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MARKET ANALYSIS OF AGRIVOLTAICS IN KERN COUNTY

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EXECUTIVE SUMMARY

Integrating solar energy generation on active agricultural land in Kern County has the potential to deliver economic, environmental, and social benefits to the local community. These systems – known as agrivoltaics (APV) – can bolster economic resilience through industry diversification, advance the evolution of traditional sectors, and support sustainability objectives. Regional and site-specific contextual information is critical to the success of potential agrivoltaic systems, and implementation requires active collaboration amongst key stakeholders as it relates to engaging the local community, siting demonstration sites, and collecting data on observed benefits and/or risks.

Kern County's geographic and socioeconomic context present opportunities for agrivoltaics. However, a lack of local precedent for APV projects encourages the implementation of demonstration sites. An 8ft elevated 500kW behind-the-meter solar photovoltaic (PV) configuration is likely to be a low-cost option for a demonstration site, as this will bypass challenges due to interconnection, streamline permitting processes, align with grant funding limitations, and demonstrate technical feasibility on a multi-acre scale. Most of Kern County qualifies for an additional 10% Investment Tax Credit (ITC) under the Inflation Reduction Act, proving the region's appeal for solar development. Leveraging possible grant funding options, such as the Rural Energy for America Program (REAP), alongside ITCs will significantly reduce upfront costs for APV projects and enable the sale of energy at a competitive price.

Current agrivoltaics literature and Kern County agricultural data support table grapes as an immediate implementation option within an 8ft elevated single-axis tracker agrivoltaics system. Wine grapes, tomatoes, and alfalfa also showed encouraging indicators of suitability with agrivoltaics, however a lack of case studies regarding almonds, pistachios, and carrots suggests a need for further research on implementation. Crop responses to shading, water demand and accessibility, and cultivation methods and machinery were key drivers of suitability in our model.

A holistic cost-benefit analysis showed that, compared to an agriculture-only baseline, an agrivoltaics scenario using our technical, financial, and agricultural assumptions yielded a 19% higher net present value (NPV). Although a solar-only scenario yielded an even higher NPV due to higher energy density and no agricultural costs, this assumes a complete loss of farm-related jobs and economic activity. Agrivoltaics allows for economic improvement while benefiting all key stakeholders; APV has the potential to improve agricultural output, reduce the risk of heat-related illness in laborers, mitigate environmental impacts, and diversify revenue streams for landowners. Establishing local demonstration sites and structuring active engagement channels with community leaders will be vital for the advancement of agrivoltaics in Kern County.

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INTRODUCTION

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Our Approach

Over the course of 14 weeks, our group – in close partnership with our client, the City of Bakersfield – analyzed the impact of agrivoltaics on energy, agriculture, and the community within Kern County. The project was divided into three phases: research, analysis, and recommendations. A combination of desk research, industry expert interviews, and farm visits in Kern County helped refine the information our group used in creating our analyses. We produced a variety of deliverables related to crop suitability, solar project financing, stakeholder dynamics, and a holistic cost-benefit analysis. All deliverables required multiple rounds of stakeholder validation meetings to affirm the assumptions and processes were aligned with the regional context; this collaborative and engaging method was paramount to our ability to provide insights for our client. Once we identified the opportunities for agrivoltaics and presented the tools to assess project viability, our team focused on practical recommendations for the City to leverage amidst their efforts to scale agrivoltaics in the region.

About Agrivoltaics

Demand for solar power has continued to rise as it has become a more cost-competitive source of energy. However, solar panel installations require far more land per unit of power produced compared to fossil fuels (USDA, n.d.). This requirement is often perceived as being at odds with agricultural land, which tends to be situated in flat and sunny areas that are desirable for solar photovoltaic (PV) installation. Agrivoltaics (APV) is being explored as a novel solution, where land is used for both agriculture and solar PV energy generation.

Agrivoltaics allows agriculture and solar energy production to complement each other rather than compete with each other. By integrating solar panels with agricultural land, APV systems offer a dual benefit of generating renewable energy while simultaneously providing shade to crops. From the agriculture perspective, the shade may protect certain crops from excessive sunlight and damaging heat exposure. Additionally, the shade helps reduce the demand for water in traditional irrigation methods, while mitigating the impact of water scarcity on crop yields. Agrivoltaic systems can potentially reduce the extent of these impacts on agriculturally productive land, thereby safeguarding the local economy by preserving valuable farmland for future generations. Most importantly, installed solar PV systems on agricultural land generate an additional income stream for landowners and reduced operating costs for farmers. Table 1 outlines the advantages and drawbacks of agrivoltaics.

Depending on the crop type, PV design, and climate, studies show that shading from agrivoltaics can potentially help improve crop yield response (Weselek et.al., 2021) and crop resistance to extreme weather (Boyd, 2023). Additionally, it might also increase panel efficiency as the crops underneath act as a natural cooling system by releasing water vapor during transpiration (USDA, n.d.). Agrivoltaics also potentially lower solar operations and maintenance costs by limiting the need for mowing (Boyd, 2023).

Table 1. Advantages and disadvantages of agrivoltaics

Advantages	Disadvantages
• Add revenue stream for farms (USDA, n.d.) • Provide shade for crops or livestock (USDA, n.d.) • Reduce irrigation requirements (Boyd, 2023) • Renewable energy generation (USDA, n.d.) • Carbon footprint reduction (USDA, n.d.)	• High capital cost (Boyd, 2023) • Perfect conditions are restricted for certain crops (Bolt, 2023) • More complex solar PV mounting systems (Davey, 2022)

There are several agrivoltaics configurations, which Gorjian et. al (2022) have classified based on several categories as shown in Appendix A. Similar to the more common solar PV installation, the main classification for APV is the mounting structure; whether the solar panels are installed in an open field (open system) or on a rooftop (closed system). Implementation on open fields is further classified into interspace and overhead PV structures. APV systems with interspace structures grow crops between the rows of mounted panels, while those with overhead structures typically grow crops underneath an elevated solar PV installation. Both configurations are designed to minimize the amount of unused agricultural land under the PV installations, however overhead designs require higher mounting systems to provide clearance for crops and farm operations.

The APV configuration is highly dependent on the type of crops grown and the agricultural activities involved. Both of these factors also influence the types of solar panel modules to use, which consist of three main types: monofacial, bifacial, and semitransparent (see Figure 1) (Trommsdorff et al, 2022). Monofacial modules are the traditional type, capturing solar energy solely from the front side, whereas bifacial modules capture energy from both their front and rear sides. The bifacial modules are particularly useful for maximizing solar energy production or for ground-mounted vertical PV installations. The semi-transparent modules function similarly to monofacial ones but feature a transparent portion that allows light to pass through. Therefore, these modules would be especially beneficial for crops that are intolerant to shade or thrive in direct sunlight.

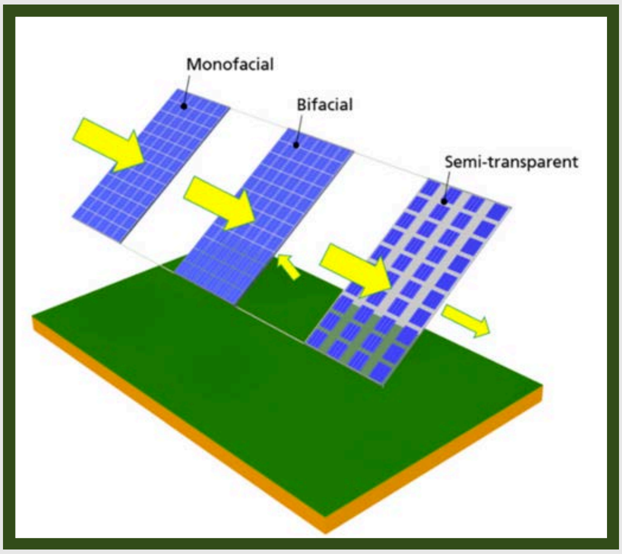


Figure 1. Main types of solar panel modules for agrivoltaics
Source: Trommsdorff et al., 2022

AGRICULTURE

02

Kern County Agricultural Profile

Kern County is located in the southern part of the San Joaquin Valley in California. Agricultural land is the dominant terrain feature of Kern County besides the mountain ranges which lie on the eastern side of the county. Kern County is bisected by the Kern river, forming two distinct groups of agricultural land in the north and south, with the city of Bakersfield nestled roughly in the middle.

Kern County is one of the top three agricultural revenue-generating counties in California (California Department of Food and Agriculture, 2023) and it consistently ranks among the top five most-productive agricultural counties in the United States (Employment Development Department State of California, n.d). According to Kern County Department of Agriculture and Measurement Standards (2023), the county boasts a diverse range of crops totaling more than 80 commodity varieties categorized into field crops, citrus, deciduous fruit and nut trees, and vegetable crops. The county's agricultural activities also include livestock, poultry, apiary, and industrial & wood commodities. The department reported in 2023, the agricultural commodities have an annual economic value of approximately US$8 billion. Figure 2 shows the vast agricultural areas of Kern County surrounding the city of Bakersfield.

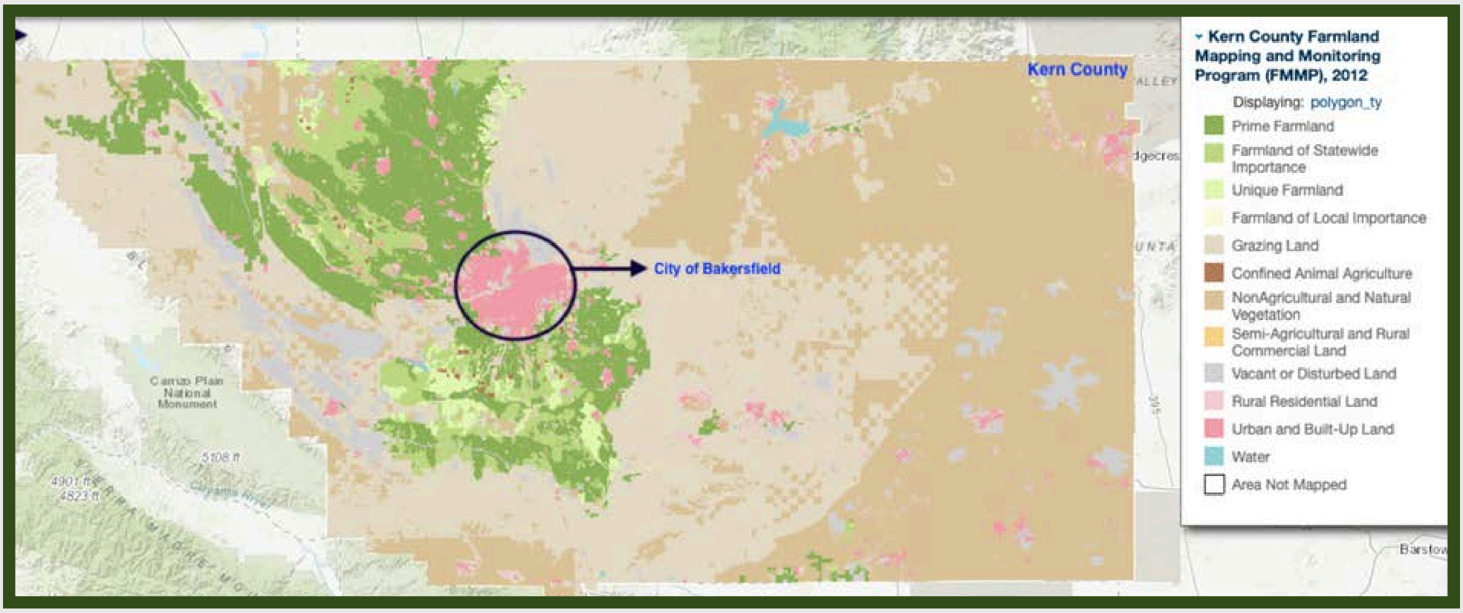


Figure 2. Kern County Farmland Map by California Department of Conservation
Note: The map has been modified to locate the city of Bakersfield
Source: Conservation Biology Institute, 2015

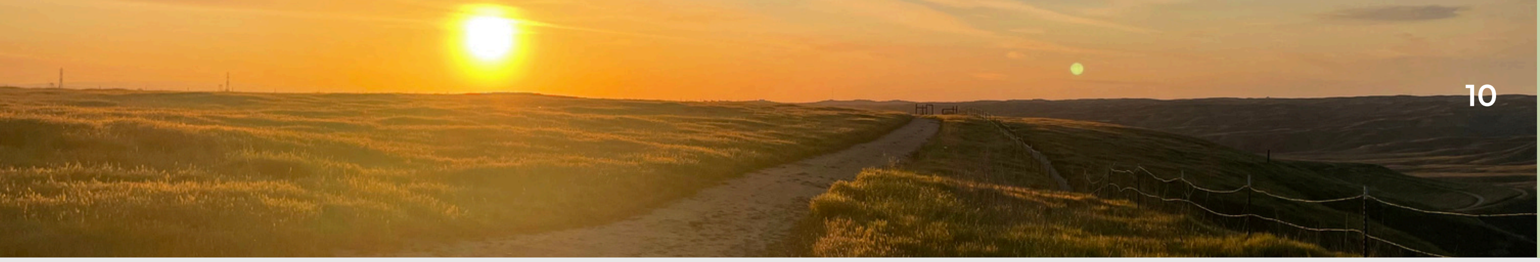
To gain a deeper understanding of Kern County's agricultural landscape, the following factors were analyzed: climate conditions, water availability, soil types, and farming practices.

Climate Conditions

Kern County is characterized by a semi-arid climate (Wartenberg et.al, 2021), which means it has little rain, though not truly arid. According to the Kern County Water Agency, annual rainfall is less than six inches per year. The USDA reports that summers in the county are cloudless, hot, and dry, in which the temperature often exceeds 100 degrees Fahrenheit and is rarely below 51 degrees. The wet season occurs from October to April and winters are typically mild and humid, with December and January characterized by frequent fog or low clouds at night (USDA, 1988). The California Energy Commission's Local Climate Change Snapshot Tool within Cal-Adapt predicts that Kern County will experience increased temperature changes, decreased annual precipitation, and more extreme heat days in the 21st century (Cal-Adapt, 2018).

Water Availability

Most of the water in Kern County is used for agriculture. 2,294,000 acre-feet are used annually for agricultural purposes, while 166,000 acre-feet are used for municipal and industrial purposes (Water Association of Kern County, 2016). According to the county’s water association, Kern County’s water sources include the Kern River, State Water Project (California Aqueduct), Federal Central Valley Project (Friant-Kern Canal), local streams, groundwater, and other sources (Poso Creek, etc.). Local farmers in the region shared that a farm will typically use multiple water sources such as a combination of surface water and groundwater. Groundwater is the main water supply source with a 36% share (Water Association of Kern County, 2016).



Groundwater is commonly used when surface water allocations are insufficient to meet agricultural demands, or when the area lacks water district services. These regions are often referred to as "white lands." Farmers extract groundwater by installing private wells and pumping the water using either electricity or diesel fuel, with this extraction typically constituting one of the main components of energy demand. Due to the implementation of California's Sustainable Groundwater Management Act (SGMA), groundwater extraction may be limited in the near future.

California's water supply has been increasingly stressed and SGMA is an effort to preserve this critical resource. The farms in Kern County rely on several water districts, with at least 24 distinct districts serving the region. Of these, only two districts servicing Kern County have been designated as "Tier 1" districts, Buena Vista Water Storage District and Kern Delta Water District. This means the majority of the farms in Kern County have less reliable and more expensive access to water. Farms that are outside of a water district, referred to as white lands, are likely to face many challenges in the future due to increased water pricing and resulting scarcity compared to otherwise similar farms that are serviced by a water district.

Besides white lands, there are signs that related costs of growing crops are already causing major shifts in the agricultural landscape in Kern County. In 2019, the total acreage of cultivated land was approximately 1,008,795 acres, and in 2023 this total was only 847,002 acres, a decrease of 16%. This trend poses significant implications for the local economy, as agriculture plays a vital role in Kern County's economic prosperity. However, amidst these challenges, the implementation of agrivoltaics systems presents a promising solution, as one of the benefits of implementing APV systems in Kern County is potential water savings.

Soil Types

According to data from California Department of Conservation (2020), sandy loam is the dominant type of farmland soil in Kern County. Sandy loam is a mixture of 15% clay, 20% silt, and 65% sand (NESDIS, n.d.). As sandy soil has a lighter texture due to its higher sand content, it inherently possesses a relatively low plant-available water holding capacity that ranges from 1.25 to 1.75 inches of water per foot of soil (University of California: Division of Agriculture and Natural Resources, 2016).

Consequently, sandy soil often requires more frequent irrigation to sustain plant growth. In hotter climates, the increased rate of evaporation further exacerbates the need for frequent irrigation. The USDA Natural Resources Conservation Service (2017) explains that because of their textures, sandy loams are more easily compacted than other soils. As addressed by the USDA (n.d.), the installation of solar panels can cause soil compaction and reduce soil quality. Therefore, soil type is an important risk consideration when installing APV systems.

Farming Practices

Kern County is well known for its large-scale industrial agriculture. Hence, big farming equipment — either for sowing, pesticide spraying, or harvesting — is likely involved in the agricultural activities of the farms in the region. Large farming equipment complicates agrivoltaics implementation as it may require larger, more sophisticated, and ultimately, more expensive solar PV configurations. These challenges will vary significantly across various crop types due to their different cultivation practices. For example, table grape cultivation relies heavily on manual labor for tasks such as tying, pruning, thinning, and harvesting and typically use tractors that are around six-seven feet tall for pesticide application and soil maintenance. On the other hand, citrus farms involve fewer manual tasks during harvesting, but maintenance activities such as tree hedging and topping require large equipment that can reach 11 feet tall. During the hedging and topping process the use of large circular blades and flying debris could pose a significant risk to the solar panels in an APV system.

Crops Grown

Data from the Kern County Department of Agriculture was used to measure the active acreage of each crop in order to assess the extent of the county’s agricultural footprint.

In 2023, there were more than 180 different crops grown across 938,135 acres of land in Kern County, parceled out to more than 12,000 distinct farm plots. Almonds, pistachios, grapes, wheat and alfalfa were some of the crops that had the largest share of the county's agricultural land. Total acreage and farm plots for each of the most common Kern County crops is listed on Table 2 below.

Table 2. Kern County crops by total acreage

CROP	NUMBER OF PLOTS	TOTAL ACRES
ALMOND	2479	211,455.95
PISTACHIO	1652	184,887.91
UNCULTIVATED AG	1073	91,132.91
GRAPE	1184	57,770.56
WHEAT FOR FODDER	591	41,220.81
ALFALFA	537	33,923.63
ORANGE	685	32,003.43
CORN FOR FODDER	462	30,543.50
CARROT	323	23,400.45
TANGERINE/SDLS	377	20,356.24
POTATO	235	17,490.94
GRAPE, WINE	158	17,134.50
TOMATO PROCESS	155	13,407.90
POMEGRANATE	90	10,984.51
WHEAT	134	9,287.80
COTTON	155	8,998.43
GRAPE-ORGANIC	134	6,832.18
GRAPE, RAISIN	56	6,622.43
LEMON	159	6,473.46

Through GIS analysis, Kern County's challenges and opportunities have been mapped, providing a nuanced understanding of the region's agricultural, water, and energy landscapes. By leveraging spatial data, we've identified a pressing need to address the escalating costs of water and the imperative to sustain croplands amidst evolving environmental pressures.

Agrivoltaics with Kern County Agricultural Commodities

This section explores the implementation of agrivoltaics around the world, specifically on the agricultural commodities of Kern County. This project focuses on examining the top 10 food crops of the county, selected based on their economic value, as reported by the Kern County Department of Agriculture and Measurement Standards in their 2022 Kern County Crop Report. These commodities are grapes, citrus, almonds, pistachios, carrots, potatoes, alfalfa, garlic, tomatoes, and onions. Preliminary research indicates that there are currently no publicly available reports or articles of agrivoltaics implementation for almond, pistachio, and carrot. Therefore, only the remaining crops are discussed in detail in this section. It is important to note that none of the studies cited are based in locations with the exact same climate as Kern County (i.e., semiarid), most most referenced APV projects are in either Mediterranean or temperate climates.

Grapes

Tresserre and Piolenc, France (Sun'Agri, 2021)

Sun'Agri, a pioneer and the global market leader in dynamic agrivoltaics, has built about 18 projects in France including notable wine grape vineyards located in Tresserre and Piolenc. These locations have a Mediterranean climate, which is characterized by mild, wet winters and warm, dry summers with three-fourths of the annual precipitation concentrated between late autumn and spring (Stefanaki & Van Andel, 2021). The world's first agrivoltaics power plant in Tresserre, Domaine de Nidolères was developed on an area of 4.5 hectares (approximately 11 acres).

A 2 MW solar farm was installed on the family-owned vineyard at a height of 4.5 m, or almost 15 feet, above the ground level. This height allows the vineyard's farming machineries to pass through and operate under the panel as shown in Figure 3. The vineyard, which grows Grenache Blanc, Chardonnay and Marselan wine grapes, has 8 feet spacings between rows and 3 feet spacings between vines. Sun'Agri reported preliminary results which showed a 20% reduction in the test plot's water consumption. Additionally, the study observed improvements on organoleptic properties, the typical sensory properties of a food including taste and appearance (Theuer, 2006). The anthocyanins, red pigments responsible for the red-purple color of grape skins (Watrelot, 2020), increased by 13% and the acidity increased 9%-14%. The vineyard benefited from minimal impact to leaf growth and scorch during the heatwaves in the summer of 2019.

Figure 3. A tractor passing through agrivoltaics at Domaine de Nidolères, Treserre, France
Source: Martin-Cocher, 2022

Similar results were reported for Sun'Agri's experimental plot in Piolenc which showed a 34% reduction in water requirements. This experimental site grows Grenache Noir wine grapes and has similar agrivoltaics dimensions to the previous plot, with solar panels that can be rotated within a range of +/- 90° from their initial position.

Onjin-Gun, South Korea (Cho et al., 2020)

This study was conducted in 2019 at an experimental site located in Onjin-Gun, South Korea that has a temperate climate. The experiments involved three types of solar panels – monofacial, bifacial, and transparent – installed above an unspecified grape farm with an integrated rain-hit protection structure, where transparent canopy shields the vine from rain. The structure with acrylic panels on top had row widths of about 8 feet and a height about 7 feet above the ground. The PV were installed on clear acrylic panels formed at a 15° angle to force the rain to drop in a specific direction. In the case of the monofacial solar panel, it was a turnable type that was installed on top of the rain-hit protection structure. The bifacial and transparent panels were placed on the rain-hit protection roof with a checkerboard pattern and shaded about 30% of the total roof area.

Figure 4. Installation of three different types of solar panels from left to right: normal, bifacial, and transparent.
Source: Cho et al., 2020

The study found a negligible impact on yield. A slight increase in soil temperature was observed due to the application of agrivoltaics, attributed to the heat of the solar panels and their contribution to blocking cold air. In terms of fruit quality, there was a lower sugar concentration observed along with a slight delay in grape growth of approximately 10 days. Additionally, there was a delay in coloration observed for berry growth under the solar panels.

Citrus (Petroni, 2023)

Currently, there is only one citrus site with agrivoltaics which has publicly available data. This citrus site is located in Scalea, Italy, and has a mediterranean climate. This family-owned site grows citron (Citrus medica) and lemon under the agrivoltaics system, featuring alternating lines of transparent plastic sheets and photovoltaic panels installed on the racking structure. The PV panels are positioned approximately 12.5 feet above the ground, creating alternating lines with transparent plastic sheets that cover the farm (see Figure 5).

Figure 5. Topping process under agrivoltaics system of a citrus farm at Scalea, Italy
Source: Gibson, 2023

This agrivoltaics system resulted in a 70% reduction of water consumption. The physical properties of the fruits also improved, bolstering larger fruits, more vibrant colors, fewer defects, and a higher concentration of essential oils in their rind.

Potatoes

Oregon, United States (Garrett et. al, 2021)

In 2021, Oregon State University conducted an agrivoltaics trial at Corvallis, Oregon, which has a temperate climate throughout the year. Belmonda and MonDak gold potato varieties were planted under a dry-farming practice in between traditional ground-mounted solar panels which provided partial shade. The study reported an overall yield increase of 20% compared to potatoes cultivated under the full sun treatment.

Hegelbach Farmland, Germany (Trommsdorft et. al, 2021)

An experiment in a community farm in Southern Germany applied an elevated mounting system design, which allows potato cultivation under solar arrays tilted at 20°. This experimental site, which also experiences a temperate climate, raised the mounting system to approximately 16 feet above the ground to provide vertical clearance. Additionally, the width clearance between rows is 19 m or approximately 62 feet. These dimensions allow the operation of large machinery (see Figure 6), which is typically employed in large-scale potato cultivation.

Figure 6. Potato harvesting under agrivoltaics at Haggelbach Farm
Source: Schindele et al., 2020

In 2017, there was an observed 18% decrease in potato yield, however, the following year saw an 11% increase in yield due to increased air temperatures and significantly reduced precipitation. However, water distribution was uneven during periods of heavy rainfall due to the presence of elevated PV panels. As a result, some plants experienced water shortages while others were flooded.

Alfalfa (Edouard, 2023)

An agrivoltaics experiment using Alfalfa was performed in the temperate Seine et Marne, France. Three rows of solar panels were elevated to approximately 15 feet above the ground and spaced approximately 39 feet apart. The panels are mounted on dual-axis trackers and can be tilted by +/- 50° on both axes of rotation, as shown in Figure 7. The results indicate that alfalfa yields increased by 10% when the shading percentage ranged from 29% to 44% compared to conditions with full sun exposure. Additionally, the shade from the agrivoltaics system increased the amount of water available to the soil roots when compared to an open field agricultural configuration without PV.

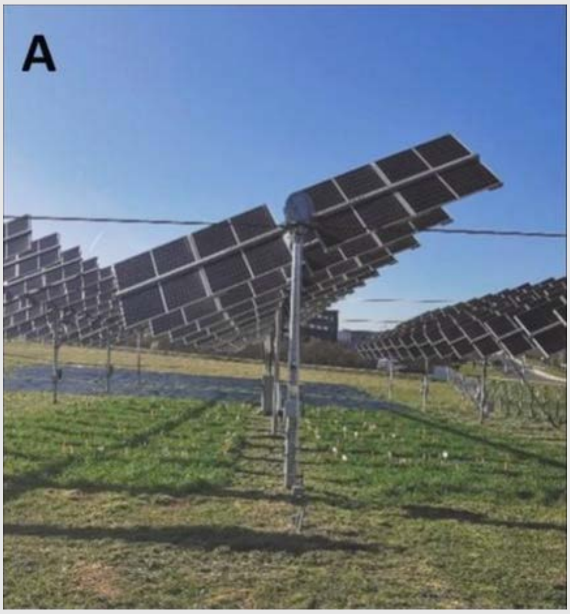


Figure 7. The agrivoltaics system of the alfalfa experiment
Source: Edouard, 2023

Garlic and Onion (Jo, 2022 & Ko, 2023)

A field experiment in Naju, South Korea (Ko, 2023) cultivated garlic in an agrivoltaics system under warm climate (see Figure 8). The solar panels, angled at 30°, were installed at a height of approximately 11 feet above the ground. Results showed average garlic yields were reduced by 15% compared to open fields.

A similar experiment conducted in Pohang yielded comparable results. In Pohang, using the same mounting structure dimensions but with a higher tilt angle of 35°, crop yields were reduced by 18.7% (Jo, 2022). In this secondary site, onions were also planted, which experienced a 14.6% yield reduction.

Figure 8. The agrivoltaics system of the garlic experiment at Naju (left) and Pohang (right) with a combination of onion, South Korea
Source: Jo, 2022 & Ko, 2023

Tomatoes

Oregon, United States (AL-agele, 2021)

In a study conducted in Corvallis, Oregon, tomatoes were grown under solar panels built at a height of about 6 feet with panels tilted at an 18° angle. This configuration resulted in a tomato yield reduction up to 62% compared to crops receiving less shade. However, there was a significant reduction in water consumption of up to 55%.

Puglia, Italy (Mohammedi, 2023)

In Puglia, Italy, which has a Mediterranean climate, agrivoltaics experiments with tomatoes were conducted utilizing both monofacial and semi-transparent solar panels with 50% and 80% shading, respectively. The results show that soil temperature varied with shading percentage, as soil temperature under monofacial panels decreased by 1.3°C while semi-transparent panels showed a decrease of 2.3°C. Both configurations showed promising results for water conservation, as monofacial panels reduced water use by 21% – slightly more than the 16% reduction observed with monofacial panels. However, crop yield reductions were significant: up to 40.7% reduced tomato yield for semi-transparent panels and monofacial panel configurations reduced tomato yield by an even higher 58.3%.

Figure 9. Experimental agrivoltaics site for tomatoes cultivation in Puglia, Italy
Source: Mohammedi, 2023

Crop Suitability Scorecard

The suitability of potential APV sites is dependent on multiple factors specific to each farm. Compatibility of relevant Kern County crops within an agrivoltaics setup was evaluated based on data from the prevailing literature. Suitability scoring was achieved by comparing Kern County's top crops across four criteria groups: cultivation methods, land use, economics/profitability, and community impact. A few parameters were evaluated within each criteria group (See Figure 10 below). Currently, suitability was evaluated based on integration with an 8ft elevated single-axis tracker agrivoltaics system as informed by the optimal solar performance for energy generation (see Energy section for more details).

The current data for each parameter are sourced from secondary research and literature highlighted in the previous sections. Parameter data across all included crops are translated to compatibility scores on a scale of 0-10 using percentile ranking. In order to arrive at an overall suitability score for each crop, the scorecard model calculates the sum-product of all parameter scores and their assigned weights. The suitability score for each crop is given on a scale of 0-10 where 0 represents the crops that are least compatible with an 8ft elevated agrivoltaics system and 10 represents the crops that are most compatible. The current state of the scorecard model assumes an equal weighting across all parameters with the option to adjust these weights as future localized demonstration sites may provide more relevant input data for suitability in Kern County. Due to limitations in data availability, the scorecard model was built to provide flexibility for future refinement.

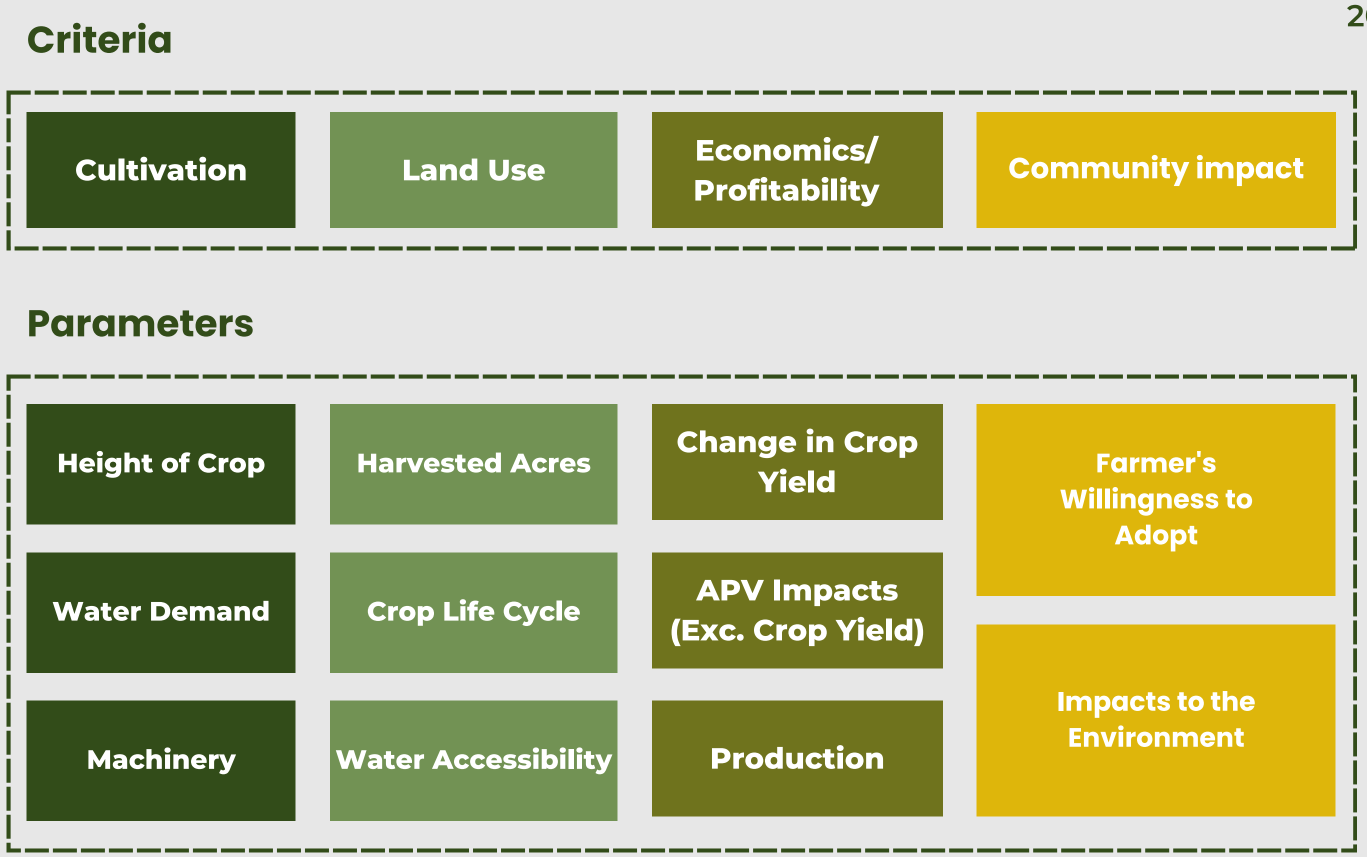


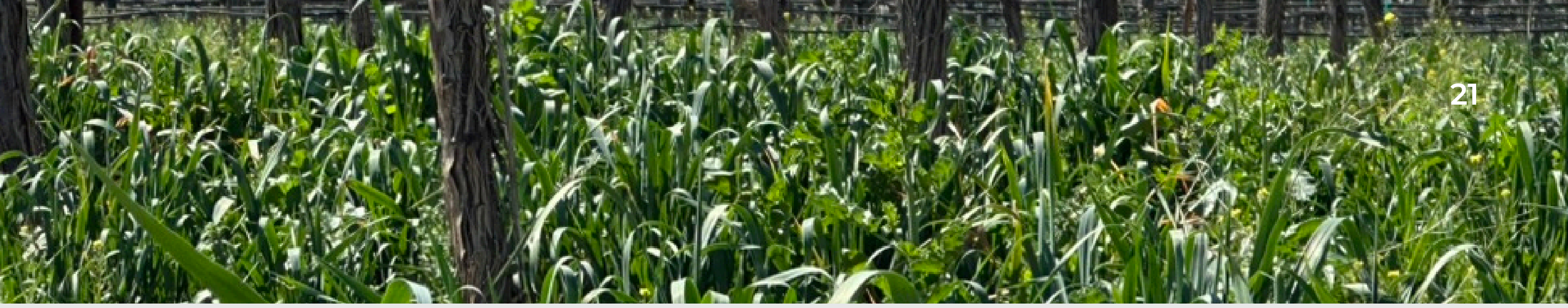
Figure 10. Crop suitability framework

Cultivation

Cultivation criteria play a critical role in developing a comprehensive crop scorecard specifically tailored for agrivoltaics. Parameters like height of the crop, water demand, and machinery are particularly important in determining successful cultivation alongside APV.

Crop height is essential for maintaining an appropriate balance between shading for solar panels and maximizing crop productivity. The optimal threshold for height of crops was set between 6 feet and 7 feet considering an 8 ft elevated system configuration. Crop height could be a limiting factor for successful agrivoltaics integration, as certain crops may grow higher than the heights at which PV panels can be built cost-effectively. In our model, crop height poses suitability challenges for crops such as citrus, almonds, and pistachios.

Water demand directly affects plant growth and productivity, as well as overall costs. Assessing water demand per crop in comparison to available water resources can reflect how much groundwater needs to be extracted for irrigation to support proper crop development. For instance, a water demand parameter is quantified using crop water use data (in inches per year) sourced from local weather stations; this crop-specific information is then compared to the average annual precipitation in Bakersfield to determine excess water demand.



Considering cultivation methods is critical to ensure compatibility with solar panel configurations and ease of maintenance. After considering multiple configurations, an 8 ft elevated agrivoltaics setup would likely work best for crops with manual harvest methods as opposed to those that use large farming equipment for harvesting and trimming. Agrivoltaics with machinery can still be a viable option as long as the machinery is compatible with the solar panel setup (i.e. the height, width, and spacing between panels), though it is less likely to be favorable if harvesting or tending crops involves heavy equipment. Cultivation methods could be a major limiting factor due to the use of heavy equipment such as tractors, mowers, choppers, balers, mergers, tedders, and trucks or chopper wagons during various stages of the crop lifecycle. However, customized agrivoltaics configurations can help address some of these challenges.

Incorporating these cultivation criteria into a crop scorecard can enable farmers and stakeholders to make more informed decisions about favorable crop selection, leading to sustainable and synergistic outcomes alongside agrivoltaics, where both energy generation and agricultural production can thrive harmoniously.

Land Use

Land use criteria are fundamental components for determining a crop's suitability, as parameters such as harvested acreage, crop lifecycle, and water accessibility help narrow down those crops which may be most resource-efficient.

The harvested acreage parameter considers both the spatial requirements and variability in harvested acreage for each crop in Kern County in order to identify the most preferred crops for production.

The life cycle of a crop, whether perennial, annual or biennial, needs to be taken into account when considering interactions with solar PV. Perennial crops have a longer lifespan and require less frequent replanting and tending compared to annual and biennial crops. This characteristic can make certain crops more compatible with agrivoltaic systems, as they can provide consistent vegetation cover year-round. Perennial crops can also have deep root systems that help stabilize soil and reduce erosion, which is beneficial when considering the installation of solar PV.

Additionally, considering water access ensures that selected crops can efficiently utilize those resources, especially in regions where water availability may be limited, such as in Kern County. This is characterized by our classification of the local geography by water districts and white lands derived from geospatial analysis. Water districts in Kern County provide public access to water, while white lands are areas not serviced by water districts that solely rely on pumping groundwater.

By integrating these land use criteria into the crop scorecard, stakeholders can make informed decisions regarding crop selection and management, promoting sustainable and efficient land utilization in agrivoltaics setups.

Economics/Profitability

Economics and profitability criteria help determine crop productivity when paired with solar PV, thus differentiating those crops that are more likely to experience yield benefits in APV projects.

Crop yield directly impacts production value and profitability, emphasizing the importance of selecting those crops that thrive underneath the shade of solar panels. This affect that shading has on crop yield can have a significant impact on profitability, thus the current data points are sourced from secondary research at locations with similar climate profiles as that of Kern County in order to model yield results from a similar environmental context. The robustness of this data can be improved by utilizing observed yield data from future Kern County APV demonstration sites.

Agrivoltaic-related crop impacts (excluding yield) include reduced water use, higher moisture levels in the soil, cooler soil temperatures and improved physical/organoleptic properties such as larger fruit, better color, fewer defects, and better sugar content. These properties enhance the quality of the crop, making them more valuable in commercial markets by improving their marketability and potentially commanding higher prices.

Production value considers the overall economic output generated by a crop, factoring in both quantity and price within the context of Kern County. Crops with larger, more positive growth in value signal local economic importance and could ultimately support adoption in the region.

By integrating these economic and profitability criteria into a crop scorecard, stakeholders can make informed decisions about crop selection, resource allocation, and financial planning, ultimately driving the economic sustainability and success of agrivoltaics initiatives.

Community Impact

Community impact criteria are included to assess the viability of agrivoltaics within the regional context. Farmers' willingness to adopt new farming techniques is vital for the successful integration and support of agrivoltaics, as it influences overall productivity and acceptance within the community. The weighting for the 'Farmers' willingness to adopt' parameter is currently set to 0% due to a lack of responses from farmers in the distributed survey (see Stakeholder Analysis section), however this is provided as a placeholder that can be updated with data points in the future with further research. Our Life Cycle Assessment (LCA) screening identified the potential environmental impacts of agrivoltaics integration by crop type. These LCA results are direct inputs into the environmental impact criteria for the crop scorecard, with lower scores indicating a higher intensity of environmental impact.

Life Cycle Assessment (LCA)

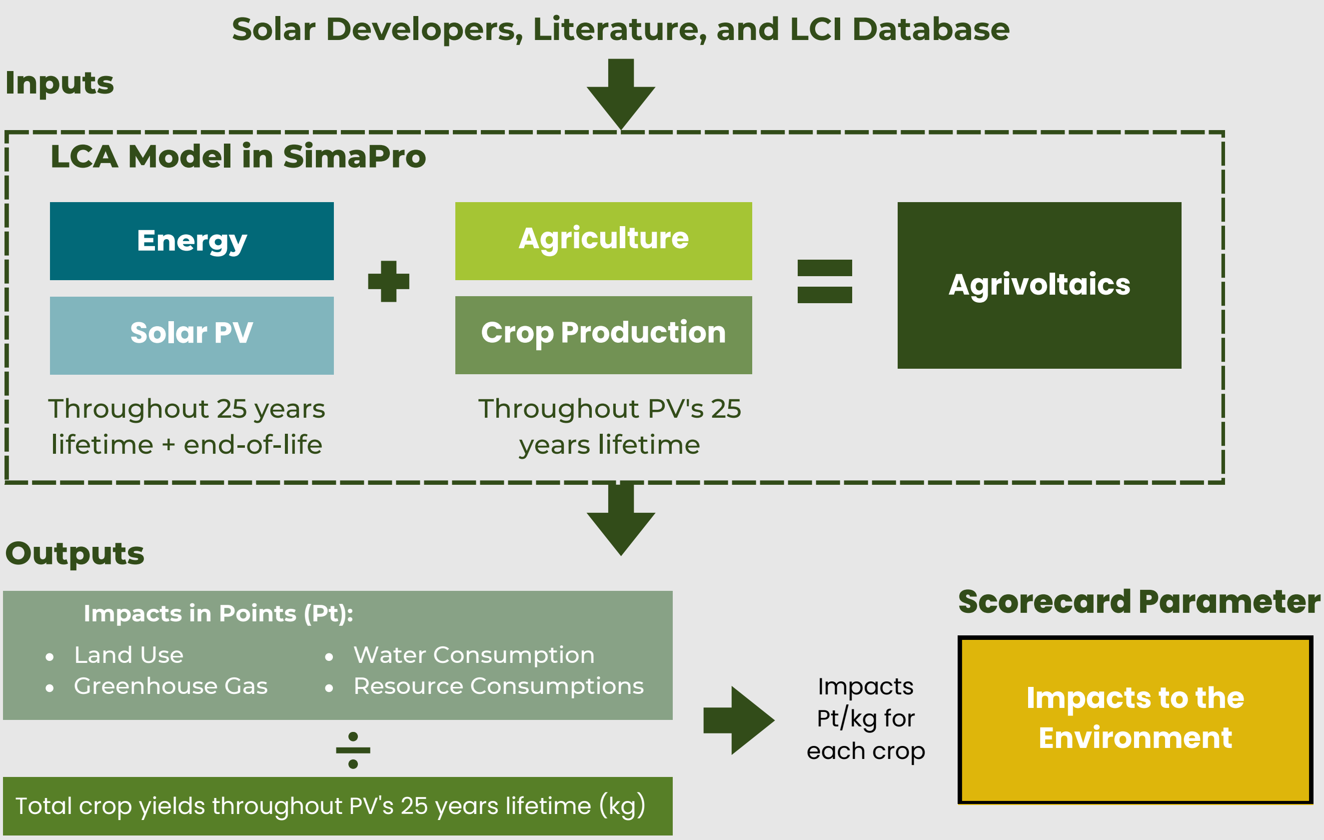
Life Cycle Assessment (LCA) was used to measure the environmental impacts of agrivoltaics and those results also serve as an evaluation parameter in our crop scorecard. According to ISO 14040 (2006), LCA is defined as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. Inputs include raw materials, ancillary materials, and energy, while the outputs include the products, emissions to air, water, and soil, as well as waste generated. By compiling and evaluating these inputs and outputs quantitatively, LCA results provide the magnitude of the potential environmental impacts (e.g. global warming potential in kg CO2 equivalent, or water consumption in m3) of the product system.

The LCA framework has four iterative processes (ISO, 2006): goal and scope definition; life cycle inventory; life cycle impact assessment; and interpretation of results. Depending on the project scope, a rigorous LCA of a single product system, can sometimes take months. Due to time constraints, LCA screening will be used for this project to estimate the environmental impacts of agrivoltaics implementation, specifically on land use, water and resource consumption, as well as global warming potential. The results are intended to be used as one of the parameters in the crop scorecard and to provide preliminary insights for applicability. A comprehensive and site-specific LCA should be carried out for the actual construction of an agrivoltaics project.

LCA Screening Framework

In this project, the LCA screening model consists of two sub models, energy for the solar PV system and agriculture for crop production. Since there are 11 agricultural commodities (grapes are divided into both table and wine types) included in this project, there are 11 LCA models. Under the energy model (see Project Finance Model section), the impacts are calculated throughout the solar PV's lifetime – assumed to be 25 years – and its end-of-life. The agricultural model only calculates the agricultural production impacts on-farm throughout the solar PV's lifetime. Production outside the farm is not included as their impacts are not considered relevant to the scope of this analysis. The sum of impacts from both the energy and agriculture model builds the total impacts of the agrivoltaics system. Total impacts are divided by total crop yields to facilitate a per-unit impact comparison between crops. Figure 11 shows an overview of the framework.

Figure 11. Environmental impact assessment framework



The model is built in SimaPro, an LCA software, and the ReCipe 2016 impact assessment method was used to quantify the agrivoltaics environmental impacts on land, water, resources, and global warming. Resource consumption is represented by the impact of material inputs to solar PV structures. The decision to take this approach is supported by research conducted by Busch and Wydra (2023), which shows that more than 90% of the materials used in PV mounting structures are aluminum and steel. This finding underscores the importance of considering the environmental impacts associated with extracting these materials, as both aluminum and steel are derived from carbon-intensive ore extraction processes.

Dataset Modification

Under the LCA screening, relevant datasets from Life Cycle Inventory (LCI) databases were used for quick insights. Some key parameter values, including material consumption for mounting structures, change of crop yield, and water use for crop cultivation, were modified to represent the agrivoltaics product system. The modified values were derived from literature in respect to the agrivoltaics design assumed in this project, which is overhead 8-ft elevated solar panels as mentioned under the Crop Scorecard Section. The key parameters were classified into two areas: agriculture and energy.

Agriculture Data

Agrivoltaics could potentially increase, decrease, or have a neutral impact on crop yields and water consumption. Among the crops we analyzed, grapes and citrus show a potential increase of crop yields due to shading benefits. Conversely, for carrots, potatoes, alfalfa, garlic, tomato, and onions, a presence of shadow can potentially decrease crop yields. There are no specific studies on shading impacts on the yield of almond and pistachio, thus it is assumed to have an unknown impact for these two nut trees. There are also very few peer-reviewed sources on the potential water impacts of agrivoltaics application on almonds, pistachios, carrots, potatoes, alfalfa, garlic, tomato, and onion crops. Therefore, it is also assumed that the impacts are zero or neutral. However, studies on wine grapes, citrus, potatoes, and tomatoes show potential water consumption decreases because of the shading properties provided by agrivoltaics. Table 3 below presents the percentage increase or decrease on crop yields and the relevant water consumption. These percentages are used to modify the dataset used for the LCA screening.

Table 3. Potential % change on crop yield and water consumption because of agrivoltaics

Crops	Yield (%)	Reference	Water (%)	Reference
Wine Grapes	5%	Abeysinghe et al., 2016	-23%	Median from Sun Agri, 2021
Table Grapes**	5%		-23%	
Citrus	49%	El-Naby et al., 2020	-70%	Petroni, 2023
Almond	Unknown*	N/A	Unknown*	N/A
Pistachios	Unknown*	N/A	Unknown*	N/A
Carrots	Unknown*	N/A	Unknown*	N/A
Potatoes	-70%	Schulz et al., 2019	-19%	Median from Mohammedi et al., 2023b
Alfalfa	-24%	Querne et al., 2017	-31%	Edouard et al., 2023
Garlic	-15%	Ko et al., 2023	0%*	N/A
Tomato	-28%	Mohammedi et al., 2023b	-19%	Mohammedi et al., 2023b
Onions	-14%	Jo et al., 2022	0%*	N/A

***No study available, thus the changes are assumed to be neutral;**
****There is no specific information on table grapes, thus currently the changes are assumed to be same as on wine grapes**

Due to the unavailability of a specific LCI dataset for Kern County, the LCA screening used datasets representing U.S. average crop production. If unavailable, datasets from countries like Chile, Mexico, Israel and South Africa with similar climate conditions to California were utilized. In cases of further data unavailability, a global average dataset served as a proxy. Data related to land, water, and energy in non-U.S. datasets used in this study are modified to match U.S. conditions. This ensures that the data at least represents the U.S.

context, aligning with our impact assessment goals. Furthermore, solar energy generated from agrivoltaics replaced data for grid electricity used for irrigation, following the assumption that the solar energy generated from APV is consumed directly by farmers for their agricultural activities. While California – and Kern County in particular – are renowned for their advanced farming practices, it is acknowledged that the general datasets may not precisely reflect local impacts. However, this screening aims to provide initial insights and direction on which crops have minimal impacts to the environment when integrated with solar power generation. A site-specific and comprehensive LCA should be conducted when initiating an actual agrivoltaics project. Appendix B provides information on the LCI dataset used in this study.

Energy Data

For the mounting structure of ground-mounted PV, global average data by Ecoinvent life cycle inventory database v3.9 will be used as the dataset: Photovoltaic mounting system, for 570kWp open ground module. This dataset comprises all inputs and outputs related to the production of a PV mounting system. The quantities of each material are adjusted to reflect the impact of varying heights of agrivoltaics mounting structures, influenced by crop height and farming practices. According to Busch and Wydra (2023), the following materials are changed as the height of mounting structure increases: aluminum, packaging (carton), plastic parts, steel components, and stainless steel components. Stainless steel is used for steel spinning anchors, which replace typical concrete foundations that make agricultural work more difficult.

A linear interpolation was carried out using the data from Busch and Wydra (2023) to estimate the change in impact per foot of each material. In their study regarding LCA of combined agrivoltaics with conventional potato production in Germany, the height of the agrovoltaic mounting structure was assumed to be 5 meters, or roughly 16 ft. This is much higher than a traditional ground-mounted solar PV structure, which is about 4.6 ft (Horowitz et al., 2020). The complete list of changes in material consumption for the mounting structure can be found in Appendix C. In this LCA screening, it was assumed that all crops were grown within an 8-feet elevated agrivoltaics system on an area of 9 acres, which is the minimum area needed to make the project economically viable at a Power Purchase Agreement (PPA) rate of $0.12/kWh. According to our project finance model, this corresponds to a 920 kWp system,[1] which generates 1,561,224 kWh in Year 1 and 36,776,128 kWh over its 25-years lifetime. At a $0.12/kWh PPA rate, we calculated these solar projects would achieve roughly a 10% rate of return which was our threshold for economic viability. Please see Project Finance Model for more detail on the specifics of this project configuration.

Regarding the type of land use for the mounting system installation, the original dataset used an industrial area that was previously converted from man-made pasture. In the context of agrivoltaics, the type of land use is changed to cropland, either vineyard, permanent cropland, or annual cropland, depending on the type of crop. In addition, as the land is used for two different purposes, in the LCA model the land area is divided between solar energy production and crop production. An economic approach was applied, which means the division is based on the economic values of the products (i.e., the crops and energy generated). The crop values are varied, based on inputs from Kern County's 2022 Crop Report, while the energy generated is valued based on the PPA rate of $0.12/kWh. Table 4 provides information on the land allocation for each crop. Furthermore, it is assumed there is no land lost during the installation of the mounting system, so the land transformation process is eliminated.

Table 4. Economic allocation for land use between crops produced and energy generated

Crop Type	Estimated Crop Yield under APV (kg)	Unit Price 2022 ($/kg)	Total Crop Value under APV ($)	Allocation (%)	Energy Gen. (kWh)	PPA Rate ($/kWh)	Total Energy Revenue ($)	Allocation (%)
Table Grapes	2,781,974	2.33	6,482,000	59.5%	36,776,128	0.12	4,413,135	40.5%
Wine Grapes	1,300,256	0.38	497,998	10.1%	36,776,128	0.12	4,413,135	89.9%
Citrus	4,332,217	1.22	5,298,301	54.6%	36,776,128	0.12	4,413,135	45.4%
Almond	281,508	3.66	1,030,321	18.9%	36,776,128	0.12	4,413,135	81.0%

1. The LCI dataset used is based on a 570 kWp system, and no extrapolation is made to a 920 kWp system due to the uniform assumption of system design across all crops, resulting in identical performance. Therefore, extrapolation is not considered necessary to compare impacts between crops.

Crop Type	Estimated Crop Yield under APV (kg)	Unit Price 2022 ($/kg)	Total Crop Value under APV ($)	Allocation (%)	Energy Gen. (kWh)	PPA Rate ($/kWh)	Total Energy Revenue ($)	Allocation (%)
Pistachios	285,546	4.45	1,270,682	22.4%	36,776,128	0.12	4,413,135	77.6%
Carrots	4,954,440	2.07 [2]	10,230,919	69.9%	36,776,128	0.12	4,413,135	30.1%
Potatoes	1,315,553	1.19	1,558,931	26.1%	36,776,128	0.12	4,413,135	73.9%
Alfalfa	349,501	0.37	129,316	2.9%	36,776,128	0.12	4,413,135	97.2%
Garlic	1,373,240	2.50	3,433,102	43.8%	36,776,128	0.12	4,413,135	56.3%
Tomato	1,995,423	0.11	209,519	4.5%	36,776,128	0.12	4,413,135	95.5%
Onions	3,915,337	0.74	2,913,011	39.8%	36,776,128	0.12	4,413,135	60.2%

Environmental Impact Assessment Results

The environmental impact assessment results were input into the crop scorecard under the Community Impact criteria. The preference is an integration of solar power generation with crop cultivation that has the lowest environmental impact score. The LCA results show that APV scenarios reduce the absolute adverse environmental impacts for all crops. However, relative to other crops in the analysis, the integration of solar power generation with nut tree crops – almonds and pistachios – has the highest adverse environmental impact per kilogram of crop produced. The implementation of agrivoltaics with the production of low-growing crops such as potatoes, carrots, garlic, tomatoes, and onions shows a lower relative environmental impact in the LCA results. Interestingly, a similar result is observed for citrus despite being a tall crop. This is due to the model's assumption of a potential yield increase up to 49% (El-Naby et al., 2020) and a reduction in water requirements up to 70% (Petroni, 2023) due to shading on citrus.

2. In 2024, the approximate wholesale price range for U.S. carrots is between US$ 1.38 and US$ 2.75 per kg or between US$ 0.62 and US$ 1.25 per pound (lb).

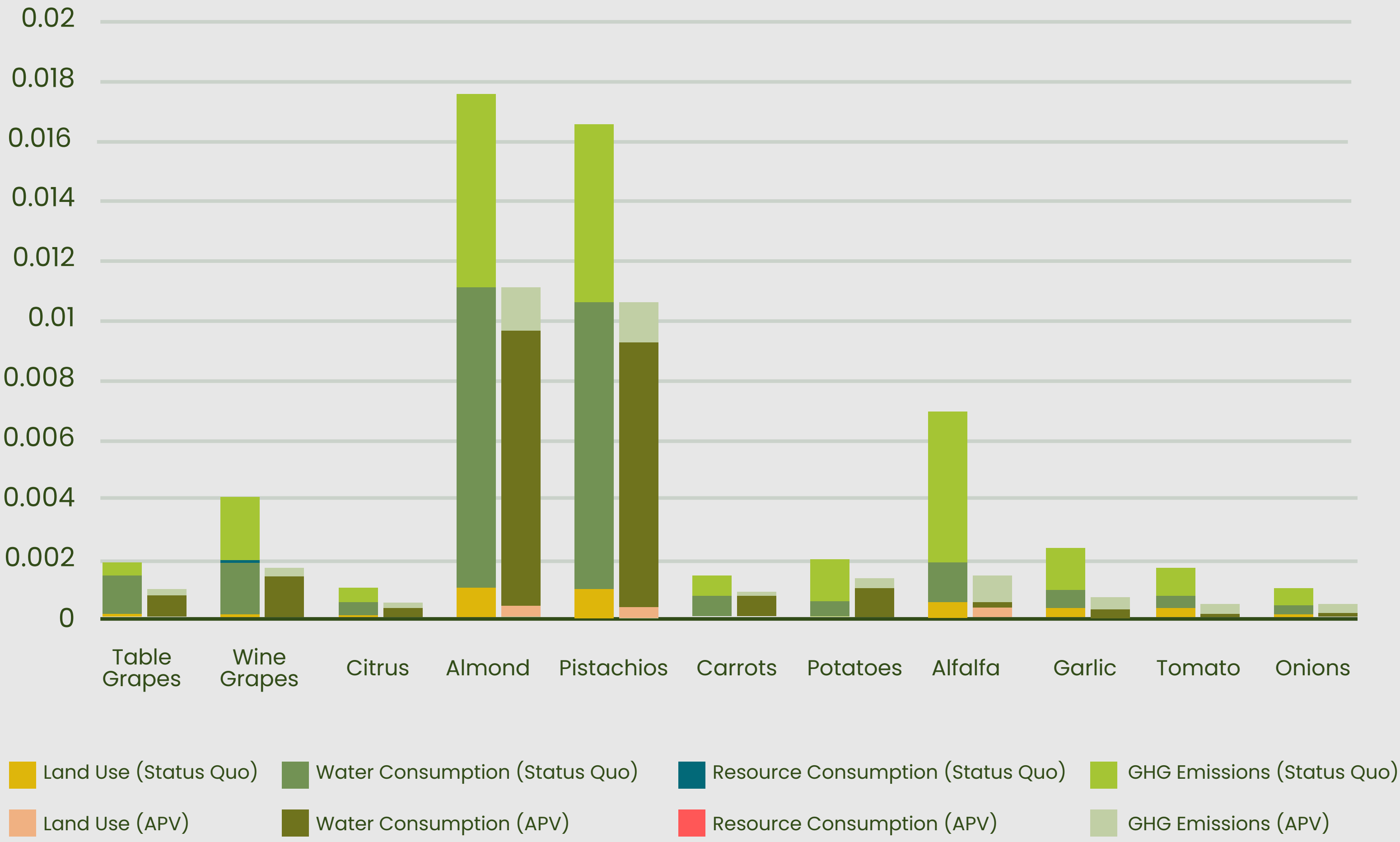
This study's LCA model shows that agrivoltaics or APV can significantly reduce environmental impacts compared to the status quo, which is where electricity generation is primarily sourced from the average Western Electricity Coordinating Council (WECC) market (see Figure 12). The WECC impact profile is based on data from the Ecoinvent database v.3.9: Electricity, low voltage {WECC, US only}| Market for electricity, low voltage | Cut-off, U. By shifting from predominantly fossil fuel-based electricity to solar power, GHG emissions are significantly reduced from the status quo, which is aligned with the goals of our stakeholders in California.

For APV implementation in potatoes, lower yields may result in higher water use intensity per kilogram of crop produced, indicating inefficiencies in water use. However, the overall impact indicates a significant reduction in potential environmental impacts under APV. The potential environmental impact reduction ranges from 32% to 85%. It's important to recognize that these results are closely related to the assumptions made in the LCA Methodology section.

By incorporating these community impact criteria into a crop scorecard, stakeholders can evaluate the social and environmental implications of crop choices within agrivoltaics, fostering inclusive and sustainable practices that benefit both farmers and the broader community.

Figure 12. A comparison of total environmental impacts between agrivoltaics and status quo

Note: Impact points from grid electricity and crop production (left bar) vs. APV integration (right bar)



Crop Suitability Results

Based on the assumptions stated above, the crop scorecard shows promising results for table grapes along with positive indicators for other crops such as wine grapes, tomatoes, and alfalfa. In evaluating crop suitability, the following results stood out:

- Physical limitations such as height of the crop and cultivation method heavily influenced suitability in our assessment as crops that grow higher than the panel and require heavy machinery often require greater than 8 ft elevated APV configurations. Hence, the crops that grow to a maximum height between 6 feet and 7 feet and require manual cultivation methods throughout the crop lifecycle are favored.

- Water demand and water accessibility were leading indicators of suitability as crops that are outside white lands and command higher water use stand to benefit from agrivoltaics; the integrated approach to farming can mitigate water loss from the soil surface, enhancing water retention and reducing overall irrigation needs.

- Crop yield and other APV impacts focus on the economic benefits of agrivoltaics integration, favoring crops that yield positive results under the influence of shading from the panels. However, our research found that economic criteria were not the main driver of suitability, suggesting the relative importance of environmental, social and operational considerations.

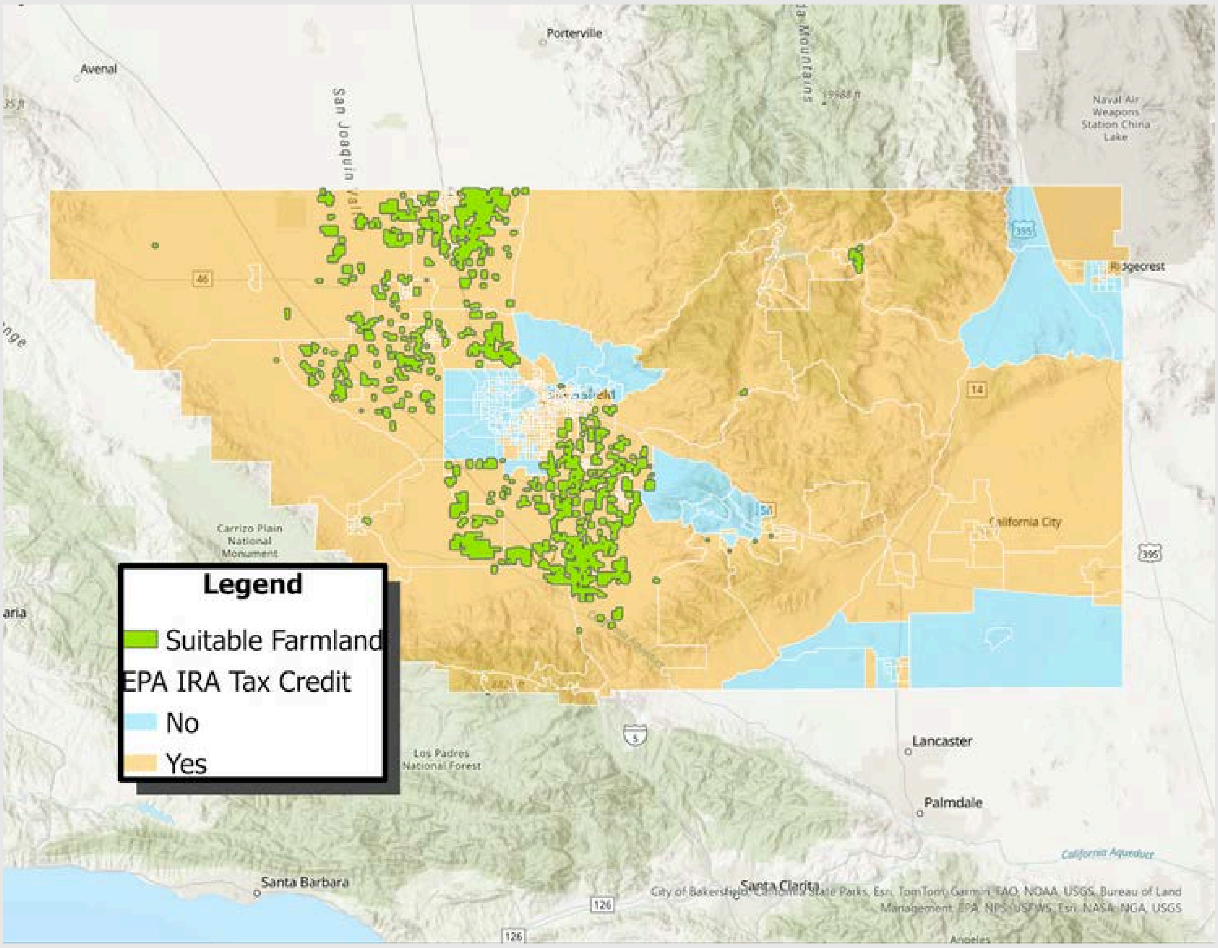
- Parameters such as growth in harvested acres and crop lifecycle were other considerations that signaled the growing demand for a particular crop in the region, suggesting valuable commodities that may be prioritized for a demonstration site.

We found that table grapes are accessible for immediate implementation within an 8ft elevated single-axis tracker agrivoltaics system. Table grapes showed relatively positive results across our range of parameters while wine grapes, tomatoes and alfalfa also showed encouraging results for successful agrivoltaics integration.

Table grapes scored well due to crop height, manual cultivation methods, positive indicators for water demand and accessibility, positive crop yield effects, and growing demand signaled by an increase in harvested acres. Implementing agrivoltaics on all suitable acres of table grapes would result in valuable reductions in water demand (see *Surface and Groundwater Depletion due to Irrigation Demands* within the Cost-Benefit Analysis section for more details).

Figure 13 below identifies land parcels growing grapes, tomatoes, and alfalfa that are situated within the EPA IRA tax credit zone. The average size of these farm plots is about 60 acres. This selection represents more than 116,000 total acres belonging to roughly 2,000 individual farm plots. If agrivoltaics were to be implemented with just these three crops in farms eligible for the tax credits mentioned above, APV could potentially quadruple the amount of renewable energy generated in the county. However, considering the massive amount of agricultural land in Kern County, the extent of the identified land suitable for APV implementation is only about 12% of the total acreage of farmland in Kern County.

Figure 13. Grape, alfalfa, and tomato farmland in Kern County, including regions eligible for IRA tax credits



ENERGY

03

Kern County Energy Profile

Energy is one of the driving factors behind California's massive economy. If energy and electricity are foreign concepts, please refer to the Supplemental on Electricity, Power, and Energy for a primer on standard industry terms. In 2022, the State had a total electricity consumption[3] of 287,826 gigawatt-hours – hereafter abbreviated as GWh (California Energy Commision, n.d.). Kern County accounted for about 5% of that total with a consumption of 14,862 GWh, claiming the spot of 7th largest county by electricity consumption in 2022. However, this rank was trumped by more energy-intensive counties, such as Los Angeles, which accounted for about 24% of the State's entire electricity consumption. Based on a 2017 baseline, California projects that its annual energy consumption will continue to grow at a rate of 1.64% through 2030, largely driven by electrification efforts, such as the conversion of internal combustion engine vehicles to electric. This could drive the total consumption as high as 350,000 GWh by 2030 (Commission, C.E., n.d.). In order to meet this demand, California's energy supply will have to grow accordingly.

In 2022, California's total energy generation reached 203,256 GWh, as reported by the California Energy Commission. Notably, this figure excludes behind-the-meter solar photovoltaic generation. Regardless, it is clear that a supply and demand imbalance is present, considering there is a delta of almost 85,000 GWh which cannot fully be made up by behind-the-meter generation which is typically small in scale. California, through being part of the Western Electricity Coordinating Council, relies heavily on energy imports from surrounding states to meet its energy needs. These imports travel from surrounding states such as Nevada – and even as far away as Canada – to meet the energy needs of California. Imports have been relatively consistent the past few years at just beneath 84,000 GWh, accounting for 29% of the total electricity generation on California's grid (Commission, C. E., 2022).

For the remaining 71%, renewable energy is becoming an increasingly popular part of the mix. Largely driven by the California's Renewable Portfolio Standard (RPS), utilities are highly incentivized to increase their procurements of energy from renewable resources. The RPS was established in 2002 by Senate Bill (SB) 1078. It initially required that 20% of electricity retail sales be served by renewable resources. It established a 15-year timeline for the state to meet this law by 2017. Upon achieving this goal early, the order was accelerated in 2015 to a 50% RPS target by 2030. Additionally, this established that RPS procurement should be derived from long-term contracts (10 years or more) with renewable

3. To understand the significance of a GWh, a helpful reference point is that the average American home consumes 11,000 kilowatt-hours annually. Therefore, a single GWh represents the annual electricity consumption of roughly 91,000 homes.

energy generators. The law was expanded once again with SB 100 in 2018, which increased the 2030 target to 60% and required all electricity to be generated from carbon-free resources by 2045 (State of California, 2024).

Kern County in particular plays an important role in California's electricity generation, representing 16% of the State's total generation. More importantly for the purposes of our research, Kern County accounts for 25% of the state's total renewable energy generation, making it the largest generating county in California (Commission, C. E., 2022). Of this installed base of renewable generation in Kern County, 1% is biomass, 1% is small Hydro, 43% is wind, and 55% is solar photovoltaic. The county has been an attractive location for the development of solar systems because of land availability, high solar irradiation, and access to transmission lines. However, the prospect of bringing new solar generation online is more challenging than ever in Kern County, and California more broadly, due to transmission line constraints and a large backlog of interconnection applications. This is exemplified by the decision that the California Independent System Operator (CAISO) made in February 2024 to postpone any new utility-scale energy projects from requesting to be interconnected to the grid by a full year (CAISO, 2024). In order to meet the Renewable Portfolio Standard (RPS) goals as well as the ever-growing demand for energy, a creative approach is needed to leverage the mature solar industry in Kern County despite these challenges.

Interconnection

In order to make financial use of the energy produced by the solar panels, new systems must be connected to the grid through an interconnection process with the utility. Electrical distribution and transmission in Kern County is primarily served by Pacific Gas & Electric (PG&E) and Southern California Edison (SCE). The interconnection process is relatively simple at a smaller scale and gets more difficult as the potential impact to the grid increases. There are opportunities and challenges of interconnecting a solar system to serve only the electrical load of the farm (behind the meter, or BTM) and interconnecting to push clean energy to the grid to serve the utility or community (front of meter, or FTM).

Behind the Meter

Behind the meter configurations are intended to offset electrical use on the farm, thus limiting the number of panels the farm can install. For our analysis, we assumed that the primary electrical load – where the solar panels could be sited to provide power – will be at the same meter as the primary irrigation pump. From our site visit in mid-March, we identified that many of these pumps do not draw a significant amount of energy, with observations between 30kW and 120kW.

Most BTM solar projects in CA are built using a Net Energy Metering (NEM) agreement with the utility, as determined by the California Public Utilities Commission (CPUC). Through this policy, customers produce energy from solar to offset their own electricity use and sell back excess power to the utility at approximately the same price that they would purchase it. Agricultural customers could take advantage of a policy known as NEM Aggregation, which allows customers with multiple meters to use the energy produced by solar panels on one meter to offset energy use on a different meter. The NEM policy in California recently went through a large overhaul, changing the value of the exported solar energy to match the value that CPUC ascribes to the utility for adding distributed energy resources to the grid at that time. The NEM Aggregation advantage was also eliminated for agricultural customers. This has largely resulted in much lower compensation for solar customers.

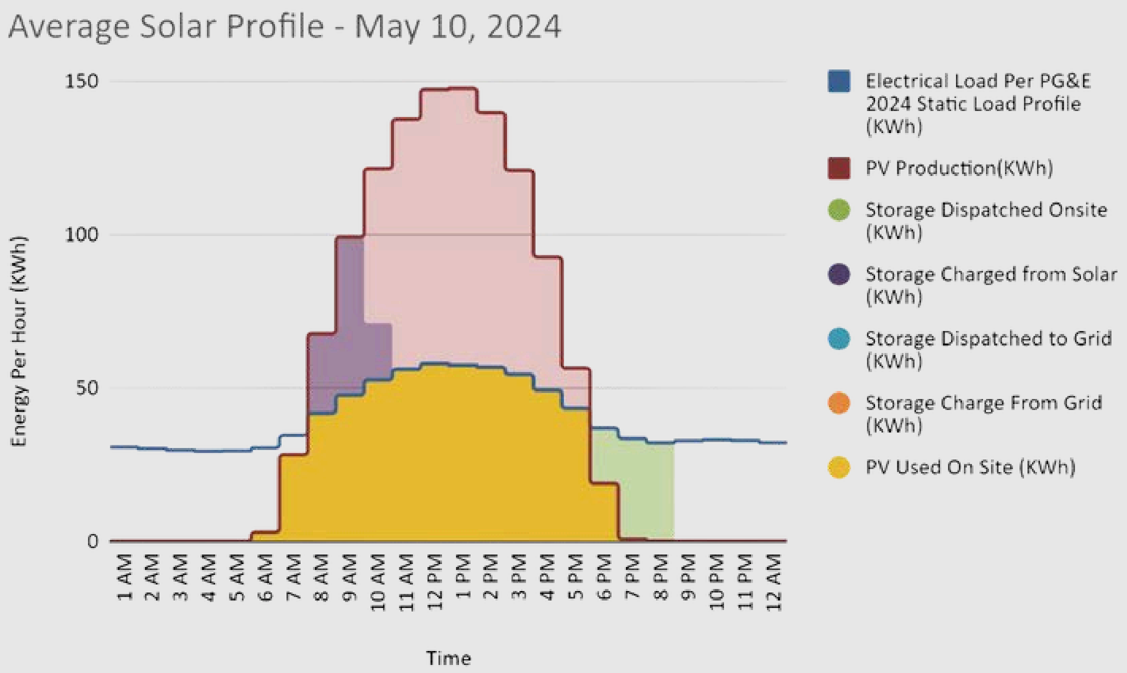
Under this new policy, the value of exported electricity changes depending on the hour of the day, calculated according to a public tool known as the Avoided Cost Calculator. This tool, developed by energy consulting company, Energy & Environmental Economics (E3), has been used by the CPUC in the past to model the impact of renewable resources on the California grid. The largest California utilities coordinated with E3 to develop the tool, and can use it to develop PV export rates that change every hour. Factors such as electricity demand, influence of other distribution sources on the grid, and greenhouse gas emissions influence the hourly rates. These hourly rates can also change per month and from weekday to weekend. This makes forecasting potential compensation difficult, as there are now 588 unique export rates per year. As a result, the value of the exported energy can vary from less than $0.01/KWh, to $3.75/KWh (Energy & Environmental Economics, 2022). A goal of this new policy, known as the Net Billing Tariff or NEM 3.0, is to encourage the adoption of energy storage to offset power use during peak energy demand (typically around 5-8PM), when the sun is going down. At this time, solar panels that were active during the day are now shutting down, but a large amount of power is demanded by customers as they return home and turn on electrical appliances and air conditioning.

This emphasis is reflected in the export compensation rates determined by E3's Avoided Cost Calculator. Since the export rates, compared to the previous NEM structure, are lower at all times except during peak hours, those systems that can export during peak demand periods will be more financially viable. The CPUC hopes to encourage the adoption of energy storage, which previously has struggled since batteries were not economically viable in many cases.

The interconnection process for new projects under 1 MW is straightforward. The customer pays a fee (as of this report, $75) to the utility (PG&E, 2018). Any upgrades to the distribution required to accommodate the new project are paid for by the utility. A developer can build a BTM project larger than 1MW, but then they are subject to higher fees and financial responsibility for utility upgrades to accommodate the new generation. For any new project, it is recommended to size less than 1MW to avoid high interconnection costs.

To analyze the financial case for installing panels behind the meter, we added a time series analysis of electricity consumption and production in a year. This models the electricity demand from an agricultural customer, electricity production from an example solar system, and an energy storage system that will offset electricity at high value periods based on the Avoided Cost Calculator. Energy storage is included in Figure 14 for a reference of the potential benefit of including energy storage. However, our provided financial model does not include the impact of energy storage, due to several site specific cost factors that were too specific to accurately predict or provide valuable assumptions about. Electricity demand is modeled using static agricultural load profiles from PG&E. These load profiles model the hourly electricity demand of a typical agricultural customer over a calendar year, based on historical averages of agricultural electricity use. PG&E and SCE both offer public load profiles for their different rate classes. The PG&E load profiles are used because they were simpler to import into the model, but both models offer similar load shapes. This demand can be scaled based on electricity use at the farm per year. Solar generation is modeled using the National Renewable Energy Laboratory's (NREL) model known as PVWatts, a widely-used solar forecast modeling software. This software can generate hourly solar generation profiles based on location and equipment inputs (NREL, 2023). Finally, a simple energy storage model was built using factors from NREL's Annual Technology Baseline (NREL, 2023).

Figure 14: Net billing tariff sample output



Once all electricity imports and exports are calculated for all 8760 hours in a year, the imports are valued per PG&E's time-of-use agricultural electricity rates. Since any customers seeking to utilize a NEM configuration are required to be on a time-of-use tariff, the model does not consider other tariffs from PG&E (PG&E, 2024). Exports values are set according to the Avoided Cost Calculator and are closely tied to real values for 2024, however there is some complexity in forecasting these export values. The CPUC ruled that the calculator must be re-analyzed on a yearly basis to true up the value of the distributed resources to the grid as new small and large-scale renewable energy projects come online each year (CPUC, 2022). As such, the values modeled will be accurate for export values in 2024 although future years may vary. For the purpose of this model, export values are escalated each year at the same rate as the price of electricity. The uncertainty of projected export values increases over the project's time horizon.

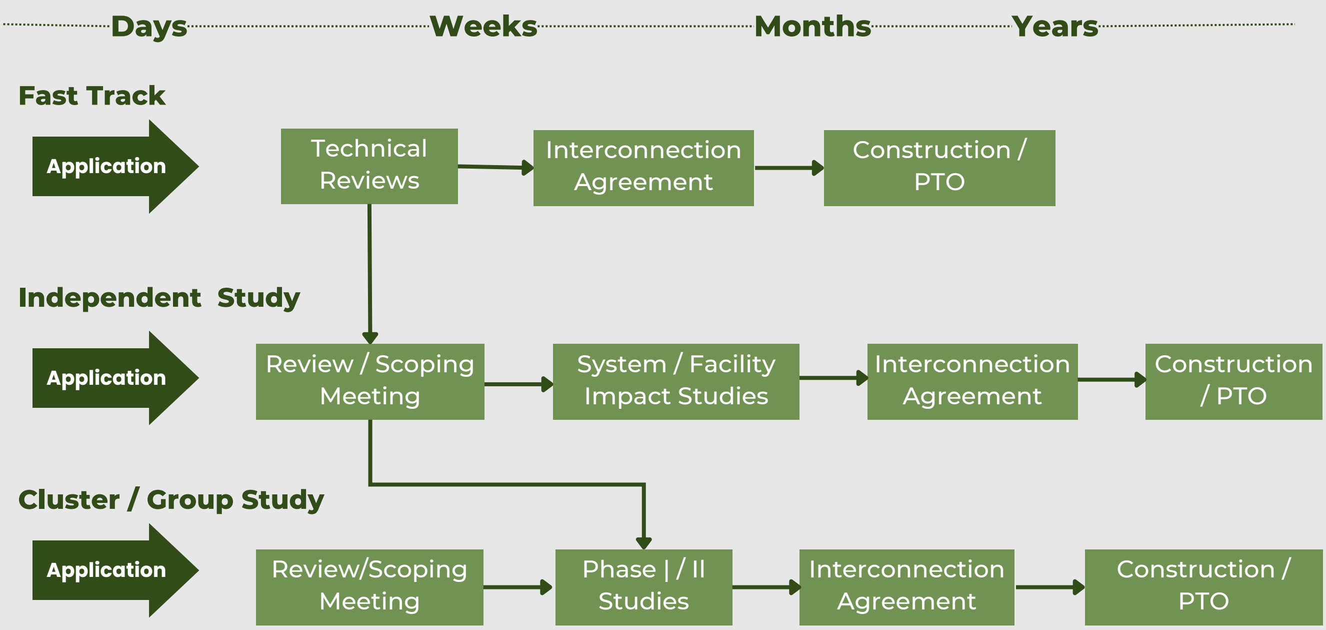
Generally, due to the small payback of exporting power to the grid, limitations on size of the solar panel system, and higher capital costs compared to a ground or roof-mounted solar system, installing an agrivoltaics system behind the meter does not have a compelling financial case as it takes very long to recoup the costs of construction. In conversations with NREL, there has not yet been an agrivoltaics project studied that implements a BTM configuration. However, due to its short and predictable interconnection timeline, BTM configurations could be a viable route in the context of establishing a demonstration project.

Front of the Meter

Test projects studied by NREL have all been installed in a front-of-the-meter (FTM) configuration, where power is generated by the solar panels and pushed straight to the grid without offsetting energy use on the property (McCall, 2024). The generator is paid according to the wholesale tariff that the utility pays for energy. This configuration is commonly used for large-scale projects meant to provide power to multiple customers or communities. Depending on the size and location of the project, the interconnection process could add construction time and cost to a new solar project.

When large energy generation projects are connected to the grid, studies must be done by the utility and CAISO to determine both the impact on the grid and the potential need for new electrical infrastructure. There are multiple ways to apply, each with their own time requirements and cost implications. See Figure 15 below for general timelines and descriptions of the types of applications, including some of their constraints and considerations.

Figure 15: Interconnection process flowchart
Source: SCE, 2024



Applying to the interconnection process can be done independently or as part of a group study, where the proposed project is studied in coordination with other distributed generation projects that may be in similar regions and/or have similar timelines. For projects subject to Rule 21, where the utility is the primary interconnection partner, the utility may identify required distribution upgrades as part of their study. The costs of these upgrades must be paid for by the projects applying for interconnection. In this case, group studies are preferable to apply to, as the costs are distributed among the other interconnection applicants based on contribution to the required changes, as calculated by the utility. If the utility determines there are no additional upgrades required to their distribution system, the cost of interconnection is limited to the cost of application and any required arbitration (PG&E, 2018). The study that the project will apply to is dependent on the project size, timeline, and requested interconnection point. Generally, distribution or transmission lines over 60 kilovolts (kV) will be required to apply as part of a CAISO Cluster study, which have much longer timelines than other options. Review detailed costs and timelines from PG&E in Appendix D. The table also includes details about deliverability studies, which are optional depending on the project location and interconnection conditions.

To determine an interconnection timeline potential, the public interconnection queues for CAISO, PG&E, and SCE were analyzed. When applying for interconnection with SCE or PG&E in a group, independent, or fast track process, larger projects generally take longer to study and are at a higher risk of additional costs due to the need for distribution upgrades. At this level, many projects apply for fast track status below 5 MW to avoid significant study costs.

Completed interconnections for projects in the interconnection queues are shown in Figure 16 and Figure 17 below. Smaller projects under 2MW are often able to be completed in less than a year, while larger projects often require multiple years.

Figure 16: PG&E completed photovoltaic interconnection projects

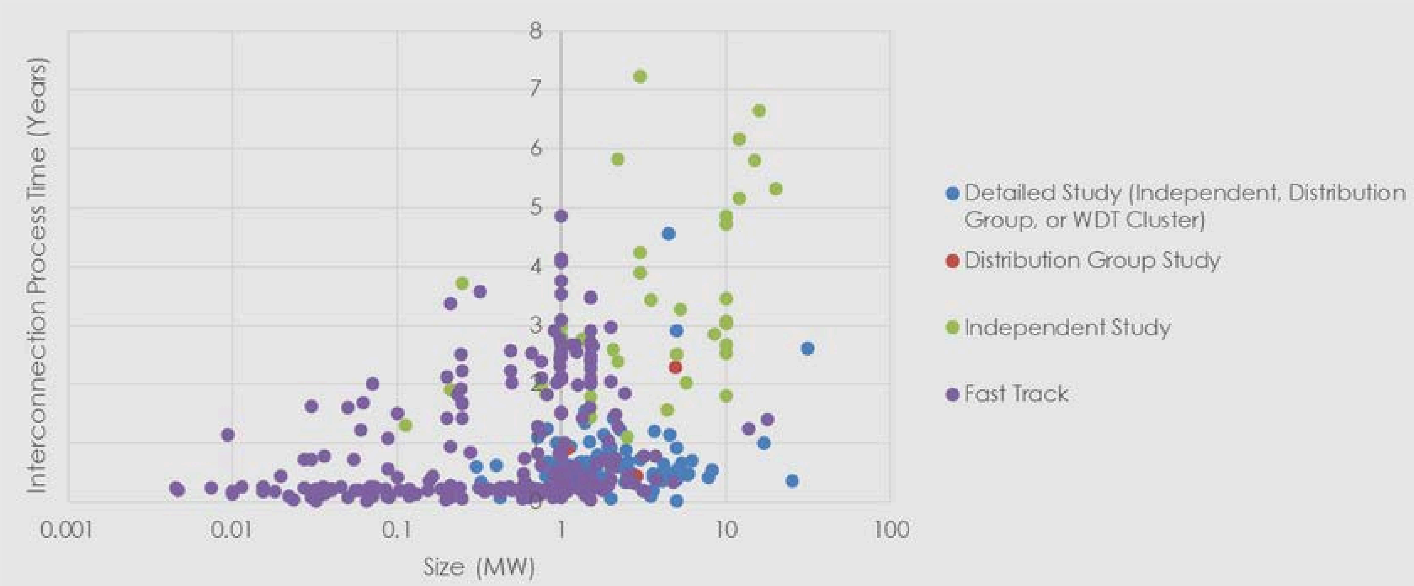
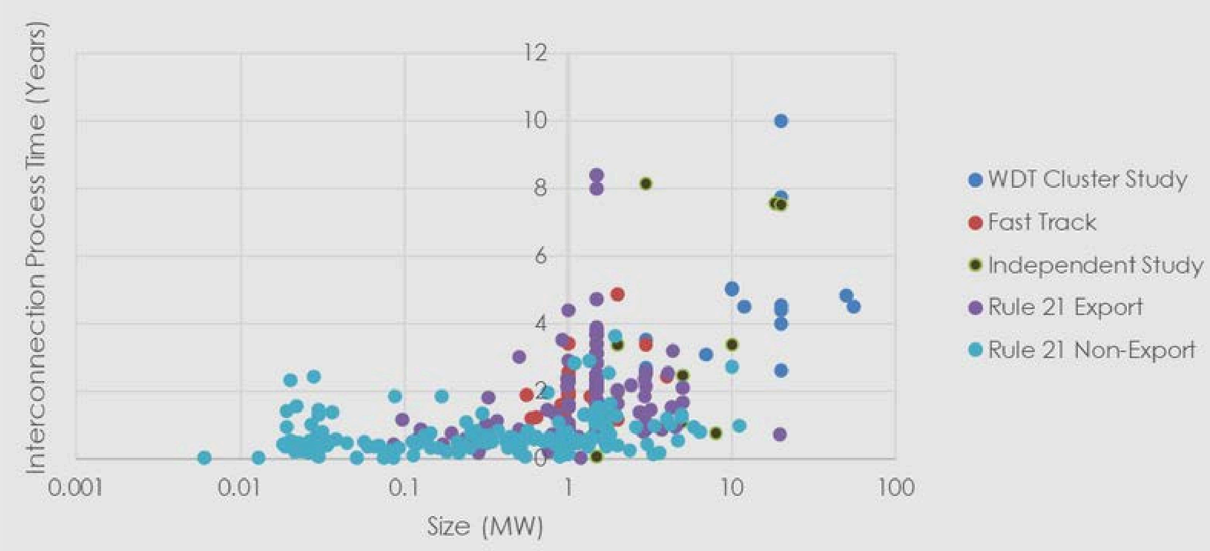
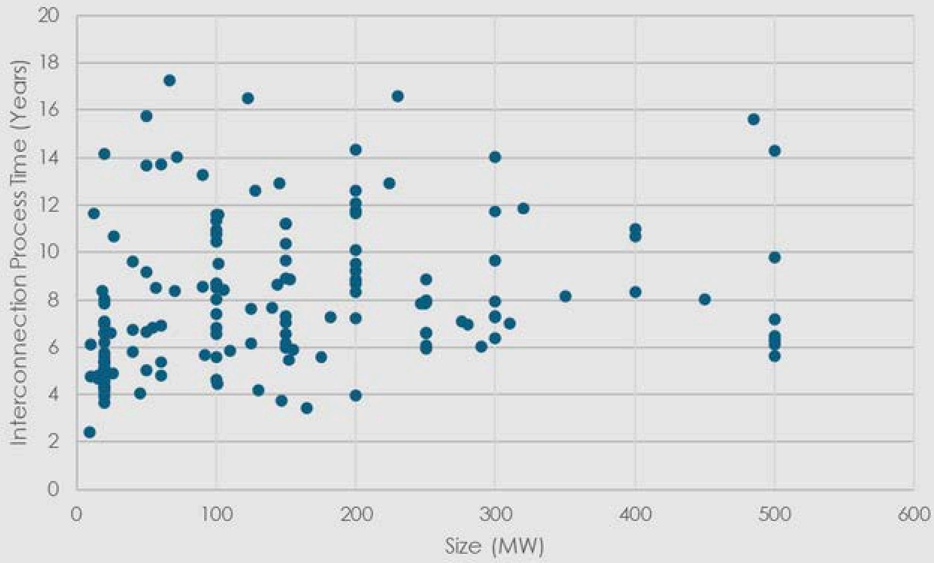


Figure 17: SCE completed photovoltaic interconnection projects



Projects applying via a CAISO Cluster study will undergo multiple years to complete the survey and are at risk of high costs (see Figure 18 below). The cluster application process is intended to distribute costs of infrastructure upgrades among applicants in the same study, but this also makes projecting costs difficult as applicants are not easily able to determine the existing capacity remaining in the grid, how much total capacity will be added by current or future projects, or how long any upgrades will take. Any upgrades to transmission facilities will require multiple years to complete.

Figure 18: PG&E completed photovoltaic interconnection projects



Despite these risks, over 150 new projects are currently in the interconnection process in Kern County (see Table 5), with a potential to add over 32 GW of renewable energy to the grid – representing more than is currently active in California. However, not all projects are guaranteed to come online. Depending on costs of distribution or transmission upgrades that come out of the studies, some projects may withdraw their request rather than pay the high fees, waiting until another customer chooses to pay the upgrade costs. Last year, California added 5.5 GW of renewable energy to the grid, and California currently supports around 20 GW of renewable power. Adding another 32GW to the grid is already a huge undertaking that will require significant upgrades to the grid in Kern County. Many projects applying under PG&E and SCE's Rule 21 and WDT processes are limiting their projects to 5MW to avoid significant delays. In CAISO's 2023-2024 Transmission plan, PG&E identifies several substations and interconnection points at a high loading point, and CAISO recognizes the potential of new resources to be added in the area. There are six transmission upgrade projects currently underway to increase capacity in Kern county, which should be complete within the next 10 years (CAISO, 2023).

Table 5: Kern County generation projects in the interconnection queue

	PG&E	SCE	CAISO
Number of Projects in Queue	26	27	104
Average Project Size (MW)	5.2	4.9	306
Total Potential Added Capacity (MW)	136	131	31,819

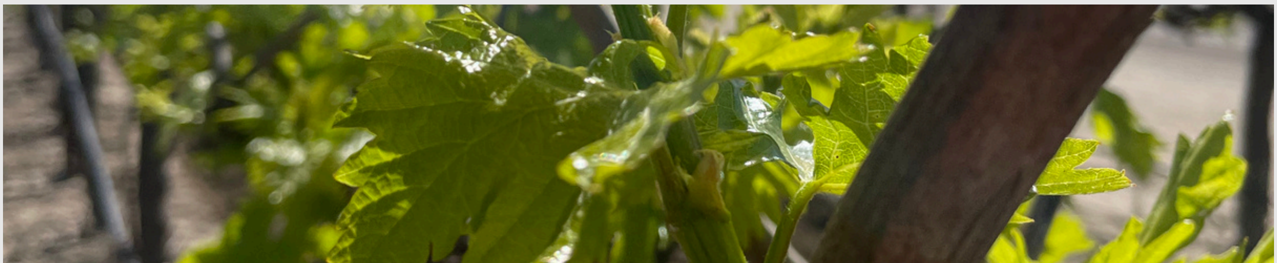
SCE and PG&E release publicly available maps of existing distribution resources for project developers to assess potential interconnection points and risks of higher interconnection costs. This map was analyzed to determine the potential of high interconnection costs and time due to upgrades of the distribution and transmission grid. PG&E, SCE, and CAISO also publish their interconnection queues, containing a list of projects currently in the study process for interconnecting new generation. This list was reviewed for average timelines for interconnection to inform our financial model and give considerations to early projects.

Ranges of costs of interconnection were included in the financial model based on an NREL study of 96 projects that applied for interconnection. This was averaged and compared with a standard value held for interconnection costs from a solar developer we interviewed. The NREL data is from 2014 and ranges across numerous U.S. states. Given the age of the data, interconnection costs should be assumed to be underestimated. Due to the uncertainty of the required distribution and/or transmission costs to enable interconnection, costs are highly variable and difficult to forecast accurately.

Permitting

Permitting is a necessary step in developing a new solar project and is often expensive and time consuming for larger projects. Permitting ensures that projects comply with regulations and avoid harm. Clear permitting frameworks provide investors with confidence that projects can be developed and operated without surprises, however permitting is a complex and nuanced topic. This section does not attempt to cover every possible aspect of permitting; it focuses on the areas that are most pertinent to agrivoltaics compared to traditional solar projects. This section should not be taken as legal advice. This work focuses on county code application because the majority of agriculture land in this region is under county jurisdiction. These codes are not for land under city jurisdiction

Permitting in the United States happens mostly at the state and local level (Pascaris, 2021), so we reviewed the academic literature and industry publications on permitting for both solar and agrivoltaics in California. From this literature we identified the key areas of permitting that impact agrivoltaics. We then interviewed people from three companies who have developed small- to medium-sized solar projects in Kern County and neighboring counties to validate the literature review.



We reviewed the relevant policies, and compared guidance from Kern County to guidance from other counties in California. Finally, we interviewed the director of Kern County's planning department.

The two most important considerations for agrivoltaic permitting in Kern County are the California Environmental Quality Act (CEQA) and the California Land Conservation Act of 1965. Beyond CEQA and the Williamson Act, other permitting considerations include stormwater runoff plans and local ordinance around the height of a solar structure. We did not research stormwater runoff plans in depth. From our interviews with solar developers, these plans are standard requirements for commercial solar installations and can be easily addressed by an engineer during the design phase.

Although we could not find any state or county-level guidance on height ordinance, solar developers and other industry stakeholders mentioned that keeping structures underneath 8 ft is typically preferred from a permitting standpoint as it prevents it from being classified as a different structure.

Williamson Act

The California Land Conservation Act of 1965 (known as the Williamson Act, California Government Code § 51243) is one of the oldest agricultural conservation programs in the United States (Wetzel et al., 2012). The purpose was to preserve agricultural land as an economic resource, to ensure food production, and to avoid conversion of farmland into urban use (California Department of Conservation, 2023).

When the Williamson Act became law, the only widespread use of solar panels was to power satellites (Perlin, 1999) so the legislation did not contain guidance on whether solar panels were an appropriate use of agricultural land. More recent legislation, Section 65850.5 of the California Government Code, is explicitly encouraging of solar for agricultural businesses:

> *It is the intent of the legislature that local agencies not adopt ordinances that create unreasonable barriers to the installation of solar energy systems, including, but not limited to, design review for aesthetic purposes, and not unreasonably restrict the ability of homeowners and agricultural business concerns to install solar energy systems.*

This ambiguity has led to counties having different permitting rules, creating a challenging permitting environment for solar developers (Sungu, 2011). In March 2023, the California Division of Land Resource Protection (DLRP) issued a white paper to address this, "Solar Power and the Williamson Act", which outlines five ways that solar may be installed on land that is subject to the Williamson Act (California Department Of Conservation, 2023). We summarized the various approaches below:

1. Compatibility

The first option is the best scenario for a developer looking to build an agrivoltaics project: solar is deemed compatible with agricultural land use and does not require ending the Williamson Act contract. This compatibility determination is a discretionary action of the local government. The Act contains three ways that solar may be compatible.

First, the Act allows for an "electrical facility" on non-contracted land within an agricultural preserve. However "electrical facility" is not defined in the Act. Some counties have a narrow definition (only electrical transmission lines) while other counties have a broad definition (allowing for construction of electrical generation facilities), and other counties have no definition. This option is not very useful for agrivoltaics, as it is unlikely that landowners would have significant agricultural land that is not contracted.

Second, Government Code Section 51238.1(a) defines "principles of compatibility" that would allow solar on contracted land. The statutory tests direct counties to look at the potential interference between proposed solar and agricultural use. The local jurisdiction could allow solar if the displacement could be reasonably forecast to not displace significant agricultural production. In 2011, Alameda County adopted a rule that solar was a "compatible non-agricultural" use up to 10% of the contracted property or up to 10 acres, whichever is less (Alameda County Uniform Rules and Procedures, 2011).

Third, a county may approve solar even if it is inconsistent with the principles of compatibility, if the following are true:

1. The proposed project is on non-prime land
2. The proposed site is approved in accordance with a conditional use permit (CUP)
3. The CUP requires mitigation or avoidance of impacts to agricultural operations
4. The productive capability of the land has been considered
5. The solar project is consistent with the intention of the Williamson act, for example by preserving agricultural use of the land
6. The solar project does not include a residential subdivision

Kern County Code § 19.12.030 section G states that solar energy electrical generators are permitted with a conditional use permit, when not accessory to a permitted or conditionally permitted use.

2. Non-renewal

The second option listed in the DLRP white paper to install solar on Williamson Act land is to not renew the contract. This process takes 10 years, which is an infeasible amount of time for a solar project with a 25-year lifespan. Non-renewal leads to land not being protected for agricultural use, so is less aligned with the purpose of building an agrivoltaics project.

3. Cancellation

Cancellation is much faster than non-renewal, but requires paying a fee of 12.5% of the unrestricted value of the property to the state. From conversations with solar developers, this fee can be thousands of dollars and is legally cumbersome (Sungu, 2011). Although this process is expensive, it is still financially viable for large solar projects. The Maricopa Sun Solar Complex, a 700 megawatt project in Kern County, paid over $755,000 to cancel (California Senate Appropriations Committee, 2011). Solar projects are a major cause of Williamson Act cancellations (Owley & Morris, 2019). Similar to non-renewal, cancellation leads to less land being protected for agricultural use, so is not aligned with agrivoltaics.

4. Eminent Domain

Public agencies can use eminent domain to void a Williamson Act contract without any cancellation fees. Eminent domain was used to mitigate for land used in San Luis Obispo County for the Topaz Solar Farm, but has never been used in California for siting a solar project (Owley & Morris, 2019).

5. Solar Use Easement

California Senate Bill 618 ("SB 618") created solar easements, signed into law in 2011. Land that is not designated as "important" can be taken out of the Williamson Act for a fee of 6.25% of the fair market value, and placed into a solar use easement for a minimum of 10 years. Very few solar use easements have happened as fees typically went to the State, lacking incentives for Counties to support this process. The bill has a fairly narrow scope so developers report that cancellation is usually a better option (Owley & Morris, 2019).

California Environmental Quality Act

The California Environmental Quality Act (CEQA) is the state's environmental review statute, introduced in 1970 (CAL. PUB. RES. CODE § 21002). The goals of CEQA are to prevent or minimize avoidable damage to the environment, to create public disclosure, to increase public participation, and to increase transparency in the environmental review process (California Department of Conservation, n.d). CEQA requires environmental review for projects that may have a "significant effect on the environment" and that need discretionary approval from government agencies (Owley & Morris, 2019).

CEQA is likely to impact every large solar project on agricultural land, and any smaller solar project that requires cancellation of a Williamson Act contract. If a project is determined to have the potential for a significant environmental impact, the lead government agency will prepare an initial study. This study will result in one of three decisions: to prepare an environmental impact review (EIR), a mitigated negative declaration (MND), or a negative declaration.

EIRs are common for large solar projects, but the process and requirements vary between counties. In Kern County, the project developer is responsible for preparing the EIR, which is a significant process that requires lawyers and other specialists. From our interviews with solar developers, this typically costs over $100,000 and takes around a year. Our interviews found that for large projects the EIR process is a hurdle, but permitting is seen as less of a challenge than interconnection. However, the cost and time of an EIR would likely make a small project inviable.

If there is found to be a potential environmental harm that can be mitigated in some way, the lead agency can decide on a mitigated negative declaration (MND). This MND tends to be a significantly cheaper and quicker process than an EIR. Several counties, including Tulare County to the north of Kern County, have adopted a standard process of initial review and MND for CEQA compliance for commercial-scale solar projects (Kelly & Delfino, 2012).

A negative declaration is only issued when there is shown to be no negative impact. In our interviews with solar developers, and in reviewing the literature, we did not come across any examples of this happening for large solar projects.

Permitting Recommendation

The cost and effort for permitting and the associated environmental reviews reflect the size and potential impact of a proposed new solar project. In the short-term, we recommend that efforts are focused on smaller BTM agrivoltaics projects where permitting requirements will be minimal. From discussions with the director of planning for Kern County, BTM projects do not require environmental impact review. If a very large FTM agrivoltaics project is otherwise financially viable, then the cost and time associated with an EIR should be factored in.

At the State level, it would be helpful for clear guidance to be issued stating that agrivoltaics are a compatible use under the Williamson Act. This could make agrivoltaics a more appealing opportunity for solar developers, potentially reducing the amount of farmland that is taken out of the Williamson Act and converted to traditional solar. Language about this was included in Senate Bill 688 proposed by Senator Padilla in 2023 but that section was removed. The Farm Bureau filed a letter of concern about this change to the definition of “agricultural use” (California Farm Bureau, 2023). It is unclear if Padilla’s bill will move forward, but we recommend that stakeholders engage with the Farm Bureau to understand their concern with agrivoltaics being considered a compatible use. We recommend that stakeholders contact Senator Padilla to discuss adding this language back into the bill.

Technology

To analyze the various considerations in system design and technology options in the context of agrivoltaics, a literature review was conducted to gather preliminary information. This information was further discussed with expert stakeholders including those working in solar development research, policy research, and academia to validate our assumptions.

Solar projects are never one-size-fits-all. Within each solar project, there are key design and technology decisions such as height, spacing, direction, mono vs. bifacial panels, fixed-tilt or tracking system, and battery storage needed depending on the project’s financial capabilities and energy production goals (Toledo et al. 2021, Katsikogiannis et al. 2022).

To compare the design options for agrivoltaic projects, the ground-mount solar design was selected as a baseline. This project design is widely used across the solar industry for utility- and community-scale solar projects. There are three main APV system types: fixed mount canopy systems, axis-tilt canopy systems, and vertical bifacial systems. There are trade-offs across each system design. Fixed-mount canopy systems are typically cheaper to construct than single or double axis tracking canopy systems, but lose optimization of solar energy absorption. Vertical bifacial systems require less steel than canopy systems, but may not contribute significantly to water savings since the vertical orientation provides minimal sun protection at the hottest times of the day.

The height for each of the canopy systems varies based on the height requirements associated with each crop, with many APV systems found between 7 ft and 13 ft tall. Spacing of panels varies considerably as it depends on spacing between crops within each row and between rows.

Spacing of solar panels was found to be between 0 ft to 2 ft and the spacing between rows was found to be between 16 ft and 32 ft apart. This results in a lower energy density of APV systems (7-14 acres / MW) compared to traditional ground-mount solar systems (4-6 acres / MW) (NREL 2020). When it comes to bifacial paneling vs. monofacial paneling, bifacial panels have been shown to improve yield of specific crops due to the partial shading effect under the translucent paneling (Katsikogiannis et al. 2022).

Recent changes to the political incentives from NEM 3.0 have increased the attractiveness of battery storage in conjunction with solar development in California. While there are considerable capital expenditure increases associated with battery storage, this technology has potential to further decarbonize farm operations (such as electric farm machinery charging) or increase revenue associated with returning energy to the grid at off-peak times (NREL 2023, Klokov et al. 2023).

Technology Recommendation

APV design differences represent a significant portion of energy production and cost variability, and we see substantial opportunity to optimize across each of these variables. We recommend further studies to continue innovating on APV system designs. Doing so would bolster modeling accuracies and ensure easier scaling and replicability of APV systems. In addition, we recommend further research into additional revenue generation from battery storage and exact costs associated with battery storage infrastructure, as these will be critical components of relevant financial models for agrivoltaics.

Energy Model Inputs

Data collection for the energy model inputs was conducted using multiple approaches. First, a literature review was conducted and relevant research papers across each of the inputs were collected and analyzed. Second, upon completion of this initial research phase, an expert stakeholder meeting was held to validate the methodology and assumed inputs for the model. These stakeholders included those working in solar development research, policy research, and academia. Following the feedback from these stakeholders, the team reassessed any methodologies and inputs that were contended in the meeting before returning to the expert stakeholders for a final round of validation. This process ensured that there is a high level of confidence energy model inputs, given the current availability of data.

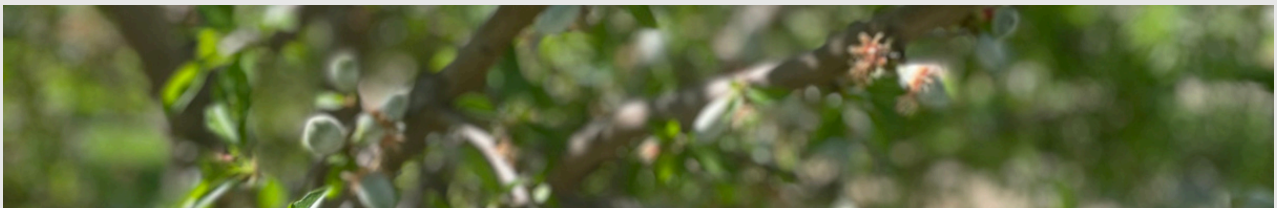
Capital Expenditure (CapEx)

Preliminary Methodology

To calculate capital expenditure (CapEx), an initial literature review was conducted yielding four publications that were used for their explicit financial breakdown of agrivoltaics (Fraunhofer ISE 2022, NREL_2020, Schindele et al. 2020, Trommsdorff 2016). Given that each of these studies varied by location and year, a normalization methodology was created to examine the costs in a California-specific context. This methodology involved a currency conversion using the OECD Purchasing Power Parity conversion in the year and county of the study to the U.S for that same year (OECD, 2023). To convert from a U.S average to a California specific value, the Regional Price Parity from the U.S Bureau of Economic Analysis was used (BEA, 2023). Lastly, the Consumer Price Index (CPI) Inflation Calculator from the Bureau of Labor Statistics (BLS) was used to bring the values into today's dollars (BLS, n.d). Following the normalization of the collected CapEx figures, the costs were averaged by system type, and a comparative analysis was presented to the expert stakeholder group for validation along with the respective methodology. From the stakeholder feedback, it was found that CapEx figures based in Europe, even with economic conversions to U.S currency, were still well below the expected range of CapEx figures to be found in the U.S.

Final Methodology

Following the initial stakeholder feedback, a second methodology was created to calculate CapEx. In the second analysis, the percent differences were calculated across each of the studies identified in the literature review. More specifically, the percent increase of each APV system type (e.g., vertical bifacial, 8ft mounting APV, 13ft mounting APV) was calculated above the CapEx of the ground-mount photovoltaic system (GM PV) baseline used for each study. The range of APV CapEx increases was then applied to a California specified GM PV average. One of these GM PV figures was supplied by a solar developer doing utility-scale PV in California. This figure was then adjusted from 5MW to 500kW using an NREL-derived Economies of Scale adjustment (EoS). Once the new range of CapEx figures were established based on this methodology, a ~8% increase was added using an Uncertainty Factor adjustment which incorporated uncertainties unable to be captured in the initial conversion, short vs. medium term technology costs, California specified premiums, etc. This ~8% adjustment was calculated using NREL's Annual Technology Baseline, using the percent increase in estimated costs of utility and commercial PV systems from 2029 to 2024 in the conservative technology assumptions.



CapEx Analysis

There were many different inputs considered across each of the research studies discussing APV CapEx. Appendix E shows a list of potential CapEx inputs broken down into cost categories. The finalized methodology resulted in the CapEx numbers displayed below (Table 6). These figures are considered to be aligned with other calculated and realized CapEx figures, as validated from various U.S APV stakeholders. These figures were used to inform the project finance model described. It is important to note that these figures do not include costs associated with battery storage.

Table 6: Finalized CapEx average and ranges by solar system type

PV Build (500kW Size)	Average $ / Wp	Range $ / Wp
GM PV (EoS adjustment only)	$1.82	$1.76 - $1.88
Agrivoltaics - Vertical	$2.34	$2.26 - $2.42
Agrivoltaics (~8 ft racking height - normal)	$2.69	$2.59 - $2.80
Agrivoltaics (~8 ft racking height - reinforced)	$2.97	$2.86 - $3.07
Agrivoltaics (13+ feet racking height)	$2.97	$2.48 - $3.51

Operational Expenditure (OpEx)

Methodology

The same methodologies described for CapEx were replicated for operational expenditure (OpEx) calculations, and followed the same feedback and correction. Unlike the CapEx literature review, the OpEx literature review only uncovered two studies from Germany that yielded explicit OpEx figures. OpEx percent changes were applied to a California specified GM PV OpEx cost provided by a solar developer. No uncertainty factor adjustments were made.

There were many different inputs considered across each of the research studies discussing APV OpEx. Appendix F shows a list of potential OpEx inputs broken down into cost categories. The finalized methodology resulted in the OpEx numbers displayed below (Table 7). These figures are considered to be aligned with other calculated and realized OpEx figures, as validated from various U.S APV stakeholders. These figures were used to inform the financial model described below.

Table 7: Finalized OpEx $/kWp average and ranges by solar system type

PV Build	Average $ / kWp	Range $ / kWp
Ground Mount PV	$30.06	No range
Agrivoltaics	$26.60	$26.19 - $27.00

Grant Funding

Renewable Energy for America Program (REAP)

Within the Inflation Reduction Act, the Renewable Energy for America Program (REAP) provides access to agricultural producers and rural small business owners to make energy efficiency improvements or renewable energy investments, helping lower energy costs, generate new income, and strengthen operations resilience (REAP, n.d). Through REAP, farmers are eligible for grant funding up to 50% of the costs of a renewable energy project with a maximum of $1,000,000.

San Joaquin Valley Air Pollution Control District (SJVAPCD)

Kern County is located within the jurisdiction of the San Joaquin Valley Air Pollution Control District (SJVAPCD). The SJVAPCD's posted mission statement reads:

> *"The San Joaquin Valley Air District is a public health agency whose mission is to improve the health and quality of life for all Valley residents through efficient, effective and entrepreneurial air quality management strategies. Our Core Values have been designed to ensure that our mission is accomplished through common sense, feasible measures that are based on sound science."*

As part of their mission, the SJVAPCD acts as a sponsor or funding source for air quality improvement projects. In Kern County, the majority of these projects are electrification or fuel efficiency projects, such as converting natural gas-powered pumps to electric pumps, or upgrading older diesel vehicles to newer, higher efficiency vehicles by providing grant funding. In our discussion with the SJVAPCD, they expressed an interest in supporting agrivoltaics projects through some of their funding channels if such projects aligned with their overall mission. Most particularly, they felt that agrivoltaics could contribute to a greater farm electrification project, such as tractor electrification or a microgrid resiliency project. While SJVAPCD was not able to quantify the amount of funding that may be available for agrivoltaics projects at this time, the alignment between agrivoltaics and their mission is strong enough for us to recommend that the City of Bakersfield engages in continued conversations with them on this manner. (San Joaquin Valley APCD Home Page, 2012)

Grant Funding Analysis

To incorporate potential grant funding into the financial model, the stipulations of the REAP grant were incorporated. This allows for the user to select a range from 0-50% of grant funding with that funding not exceeding $1,000,000. Neither this analysis nor the model indicates whether a farmer is eligible for the REAP grant, but offers insight into capital expenditures costs of an agrivoltaics system if grant funding were awarded.

The SJVAPCD grant options were not incorporated into the solar financial model as they only provide grant funding to auxiliary energy evolution technologies. While this funding can help farmers further decarbonize their farm operations, it will not reduce the cost associated with building the initial energy infrastructure.

Tax Credits

The Investment Tax Credit (ITC) is a tax credit that reduces the federal income tax liability for a percentage of the cost of a solar system that is installed during the tax year. Initially enacted as Section 48 in the Revenue Act of 1962, the ITC aimed to stimulate economic growth by incentivizing investments in various capital projects spanning industries such as energy, transportation, and communications.

Since its inception, Section 48 has undergone multiple amendments with the most recent being through section 13102 of Public Law 117–169, known as the Inflation Reduction Act of 2022 (IRA) (Shah, A., 2023). Since solar photovoltaic was included in the ITC back in 2006, the industry has grown by two-hundred times (Solar Energy Industries Association, n.d.). The IRA brought several changes to Section 48 in an effort to continue this explosive growth of the renewable energy industry.

One of the major changes through the IRA was increasing the percentage cost of the solar system that is eligible for the tax credit. Prior to the IRA, this percentage was 22%, but the IRA increased this to 30% where it will remain until 2033 and then slowly phase out through 2036. It is important to note that all costs related to the construction of a solar system are not eligible for the tax credit. Section 48 breaks this up into "Integral Property" and "Non Integral Property". Non Integral Property covers the items that are not eligible for the ITC, and these include items such as transmission upgrades, access roadways, and fencing. Additionally, the ITC can only be claimed by the party that is the taxpayer for the solar facility. Due to this stipulation, solar owners have historically entered into arrangements with financial institutions that are referred to as Tax Equity partnerships. Through these partnerships, the tax credits could be allocated to an entity that has the tax liability to monetize them, like a financial institution, and the solar developer would receive a larger percentage of the project revenues to compensate. The IRA specifically addresses this complex contracting structure by creating two additional pathways to monetize the ITC; Direct-Pay and Transferability (Shah, A., 2023).

Direct-Pay, also referred to as Elective pay, was established to help tax-exempt and government entities benefit from investments in clean energy producing projects. Direct-Pay makes certain tax credits refundable, allowing the entity to receive the full value of the tax credit as a cash payment. If the entity claims the elective payment on their tax return, the IRS will treat it as a tax payment. Since these entities have no tax liability, this will be registered as an overpayment, triggering a cash refund to the entity. The White House released a detailed guide to the Direct-Pay eligibility and process which we have cited in our sources (Direct Pay | Clean Energy, n.d.).

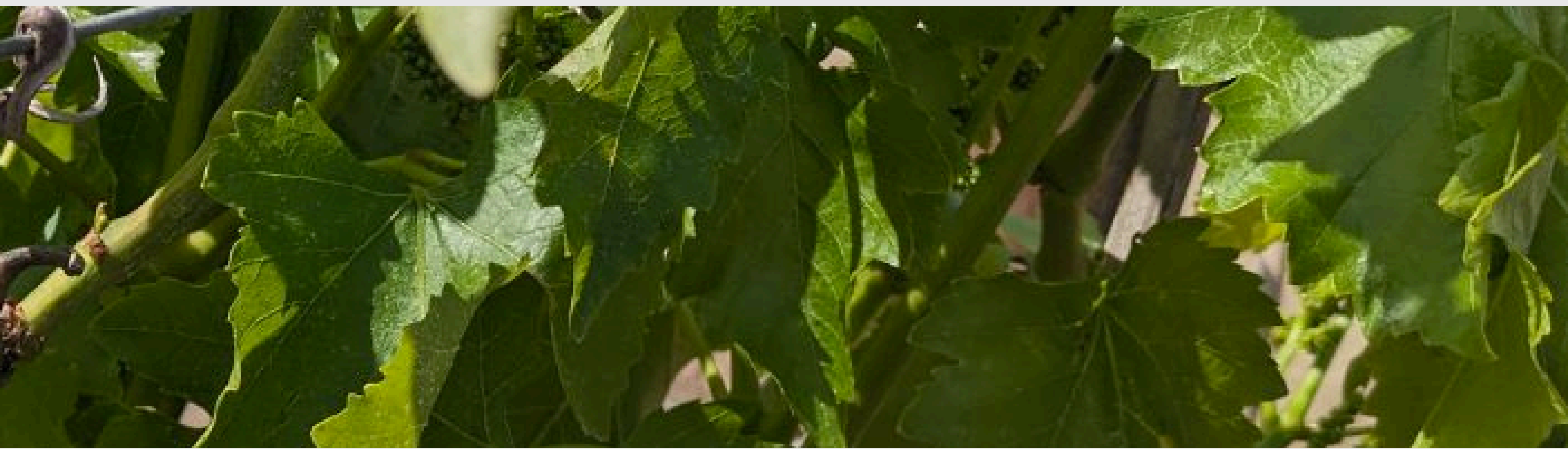
Transferability allows other entities who are not tax-exempt an avenue to monetize tax credits by effectively selling them to another entity for cash. The two entities would negotiate the terms of the agreement, which can include the environmental attributes (e.g., renewable energy certificates) of the project as well.

While both of these avenues have their stipulations and limitations, they have accomplished their goal of creating a simpler process for monetizing tax credits compared to the tax equity partnerships that the industry has been accustomed to for the past decades (Elective Pay and Transferability, 2024).

In addition to creating different options for monetizing the tax credits, the IRA also introduced pathways for projects to receive greater than the standard 30% ITC. By locating the project within certain communities, known as Energy and Disadvantaged Communities, the project may receive additional Investment Tax Credits for each category.

The IRA defines 3 qualifying traits for an energy community. The first type of community that would qualify is a “brownfield site”, citing the definition of brownfield from the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 which defines a “brownfield site” as “real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.” (U.S.C. Title 41 - THE PUBLIC HEALTH AND WELFARE, n.d.) In addition to brownfield sites, any area which has – or, at any time during the period beginning after December 31, 1999 – had significant employment related to the extraction, processing, transport, or storage of coal, oil, or natural gas (as determined by the Secretary) would also qualify for this additional tax credit. The last category of energy communities are Census tracts where a coal mine closed after 1999 or where a coal-fired electric generating unit was retired after 2009 (and directly adjoining census tracts). Due to the size of the oil and gas industry in Kern County, our research has shown that the second category of energy communities is most applicable to Kern County. Specifically, our research suggests that about 95% of the farms in Kern County are within the tax credit zones for energy communities due to the amount of oil and natural gas employment in Kern County (Weaver, J.F., 2022).

Disadvantaged Communities refer to specified low-income communities or residential developments that



display a clear benefit to a low-income community. This potential ITC adder is limited to solar or wind facilities with a maximum net production of less than 5 MW. The IRS released additional guidance under Notice 2023-17 to split the low-income community benefit statutory requirements into four categories of facilities (Part III - Administrative, Procedural, and Miscellaneous, 2023).

1. any facility located in a “low-income community”, defined as the poverty rate being at least 20%.
2. any facility located on federally identified Indian land.
3. any facility located on a qualified low-income residential building development and the financial benefit of the electricity produced is equitably allocated to the residents.
4. any facility providing at least 50% of the financial benefit of the electricity produced to low-income households.

Both of these first two categories would qualify for an additional 10% ITC. Both categories three and four are more complicated than the first two, as they require benefits of not just the initial investment, but also of the ongoing energy supply, to support the low-income communities. For this additional requirement and complexity, the projects qualify for an additional 20% ITC. The projects do not automatically qualify for this Disadvantaged Community adder. They must request it from the Treasury, and if the Treasury determines they qualify, they may receive an allocation which comes from a pool of funds referred to as the Environmental Justice Solar and Wind Capacity Limitation (IRS Issues Guidance for Energy Tax Credits in Low-Income Communities - Notice 2023-17, 2023).

To qualify for either of these additional tax credits categories, there are requirements for prevailing wage to ensure that tradespeople for the project are paid a competitive rate for their area. Our indicative view, based on our understanding of the guidance that has been released, is that the majority of Kern County will qualify as both an energy community and a disadvantaged community.

Throughout the course of our research, the IRS has been periodically releasing updated guidance on how to interpret these new tax rules. As we are not tax professionals and this report does not constitute a replacement for tax advice, we advise the City of Bakersfield to engage a qualified tax professional to inform your final interpretation of how these new rules introduced by the IRA may correspond with agrivoltaics projects in Kern County (*IRS issues guidance for energy communities and the bonus credit program under the Inflation Reduction Act* | Internal Revenue Service, 2024).

Renewable Energy Certificates

A Renewable Energy Certificate, also known as a REC, is a tradeable, market-based instrument that reflects the environmental attributes of clean energy production. A REC is issued when 1 megawatt-hour (MWh) of electricity is generated and delivered to the grid or consumed locally.

RECs were created to spur additional investment in renewable energy by creating another revenue stream for these projects, as well as creating an instrument for entities to accurately track the amount of renewable energy they were generating or procuring without the risk of double-counting. In order to claim the environmental attributes of a REC, an entity must “retire” it, which means it is permanently taken out of the market-place (US EPA, O, 2022). In California, REC issuance, tracking, trading, and retirement is done through a web-based platform called Western Renewable Energy Generation Information System (WREGIS). There are three classifications of RECs that can be issued in California; Portfolio Content Category (PCC) 1, 2 and 3.

PCC1 RECs refer to RECs that are procured from facilities located within CA and bundled with the actual energy commodity. These bundled-RECs are commonly procured by the load-serving entities (LSEs) of California, such as SCE and PG&E, in order to meet their Renewable Portfolio Standard (RPS) obligations. As mentioned earlier, the RPS program requires all the state's electricity to come from carbon-free resources by 2045 (State of California, 2024).

PCC2 RECs are very similar to PCC1 RECs, but it refers to bundled energy and RECs that are procured from generators outside of California that import their electricity into the State. Since the scope of our research is focused on Kern County, PCC2 RECs are not applicable.

PCC3 RECs are unbundled RECs; RECs that are purchased on their own, without the underlying renewable energy as well. PCC3 RECs can also be generated if generators failed to meet their obligations regarding ensuring PCC1 or PCC2 RECs (California Public Utilities Commision, 2023).

In our research, the most common offtakers of PCC3 RECs were enterprise customers who had voluntary sustainability commitments. Since PCC1 RECs are a mandatory obligation for LSEs in California, they demand a much higher price. While PCC1 RECs trade for around $40 each, our research showed that PCC3 RECs trade around $7 each. One exception to this rule was regarding Low-Carbon Fuel Standard procurements. The Low Carbon Fuel Standard is designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low-carbon and renewable alternatives. It does this by establishing a tradeable market instrument that is very similar to a REC, called an LCFS credit. If low carbon intensity (CI) electricity is procured to support the extraction of a transportation fuel, that becomes eligible to generate LCFS credits. We found that commodities traders are actively selling PCC3 RECs to two specific types of customers in California, O&G fields and EV charging station owners, for up to 100% premiums. This is because by procuring PCC3 RECs, both of these customers can receive additional revenues through the LCFS program. A Chevron Oil field in Kern County is employing this exact strategy (Chevron Corporation, 2022).

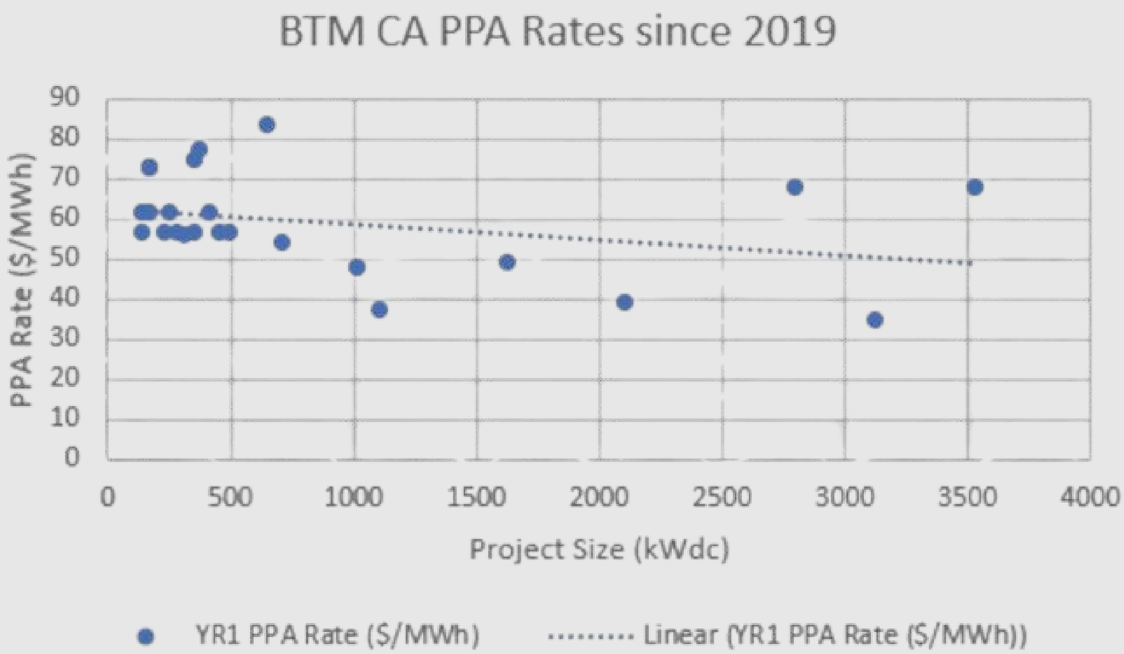
Power Purchase Agreements

As explained in the REC section, it is very common for both energy and RECs to be sold as a bundled product in California referred to as a Power Purchase Agreement (PPA). Since these are private transactions and not listed on any type of public database, it was very difficult to find information to perform a market analysis on what prices these transactions are clearing at. The two markets for solar projects, behind-the-meter (BTM) and front-of-the-meter (FTM) are two distinct markets with very different pricing due to their scale and value propositions, therefore we decided to evaluate them separately.

To begin our BTM PPA analysis, we began by reaching out to solar developers and owners in California that have been active over the past 5 years. Upon speaking with a few of them, we were able to receive an anonymized list of BTM solar projects, all closed over the last 5 years, that showed various PPA prices ($/MWh) for various system sizes.

Using this information, we were able to plot them and see a general trend that as system size grows, the solar developers are able to offer a lower PPA rate due to economies of scale. This dataset informed a range of BTM PPA pricing from $35-85/MWh, with an average around $60/MWh, as shown in Figure 19 below.

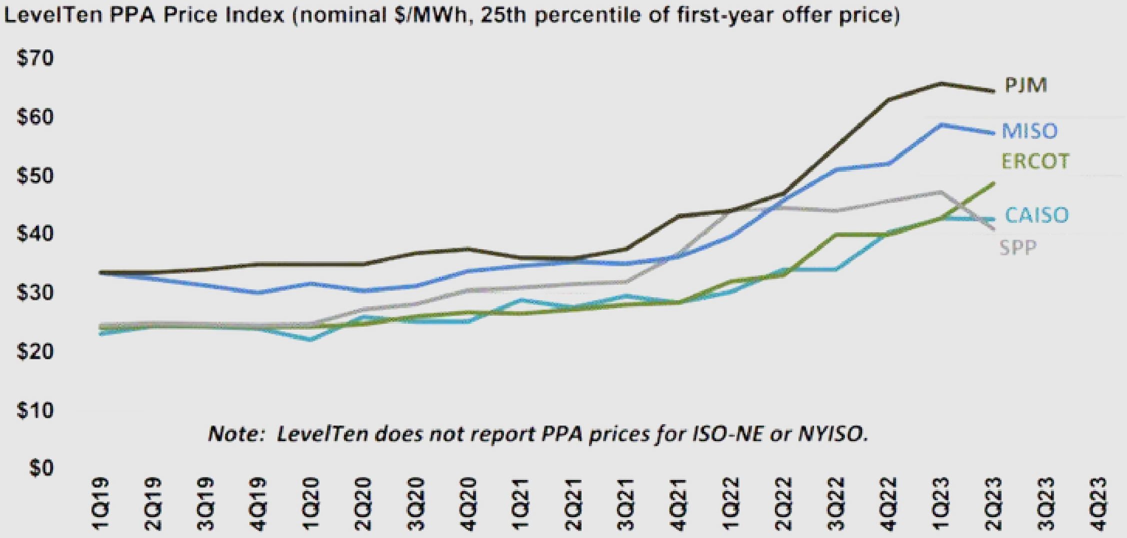
Figure 19: Anonymized behind-the-meter PPA rates



Upon sharing this range with other solar developers, they informed us that they felt this range was low compared to where they have been able to offer pricing on similarly sized projects. The reasoning for this abnormally low price range could be that the projects received outsized incentives or grants which drove pricing down, or the projects were developed by an inexperienced company who did not fully understand the total costs of the system when the PPA was negotiated. Accounting for all of the market feedback, we decided to raise our view of the average BTM PPA to $90/MWh, with a range of $65-120/MWh.

FTM PPA analysis experienced a similar lack of publicly available information. Additionally, solar developers were less willing to share anonymized project-level information with us on this topic. However, we were able to receive a market report from the Berkeley Lawrence Lab which contained a utility-scale PPA price chart gathered from an energy marketplace provider called LevelTen (Bolinger, 2023). The chart, shown in Figure 20, shows CAISO transacting in the low-$40/MWh range, while WoodMackenzie showed CAISO projects transacting slightly higher in the mid-$50/MWh range. To be conservative, our view on the average FTM PPA was $53/MWh.

Figure 20: LevelTen PPA price index



Solar Energy System Sizing

The amount of energy production and acreage requirements will vary depending on the agrivoltaics approach taken (explained in the CapEx section). This is because various APV designs have different structural foundations and tilt angles for their solar panels

Using NREL's PVWatts tool, we were able to estimate solar energy generation per installed kW for different APV designs. After inputting different technical configurations, we were able to receive indicative values of 1300kWh/kW for the vertical bifacial design, 1700kWh/kW for the elevated agrivoltaics design, and 2000kWh/kW for a standard ground-mount design. We have included screenshots of the PVWatts system output in Appendix G for reference.

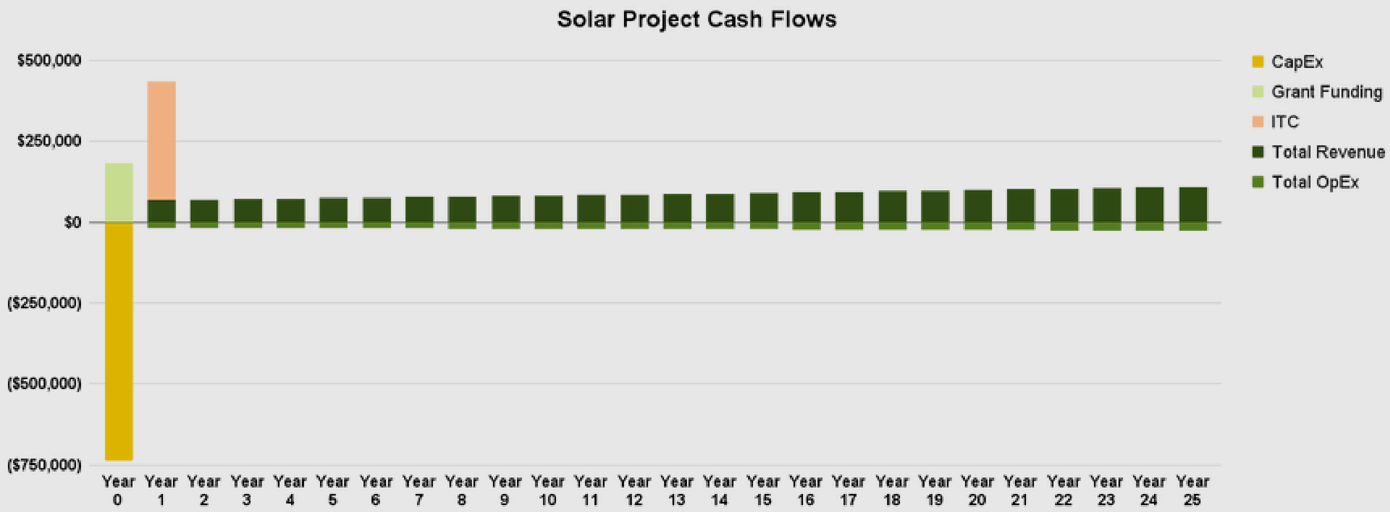
Due to the lack of installed agrivoltaics projects in Kern County, the acre/MW findings from the 2020 NREL report became the assumption that we proceeded with in our analysis. This assumes a 5.9 acres/MW requirement of a ground-mount system with a 1-axis tracker, a 7 acres/MW requirement for a vertical bifacial design, and 9.8 acres/MW for an elevated agrivoltaics design (Horowitz, 2020). Through our research and stakeholder interviews, we validated that a $1200/acre/year would be a market-rate lease payment from a solar developer to a landowner in Kern County (Ayers, 2022).

Project Finance Model

The final step in our financial analysis of agrivoltaics in Kern County was to summarize all of our validated energy parameters into a succinct and easy to understand financial model that calculates whether a specific project is expected to be economical.

The type of financial model that we decided to build to evaluate an agrivoltaics project is called a discounted cash flow (DCF) model. This type of model looks at the cash flows, both revenues and costs, in all years of the project, from year 0 (construction) all the way through end-of-life. It then discounts the cash flows occurring in later years back to their present day value. This type of financial analysis helps determine if the future cash flows are significant enough to make the upfront investment attractive for a prospective investor. As a helpful visual, Figure 21 below shows an indicative example of this using a bar graph.

Figure 21: Indicative example of discounted cash flow model



In addition to validating specific cost and revenue inputs with industry experts and the City of Bakersfield, we also validated general financial assumptions as well. We aligned on an 8% discount rate, justified by the 10-year US Treasury rates currently being at 4%. We assumed a 2.5% inflation rate to be applied to the PPA rate, and a 2% inflation rate on operating expenses and the lease rate. We also assumed a 25-year life for the project and did not account for decommissioning costs, as we assume the project may still be useful at year 25 and can be transferred or sold to another asset owner if desired, rather than decommissioned.

Once our model was built and validated, there were a few key scenarios that we analyzed to understand both the potential for agrivoltaics in Kern County, and specifically how APV compared to standard ground-mount solar projects. The first scenario involved calculating the PPA rates needed to make all types of solar systems financially viable at different sizes. The outputs of our model are summarized in the below Table 8.

Table 8: PPA rates needed for 100 MW and 500 kW APV projects to achieve acceptable financial return

System Type	PPA Rate Needed for 10% IRR (S/MWh)*	System Size (MW)	Acreage (acres)
Utility Scale (FTM)	Market Rate = $53 (+/- 25%)		
Ground-Mount	$59	100	590
Vertical Bifacial	$118	100	700
Elevated Agrivoltaics	$99	100	980
Farmer Electrical Load (BTM)	Market Rate = $90 (+/- 25%)		
Ground-Mount	$81	0.5	2.95
Vertical Bifacial	$149	0.5	3.5
Elevated Agrivoltaics	$130	0.5	4.9

Our model shows that ground-mount is competitive with our market-rate PPA range at commercially reasonable system sizes, and both types of agrivoltaics are not. Vertical bifacial is further out of the feasible PPA range compared to 8ft-elevated systems in this category. This scenario seems to prove that although elevated systems cost more upfront and require more space, they produce more energy over their lifetime due to more optimal tilt angles. The increased revenues from this increased energy production more than offsets the higher upfront costs.

The second scenario we evaluated was at what minimum size these systems start to become competitive with the market rate PPAs we observed in our research. The outputs of our model are summarized below in Table 9.

Table 9: System size needed for economies of scale to bring cost in-line with market rate

System Type	System Size Needed for 10% IRR with Market Rate PPA (MW)*
Utility Scale (FTM)	Market Rate = $53 (+/- 25%)
Ground-Mount	78
Vertical Bifacial	N/A
Elevated Agrivoltaics	N/A
Farmer Electrical Load (BTM)	Market Rate = $90 (+/- 25%)
Ground-Mount	Any
Vertical Bifacial	N/A
Elevated Agrivoltaics	8

Our model shows that for utility-scale agrivoltaics, there is no size where the economies of scale allow them to be competitive with traditional ground-mount PV systems. These systems are so burdened by higher capital costs and lower energy production that while size helps them offer a lower PPA rate, it never drops to within a reasonable range, per the current CAISO market.

For behind-the-meter agrivoltaics, vertical bifacial types cannot become competitive from scale alone. Grants or other incentives would be needed due to poor revenue potential from lower solar insolation. We found that elevated agrivoltaics should achieve economies of scale to become competitive at around 7.8MW. Unfortunately, this would be a significantly sized BTM solar system, and it is very unlikely that any farmers have a large enough electrical service to support this size of system. Unless the elevated APV system were able to be co-located with a facility that had a meaningfully larger electrical load (e.g., oil field, cold storage facility, dairy processing plant, etc.), the average BTM system at a farmer will likely be limited to a few 100kW at most.

The third scenario we evaluated was, specifically for 500kW agrivoltaics systems, how differing amounts of REAP funding would change the PPA rate required to become financially viable. We also assumed an additional 10% ITC for this scenario, bringing the total ITC for the APV project to 40%. This is due to a high level of confidence that many projects within Kern County will qualify for this additional ITC benefit due to being located within an Energy Community under the IRA. The results of our model can be seen in Table 10.

Table 10: Impacts of 40% ITC and grant funding on a 500kW demonstration project

500kW BTM Demonstration Site	
REAP Funding (%)	**PPA Rate Needed to achieve 10% Return ($/MWh)***
Vertical Bifacial	
10%	$120
20%	$98
30%	$77
40%	$55
50%	$34
Elevated Agrivoltaics	
10%	$105
20%	$85
30%	$66
40%	$47
50%	$27

Our model shows that vertical bifacial 500kW BTM projects become economical at standard market rate PPAs with ~30% Grant Funding. Elevated agrivoltaics demonstration projects are slightly more attractive, becoming economical with only ~20% Grant Funding. This percentage and magnitude of grant funding is feasible through identified funding channels such as REAP Grants.

COMMUNITY IMPACT 04

Stakeholder Analysis

By definition, a stakeholder is “a person with an interest or concern in something” (Bisset, 1998). In the context of this project, the stakeholders are individuals or groups of individuals who have an interest, influence, or impact on a decision in their community. Every individual has their own specific interests or concerns, driven by their unique needs and resources. Understanding the interrelationships of these stakeholders and how they might ultimately impact the success of a decision, event, or project is a critical component of project management. This crucial analysis helps understand how individuals, groups of individuals, and organizations might influence a specific event or project given their behavior, interests, agendas, interrelations, and resources (Brugha and Varvasocszky, 2000).

Several case studies have been conducted on the effectiveness of a stakeholder analysis when examining popular environmental management topics such as renewable energy integration and natural resource allocation. Requirements and potential limitations of this kind of analysis can be drawn from these case studies. The key requirements to ensure a successful stakeholder analysis include an emphasis on transparency to mitigate misinterpretations or misapplications, consideration of marginalized stakeholders, and a need for an unbiased and objective approach (Bendtsen, 2021). Stakeholder analysis can be a useful tool to assess the needs of relevant stakeholders in Kern County within the context of agrivoltaics. The goal of this analysis is to facilitate thoughtful and thorough decision-making through cooperative communication with stakeholders who may be involved in agrivoltaics projects.

This stakeholder analysis was a constructive exercise that fed into our findings related to stakeholder engagement, cost benefit analysis, and an overall impact assessment.

Methodology

Critical groups that are both impacted by and may have an impact on the trajectory and success of future agrivoltaics projects in Kern County were defined. The methodology for the stakeholder analysis is detailed below:

1. Understand general Kern County demographics

U.S. census data and other government websites informed the general demographics of the area. See data in Appendix H.

2. Group individuals based on shared characteristics

Using the general makeup of the population in Kern County, individuals were grouped based on their shared characteristics into five distinct stakeholder groups. The main stakeholder groups related to potential agrivoltaics projects in Kern County are outlined below in Figure 22. These groups were created in an effort to remain unbiased, though farmers were ultimately differentiated into landowning and non-landowning farmers in order to demonstrate the difference in decision-making power between those who owned land and those who were employed to work it. Further information on the definition of the various groups can be found in the Appendix I.

Figure 22: Identified stakeholder groups for agrivoltaics in Kern County

Landowners	Farmers	Business Owners	Solar Developers	Non Ag, Non Business Owner Residents
Owns land in Kern County and the jurisdiction to rights and decision-making power over the land.	Employed in the agriculture industry in Kern County.	Owns a business in Kern County and is the primary decision-maker for the company.	Solar companies interested in potential developments in Kern County.	Individuals who live in Kern County, but do not work on a farm, own land, or own a business - includes all other residents.

3. Identify data gaps for stakeholder management

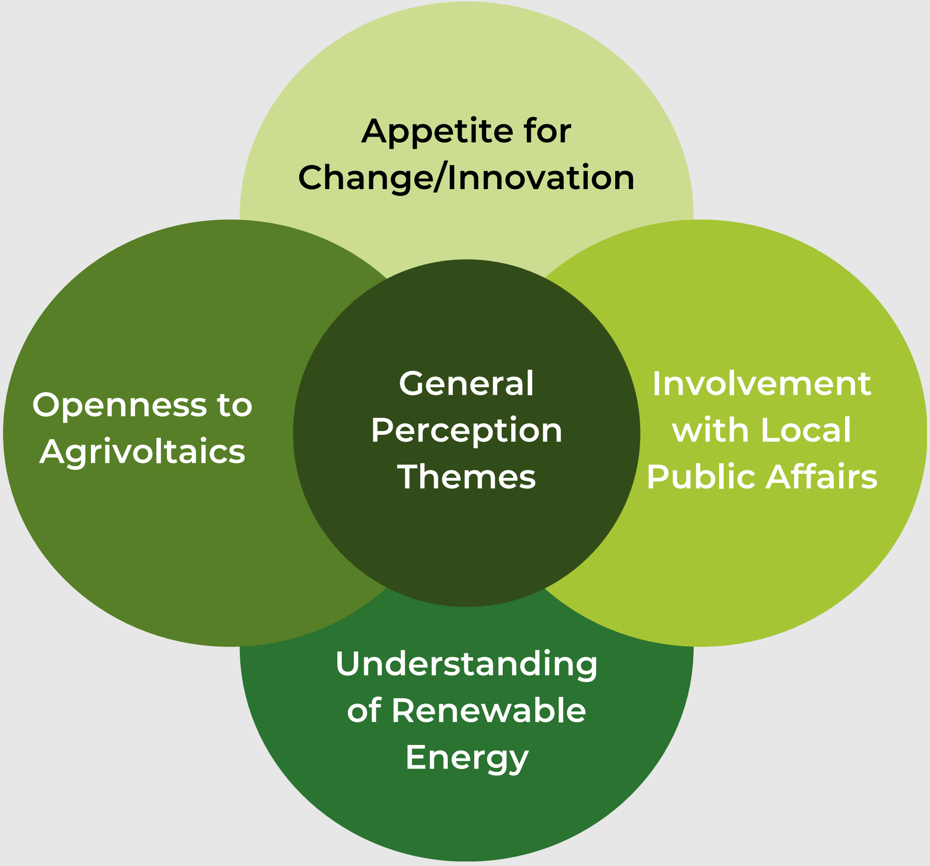
A perception baseline was established for each group in order to have effective communication and engagement with the stakeholders. Information such as familiarity with renewable energy, perception of agrivoltaics, and overall appetite for change were crucial inputs in understanding the dynamics of various groups as they relate to potential agrivoltaics projects. These dynamics informed the power and interest of each stakeholder. In the context of this project, power is defined as a measure of authority (financial, political, etc.) a particular stakeholder can exercise to impact the scope of a potential APV project. Interest is defined as a measure of individual vested interest (perception, understanding of agrivoltaics, desire for renewables, etc.) that can potentially impact the scope of the project. With these needs in mind, our team determined the relevant data gaps necessary to investigate in order to formulate a holistic stakeholder analysis.

4. Use data gaps to formulate survey questions

Identified data gaps informed a stakeholder survey, described in more detail in the next section. Familiarity and perceived impacts of agrivoltaics specific to each stakeholder group were also assessed in order to understand current impressions of agrivoltaics within the community. Survey responses could therefore help determine the relevant power and interest of each group as well as general perception themes, detailed in Table 11 below. Among other insights, the survey provided a foundation to better understand the needs and interests of the different stakeholder groups, and helped determine the most relevant recommendations.

Table 11: Key metrics captured in stakeholder survey

Landowners	Farmers	Business Owners	Solar Developers	Residents
• Size of land (acres) • Type of ownership • Length of ownership (years) • Employees • Commercial activity on land	• Sources of water • Installed renewables • Types of crops • Appetite for innovation • Length of residency (years)	• # of employees • Annual revenue • Investment in political initiatives • Position held • Type of company	• # of employees • Annual revenue • Investment in political initiatives • Position held • Experience with PVs	• Length of residency • Profession • Education level • Involvement with political initiatives



5. Utilize survey results to plot stakeholders on the power–interest matrix
Using the results from the stakeholder survey, stakeholder groups were mapped onto a power vs. interest matrix referred to as a "stakeholder map." The survey results and associated insights are detailed below.

Survey Overview

As previously described, the stakeholder survey was a fundamental tool in understanding the relative power, interest, and perceptions of the Kern County community. The survey was built and distributed through Qualtrics, a survey platform. It was then shared through relevant channels to engage the key groups identified in the stakeholder analysis—landowners, agricultural workers, local businesses, solar energy employees, and Kern County residents. Questions were tailored to each stakeholder group in order to reflect their unique experiences and needs. The insights from this survey will help shape future engagements, ensuring that any move towards agrivoltaics is both informed and supported by the community. Each group's input has been invaluable in assessing the viability of agrivoltaics initiatives.

To address the linguistic diversity in Kern County, where about 44% of households speak a language other than English (Hoyle 2023), communications materials were made available in English, Spanish, and Punjabi—the three dominant languages in the region. The survey was digitally translated by Qualtrics and reviewed by native speakers in order to maintain consistency across all versions, ensuring inclusivity and ease of access for all participants.

The survey was distributed exclusively through online channels. The City of Bakersfield, Kern County Farm Bureau, Northwest Kern County Resource Conservation District, East Kern County Resource Conservation Districts, and Kern Community College District (KCCD) shared the survey link through their email networks. KCCD and the City of Bakersfield also shared the link on their social media channels, and the City of Bakersfield included the link in a carousel of news on their website homepage. To reach solar developers specifically, we circulated the survey among employees of a specific solar development company. Finally, The Bakersfield Californian included the survey link in a local news story they published about the research project (Cox 2024).

The structure of the survey was derived from expert interviews and research, with a similar stakeholder survey conducted by the Alaska Center for Energy and Power (ACEP) serving as a particularly valuable reference. The survey included the following sections:

Disclosure Statement

Participants were informed of how their responses were informing this research project, as well as the entities conducting the research (i.e. Columbia University and the City of Bakersfield).

Time & Privacy

Respondents were alerted that the survey would take 5-10 minutes to complete and ensured the confidentiality of their responses and voluntary participation.

Short Educational Video

A brief educational video from Jack's Solar Garden (Kominek 2022), a Colorado-based agrivoltaics project serving as an educational resource for developing APV markets, was included. This video provided a visual example of functioning agrivoltaics to ensure participants had an accurate, albeit high level, impression of the system.

Stakeholder Demographics

The initial questions in the survey aimed to determine the respondent's relevant stakeholder group, position within the group, and location. The stakeholder group selected would trigger a logic flow that only surfaced questions relevant to that group. This section also asked respondents to assess their own local political activism on a scale of 1 to 10 in order to inform the relative political power within the community.

Perception of Agrivoltaics

All stakeholders were asked about their initial perceptions of agrivoltaics, including their support of solar and renewable energy in general, and perceived benefits and concerns of integrating photovoltaics onto farmland. The perception of solar and renewable energy was ranked on a scale of 1 to 10, with 10 being strongly in support. Stakeholders were also asked to select any of their primary concerns around agrivoltaics and what they perceive to be benefits from a provided list, with the option to write in their own response. These lists were compiled from research with guidance from expert interviews. Respondents were asked if they had heard of agrivoltaics before in order to gauge familiarity with the concept, and where they receive information or news. This last question was valuable in understanding the most effective communication channels for each stakeholder group.

Stakeholder-Specific Sections

Tailored to each stakeholder group, these sections possibly included questions about stakeholders' business or farm operations, energy consumption, interest in installing solar panels, and education level. Those employed in the solar industry were asked more in depth questions about their experience with consumer demand for agrivoltiacs, as well as their perceived challenges or benefits around integrating battery storage with solar projects. All stakeholders were asked if they had any additional questions, and if they would be interested in learning more. The entirety of survey questions are detailed in Appendix J. The specific areas of interest for each stakeholder group are detailed below.

Focus Areas by Stakeholder Group

Landowners

Landowners in Kern County play a critical role in the adoption and success of agrivoltaic systems. These stakeholders primarily manage vast areas of agricultural land with high potential for solar panels. Their practices and decisions on land use, workforce management, and openness to new technologies are crucial considerations in the planning of agrivoltaics projects. The survey collected data on the size and primary use of their land, ownership details (freehold or leasehold), the number of employees working on the land, and any other businesses operating on their premises. As landowners are economically vested in their land, we found it crucial to assess their level of interest and preparedness as it relates to integrating dual-use systems that could significantly alter traditional farming practices and land utilization.

Farmers

Farmers are directly affected by new projects on the land they own or work on, putting them at the core of the agrivoltaics discussion. The survey questions addressed farmers' agricultural practices and sustainability measures, including crops cultivated, water sources, and use of renewable energy. These insights are important in understanding the feasibility of agrivoltaics for the specific farmers of Kern County.

Business Owners

The survey explored the potential economic impact and engagement of business owners with regards to agrivoltaics, focusing on company size, revenue, and political involvement. Understanding the economic landscape is crucial for assessing how agrivoltaics can enhance the profitability and sustainability of business operations, or alternatively, pose challenges to the established economic balance of local business owners. The feedback from this group offers a glimpse into the business community's perspective on integrating agrivoltaics into the local economy.

Solar Industry Employees

Those employed in the solar industry are instrumental to solar development on agricultural land. As of 2024, there are currently two agrivoltaics projects in preliminary stages in Kern County (Bureau of Land Management, 2024).

These projects are focused on testing the viability of agrivoltaics systems in local conditions. Exploring developers' perspectives on agrivoltaics could encourage involvement in opening the market for such projects. This group's responses help to understand the technical and market readiness for agrivoltaics in Kern County.

Residents (Non-agricultural, non-business owners)

Including non-agricultural and non-business owner stakeholders in the analysis is crucial as their input offers a broader community perspective to consider in agrivoltaic initiatives. Residents were specifically asked about their education level in order to understand the relationship between education level and support of renewable energy projects, and inform future educational outreach.

Survey Results

Survey respondents indicated an overall positive sentiment towards agrivoltaics across different stakeholder groups, with a strong desire for more information. Significant findings are detailed below, and exhaustive survey results can be found in the Appendix K.

General lack of engagement

Certain stakeholder groups, notably non land-owning farmers, showed minimal survey engagement. Online distribution methods might not have effectively reached or motivated all targeted groups to participate.

Positive perception towards renewables

Survey results indicated that a majority of stakeholders support renewable energy, particularly landowners and business owners. To measure perception around renewable energy, respondents were asked to rank their position on a scale of 1 to 10 from "Harmful / Do Not Support" to "Beneficial / Strongly Support." A score of 10 is the highest favorable opinion. Notably, all non-farmer landowner respondents ranked themselves at 10/10, demonstrating an enthusiasm for renewable energy.

Low political involvement

On a scale of 1 to 10 for how involved in local political affairs respondents consider themselves (1 being "Not at all involved" and 10 being "Highly involved"), the average across all stakeholder groups was just over 4. This indicates relatively low political activism among respondents. This score is important because political viewpoints can greatly affect the direction and adoption of policy.

Non-farmer landowners ranked themselves highest among the stakeholder groups at 7.5/10, while the one farmers without land ownership who respondent to the survey ranked themselves at 1/10, or "Not at all involved." Future engagement and education about agrivoltaics can include encouraging policy advocacy.

Demand for more information

70% of all respondents expressed that they would be interested in learning more about agrivoltaics, indicating an opportunity for educational initiatives.

High awareness

69% of respondents indicated that they were familiar with the term "agrivoltaics." Landowners, both farmer and non-farmer, all reported that they were familiar, as did all respondents employed in the solar industry. Less than half of residents (46%) indicated that they were familiar, demonstrating an opportunity for increased education.

Perceived benefits and concerns

The stakeholder feedback suggested certain perceived benefits of agrivoltaics, with the most common being increased renewable energy production and new job opportunities. Other significant advantages highlighted include improved energy security, the stabilization of energy prices, enhanced land utilization, and the preservation of groundwater resources. These selections offer an encouraging view that stakeholders within Kern County generally understand the potential positive impacts of agrivoltaics as a multifaceted approach to environmental and economic challenges in the community.

However, alongside these perceived benefits, there are several concerns that stakeholders frequently mentioned. High costs of installing and maintaining agrivoltaic systems and removal and disposal of solar panels at the end of their life cycle were the two most frequently selected concerns, reflecting apprehension about the long-term return on investment and environmental impacts. Conflicts with existing land use, along with the potential to negatively impact crop yields, were also frequently selected.

The generalizability of the survey findings is limited by the low volume of responses and varied representation across stakeholder groups. While the sample size is unknown due to survey distribution through social media and various online channels, the average response rate for market research surveys is approximately 30% and response rates above 20% are generally considered representative for public surveys (Lindemann 2024). The survey's low engagement levels, such as in the case of one non-landowning farmer respondent, therefore limit its ability to represent and direct decisions for an entire stakeholder group.

The results, while informative, represent a relatively narrow segment of the total population and we caution against drawing broad conclusions at this point.

Nevertheless, our direct engagements such as in-person site visits and discussions with various stakeholders support the insights gathered through the survey, allowing placement in the stakeholder map and recommendations for future engagement strategies.

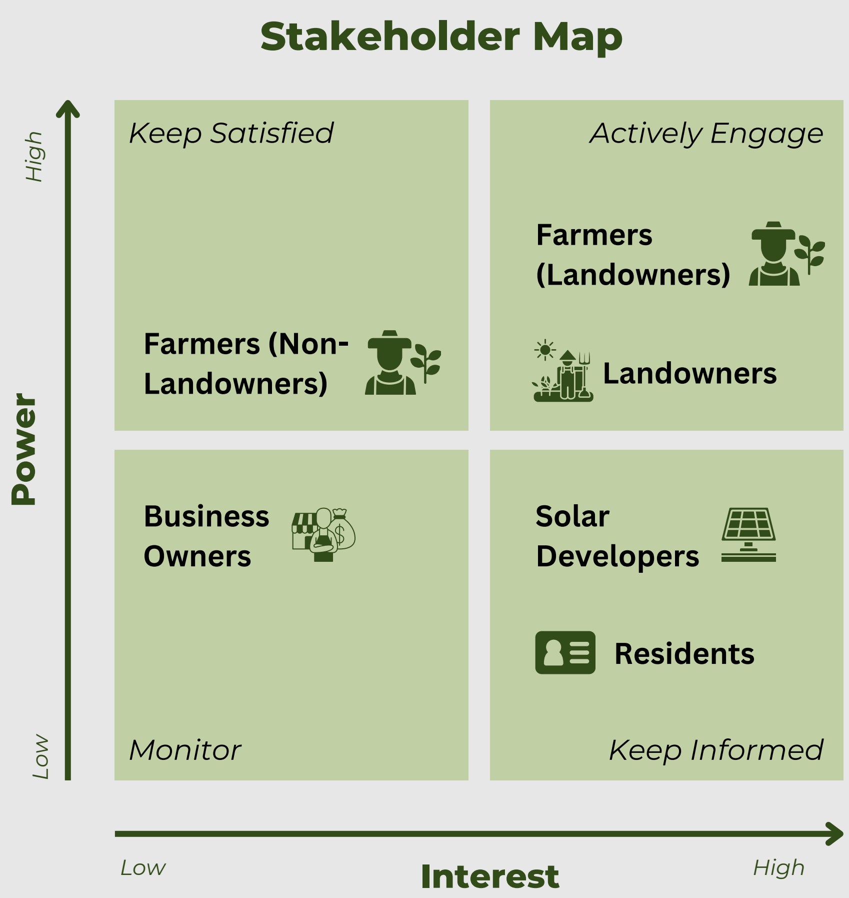
Stakeholder Map

Both the aforementioned survey results and the insightful conversations during our team's site visit to Kern County led to the positioning of stakeholder groups within a power vs. interest matrix. The visual representation of this relationship between power and interest can be seen in the stakeholder map below (Figure 23).

The four quadrants of the stakeholder map are described below:

1. **Actively Engage** (high power, high interest): Engage regularly and transparently with key players that have high potential to influence decision-making and impact project success.
2. **Keep Satisfied** (high power, low interest): Consult with these entities to avoid garnering influential detractors and increase interest.
3. **Keep Informed** (low power, high interest): Maintain engagement and share information as necessary.
4. **Monitor** (low power, low interest): Provide periodic updates to indirectly affected parties who may not desire excessive communication.

Figure 23: Stakeholder map results



Key Insights

Farmers

Due to stakeholder feedback, the farmer stakeholder group was divided into farmers who are landowners and farmers who are not landowners (i.e. those who work on the farm). Given the fact that landowning farmers are likely the ultimate decision-makers for the allocation of resources for new projects being implemented on their farms, they hold the highest level of power in the context of this project. Through an analysis of survey responses and conversations held on farm sites in Bakersfield, farmers are open to solar installations and eager to learn more about agrivoltaics. Non-land owning farmers do not have the same level of decision-making power seen in landowning farmers. However, these farmer groups have the potential to be detractors or champions for agrivoltaics implementation given their daily involvement on potential sites. Farmers are high priority stakeholders who require active engagement throughout the planning and implementation of APV projects.

As the survey only yielded one response from a non-landowning farmer, we emphasize the importance of relevant communication mediums based on the stakeholder group. Although the survey was ineffective at reaching farmers, in-person communication during our site visit proved to be constructive. Establishing context-driven communication channels is critical in effectively communicating the benefits and importance of agrivoltaics.

Landowners

Similar to landowning farmers, non-farmer landowners are critical stakeholders in terms of engagement efforts. Given their decision-making power, self-identified level of political involvement, and indications of high interest through the survey, these stakeholders have the potential to be tremendous advocates for agrivoltaics. Conversely, without the support of landowners, an APV project is unlikely to be successful. Landowners are priority stakeholders to actively engage through an APV project’s life cycle.

Business Owners

Business owners indicated they were generally interested in learning more about agrivoltaics in the survey, but at the same time selected multiple concerns. Though these stakeholders reach a broad group of individuals through their presence in the community, survey responses indicate that their potential for impact is low in the scope of agrivoltaics implementation. Given their relatively low political involvement and limited influence to the scope of APV projects, business owners have been identified as the lowest priority for engagement.

Solar Developers

Though there are no agrivoltaics-only solar developers in Kern County, these stakeholders still hold significant power given their expertise in PV project development. The survey delivered mixed perception results from solar developers that showed a significant amount of skepticism in regards to agrivoltaics. Given their occupation in renewable energy, it was surprising to see solar developers raising concerns about the feasibility of agrivoltaics. The reasoning behind this skepticism should be explored in further research within Kern County. Solar developers should be informed regularly throughout APV project implementation in order to stay abreast of local industry developments.

Residents

This group was the most active in terms of responses to the stakeholder survey, contributing to their placement on the high end of the interest axis. Given the group's relatively low self-identified political involvement and decision-making power, residents ranked the lowest in terms of power. Though this group is not a priority segment in terms of active engagement throughout APV project implementation, residents should be informed regularly through relevant communication channels.

When referencing the stakeholder matrix in terms of engagement efforts, it's helpful to think of the segments by the upper and bottom halves. The top half includes the three stakeholder groups identified as high-priority for stakeholder engagement, farmers (non-landowning and landowning) and landowners, as these stakeholders have the potential to be either champions or detractors for agrivoltaics implementation. Although all stakeholders have the ability to influence the success of an APV project, farmers and landowners could disproportionately influence the potential for implementing agrivoltaics in Kern County. The bottom half of the matrix, including business owners, solar developers, and residents, are stakeholders that require less consistent engagement. We recommend reflecting these priority levels by diversifying the type, frequency, and method of communication based on the stakeholder group.

Stakeholder Engagement

Gap Analysis Methodology

While initial findings from both the survey and in-person site visits provide valuable insights on stakeholder perceptions and influence around agrivoltaics, additional research is needed for the City of Bakersfield to gain a more accurate understanding of its diverse constituents and their unique

relationships to these projects. In order to determine next steps, we conducted a gap analysis to identify the specific areas of opportunity for the City of Bakersfield to effectively engage with its stakeholders.

Gap analyses are commonly employed by companies and organizations to compare actual performance to desired or potential performance and provide data-backed insights for decision-making. Conducting a gap analysis involves assessing an existing state, defining a target state, and identifying opportunities to overcome the shortcomings, or "gap."

For this analysis, we evaluated both stakeholder survey engagement and their perceptions regarding agrivoltaics and renewable energy. Target states were determined by industry averages or our team's estimation of realistic improvements from the current baseline. This analysis should be completed periodically to gauge progress and understand if efforts to increase engagement or address knowledge gaps are successful.

Completion Rate

Our survey had a 54% completion rate, which indicates the percentage of respondents that started the survey and submitted it after the last question. According to SurveyMonkey, the average completion rate for a survey with 10-20 questions is 87-89%. Survey length and complexity of question are the greatest drivers of completion rate. For example, surveys with 10 open-ended questions have a mean completion rate of 78% while those with 1 open-ended question have a mean completion rate of 88% (SurveyMonkey, 2024). Shortening the survey where possible and replacing free response questions with multiple choice can improve survey completion rates.

Studies show that monetary incentives are correlated with significant increases in survey response and completion rate (Abdelazeem et al., 2023). Prepaid cash rewards are the most effective when compared with lottery systems and vouchers. However, when looking to garner a large volume of survey responses, a lottery system is more cost-effective and realistic than unconditional monetary incentives (i.e., paying each respondent upfront).

Monetary incentives are commonly used to increase survey participation by many institutions, including federal and local governments. A review of federal survey programs by the Bureau of Labor Statistics found that offering cash payments of $10 or $20 has been common practice across government surveys (To, 2015). We recommend a lottery prize of $100, which has been shown to be as effective at increasing survey participation as larger dollar amounts (Kang, 2016).

Response Distribution

The greatest proportion of total survey responses came from residents, who made up 55% of all responses. While their input is valuable, they are placed lowest in priority on the stakeholder map based on their level of power and interest in agrivoltaics projects. The target stakeholder response distribution is correlated with level of influence and relevance, as indicated by the metrics below.

The stakeholder groups in the “Actively Engage” quadrant, specifically landowners, both farmers and otherwise have the highest target percentage of survey responses as they are highest in priority on the stakeholder map. Stakeholders in the “Keep Satisfied” and “Keep Informed” quadrants (non-landowning farmers, solar industry employees, and residents) are weighted second highest, and stakeholders in the “Monitor” quadrant (business owners) are weighted the lowest. From these rankings, we deduced a target proportion of total responses from landowners and landowning farmers is 23%, compared to 15% for non-landowning farmers, solar industry employees, and residents. The target proportion of responses from business owners is around 8% of total responses.

Out of all the stakeholder groups, residents (55%) and business owners (13%) exceeded their target response percentage, and were excluded from the gap analysis. To increase participation in the other stakeholder groups, we recommend engaging more directly with communities through trusted community leaders, in-person gatherings, and industry networks.

Table 12: Stakeholder engagement gap analysis

Item	Current State	Target State	Gap	Recommendation
Completion rate	54%	85%	+31%	Reduce number of questions, replace free response questions with multiple choice, offer financial incentive
Landowner response distribution	6% of total responses	23% of total response	+17%	Distribute through industry networks
Landowning farmer response distribution	11% of total responses	23% of total responses	+12%	Establish community champions, distribute at in-person gatherings
Non-landowning farmer response distribution	2% of total responses	15% of total responses	+13%	Establish community champions, distribute at in-person gatherings
Solar industry response distribution	11% of total responses	15% of total responses	+4%	Distribute through industry networks

Engagement Recommendations

Industry Networks

Online distribution and digital communication is the fastest way to reach a wide audience. However, with the abundance of emails and notifications that people receive each day, targeted outreach through industry networks can be more effective at reaching relevant stakeholders. This could be local organizations that serve the stakeholders, or networks which they may be a part of with curated email lists. When speaking with representatives of American Farmland Trust, for example, they advised communicating with farmers through organizations active in Kern County such as local Resource Conservation Districts, the University of California Cooperative Extension, Agricultural Conservation Easement Program (ACEP), California Chapter of the

American Society of Farm Managers and Rural Appraisers (CALASFMRA), and related service providers with county-level presences. In the case of landowners, this could include Kern County Planning and Natural Resources Department, Bureau of Land Management Bakersfield Field Office, Kern County Farm Service Agency, and other county departments. Solar industry employees could be reached through networks such as California Solar & Storage Association (CALSSA) and California Solar Energy Industries Association (CALSEIA), in addition to the California Renewable Energy Laboratory.

Community Leaders

In some cases, online distribution is not the most effective channel to communicate with stakeholders. Engaging trusted community leaders who understand the needs and concerns of the community has the potential to reach more stakeholders directly and encourage them to share honestly.

For example, during our site visit to Bakersfield, our team identified a table grape and citrus farmer who is considered a leader within the community. This farmer is particularly open to innovations and was curious about opportunities with agrivoltaics. Such a stakeholder would be an ideal champion to garner survey participation and convey the value of this research to fellow farmers.

In-person Gatherings and Forums

Another reason information distributed through email and social media is not effective for some stakeholder groups is that some, particularly farmers, are spending a majority of their time in the fields and away from computers. Farmers are busy, and the time it takes to fill out a survey may not seem valuable when compared to other responsibilities.

One way to address this hurdle is by engaging with in-person gatherings such as conferences, town halls, or informal meet-ups. For example, our team attended the Outlook 2024 Agribusiness Conference held by the California Chapter of the American Society of Farm Managers and Rural Appraisers (ASFMRA) Western Ag Professionals in Bakersfield. There, participants were able to engage directly with stakeholders and hear about pressing concerns within the community. The community leaders mentioned above can help identify the forums most relevant to their communities.

Utilizing these channels can more directly reach stakeholders and increase survey participation, furthering the City of Bakersfield's understanding of its stakeholders' perceptions and concerns. Meeting the stakeholders where they are also demonstrates the City's dedication to including their input in decision-making. These findings can inform ongoing communications strategy to educate the community and encourage support of future agrivoltaics projects.

Table 13: Stakeholder perception gap analysis

Item	Current State	Target State	Gap
Familiar with the term “agrivoltaics”	46%	66%	+20%
Survey respondents concerned about removal and disposal of solar panels	19%	10%	-9%
Survey respondents concerned about high costs of agrivoltaics	17%	10%	-7%
Survey respondents seeing improved groundwater conservation as a potential benefit	13%	20%	+7%
Survey respondents seeing new revenue opportunities as a potential benefit	13%	20%	+7%

While these findings are not indicative of all stakeholders’ sentiments, early insights from our survey, stakeholder interviews, and research can help guide the City of Bakerfield’s future communication efforts. Currently, 72% of survey respondents expressed support of renewable energy (their response indicated a score above 7). This support level is higher than the national average of 67% of U.S. adults prioritizing the development of alternative energy sources, as found by Pew Research Center (Kennedy et al. 2023).

The main challenge is familiarizing stakeholders with the specifics of agrivoltaics. Our stakeholder interviews and research have demonstrated that increased understanding for agrivoltaics can be heavily influenced by seeing successful demonstrations. Education addressing the benefits of agrivoltaics, particularly around groundwater conservation and revenue diversification, as well as addressing operational and economic concerns can lead to better understanding of the opportunities ahead.

These insights, along with the stakeholder map, informed our recommendation for a future communications strategy, seen in Table 14. Tailoring communications to be specific to the context of each stakeholder should benefit the efficacy of engagement with each group.

Table 14: Stakeholder communication strategy guidelines

	Landowners (non-farmers)	Farmers	Business Owners	Solar Developers	Residents
Method	Local News Radio Newsletters Social Media Industry Groups	Local News Radio In-Person Forums Industry Groups Community Leaders	Local News Newsletter Social Media	Social Media Radio	Local News Social Media Radio Newsletters YouTube National News
Content	Proof of concept, financing options	Proof of concept, information about renewable energy, financing options	Information about agrivoltaics and environmental impacts	Updates on Kern County agrivoltaics	Information about agrivoltaics, renewable energy, updates on Kern County agrivoltaics
Frequency	Weekly	Weekly	Quarterly	Monthly	Monthly

Method is guided by the self-proclaimed primary means of receiving news and information in the survey. Channels such as social media, radio, local news, and newsletters are most effective for stakeholder groups excluding farmers. We recommend engaging with farmers in person or through community members for most direct communication.

Content was determined by the primary concerns listed by survey respondents. For stakeholders most directly impacted by agrivoltaics projects, farmers and landowners, information concerning the financial details and proof of concept (including economic return) from local demonstration sites would be valuable to increasing their understanding. Conversations during our site visit with table grape farmers of Cattani Farms, for example, revealed that demonstration sites active for at least five years are important to convince them that agrivoltaics would be successful in the area.

As agrivoltaics is still not widely known or understood, we recommend prioritizing descriptive language such as "renewable energy and agriculture" or "solar panels on productive farmland" where possible. Rather than using a general term that may lead to different interpretations, providing additional explanation and context to accurately represent what the system is referring to will reduce confusion and misunderstanding.

Frequency is guided by the position on the stakeholder map. Stakeholder groups in the "Actively Engage" quadrant warrant the most frequent communication because of their highest relative power and interest. Stakeholders in the "Keep Satisfied" and "Keep Informed" quadrants can be informed on a monthly basis, and stakeholders in the "Monitor" quadrant can be informed quarterly or as needed.

Impact Assessment

Cost-benefit analysis (CBA) serves as a methodical approach to compare the projected costs, disbenefits, and benefits of a project and its alternatives in order to determine if the project is economically justified. Costs refer to the monetary expenses required to implement a project, disbenefits are the adverse impacts that result from the project, and benefits are the positive impacts arising from it. This method involves identifying and assigning monetary values to all associated costs and benefits, both financial and non-financial. Subsequently, the total costs and disbenefits are deducted from the total benefits to determine the net economic impact of the project (Stobierski, 2019).

Specifically, *Ex Ante* CBA, which is conducted prior to the start of a project, is particularly suitable for assessing the feasibility of implementing agrivoltaic practices, as opposed to *Ex Post* CBA, which is conducted after the project is completed, or *In Medias Res* CBA, which is conducted throughout the project. The following nine-step procedure is advised for a thorough evaluation (Boardman *et al*., 2018), facilitating a clear-decision making framework.

1. Identify the set of alternative projects

We assessed one baseline scenario and two alternative options, each defined by different land use strategies. The baseline involves dedicating land solely to agriculture. The first alternative involves replacing productive agricultural land with solar panels. The second alternative is an agrivoltaics project using the land simultaneously for both crop production and energy generation.

2. Identify stakeholders

Understanding the interests, power dynamics, and positions of stakeholders is essential for evaluating the feasibility and effectiveness of proposed measures. This insight allows for more informed and balanced assessments of benefits and costs (Jenkins *et al*, 2010). Based on our stakeholder analysis, five groups of stakeholders were identified:

A. Landowners
B. Farmers (including landowners and non-landowners)
C. Business Owners
D. Solar Developers
E. Residents

3. Identify benefits, disbenefits, and costs

The list of potential impacts, both positive and negative, was derived from a collaborative approach. Our team held a workshop to discuss and identify the possible impacts that could occur as a result of agrivoltaics implementation. Additionally, three environmental, social, and governance (ESG) frameworks were used to validate and expand the list of impacts: The Taskforce on Nature-related Financial Disclosures (TNFD), The Taskforce on Climate-related Financial Disclosures (TCFD), and the Sustainability Accounting Standards Board (SASB). These frameworks help organizations identify, assess, and report on sustainability risks and opportunities, thereby facilitating more informed decision-making. Specifically, two industries from SASB's Sustainable Industry Classification System (SICS) were closely examined to identify material impacts: Agricultural Products and Solar Technology & Project Developers. By combining the team's inputs with the guidance from these ESG frameworks, a final list of 14 potential impacts was compiled and validated with key stakeholders.

Impacts were categorized into two main areas: agriculture and energy, with the latter focusing on photovoltaic panel manufacturing, installation, and waste management. Each impact area was further divided into environmental, social, and economic dimensions, with detailed breakdowns provided in the accompanying Appendix L. This comprehensive approach ensured that the identified impacts covered a wide range of considerations, incorporating perspectives from both internal stakeholders and established ESG frameworks.

Initially, 14 impacts were identified (see full list in Appendix M). These impacts were then scored based on three factors: timeframe, scale, and likelihood. Each factor was assigned a weight ranging from 1 to 3 based on the scale of impact within each factor (see Table 15). Higher weights indicate greater impact significance to the client.

Table 15. CBA criteria for impact scores

Factors	Categories	Weights	Criteria
Timeframe	Near Term	1	Duration of impacts last <1 year
	Medium Term	2	Duration of impacts last 1-25 years (scope of solar project)
	Long Term	3	Duration of impacts last >25 years
Scale	Farm	1	The impacts are site-specific
	County	2	The impacts affect multiple stakeholders across Kern County
	State	3	The impacts affect multiple stakeholders across California
Likelihood	Low	1	**Limited or Negative Evidence**: 1 or fewer sources *suggest* some relevance of the impact
	Medium	2	**Mixed Evidence: 1** or more sources *suggest* the relevance of the impact
	High	3	**Strong Positive Evidence:** Multiple sources *explicitly* state the relevance of the impact

The overall score for each impact was calculated by multiplying the weights of the three factors.

*Impact Score= (Timeframe) * (Scale) * (Likelihood)*

The scoring system used to evaluate impacts ranges from 1 to 27. A score of 1 signifies that all three factors—timeframe, scale, and likelihood—received the minimum weight of 1. Conversely, a score of 27 indicates that each factor was given the maximum weight of 3. The scores are categorized into three levels: low (1-9), medium (10-18), and high (19-27). Impacts with a level of medium or high, scoring above 10, were considered significant and included in the CBA. Six impacts surpassed the threshold score and were shortlisted, as shown in Table 16.

Table 16. Shortlisted CBA impacts

Potential Impacts	Timeframe	Scale of Impact	Likelihood	Score
Surface water and groundwater depletion due to irrigation	Long Term	State	High	27
Shading impact on crop yield	Medium Term	State	High	18
Change in GHG emissions from energy use	Medium Term	State	High	18
Heat-related illness for farmworkers	Medium Term	State	Medium	12
Sustained job security & benefits	Long Term	County	Medium	12
Contamination of soil & water due to panel disposal at end-of-life	Long Term	County	Medium	12

4. Estimate the project's duration

The duration of the project is set to be 25 years, aligning with the expected lifetime of the installed photovoltaic panels. This estimate is supported by the standard industry practice that the lifespan of solar panels falls within the range of 20 to 25 years (Yasar 2022).

5. Quantify monetary value of shortlisted impacts

The next step in the analysis is to quantify the monetary value of the six shortlisted impacts across three distinct scenarios. The methodology for valuing these impacts is outlined in Table 17. The variables are defined below the table.

Table 17. Valuation methodology across all impacts and scenarios

Impacts	Valuation Methods Across 3 Scenarios		
	Agrivoltaics	**Traditional Farming**	**Solar Generation**
Impact 1: Change in GHG emissions from energy use	(NRE - RE)*COC	*No Emissions Reduction*	(NRE - RE)*COC
Impact 2: Surface and groundwater depletion due to irrigation	AWC - (AWC*SS) + (AWK*COW)	AWC*COW	AWK*COW
Impact 3: Shading impact on crop yield	(AP*YC)+SP	AP	SP
Impact 4: Heat-related illness for farmworkers	CF*AHR*HC	CF*HR*HC	*No Farm Workers*
Impact 5: Sustained job security & benefits	(AF*CI) + (CJ*YI*CI) + (OJ*YI*CI)	AF*CI	(CJ*YI*CI) + (OJ*YI*CI)
Impact 6: Contamination of soil & water due to panel disposal at end-of-life	*Impact is evaluated qualitatively*		

Impact 1: Whole System Emissions Reduction Benefit
NRE: kWh of energy consumed per year * non-renewable energy emission factor
RE: kWh of energy consumed per year * renewable energy emission factor
COC: Social Cost of Carbon, used to monetize the emissions reduction benefit

Impact 2: Per Acre Water Depletion Cost
AWC: Current annual water usage per crop acre.
AWK: Annual water usage per kWh of energy generated.
SS: Percentage of water savings achieved through shading from solar panels.
COW: Cost of water per unit.

Impact 3: Per Acre Shading Yield Benefit
AP: Annual agricultural production value per acre.
SP: Annual solar production value per acre.
YC: Percentage change in crop yield at the optimal reduced solar radiation level.

Impact 4: Per Acre Heat-Health Cost
CF: Number of crop farm workers per acre.
HR: Average annual hospitalization rate for heat-related illnesses among farmworkers.
HC: Hospital cost for treating heat-related illnesses.
AHR: Adjusted average annual hospitalization rate for heat-related illnesses among farmworkers, accounting for shading effects.

Impact 5: Per Acre Jobs Tax Revenue Benefit[4]
AF: Average number of farmworkers per acre per year.
CI: Income tax rate for workers in California.
CJ: Number of construction jobs created in the first year of the project.
OJ: Number of operation and maintenance jobs created over the project lifetime.
YI: Average yearly income for workers.

Impact values are calculated on a per acre basis, except for Impact 1 which represents the total emissions reduction benefit over the project's lifetime, and is dependent on the energy generated at the site. In order to obtain the total values for Impacts 2-5 at an APV demonstration site, the per-acre values are multiplied by total site acreage.

4. Note that construction jobs are only considered in the first year, while operation and maintenance jobs are considered throughout the project lifetime.

6. Discount both the benefits and costs to obtain the present values (PV)

Since the project is expected to span 25 years, the associated benefits and costs need to be discounted to account for the time value of money. This process allows for the aggregation of benefits and costs that occur over multiple years (Boardman *et al.*, 2018). While there are various methods to apply a discount rate, the standard approach is to use a constant discount rate, which assumes an invariant rate over time (Guerriero and Pacelli, 2020). The objective of this step is to determine the Present Values (PV) of the benefits and costs. PV was calculated per the below formula:

$$PV = FV \frac{1}{(1+r)^n}$$

where,

PV: Present Value
FV: Future Value, based on the net benefits of each year
r: 3.4% discount rate based on Ramsey's growth model that is suitable for public-related CBA (Boardman *et al.*, 2018)
n: Number of periods (years)

7. Calculate the Net Present Value (NPV) of each of the identified alternatives

After determining the PV of benefits and costs across all alternatives, the next step is to calculate the Net Present Value (NPV) for each alternative. The NPV will give an indication of whether the benefits exceed the costs (NPV > 0) or vice versa (NPV < 0). The NPV is defined as the difference between the PV of benefits (B) and the PV of costs (C):

$$NPV = PV(B) - PV(C)$$

8. Perform sensitivity analysis

The cost-benefit analysis (CBA) methodology requires making certain assumptions. Therefore, conducting a sensitivity analysis is an integral part of the CBA process. By examining uncertainties and variations in assumptions, the sensitivity analysis enhances the reliability and credibility of the cost-benefit assessment (McCabe et al., 2020). The sensitivity analysis assesses water savings in the cultivation of grapes, indicating possible reductions ranging from 12% to 34% (Sun'Agri, 2021). The Monte Carlo simulation, a tool widely employed in statistics and other scientific areas, is used to determine the differences in parameters between two random processes, effectively reducing the variance of these estimates (Gentle, 2014).

9. Determine recommendations

Across the two alternatives evaluated against the agricultural baseline, the CBA will indicate the option that offers an increase to net present value (NPV), presents the lowest risk, and benefits the greatest range of stakeholders.

Cost-benefit Analysis Methodology

Agriculture Costs

The costs incurred in the CBA model stem from agricultural and energy costs. Agricultural cost assumptions come from the University of California (UC) Agriculture and Natural Resources Cooperative Extension in 2018, which specifically discusses the sample costs to establish and produce table grapes. The costs include operating costs per acre, which comprises pre-planting costs, planting costs, cultural costs, and harvesting costs. Moreover, the per-acre agricultural costs include cash overhead such as property taxes and non-cash overhead costs, which includes the capital recovery cost for equipment and other farm investments. The average operational cost, based on UC Davis agricultural data, was $44,853 per year for a 5-acre plot. The costs related to water is not included in agricultural costs as it is accounted for in another impact, surface water and groundwater depletion due to irrigation.

Energy Costs

In our analysis, we considered the costs associated with energy generation, which were informed by our energy financial model. This model accounted for the initial capital expenditure (CapEx) in year 0 and the annual operational expenditure (OpEx) until year 25. The cost of energy is differentiated between the agrivoltaics scenario and the traditional solar scenario, which utilizes ground-mounted PV with higher energy density.

The CapEx in agrivoltaics and ground-mounted photovoltaics are $1,370,578 and $1,480,542, respectively. The average annual OpEx is 25,229 and $40,479 for agrivoltaics and ground-mounted photovoltaics, respectively. The CapEx of ground-mount solar is higher than that of agrivoltaics because it can contain more solar panels within the same amount of land. This higher energy density translates to an increase in upfront costs, but also increases the long-term revenue generated by that solar system. The modeled OpEx is lower in agrivoltaics compared to ground-mount solar because of the differences in land management between system types. Solar-only systems require continued maintenance in the form of mowing, pesticide spraying, and other land maintenance activities that no longer apply when the farmer is managing the land.

BENEFITS (B)

Emission Changes

Emission reduction benefits of solar and agrivoltaics were calculated in comparison to agriculture only, which represented no change in emissions. The assumption is that energy generated through local solar energy production is lowering emissions of energy normally supplied through the grid's energy sources. To calculate baseline energy emissions, an emissions factor was generated from an energy mix consistent with what would be found in Bakersfield. This baseline energy mix consisted of 60.6% solar, 34.57% natural gas, and 4.84% from conventional hydroelectric (findenergy, n.d.). The emissions factor generated from this energy mixture was 0.204 kg CO2e / kWh (direct emissions) and was derived from an LCA informed with data inputs from SimaPro. As solar photovoltaic energy generation doesn't release direct emissions, energy generated from a traditional solar or agrivoltaic system would reduce grid emissions by the same 0.204 kg COe / kWh. The emissions reductions for each system were then converted into a monetary value using the social cost of carbon of $51/ton of CO2e, estimated by the Biden administration (Fisher, 2024).

The difference in emissions reduction between the agrivoltaic scenario and the traditional solar scenario depends on the total kilowatt-hours (kWh) of energy produced over the project's lifetime. Based on energy density assumptions from our project finance model, the energy produced over 25 years from traditional solar only is approximately 48% higher than the agrivoltaics scenario (39,925,341 kWh compared to 20,431,182 kWh). A larger emissions reduction in the solar scenario is because for the same acre, traditional solar projects contain more photovoltaic panels than agrivoltaics as those projects do not need to consider adjustments for crop spacing.

Shading Yield Benefit

As discussed in the agriculture section, APV shading could potentially increase the yield of table grapes. The shading yield benefit is highest for the agrivoltaics scenario at $38,202 per acre per year from combined agricultural and solar production values, compared to $19,260 for the agriculture-only scenario and $35,134 for the solar-only scenario. The increase of revenue in the agrivoltaics scenario was based on the Sun'Agri analysis of a 5% grape yield increase with 30% reduced solar radiation, both of which were factored into our calculation. For the solar-only scenario, the value is derived solely from the annual solar production per acre which was informed by our financial model.

Job Security

The jobs tax revenue benefit is greatest for the agrivoltaic scenario at $8,510 in the first year and $7,930 thereafter from combined farmworker, construction, and operations jobs. Comparatively, tax revenue from construction and operations equated to $6,539 and $6,152, respectively, for the first and subsequent years in the solar-only scenario, and just $1,778 for the agriculture-only scenario.

DISBENEFITS (D)

Surface and groundwater depletion due to irrigation demands

The hypothetical 5 acre site that this CBA was modeled on is located in the Kern Delta Water District. This assumes that water comes from a mix of district utility-supplied water (85-90%) and state-supplied water (10-15%). Utility-supplied water cost $24 / acre ft and state-supplied water cost $80-118 / acre ft. The weighted average mix is $33 / acre ft used in our water cost calculations. Moreover, the water used to clean the solar panel is estimated to be ⅔ cup of water per megawatt hour (Clarke, 2014), equivalent to 66.54 gallons per kWh.

To calculate the potential water savings from implementing agrivoltaics for table grape cultivation, the total annual water requirement table grapes was first determined. This was achieved by multiplying the eligible acreage for table grapes (57,770 acres based on our GIS data) with the water requirement per year, 36.66 inches (De C Teixeira et al., 2007). The resulting value in acre-inches was then converted to acre-feet using the conversion rate of one acre-foot equivalent to 12 acre-inches. This results in 176,503 acre-ft. Based on studies conducted in France, the potential reduction in water consumption with agrivoltaics ranges from 12% to 34%, with a median value of 23%. This was applied to the total annual water requirement calculated earlier to estimate the volume of water that could be saved through agrivoltaics, which is 40,595 acre-ft. Finally, to provide a better understanding of the magnitude of these savings, the volume of water saved was converted into the number of households it could supply for a year. According to the Water Education Foundation (2020), the average California household typically consumes between one-half and one acre-foot of water annually, averaging about 0.75 acre-feet per year. This translates to a water-saving equivalent of providing enough water for over 54,000 households in California, or roughly one-fifth of Kern County residents.

The results show that the agrivoltaics scenario has a lower water depletion cost of $393 per acre per year versus $510 for the agriculture-only scenario, though costs are higher than the solar-only scenario at $0.03, which doesn’t need water for productive crops.

Heat-related illness impacts of shading for farmworkers

To determine the baseline costs of heat-related illness treatment for farmworkers, the national total of heat-related emergency department visits in 2020 (Dring 2022) was adjusted for the 10.9% increased prevalence of heat-related illness among those employed in agriculture in nearby Los Angeles County (Riley 2018). The estimated 0.02% of farmworkers visiting the emergency department for heat-related illnesses per year is likely conservative, as high temperatures and the large agricultural industry in California could contribute to higher rates of heat-related illness.

The average cost of heat-related illnesses is based on the average costs of emergency department visits in the United States in 2017 from the Healthcare Cost and Utilization Project (HCUP) (Moore & Liang 2020) and the nationally adjusted mean cost per heat-related illness hospitalization using the 2001 to 2010 Nationwide Inpatient Sample (NIS) (Schmeltz et al. 2016). Treat-and-release costs were $530 and hospitalization costs were $5,359. These respective costs were then applied to Nationwide Emergency Department Sample (NEDS) data, which found that from 2006 to 2010 the majority of heat-related emergency department visits were treat-and-release visits at 88.2% compared to admitted hospitalizations at 11.8% (Hess 2017). Using these data, we calculate the weighted average estimated cost of heat-related illness to be $1109.48.

Drawing from a study assessing the impacts of shade provision on summer heat stress in a hot Mediterranean climate similar to that of California, the shade provided by solar panels has the potential to reduce heat stress on agricultural workers by around 30% (Aleksandrowicz & Pearlmutter 2023). We applied this reduction to related health costs and normalized per acre, finding that heat-related illness costs were lowest for the agrivoltaic scenario at $0.37 per acre, higher for the agriculture-only scenario at $0.53, and zero for the solar-only scenario where no farmworkers are involved. The lower cost in the agrivoltaics scenario demonstrates the potential reduction in heat-related illness for farmworkers due to increased shade provided by solar panels in the field.

Contamination of soil and water due to panel disposal at end-of-life (qualitative assessment)

Due to the limitations of available research on the quantitative impacts of soil and water contamination from the disposal of solar panels, we chose to evaluate this impact qualitatively. The specific impact also depends on the location of solar panel disposal. Ultimately, the lack of information and reliance on assumptions would result in too inaccurate of a conclusion to provide value to our quantitative cost-benefit analysis. However, because of the relevance to Kern County stakeholders, we determined it was still valuable to discuss the findings of available research.

Solar modules are most commonly disposed of in landfills, managed as hazardous waste, or recycled. In California, solar panels were reclassified in 2021 as "universal waste" rather than hazardous waste in an effort to encourage recycling, though modules above a certain toxicity level may still be classified as hazardous waste (DTSC 2020). However, according to the US National Renewable Energy Laboratory, less than 10% of decommissioned panels are recycled nationally (Curtis et al. 2021). The U.S. Department of Energy states that the cost of waste generators to recycle photovoltaic modules is around $15-$45 per module, significantly higher than the landfill fee of $1-$5 per module (SETO 2022).

When solar panels are disposed of in landfills or other improper facilities, there is a risk that toxic materials in the composition of the panels can leach out over time, contaminating the soil and potentially impacting groundwater as well. Some of the materials in solar panels that raise the risk of contamination include lead, cadmium, selenium, tin, silicon, copper, and other trace metals. When these components degrade over time, they can release chemicals into the soil that may be harmful to the environment and human health (EPRI 2018). In a study conducted on soil contamination from thin-film solar panels in acidic environments, increased concentrations of heavy metals such as copper, nickel, zinc, silver, and lead in soil samples were correlated to the amounts of solar panels buried (Su et al. 2019). Several of these metals are found in the bifacial mono-crystalline silicon (c-Si) solar panels used in our analysis.

As the production, use, and disposal of solar panels increases, it is crucial to develop proper recycling infrastructure to reclaim valuable materials, such as glass and metals, and ensure solar panel waste does not contaminate local soil and waterways. Given that most photovoltaic modules have an estimated lifetime of 30 years, forecasts suggest that there will be 8 million metric tons of panels disposed of by 2030 and 80 million metric tons by 2050 (Heath et al. 2020). In the United States, there are currently no federal regulations mandating solar panel recycling. However, policy changes and technological improvements are underway to increase photovoltaic recycling. The U.S. Department of Energy is currently funding research and development projects to improve solar panel recycling technologies (SETO 2022). Experts predict that as the volume of retired solar panels increases, the value of recovered materials such as silver, copper, and silicon will make recycling more economically viable and widespread (Hurdle 2023). These advancements can greatly reduce the risk of soil and water contamination from solar panel disposal.

Cost-benefit Analysis Results

The cost-benefit analysis was conducted for a hypothetical demonstration site of either an agriculture only site, a 850kW ground-mount solar only site, or a 500 kWp agrivoltaic system. This system is placed on 5 acres of land, with table grapes acting as the targeted crop. The analysis considered an annual degradation rate of 0.5% for the solar panels over a 25-year project lifetime. The overall result of the CBA showed that the agrivoltaics scenario had a 19% higher NPV compared to the agriculture baseline, while traditional solar produced a 30% higher NPV. The detailed values can be found in Table 18. Despite the lower NPV compared to the solar only scenario, the agrivoltaic scenario is recommended as the preferred option due to its holistic benefits distributed across all stakeholder groups. Farmers in particular benefit from agrivoltaics systems since their jobs are assumed to be unhindered, whereas they are excluded from the solar-only scenario in which their agricultural jobs are no longer needed. Adhering to the Pareto Principle and Pareto Relevance in CBA, which ensures that adopting projects with positive net benefits enhances overall well-being and efficient resource allocation (Zerbe & Scott, 2014), the agrivoltaics scenario emerged as the recommended choice.

Table 18. The result of cost-benefit analysis: 500 kWp table grapes

Categories	Agriculture	Solar	Agrivoltaics
Benefits (B)			
Emission Changes	$0	$276,842	$141,670
Shading Yield Benefit	$1,604,498	$2,927,010	$3,182,575
Job Security	$29,625	$102,877	$132,689
Disbenefits (D)			
Water Depletion	$8,494	$1	$6,558
Heat Related Illness	$9	$0	$6
Costs (C)			
Agriculture Costs	$741,749	$0	$741,749
Solar Costs	$0	$2,154,997	$1,660,294
NPV (B - D - C)	**$883,871**	**$1,151,733**	**$1,048,327**

CONCLUSION

This report presents an analysis of the economic, social, and environmental considerations regarding agrivoltaics implementation in Kern County, California. The industry is still in an early stage of development within the region, however the county remains an attractive location for APV projects due to its well-developed agricultural economy and scalable solar energy capabilities. Kern County is uniquely positioned to benefit from agrivoltaics implementation as analysis found that APV can improve agricultural output, mitigate water demand, provide resilience to water scarcity, reduce carbon emissions from energy generation, and provide health benefits to farm laborers.

Demonstration sites are encouraged as a lack of local agrivoltaics examples led to data challenges related to crop suitability and community perception. We recommend the City to initiate active engagement with key regional stakeholders regarding the planning of APV demonstrations. The frequency and format of stakeholder engagement should be tailored to each group based on their communication styles and relative power in relation to APV deployment. Our stakeholder analysis showed a high level of interest across stakeholder groups, yet concerns remain about shifting business practices. We recommend the City to conduct further research on potential skills gaps and job training opportunities as they pertain to agrivoltaics adoption across the region's extensive agricultural economy. Educating community members on the benefits of agrivoltaics – particularly around groundwater conservation and revenue diversification – will be critical to the success of future projects.

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SUPPLEMENTAL ON ELECTRICITY, POWER, AND ENERGY

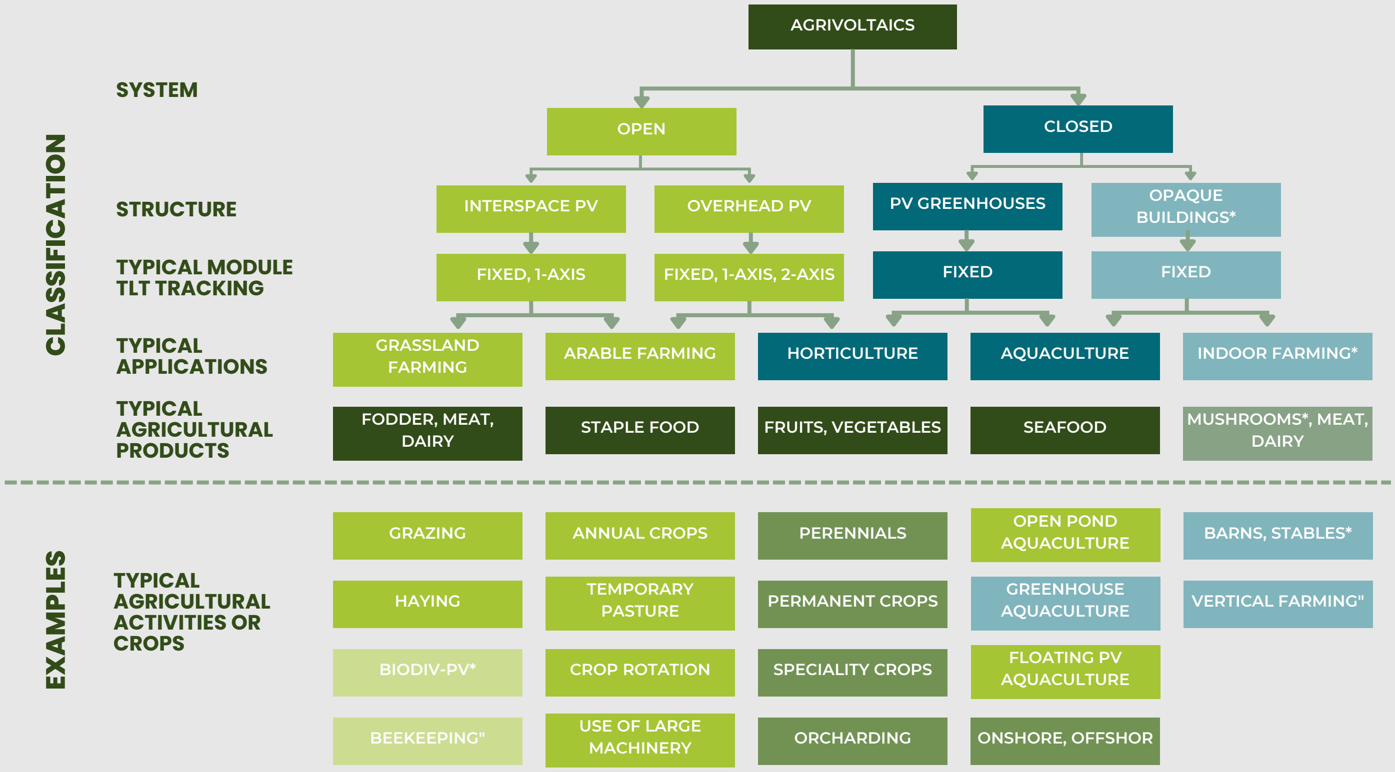
Electricity is a form of energy resulting from the flow of electrically charged particles called electrons. These electrons move through a wire made of a conductive material such as copper. This flow creates electrical and magnetic fields that can do work in the physical world such as powering a lightbulb. As electrons are microscopic particles that are difficult to visualize, it can be helpful to draw an analogy to the flow of water. If one were to fill up a bucket of water with a hose, then the hose would represent the conductor and the water flowing through the hose would represent the electrons.

In electricity, there are two important concepts called power (W, kW, MW, GW) and energy (Wh, kWh, MWh, GWh). Power is the rate at which electrical energy is used or consumed. For example, a 100W light bulb will consume 100W of power per second. Looking at this from the water analogy, power is similar to the flow rate of the water through the hose. Energy is the total amount of power used over time. For example, if that same 100W light bulb was left on for an hour, it would have consumed 100 Watt-hours (Wh). In the water example, energy would be equivalent to the amount of water in the bucket over a given period of time.

In solar energy systems, power is typically referred to in terms of nameplate capacity. This is a listing on the manufacturer's nameplate on the generation equipment that explains the power it can generate at maximum output. As the strength of the sun is dynamic over the course of the day, a solar energy system would not produce power at nameplate capacity very frequently. Rather, the power can be seen as slowly ramping up throughout the day, peaking sometime between 12-3pm, and then falling back to zero as the sun sets. On a perfectly sunny day, a graph of solar energy produced would typically look like a standard bell curve with power plotted on the y-axis and time on the x-axis. Since energy is a measure of how much power was produced over a period of time, the energy production of the system can be calculated by finding the area underneath that bell curve.

APPENDIX

Appendix A. Agrivoltaics Systems Classification (Source: Gorjian et al., 2022)



Appendix B. LCI Dataset Used for Crops

Crops	Dataset	Database
Wine Grapes	Grape, wine grape, at farm (WFLDB)/US U	World Food LCA Database 3.5
Table Grapes	Grape, table grape, at farm (WFLDB)/CL U	World Food LCA Database 3.5
Citrus	Orange, fresh grade, at farm (WFLDB)/US U	World Food LCA Database 3.5
Almond	Almonds, in shell, at farm (WFLDB)/US U	World Food LCA Database 3.5
Pistachios	Pistachio, in shell, at farm (WFLDB)/US U	World Food LCA Database 3.5
Carrots	Carrot, at farm (WFLDB)/IL U	World Food LCA Database 3.5
Potatoes	Potatoes, at farm {US} Economic, U	Agri-footprint 5
Alfalfa	Alfalfa-grass silage {ZA}| alfalfa/grass silage production | Cut-off, U	Ecoinvent 3.9
Garlic	Garlic, fresh, at farm (WFLDB)/US U	World Food LCA Database 3.5
Tomato	Tomato, fresh grade {MX}| tomato production, fresh grade, open field | Cut-off, U	Ecoinvent 3.9
Onions	Onion, at farm (WFLDB)/GLO U	World Food LCA Database 3.5

Appendix C. Modified Life Cycle Inventory Dataset of 8ft Mounting Structure: Original Dataset is Photovoltaic mounting system, for 570kWp open ground module {GLO}| production | Cut-off, U by Ecoinvent v3.9

Input/ Output	Group (Literature)	Inventory	Unit	Original Amount (4.6ft Traditional Ground Mounted)	% in Group	Adj. Amount (8-ft Elevated)
Input	Aluminum, production mix	Aluminum, wrought alloy {GLO}| market for | Cut-off, U	kg	3.98	50%	6.03
	Aluminum, production mix	Section bar extrusion, aluminum {GLO}| market for | Cut-off, U	kg	3.98	50%	6.03
	Other (Not from Literature)	Occupation, permanent crop, vine	m2a	141		25.00
	Other (Not from Literature)	Transformation, from permanent crop, vine	m2	4.7		0.10
	Other (Not from Literature)	Transformation, to industrial area	m2	4.7		0.10
	Other (Not from Literature)	Waste paperboard, unsorted {GLO}| waste paperboard, unsorted, Recycled Content cut-off | Cut-off, U	kg	-0.086364		-1.19E-01
	Other (Not from Literature)	Zinc coat, coils {GLO}| market for | Cut-off, U	m2	0.11	41%	0.88
	Other (Not from Literature)	Zinc coat, pieces {GLO}| market for | Cut-off, U	m2	0.156	59%	1.25
	Packaging (carton)	Corrugated board box {CA-QC}| market for corrugated board box | Cut-off, U	kg	0.00075403	1%	1.36E-03
	Packaging (carton)	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	kg	0.01838254	21%	3.31E-02
	Packaging (carton)	Corrugated board box {RoW}| market for corrugated board box | Cut-off, U	kg	0.04698493	54%	8.45E-02
	Packaging (carton)	Corrugated board box {US}| market for corrugated board box | Cut-off, U	kg	0.02024249	23%	3.64E-02
	Plastic parts	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U	kg	0.00090909	17%	1.84E-03
	Plastic parts	Polystyrene, high impact {GLO}| market for | Cut-off, U	kg	0.0045455	83%	0.01
	Steel components	Reinforcing steel {GLO}| market for | Cut-off, U	kg	7.25	49%	11.32

Input	Steel components	Section bar rolling, steel {GLO}| market for | Cut-off, U	kg	6.15	42%	9.60
	Steel components	Steel, chromium steel 18/8, hot rolled {GLO}| market for | Cut-off, U	kg	0.25	2%	0.39
	Steel components	Wire drawing, steel {GLO}| market for | Cut-off, U	kg	1.1	7%	1.72
Output	Aluminum, production mix	Scrap aluminum {CH}| market for scrap aluminium | Cut-off, U	kg	0.05923299	1%	0.09
	Aluminum, production mix	Scrap aluminum {Europe without Switzerland}| market for scrap aluminium | Cut-off, U	kg	1.26248698	32%	1.91
	Aluminum, production mix	Scrap aluminum {RoW}| market for scrap aluminium | Cut-off, U	kg	2.65828003	67%	4.03
	Steel components	Scrap steel {CH}| market for scrap steel | Cut-off, U	kg	0.00231375	0%	0.00
	Steel components	Scrap steel {Europe without Switzerland}| market for scrap steel | Cut-off, U	kg	1.82621405	24%	2.85
	Steel components	Scrap steel {RoW}| market for scrap steel | Cut-off, U	kg	5.6714722	76%	8.86
	Plastic parts	Waste polyethylene/polypropylene product {CH}| market for waste polyethylene/polypropylene product | Cut-off, U	kg	7.65E-06	0%	2.59E-06
	Plastic parts	Waste polyethylene/polypropylene product {Europe without Switzerland}| market for waste polyethylene/polypropylene product | Cut-off, U	kg	0.00025499	5%	8.62E-05
	Plastic parts	Waste polyethylene/polypropylene product {RoW}| market for waste polyethylene/polypropylene product | Cut-off, U	kg	0.00064644	12%	2.19E-04
	Plastic parts	Waste polystyrene isolation, flame-retardant {CH}| market for waste polystyrene isolation, flame-retardant | Cut-off, U	kg	3.83E-05	1%	1.49E-04
	Plastic parts	Waste polystyrene isolation, flame-retardant {Europe without Switzerland}| market for waste polystyrene isolation, flame-retardant | Cut-off, U	kg	0.00127498	23%	4.97E-03
	Plastic parts	Waste polystyrene isolation, flame-retardant {RoW}| market for waste polystyrene isolation, flame-retardant | Cut-off, U	kg	0.00323226	59%	1.26E-02

Appendix D: Electrical Interconnection Application Options, Costs, and Tentative Timelines (PG&E, 2024)

Study Process	Eligibility	Studies	Timelines1	Process Costs	Deliverability Eligibility
Application Fee	All generator interconnection requests	All	N/A	$800 (non-refundable)	N/A
Fast Track (FT)	Rule 21: No size limit for Fast TrackWDT: Certified, Adivsory limit of 2MW on 12kV and 3MW on 21 kV	Initial Review (IR) &Supplemental Review (SR)	IR - 15 BD2SR - 20BD	Rule 21: Non-refundable feeWDT:IR: $1,000 depositSR: $2,500 deposit	Energy Only
Independent Study Process (ISP)	Must pass both EIT screens:Rule 21: no size limit but, given current programs, rare to exceed 20MWWDT: No size limit	System Impact Study (SIS) &Facilities Study (FAS)	SIS - 60 BDFAS - 60 BD	5MW or less:SIS - $10K depositFAS - $15K deposit>5W:$50K + $1K/MW up to $250K	Rule 21: Energy OnlyWDT: Energy Only or Full Capacity
Distribution Group Study Process (DGSP)	Must pass Transmission EIT4 ScreenRule 21: no size limit but, given current programs, rare to exceed 20MWWDT: No size limit	Phase I Study &Phase II Study	Phase I - 60 BDPhase II - 60 BD	5MW or less:Ph I - $10KPh II - $15K>5W:$50K + $1K/MW up to $250K	Rule 21: Energy OnlyWDT: Energy Only or Full Capacity
Cluster Study Process (CSP)	For projects that fail EIT Transmission Screen:Rule 21: N/A; Use WDT processWDT: No size limit	Phase I Study &Phase II Study	Phase I - 170 CD3Phase II - 205 CD	$50K + $1K/MW up to $250K	Rule 21: N/AWDT: Energy Only or Full Capacity
Deliverability Study Options					
Full Capacity Deliverability Study (FCDS)	Rule 21: Not eligibleWDT: Any ISP, DGSP, or CSP Wholesale Project	Phase I Study &Phase II Study	Phase I - 170 CDPhase II - 205 CD	$50K + $1K/MW up to $250K	N/A
Distributed Generation Deliverability (DGD)	Rule 21: Exporting projects onlyWDT: Any active wholesale project	Single Application and project review to determine allocation, if any	~3 months from application	Free	N/A

Notes
1. Utilities are required to make best efforts to meet study deadlines, and inform the customer if deadlines cannot be met. Timelines vary widely based on location and complexity of transmission infrastructure.
2. BD - Business Days
3. CD - Calendar Days
4. EIT - Electrical Independence Test

Appendix E. List of Potential CapEx Inputs by Category

Electrical	Civil	Engineering	Financial	Other
BOP (XFMRs, Switchboards, Panelboards, DAS, AC Disconnects, etc.)	Civil Work (site prep)	Engineering (civil and electricity supervision and autocad)	Permitting Fees	Environment al Monitoring (species monitoring)
Electrical (panel installation and wiring)	Mechanical (inverter HVAC units)	System Design, Management & Administrative Costs	Development Fees	Taxes
Combiner Box	Fencing	Project Planning	Cost of Tendering Procedure (Fees, risk, premia, etc.)	Performance Security
Misc. Electrical Components	Site Prep. & System Installation		Due Diligence	Legal Advice
Grid Connection	Soil Protection		Cost of Tendering Procedure	Other Costs
Electrics	Install Labor + Equipment		Interconnection Fee	Sales Tax
Electrical BOS	EPC Overhead		Contingency (3%)	Land Cost (property)
Grid Connection	Developer Overhead			
	Mounting Structure & Hardware			

Appendix F. List of Potential OpEx Inputs by Category

Maintenance	Financing	Security	Other
Scheduled O&M	Insurance	Security/Alarm Service	Property Tax
Unscheduled O&M	Legal and Professional Fees	Surveillance	Telecom
Vegetation Abatement	Land Lease Costs	Monitoring	Miscellaneous
Module Cleaning	DAS + SatData fee		
Commercial Management	Asset Management Fees		
Inverter Replacement Reserve	Asset Management Software Fee		
Repair Services	Bank Fees		
Cleaning	Environmental and Permitting Fees		
Maintenance/Mowing	Land Costs		
	Insurance (APV-sensitive)		

Appendix G: Insolation Values of different APV Designs in Bakersfield, CA.

Source: National Renewable Energy Laboratory's PVWatts Calculator

Ground Mount:

Location and Station Identification	
Requested Location	1600 Truxtun Ave, Bakersfield, CA 93306
Weather Data Source	Lat, Lng: 35.37, -119.02 0.2 mi
Latitude	35.37° N
Longitude	119.02° W
PV System Specifications	
DC System Size	1 kW
Module Type	Standard
Array Type	1-Axis Tracking
System Losses	14.08%
Array Tilt	0°
Array Azimuth	180°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	Yes (0.7)
Monthly Irradiance Loss	Jan 2%, Feb 2%, Mar 2%, Apr 2%, May 2%, June 2%, July 2%, Aug 2%, Sept 2%, Oct 2%, Nov 2%, Dec 2%
Ground Coverage Ratio	0.4

RESULTS

Print Results

2,039 kWh/Year*

System output may range from 1,942 to 2,108 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.04	75
February	4.81	108
March	6.73	162
April	8.46	195
May	10.01	235
June	11.34	252
July	10.85	244
August	10.03	227
September	8.56	192
October	6.46	154
November	4.38	105
December	3.61	90
Annual	7.36	2,039

Elevated Agrivoltaics:

Requested Location	1600 Truxtun Ave, Bakersfield, CA 93306
Weather Data Source	Lat, Lng: 35.37, -119.02 0.2 mi
Latitude	35.37° N
Longitude	119.02° W
PV System Specifications	
DC System Size	1 kW
Module Type	Standard
Array Type	Fixed (open rack)
System Losses	14.08%
Array Tilt	44°
Array Azimuth	180°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	Yes (0.7)
Monthly Irradiance Loss	Jan 2%, Feb 2%, Mar 2%, Apr 2%, May 2%, June 2%, July 2%, Aug 2%, Sept 2%, Oct 2%, Nov 2%, Dec 2%

RESULTS

Print Results

1,693 kWh/Year*

System output may range from 1,630 to 1,729 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.77	92
February	5.27	117
March	6.14	146
April	6.55	150
May	6.73	157
June	6.94	152
July	6.95	155
August	7.21	162
September	7.31	162
October	6.66	157
November	5.34	126
December	4.82	118
Annual	6.14	1,694

Vertical Bifacial:

Location and Station Identification	
Requested Location	1600 Truxtun Ave, Bakersfield, CA 93306
Weather Data Source	Lat, Lng: 35.37, -119.02 0.2 mi
Latitude	35.37° N
Longitude	119.02° W
PV System Specifications	
DC System Size	1 kW
Module Type	Standard
Array Type	Fixed (open rack)
System Losses	14.08%
Array Tilt	90°
Array Azimuth	270°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	Yes (0.7)
Monthly Irradiance Loss	Jan 2%, Feb 2%, Mar 2%, Apr 2%, May 2%, June 2%, July 2%, Aug 2%, Sept 2%, Oct 2%, Nov 2%, Dec 2%

RESULTS

Print Results

1,296 kWh/Year*

System output may range from 1,248 to 1,332 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.08	51
February	3.10	70
March	4.20	103
April	5.33	126
May	6.16	148
June	6.88	158
July	6.61	154
August	6.18	144
September	5.25	120
October	4.03	97
November	2.88	68
December	2.35	58
Annual	4.59	1,297

Appendix H. General demographics of Kern County from 2022 census data

Area	Sub-Area	Metric
Population	Total population (# of people)	909,235
	Median age	32.90
	Language other than english spoken at home	46.00%
	Foreign born population	19.10%
	Older population (>60 years old)	11.80%
	Life expectancy (years)	76.50
	Residential Mobility	0.60%
Race and Ethnicity	Hispanic or Latino	499,158
	American Indian and Alaska Native	18,163
	Asian	46,777
	Black or African American	50,130
	Native Hawaiian and Other Pacific Islander	1,508
	Not Hispanic or Latino	279,600
	Some other race	274,153
	Two or more races	146,770
	White	371,734
Education	Bachelor degree or higher	19%
	High school or equivalent degree	28%
	Some college, no degree	23%
	Associate's degree	8%
	Bachelor's degree	13%
	Some graduate degree	7%

Employment Rate	Employment rate	54.70%
	Local, state, and federal gov. workers	17.50%
	Employee of private company workers	67.70%
	self employed in own incorporated business workers	3.00%
	Private not-for-profit wage and salary workers	6.10%
	self employed in own not incorporated business workers and unpaid family workers	5.70%
	Average travel time to work (minutes)	24.50%
	Agriculture, forestry, fishing, hunting, mining	13.00%
	Construction	6.80%
	Manufacturing	6.20%
	Retail Trade	11.70%
	Transportation and warehousing, and utilities	6.50%
	Information	0.80%
	Finance and Insurance, and real estate and rental and leasing	3.20%
	Professional, scientific, management, and administrative and waste management services	9.20%
	Educational services and health care and social assistance	21.60%
	Arts, entertainment, and rec, accommodation, and food services	8.10%
	Other services (not public admin)	4.50%
	Public admin	6.30%

Income and Poverty	Median household income	$66,234
	Families income	$74,021
	Married couple families income	$92,998
	Nonfamily household income	$35,832
	Poverty	17.90%
Health	Without healthcare coverage	6.60%
	Disability	11.90%
Families and Living Arrangements	Total households	283,510
	Average family size	3.66

Appendix I. Stakeholder group definitions in more granularity

Stakeholder Group	Sub-Area
Group A: Landowners	• Owns land in Kern County & the jurisdiction to rights over the space • Holds decision-making power over land (either farm land or residential) • Pays the utility bills (water, energy, etc.) • No minimum land size or length of ownership stipulation to be characterized in this group
Group B: Farmers	• Employed in the agriculture industry in Kern County • Member of the Kern County Farm Bureau • Must work for a farm themselves - not just association (family) of farmers
Group C: Business Owners	• Owns a business in Kern County • Makes decisions on financial allocation, political involvement, and other relevant topics for their company • Can be family-owned or a large establishment
Group D: Solar Developers	• Solar companies with developments in Kern County • Decision makers for project development • If possible, extending the group beyond to include solar companies considering agrivoltaics
Group E: Non Ag Non Business Owner Residents	• Individuals who live in Kern County, but do not work on a farm, own land, or own a business • Includes all residents (including students) • Includes those who have voting rights in Kern County

Appendix J. Survey Questionnaire

Stakeholder Demographics

Disclosure: Thank you for participating in this survey on renewable energy and agriculture in Kern County for a collaborative research project between the City of Bakersfield and Columbia University. We are researching the potential environmental and community impacts of agrivoltaics, the co-use of land for both energy and agricultural production. Results from this survey will be used to guide additional research and outreach through the City of Bakersfield.

Time & Privacy: The survey will take 5-10 minutes. Participation is voluntary, and you can opt out or skip questions anytime. All personal information will be kept confidential. If you decide to share your name or contact information, it will only be used for our communications with you.

Overview: With the City of Bakersfield, we are exploring how agrivoltaics can potentially enhance agricultural production, boost Kern County's economy, and support sustainable energy. Your feedback is crucial for guiding the direction of this initiative and addressing any challenges.

Please proceed to the questions below.

Which of the below best describes you?

- Land Owner (Non-Farmer) You own land but do not actively engage in farming. This might include leasing land for agricultural use by others or having land for non-agricultural purposes.
- Farmer and Land Owner You own and actively use your land for farming or agricultural activities.
- Farmer (Non-Land Owner) You are actively engaged in farming or agricultural activities but do not own the land you farm on. If you do own the land you farm on, please select "Farmer and Land Owner."
- Employed in the Solar IndustryYour primary business activity involves the development of solar energy projects, including but not limited to the installation, leasing, or management of solar energy systems.
- Business Owner You own or operate a business but are not yourself a land owner, farmer, or employed in the solar industry. This includes businesses of all sizes across various sectors.
- Resident You reside in Kern County and do not fall into the categories of farming, land/business ownership, or solar development. This includes individuals engaged in various professions, students, and retirees.
- If none of the above categories accurately describes your role, please provide a brief description. ____

What business, farm, or other organization (school, community group, etc) are you affiliated with?

____

What is your role or title within your organization?

____

What part of Kern County do you live in?
- Bakersfield
- North Kern (Delano, McFarland)
- South Kern (Arvin, Lamont, Frazier Park)
- West Kern (Taft, McKittrick)
- East Kern (Ridgecrest, Mojave)
- Other ______________________________________

How involved in local political affairs are you? (0 = not involved, 10 = extremely involved)
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Social Perception of Agrivoltaics

What is your general perception of solar and/or renewable energy? (0 = most unfavorable, 10 = most favorable)

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Have you heard of agrivoltaics before?

- Yes
- No

What are your concerns around agrivoltaics? Select all that apply.

- Conflicts with available agricultural land
- Potential to negatively impact crop yield
- High costs (installation, new machinery, maintenance)
- Eyesore on landscape
- Increased worker liability
- Additional logistical coordination (i.e. with utilities, leasees, etc.)
- Not feasible in my community/suitable for my operation
- Not enough information available from trusted sources
- Impacts to environment (e.g., soil, water) or food safety
- Removal & disposal of solar equipment (e.g., panels, foundations, racking) at end of life
- Other (please explain) ______________________________

Please provide more detail about the top concerns you selected.

____

____

____

____

____

What do you perceive to be benefits of agrivoltaics? Select all that apply.

- New job opportunities
- Increased production of renewable energy
- Stabilizing and/or reducing energy prices locally
- Improving crop yield and/or resilience to drought and extreme heat
- Improved groundwater conservation
- Protection for farmworkers from extreme heat and sun
- Reduced on-farm utility costs (e.g., water, electricity)
- Tax incentives or new revenue opportunities through energy production
- Maximizing land use while preserving productive agricultural land
- Avoiding conversion of previously undisturbed lands to solar
- Increased energy security and resilience to power outages
- Other (please explain) ______________________________

Please provide more detail about the top benefits you selected.

____
____
____
____

How do you currently receive information or news?

- Local news outlet
- Television
- Radio
- Social media (e.g., Facebook, Instagram, LinkedIn)
- Newsletters
- State agencies (e.g., CDFA)
- Federal agencies (e.g., USDA)
- Word of mouth
- I don't get news
- Other ______________________________

Land Owners (Non-Farmers)

What is the size of your land ownership?

- Less than 1 acre
- 1 to 9 acres
- 10 to 49 acres
- 50 to 179 acres
- 180 to 499 acres
- 500 to 999 acres
- 1,000 acres or more

What is the land's primary use?

- Agricultural
- Residential
- Commercial
- Other ______________________________

Could you specify the type of ownership you hold over the land?

- Freehold
- Leasehold
- Other ______________________________

On average, how much is your monthly electrical utility bill for your property?

- Under $1000
- $1,000 to $5,000
- $5,000 to $10,000
- $10,000 to $20,000
- $20,000-$30,000
- $30,000-$40,000
- Over $40,000
- Prefer not to say

Would you consider installing solar panels?

- Yes (please explain) ______________________________
- No (please explain) ______________________________
- I already have solar panels

Do you have any additional thoughts about renewable energy, solar panels, or mixed-use solar and agricultural production (agrivoltaics) you'd like to share?

____

____

____

Are you interested in learning more about agrivoltaics?

- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

____

Farmer and Land Owner

What is the size of your land ownership?
- Less than 1 acre
- 1 to 9 acres
- 10 to 49 acres
- 50 to 179 acres
- 180 to 499 acres
- 500 to 999 acres
- 1,000 acres or more

What types of commodities do you produce?
- Table Grapes: Autumn King, Princess, or other green variety
- Table Grapes: Scarlet Royal, Summer Royal, Sweet Scarlet, or other red variety
- Grapes: Raisin
- Grapes: Wine
- Tree nuts
- Citrus
- Carrots
- Potatoes
- Garlic
- Tomatoes
- Onions
- Cattle & Calves
- Dairy
- Sheep & Lambs
- Hogs
- Poultry & Eggs
- Silage & Forage
- Alfalfa
- Nursery (fruit, nut trees, and vines)
- Cherries
- Pomegranates
- Berries
- Stone fruits (peaches, plums, pluots)
- Pasture
- Industrial & Wood
- Other ____

How large is your herd or flock?

____

On average, how much is your monthly electricity bill for your farm operations?

- Under $500
- $500 to $1,000
- $1,001 to $2,500
- $2,501 to $5,000
- $5,001 to $10,000
- Over $10,000
- Prefer not to say

Would you consider installing solar panels?

- Yes (please explain) ____
- No (please explain) ____
- I already have solar panels

What is the source of water for your farm operations?

- Private wells
- Public wells
- Water district
- I don't know
- Other ____

What is your annual water demand for crop irrigation?

- Less than 10 acre-feet / Less than 3,258,510 gallons
- 10 to 100 acre-feet / 3,258,510 to 32,585,100 gallons
- 101 to 500 acre-feet / 32,943,851 to 162,925,500 gallons
- 501 to 1,000 acre-feet / 163,251,501 to 325,851,000 gallons
- 1,001 to 3,000 acre-feet / 325,926,851 to 977,553,000 gallons
- 3,001 to 5,000 acre-feet / 978,228,351 to 1,629,255,000 gallons
- 5,001 to 8,000 acre-feet / 1,629,930,851 to 2,606,808,000 gallons
- More than 8,000 acre-feet / More than 2,606,808,000 gallons

Do you have any additional thoughts about renewable energy, solar panels, or mixed-use solar and agricultural production (agrivoltaics) you'd like to share?

____

____

Are you interested in learning more about agrivoltaics?

- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

____

Farmers (Non-Land Owners)

What is the size of the land you farm on?

- Less than 1 acre
- 1 to 9 acres
- 10 to 49 acres
- 50 to 179 acres
- 180 to 499 acres
- 500 to 999 acres
- 1,000 acres or more

What types of commodities do you produce?

- Table Grapes: Autumn King, Princess, or other green variety
- Table Grapes: Scarlet Royal, Summer Royal, Sweet Scarlet, or other red variety
- Grapes: Raisin
- Grapes: Wine
- Tree nuts
- Citrus
- Carrots
- Potatoes
- Garlic
- Tomatoes
- Onions
- Cattle & Calves
- Dairy
- Sheep & Lambs
- Hogs
- Poultry & Eggs
- Silage & Forage
- Alfalfa
- Nursery (fruit, nut trees, and vines)
- Cherries
- Pomegranates
- Berries
- Stone fruits (peaches, plums, pluots)
- Pasture
- Industrial & Wood
- Other ____

How large is your herd or flock?

____

On average, how much is your monthly electricity bill for your farm operations?
- Under $500
- $500 to $1,000
- $1,001 to $2,500
- $2,501 to $5,000
- $5,001 to $10,000
- Over $10,000
- Prefer not to say

Would you consider installing solar panels?
- Yes (please explain) ____________________________________
- No (please explain) ____________________________________
- I already have solar panels

What is the source of water for your farm operations?
- Private wells
- Public wells
- Water district
- I don't know
- Other ____________________________________

What is your annual water demand for crop irrigation?
- Less than 10 acre-feet / Less than 3,258,510 gallons
- 10 to 100 acre-feet / 3,258,510 to 32,585,100 gallons
- 101 to 500 acre-feet / 32,943,851 to 162,925,500 gallons
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- 5,001 to 8,000 acre-feet / 1,629,930,851 to 2,606,808,000 gallons
- More than 8,000 acre-feet / More than 2,606,808,000 gallons

Do you have any additional thoughts about renewable energy, solar panels, or mixed-use solar and agricultural production (agrivoltaics) you'd like to share?

____

____

Are you interested in learning more about agrivoltaics?

- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

____

Business Owners

What is the total number of employees in your company?

- 1-10 employees
- 11-50 employees
- 51-200 employees
- 201-500 employees
- 501-1,000 employees
- Over 1,000 employees

What is your company's annual revenue?

- Less than $100,000
- $100,000 to $500,000
- $500,001 to $1 million
- $1 million to $10 million
- $10 million to $50 million
- Over $50 million

What percentage of your company's budget is typically allocated to political spending?

- 0% (No budget allocated to political spending)
- Less than 1%
- 1% to 5%
- 6% to 10%
- Over 10%

Do you have any additional thoughts about renewable energy, solar panels, or mixed-use solar and agricultural production (agrivoltaics) you'd like to share?

Are you interested in learning more about agrivoltaics?

- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

Employed in Solar Industry

Is your primary focus on developing solar projects for industrial or residential areas, or both?

- Residential
- Utility/Community Scale
- Commercial/Industrial
- Other ____________________

Have you seen demand from agricultural customers to install solar panels?

- Yes
- No

If yes, please provide details on how frequently you see demand and any additional information about the projects.

In your opinion, what additional challenges could arise from adding batteries to agrivoltaic projects? How could they be addressed?

____
____
____
____
____

On the other hand, what additional opportunities or benefits could come from integrating battery storage with solar projects, particularly in agrivoltaic systems?

____
____
____
____
____

Do you have any additional thoughts about mixed-use solar development or agrivoltaics you'd like to share?

____
____
____
____
____

Are you interested in learning more about agrivoltaics?

- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

____

Residents (Non Ag, Non Business Owner)

What is your highest education level?
- Some high school
- High school graduate
- Some college
- College graduate
- Trade/technical/vocational training
- Postgraduate degree

Do you have any additional thoughts about renewable energy, solar panels, or agrivoltaics (mixed-use solar and agricultural production) you'd like to share?

Are you interested in learning more about agrivoltaics?
- Yes
- No

If you would be interested in receiving more information about agrivoltaics and related initiatives in Kern County, please provide your name and email below. Your personal information will be kept confidential.

Appendix K. Survey Results

	Landowners (non-farmers)	Farmers (landowners)	Farmers (non-landowner)	Business owners	Solar Developers	Resident
# of responses	3	6	1	7	6	29
Involvement in political affairs	7.5	3.8	1	6.3	3	5
Support of renewable energy	10	7.6	4	8.8	8.8	8.3
Awareness of agrivoltaics	100%	75%	0%	67%	100%	46%
Concerns	Conflicts with available agricultural land, Potential to negatively impact crop yield, High costs, Removal & disposal	Conflicts with available agricultural land, High costs	High costs, Removal & disposal, Additional logistical coordination	Impacts to environment (e.g., soil, water) or food safety, Removal & disposal, Potential to negatively impact crop yield, High costs	Storage/Battery technology & disposal, Fire risks & environmental impact, High costs & tough regulatory environment, Misinformation & Public opinion around batteries	High costs, Removal Disposal, Eyesore on landscape, Concerns around feasibility, legal framework and infrastructure (ie. power lines)
Benefits	Increased renewable energy production, Groundwater preservation, Tax Incentives, Maximize land use, Increase energy security, Stabilize energy prices	New job opportunities, Increased renewable energy production, Energy stability & reduced pricing	New job opportunities, Increased renewable energy production, Energy stability & reduced pricing, Tax Incentives, Maximize land use, Farmer protection from heat	Increased renewable energy production, Maximize land use, New job opportunities, Groundwater preservation, Tax incentives, Increase energy security, Improving crop yield	Increased energy security/stability, Economic development/benefits, Increased renewable energy production, New job opportunity, Potential to help with electrifying farming equipment	Increased renewable energy production, Farmer protection from heat, Reduced costs, Maximize land use, New job opportunities
News source	Local News, Radio, Newsletter, Social Media, National News	Local News, Radio, Newsletter	TV	Local News, Newsletter, Social Media	Social Media, Radio	Local News, Social Media, Radio, Newsletters, YouTube (Bakersfield Channels), National News (WSJ, LA Times, Washington Post)

Appendix L. Impact Categories Breakdown and Definition

Impact	Category	Breakdown	Definition
Agriculture/ Energy	Environmental	Land geomorphology	Encompassing mountains, valleys, and other landforms play a crucial role in regulating ecosystem services like erosion control. (ENCORE Nature, n.d.)
		Soil and Sediments	Foundational layers, including topsoil, subsoil, and ocean sediments, sustain life on Earth and provide regulatory services. (ENCORE Nature, n.d.)
		Water	In various forms (surface water, groundwater, ocean water, fossil water, and soil moisture), water is indispensable for a wide array of ecosystem services. (ENCORE Nature, n.d.)
		Minerals	Natural metallic and non-metallic compounds found in the earth – that are not made by living things – play an important role in maintaining soil health and supporting plant and crop growth. (ENCORE Nature, n.d.)
		Atmosphere	The layer of air surrounding the Earth, containing gases like oxygen for breathing and regulating temperature, makes life possible. (ENCORE Nature, n.d.)
		Habitats	Environments that provide the necessary conditions (water, food, temperature, and safety) for different species to survive and thrive, ranging from small areas for specific populations to larger areas like forests and coastlines supporting diverse life forms. (ENCORE Nature, n.d.)
	Social	Welfare	The physical and mental well-being of employees, including access to essential services, quality of life, and a safe, healthy environment.
	Economic	Financial	The economic circumstances of individuals, businesses, and communities affected by the agrivoltaics project.
		Operational	Alterations in the day-to-day operations of agricultural activities.

#	Workstream Categories	Impact Categories	Detailed Impact Categories	Potential Impacts	Time-frame	Scale of Impact	Likelihood	Score
1	Agriculture	Environmental	Water	Surface and groundwater depletion due to irrigation demands	Long Term	State	High	27
2	Agriculture	Environmental	Operation	Shading impacts on revenue from crop yields	Medium Term	State	High	18
3	Both	Environmental	Atmosphere	Change in emissions generated from energy use	Medium Term	State	High	18
4	Both	Social	Workforce Health & Safety	Heat-related illness impacts of shading for farmworkers	Medium Term	State	Medium	12
5	Both	Social	Welfare	Sustained job security and benefits	Long Term	County	Medium	12
6	Energy	Environmental	Soil and Sediments	Contamination of soil and water due to panel disposal at end-of-life	Long Term	County	Medium	12
7	Agriculture	Environmental	Habitats	Enhanced pollinator habitats through the strategic use of shade and elevated structures	Medium Term	Farm	High	6
8	Energy	Environmental	Water	Rate of soil erosion related to water distribution and soil moisture (increase or decrease)	Medium Term	Farm	High	6
9	Agriculture	Economic	Financial	Change in financial security due to additional revenue streams to agriculture	Medium Term	Farm	High	6
10	Energy	Social	Welfare	Immediate employment gained during construction phase	Near Term	County	High	6
11	Agriculture	Environmental	Land geo-morphology	Soil compaction and reduced soil quality due to heavy machinery and solar panel construction	Medium Term	Farm	High	6
12	Both	Social	Welfare	Immediate employment gained during construction phase	Near Term	County	High	6
13	Agriculture	Social	Operation	Disruption to farming operations during solar panel construction	Near Term	Farm	High	3
14	Energy	Social	Operation	Land rights and site permitting issue for solar panel development	Near Term	Farm	Medium	2

Additional: Financial Model Comparison

	Sandia	Re-opt	System Advisor Model (SAM)	INSpire Financial Calculator	PVWatts	Bakersfield Financial Model
Creator	Sandia National Laboratory	NREL	NREL	NREL	NREL	Columbia Capstone Team
Year Created	2004	2017	2007	2022	2013	2024
Update Frequency	Multiple times per year	Multiple times per year	Multiple times per year	Not stated, last updated January 2023	Multiple times per year	N/A
Purpose	Model reliability of PV components over project lifetime	Optimize PV, wind, battery, or CHP system size for user based on utility energy use and goals	Provide no-cost in depth renewable energy performance and cost model	Provide basic financial tool for agrivoltaics forecast	Provides detailed solar generation profiles	For understanding of potential agrivoltaics economic outcomes
Intended Audience	Academic	Academic, Commercial	Academic, Commercial	Academic	Academic, Commercial	Bakersfield
Complexity	High, probalistic inputs are required. Intended to be close to reality.	Low, inputs are limited. Default values are provided.	High, detailed inputs required for each component. Detailed outputs for performce and cost are provided. Interconnection to several databases are provided.	Low, basic inputs with several assumptions used.	Low, inputs are limited. Default values are provided.	Low, inputs and data are limited.
Data Inputs	Probability curves, load profile, solar parameters and generation profiles	Utility Rate - specific based on OpenEI databaseSolar Parameters - Uses PVWatts backend	Cost, component data, utility rate, export values, financial constraints	Location, type of agriculture, type of PV setup, sizes, $/W incentive	Location, basic solar system parameters	Farm size, basic economic constraints
Time Resolution	Hourly	Hourly	Hourly	Monthly	Hourly	NEM - Hourly; FTM - Yearly
Space Resolution	Regional	Coordinates	Coordinates	Coordinates	Coordinates	Bakersfield Only
Model Validation	Yes	None Indicated	Yes	None indicated	None indicated	Stakeholder Validation during creation

Additional: Financial Model Comparison

	Sandia	Re-opt	System Advisor Model (SAM)	INSpire Financial Calculator	PVWatts	Bakersfield Financial Model
User Interface	Goldsim Software download - only available on windows	Web-based, API, and open-source code	Software download, compatible on mac, windows, linux	Web-based	Web-based, API	Excel Spreadsheet
Renewable Technologies Modeled	PV	PV, Battery, Wind, CHP, Heat Pumps	PV, Battery, Wind, marine PV, biomass, solar water heating	PV	PV	PV, Small-scale battery
FTM Capabilities	No	The manual states yes, but it's not available on the web tool	Yes	Yes	Yes	Yes
NEM 3 Forecasting	No	Not available on the web tool	Yes, but export values must be manually entered	No	No	Yes
Notes	Can model reliability scenarios - ie what would happen if there are equipment failures. Cost is not modeled.	Optimizes sizing based on user goals (save costs, resiliency, max renewable energy)	Most in depth free tool that uses NRELs databases.	Gives an introduction to the financial case for agrivoltaics, but the INSpire website is a database for agrivoltaics.	NREL's other solar tools use PVWatts API in their backend to model solar generation. Does not model costs.	Tool created specifically for agrivoltaics financial modeling in Kern County.

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