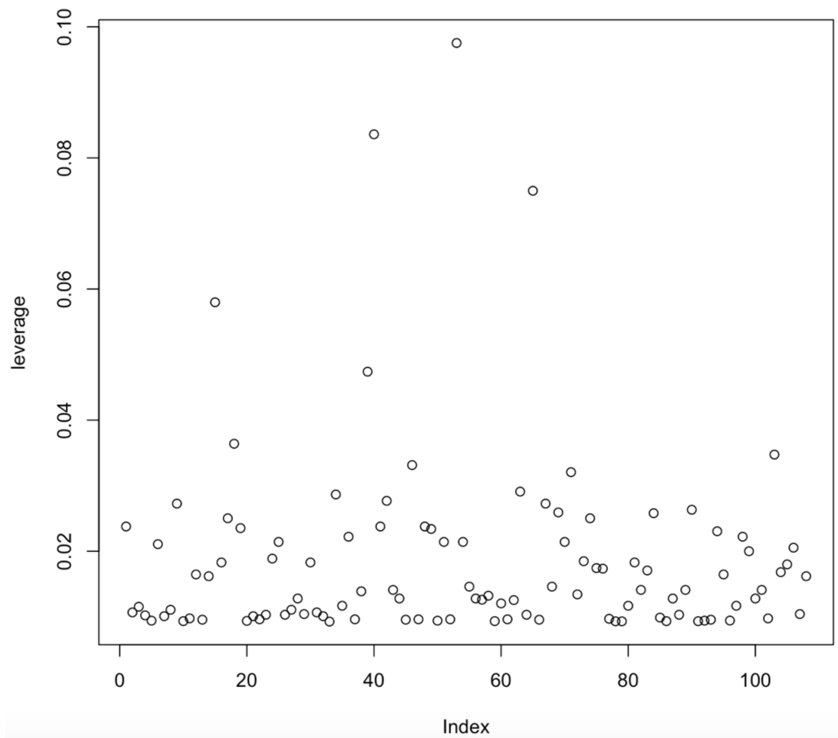


Figure A 15. Leverage plot for Model I

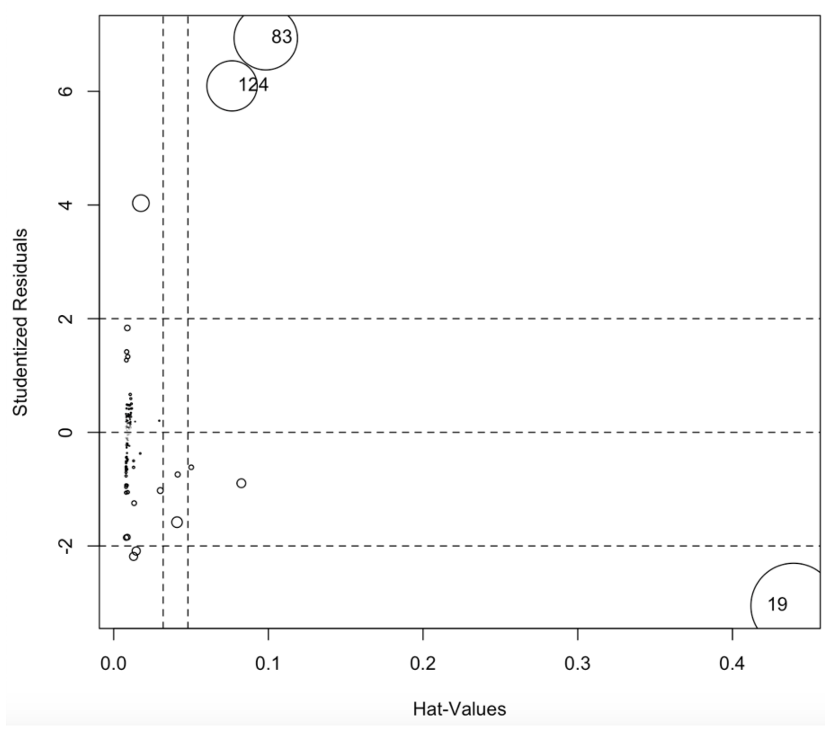


Figure A 16. Influence plot Model I

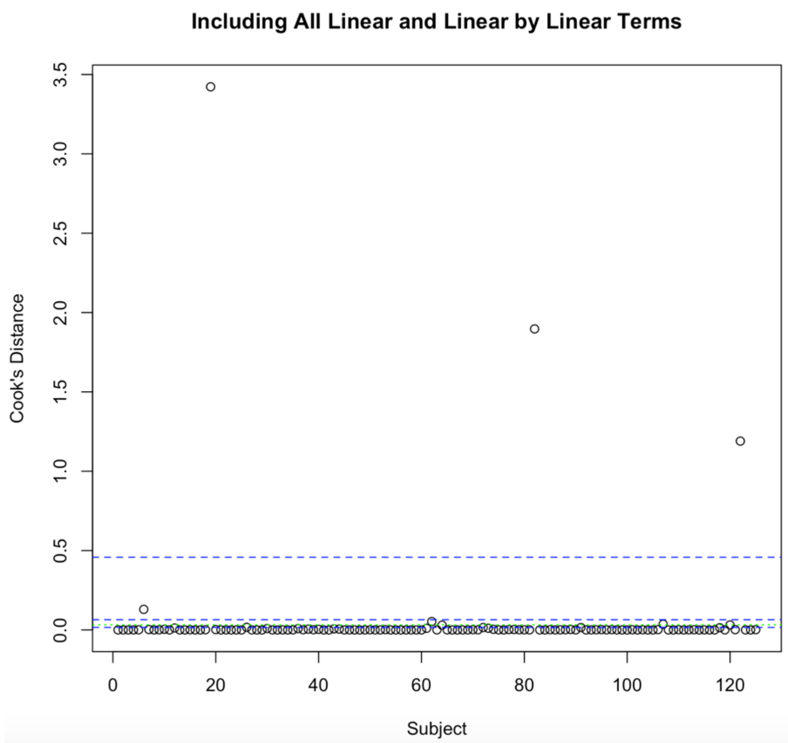


Figure A 17. Cook's Distance for Model I

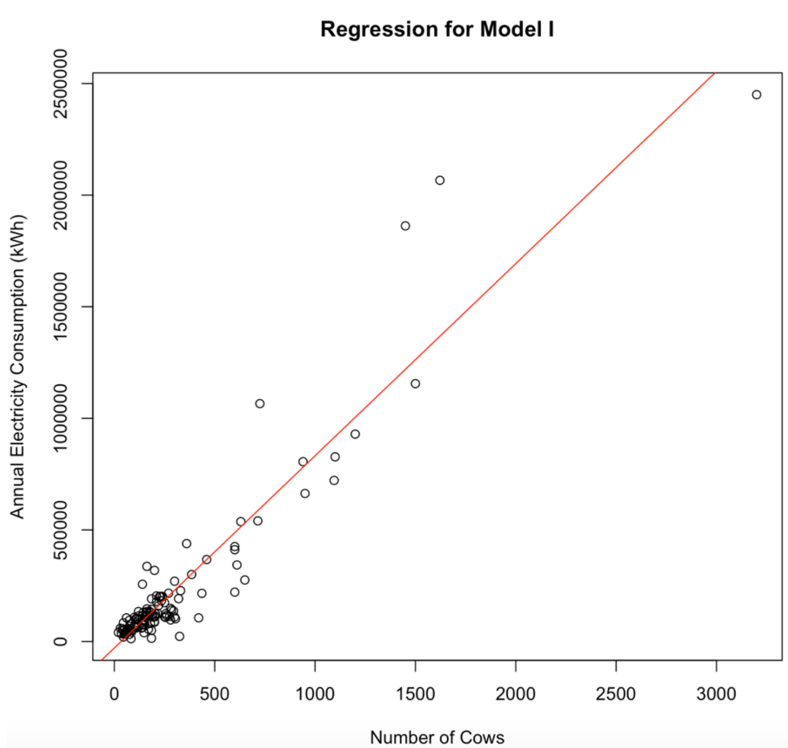


Figure A 18. Regression and line of best fit for Model I

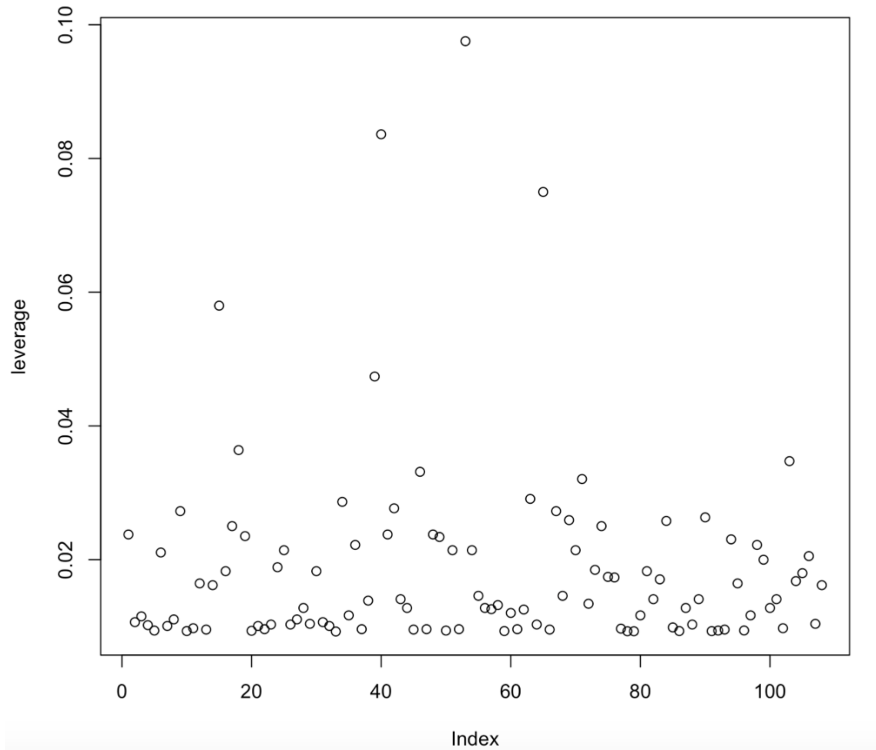


Figure A 19. Leverage plot for Model II

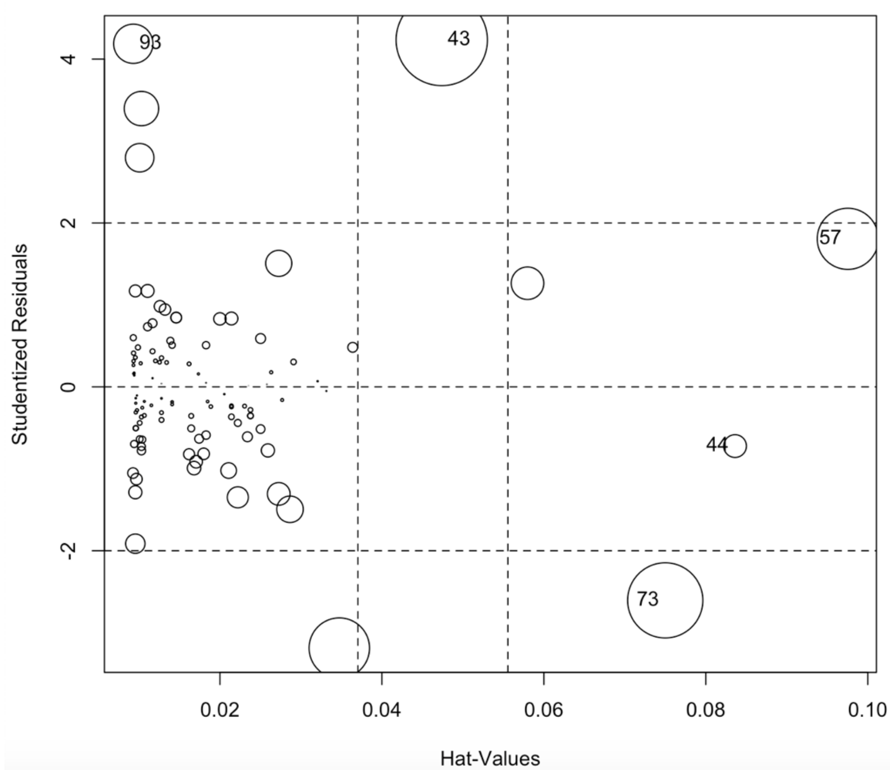


Figure A 20. Influence plot for Model II

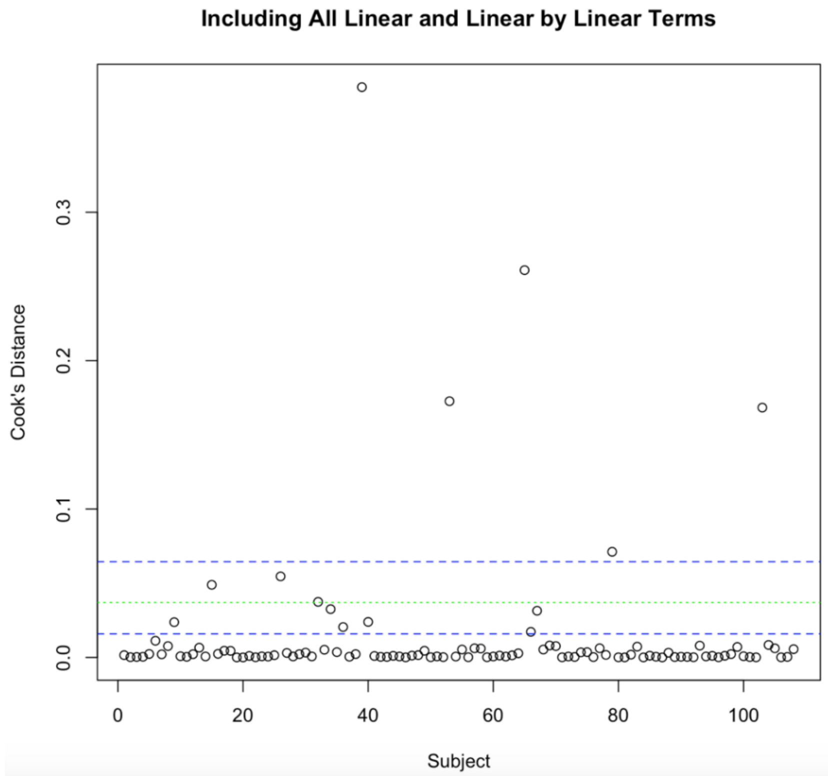


Figure A 21. Cook's Distance plot for Model II

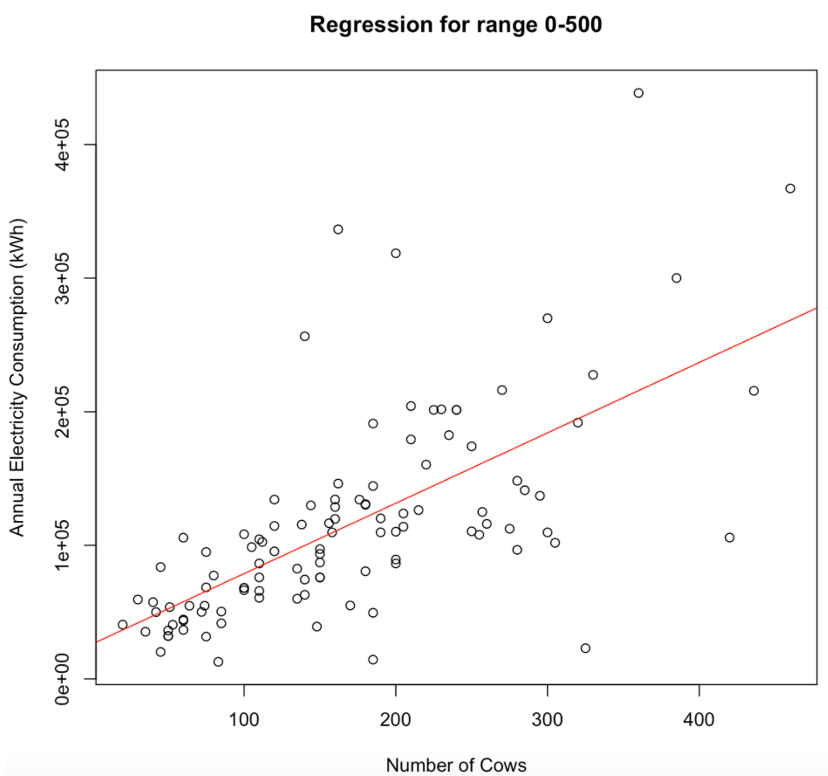


Figure A 22. Regression and line of best fit for Model II

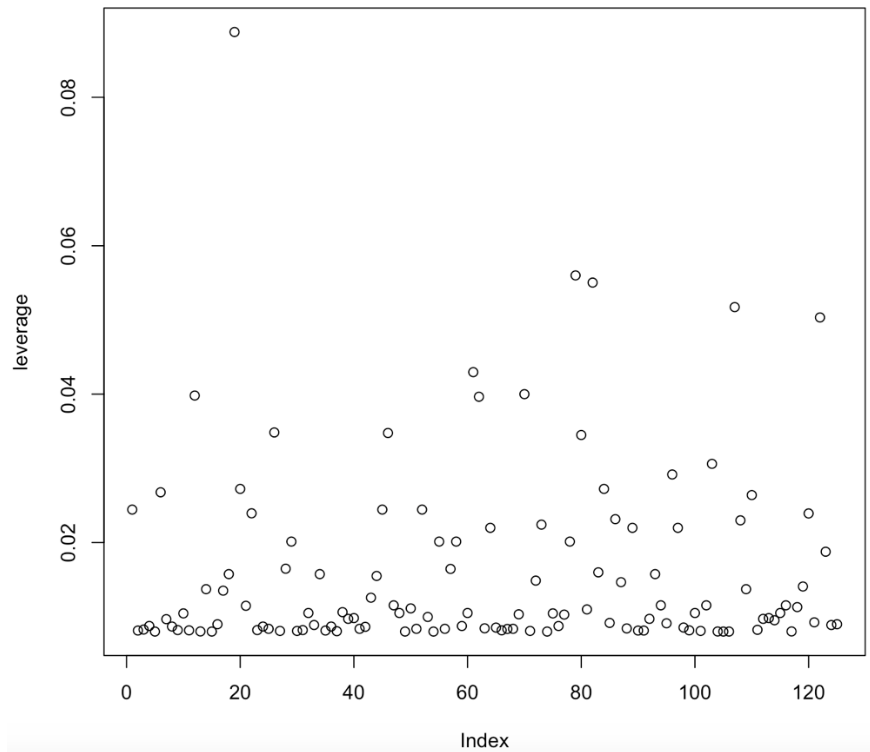


Figure A 23. Leverage plot Model III

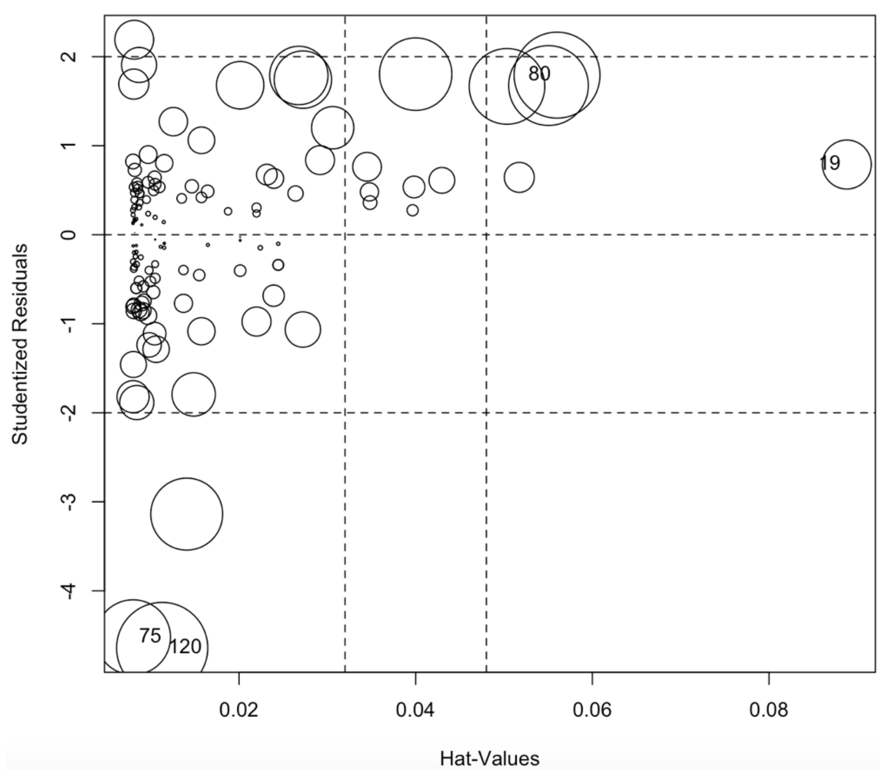


Figure A 24. Influence plot for Model III

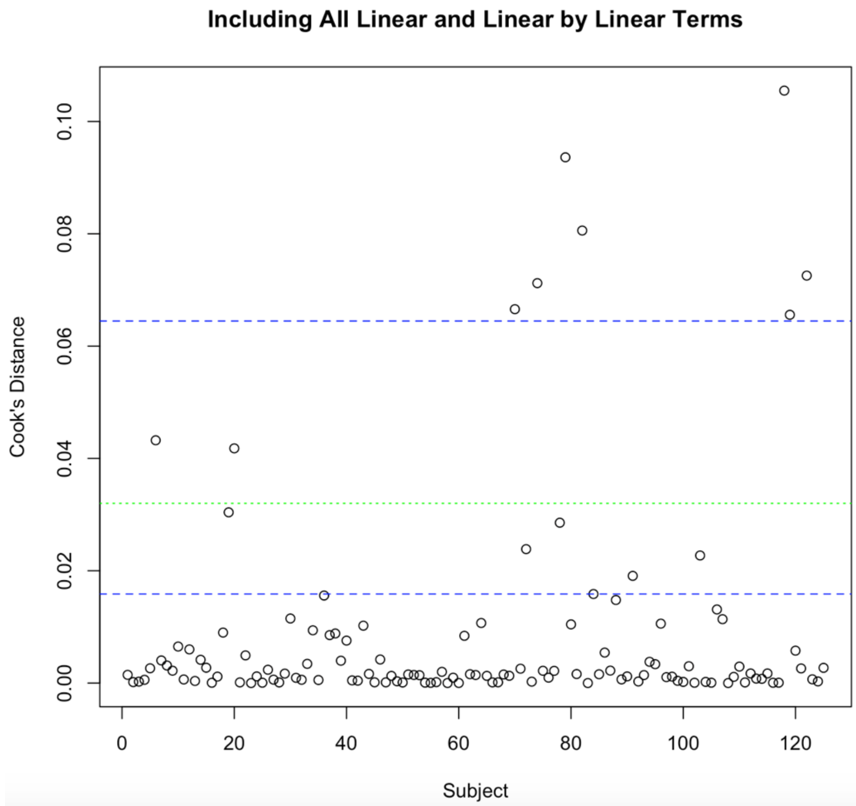


Figure A 25. Cook’s Distance for Model III

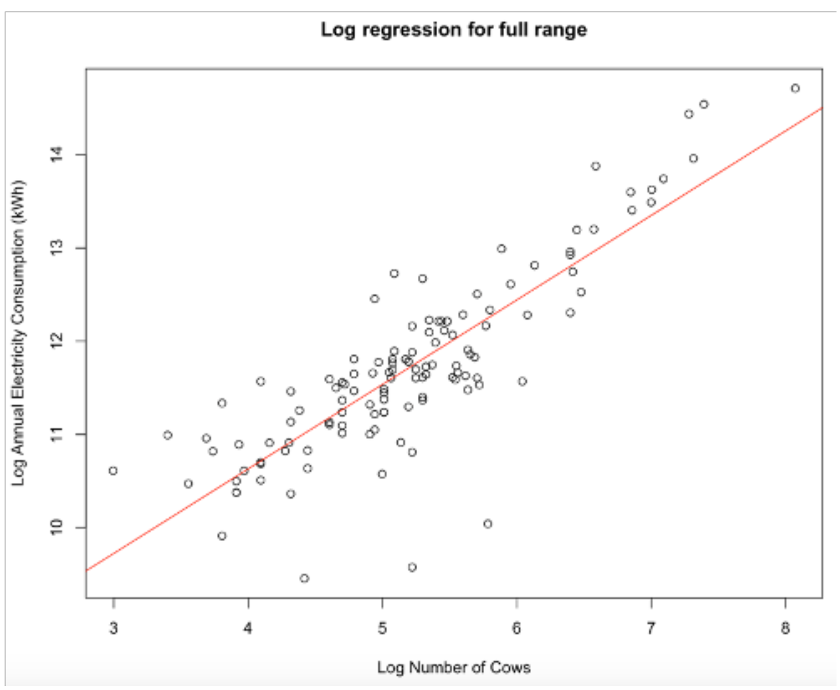


Figure A 26. Regression and line of best fit for Model III

	Variable	Unit	Javascript designation	Source	Notes/equation used	Reference
User Inputs						
	number of cows	cows	cows	user input	type in	-
	square footage available	ft^2	squareFeet	user input	type in	-
	percent of total produced	%	percentProduced	user input	type in	-
Energy Generation						
	annual electricity usage	kWh/yr	annualElectricityConsumpt	regression eq	equation good? Perhaps IF user doesn't input their own, default is regression equation	regression analysis
	annual electricity generated	kWh/yr	annualGeneration	equation	(percent/100)*(annualElectricityConsumption)	-
	hourly energy generated	kW/hour	hourlyGeneration	equation	(annualGeneration)*(1/365)*(1/24)	-
Number and Type of Panels						
	peak sunlight hours in Michigan	hours	peakSunlight	constant	4.1	MI solar
	number 150W panels	panels	numberSmallPanels	equation	(hourlyGeneration)*(peakSunlight)/150	-
	number 370W panels	panels	numberLargePanels	equation	(hourlyGeneration)*(peakSunlight)/370	-
	dimension of one 150W panel	ft^2	smallDimension	constant	10.47	calculation in case study
	dimension of one 370W panel	ft^2	largeDimension	constant	18.61	calculation in case study
	dimension of small panel configuration	ft^2	smallConfiguration	equation	(numberSmallPanels)*(smallDimension)	-
	dimension of large panel configuration	ft^2	largeConfiguration	equation	(numberLargePanels)*(largeDimension)	-
	number of panels	panels	numberPanels	if-then function	IF (smallConfiguration) < (squareFeet), THEN numberPanels is (smallConfiguration). IF (smallConfiguration) > (squareFeet), THEN numberPanels is (largeConfiguration).	-
	panel number and wattage	wattage	panelWattage	equation	IF (smallConfigurationFootage) < (squareFeet), THEN wattage is (150). IF (smallConfigurationFootage) > (squareFeet), THEN wattage is (370).	-
Cost of Installation						
	size system	kW	systemSize	equation	(numberPanels)*(panelWattage)	-
	Cost is based on NREL commercial cost benchmarks 2022, by system size	dollar / DC Watt	costPerWatt	if-then multiplier	IF (systemSize) <10kW, THEN (costPerWatt) is 2.95. IF (systemSize) >10kW, THEN (costPerWatt) is 1.84.	NREL
	cost of installation	dollars	installationCost	equation	(systemSize)*(costPerWatt)	-
Economics Equation Values						
	lifespan of project	years	lifespan	constant	25 years	NREL
	inflation	%	inflation	constant	0.03	US Inflation Average
	electricity increase per year	%	electricityIncrease	constant	1.0296	Solar Reviews, 2022
	salvage value	dollars	salvageValue	constant	0	assumption
	straightline depreciation annually	dollars/year	depreciation	equation	((installationCost)-(salvageValue))/(lifespan)	assumption
	insurance annually	dollars/year	annualInsurance	equation	(totalCost)*(0.25/100)	NREL
	panel degradation	%	annualDegradation	constant	0.5% per year	NREL
	annual maintenance	dollars	annualMaintenance	constant	$17/kW/year	NREL
	tax credit	%	taxCredit	constant	0.3	ITC
	cost of electricity	$/kWh	costElectricity	changes by year	0.16 *1.0296 increase per year	0.16 currently
	savings on electricity per year	dollars	annualElectricitySavings	equation	(annualElectricityConsumption) * (electricityRate)	-
	net of all benefits (total saved)	dollars	netAnnualBenefits			-
	net of all costs	dollars	totalCost	equation	(installationCost)+(insurance)+(maintenance)+(depreciation)	-
	present value benefits	dollars	presentValueBenefits	equation	sum of years (Bt)/(1+i)^t	-
	present value costs	dollars	presentValueCosts	equation	sum of years (Ct)/(1+i)^t	-

Figure A 27. Organization of JavaScript variables and equations

Table A 1. Mouseover text included throughout calculation results

Section	Value	Mouse-Over Text
User Input	Number of cows	The number of cows is used to determine how much energy your farm needs to generate per year.
	Square feet available	The square footage of roof and non-arable land determines what size of panels and how many panels can be used to generate the electricity needed.
	Percent generated	This is the percent of your electricity use that you would like to generate using solar panels.
Energy Generation	Annual electricity consumption	This is how much electricity your farm consumes per year. If you typed in an answer, the value will be the same. If not, the electricity consumed is based on the number of cows on your farm. If this value does not seem accurate, please refresh the page, and try an estimate that is based on your electric bill.
	Annual electricity generation	This is the amount of electricity your panels will generate each year. This is electricity consumed times the percentage of consumption that you want the solar panels to cover.
	Hourly solar panel generation	This is an average of how much electricity your panels will generate per hour, based on average number of peak sunlight hours per day in Michigan.
System Specifications	Total panel configuration	Panel configuration is the square footage that your solar array will use on your roof and/or non-arable land.
	Number of panels	This is the number of panels in your configuration, as well as the size of each panel (in Watts).
	System size	The size of your solar panel array is the number of panels times the size (wattage) of each panel.
	Cost of installation	This value is an estimate of how much it will cost to install your solar panel array. This value is based on the cost estimates provided by the NREL cost benchmark 2022.

Table A 1 (cont’d)

Economic Evaluation Criteria	Net present value	The net present value (NPV) is the present value of all benefits minus the present value of all costs over the lifespan of the panels. The lifespan of your solar panels is estimated to be 25 years. It is generally considered to be a good investment if your NPV is greater than zero.
	Equivalent annual worth	The equivalent annual worth (EAW) looks at the lifetime of the solar panels and estimates the benefits of your project each year. It is generally considered to be a good investment if your EAW is greater than zero.
	Benefit to cost ratio	The benefit to cost ratio (B/C) is the present value of all benefits divided by the present value of all costs. It is generally considered a good investment if your B/C is greater than one.
Loans	Loan Amount	Loan principle is the amount borrowed for the loan.
	Loan interest rate	If you did not input an interest rate on the form above, the default value is 5.34%. This number was the average of several loan options but can be edited by refreshing the page and typing in a new interest rate.
	Time to pay off	Duration of the loan is how many years it will take to pay off. The default value is 25 years, or the lifetime of the panels. This value can be edited by refreshing the page and using the form at the top.
	Annual loan payment	This is the amount to be paid per year on the loan.
	Monthly loan payment	This is the amount to be paid per month on the loan. It is the annual loan payment divided by 12.

Dairytosolar.com

Short Pitch

Dairytosolar is a program designed to help dairy farmers explore the potential of installing solar energy on their non-arable farmland.

Long Pitch

Dairytosolar is a tool that aims to support dairy farmers through increasing production costs and stagnant milk prices. This program will provide them with farm-specific technology that does not have the typical learning curve of other computer models. Dairytosolar will include *How Photovoltaic Technology Works*, an *Economic Feasibility Analysis* of solar panel investment, *Sources of Funding*, and provide *Local Resources* of nearby vetted vendors and Extension programs. Dairytosolar aims to help the dairy industry achieve their goal of zero carbon emissions by 2050 and hopes to protect dairy farmers from the market volatility of increasing electricity prices.

Personas

Dairy Farmer: A dairy farmer in Michigan who is curious about the potential of solar technology on their farm but is unsure that it is financially feasible. This farmer is motivated by saving money but is discouraged by complicated technology and time-consuming decisions.

Financial Advisor: A financial advisor helping dairy farmers make informed business decisions regarding their farm. This user has a strong understanding of the financials of farming but is not well versed in photovoltaic technology or the economics of solar panel installation.

Solar Installation Company: A solar installation company that is curious what barriers prevent farmers from investing in their product. This company wants to gain customers in this market segment and will do so by determining how to optimize installation and maintenance for farmers.

Comps

NREL PVWatts Calculator https://pvwatts.nrel.gov

How Does Solar Work? https://www.energy.gov/eere/solar/how-does-solar-work

NREL System Advisor Model (SAM) https://sam.nrel.gov

Figure A 28. Original website pitch board

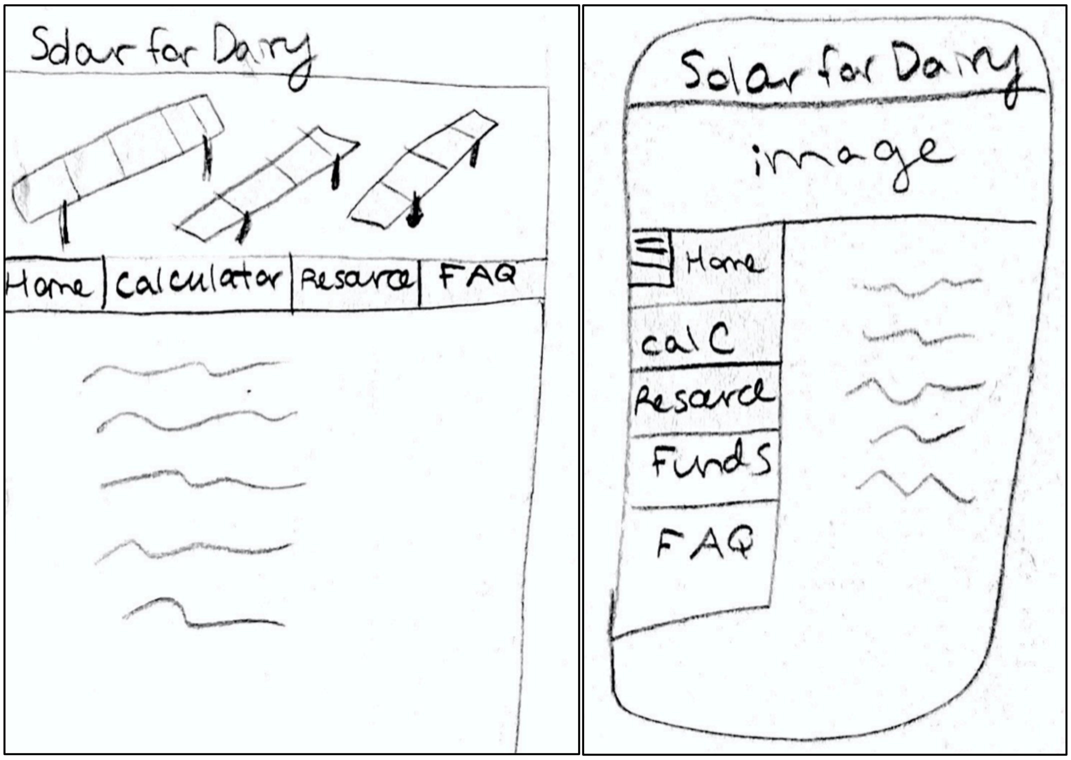


Figure A 29. Hand drawn wireframes for website design

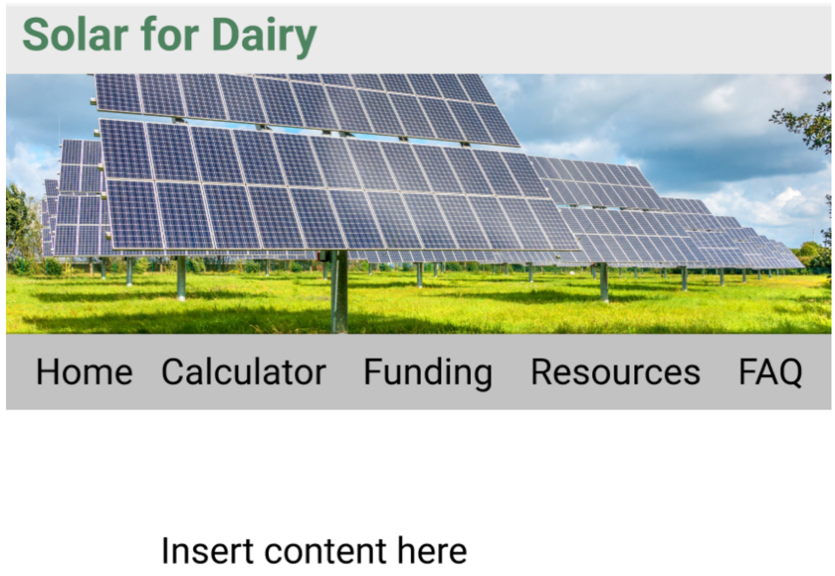


Figure A 30. Website design layout using Figma design application

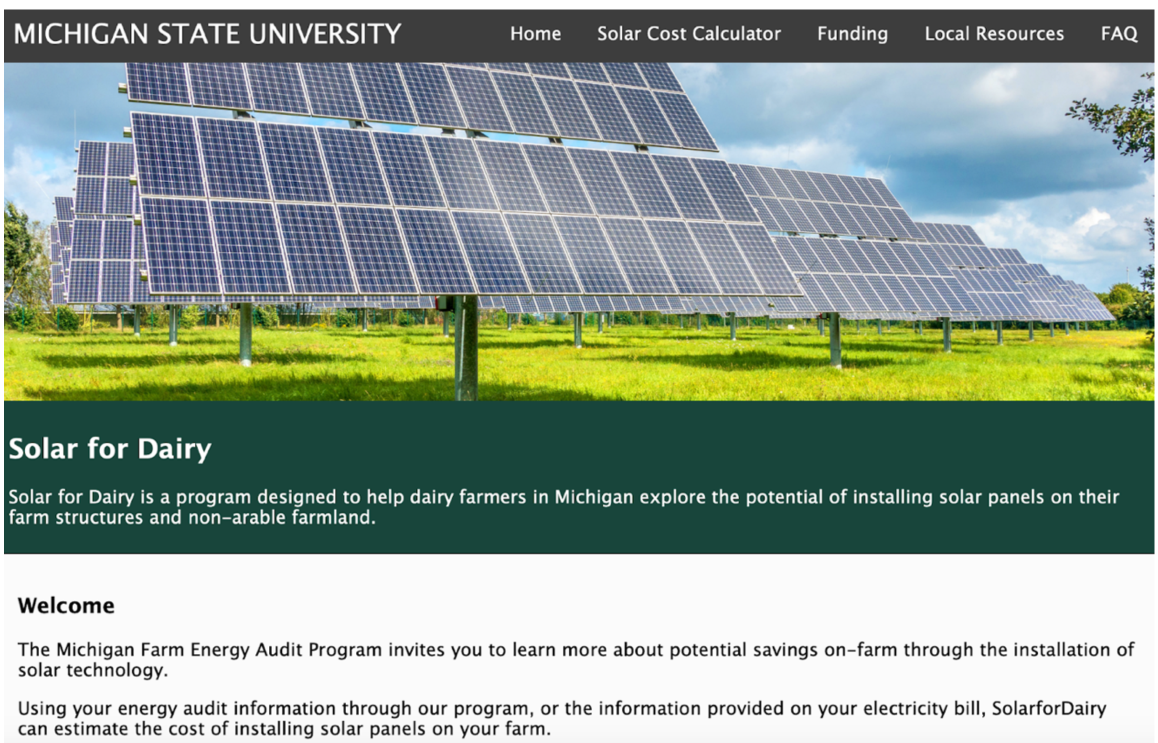


Figure A 31. Website design after coding and troubleshooting design layout

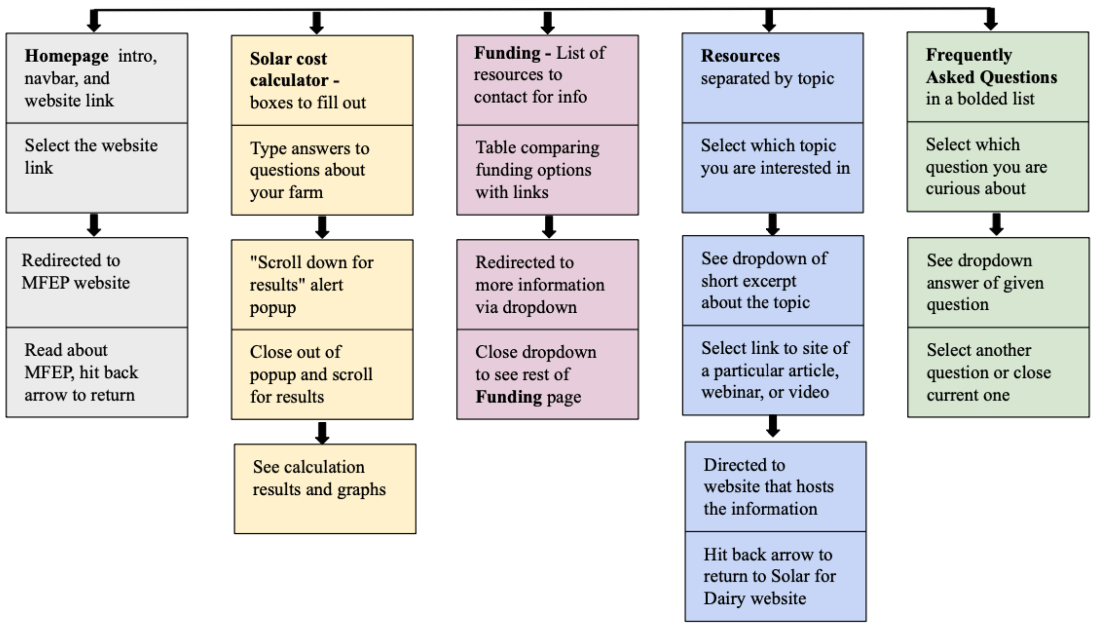


Figure A 32. Shorthand workflow of website

Figure A 33. Public Domain Dedication associated with each image used on the website

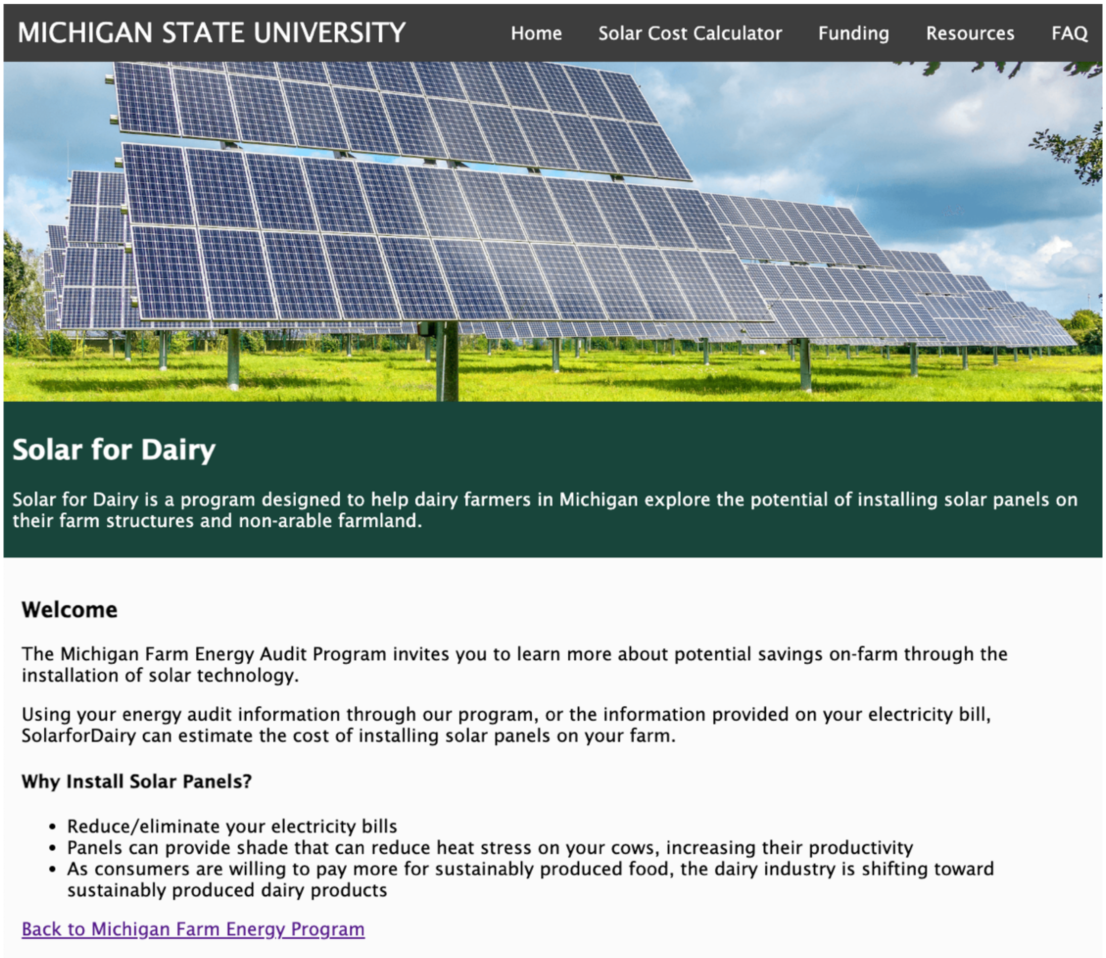
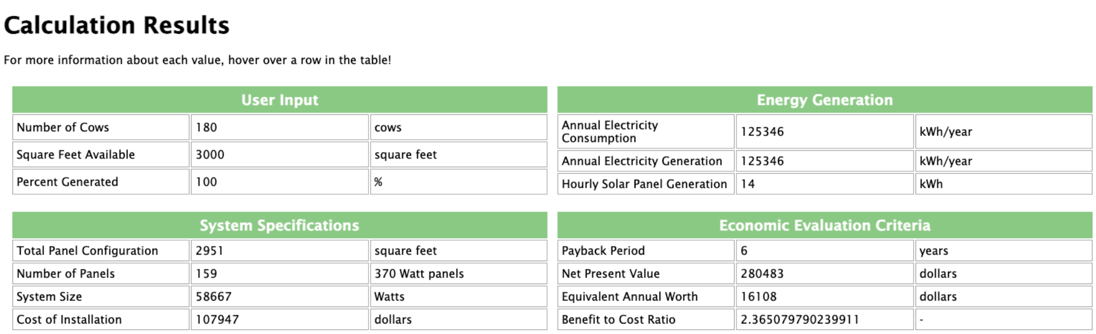


Figure A 34. Home page of Solar for Dairy website

Figure A 35. Solar Cost Calculator page of website: User input form



Calculation Results

For more information about each value, hover over a row in the table!

User Input		
Number of Cows	180	cows
Square Feet Available	3000	square feet
Percent Generated	100	%

Energy Generation		
Annual Electricity Consumption	125346	kWh/year
Annual Electricity Generation	125346	kWh/year
Hourly Solar Panel Generation	14	kWh

System Specifications		
Total Panel Configuration	2951	square feet
Number of Panels	159	370 Watt panels
System Size	58667	Watts
Cost of Installation	107947	dollars

Economic Evaluation Criteria		
Payback Period	6	years
Net Present Value	280483	dollars
Equivalent Annual Worth	16108	dollars
Benefit to Cost Ratio	2.365079790239911	-

Figure A 36. Solar Cost Calculator page of website: Calculation results

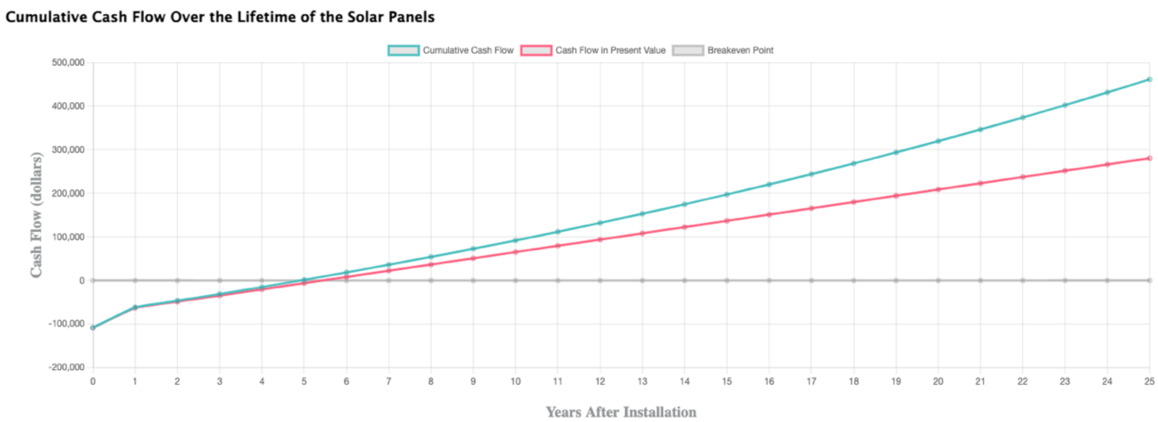


Figure A 37. Solar Cost Calculator page of website: Cash flow over lifetime of panels

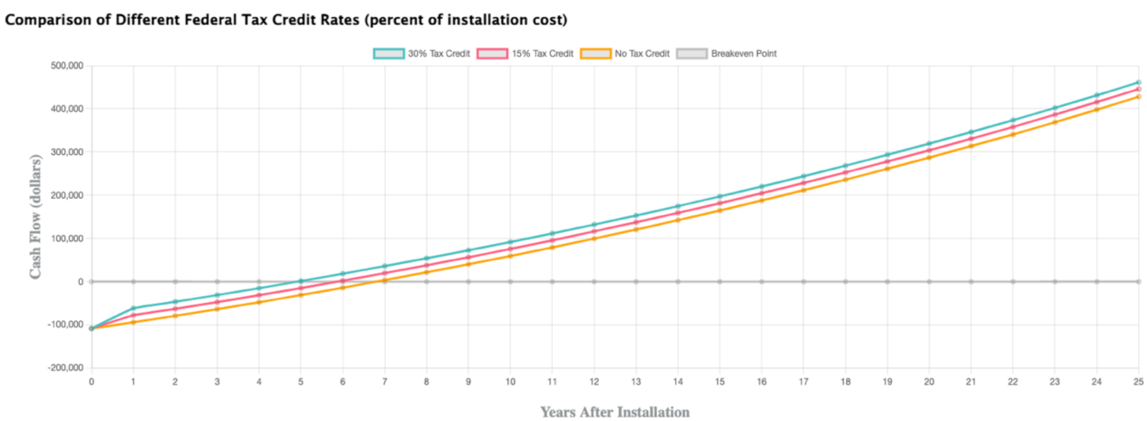


Figure A 38. Solar Cost Calculator page of website: Federal tax credit rate comparison

Loan Information		
Loan Amount (Principal)	107947	dollars
Loan Interest Rate	5.34	%
Time to Pay Off	25	years
Annual Loan Payment	7922	dollars/year
Monthly Loan Payment	660	dollars/month

Loan Schedule

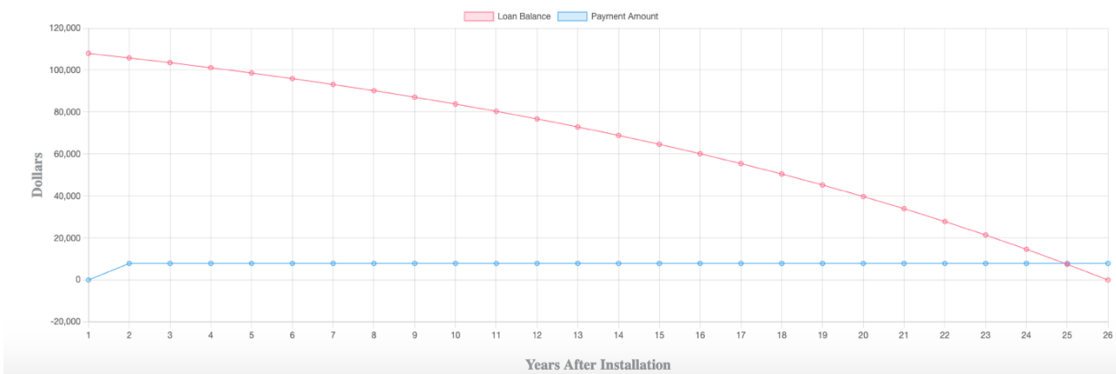


Figure A 39. Solar Cost Calculator page of website: Loan calculation and graph

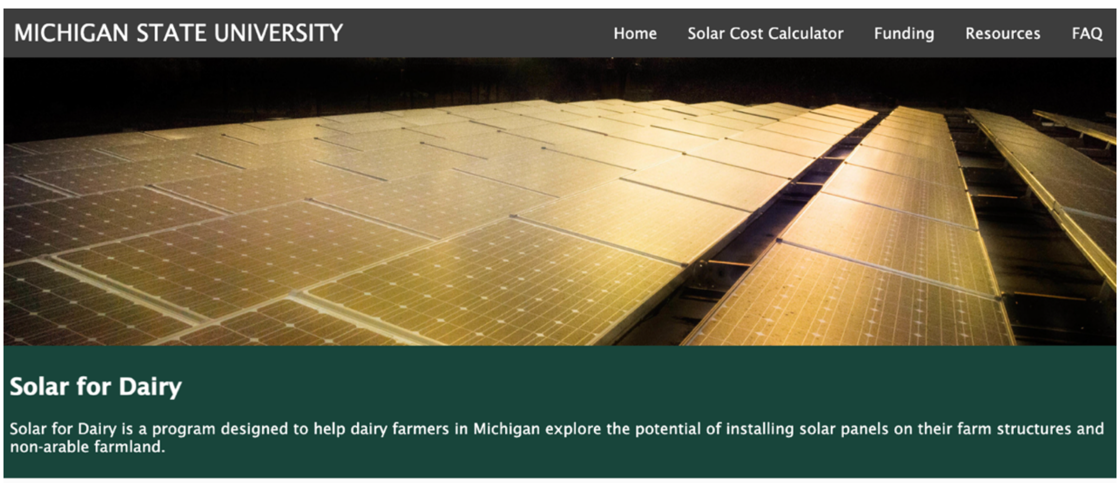


Figure A 40. Funding page of website

Funding Options

Disclaimer: This page is intended to provide an informational overview of funding options for farmers interested in installing solar panels. It is not intended to be official financial guidance. Farmers interested in installing photovoltaic products should consult with a licensed tax professional before making any purchase or investment.

Organization	Type	Amount	Notes	Resources
Federal Tax Credit	Tax credit	30% of installation cost	For panels installed by 2033	More info
Rural Energy for America Program	Loan	Up to 75% of eligible costs	Interferes with federal tax credit	Fact Sheet Eligibility More info
Rural Energy for America Program	Grant	Up to 50% of eligible costs	Interferes with federal tax credit	Fact Sheet Eligibility More info
Michigan Saves	Loan	Varies based on available financing	Non-profit green bank	More info
Property Assessed Clean Energy Program	Loan	100% financing	No down payment, ensures loan payment is less than annual savings	Fact Sheet Eligibility More info
National Energy Improvement Fund	Loan	100% financing		Fact Sheet More info

Figure A 41. Funding page of website: Table of funding options (screen over 900 pixels)

Federal Tax Credit
Tax credit
30% of installation cost
For panels installed by 2033
More info
Rural Energy for America Program
Loan
Up to 75% of eligible costs
Interferes with federal tax credit
Fact Sheet Eligibility More info
Rural Energy for America Program
Grant
Up to 50% of eligible costs
Interferes with federal tax credit
Fact Sheet Eligibility More info
Michigan Saves
Loan
Varies based on available financing
Non-profit green bank
More info
Property Assessed Clean Energy Program
Loan
100% financing
No down payment, ensures loan payment is less than annual savings
Fact Sheet Eligibility More info
National Energy Improvement Fund
Loan
100% financing
Fact Sheet More info

Figure A 42. Funding page of website: Table of funding options (screen under 900 pixels)

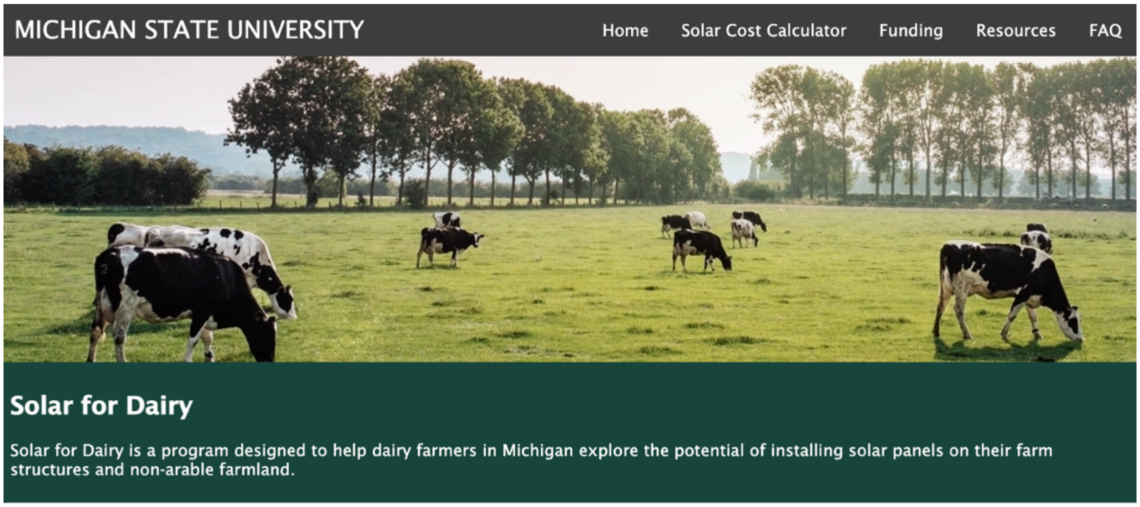


Figure A 43. Resources page of website

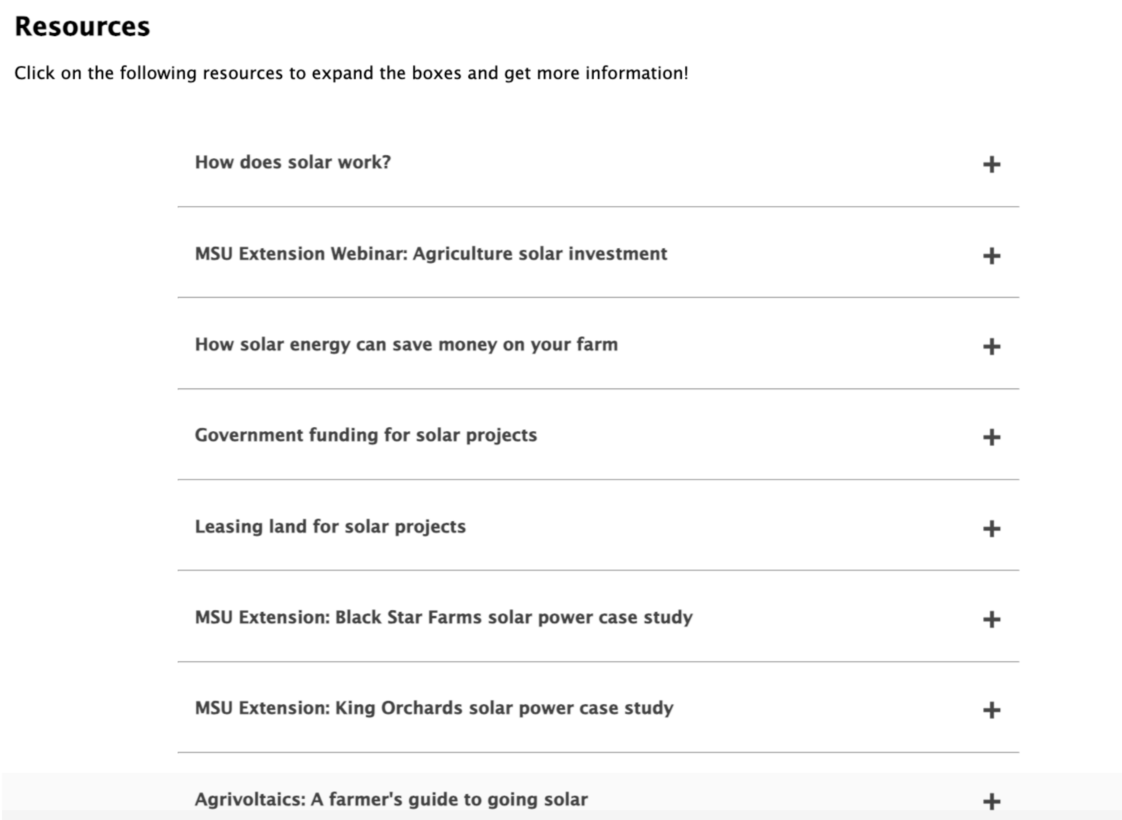
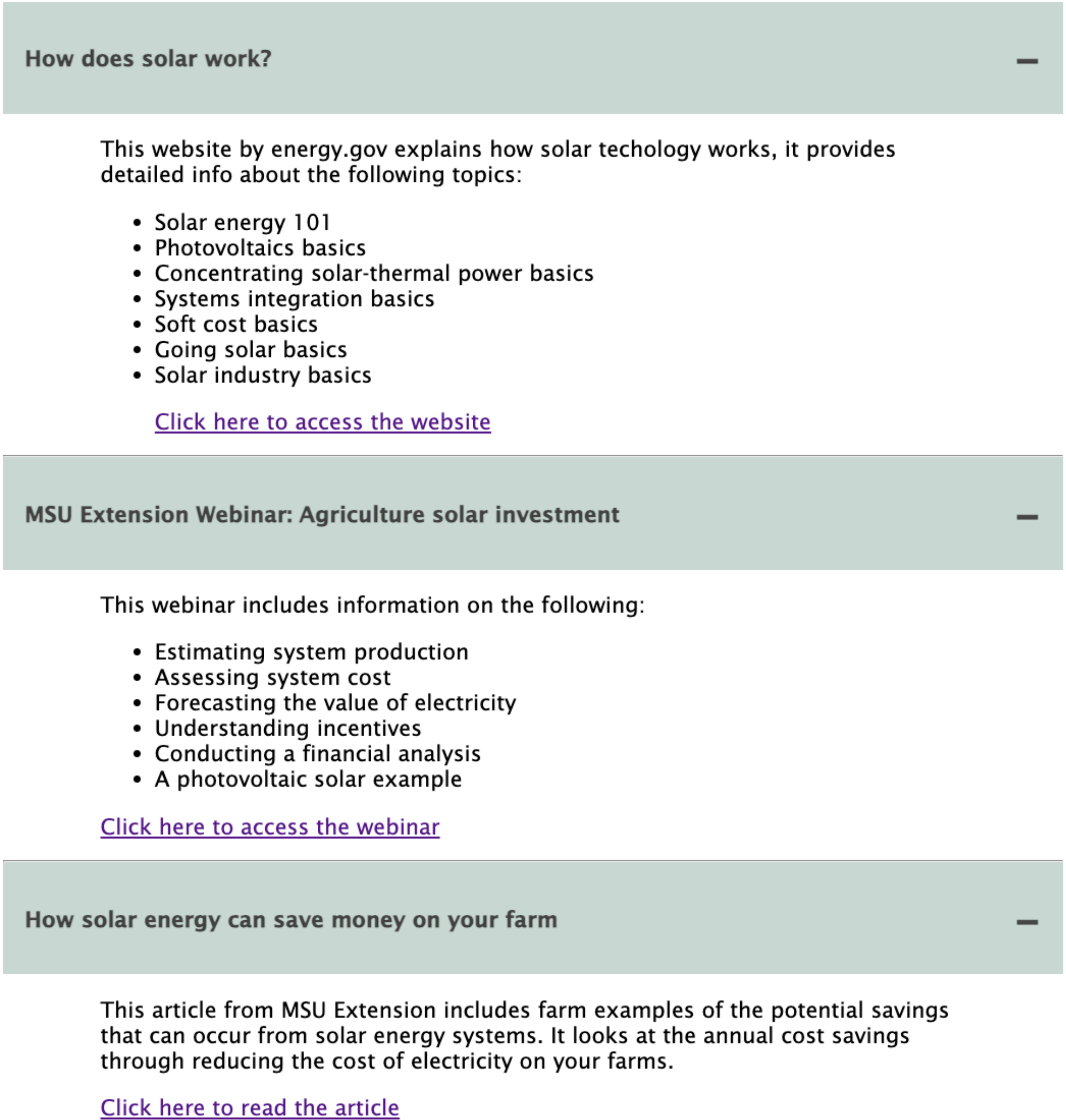


Figure A 44. Resources page of website: Resource containers compressed



How does solar work? —

This website by energy.gov explains how solar techology works, it provides detailed info about the following topics:

- Solar energy 101
- Photovoltaics basics
- Concentrating solar-thermal power basics
- Systems integration basics
- Soft cost basics
- Going solar basics
- Solar industry basics

Click here to access the website

MSU Extension Webinar: Agriculture solar investment —

This webinar includes information on the following:

- Estimating system production
- Assessing system cost
- Forecasting the value of electricity
- Understanding incentives
- Conducting a financial analysis
- A photovoltaic solar example

Click here to access the webinar

How solar energy can save money on your farm —

This article from MSU Extension includes farm examples of the potential savings that can occur from solar energy systems. It looks at the annual cost savings through reducing the cost of electricity on your farms.

Click here to read the article

Figure A 45. Resources page of website: Resource containers expanded

Government funding for solar projects

MSU Extension wrote an article on government programs, and how they can reduce the installation costs of your solar energy system.

Click here to access the article

Leasing land for solar projects

Have companies approached you asking to lease your land for solar projects? Are you unsure if this is a sound decision? MSU Extension created a webinar to educate farmers on this decision and answer any questions you may have. Here are the topics covered by the webinar:

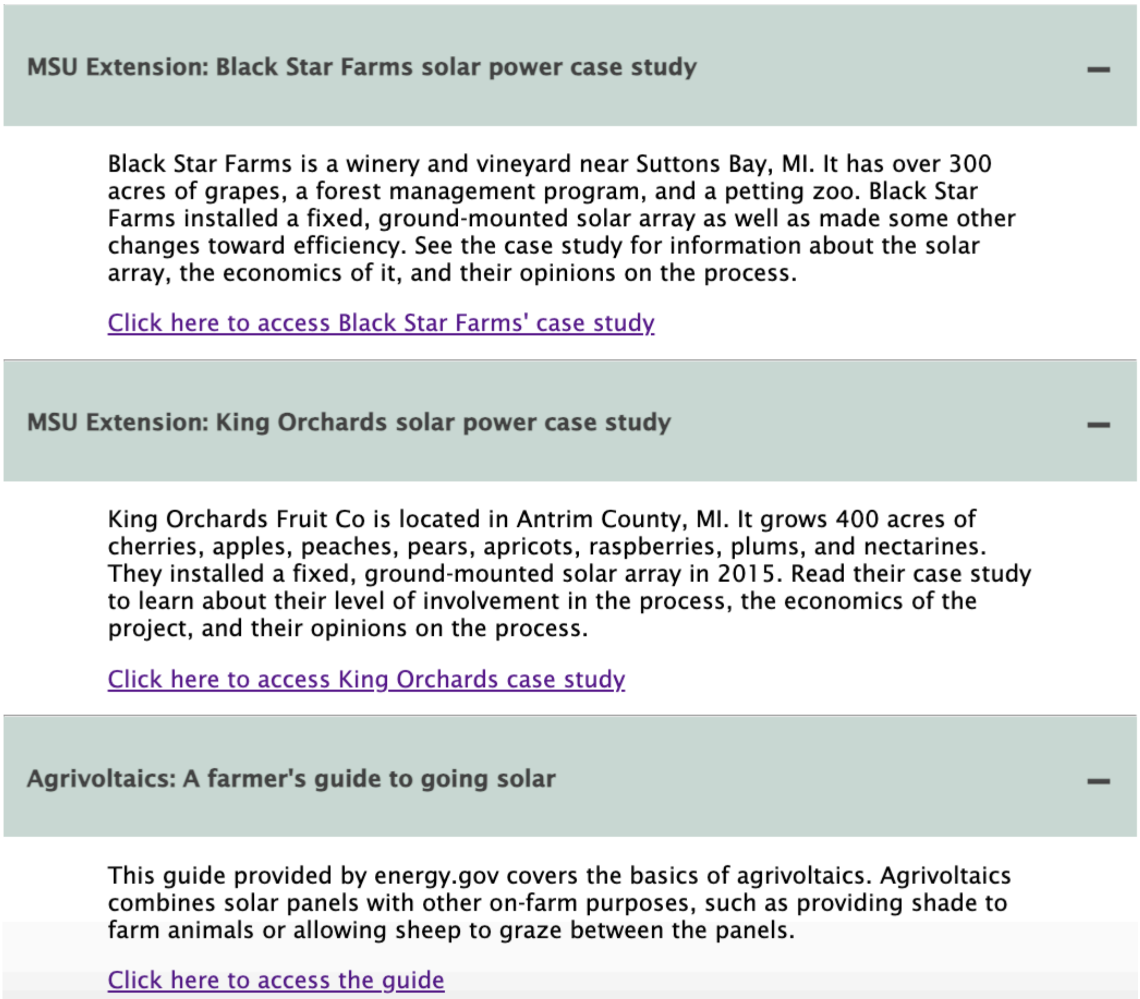
- Context for solar energy development on Michigan farmland
- Community vision for solar energy
- Zoning approaches
- Siting considerations for utility-scale solar
- Integrating solar with existing ag systems
- Understanding solar energy lease agreements
- Taxation guidance including impact of PA 116

Click here to access the webinar

More questions about solar energy lease agreement considerations?

Watch this video from MSU Extension

Figure A 46. Resources page of website: Resource containers expanded



MSU Extension: Black Star Farms solar power case study

Black Star Farms is a winery and vineyard near Suttons Bay, MI. It has over 300 acres of grapes, a forest management program, and a petting zoo. Black Star Farms installed a fixed, ground-mounted solar array as well as made some other changes toward efficiency. See the case study for information about the solar array, the economics of it, and their opinions on the process.

Click here to access Black Star Farms' case study

MSU Extension: King Orchards solar power case study

King Orchards Fruit Co is located in Antrim County, MI. It grows 400 acres of cherries, apples, peaches, pears, apricots, raspberries, plums, and nectarines. They installed a fixed, ground-mounted solar array in 2015. Read their case study to learn about their level of involvement in the process, the economics of the project, and their opinions on the process.

Click here to access King Orchards case study

Agrivoltaics: A farmer's guide to going solar

This guide provided by energy.gov covers the basics of agrivoltaics. Agrivoltaics combines solar panels with other on-farm purposes, such as providing shade to farm animals or allowing sheep to graze between the panels.

Click here to access the guide

Figure A 47. Resources page of website: Resource containers expanded

Figure A 48. Frequently Asked Questions page of website

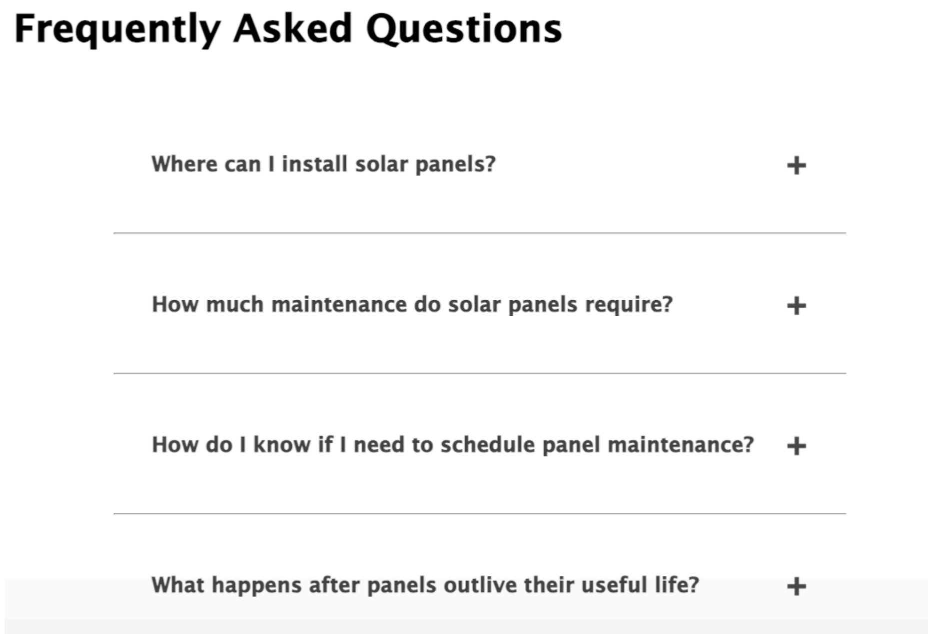


Figure A 49. Frequently Asked Questions page of website: Question containers compressed

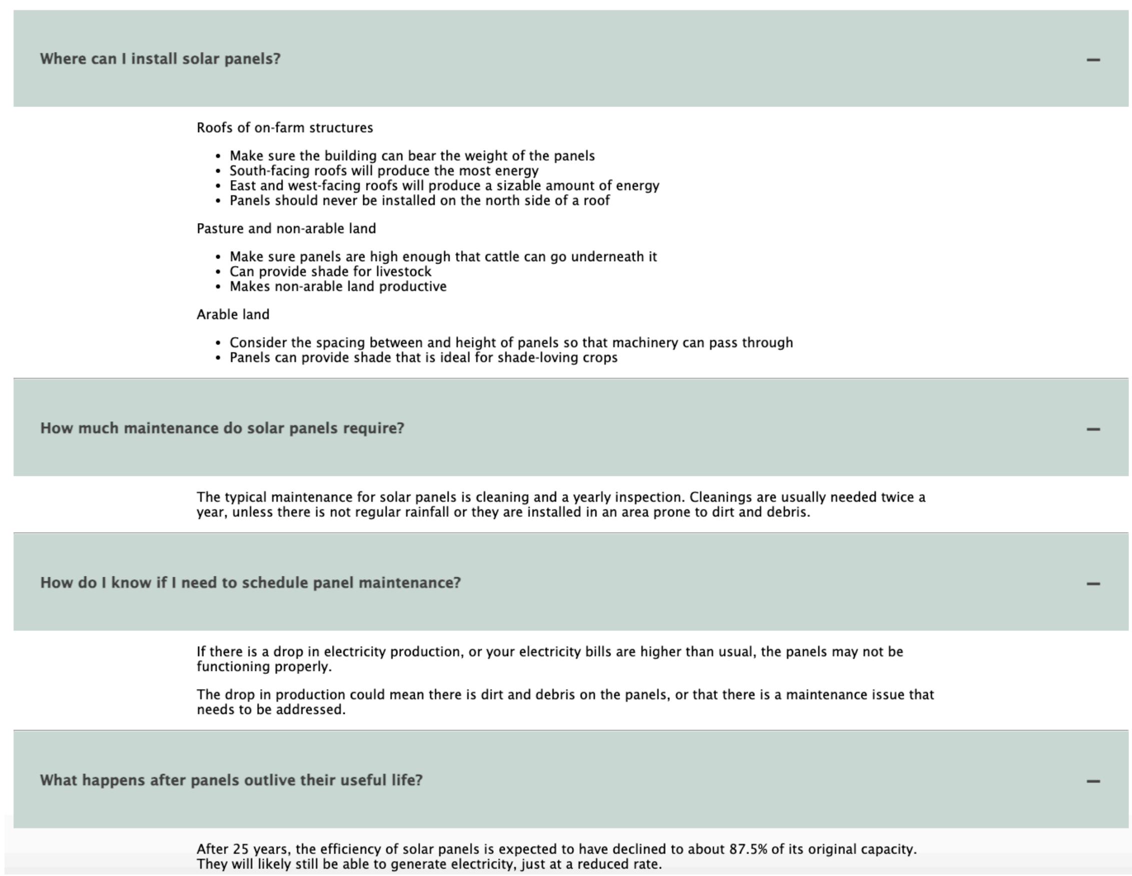


Figure A 50. Frequently Asked Questions page of website: Question containers expanded