Path to Zero Net Energy: A hands-on approach

Spring Quarter 2017

Final Report for Russell Ranch Sustainability - Solar PV Project

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Prepared by Thea French, Erin Martin and Simon Wu

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Introduction

Solar energy collection is increasing as a primary source for renewable energy alternatives for both residential and commercial applications. Land use for food production is being sacrificed for the installation of solar collectors. Russell Ranch wants to incorporate renewable energy production and agricultural applications to create an agrophotovoltaic (APV) system to be showcased as a viable alternative to fossil fuel generate electricity in order to meet the energy needs of an agriculture facility. This research will address supplementing fossil fuel energy sources with renewable solar energy providing viable solutions to not sacrifice valuable agriculture land.

Brief History

Russell Ranch is a 300-acre agricultural facility operated by the UC Davis Agricultural Sustainability Institute (ASI) that researches dryland and irrigated agriculture (Scow, 2012). There are 72, 1-acre plots of experimental crops that include grasses, grains, tomatoes, corn and hedgerows. These plots are a part of a 100-year, sustainable agriculture study. A small portion of their research comprises of long-term impacts on crop rotation, farming systems, and inputs of water, nitrogen and carbon. The ranch has multiple structures on the property: a barn workshop, two, large storage sheds/covered ports to house large farm mechanical equipment, and an office. Additionally, it has two variable speed well pumps, 100hp and 200hp, that service the 72, 1-acre plots.

Problem description

Russell Ranch hopes to take their passion for sustainability to become a showcase facility by incorporating solar technology onto their farm, setting a precedent for farms around the world. Our client wishes to become a zero net energy farm in the future, however, they know very little about renewable technology. Because Russell Ranch is a farming facility, their land is precious. A major constraint of this project is the conflict of land use. The photovoltaics would be competing with agricultural land use needs, thus, there must be a newer innovative way to combine agriculture with solar technology without compromising the farming.

The input of water is provided by annual rainfall and scheduled irrigation during dry months. Average annual precipitation in the Davis, CA, area is 19.66 inches; most of the rain falls 6 consecutive months each year (Commerce, 2017). During the alternative 6-months, water is irrigated by pumping well water onto the fields. The biggest step for Russell Ranch to become a zero net energy facility would be to offset the energy of the well pumps.

Description of Project

The purpose of this project was to research solar technologies, provide information and insights to our client, and make recommendations for how to incorporate photovoltaic solar onto agricultural land. The primary focus of this project is to research innovative ways to provide alternative energy sources to support the well pumps during dry months. An additional area to consider are power needs of the barn workshop and the two small buildings that house office space. The position/collection of traditional PV panels is of consideration. As there is limited available land, the placement of these panels must not impede upon the ranch's ability to grow their crops.

Scope

Our team researched innovative methods to implement photovoltaic cells (PV) to provide on-site energy collection for the Russell Ranch Sustainable Agriculture Facility. The factors considered in the project, specific to the client's needs, were minimal use of agricultural land, offsetting the two variable well pumps, and exploring a cutting edge approach to tackle energy use on the facility. The project focused on comparing four types of solar technologies that showed a range in cost, feasibility, land use, and availability: standard solar panels, solar towers, solar greenhouses, and mobile repurposed benches

Methodology

Research was primarily conducted through analysis of available data, searches of the internet, class discussions, and interviews with Professor Scow and Israel Herrera. Initial research was broadly defined to the technicalities of how PV solar collection works and new innovations to collect energy with PV panels on agriculture land. Energy usage data was collected from monthly electricity bill invoices.

Considerations

- Excess energy production
- Where to put the PV – land use
- Distribution Infrastructure
- What the current contract with the local energy company outlines for possible input of excess energy production
- Cost vs. Payback period/Return of Investment

Constraints

- Lack of detailed breakdown of energy usage and applications of energy use
    - Need an energy audit - annual energy usage, costs and applications
- Actual KWh usage for well pumps vs. buildings is unknown
- Well pumps operate 6 months per year
- Lack of infrastructure to distribute produced energy
- Electricity lines cannot be installed above plot land

- Solar panels are not to be installed on buildings.
    - Identify alternative locations based on discussions with the client.

<u>Assumptions</u>

- Average monthly bill is $1750.00
    - Yearly total is $20,952.24
- Average month consumed is 7019 kWh
    - Yearly total is 84,228 kWh

<u>Metrics Analysis</u>

Based on Russell Ranch's monthly PG&E average energy use data, radiation data from energysage.com, and solar panel data from Sunpower, we calculated that 82.2 kW system would offset the two well pumps' energy usage.

Based on efficiency, a panel may be able to produce 200W (City, 2017). If this efficiency is accurate, 25 panels can produce 5kW, which means the ranch would need 290 panels to produce enough energy annually. Per solar radiation research at pvwatts.nrel.gov, as shown in figures 3 and 4, a DC system will need 290 PV panels to power the ranch, including the pumps to absorb the current average yearly electricity fees.

"Year-to-year variations in solar radiation mean that some years your system will produce more or less energy than the typical year. Based on 30 years of historical weather data for nearby SACRAMENTO, CA,… a Fixed (open rack) PV system has a 90% likelihood of generating at least 98% of a typical year's production. Similarly, it has a 10% chance of generating more than 102% the typical year's output. A typical year's energy output is based on the Typical Meteorological Year (TMY) 2 data set." ((NREL), 2017)

Month	Solar Radiation (kWh / m2 / day)	AC Energy (kWh)	Energy Value ($)
January	2.42	3,630	871
February	3.8	4,992	1,198
March	5.01	7,226	1,734
April	6.42	8,756	2,101
May	7.33	9,991	2,398
June	7.68	9,949	2,388
July	7.89	10,372	2,489
August	7.54	9,954	2,389
September	6.7	8,657	2,078
October	5.09	6,995	1,679

November	3.18	4,388	1,053
December	2.34	3,434	824
Annual	5.45	88,344	$21,202

Figure 3: Annual Solar Radiation Production

Location and Station Identification	
Requested Location	37880 Russell Blvd, Davis, ca
Weather Data Source	(TMY2) SACRAMENTO, CA 17 mi
Latitude	38.52° N
Longitude	121.5° W
PV System Specifications *(Commercial)*	
DC System Size	58 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1
Economics	
Average Cost of Electricity Purchased from Utility	0.24 $/kWh
Performance Metrics	
Capacity Factor	17.40%

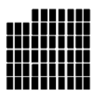
Figure 4: Weather Station Data

Equipment Analysis

Russell Ranch needs to produce 84,228 kWh of AC power annually to supply energy to well pumps K-12, J-12 and ranch facilities. Below is analysis for a readily available dual axis solar panel analysis and conceptual systems.

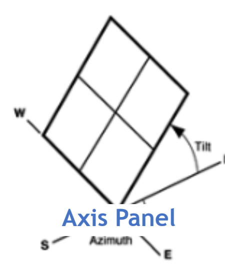
Russell Ranch needs to produce 84,228 kWh of AC power annually to supply energy to well pumps K-12, J-12 and ranch facilities. Below is analysis for a readily available dual axis solar panel analysis and conceptual systems.

According to Solar City, a single solar panel produces 5.45 kWh --> 1,525 AC kWh (City, 2017). Each item will require different amounts of space; furthermore, according to Sunrun, Inc., each PV panel runs anywhere from $1,000 - $1,200[1] each (Eric, 2017) not including installation costs.

Technology	Area	Availability	Cost	Additional Cost Considerations
Standard PV Panel 	 3.43ft x 5.11ft = 17.5sqft 242 Panels + spacing 8,274 sqft	In Market	$242,000	Installation costs Maintanence costs Overgeneration Accomidations
Mobile Repurposed Benches 	 242 panels = 41 benches 105.2sqft each 4,313 sqft	In market repurposed materials	$303,500	Installation costs Maintanence and movement costs Mobility: there would have to be added Added infrastructure or an investment in batteries.
Semi-transparent Solar Greenhouse 	 57 Greenhouses 12ft x 24ft = 288sqft 16,240 sqft	In Market	$1,710,000	Installation costs Ventilation Maintainance costs Greenhouse materials
Solar Tower 	3.43ft x 5.11ft = 17.5sqft 242 Panels + spacing 551.04 sqft	In Research developement	>$300,000 most expensive	Research/ experimentation costs Installation and construction costs Maintanence costs Added infrastructure

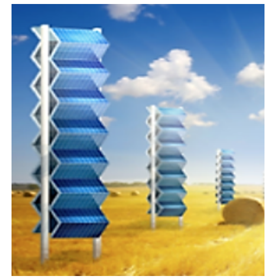
All standard PV, mobile benches, and solar tower cost estimations were made based on the 3.34ft x 5.11ft panel cost quote from Sunpower.com. The benches were estimated based on the solar panels of Sunpower in addition with a quote from farmshow.com. The semi transparent greenhouse cost was quoted by the CEO of Soliculture and scaled by group member Simon Wu.

Dual Axis Solar Panels – 240-290 panels



- Space – each axis panel (4 panels) Ground Coverage Ratio (GCR) is approximately $1m^2$ / $16.4ft^2$
  - $290_{\text{solar panels}}$ x $1m^2/16.4ft^2$ = $290m^2$ / $4,756\ ft^2$
  - Cost - $290,000 - $348,000 + installation

[1] This is a retail cost – not a negotiated cost for such a large amount. Also, the CA/national tax credit is not applicable as Russell Ranch is a non-profit organization.



Solar Towers (Concept model) – 290 panels

- ~20 panels per tower = ~15 towers
- 4 x 25m² /269ft² = 100 m² / 1,076 ft²
- Cost - $290,000 - $348,000 + tower construction + installation

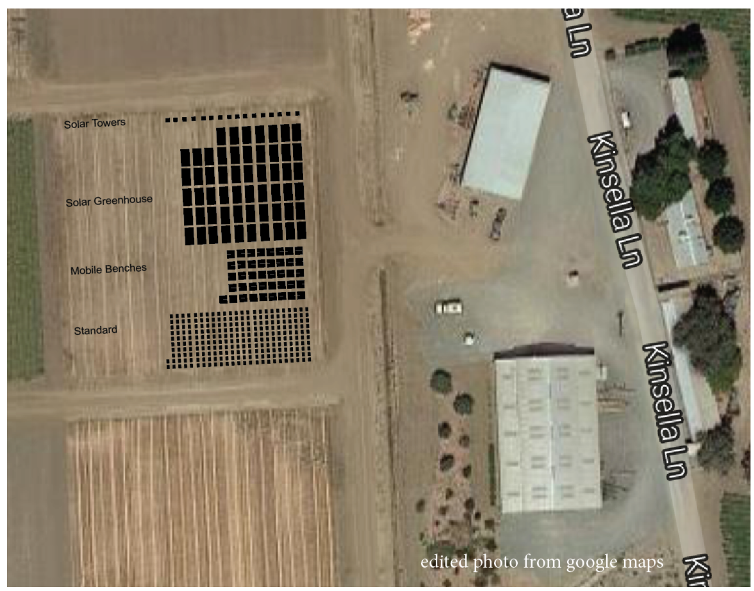
Mobile Benches - 49 mobile units

- 6 panels per unit = 10 mobile units
- Cost - $290,000 - $348,000 + mobile-unit construction + installation

Solar Greenhouse

- 12x 24ft 57 Greenhouses = 16, 240sqft
- Cost $1,710,000

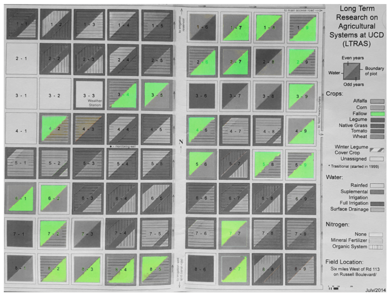
The installation costs vary depending on the design of the PV system. There is not an available and accurate price quote available at this time. However, it should be noted that based on the economic and availability of product, a dual axis panel design will be the most cost-effective choice.



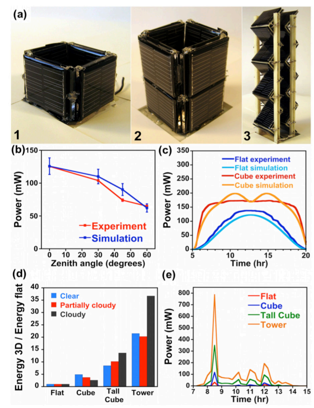
__Recommendations and Considerations__

Standard PV System: The most feasible and immediate solar energy offset would be from installing the 242 modern solar panels into the farm facility. The standard PV Solar system could be implemented onto the roof of the barn in combination with the car port sheds and the office buildings to offset the well energy use. The solar panels could also be placed near the buildings in some open space around the facility because there are only 242 panels taking up 8,274 sqft. Although this idea is not considerably innovative, it is the easiest and cheapest way to offset the energy of the farm. If Russell Ranch wishes to be a zero net energy farm within the next couple years, this is their best solar option.

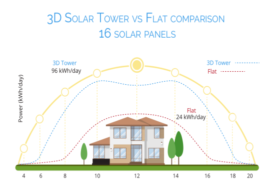
Mobile Benches: Russell Ranch has shade trailers for the farmers to use while harvesting. Because the farming system has seasonal fallow plots, our group would advise Russell Ranch to consider using that unused land to produce power using the mobile benches. If the farm is most concerned with land use then the mobility of the benches is a novel solution. Second



to the standard system, the repurposed benches are the next most feasible, and quickest option for Russell Ranch. The benches would be expected to hold 6 solar panels each. Thus, there would need to be 41 benches for a complete offset of the well pumps. The benches would need to be modified to support the panels and include added electrical infrastructure or energy storage technology to allow for the benches to be mobile. If the benches are placed onto the farms fallow plots, the purpose of their mobility would be to take up minimal agriculture land. This idea, however, would require a lot of manual up-keep to constantly move the benches.



Solar towers: Solar towers are currently being researched for the efficiency of vertical space and reflective light. Although this is a newer discovery to the solar industry, it is likely that solar technology will evolve as the need for renewable resources becomes more evident. The research presented in the diagrams on the right are from Wiocore Energy, a company in Serbia fabricating full scale towers, and M.I.T., a highly recognized university currently testing prototypes. It is difficult to determine the credibility of the research because it it so underdeveloped and new. Both sources of information state that solar towers are 2-12 times more effective at absorbing solar radiation than a flat panel but it is unclear how. If the technology is as efficient as MIT and Wiocore Energy promise, then this could be a worthwhile investment for Russell Ranch. There is an opportunity presented with getting involved in the research of vertical solar energy collectors. "With drought and climate change affecting Californians and California businesses, climate-related research across UC has surged to meet the demand for innovation and practical solutions" (universityofcalifornia.edu). Russell Ranch potentially has the opportunity to be ahead of the solar industry and become a major contributor to improving renewable energy technology. Russell Ranch could work with students, perhaps senior student engineers, to build, test, and implement solar towers onto the farming facility. They would be a showcase facility, setting an example for sustainable farms around the world. The solar towers use the least amount of agricultural land. However, they are also presumably the most expensive. The calculated $300,000 minimum is an estimate simply based on the cost of the standard solar panels. However because the credibility of the data presented was at question we did not account for the efficiency of the towers. Thus, the cost could be substantially reduced due to the need for less materials. Additionally, because this technology is newly discovered, it would take longer and cost more money to research and implement onto Russell Ranch. If Russell Ranch works with student research groups, the cost of research would reduce and there would be room to foster a greater relationship between Russell Ranch and the UC.



Greenhouse: The greenhouses our group looked at were ones being developed by Soliculture. They're translucent, and red. The red coloring serves to concentrate the energy. This newly developed research uses a fluorescent dye to absorb light and make solar panels significantly more efficient. "The concentrator dye absorbs the sunlight and then re-emits it as lower energy photons. This means you can use a lot fewer solar panels, because the absorber is doing the work"(Murdock). "Grow lamps optimize the colors of light that plants actually use to grow. The solar panels developed in the Soliculture lab absorb green light and emits red light to enhance the power generation of the solar cell – and the excess red light happened to fall exactly in the range of the spectrum that plants use" (Murdock)

Russell Ranch storage port

Further economic analysis is needed to justify costs. Considerations for installation costs, maintenance and opportunity costs pertaining to land use. Net gains should consider the payback period as well as excess energy sold back into the grid.

Pilot Program

Photovoltaics at Lake Constance, Germany

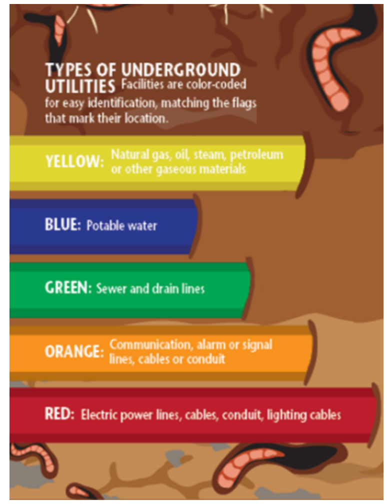
The Institute of Landscape and Plant Ecology at the University of Hohenheim, Germany, has been working with the Fraunhofer Institute for Solar Energy Systems (ISE) on integrating solar energy collection systems within agriculture. March 2015, the University, ISE and other partners installed a system above wheat and potato fields on an organic farm at Lake Constance. The program will be monitored until 2019 (Systems, 2016).

This is an agrophotovoltaic (APV) system of bifacial PV modules. These modules were installed on top of steel girders five meters above the field, covering about 0.82 acre. The system can produce 194 kWp,

The Institute of Landscape and Plant Ecology at the University of Hohenheim, Germany

(kilowatt peak) per hour – working at maximum capacity, providing power to 62 households. Their goal is to produce solar energy and harvest at least 80 percent of the reference crop. The crops beneath the panels and reference crops are to be harvested during the summers of 2017 and 2018. It would be in the best interest of Russell Ranch and other innovative farms/ranches to follow the progress of the Lake Constance pilot program as it becomes available (Schindele, 2017).

Installation of PV conduit pipes below a subsurface drip system was discussed as an option. Support infrastructure for this type of APV system typically is either overhead lines, or at grade level. An option to distribute the electrical conduit across agricultural land could be to bury a tandem underground conduit system for both irrigation and electrical lines. Based on the geometry and locations of the APV installation, it is recommended to layer the necessary conduit system as shown in figure 9.



Conduit lines

- Yellow = Natural gas, oil, steam, petroleum, or other gaseous materials
- **Blue = Potable water**
- Green = Sewer and drain lines
- Orange = Communication, alarm or signal lines, cables or conduit
- **Red = Electrical power lines, cables, conduit, lighting cables**

After analyzing the limited data for energy needs, production rates, panel efficiencies and economic feasibility, the recommendation is to install Axis PV panels that are readily available on the market. The system itself is an opportunity to be a net-energy producer that should be installed as such.

A dual axis panel design will require minimal maintenance as compared to other models. Additionally, it is the most cost-effective plan. The panels should be installed along the perimeter of the property in between the offices and wells J-12 and K-12. Moreover, based on the geometry and locations of the PV installation(s), it is recommended to incorporate electrical conduit for the inverter systems' electrical lines during the construction of an underground watering system design.

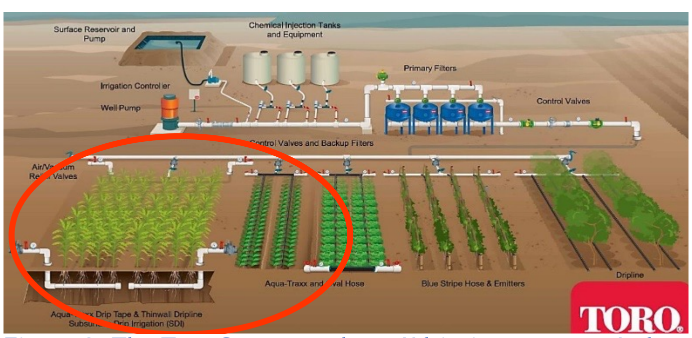


Figure 9: The Toro Company. http://driptips.toro.com/subsurface-drip-irrigation-sdi/

Figure 9 shows a diagram of a typical drip system layout. The below grade area within the red oval is an example of where electrical conduit may be installed in tandem with subsurface drip irrigation.

In Conclusion

Renewable energy production through solar energy production is a viable asset when it does not sacrifice other resources, or commodities. Solar farming exclusively is not a productive use of land when agricultural land is replaced. Researching ways to integrate solar energy collection will provide valuable insights into innovative methods to harness this resource. The technology is available; however, the efficiency of the technology is not enough to justify economic considerations when a model is scaled up. The energy needs of an agricultural facility per kW are minimal. The needs of a surrounding community are much more. Combining technology to capture solar energy to provide power on a larger kW scale will require more efficiency of the solar cells.

Until the technology is made more efficient, continued economic analysis should be done to justify costs. Considerations for installation costs, maintenance and opportunity costs pertaining to land use should be included. Net gains should be considered in the payback period as well as excess energy sold back into the grid.

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