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| University of Illinois-Champaign Urbana  SSF Electric Vehicles and Solar Panels Analysis |
| NRES 285: Sustainability Metrics Analysis  Haley Smetana  May 2nd, 2014 |

# About NRES 285

Sustainability Metrics Analysis is a course within the Natural Resources and Environmental Science Department that gets students in the field working on projects similar to those they will be doing in their careers. The Professors, Jody Endres and Warren Lavey are both expert lawyers that understand the importance of analysis and data gathering to produce truly sustainable projects and an efficient use of resources. By encouraging our class to think beyond the obvious and analyze our projects using a systems approach, we were able to develop the savings and effect of many completed sustainable projects the University of Illinois has proudly funded.

Summary

The goal of this project was to assess the success of the electric vehicles and solar panels on the Student Sustainable Farm (SSF). In 2010, through Engineering 298, the farm received a 1960 Allis-Challmers G Cultivating tractor that has been retrofitted to contain an electric powered motor. The following year, the same course began a new project to install 8 PV cell solar panels and charging station to service the SSF’s tractor. In 2012, a new course, Engineering 315, proposed and developed a project that would give the farm a delivery truck powered by an electric motor and a set of 24 PV solar panels and charging station to supply enough electricity for the truck’s daily use. As of now, all projects have been installed and are currently being used on the SSF except for the delivery truck, which has taken longer to construct than previously thought. The goal for all three projects is to offset the farm’s fuel costs and reduce greenhouse gas emissions. While these projects have been funded and constructed with the intent they will make significant reductions to the farms energy cost and reduce emissions, they have not been appropriately assessed after implementation to measure if these goals have truly been achieved. With the help of Zack Grant, the SSF manager, the expertise of my professors, and extensive research, I have developed measures reflecting the performance of these projects and the impact they’ve had. I’ve measured water savings, carbon savings, and cost savings in order to express how the Student Sustainability Committee’s (SSC) money has been spent. With this information, I hope to provide honest feedback to the SSC so they can maximize their investments and provide our campus with projects producing the greatest energy savings for the cost. My intent for this paper is to teach people what sustainable really is, not to suggest that this or any other SSC funded projects are bad. I truly believe the work of the SSC is essential to our campus for guiding our students to become stewards of sustainability.

Projects

All projects I am analyzing have been installed to reduce the amount of energy consumed by the SSF. Engineering Course 298 proposed the first project in 2010, which was to supply the farm with an electric tractor. The course comprised four students who were responsible for designing the project, obtaining the materials, and rebuilding the tractor.[[1]](#footnote-1) The project was completed in 2011 and has been used for one growing season since then. Some specific tasks the tractor preforms include making raised beds, cultivating the soil, and hauling. The tractor has been especially useful for forming raised beds by reducing the amount of time it takes to build one by 83%. Overall, the tractor is only used about 40 hours each season.[[2]](#footnote-2) Despite this low use, the tractor has the potential to be used to plow and plant seedlings but would require additional attachments.[[3]](#footnote-3) Additionally, the tractor is expected to last indefinitely2 but for the purpose of analysis, I chose to set its expected lifespan at 30 years.

The second project is a set of 8 PV solar panels, which were installed to charge the electric tractor. This was completed by ENG 315 in 2011 and is mounted on the roof of the tractor’s shed. A charging station to connect the tractor to the panels was also installed during this project. These solar panels are expected to last for 30 or more years. They’re under warranty for the first 25 years and shouldn’t require additional maintenance apart from routine cleaning to maximizes sunlight absorbance.

The third project is still not completed, despite being proposed in 2012. It consists of two separate projects overseen by ENG 315. The first is an electric delivery truck that was constructed out of a 2003 Ford 250[[4]](#footnote-4); this project has supplied the course with many challenges and is still not ready for use. They are hoping to have the truck done by the end of the 2014 summer but no guarantees can be made.2 The truck will be used to deliver produce from the farm to both the dining hall and student farmers market and is expected to last for 10 years.[[5]](#footnote-5) The farm is currently using a 1993 truck that gets 5mpg and is looking forward to the new electric one.2 The truck is expected to travel around 3,360 miles a year.5

The fourth project is a set of 24 PV solar panels that will supply the delivery truck with enough energy to travel 40 miles round trip. These were proposed at the same time as the delivery truck and were also constructed by ENG 315. The panels were installed alongside the original set of 8 and will also require a charging station in order to feed energy to the delivery truck. These, like the original set of 8 panels, are expected to last 30 years but have the potential to last much longer. In addition to supplying energy to the electric delivery truck, the solar panels can be used to charge electric tools used around the farm.

Analysis Method

In order to analyze these four projects I needed to have several pieces of data that could accurately reflect the total energy use/savings of the project and the overall cost expenditure and savings of the project. For the tractor and truck, this included the expected lifespan, maintenance cost, embodied energy, days per year used, daily energy use (kWh/day), cost of electricity ($/kWh), and energy input (CO2 & water) for electricity ((lb CO2/kWh), and (gal water/kWh)). For the solar panels this included the expected lifespan, maintenance cost, average daily energy generation, cost of electricity ($/kWh), and embodied energy of solar panels. In addition to this data, I relied on the Internet to find other necessary pieces of information.

Energy Analysis

My energy analysis began by calculating overall water use by comparing total water savings against total water consumption. I looked at this data for each project and found totals for annual savings as well as lifetime savings. I also analyzed total carbon expenditure and savings to calculate yearly CO2 savings and lifetime CO2 savings. The results are as followed:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | Water/yr | Water/lifetime | CO2/yr | CO2/lifetime |
| Tractor | 10.5 gal | 315 gal | 75.6 lb | 2,268 lb |
| Solar Panel Set 1 | 15,085 gal | 452,535 gal | 1,639 lb | 48, 867 lb |
| Delivery Truck | 517 gal | 5,169 gal | 9,586.5 lb | 95, 864 lb |
| Solar Panel Set 2 | 19,055 gal | 571,649 gal | 2,551 lb | 76,530 lb |
| Total | 34,666gal | 1,029,825gal | 13,852 lb | 223,529 lb |

As you can see, these projects successfully reduced the farms total water use and carbon dioxide consumption by 1,209,825 gallons and 223,529 lb throughout the expected lifetime of the project. The lifetime length I used to calculate these numbers is 30 given this is equal to the expected lifetime for the solar panels and tractor. The delivery truck is only expected to last 10 years so it only contributed 10 years worth of savings to the total.

The water savings for the truck and tractor come from the discontinued use of diesel and gasoline. The tractor and truck uses gasoline/diesel, which consumes 2 gallons of water for every gallon of gasoline produced.[[6]](#footnote-6) However, I did add water consumption per kWh electricity generated by our campus grid. Additionally, the four tires used for the electric tractor consumed a combined 634 galH2O/lifetime[[7]](#footnote-7), which must be accounted for in our analysis. This would reduce total water savings form 315gal to -319gal, meaning this project consumed more water than it saves in a lifetime.

The solar panels saved water by not using electricity, which consumes 25 gallons of water per kWh generated.[[8]](#footnote-8)

The carbon savings for the truck and tractor also come from the discontinued use of diesel/gasoline. For 1 gallon of diesel, 22.2 pounds of CO2 are emitted; for 1 gallon of gasoline, 19.4 pounds of CO2 are emitted.9 The embodied energy consumed from the production of tractor tires equal to 1,378lbCO2 for the lifetime of each tire so the combined consumption of CO2 is 5,512lb7. This brings down net savings of CO2 to -3,244lb meaning this project consumed more carbon than it saved in a lifetime.

The carbon savings for the solar panels comes from the discontinued use of coal-powered electricity, which is roughly 1.67CO2lb/kWh[[9]](#footnote-9). Unfortunately, each panel does consume as much CO2 in the manufacturing process as is created in 7 years.[[10]](#footnote-10) Each year the panels save 205lbCO2 so in seven, they must produce 1,434lbCO2 during the manufacture process. There are 8 panels in the first set, so total CO2 savings is reduced to 37,395 lbCO2/lifetime. The second set of 24 now only saves 42,114lbCO2 during their lifetime.

While this is important information when planning for future projects, it is more important to question if these results show that we’ve completed the goals of the projects set forth by the SSC. The goal is, “to reduce greenhouse gas emissions from fuel consumption[[11]](#footnote-11).” In general, these projects successfully fulfilled this goal; however, the tractor did not meet the goal and consumed more CO2 and water than was saved. Overall, the projects saved 1,029,506 gallons of water and 189,113 lbCO2.

Cost Analysis

My cost analysis began by comparing overall project expense with overall project savings. I gathered the total cost of the projects as well as lifetime maintenance cost and compared it to fuel cost savings. The results are as follows:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria | savings/yr | savings/lifetime | Total cost | Payback period | ROI | Lifetime Cost |  |  |
| Tractor | $32.2 | $1,036.84 | $5,251 | 163 yrs | $-4,285 | $1,700 |  |  |
| Solar Panel Set 1 | $322 | $9,660 | $4,574[[12]](#footnote-12) | 14.2 yrs | $5,086 | $0 |  |  |
| Delivery Truck | $2,283 | $22,830 | $47,250 | 20.8 yrs | $-24,420 | $200 |  |  |
| Solar Panel Set 2 | $429.3 | $12,879 | $18,720 | 43.6 years | $-5,841 | $0 |  |  |
| Total | $3,066 | $46,335 | $75,115 | 60.4 yrs | -29,460 | $2,580 |  |  |

As you can see, these projects have clear cost savings over their lifetime but unfortunately these savings do not exceed the upfront cost of the projects. While a positive return on investment (ROI) is ideal of any project, it was not a goal of the SSC. The SSC was concerned with saving fuel costs, which it succeeded in doing. Therefore, based on the criteria set for by the SSC goals, we can call this project a success both in fuel cost and energy savings.

The cost savings incurred from the tractor comes from the cost of diesel fuel, which averages at $3.80/gal for Champaign Co.9 The tractor only would have needed 1 tank of gasoline (around 7 gallons)3 per year to operate. The total cost of the tractor comes from the estimated total price of conversion, $3,551 in additional to lifetime and electricity costs1. I subtracted the cost of electricity ($.0746/kWh)[[13]](#footnote-13). Finally, I subtracted the maintenance cost for the batteries, which is estimated at $340 every 4-6 years.1

The cost savings incurred from the delivery truck come from the cost of fuel and the cost of electricity. It is expected that the truck was spending $2,533 a year on gasoline and would now only need to pay $250 for electricity9.

The cost savings incurred from both sets of solar panels comes from the savings generated by electricity costs minus the cost of purchase and installation of solar panels. The savings depend on total amount of kWh produced each year by the solar panels. This data was gathered by a 3kW solar system in Sydney Australia.[[14]](#footnote-14) Many adjustments had to be made including number of solar panels, amount of sunlight exposure annually[[15]](#footnote-15), unit conversion to kWh, and length of analysis. Due to the fact that on average Sydney experiences more sunny/partly-sunny and fewer cloudy days than Champaign, I needed to account for this difference by calculating the variation between amounts of sun. For Sydney, there is an average of 107 sunny days, 129 partly cloudy days, and 129 cloudy days.15 For Champaign, there are on average 104 sunny days, 94 partly sunny days, and 167 cloudy days.[[16]](#footnote-16) In order to adjust the data, I calculate the reduction of sunlight exposure in a percentage and averaged the percentage of the three (.787%). I then multiplied yearly kWh production for Sydney by this percentage. I then multiplied the new total by .75 to account for the fact that the data provided is over the 40-year lifespan of a solar panel and my analysis extends 30 years.14 The completely adjusted data totals to 110,919 kWh produced annually or 4.5kWh produced each day for panel set 1 and 13.5kWh produced each day by panel set 2.

Things to keep in mind

While the overall energy savings sometimes did not exceed energy expenditure and ROI was negative for most projects, there are some things to bear in mind before concluding this project as a failure.

The first consideration that I would like to bring to attention is the fact that our campus has very cheap electricity. On average our electricity costs 7.46¢ per kWh13.This is much less than the state average (10.33¢) and the average in other parts of the United States. In New England, the average cost of electricity is 17.9¢ and in Hawaii it’s 37.00¢[[17]](#footnote-17). This implies if these projects had been implemented in another part of our state or country, it would likely have delivered a positive return on investment.

Another consideration is the average annual use of the tractor, which is only 40 hours.2 This is a very small amount and was likely not considered when the project was initially proposed. However, the average annual use could potentially increase in the future. The tractor has only been used for a single season, and the Zack may not have discovered all the potential uses the tractor has. This tractor is currently used to build raised beds and cultivate the soil; however with additional attachments it can be used to plant seeds, plow and haul.3 The battery replacement length is suggested at 4-6 years but has the potential to last much longer if the tractor is only going to be used 40 hours a year.2

Each project has the potential to last beyond the expected lifetime length that I analyzed it for. Many resources I found indicated the potential for most solar panels to last 50 years. Additionally, the tractor has an indefinite lifespan that I limited to 30 years for analysis sake. The frame of the tractor is already 50 years old and still in good condition2, so with the proper maintenance and some minor replacements, the tractor could last longer than 30 years.

Climate change is also going to have visible effects in the next 30 years, which could influence the productivity of the solar panels. The estimated climate trend for the Champaign region is warmer dryer weather.[[18]](#footnote-18) This would likely lead to more sunny days and intense rays, which will increase the productivity of the panels but this is only speculation. The opposite could happen and climate change could cause a reduction in productivity.

One thing that is for certain is the cost of fuel will continue to increase. My fuel cost savings analysis used current prices that I then extrapolated 30 years in the future, which will not accurately reflect the actual lifetime cost savings. My prediction is the savings will be much greater, if you look at the changes in fuel prices in the last 30 years, you will see that prices have increase by 300% ($1.20 to $3.51 per gallon).[[19]](#footnote-19) This same increase would set future fuel prices at $10 per gallon by 2044.

A lot of research data that measures ROI and cost savings analyzes solar panel/electric motor technology in isolation. I analyzed the projects as a whole and included the cost of infrastructure. The tractor and delivery had motors installed on newly purchased vehicles rather than retrofitting a previously owned vehicle into an electric. This is different from most cost savings analysis you’ll find on the Internet because it calculates the cost of conversion without the cost of purchasing the machine. Additionally, many solar panels’ ROIs you’ll find only look at the solar panels themselves and not the other equipment needed to use the solar panels. In order to use the solar panels, the farm had to construct a shed, a roof that can hold the weight of the solar panels, and a charging station. This had a tremendous effect on the cost of the project.

Finally, the last consideration I want to bring to attention is the projects were completely built by students. Overall, the 11 students worked roughly 1,485 hours4, to disassemble and reassemble the truck. Had a professional been hired to complete the same task, I would expect their performance to be much faster than what the students accomplished and experience fewer troubles along the way.

Qualitative Value

In addition to reducing GHG emissions and water use, these projects provided additional services to the campus and community.

Both the electric tractor and electric delivery vehicle will reduce the number of man-hours used in a day. The electric tractor’s most significant contribution to the SSF is the time it takes to construct a raised bed. Originally, raised bed construction took the farm 30 minutes per bed made but using the tractor, this time has been cut down to 5 minutes per bed.2 In addition, both the tractor and delivery truck do not need to refuel, which for the truck means eliminating trips to the gas station. In addition, an electric motor does not require the typical routine maintenance that a car requires, which saves the farm both time and money.

The campus and community were highly involved in this project and exposed many students to the efforts of the farm and the concepts of sustainability. Three engineer courses, one ENG 2981 and two ENG 3154, and 22 students were responsible for the design and construction of all three projects. Additionally, children from Don Moyer’s Boys and Girls Club were involved in some construction of the delivery truck, design of the truck’s logo, and the creation of posters that share the electric vehicle with the public. Habitat for Humanity also brought volunteers out to help with the electric delivery truck.4 Finally, the student farm attracts many classroom tours and visitors. Zack Grant, the SSF manager estimates around 100 to 200 people visit the farm on an annual basis and he always makes sure to show off the electric tractor and solar panels.2

The project has also accomplished a University goal to bring the Agricultural Department together with the Engineering Department on campus. Five of the students that worked on the delivery truck project are studying to become electrical engineers, three others are studying a different engineer discipline, one is a finance major, another communications, and the last a student in Natural Resources and Environmental Science.4 Additionally, this project will service the need of our student farm, which integrates agriculture needs with engineer design.

Apart from these three main values, the projects serviced the community by reducing noise pollution, reinforcing the SSC’s commitment to sustainability,11 and has been used as a model for other small farms interested in using electric vehicles.2 Other community small-scale farmers looking to convert their tractors electric have approached Zack and he has provided them with some guidance as well as helpful resources.

Suggestions for the SSC

The purpose of my post project analysis of the electric vehicles and solar panels implemented on the SSF is to provide critical feedback to the SSC so they can more thoroughly and thoughtfully critique future project proposals and maximize energy savings per dollar expenditure. Looking at the issues and oversights made during these projects, I have developed some recommendations to improve the sustainability analysis of a project. One important question to ask is how useful the project will be. The electric tractor is only used 40 hours a year and therefore doesn’t generate a significant amount of water or energy savings, especially considering it’s $5,000 price tag. This project would definitely generate a positive ROI and larger energy savings if the tractor were used just six times as much. This may seem like a lot but it translates to only using the tractor about six hours a week for a 30-week-long season. Additionally, the SSC should consider a positive return on investment as a requirement for any project. While the main goal of the SSC is to generate energy savings, not cost, they should minimize money spent while maximizing energy savings to create significant energy reduction campus wide. Demanding a positive return on investment will ensure an efficient use of money. Another question the SSC should ask is if a project is appropriate for our campus? One reason solar panels cost more than they generate is because our cost of electricity is so low. This should be considered when going forward with solar panel projects on campus. Finally, the SSC should demand data that establishes the expected lifetime of the project. This data is fundamental for analyzing ROI, total cost savings, total energy savings, and lifetime replacement cost.

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1. Beran, Z. *et al*. (2012). “ENG 298 Electric vehicle initiative.” [↑](#footnote-ref-1)
2. Grant, Z. Personal Interview. 21 April. 2014 [↑](#footnote-ref-2)
3. *Yesterday’s Tractors.* “Allis Chalmers Model G” Retrieved: www.yesterdaystractors.com/profiles/acgprof.htm [↑](#footnote-ref-3)
4. LINC. (17 Feb. 2013). “Electric vehicle initiative project proposal.” [↑](#footnote-ref-4)
5. *SSF Electric Car LINC Project Application*. University of Illinois Student Sustainability Committee. [↑](#footnote-ref-5)
6. Wu, May, et al. (Dec. 2008). Consumptive Water use in the Production of Bioethanol and Petroleum Gasoline. Pg. 49-50. Retrieved:http://www.acs.org/content/dam/acsorg/policy/acsonthehill/briefings/energywaternexus/12-08-anl-water-use-in-bioethanol-gas.pdf [↑](#footnote-ref-6)
7. Kromer, S. et al. “Lifecycle Assessment of a Car Tire.”Centinental. Retrieved: <http://www.continental-corporation.com/www/download/csr_com_en/themes/ecology/download/oekobilanz_en.pdf> [↑](#footnote-ref-7)
8. Jones, W. D. (1 Apr. 2008). Spectrum. “How much water does it take to make electricity?” Retrieved: <http://spectrum.ieee.org/energy/environment/how-much-water-does-it-take-to-make-electricity> [↑](#footnote-ref-8)
9. SSF Electric Car LINC Funding Application. University of Illinois Student Sustainability Committee. [↑](#footnote-ref-9)
10. Blakers, A. & Weber, K. (Oct. 2000). “The energy intensity of photovoltaic systems.” Retrieved: http://www.ecotopia.com/apollo2/pvepbtoz.htm

    [↑](#footnote-ref-10)
11. *SSF Electric Car LINC Project Application.* University of Illinois Student Sustainability Committee [↑](#footnote-ref-11)
12. Harper, S. et al. (2011). “ENG 315: Electric Vehicle Initiative: Electric to solar conversion for the sustainable student farm final report.” [↑](#footnote-ref-12)
13. SSF Electric Car LINC Project Budget Details. Student Sustainability Committee. Retrieved: <http://ssc.union.illinois.edu/bootstrap/projects/2012-2013%20Projects/SSF%20Electric%20CAR%20LINC%20Project/SSF-LINCEVBudget%20Details.pdf> [↑](#footnote-ref-13)
14. *Climate & Weather Information.* “Grid Connected Solar Power System Calculations & Output.” Retrieved: <http://www.energymatters.com.au/climate-data/grid-calculate-solar.php> [↑](#footnote-ref-14)
15. Current Results. “Average sunshine a year in Australia's Cities.” Retrieved: <http://www.currentresults.com/Weather/Australia/Cities/sunshine-annual-average.php> [↑](#footnote-ref-15)
16. Angel, Jim. *Illinois State Water Survey*. “Cloudiness in Illinois.” Retrieved: <http://www.isws.illinois.edu/atmos/statecli/General/cloudiness.htm> [↑](#footnote-ref-16)
17. U.S. Energy Information Administration. (27 Sept. 2012). “Electric Power Monthly.” Retrieved: http://www.eia.gov/electricity/monthly/epm\_table\_grapher.cfm?t=epmt\_5\_6\_a [↑](#footnote-ref-17)
18. U.S. EPA. “Climate Impacts in the Midwest.” Retrieved: http://www.epa.gov/climatechange/impacts-adaptation/midwest.html [↑](#footnote-ref-18)
19. U.S. Energy Information Administration. (27 Sept. 2012). “Total Energy.” Retrieved: <http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0524> [↑](#footnote-ref-19)