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A net zero greenhouse gas feasibility study for Green Fence Farm

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A Net Zero Greenhouse Gas Emissions Feasibility Study for Green Fence Farm

An Honors Program Project Presented to

the Faculty of the Undergraduate

College of Integrated Science and Engineering

James Madison University

In Partial Fulfillment of the Requirements

For the Degree of Bachelor of Sciences

by Ashleigh Marie Cotting

May 2015

Accepted by the faculty of the Department of Integrated Science and Technology, James Madison University, in partial fulfillment of the requirements for the Honors Program.

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PUBLIC PRESENTATION

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Abstract

The purpose of this project is to assess the ability of Green Fence Farm, a 17 acre sustainable farming operation located in Greenville, VA, to become a net zero greenhouse gas farm operation. This project was conducted in several phases. First, the types and quantities of emissions were determined through an onsite fuel consumption evaluation and a greenhouse gas inventory of farm operations. Next, and calculations were used to determine the carbon sequestration capabilities of the soil and trees on the farm. Finally, ways to reduce emission and increase sequestration were examined with the intent of reaching net zero greenhouse gas emissions.

All of this information was used to develop a comprehensive plan for how Green Fence Farms can reach net zero greenhouse gas emissions through changes in farming practices, energy conservation and efficiency measures, fuel switching, and increasing carbon sequestration. The plan includes suggested steps to take, as well as economic analyses for each recommendation.

This project is of global significance because agriculture is one of the world's leading sources of annual greenhouse gas emissions. Meeting the food and fiber needs of the world's growing population will require the agricultural sector to grow. However, given that the effects of global climate change continues to worsen, it is imperative that while the agricultural sector grows, its emissions do not. Reducing the greenhouse gas emissions of small farming operations is one way to lessen the global impact of the agricultural sector.

Introduction and Background

Climate Change as a Global Issue

The evidence in favor of rapid climate change is overwhelming. Global sea levels have risen 6.7 inches in the last century. The 10 hottest years on the planet have all occur within the past 12 years. Oceans have warmed 0.302°F since 1969 and ice sheets in Greenland and Antarctica are rapidly losing mass. Glaciers around the world are retreating, the oceans have become 30% more acidic since the Industrial Revolution, and snow cover across the Northern Hemisphere is decreasing. 97% of climate scientists agree that these changes are very likely caused by human activities that produce greenhouse gases[1].

According to the Environmental Protection Agency (EPA), net worldwide greenhouse gas emissions increased 35% between 1990 and 2010. **Error! Reference source not found.** shows the worldwide emissions of the main greenhouse gases, including carbon dioxide, methane, and nitrous oxide. Carbon dioxide emissions have increased 42%, methane by 15%, and nitrous oxide by 9%.

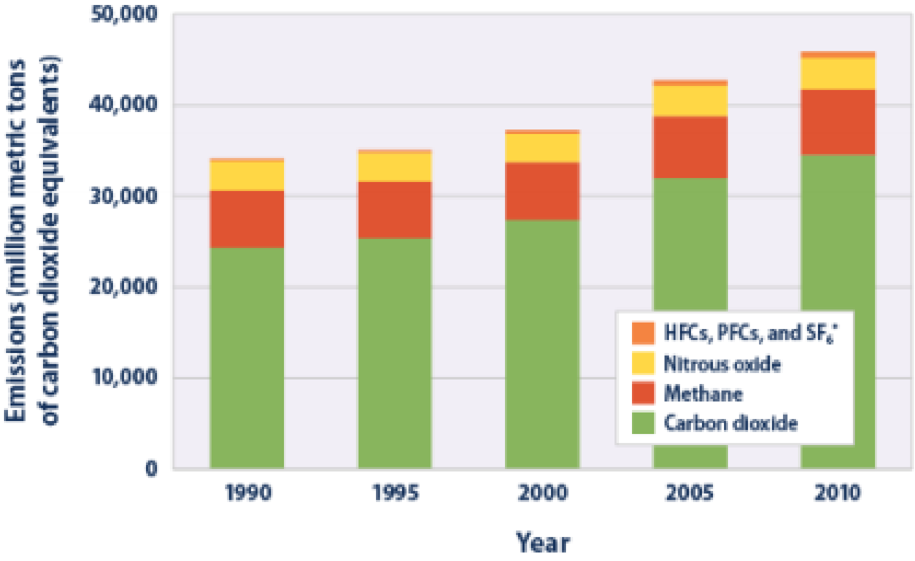

Figure 1. Global Greenhouse Emissions by Gas, 1990-2010 (EPA, 2011).

These increasing emissions have global ramifications. In 2014, the Intergovernmental Panel on Climate Change (IPCC) published “Climate Change 2014: Impacts, Adaptation, and Vulnerability[2].” This document begins by outlining the impacts of climate change on natural systems. Shrinking glaciers have had adverse effects on downstream water resources, disrupting the fresh water supply for regions around the world. The localized effects of climate change have caused terrestrial, freshwater, and marine species to shift their geographic ranges, seasonal activities migration patterns, and species interactions, all of

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[1] http://climate.nasa.gov/evidence/

[2] http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf

which can affect human food supply. The increase in climate extremes has had negative effects on crop yields, disturbing food production and reducing the food security of many nations. Extreme weather events such as hurricanes, flooding, and forest fires have caused damage to infrastructure and settlements in countries at all levels of development[2].

The effects of climate change aggravate other issues within countries both directly and indirectly. For instance, when food production is interrupted, the farmer is directly affected because he now may not be able to feed his family. His crop failure indirectly affects global food prices, meaning he may not be able to make a profit that year. These direct and indirect effects are felt by people in all countries; no level of development is immune[2].

Climate change has caused a reduction in significant reduction in essential resources for some regions of the world. If these situations cannot be reversed, violent conflicts are going to break out in resource scare areas. Countries will fight for food, water, and energy resources. The current imminence of these conflicts threatens the safety of people worldwide.

Clearly, climate change has far reaching, long term effects. That being said, they are not unpreventable. The good news about the anthropogenic nature of climate change is that humans can change their behavior and reduce their impact. People have the ability to affect positive change by reducing greenhouse gas emitting activities.

Agriculture: A Growing Greenhouse Gas Contributor

The issue of climate change can be overwhelming at first; its consequences alter incredibly complex systems. One effective strategy for approaching such a complicated problem is by breaking it down into smaller parts. For instance, global emissions can be broken down by the economic activities that lead to their emission. This breakdown is shown in Figure 2. By focusing on one sector at a time, it is possible to determine ways to reduce greenhouse gas emitting activities.

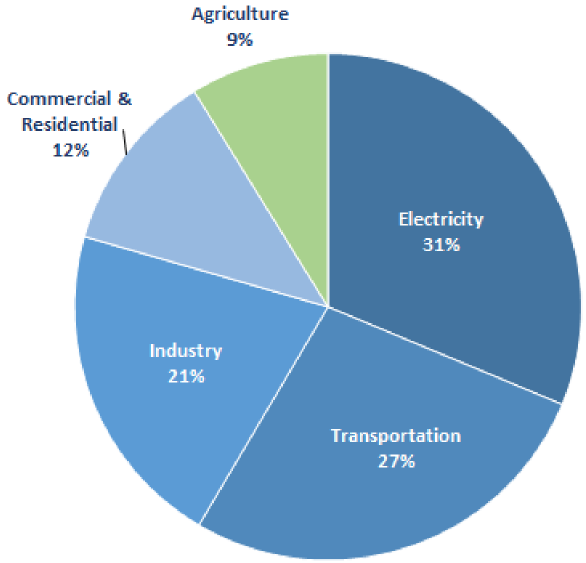
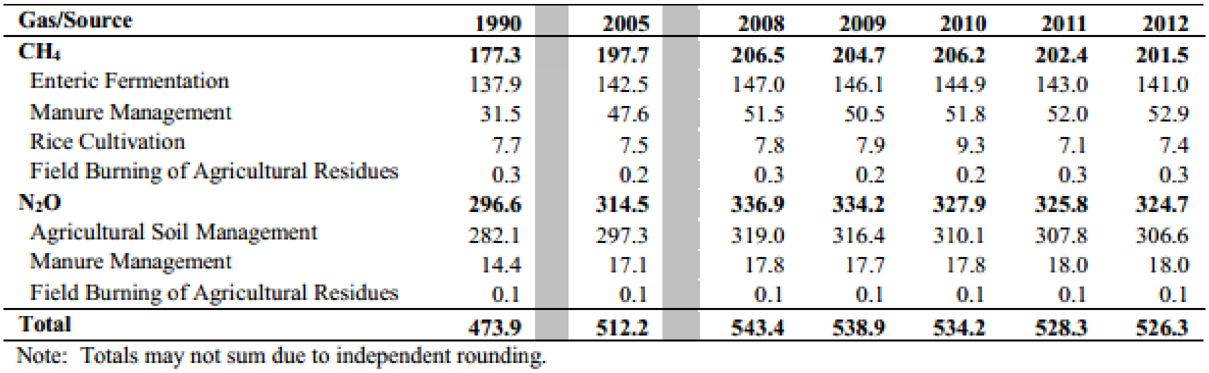


Figure 2. Global Greenhouse Gas Emissions by Source. (EPA, 2013)

As the above chart shows, agricultural activities account for 9% of global greenhouse gas emissions[3]. Since 1990, greenhouse gas emissions have increased 19%[4]. The sector is worth examining because it is associated with all three of the most problematic greenhouse gases: methane, nitrous oxide, and carbon dioxide. Methane and nitrous oxide emissions come directly from agricultural practices such as manure and land management, crop cultivation, and burning of agriculture residues[5]. Figure 3 shows estimates for methane and nitrous oxide emissions from US agriculture activity from 1990-2012.



Gas/Source	1990	2005	2008	2009	2010	2011	2012
CH_4	**177.3**	**197.7**	**206.5**	**204.7**	**206.2**	**202.4**	**201.5**
Enteric Fermentation	137.9	142.5	147.0	146.1	144.9	143.0	141.0
Manure Management	31.5	47.6	51.5	50.5	51.8	52.0	52.9
Rice Cultivation	7.7	7.5	7.8	7.9	9.3	7.1	7.4
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.2	0.2	0.3	0.3
N_2O	**296.6**	**314.5**	**336.9**	**334.2**	**327.9**	**325.8**	**324.7**
Agricultural Soil Management	282.1	297.3	319.0	316.4	310.1	307.8	306.6
Manure Management	14.4	17.1	17.8	17.7	17.8	18.0	18.0
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**473.9**	**512.2**	**543.4**	**538.9**	**534.2**	**528.3**	**526.3**

Note: Totals may not sum due to independent rounding.

Figure 3. EPA Emissions from Agriculture (Tg CO2 Eq.)

As Figure 3 shows, there are many aspects of agricultural practices that have the potential to be altered to reduce methane and nitrous oxide emissions.

Carbon dioxide emissions from agriculture result mainly from on-farm energy use. The agricultural sector also plays a crucial role in carbon fluxes. When land is converted for agricultural use, it can release carbon dioxide and reduce an area’s sequestration capabilities. In 2007, proper forest management resulted in an offset of 14.9% of US greenhouse gas emissions[6]. Farms are provide an opportunity to implement land and forest management practices that optimize carbon sequestration.

The future of the sector is certain; people will always need food, so agricultural activities will continue on. In fact, the U.N. Population Division estimates that by mid-century, the world population will be at 9.2 billion[7], suggesting that the sector will have to continue to grow. In light of the rapidly changing climate, it is crucial for the world’s health that as the agriculture sector grows, its emissions do not. Fortunately, there are many opportunities to reduce agricultural emissions, and people have begun to take an interest in doing so.

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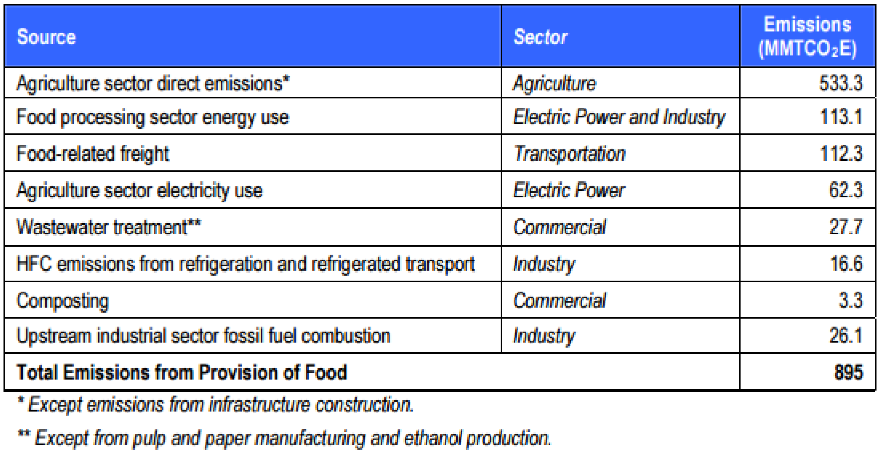
[3] http://epa.gov/climatechange/ghgemissions/sources/agriculture.html
[4] http://epa.gov/climatechange/ghgemissions/sources/agriculture.html
[5] http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-6-Agriculture.pdf
[6] http://unfccc.int/resource/docs/natc/usa_nc5.pdf
[7] http://www.worldwatch.org/node/6038

Stakeholder Analysis

Stakeholders at various stages of the food production process have become aware of the impact agriculture has on global greenhouse gas emissions, and as a result have decided to take action to reduce these emissions.

A More Conscious Consumer

Global food trade has proven to be essential for feeding the world population because it allows food to be transported from lands that can effectively produce it to larger population centers. In 2015, the journal *BioScience* published a study on the global food trade. This study found that over one-fifth of the calories grown in farm fields are ultimately traded, bringing the industry to a total US$522 billion[8]. According to the National Resources Defense Council, in 2007 the typical American meal contained, on average, ingredients from five other countries[9]. In 2006, food provision released 895 MMT of carbon dioxide equivalents. Therefore, 12% of the greenhouse gas emissions from food are just from getting it from the farm to the consumer[10].



Source	Sector	Emissions (MMTCO$_2$E)
Agriculture sector direct emissions*	*Agriculture*	533.3
Food processing sector energy use	*Electric Power and Industry*	113.1
Food-related freight	*Transportation*	112.3
Agriculture sector electricity use	*Electric Power*	62.3
Wastewater treatment**	*Commercial*	27.7
HFC emissions from refrigeration and refrigerated transport	*Industry*	16.6
Composting	*Commercial*	3.3
Upstream industrial sector fossil fuel combustion	*Industry*	26.1
Total Emissions from Provision of Food		**895**

** Except emissions from infrastructure construction.*

*** Except from pulp and paper manufacturing and ethanol production.*

Recently, however, consumers have become more conscious about where their food comes from. Many have begun to participate in what is known as the "locavore movement," in which they try to eat within a certain radius of their home[11]. The radius could be as small as 100 miles, or extend up to an entire state; the definition is not yet standardized. To find local food, consumers are turning towards farmers markets, community-supported agricultural organizations (CSAs) and farmers themselves. As a result, the number of farmers markets increased by more than 50% from 2000 to 2005. In 2006, sales at farmers markets passed $1 billion. The number of families with CSAs has more than quadrupled since 2000, and some communities cannot meet the demand and have to wait-list families[12]. A study conducted by the USDA found that direct-to-consumer sales on farms increased by 32% between 2002 and 2007, indicating an increase in consumer desire for a transparent food supplier[13].

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[8] http://environment.umn.edu/food/unraveling-the-complex-web-of-global-food-trade/
[9] https://food-hub.org/files/resources/Food%20Miles.pdf
[10] http://www.epa.gov/oswer/docs/ghg_land_and_materials_management.pdf
[11] http://www.pbs.org/now/shows/344/locavore.html
[12] http://www.bloomberg.com/bw/stories/2008-05-20/the-rise-of-the-locavorebusinessweek-business-news-stock-market-and-financial-advice
[13] http://www.ers.usda.gov/media/1763062/ap068_report-summary.pdf

In 2011, the Food Marketing Institute conducted a survey to determine why consumers were participating in the locavore movement. Another survey found that 27% of participants chose to buy local because due to concerns over the environmental impacts of food transportation**Error! Bookmark not defined.**.

The same survey found that 83% of those surveyed said they buy local food because it is fresher, while 56% said they prefer the taste. This suggests that consumers are also beginning to pay attention to who their food is grown. According to the United States Department of Agriculture (USDA), the demand for organic food has consistently shown double-digit growth since 2005[14]. This growth is shown in Figure 4.

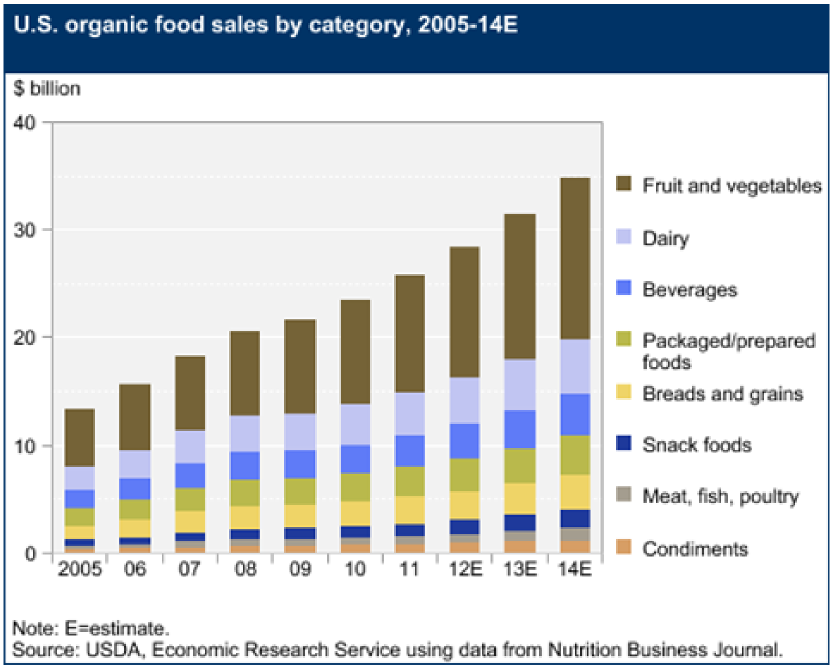

Figure 4. U.S. Organic Food Sales by Category. (USDA 2014)

This transition to purchasing locally produced organic food has been shown to have a variety of environmental impacts[15]. The food is produced without the use of pesticides and chemicals that can pollute soil and water. Additionally, organic farming incorporates techniques that conserve water and deliver nutrients back to the soil. Furthermore, the food also has a smaller greenhouse gas footprint because it travels a far shorter distance from the farm to the consumer[15]. As the locavore movement continues to grow, so will the associated environmental benefits.

Increase in Organic Farms

As the locavore movement has become more popular, farmers have begun to change their practices to cater to the demand for fresher, local organic food. Between 2002 and 2006, the number of small farms in the United States increased 20%[12]. In 2012, 7.8% of U.S. farms were marketing their products locally and 70% of those sold their products directly to their customers[13].

By using organic farming practices, farmers increase the overall sustainability of their farming operation[16]. Practices like crop rotation, cover cropping, and using compost for fertilizer all build soil

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[14] http://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market-overview.aspx
[15] http://www.voanews.com/content/organic-farming-17jan13/1585578.html
[16] http://www.fao.org/organicag/oa-faq/oa-faq6/en/

health by returning nutrients to the soil. The water used on site is not polluted by pesticide runoff. Varying the crops grown through practices like symbiotic cropping increases the biodiversity of the farm, which can optimize nutrient and energy cycling on the farm[16].

Producing and selling organic produce locally also has economic benefits for the farmer. Organic farming can have lower production costs because it does not require pesticides or the intensive land management techniques that conventional farming does[17]. Additionally, farmers selling organic products to local customers can do so at a premium price. As a result, organic farming is economically feasible and, in the right context, can be more lucrative than conventional farming[17].

The number of farmers running organic operations and selling their products locally has been increasing to the point that it has influenced policy. When the Farm Bill was updated in 2008, $2.3 billion was set aside for specialty crops that are typically produced by smaller farms instead of big agribusinesses. Additionally, the bill allowed farms to get up to 75% of their organic certification costs reimbursed[12]. As the small, organic farming industry grows, similar policy changes are bound to occur, making the business even better for farmers.

Benefits to Communities around Farms

The communities around farms that sell their organic produce locally see benefits as well. A study conducted by the Union of Concerned Scientists found that expanding local food systems can improve the local economy. Farmers markets, for instance, create jobs and ensure that a greater percentage of the sales revenue is retained locally. Furthermore, farmers who sell locally are connected to their communities and are therefore likely to purchase their equipment and raw materials from local suppliers. This can increase labor and household incomes, which in turn encourages community residents to spend more, strengthening the economy further[18].

Having access to locally grown organic food is also beneficial for the health of a community. For instance, the Farm to School program has vastly improved student health by providing them with access to healthier food options in the cafeteria[19]. Children who attend a school with the Farm to School program receive on average 0.99-1.3 additional servings of fruits and vegetables each day. Furthermore, the program teaches children about agriculture, the environment, and the relationship between the two. The children are then able to bring this knowledge home to their families, which encourages them to shop locally and purchase healthy foods. This increased awareness of eating healthy tends to translate into an interest in how to be healthy in other ways, such as increased physical activity. Without a farm in the area to supply the Farm to School program, communities would not see these health and education benefits[19].

Farms that operate organically and sell their produce locally release far less greenhouse gases than large agribusinesses do, offering benefits to the national, local, and global communities. By shortening the distance food travels from the farm to a consumer, farmers can lower the greenhouse gas emission associated with food transportation. Organic practices like no-till, returning crop residue to soil, and cover cropping help sequester carbon on site. According to a study conducted by Rodale Institute, if all cropland were converted to organic farmland, the land could sequester up to 40% of annual carbon dioxide emissions. The same study found that and organic farm with the same yield as a conventional farm has a

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[17] http://www.sciencedaily.com/releases/2011/09/110901093715.htm

[18] http://www.ucsusa.org/sites/default/files/legacy/assets/documents/food_and_agriculture/market-forces-exec-summary.pdf

[19] http://www.farmtoschool.org/Resources/BenefitsFactSheet.pdf

lower energy input requirement, further lowering its greenhouse gas footprint[20]. Figure 5 graphically depicts these differences.

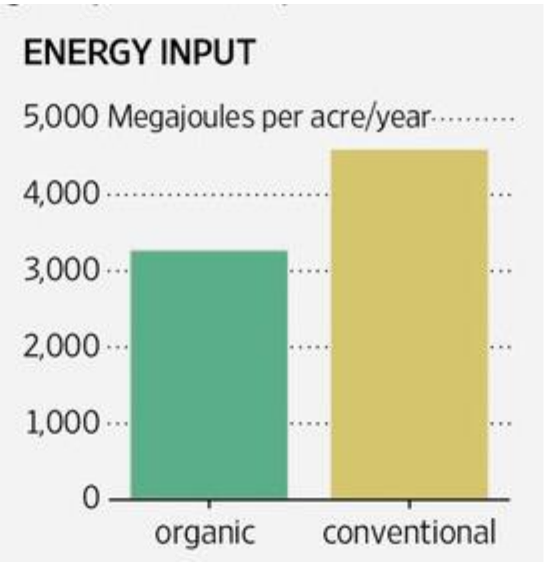

Figure 5. How Organic and Conventional Farming Compare Side by Side over 30 Years. (Rodale Institute, 2014).

By reducing emissions at both the production and transportation stages of food production, organic farms that sell food to local customers reduce their environmental impact on the communities they operate in.

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[20] http://blogs.wsj.com/numbers/can-organic-farming-counteract-carbon-emissions-1373/

Project Description

Project Statement

As consumers move towards purchasing from local organic farms, it becomes more important to ensure that these farms do in fact operate in an environmentally friend, sustainable manner. Purchasing locally grown organic food only yields environmental benefits when the farm is operating efficiently. One way to maximize the environmental sustainability of a farm is to make it a net zero greenhouse operation. This project serves as a case study to determine what steps can be taken to get a small organic farming operation to net zero.

Introduction to Green Fence Farm

Green Fence Farm is a 17 acre multi-product sustainably run farming operation owned by Katherine Sparks and Nick Auclair. The farm is located in Greenville, Virginia which is approximately 40 minutes south of Harrisonburg, Virginia.

Farming Operations

Sparks and Auclair use their land to grow crops and raise animals. The land on the farm is divided up into three different use categories, which can be seen in Table 1.

Table 1. Property Breakdown of Green Fence Farm.

	Percentage	Acres	Hectares
Forested	59%	10.00	4.05
Grassland	35%	6.00	2.43
Cropland	6%	1.00	0.40

Green Fence Farm used to be a Christmas tree farm and is today still heavily forested with loblolly pine trees. This area, combined with the grassland, serves as grazing areas for the animals on site. Table 2 provides the animal head count for summer 2014.

Table 2. Animal Head Count for Summer 2014.

Animal	Head Count
Dairy Cows	0
Other Cattle	0
Buffalo	0
Sheep	10
Goats	0
Camels	0
Horses	0
Mules and Asses	0
Swine	5
Poultry	75
Other[2]	50

Every spring, Sparks and Auclair purchase piglets, lambs, and turkeys to raise throughout the summer. In the fall, the turkeys are slaughtered on site and sold to individual customers. The pigs and sheep are sold to local restaurants. The pigs reside in a pen that is mainly in the forested area of the property. The sheep are allow free range of the grassland and forest. The turkeys graze rotationally and live in houses than can be moved by hand. An example of the turkey houses can be seen in Image 1.

Image 1. Turkey House Designed for Rotational Grazing.

Sparks and Auclair also have a brood of egg laying hens. During the spring, summer, and beginning of fall, the hens reside in a mobile hen house, shown in Image 2.

Image 2. Mobile Hen House Designed for Rotational Grazing.

This hen house is designed such that it can be manually moved once the hens have thoroughly grazed an area. When the house is moved to a new spot, it is encircled with electric fencing to provide the chickens with area to graze and roam. They lay their eggs in the hen house and each day Sparks and Auclair collect them. The eggs are stored on site until they are sold either directly to customers or to local markets and restaurants.

Produce is grown seasonally on site in raised beds, as seen in Image 1, and in cold boxes during the winter. The raised beds and cold boxes are filled with a combination of soil and compost from a nearby composting facility. All crops are planted, watered, weeded, and harvested by hand. The majority of the produce grown at Green Fence Farm is consumed by Sparks, Auclair, and their family. Excess produce is stored on site in freezers for later use.

Image 3. Raised Beds Used to Grow Crops.

Other features of Green Fence Farm include a fungi garden, a hand planted meadow, a passive rainwater collection system, and a bee keeping facility. Sparks and Auclair have a home on the farm, but its energy usage and associated emissions were excluded from this analysis.

Project Purpose

The purpose of this project is to assess the ability of Green Fence Farm, a 17 acre sustainable farming operation located in Greenville, VA, to become a net zero greenhouse gas farm operation. Despite all of the sustainable practices being implemented at Green Fence Farm, there are many opportunities for improvement. A significant contribution that agricultural systems can make to the environment is through reduced greenhouse gas emissions. Helping Green Fence Farm assess their ability to get to net zero greenhouse gas emissions would be a major step in achieving overall sustainability. Furthermore, the model developed for Green Fence Farm can serve as a best practices guide for other small sustainable farms in the area.

Methodology

In order for Green Fence Farm to be a net zero greenhouse gas farming operation, its greenhouse gas emissions must be equal to its on-site greenhouse gas storage capabilities.

This project was completed in four phases. First, several site visits were made to learn about the farm and its associated activities. Next, the current levels of greenhouse gas emissions were determined. Then, a carbon sequestration analysis was performed to determine how much carbon is currently stored on site in carbon sinks. Finally, methods for reaching net zero greenhouse gas emissions were researched. This included a renewable energy assessment and research regarding how to increase carbon sequestration on site.

Farm System Analysis

This project began with a series of farm visits. These visits were used to catalogue information regarding farming inputs, processes, and outputs. Photographs were taken in addition to written documentation. This information was then used to create a series of systems diagrams that separated the components of the farming system into appropriate categories. This process was used to draw the system boundary for the analysis. Only the farming activities that occur on the farm itself were considered in this analysis.

Determining Current Greenhouse Gas Emissions

During the second phase of this project, current greenhouse gas emissions were quantified. This was accomplished through an analysis of on farm fuel usage, as well as a greenhouse gas inventory for farm activities.

It should be noted that all greenhouse gas emissions are given in units of carbon dioxide equivalents. This methodology was chosen because emission levels of methane and nitrogen dioxide were too low to financially justify specific mitigation techniques.

On Farm Fuel Usage

The first step taken in determining Green Fence Farm’s current levels of greenhouse gas emissions was examining utility bills. The farm has three energy systems: electricity, gas, and a backup propane generator. Utility data from the past 18 months was collected and analyzed. This data was logged into an Excel file. To create a representative year of fuel usage, months with two or more data points were averaged together.

Once the representative year was created, the associated annual greenhouse gas emissions were calculated. This was done using Emissions Factors for Greenhouse Gas Inventories provided by the EPA[21]. Once the correct carbon dioxide factor was selected, Equation 1 was used to calculate the emissions from Green Fence Farm’s energy usage.

$$CO_{2e} = [energy\ used\ (MMBtu)] \times [CO_2\ factor\ (\frac{kg\,CO_2}{MMBtu})] \qquad \text{Equation 1}$$

Once the emissions for each fuel source were calculated, the total carbon dioxide emissions for on-site energy usage was determined. This was calculated by adding all of the emissions from electricity, gas, and propane together.

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[21] http://www.epa.gov/climateleadership/documents/emission-factors.pdf

Greenhouse Gas Inventory

The next step taken for this project was determining the amount of greenhouse gas emissions from farming activities. This was conducted using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories for Agriculture, Forestry, and Other Land Use[22]. This inventory method was chosen over other options because it could be tailored to Green Fence Farm. The document, which is broken down primarily by land use category, provides step by step guidance for calculating the greenhouse gas emissions associated with individual agricultural and land management activities. The first step in creating an inventory specific for Green Fence Farm was to determine which sets of calculations were to be included based on the farming operation. Each activity selected had an accompanying worksheet in the IPCC guidelines. These worksheets were downloaded and compiled into one Excel workbook. The specific calculations each worksheet required were performed using data from Green Fence farm (shown in Tables 1 and 2) and factors from the IPCC document which were based on information such as location and soil type.

The IPCC greenhouse gas inventory calculations provided the greenhouse emissions associated with on farm activities in terms of kilogram of methane, nitrogen dioxide, and carbon gains or losses. Due to the nature of this analysis, values given for methane nitrogen dioxide emissions were converted into carbon dioxide equivalents. This was done using Emissions Factors for Greenhouse Gas Inventories[21].

The greenhouse gas emissions calculated through the greenhouse gas inventory were then combined with the emissions calculated for on-site energy usage to determine total annual emissions for Green Fence Farm.

Determining Current Carbon Sequestration Capabilities

The goal of the third phase of this project was to calculate how much carbon is currently stored on site. This was accomplished by analyzing the sequestration capabilities of the soil and the trees.

Sequestration Capabilities of Soil

The carbon gains and losses associated with the soil were calculated during the greenhouse gas inventory that occurred during Phase I. The same methodology was used to determine how much carbon the soil sequesters based on land use and management.

Sequestration Capabilities of Trees

The methodology for this part of the project was adapted from a Geographic Science lab taught by Dr. Zachary Bortolot at James Madison University.

The first step in determining the amount of carbon sequestered by trees on site was to take a random sample of tree circumferences. To do this, an evenly spaced sampling grid was created using Google Earth. This sampling grid is shown in Figure 6.

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[22] http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Figure 6. Evenly Spaced Sampling Grid for Tree Circumference Sampling.

Once the sampling grid was created, the pinpoint function in Google Earth was used to find GPS coordinates for one point within each square. This process is shown in Figure 7.

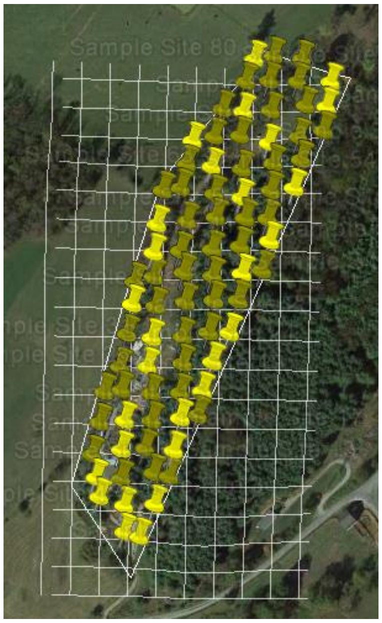

Figure 7. Pinpointed Sampling Locations for Tree Circumference Sampling.

A handheld GPS was taken out to the farm to locate the predetermined sampling sites. At each set of GPS coordinated, the breast height circumference of a randomly selected tree was measured, as shown in Image 4. In total, 82 circumference measurements were taken, which is estimated to about 33% of the trees on the farm. The type of tree, either broadleaf or needle leaf, was also recorded.

Image 4. Measurement Method for Tree Circumferences.

Once the circumference measurements were taken, they were logged into an Excel workbook. The circumference measurement data was converted into corresponding diameter measurements in centimeters. Once the diameter was known, Equation 3 (for broadleaf) or Equation 4 (for needle leaf) was used to calculate the amount of carbon stored by the tree.

$$Carbon\ (broadleaf) = 0.25 \times \frac{25000D^{2.5}}{D^{2.5}+246872} \qquad \text{Equation 3}$$

$$Carbon\ (needle\ leaf) = 0.25\ \times \frac{15000D^{2.7}}{D^{2.7}+364946} \qquad \text{Equation 4}$$

After calculating how much carbon could be stored by the trees sampled, the amount of carbon dioxide that could be stored was calculated. This was accomplished by multiplying the amount of carbon stored by the atomic weight ratio of carbon to carbon dioxide, which is 3.66.

Once the amount of carbon dioxide stored by the trees sampled was calculated, this value was extrapolated out to estimate the sequestration capabilities of the entire farm.

The carbon sequestration capabilities of the orchard were also calculated. In this case, the circumference of each tree in the orchard was measured. The methodology for calculating carbon stored is the same, but only Equation 3 was used because all of the trees in the orchard are broadleaf.

Examining Ways to Reach Net Zero Greenhouse Gas Emissions

The final phase of this project was to examine ways to reach net zero greenhouse gas emissions. This involved a renewable energy assessment and research into ways to increase on site carbon sequestration capabilities.

Lowering Carbon Dioxide Emissions

The most effective way to lower carbon dioxide emissions is through energy management. The Energy Management Pyramid, shown in Figure 8, was used as a guide for this portion of the project.

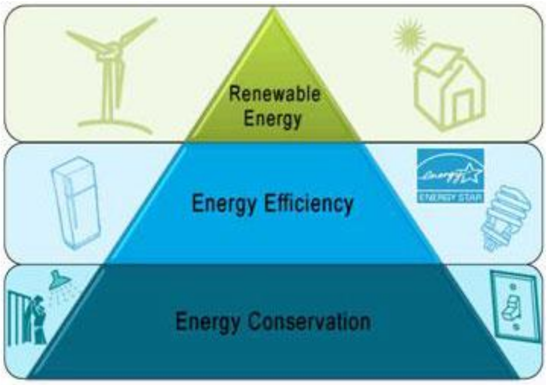

Figure 8. The Energy Management Pyramid. (DOE, 2007).

In accordance with this pyramid, energy conservation options were researched first. Next, ways to improve energy efficiency were research. To see the results of this research, refer to the section of this report entitled Conservation and Energy Efficiency Results.

Finally, a renewable energy assessment was performed to evaluate potential fuel switching options on site. Four potential systems were evaluated: a roof mount solar system, a ground mount solar system, a residential scale wind turbine, and switching to a new rate provided by the farm's electric utility.

Roof Mount Solar PV System

The first step in assessing the potential for a roof mount solar PV system was selecting a building. The workhouse was chosen based on the fact that it has a large roof area and contains energy using devices for the farm.

Once the workhouse was selected, it was modeled in Google SketchUp by following a SketchUp tutorial in the program's User Manual. Then, a SketchUp plug-in called Skelion was used to model a solar system for the roof. This was accomplished using the Skelion User Manual. The SketchUp model of the workhouse is shown in Figure 9.

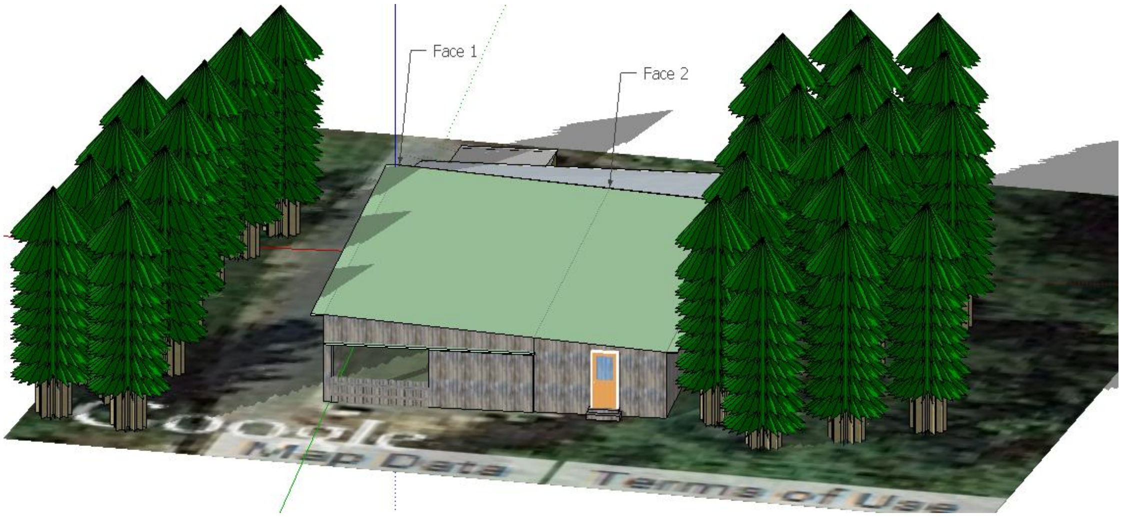

Figure 9. Google SketchUp Rendering of the Green Fence Farm Workhouse.

In order for the Skelion report to be accurate, it was necessary to determine a shading factor for the workhouse roof. This was accomplished using a Solar Pathfinder, which is show in Figure 10.

Figure 10. Solar Pathfinder Kit (Solar Pathfinder, 2015)

A Solar Pathfinder was brought out to the farm. The first step in using the Pathfinder is to assemble the structure, which was done by setting up the tripod and putting the base piece on top. Next, the annual solar path diagram sheet that corresponded with Green Fence Farm's latitude was attached to the base. This structure was then placed on the roof of the workhouse. Next, the instrument section, which is the clear dome piece shown in Figure 9, was placed on top of the base piece. The level on the instrument section was used to ensure the Pathfinder was kept level throughout the data taking process. Once the instrument was level, it was adjusted such that it faced true North according to the compass on the instrument piece. The reflective dome of the instrument showed the tree profile for the roof, as seen in Image 5.

Image 5. Photograph of the Solar Pathfinder on the Workhouse Roof.

This profile was traced onto the annual solar path diagram using the chalk provided with the Solar Pathfinder kit. This profile was used to determine what percentage of the year the roof is shaded. This is done by adding up the tick marks that on the paper that do not fall within the tree profile for each month. These tick marks are then summed to determine shade the roof receives each month. Monthly shading percentages were added and averaged to determine the shading for the year.

Image 6 shows how the Solar Pathfinder data collection was carried out in the field.

Image 6. Photograph of Shading Factor Data Collection.

One side of the roof is shaded more than the other, so Solar Pathfinder measurements were taken at each side and averaged to determine the estimated shading factor for the entire roof. This shading factor was then put into Skelion. Skelion then used the information from the Google SketchUp model to run a PVWatts report that predicted the annual generation for the solar system.

Ground Mount Solar PV System

The first step in evaluating a potential ground mount solar PV system was selecting a site. The least shaded ground area on site was determined to be located in the grazing area, just beyond the raised beds. This area is shown in Image 7.

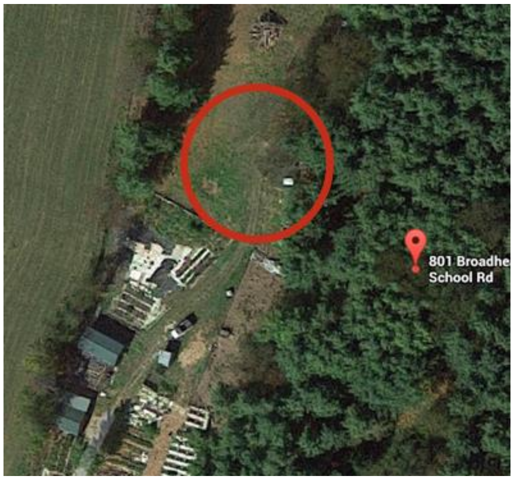

Image 7. Location for a Potential Ground Mount Solar PV System.

Once the location was selected, the potential system was analyzed using the same methodology as the roof mount solar PV system.

Residential Scale Wind Turbine

The first step taken to determine the potential electricity generation for a wind turbine on site was to mine raw wind measurements using ArcMap. The latitude and longitude of Green Fence Farm were entered into ArcMap. The following layers were then activated:

- Speed at 80m (average, m/s)

- Elevation (of farm, m)
- Speed at 50m (average, m/s)
- Speed at 34m (average, m/s)
- Speed at 20m (average, m/s)

After activating these layers, the average wind speed, frequency, average power output, Weibull c, and Weibull k constants were generated. This data was then imported into an Excel file.

All of the raw data from ArcMap was given at a hub height of 80 meters. The data had to be scaled down to the desired hub height for a turbine on the farm, which is 20 meters. This was done in Excel using Equation 5, known as the Weibull distribution.

$$f(v) = \frac{k}{A}\left(\frac{k}{A}\right)^{k-1} exp\left(-\left(\frac{v}{A}\right)^{k}\right) \qquad \text{Equation 5}$$

In Equation 5, *k* is the Weibull k value generated from ArcMap, *A* is the Weibull c value generated from ArcMap and *v* is the wind speed, which increases in intervals of 1 m/s. Next, the 80 meter Weibull curve (which uses raw data from ArcMap) was plotted alongside the 20m Weibull curve (which uses scaled data) to verify that they have the same shape with different means

Next, the verified scaled 20 meter data was used to estimate annual generation. First, the number of hours per year that a certain wind speed occurs was determined by finding the product of the frequency (from the Weibull distribution) and the total hours in a year. Then, the expected power outputs for a Bergey Excel 10kW turbine from the Small Wind Certification Council[23] were logged into the Excel file. The energy output was then determined using Equation 6.

$$Energy\ Output = (hours\ per\ year\ at\ wind\ speed\ \mathrm{x}) \times (estimated\ output\ for\ that\ wind\ speed) \qquad \text{Equation 6}$$

The energy output for each wind speed was then converted into kilowatt-hours. The potential energy outputs for each wind speed in kilo-watt hours was then summed to estimate annual generation from the turbine.

The manual estimates done using data from ArcMap were then verified using Windographer. To do this, the Berkey Excel 10kW turbine was selected from Windographer's wind turbine library. A copy of this turbine was made in Windographer and the SWCC power output data was inserted into the model. Next, the copy of the Bergey Excel 10kW turbine was run for a hub height of 20 meters.

Economic Analysis of Renewable Energy Systems

An economic analysis was performed for each renewable energy system evaluated during this phase of the project. The first step in this process was to determine how much electricity usage would be offset by the renewable energy system. This was done in Excel by finding the difference between the annual energy generated by the renewable energy system and the annual electricity consumption for Green Fence Farm.

Next, research was conducted to determine the purchase, installation, operation, and maintenance costs for each renewable energy system. The information for the solar PV systems was determined through an e-mail exchange with solar installation company Sigora Solar. The costs for the wind turbine were determined using the SWCC website[23]. This cost data, along with electricity usage offset data, were used to perform several economic analyses to determine the financial viability of each system.

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[23] http://bergey.com/documents/2012/05/excel-10-swcc-summary-report.pdf

Research was also conducted to determine what financial incentives would be available to assist in funding the renewable energy system's installation and operation. This research was conducted using the Database of State Incentives for Renewables and Energy Efficiency[24]

Simple Payback Period Analysis

The first economic analysis performed was a simple payback period. To do this, the first step was to determine the annual energy cost savings each system would provide. This was done using Equation 7.

$$\begin{aligned} &Annual\ Energy\ Cost\ Savings \\ &\quad = (Annual\ Electricity\ Usage\ \{kWh\} - Renewable\ Energy\ Generation\{kWh\}) \\ &\quad \times Cost of Energy\{\frac{\$}{kWh}\} \end{aligned}$$

Equation 7

Once the annual energy savings were known, they were inserted into Equation 8 to determine annual net savings.

$$\begin{aligned} &Annual\ Net\ Savings \\ &\quad = Energy\ Savings + Tax\ Rebate - Purchase\ and\ Installation\ Costs \\ &\quad - O\&M\ Costs \end{aligned}$$

Equation 8

The simple payback period analysis was run for the lifetime of the renewable energy system. Payback on the system occurred in the year that the net savings value first turned positive.

Discounted Payback Period Analysis

Once the simple payback period analysis was performed, it was modified slightly to yield the discounted payback period. For this analysis, the annual energy savings were escalated on an annual basis using Equation 9.

$$\begin{aligned} &Escalated\ Energy\ Savings \\ &\quad = Annual\ Energy\ Savings \times (1 + Electricity\ Purchase\ Escalation\ Rate)^t \end{aligned}$$

Equation 9

In Equation 9, the Electricity Purchase Escalation Rate used came from the Federal Energy Management Program's Commercial Electricity Cost Escalation rates[25]. For the mid-Atlantic region, this escalation value was 0.59%. In Equation 9, *t* is the number of years after the installation of the project. Operations and maintenance costs were escalated using Equation 9 with an escalation rate of 2%.

Once the escalated energy cost savings and operation and maintenance costs were calculated, they were used in Equation 10 to determine the annual net savings for the renewable energy system.

$$\begin{aligned} &Annual\ Net\ Savings \\ &= \frac{Discounted\ Annual\ Savings + (Tax\ Rebate + Escalated\ Enegy\ Cost\ Savings - Escalated\ O\&M\ Costs)}{(1 + Discount\ Rate)^t} \end{aligned}$$

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[24] http://www.dsireusa.org/

[25] http://www.nrel.gov/analysis/lcoe/includes/pdfs/us_map_cost_escalations_title.pdf

Equation 10

In Equation 10, the discount rate used was 5%. The discounted payback period analysis was run for the lifetime of the renewable energy system. Payback on the system occurred in the year that the net savings value first turned positive.

Life Cycle Cost

The life cycle cost for each renewable energy system was calculated using Equation 11.

$$Life\ Cycle\ Cost = Discounted\ Net\ Savings\ at\ End\ of\ Usable\ Life \quad \text{Equation 11}$$

The usable life varied from system to system.

Greenhouse Gas Offset by Renewable Energy Systems

The first step in determining the amount of greenhouse gas emissions offset by each renewable energy system was to calculate annual electricity usage savings. This was done in Excel by finding the difference between the annual energy generated by the renewable energy system and the annual electricity consumption for Green Fence Farm.

Once the annual electricity savings were determined, Equation 12 was used to calculate the corresponding carbon dioxide offset.

$$Annual\ CO_2\ offset = Electricity\ Savings\ \times eGRID\ factor \quad \text{Equation 12}$$

In Equation 12, the eGRID factor for carbon dioxide for Virginia is 1,624 pounds of CO_2 per mega-watt hour[26].

Renewable Energy Option SVEC

The final option that was considered to lower carbon dioxide emissions on the farm was to switch to a new electricity tariff. Green Fence Farm is serviced by the Shenandoah Valley Electric Cooperative. This utility offers members the option to purchase 100% of their electricity from renewable energy sources. This option comes at a cost of an additional \$0.015 per kilowatt-hour[27]. The additional annual cost to Green Fence Farm was calculated using Equation 13.

$$Additonal\ Annual\ Cost = Annual\ Electric\ Bill + \left(Annual\ Electricity\ Usage \times 0.015\frac{\$}{kWh}\right)$$

Equation 13

The annual carbon dioxide offset from switching to the renewable energy option was calculated using Equation 12.

Increasing Sequestration Capabilities

When considering ways to increase the carbon sequestration capabilities of Green Fence Farm, three types of carbon sink were examined: crops, trees, and soil.

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[26] http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_GHG_Rates.pdf

[27] http://www.svec.coop/Our-Environment/Renewable-Energy-Option-Rider-R.aspx

Carbon Sequestration through Crops

Crops on site, much like the trees, can sequester carbon dioxide produce through farming activities. However, when analyzing the potential to increase carbon sequestration through crops, it was determined that they are already considered to be net zero because the crop residue is either used on site as animal feed or sent to the composting facility where Green Fence receives compost from each year. For this reason, crops were not considered as a way to increase carbon sequestration on site.

Carbon Sequestration through Trees

One option considered to boost carbon sequestration on Green Fence Farm was to plant more trees. However, this option was eliminated because the property is already 59% forested, and adding more trees would detract from the ability to farm effectively.

Carbon Sequestration through Soil

The final way to increase sequestration on site that was examined was by adding a soil amendment to the raised beds and grassland. Biochar was considered for this project. A report published by the Worchester Polytechnic Institute states that each ton added to soil can store 1.06 tons of carbon dioxide[28]. The report also recommends adding between 1 and 5 tons per acre to optimize the benefits of the soil amendment. These values were used in Equation 14 to estimate the potential increase in sequestration from a biochar soil amendment.

$$\begin{aligned} &\mathit{Increased\ Sequestration} \\ &\quad = \left(3\,\frac{\mathit{tons\ biochar}}{\mathit{acre}}\right) \times \left(1.06\,\frac{\mathit{tons\ CO_2\ sequestered}}{\mathit{ton\ of\ biochar}}\right) \\ &\quad \times (\mathit{acres\ biochar\ is\ applied\ to}) \end{aligned}$$

Equation 14

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[28] https://www.wpi.edu/Pubs/E-project/Available/E-project-031111-153641/unrestricted/BIOCHAR_CO2SEQ.pdf

Results and Analysis

Farm System Analysis

After collecting information regarding the inputs, processes, and outputs of Green Fence Farm, a comprehensive systems diagram was created. This diagram, shown in Image 8, served as a guide for the entirety of the project.

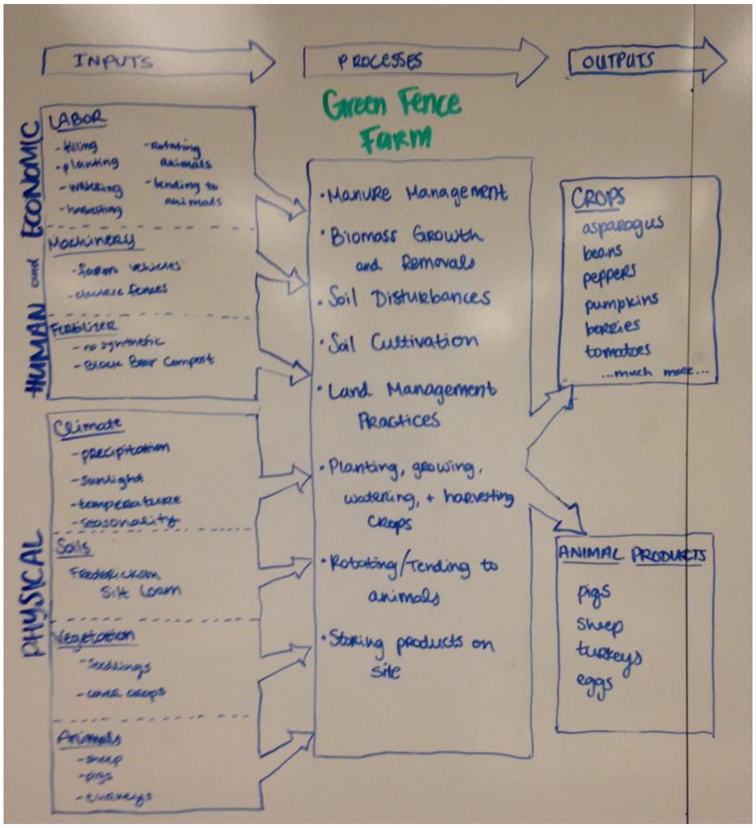


Image 8. Photograph of Systems Diagram of Green Fence Farm.

This systems diagram considered two types of inputs: human and economic inputs, such as labor and machinery, as well as physical inputs, such as soil, climate, vegetation, and animals. These inputs influence the on farm processes such as manure management, land management practices, and product storage. These farming processes turn the inputs into marketable goods in the form of produce and animal products.

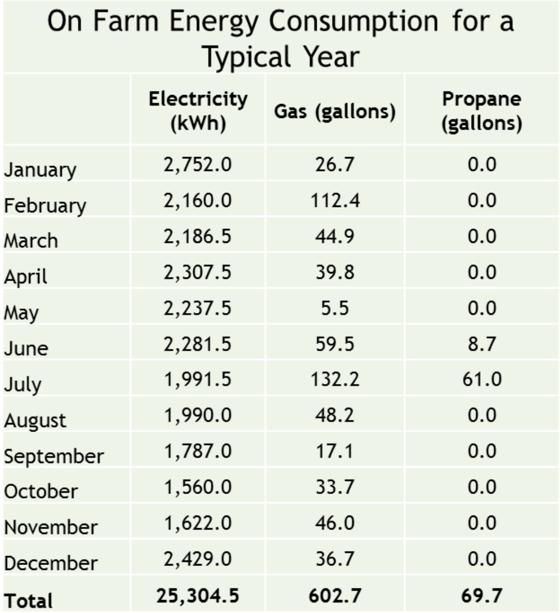
Current Greenhouse Gas Emissions

The current status of emissions on Green Fence Farm is a combination of on farm fuel usage and the results of the greenhouse gas inventory.

On Farm Fuel Usage

Table 3 shows the fuel usage for a representative year on Green Fence Farm.

Table 3. Representative Year of Fuel Consumption for Green Fence Farm.



On Farm Energy Consumption for a Typical Year

	Electricity (kWh)	Gas (gallons)	Propane (gallons)
January	2,752.0	26.7	0.0
February	2,160.0	112.4	0.0
March	2,186.5	44.9	0.0
April	2,307.5	39.8	0.0
May	2,237.5	5.5	0.0
June	2,281.5	59.5	8.7
July	1,991.5	132.2	61.0
August	1,990.0	48.2	0.0
September	1,787.0	17.1	0.0
October	1,560.0	33.7	0.0
November	1,622.0	46.0	0.0
December	2,429.0	36.7	0.0
Total	**25,304.5**	**602.7**	**69.7**

As Table 3 shows, most of the farm’s energy consumption is in the form of electricity, which powers essentials such as the electric fences and refrigerators. The next highest consumption is of gasoline, which is used to operate farm vehicles. The propane usage is the lowest because the generator is only used when the power goes out.

Figure 11 shows the annual fuel usage patterns on Green Fence Farm.

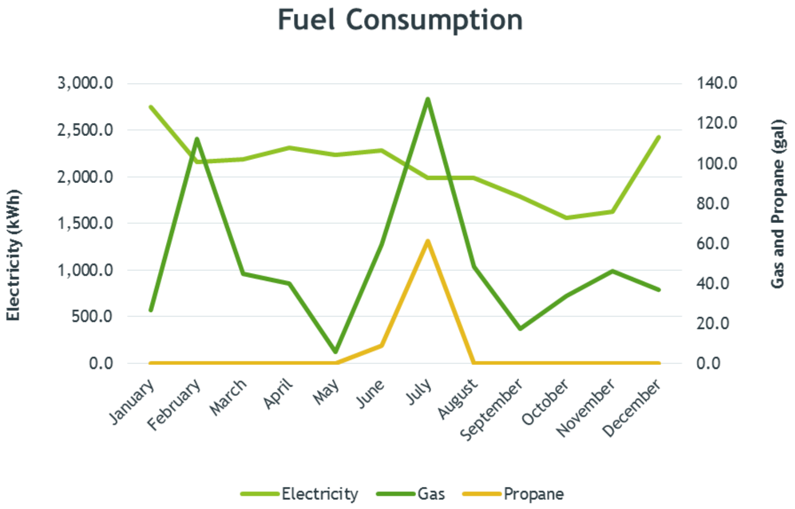
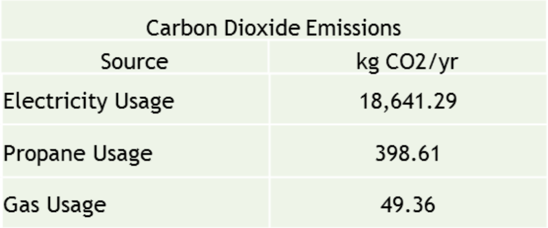


Figure 11. Annual Energy Consumption Patterns for Green Fence Farm.

Electricity consumption on the farm is the most consistent throughout the year, mainly because the load remains consistent. The gas and propane usage, though, both experience a dramatic spike from May until about August. Gas usage is highest then because farming operations are in full swing. Propane usage spikes during the summer because that is when thunderstorms are likely to knock the power out, in which case Sparks and Auclair use the backup generator.

Table 4 shows the carbon dioxide equivalents that come from electricity, gas, and propane usage on site.

Table 4. Carbon Dioxide Emissions from On Site Fuel Consumption.



Carbon Dioxide Emissions	
Source	kg CO2/yr
Electricity Usage	18,641.29
Propane Usage	398.61
Gas Usage	49.36

As expected, most of the emissions associated with on-site energy usage come from electricity. However, even though the farm uses less propane annually, it emits more carbon dioxide than the gas used on site. Despite this, it is not considered to be an energy saving opportunity because it is rarely used. The total carbon dioxide emissions from on-site fuel consumption is just over 19,000 kilograms per year.

Greenhouse Gas Inventory

The results of the greenhouse gas inventory are shown in Table 5.

Table 5. Greenhouse Gas Inventory Results.

Emission Source		Amount		CO2 Equivalents	
Manure	CH_4 emissions from Enteric Fermentation	87.50	(kg CH_4 yr^{-1})	501.09	kg CO2/yr
	Total nitrogen excretion for the MMS	3.09	(kg N yr^{-1})	260.97	kg CO2/yr
Forested Land	Annual increase in biomass carbon stocks due to biomass growth	22.82	(tonnes C yr^{-1})	75,784.68	kg CO2/yr
	Annual carbon loss due to biomass removals	53.06	(tonnes C yr^{-1})	176,192.05	kg CO2/yr
	Annual carbon loss from drained organic soils	5.50	(tonnes C yr^{-1})	18,274.32	kg CO2/yr
Crop Land	Annual increase in carbon stocks in mineral soils	0.78	(tonnes C yr^{-1})	2,593.43	kg CO2/yr
	Annual carbon loss from cultivated organic soils	8.09	(tonnes C yr^{-1})	26,874.00	kg CO2/yr

Emission Source		Amount		CO2 Equivalents	
Grassland	Annual increase in carbon stocks in mineral soils	7.27	(tonnes C yr^{-1})	24,126.13	kg CO2/yr
	Annual carbon loss from cultivated organic soils	12.14	(tonnes C yr^{-1})	40,311.00	kg CO2/yr
Annual direct N2O emissions	Annual direct N_2O emissions produced from managed soils	0.45	(kg N_2O yr^{-1})	38.04	kg CO2/yr
	Annual direct N_2O emissions from urine and dung inputs to grazed soils	40.77	(kg N_2O\ yr-1)	3,446.91	kg CO2/yr
Indirect N2O emissions	Annual amount of N_2O produced from atmospheric deposition of N volatilised from managed soils	0.20	(kg N_2O\ yr^{-1})	17.21	kg CO2/yr
	Annual amount of N_2O produced from managed soils in regions where leaching and runoff occurs	0.23	(kg N_2O yr^{-1})	19.36	kg CO2/yr

The greenhouse gas inventory considered both increases in carbon sinks, such as crop growth, and activities that release carbon, such as soil disturbances.

The manure management at Green Fence Farm releases a total of 761 kilograms of carbon dioxide equivalents per year. This is one of the highest emitters on the farm, mainly because they have so many animals on site. That being said, Sparks and Auclair already implement best management practices when it comes to dealing with the manure created on site. By rotating where their animals graze frequently, they allow the manure deposited in certain areas to release necessary nutrients back into the soil. This fertilizes the grazing area, allowing grass to grow back in a quick, healthy manner. Rotating the animals ensures that the amount of manure in an area does not exceed the amount the ground can handle, preventing issues like leaching. Therefore, manure management is not considered a greenhouse gas saving opportunity.

Each year, new growth in the forested land on site sequesters over 75,000 kilograms of carbon dioxide. However, Sparks and Auclair remove approximately 20 pine trees from their property each year, some of which is burned for fuel. These biomass removals result in the release of more than 176,000 kilograms of carbon dioxide per year. However, the removal of these trees is necessary. Trees being removed are either dead or dying, and therefore do not sequester all that much carbon anyways. Changing the forestry management practices of Green Fence Farm is not recommended.

The cropland on site, which consists of the raised beds used to grow crops, has very lower carbon storage and loss rates. This is in part due to the fact that cropland accounts for just 6% of the farm’s land usage. The emissions associated with cropland are negligible in comparisons to other aspects of the farm and are therefore not considered a greenhouse gas emissions saving opportunity. The same is true of the emissions from the grassland.

Green Fence Farm’s emission levels of nitrogen dioxide are also very low. They only use compost in their raised beds, which has a much lower nitrogen dioxide emission rate than synthetic fertilizers do. This is also why their indirect nitrogen dioxide emission rates are low; no synthetic fertilizers means there is a very small amount of nitrogen dioxide leached or volatilized from soils. The largest source of nitrogen dioxide emissions comes from manure being applied to the grassland, but, as stated earlier, the manure management at Green Fence Farm is done responsibly and is therefore not a chance to reduce greenhouse gas emissions.

At the end of the greenhouse gas inventory, the total annual emissions for farming activities in carbon dioxide equivalents was 163,430 kilograms. This, in combination with the emissions from on-site fuel consumption, brings the total annual emissions for Green Fence Farm to 182,519 kilograms of carbon dioxide.

Current Carbon Sequestration Capabilities

The carbon sinks on Green Fence Farm the soil and the trees.

Soil Sequestration

The carbon sequestration capabilities of the soil on site were calculated during the greenhouse gas inventory. The results for soil carbon sequestration and losses are presented in Table 5. Each year, the forested areas of Green Fence Farm lose 18,274 kilograms of carbon through drained organic soils. The cropland sequesters 2,593 kilograms of carbon in year in mineral soils, but loses 26,874 kilograms of carbon dioxide through soil cultivation. The mineral soils in the grassland of the farm sequester 24,126 kilograms of carbon dioxide annually, but grassland soil disturbances release 40,311 kilograms of carbon dioxide. Soil management practices result in both direct and indirect nitrogen dioxide emissions. These emissions total 55 kilograms of carbon dioxide equivalents each year.

As previously stated, the annual soil carbon sequestration and losses are part of the greenhouse gas inventory. Therefore, they have already been accounted for in the total annual emissions for Green Fence Farm.

Tree Sequestration

Table 6 provides a sample of the data collected during the tree sequestration analysis.

Table 6. Sample of Data for Carbon Dioxide Stored by Trees on Site.

Site Number	Type	Circumference (in)	Diameter (in)	Diameter (cm)	Stored Carbon (kg)	Stored Carbon Dioxide (kg)
Sample Site 1	Needleleaf	38	12.10	30.74	103.83	380.69
Sample Site 2	Needleleaf	51	16.24	41.25	222.34	815.16
Sample Site 3	Needleleaf	47	14.97	38.02	180.45	661.60
Sample Site 4	Needleleaf	36	11.46	29.12	90.07	330.22
Sample Site 5	Needleleaf	56	17.83	45.30	281.42	1031.76
Sample Site 6	Needleleaf	53.5	17.04	43.28	250.95	920.08
Sample Site 7	Broadleaf	23	7.32	18.61	37.57	137.75
Sample Site 8	Broadleaf	26	8.28	21.03	50.94	186.76
Sample Site 9	Broadleaf	10	3.18	8.09	4.71	17.26
Sample Site 10	Broadleaf	66	21.02	53.39	486.24	1782.71
Sample Site 11	Needleleaf	47	14.97	38.02	180.45	661.60
Sample Site 12	Needleleaf	14	4.46	11.32	7.19	26.37
Sample Site 13	Needleleaf	49	15.61	39.64	200.79	736.17
Sample Site 14	Needleleaf	52	16.56	42.06	233.56	856.31
Sample Site 15	Needleleaf	19	6.05	15.37	16.36	59.99

During the tree sampling, the circumferences of 73 needle leaf trees were recorded. The circumference measurements for seven broad leaf trees were also taken. The minimum diameter at breast height (DBH) for the trees sampled was 6.5 centimeters, while the maximum was 57.4 centimeters. The average DBH for all of the trees sampled was 32 centimeters.

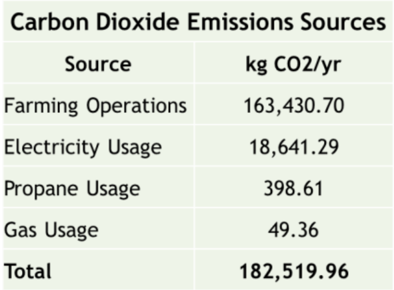
The minimum amount of carbon dioxide stored by one tree was 9.8 kilograms, while the maximum was 2,106 kilograms. The average carbon dioxide storage for the trees sampled was 542 kilograms. The trees sampled can store a total of 42,863 kilograms of carbon dioxide. This value was extrapolated out and it is estimated that the trees on the farm can store 128,589 kilograms of carbon dioxide.

The carbon sequestration capabilities of the small orchard site were also calculated. It is estimated that the orchard occupies 0.06 acres on the farm. According to a study published by the New York State Horticultural Society, an orchard can store 20 tons of carbon dioxide per acre. Therefore, the orchard at Green Fence Farm can sequester approximately 1,088 kilograms of carbon dioxide each year. This, when combined with the carbon dioxide sequestered by the other trees on site, results in an annual carbon dioxide sequestration of 129,678 kilograms.

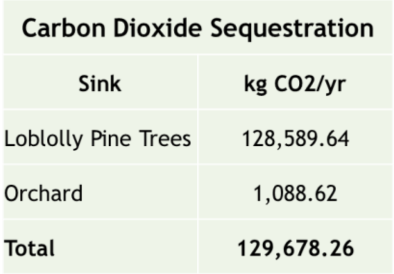
Ways to Reach Net Zero Greenhouse Gas Emissions

Table 7 describes the current state of emissions and sequestration on Green Fence Farm.

Table 7. Current State of Greenhouse Gas Emissions and Sequestration for Green Fence Farm.



Carbon Dioxide Emissions Sources	
Source	**kg CO2/yr**
Farming Operations	163,430.70
Electricity Usage	18,641.29
Propane Usage	398.61
Gas Usage	49.36
Total	**182,519.96**



Carbon Dioxide Sequestration	
Sink	**kg CO2/yr**
Loblolly Pine Trees	128,589.64
Orchard	1,088.62
Total	**129,678.26**

Green Fence Farm currently emits 182,519 kilograms of carbon dioxide annually. However, they store only 129,678 kilograms of carbon dioxide on site each year. Therefore, Green Fence Farms currently emits 52,841 more kilograms of carbon dioxide each year than it stores. To get the farm to net zero, emissions need to be lowered and sequestration capabilities need to be increased.

Lowering Carbon Dioxide Emissions

The first step in reaching net zero greenhouse gas emissions is to reduce the amount of carbon dioxide being emitted on site. This can be done through conservation, energy efficiency improvements, and fuel switching, as shown in the Energy Management Pyramid in Figure 8.

Conservation Results

The first consideration when trying to improve the energy usage on a farm is to implement conservation methods. Reducing the amount of energy used is a cost effective way to save money on annual energy costs, as well as lower emissions. Additionally, it is a crucial step for sizing renewable energy systems, which will discussed later in this section.

When considering ways for Green Fence Farm to conserve energy, the following list of recommendations was compiled:

- Do not condition spaces when they are not being used.
- Turn off appliances when they are not being used.
- When possible, perform farming activities such as planting, watering, weeding, and harvesting by hand.
- Switch to a low or no till land management strategy, which helps reduce energy usage and losses from soil disturbances.

However, all of these recommendations are already being implemented on Green Fence Farm. The only conditioned workspace is the workhouse, and when it is not in use, it is not being conditioned. Appliances are unplugged when they are not in use. Almost all farming activities are already performed by hand and they implement a low-till management strategy. Therefore, Green Fence Farm is already performing well in the area of energy conservation and there are no recommendations to be made for improvement.

Energy Efficiency Results

The next consideration when attempting to improve energy usage is to make energy efficiency improvements. When considering ways for farms to improve energy efficiency, energy consumption in the following areas are examined:

- Irrigation
- Fertilizer Usage
- Greenhouse Operations
- Farm Vehicles
- Appliances
- Lighting

Green Fence Farm does not have an irrigation system, does not use fertilizer, and does not have a greenhouse. Therefore, there are no energy efficiency improvements to be made in those categories.

As for farm vehicles, Green Fence Farm could switch to more fuel efficient vehicles than the ones currently used. However, farm vehicles are used so sparingly on site that any emissions and energy cost savings from purchasing a new vehicle would not be financially justified.

When it comes to appliances, the best way to increase energy efficiency is to switch to Energy Star products. All of the freezers and refrigerators on site, though, are already Energy Star. Therefore, there are not any energy efficiency recommendations for the appliances category.

The majority of the workspaces on Green Fence Farm are open sheds which are lit via sunlight. The workhouse, which is used to start seedlings, however, does currently use fluorescent lighting. Switching these bulbs to LEDs would help reduce electricity usage and consequently greenhouse gas emissions. This reduction, however, would be almost insignificant when compared the emissions from the rest of the farming activities.

Once conservation and energy efficiency measures were considered, renewable energy options for the site were evaluated as potential ways to offset the rest of the carbon dioxide emissions.

Roof Mount Solar PV System

Figure 12 shows the roof mount solar PV system modelled in Google SketchUp using Skelion.

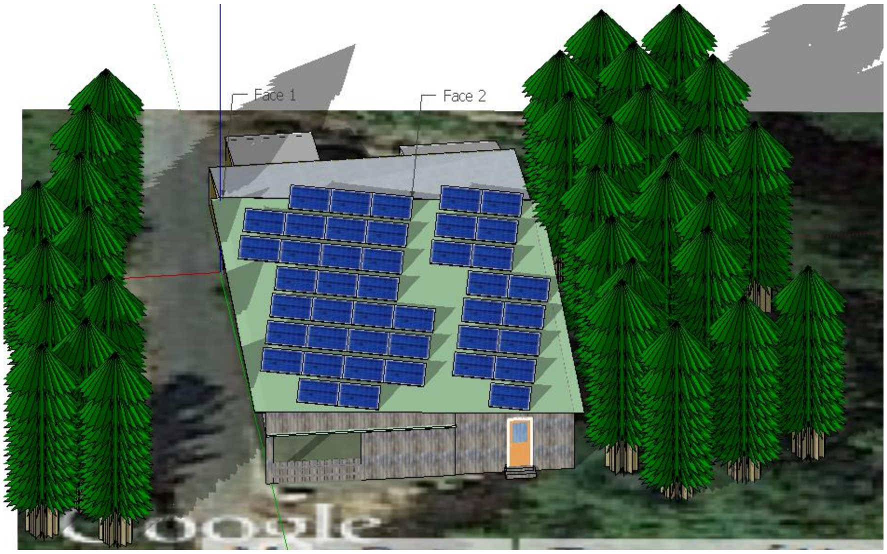


Figure 12. Roof Mount Solar PV System Rendering.

This is a 9kW roof mount system. The shading profile determine using the Solar Pathfinder is show in Image 9.

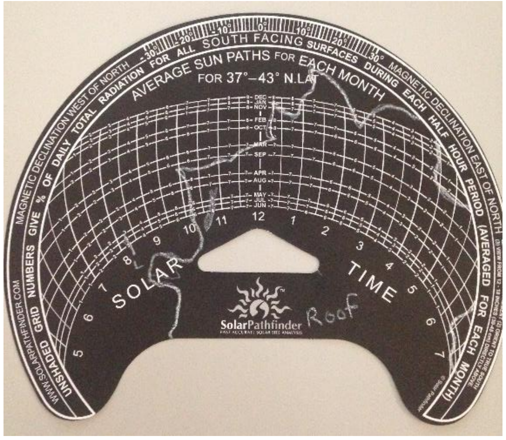


Image 9. Solar Pathfinder Shading Profile for Workhouse Roof.

The data from the Solar Pathfinder shading analysis was logged in Excel and used to estimate the shading de-rate factor for the roof. The estimated shading de-rate factor for the workhouse roof was 35%.

Skelion used this shading de-rate factor and estimated the annual generation for the roof mount solar PV system. Monthly generation estimates are presented in Table 8.

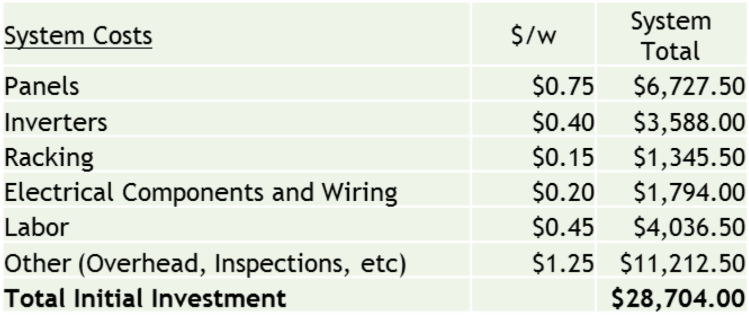
Table 8. Estimated Electricity Generation for a Roof Mount Solar PV System.

Month	Solar Generation (kWh)
January	679.16
February	552.99
March	621.5
April	941
May	950.84
June	848.41
July	790.21
August	811.35
September	664.48
October	858.38
November	610.04
December	519.46
Annual	**8,848**

According to the PVwatts report, this solar PV system would generate 8,848 kWh of electricity each year. This would result in a carbon dioxide offset of 6,518 kilograms each year and annual energy savings of just over $1,113.

Table 9 shows the anticipated system purchase and installation costs.

Table 9. Roof Mount Solar PV System Purchase and Installation Costs.



System Costs	$/w	System Total
Panels	$0.75	$6,727.50
Inverters	$0.40	$3,588.00
Racking	$0.15	$1,345.50
Electrical Components and Wiring	$0.20	$1,794.00
Labor	$0.45	$4,036.50
Other (Overhead, Inspections, etc)	$1.25	$11,212.50
Total Initial Investment		**$28,704.00**

The system purchase and installation costs would be offset slightly by the Residential Renewable Energy Tax Credit, which covers up to 30% of purchase and installation costs, resulting in a tax return of $8,611[29]. Green Fence Farm is also eligible for a grant from the Rural Energy for America Program, which funds renewable energy and energy efficiency projects on agricultural lands[30]. The amount of money available varies, so the lowest grant amount of $2,500 was used in this economic analysis in an effort to keep estimates conservative. This brought the total estimated financial assistance to $11,111.

Upon performing the simple and discounted payback period analysis, it was determined that the system does not pay itself off in either situation. The system has a life cycle cost of $8,678.

Ground Mount Solar PV System

Figure 13 shows the ground mount solar PV system modelled in Google SketchUp using Skelion.

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[29] http://programs.dsireusa.org/system/program/detail/1235

[30] http://programs.dsireusa.org/system/program/detail/917

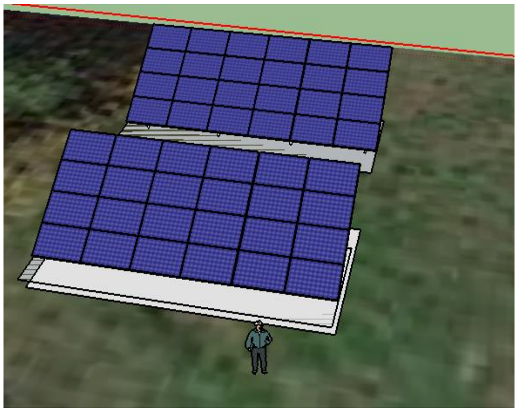

Figure 13. Ground Mount Solar PV System Rendering.

This is a 12kW ground mount system. The shading profile determine using the Solar Pathfinder is show in Image 10.

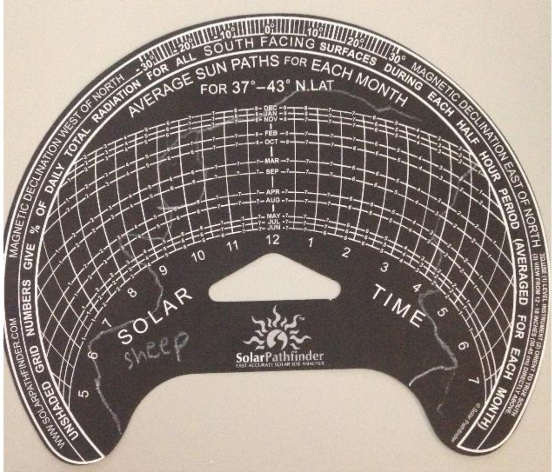

Image 10. Solar Pathfinder Shading Profile for Ground Mount System Location.

The data from the Solar Pathfinder shading analysis was logged in Excel and used to estimate the shading de-rate factor for the ground mount system. The estimated shading de-rate factor was 32%.

Skelion used this shading de-rate factor and estimated the annual generation for the ground mount solar PV system. Monthly generation estimates are presented in Table 10.

Table 10. Estimated Electricity Generation for a Ground Mount Solar PV System.

Month	Solar Generation (kWh)
January	491.69
February	493.29
March	677.38
April	1148.24
May	1315.29
June	1213.34
July	1113.61
August	1046.12
September	757.6
October	789.07
November	467.33
December	379.66
Annual	**9,893**

According to the PVwatts report, this solar PV system would generate 9,893 kWh of electricity each year. This would result in a carbon dioxide offset of 7,287 kilograms each year and annual energy savings of just over $1,217.

Table 11 shows the anticipated system purchase and installation costs.

Table 11. Ground Mount Solar PV System Purchase and Installation Costs.

System Costs	$/w	System Total
Panels	$0.75	$9,000.00
Inverters	$0.40	$4,800.00
Racking	$0.55	$6,600.00
Electrical Components and Wiring	$0.20	$2,400.00
Labor	$0.45	$5,400.00
Other (Overhead, Inspections, Trenching etc)	$1.65	$19,800.00
Total Initial Investment		**$48,000.00**

The purchase and installation costs for the ground mount system are inherently higher than the roof mount system because installing a ground mount system requires additional labor for trenching and wiring. In this case, the Residential Renewable Energy Tax Credit would result in a return of $14,400[31]. REAP funding could also be used for the ground mount system and the lowest award of $2,500 was used in this economic analysis to keep estimates conservative. This brought the total estimated financial assistance to $16,900.

Upon performing the simple and discounted payback period analysis, it was determined that the system does not pay itself off in either situation. The system has a life cycle cost of $25,168.

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[31] http://programs.dsireusa.org/system/program/detail/1235

Residential Scale Wind Turbine

Table 12 provides the raw data for average wind speed, Weibull c, and Weibull k constants that was generated in ArcMap.

Table 12. Average Wind Speeds and Weibull Constants from ArcMap.

Average Wind Speed (m/s)	
Speed 80m	4.95
Speed 50m	4.58
Speed 34m	4.30
Speed 20m	3.94
Weibull Constants	
Weibull C	5.6
Weibull K	2.2

AcrMap also generated a Weibull distribution at an 80m hub height, which is shown in Table 13.

Table 13. Weibull Distribution for an 80m Hub Height.

	Weibull at 80m	
Bin	**Speed (m/s)**	**Frequency (%)**
FREQ00T01	1	0.035
FREQ01T02	2	0.087
FREQ02T03	3	0.115
FREQ03T04	4	0.139
FREQ04T05	5	0.156
FREQ05T06	6	0.151
FREQ06T07	7	0.118
FREQ07T08	8	0.084
FREQ08T09	9	0.057
FREQ09T10	10	0.033
FREQ10T11	11	0.017
FREQ11T12	12	0.005
FREQ12T13	13	0.002
FREQ13T14	14	0.001
FREQ14T15	15	0
FREQ15T16	16	0
FREQ16T17	17	0
FREQ17T18	18	0
FREQ18T19	19	0
FREQ19T20	20	0
FREQGT20	21	0

The 80m hub height data was scaled down to 20m using the Weibull constants from Table 12 and Equation 5. The scaled data is presented in Table 14.

Table 14. Estimated Weibull Distribution for a 20m Hub Height.

Weibull at 20m	
Speed (m/s)	**Frequency (%)**
1	0.0509
2	0.1054
3	0.1455
4	0.1625
5	0.1557
6	0.1313
7	0.0986
8	0.0663
9	0.0402
10	0.0219
11	0.0108
12	0.0048
13	0.0019
14	0.0007
15	0.0002
16	0.0001
17	0.0000
18	0.0000
19	0.0000
20	0.0000
21	0.0000

The data from Tables 13 and 14 were graphed. This was to verify that the Weibull distribution for a 20m hub height had the same shape as the Weibull distribution for the 80m hub height, but with a different mean. This graph, shown in Figure 14, verified that the scaled down Weibull distribution was reasonable.

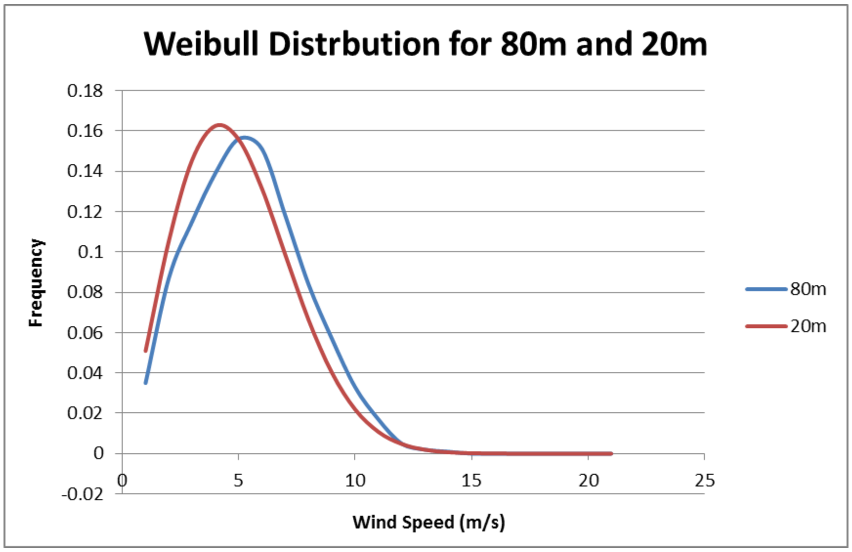


Figure 14. Graph of the Weibull Distribution for an 80m and a 20m Hub Height.

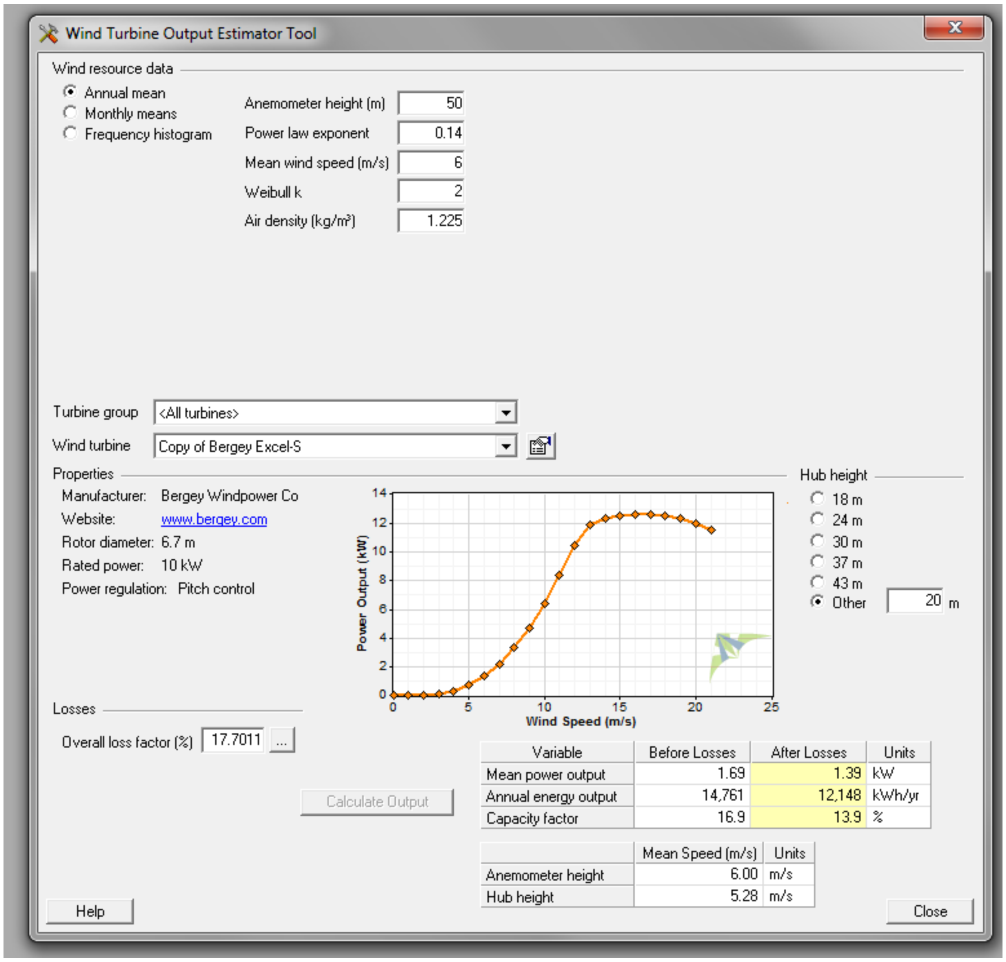
The distribution for a 20m hub height was then used to estimate the annual energy output for a Bergey Excel 10k turbine on Green Fence Farm. The estimated power output is shown in Table 15.

Table 15. Annual Energy Output Estimates for a Bergey Excel 10k on Green Fence Farm.

Speed (m/s)	Frequency (%)	Hours per year	Bergey Excel 10 Power (W)	Annual Energy (kWh)
1.00	0.05	446.45	-12.00	-5.36
2.00	0.11	924.10	-5.50	-5.08
3.00	0.15	1,275.22	70.50	89.90
4.00	0.16	1,424.22	314.00	447.21
5.00	0.16	1,365.05	722.00	985.57
6.00	0.13	1,150.90	1,330.50	1,531.28
7.00	0.10	864.11	2,170.50	1,875.56
8.00	0.07	581.60	3,275.50	1,905.02
9.00	0.04	352.22	4,688.50	1,651.37
10.00	0.02	192.34	6,408.00	1,232.48
11.00	0.01	94.81	8,356.00	792.26
12.00	0.00	42.22	10,406.50	439.32
13.00	0.00	16.98	11,819.00	200.70
14.00	0.00	6.17	12,335.50	76.12
15.00	0.00	2.02	12,472.00	25.25
16.00	0.00	0.60	12,527.00	7.51
17.00	0.00	0.16	12,529.00	2.01
18.00	0.00	0.04	12,485.00	0.48
19.00	0.00	0.01	12,302.00	0.10
20.00	0.00	0.00	11,933.50	0.02
21.00	0.00	0.00	11,495.00	0.00
Total Annual Energy Output				11,251.74

According to this estimation, Green Fence Farm experiences wind speeds between 3 and 7 m/s nearly 70% of the year. Based on the frequency distribution of wind speeds and the expected output for a Bergey

Excel 10k, the annual generation for a turbine at Green Fence Farm is 11,251 kilowatt-hours. This manual estimation was verified using Windographer. The Windographer predictions for a Bergey Excel 10k operating at the Weibull distribution frequency data from Table 14 are shown in Image 11.



● Annual mean
○ Monthly means
○ Frequency histogram

Anemometer height (m): 50
Power law exponent: 0.14
Mean wind speed (m/s): 6
Weibull k: 2
Air density (kg/m³): 1.225

Turbine group: <All turbines>
Wind turbine: Copy of Bergey Excel-S

Manufacturer: Bergey Windpower Co
Website: www.bergey.com
Rotor diameter: 6.7 m
Rated power: 10 kW
Power regulation: Pitch control

Hub height: ● Other 20 m

Overall loss factor (%): 17.7011

Variable	Before Losses	After Losses	Units
Mean power output	1.69	1.39	kW
Annual energy output	14,761	12,148	kWh/yr
Capacity factor	16.9	13.9	%

	Mean Speed (m/s)	Units
Anemometer height	6.00	m/s
Hub height	5.28	m/s

Image 11. Screen Capture of Windographer Estimates for Bergey Excel 10k Turbine on Green Fence Farm.

According to the report generated by Windographer, a Bergey Excel 10k placed on Green Fence Farm at a hub height of 20m would generate 12,148 kilowatt-hours each year. This value was within a 10% difference of the manual estimation, verifying the manual estimate. For the rest of the analysis, the manual estimate for power generation was used.

The manual estimate predicted an annual electricity generation of 11,252 kilowatt-hours. This would results in an annual energy cost savings of $1,502 and an annual carbon dioxide emissions offset of 18,274 kilograms.

The cost to purchase and install a Bergey Excel 10k turbine is estimated at $50,000[32]. The Residential Renewable Energy Tax Credit would offset 30% of this cost, resulting in a tax return of $15,000. This, in

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[32] http://www.nwwindandsolar.com/wind-power-in-seattle-and-the-northwest/residential-small-wind-systems/

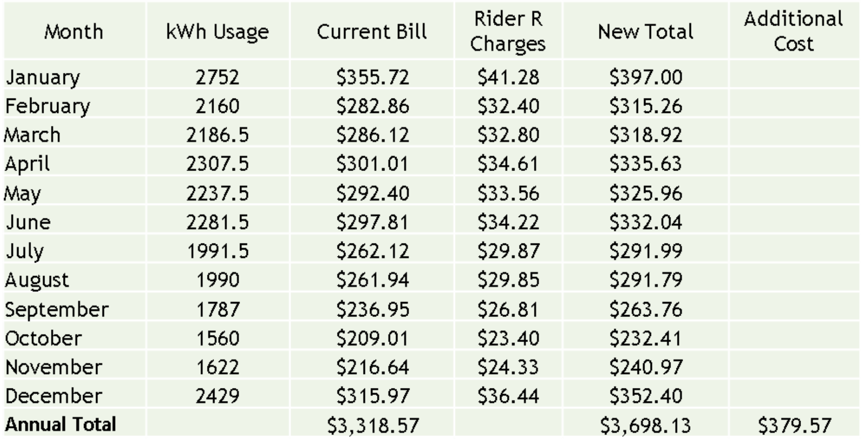
combination with the lowest grant amount provided by REAP, would result in a total financial assistance of $17,500.

Upon performing the simple and discounted payback period analysis, it was determined that the system does not pay itself off in either situation. The system has a life cycle cost of $21,749.

Renewable Energy Option from SVEC

It would be possible for Green Fence Farm to offset all electricity used on site by switching to the renewable energy option provided by SVEC. During the on-site fuel usage evaluation, it was determined that in a typical year, Green Fence Farm uses 25,304 kilowatt-hours. Purchasing all of this energy from renewable energy sources would offset 18,641 kilograms of carbon dioxide each year. The additional cost for this electricity tariff would be just below $380 each year, as shown in Table 26.

Table 16. Additional Cost to Purchase Electricity from Renewable Energy Projects.



Month	kWh Usage	Current Bill	Rider R Charges	New Total	Additional Cost
January	2752	$355.72	$41.28	$397.00	
February	2160	$282.86	$32.40	$315.26	
March	2186.5	$286.12	$32.80	$318.92	
April	2307.5	$301.01	$34.61	$335.63	
May	2237.5	$292.40	$33.56	$325.96	
June	2281.5	$297.81	$34.22	$332.04	
July	1991.5	$262.12	$29.87	$291.99	
August	1990	$261.94	$29.85	$291.79	
September	1787	$236.95	$26.81	$263.76	
October	1560	$209.01	$23.40	$232.41	
November	1622	$216.64	$24.33	$240.97	
December	2429	$315.97	$36.44	$352.40	
Annual Total		$3,318.57		$3,698.13	$379.57

Increasing Sequestration Capabilities

The other step that can be taken to help Green Fence Farm reach net zero greenhouse gas emissions is to increase sequestration capabilities on site.

Sequestration in Soil

The carbon sequestration capabilities of a biochar soil amendment were examined as a way to increase the amount of carbon dioxide stored on site. To optimize the benefits provided by biochar, three tons should be applied per acre of crop and grassland. This would result in a total of 20.9 tons of biochar being added to the soil. One ton of biochar can sequester 1.06 tons of carbon dioxide, so this soil amendment would increase the amount of carbon dioxide stored in the soil by 20,286 kilograms. Biochar can be purchased at a price of $40 per ton, so the total cost for this carbon sequestration increase would be just below $840.

Sequestration in Biomass

As previously stated, the crops on site are already considered to have net zero greenhouse gas emissions and therefor are not an opportunity to increase sequestration. Planting more trees to increase sequestration was also not considered because doing so would detract from the ability to farm the land.

Purchasing Carbon Offsets

The final strategy examined to reach net zero greenhouse gas operations was the purchase of carbon offsets. Essentially, by purchasing carbon offsets, Green Fence Farm can offset the rest any remaining emissions by investing in renewable energy projects elsewhere. Carbon offsets can be purchased for an average of $5.95 per 1000 pounds of carbon dioxide. Any excess emissions that need to be offset after the Green Fence Farm implements the recommendations from this project will be addressed through the purchasing of carbon offsets.

Recommendations

A list of recommendations for Green Fence Farm to reach net zero greenhouse gas emissions was compiled based on the results of this study. These recommendations were selected because they are the most cost effective options of the ones examine. These recommendations are summarized in Table 17.

Table 17. Recommended Steps for Green Fence Farm to Reach Net Zero Greenhouse Gas Emissions.

Current Difference	52,841.70	kg CO2/yr	Cost
Roof Mount Solar	(6,518.00)	kg CO2/yr	$28,704.00
Rider R	(12,123.29)	kg CO2/yr	$379.00
Biochar Amendment	20,286.91	kg CO2/yr	$839.00
Offsets	13,913.50	kg CO2/yr	$184.00

Currently, the farm emits 52,841 more kilograms of carbon dioxide than it sequesters each year. The roof mount solar PV system was the most financially attractive renewable energy option examined. By installing the roof mount solar PV system on the roof of the workhouse, 6,518 kilograms of carbon dioxide can be offset. It is recommended that Green Fence Farm also switch to the Renewable Energy Option (Rider R) to offset the rest of the emissions from on-site electricity usage. This will further reduce carbon dioxide emissions by 12,123 kilograms each year.

Applying a biochar soil amendment to the crop and grassland will increase on site sequestration capabilities by 20,286 kilograms. Even after taking these steps, Green Fence Farm will still be emitting 13,913 more kilograms of carbon dioxide than it sequesters each year. It is recommended that Sparks and Auclair purchase carbon offsets for an annual cost of $184 to reach net zero greenhouse gas emissions. Based on these recommendations, the total cost for Green Fence Farm to become a net zero farming operation will be $30,106.

Conclusions

In conclusion, reaching net zero greenhouse gas emissions is a challenging and potentially costly goal. However, it is a process that is going to become increasingly necessary in the future. The world's population is projected to surpass 9 billion people by 2050[33]. This means that there will be 2 billion more mouths to feed and a continually diminishing amount of resources to use. If the greenhouse gas emissions associated with the agricultural sector are not reduced, then the effects of global warming will continue to worsen, severely impacting the world's food supply chain. If, however, less greenhouse gas intensive farming practices are adopted worldwide, then perhaps the world's population can be fed without destroying the resources required for food production. Agricultural operations like Green Fence Farm represent an opportunity to develop a model for sustainable, environmentally friendly food production that could one day feed the planet.

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[33] http://news.nationalgeographic.com/news/2013/13/1307011-population-census-united-nations-un-demographics-world-population-day-birthrate/

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