Initial Findings on Cattle Agrivoltaic Design

University of California Davis
Blake Woodbury, Christopher Abel, Jacob Aldred
Path to Zero Net Energy
Dr. Kurt Kornbluth
Spring 2025

Table of Contents

Figures:

Project Background

Our clients are Thomas Patten and David Trombly of facilities management at the University of California, Davis. The main goal behind this project was to gather useful information to aid future design concepts for an on-campus cattle agrivoltaics project, with an emphasis on profitability. The clients also stated that they intend to use our results to assist with their submission to a government grant contest called Large Animal and Solar System Operations (LASSO), offered by the US Department of Energy. Our student group (three) has been researching, interviewing, and documenting our efforts this quarter to design an exhortation that unpacks the various components behind this project and gives an idea of its economic feasibility.

Tom's interested in cattle agrivoltaics due to the potential of expanding UC Davis' renewable energy system. His department is planning to expand the university's renewable energy infrastructure by installing new solar panels on a 35-acre land parcel next year. By transporting cows onto the pasture, they will, in effect, act as lawn mowers. If the concept is proven, agrivoltaic pastureland could be leased at a premium to ranchers as improved pasture. However, this is ultimately dependent on how attractive the pasture is to ranchers. The added risk of herding cattle underneath solar panels could prove to be a disincentive.

The first concern we identified had to do with expense. In order for cows to safely graze underneath the solar array, the panel's leading edge should be high enough off the ground for a few main reasons:

1. All vital components of the solar panel must be out of reach of any livestock
2. All vital components of the solar panel must be out of reach of any farm implements
3. Additional height ensures total sunlight exposure, dehydrating excrement for waste management

Due to the client's budgetary constraints, Tom determined that raising the height of the solar panels would not be necessary for their plans and opted for an alternative route to protect the solar equipment. Deviating from default commercial panel designs, such as raising the panels several feet off the ground, increases installation costs significantly. At the bare minimum to fit a cattle herd underneath, our team estimated would need to be eight feet. With this in mind, we focused on gathering more information on other design aspects.

Another problem we initially encountered involved the limited amount of available research on cattle agrivoltaics, as it's a relatively new concept; however, initial findings are positive. Professor of plant, and ecosystem ecology, Barron-Gafford discusses the beneficial effects on the microclimate under

the array, such as the increase in irrigated water efficiency[1]. Heins observed that agrivoltaic shade relieved bovine stress as indicated by observed lower respiration rate and body temperature[2]. Ana Flavia estimated that her agrivoltaic system in Brazil was efficient enough to pay for itself in seven years[3]. These articles provide insight into the viability of agrivoltaics systems and the performance of previous systems. However, more economic analysis will need to be done to determine what design choices must be made that satisfy the condition of profitability in Davis, California.

Phase 2A[4] of the LASSO competition evaluates project submissions on **four criteria**:

1. Project viability, which evaluates the system design, timeline, budget, and risk management strategies;

2. Cattle integration, which evaluates the grazing management plan for animal health, safety, sustainability, and soil and plant resource management;

3. Readiness for Phase 3, which evaluates the project's data collection plan; and

4. Financing, which requires a detailed, realistic budget and financing plan. Our client is most unfamiliar with cattle and pasture management, which Criteria 2 requires, so this project focused primarily on obtaining information to help guide our client towards the best questions to ask, the best people to work with, and pitfalls to pay attention to.

To help our client apply for the LASSO competition (to go towards funding a cattle agrivoltaics project), we decided to gather information about the more agricultural components of this project and think about how those components could function with a customized photovoltaic system. Since there is limited research publicly available, we decided to gather information through consulting local industry experts in the areas of cattle management, bovine behavior, and photovoltaics.

Methodology

To gather primary source information, we consulted with Dr. Kristina Horback at the UCD Department of Animal Science on bovine behavior. During our interview, Dr. Horback mentioned that the shade cast from a photovoltaic system would be highly beneficial for cattle's happiness and welfare. She also mentioned several important factors regarding how cattle may interact with photovoltaic systems. Tina's advice indicated that, for this system to work, the photovoltaic system would need to be designed to prevent cattle from damaging the infrastructure. This indicates that additional expenses may be

[1] A. Barron-Gafford *et al.*, "Agrivoltaics Provide Mutual Benefits,".
[2] Heins *et al.*, "Agrivoltaics to Shade Cows,".
[3] Flávia Faria et al., "Use of Solar Panels for Shade for Holstein Heifers,"
[4] U.S. Department of Energy, "LASSO Prize Rules"

necessary, but it's unclear to what extent. The details of Horback's counseling are expanded upon on page 7.

We also consulted with Professor Emeritus James Oltjen, also previously at the Department of Animal Science. James specializes in cattle management and offered insight on how a photovoltaic system could be designed and built to assist herding efforts, forage growth, and waste management. James also mentioned several important factors for consideration regarding ranchers' ability to successfully herd cattle around and underneath a photovoltaic system. His main concern was that ranchers would struggle to herd cattle underneath panels less than an estimated 12 feet tall. James offered his perspective that a single design would be difficult to scale elsewhere because many of this project's components depend on environmental conditions. The details of his advice are expanded on pages 6 and 7.

To maximize the energy output of a single-axis tracking system, the axis of tracking must be aligned North-South. The panels would follow the sun from east to west as the day progresses, but would not follow the change in the sun's elevation throughout the year.

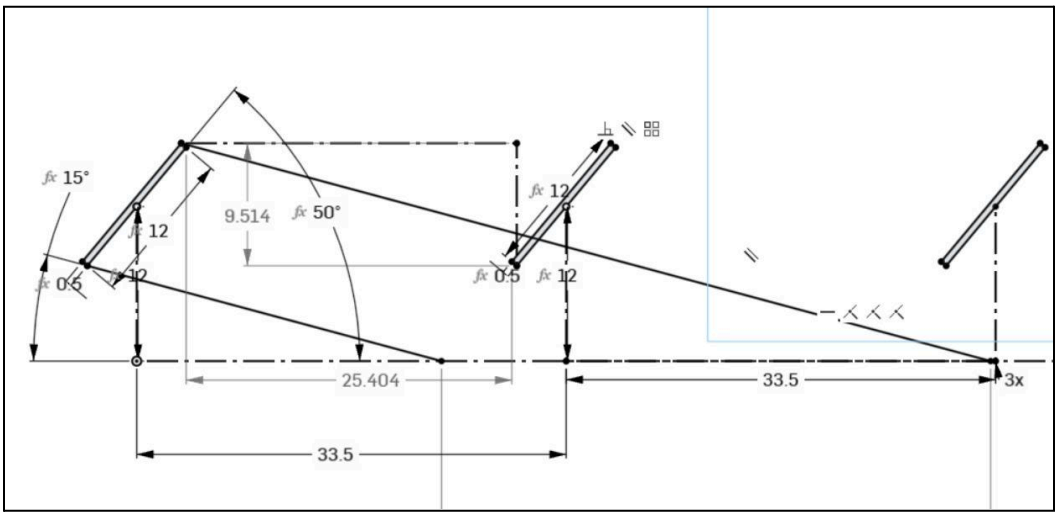

Figure 1. Diagram depicting the closest row spacing possible before the system begins to shade itself is 33.5 ft between each support going west to east.

We were able to deduce that the minimum row spacing a dual portrait solar system would need to prevent self-shading is 35 feet for the site. Using Onshape, a CAD software, we were able to create the figure above. The row spacing was based on the elevation of the sun on December 21 at the beginning and end of peak power demand, 9 am and 3 pm[5]. Correcting for the shortening of the shadows due to the azimuth of the sun at those times, the row spacing is 25.4 ft, for a row width of 33.5 ft.

[5] Greentech Renewables, "Determining Module Inter-Row Spacing"

Results & Discussion

According to our research, there are a multitude of ways to approach agrivoltaic design depending on preferred cattle management practices. Moreover, several design aspects are interrelated, requiring tradeoffs to be made between them. These include panel height, row spacing, the type of photovoltaic system, ground irrigation, and grazing strategy. For instance, tight row spacing is related to high electric production but inversely related to forage growth for the cattle.

Panel Height

The most significant component for determining this project's feasibility is likely the height of the photovoltaic panels. James informed us that many ranchers in the United States prefer to herd cattle on horseback and that allowing this would require panels to be at least 12 ft above ground. However, mechanized implements can get away with less. Furthermore, the panels would likely have to be at least 12 feet high to prevent ranchers and horses from getting injured if a horse reared or bucked underneath the panels. Moreover, horses would be more inclined to do so due to increased nervousness from being under the panels, raising concerns surrounding the introduction of horses. James also mentioned that cows are likely to mount each other underneath panels, and if they were to do so without making contact with the panels, then the panels would have to be at least 8 feet high. Dr. Horback also asserted that cows have a somewhat high probability of chewing the panel's wires if they can reach them.

However, as the support height increases, the installation cost of the system increases dramatically. Steel and the associated labor to install it consist of a significant portion of the average utility-scale solar system's cost. Thus, going higher than 6 feet from the ground would increase the total cost noticeably.

Row Spacing

Affects revenue from power production:

- Spacing can be as tight as 33.5 ft in between supports, which becomes 25 ft in between panel edges when the panels are at their maximum tilt of 50 degrees.
- Any closer and the rows begin to self-shade when the sun nears the horizon.
- Any further, and you lose revenue from power production, simply by fitting fewer rows of panels into the same plot of land

Affects forage growth:

- Tighter spacing would result in less sunlight exposure for the forage growing in the pasture, resulting in a shorter grazing season for the pasture and less utility to the rancher. However, this would produce more electricity, resulting in a better LCOE

Affects pasture hygiene:

- Because cows tend to linger under shady spots, areas that are more permanently shaded will tend to become more permanently occupied by cows, concentrating their waste into a smaller area. Over time, these areas can become marshy and unhygienic due to the lack of sunlight to dry the waste. Thus, rows must be appropriately spaced at a minimum of 33.5 feet to ensure sunlight dries out fresh manure directly underneath the array, facilitating fecal decomposition.

Cattle-ization

Along with raising panels higher than their default commercial design, further customizations would likely be necessary. Tina advised that cows will almost certainly rub and chew the panel's reachable wires. Upon further investigation, we found that ingesting wires may cause Traumatic Reticuloperitonitis, a somewhat common condition in which the reticulum, or stomach, is punctured by sharp metal debris[6]. Thus, beams might need to be smoothed, and wires will need to be placed out of the cow's reach. James also advised that the ground underneath the panels will turn into an undesirable, swamp-like state if left in permanent shade from the panels. This is because cows mostly defecate in shaded areas, which require regular sunlight for evaporation. So the panels must be designed to allow sunlight to hit each section of the ground daily. This design would also be ideal for maximising foliage's sunlight exposure and growth.

Herding is also a major concern. If panels aren't installed high enough for machinery or horses to get underneath, a new strategy must be devised. Possible solutions involve installing fences between the array's posts to prevent cows from running from row to row. Virtual fencing may also be beneficial on large acreage for the same reason. If the university were to take responsibility for herding the cattle, the cost of this labor must be factored into the overall economic viability. Luckily, UCD has an undergraduate labor force full of hungry interns at its disposal.

Irrigation

Another important question surrounds whether to irrigate the pasture or not. Irrigation presents immediate expenses such as the need to flatten the terrain underneath the panels, along with pumping water. In this case, the land is already used for hay production, thus it likely needs little improvement. If

[6] Braun et al, "Traumatic Reticuloperitonitis in Cattle."

the terrain isn't suitable to be leveled, sprinkler irrigation would be required, which Dr. Oltjen advised would likely cost more than simply flattening the terrain. Oltjen also asserted that irrigated pasture would be more attractive for ranchers since it provides higher-quality feed for cattle. He reasoned that combining irrigated foliage with panel-cast shade would make this project more desirable to ranchers than almost any other area in California. Based on this assumption, revenue from ranchers could likely help guarantee this project's overall financial feasibility. Furthermore, incorporating irrigation into this design would help render this project more easily scalable to other environments in the United States, which is an important component for the LASSO application[7].

Self-described agrivoltaics innovator, Dr. Barron-Gafford, found in his 2019 article "Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands" that agrivoltaic systems have a positive impact on irrigated water savings[8]. Depending on irrigation frequency, soil moisture was found to be anywhere from 15% to 5% greater than irrigated, unshaded pasture. Moreover, carbon dioxide uptake was found to be 65% greater, while water use efficiency also improved by 65%, resulting in significantly higher crop yields. Paired with the fact that the livestock will already need a water source, irrigation would be a logical step as it has the potential to significantly increase forage growth.

Grazing

Grazing management is a complicated topic, but can be simplified down into three important components: stocking rate, forage allowance, and forage rate. To achieve maximum utility without sacrificing ecosystem health, these three elements have to be balanced. Stocking rate refers to a specific number of animals on a given area of land and is a key determinant of forage allowance and rate, which measure units of forage to liveweight and pasture area, respectively. Ultimately, these factors can be used to deduce how intense grazing might be.[9]

There are two predominant grazing strategies: rotational and continuous. Continuous grazing consists of putting cows out to expansive pastures over an extended amount of time, with plants receiving little reprieve from grazing. Rotational grazing introduces the ability to control grazing by herding cattle in and out of smaller, fenced-in pastures. Rotationally grazed pastures have been found to recover faster after grazing, drought due to a precisely controlled grazing intensity[10]. The main drawbacks of rotational grazing come from the added cost of fencing and herding labor.

Regarding grass species that should be considered for grazing, Berber orchardgrass and fescue don't require a lot of water and have been shown to outcompete invasive weeds[11]. Both grasses are also

---

[7] U.S. Department of Energy, "LASSO Prize Rules"
[8] A. Barron-Gafford *et al.*, "Agrivoltaics Provide Mutual Benefits,".
[9] Francis Monte Rouquette, Lynn E Sollenberger, and João M Vendramini, "Grazing Management and Stocking Strategy Decisions for Pasture-Based Beef Systems: Experimental Confirmation vs. Testimonials and Perceptions,"
[10] "Rotational vs. Continuous Grazing," Martin-Gatton College of Agriculture, Food and Environment,
[11] 'Berber' Orchardgrass (Dactylis Glomerata) Conservation Plant," United States Department of Agriculture

perennials and have a lifecycle of several years, meaning they don't need to be replanted. It's also worth noting that introducing a variety of forage types may aid soil health via the benefits of biodiversity, improving forage growth in the long run.

Stakeholder Considerations

To address equity in this project, the group considered which groups of people were affected, then used the tenets of equity shown through the Path to Zero Net Energy class to make sure concerns are properly considered and addressed. The table below provides a summary of the groups affected.

Groups Affected / Equity Tenets	Solar Installation Crew	Cattle/Pasture Mgmt Crew	Neighbors	Ranchers
Procedural	Tom ✓	✗	Primate Research Center ✗	James Oltjen ✓
Recognition				
Distributive	✓	✓	- Dust & dirt kicked up - Landscape / ecosystem changes - Visual clutter ✗	✓
Restorative				

Figure 2. Table displaying the main pillars of equity and how they intersect with potential stakeholders

The main tenets of equity that intersect with this project are Procedural and Distributive. To address Procedural equity, the group has been talking with the client, Tom, and an expert in cattle management, James. The group has not considered how to incorporate the opinions of the Pasture Management crew, as there isn't one yet, and did not talk to the neighbors of the prospective installation, the Primate Research Center. The group recommends that the client get input from the Pasture management crew and try to understand what their work entails. To address Distributive equity, the group considered how the impacts would be distributed on the Solar Crew, the Pasture Crew, and the Ranchers, and found the impacts to be fair. However, the neighbors of the installation still have unaddressed issues. The group recommends that the client speak with the neighbors and inform them of the dust, dirt, and noise during construction, as well as of the potential changes to the local landscape and ecosystem. The group also recommends that the client offer potential solutions to the visual clutter, such as hedge rows.

Recommendations and Conclusions

These several components of consideration each create challenges for designing an economically feasible cattle agrivoltaics project. But these components don't seem to render profitability unfeasible.

There are several important questions left open. Therefore, we recommend conducting a small-scale pilot test to more accurately estimate this project's overall feasibility. Our recommended considerations for conducting this pilot test are outlined below:

(1) Zip Tie panel wires to prevent cows from chewing (this could be aided by applying bitter tastes/scents to wires (and beams) which cows dislike). Smoothen steel beams to discourage cows from rubbing against them (they prefer rough surfaces).
(2) Irrigate the pasture for better forage yields. Water already has to be run for the herd. Solutions can be as simple as laying a perforated hose on the topsoil.
(3) Consider installing motion-activated camera traps to learn more about cattle behavior under a photovoltaic system.
(4) Implement a variety of designs over a small amount of acreage to test cattle management strategies, forage growth parameters, and waste management efficiency.

Bibliography

Barron-Gafford, Greg A., Mitchell A. Pavao-Zuckerman, Rebecca L. Minor, Leland F. Sutter, Isaiah Barnett-Moreno, Daniel T. Blackett, Moses Thompson, et al. "Agrivoltaics Provide Mutual Benefits across the Food–Energy–Water Nexus in Drylands." Nature sustainability 2, no. 9 (2019): 848-55. https://doi.org/10.1038/s41893-019-0364-5.

Braun, Ueli, and Ingrid Lorenz. "Traumatic Reticuloperitonitis in Cattle." MSD Animal Health, June 2022. https://www.msdvetmanual.com/digestive-system/diseases-of-the-ruminant-forestomach/traumatic-reticuloperitonitis-in-cattle

"'Berber' Orchardgrass (Dactylis Glomerata) Conservation Plant." United States Department of Agriculture, n.d. https://www.nrcs.usda.gov/plantmaterials/capmcrb11842.pdf.

Dinesh, Harshavardhan, and Joshua M. Pearce. "The Potential of Agrivoltaic Systems." Renewable & sustainable energy reviews 54 (2016): 299-308. https://doi.org/10.1016/j.rser.2015.10.024.

Faria, Ana Flávia, Alex S. Maia, Gustavo A. Moura, Vinícius F. Fonsêca, Sheila T. Nascimento, Hugo F. Milan, and Kifle G. Gebremedhin. "Use of Solar Panels for Shade for Holstein Heifers." Animals 13, no. 3 (January 17, 2023): 329. https://doi.org/10.3390/ani13030329.

Greentech Renewables. "Determining Module Inter-Row Spacing," February 26, 2020. https://www.greentechrenewables.com/article/determining-module-inter-row-spacing.

Grison, Claude, Lucie Cases, Mailys Le Moigne, and Martine Hossaert-McKey. Photovoltaism, Agriculture and Ecology: From Agrivoltaism to Ecovoltaism. London: ISTE Ltd., 2021. doi:10.1002/9781119887720.

Heins, Bradley J., Kirsten T. Sharpe, Eric S. Buchanan, and Michael H. Reese. "Agrivoltaics to Shade Cows in a Pasture-Based Dairy System." AIP Conference Proceedings 2635, no. 1 (2022). https://doi.org/10.1063/5.0103148. https://doi.org/10.1063/5.0103148.

Klyk, Constantin, and Stephan Schindele. Agrivoltaics: Technical, Ecological, Commercial and Legal Aspects. Energy Engineering Series. 1st ed. Stevenage: Institution of Engineering & Technology, 2024.

Lytle, William, Theresa K. Meyer, Nagendra G. Tanikella, Laurie Burnham, Julie Engel, Chelsea Schelly, and Joshua M. Pearce. "Conceptual Design and Rationale for a New Agrivoltaics Concept: Pasture-Raised Rabbits and Solar Farming." Journal of Cleaner Production 282 (2021): 124476. https://doi.org/10.1016/j.jclepro.2020.124476.

Mamun, Mohammad Abdullah Al, Paul Dargusch, David Wadley, Noor Azwa Zulkarnain, and Ammar Abdul Aziz. "A Review of Research on Agrivoltaic Systems." Renewable and Sustainable Energy Reviews 161 (2022/06/01/ 2022): 112351. https://doi.org/https://doi.org/10.1016/j.rser.2022.112351. https://www.sciencedirect.com/science/article/pii/S1364032122002635.

Rouquette, Francis Monte, Lynn E Sollenberger, and João M Vendramini. "Grazing Management and Stocking Strategy Decisions for Pasture-Based Beef Systems: Experimental Confirmation vs. Testimonials and Perceptions." Translational Animal Science 7, no. 1 (January 1, 2023). https://doi.org/10.1093/tas/txad069.

"Rotational vs. Continuous Grazing." Martin-Gatton College of Agriculture, Food and Environment, n.d. https://grazer.ca.uky.edu/rotational-vs-continuous-grazing.

Shaheen, Sean. "Growing Agrivoltaics." Journal of Photonics for Energy 14, no. 3 (2024): 030101. https://doi.org/10.1117/1.JPE.14.030101.

Taylor, M., J. Pettit, T. Sekiyama, and M. M. Sokołowski. "Justice-Driven Agrivoltaics: Facilitating Agrivoltaics Embedded in Energy Justice." Renewable & sustainable energy reviews 188 (2023): 113815. https://doi.org/10.1016/j.rser.2023.113815.

Tresoldi, Grazyne. "Mitigating Heat Stress in Lactating Dairy Cows." University of California, Davis, 2018.

U.S. Department of Energy. “LASSO Prize Rules,” January 2025. https://americanmadechallenges.org/challenges/lasso.