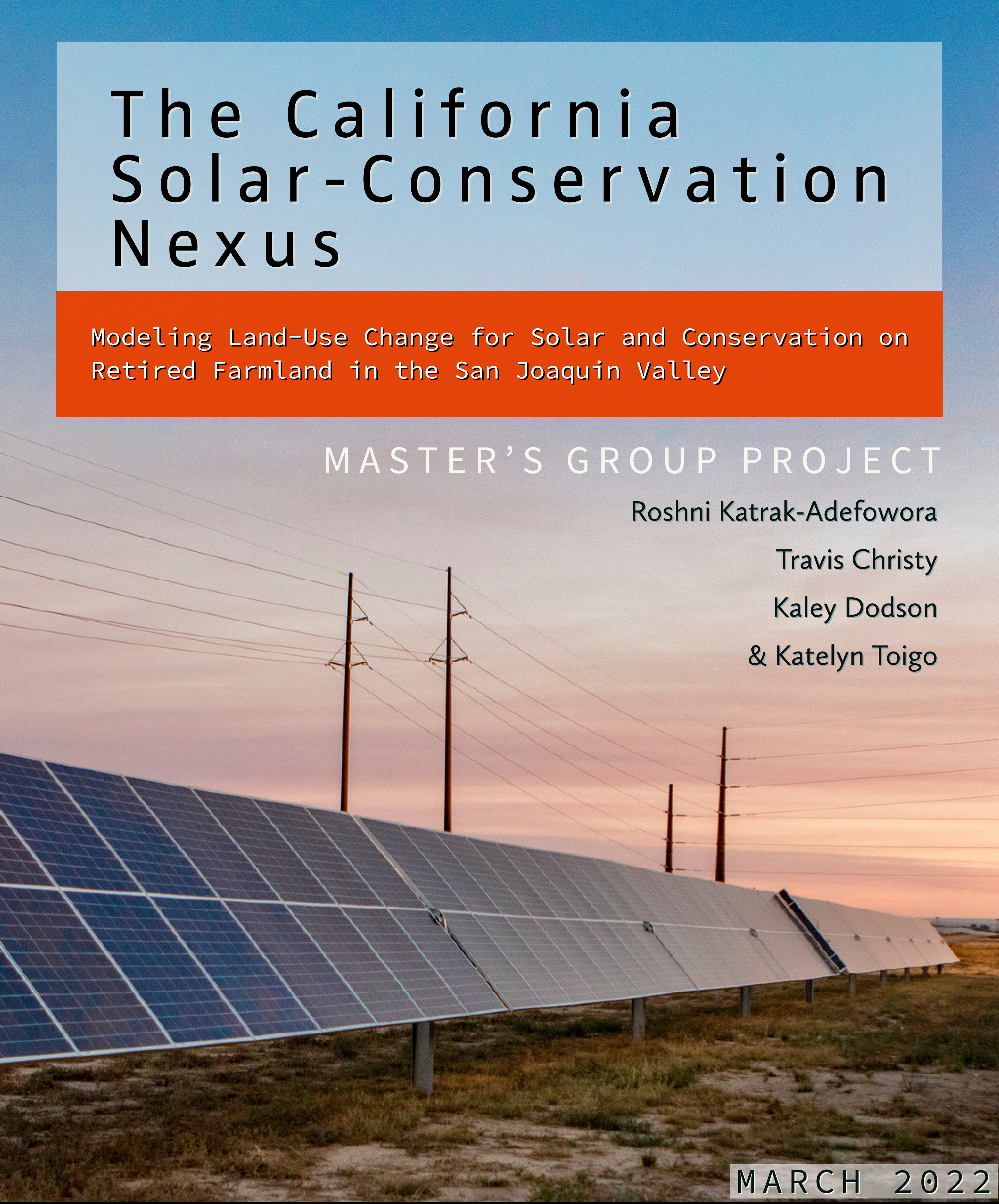


The California Solar-Conservation Nexus

Modeling Land-Use Change for Solar and Conservation on Retired Farmland in the San Joaquin Valley

MASTER'S GROUP PROJECT

Roshni Katrak-Adefowora
Travis Christy
Kaley Dodson
& Katelyn Toigo

MARCH 2022

UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Bren School of Environmental Science & Management

UNIVERSITY OF CALIFORNIA
Santa Barbara

The California Solar-Conservation Nexus

A Group Project submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Science and Management
for the
Bren School of Environmental Science & Management

by

TRAVIS CHRISTY
KALEY DODSON
ROSHNI KATRAK-ADEFOWORA
KATELYN TOIGO

Committee in charge:
KYLE MENG
GRACE WU
MIKE GIALKETSIS

MARCH 2022

The California Solar-Conservation Nexus

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

TRAVIS CHRISTY

KALEY DODSON

ROSHNI KATRAK-ADEFOWORA

KATELYN TOIGO

The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

KYLE MENG

DATE

Acknowledgements

Our team would like to thank the following for their time, guidance, support, and expertise:

Faculty Advisor

Dr. Kyle Meng, Bren School of Environmental Science & Management, UCSB

Client

Abigail Hart, The Nature Conservancy

External Advisors

Dr. Grace Wu, Environmental Studies Program, UCSB
Mike Gialketsis, Rincon Consulting

Additional Thanks

Brian Cohen, The Nature Conservancy
Dr. Scott Butterfield, The Nature Conservancy
Erica Brand, California Energy Commission
Elizabeth O'Donoghue, The Nature Conservancy
Dr. Bradley Franklin, The Nature Conservancy
Dr. Rodd Kelsey, The Nature Conservancy
Jay Ziegler, The Nature Conservancy
Mark Kramer, The Nature Conservancy
Raven Shank, The Nature Conservancy
Charlotte Stanley, The Nature Conservancy
Haozhe Yang, Bren School of Environmental Science & Management, UCSB

Table of Contents

Figures, Tables, & Equations

Figures

Tables

Equations

Abstract

Over the next 20 years, land in the San Joaquin Valley (SJV) will undergo its most extensive change since it was first converted into irrigated farmland. California's Sustainable Groundwater Management Act (SGMA), which was passed in 2014 to reduce groundwater overdraft, will lead to temporary fallowing and permanent retirement of hundreds of thousands of acres of irrigated agricultural land. Many landowners will be making difficult decisions about transitioning their land to alternative uses. This could potentially make available critical landscapes for habitat restoration. It is also an opportunity to advance the state's ambitious goals to decarbonize the economy; meeting these goals will require significant amounts of utility-scale solar energy (USSE) to be sited in the Valley. In this project, we conduct a spatial-economic analysis to determine the extent to which retired farmland could be converted to USSE or to conservation based on the relative profitability of these choices. We find that solar is more profitable than conservation on approximately 61% (130,000 acres) of predicted retired lands, conservation is more profitable on 19% (41,000 acres) of the retired lands, and neither option is profitable on 20% (43,000 acres) of the retired lands. Finally, we identify potential policy measures that will increase the compatibility of solar development and conservation.

Key words: *agriculture, groundwater, SGMA, agricultural retirement, utility-scale solar, conservation, easements, upland species, habitat*

1. Project Objectives

1. Analyze the viability of new solar development and conservation as alternative land uses for degraded or formerly irrigated lands in the San Joaquin Valley for various key stakeholder groups considering anticipated land-use changes and other socioeconomic factors.

2. Assess potential strategies for The Nature Conservancy (TNC) and other conservation organizations to leverage new solar development to achieve upland species conservation goals by aligning policy and stakeholder interests and quantifying the potential impact of those strategies in terms of its relation to TNC's habitat conservation goals for the region.

2. Background and Significance

2.1 Literature review

The southwestern United States is in its worst megadrought in over 1,200 years.[1] The strains on human and natural systems are increasingly evident as society's needs for energy, food, water, and natural areas compete. Climate change intensifies this competition, resulting in actions such as the push for renewable energy sources, one of which is solar generation.[2] The San Joaquin Valley (SJV) of California illustrates the dilemma of competing land uses due to a heavy agricultural footprint and interest from the utility-scale solar energy (USSE) industry and conservation organizations. In this region, water availability greatly determines which land uses are feasible.

2.1.1 Study Area

Our study area encompasses the SJV; specifically, it includes Fresno, Kern, Kings, Madera, Merced, Stanislaus, and Tulare Counties, with small parts of Mariposa, San Benito, San Joaquin, and San Luis Obispo Counties included as well. The region is relatively dry with annual precipitation of about 25 cm per year and temperatures ranging from about 3.7°C to 26.1°C on average.[3] The region is characterized by hot, dry summers and cool, foggy winters; precipitation falls predominantly as winter rain. Arid soils occupy the region with a few wetlands and riparian areas. The land is highly impacted by human development, especially agriculture, and erosion from surrounding mountains has produced highly fertile soil.[4]

2.1.2 Groundwater Depletion

Water is particularly scarce in the southern SJV and is supplemented by imports from the Sacramento–San Joaquin Delta for agricultural uses, which dominate overall water demand. Farmers also rely on groundwater to meet irrigation needs, and for decades have pumped water exceeding the rate at which it can be replenished.[5–7] The result is widespread overdraft of groundwater basins in the region; the SJV has the largest groundwater deficit in the state.[6]

In 2014, California passed the Sustainable Groundwater Management Act (SGMA) to combat severe groundwater overdraft. This legislation is expected to bring sweeping changes across the SJV as residents and farmers are required to reduce groundwater use to rebalance aquifer deficits. One estimate suggests that 535,000 acres or more of existing irrigated farmland in the SJV will need to be temporarily fallowed or permanently retired by 2040 to achieve groundwater sustainability.[8] This accounts for 10-20% of all irrigated farmland in the SJV. Many stakeholders do not want to retire productive agricultural land since it plays such a critical role in the local and regional economy. However, they recognize that the water supply cannot sustainably support the existing irrigated agricultural footprint.[6,9] Thus, water districts and landowners are faced with land use decisions to maximize financial returns and minimize water use. Strategic land-use change is the Valley's best hope for minimizing financial losses, restoring groundwater levels, and managing environmental objectives.

SGMA creates a structure for local management of groundwater resources. California has defined basin and subbasin boundaries, and it has prioritized those basins according to the severity of overdraft. The law requires local agencies in high and medium priority basins to balance pumping and recharge by first forming Groundwater Sustainability Agencies (GSAs) and then by creating and adopting Groundwater Sustainability Plans (GSPs) to ensure proper long-term resource management. Most basins must come into compliance by 2042; the basins identified as critically overdrafted were given an earlier deadline of 2040.[10]

In the southern SJV (defined here as the Tulare Lake hydrologic region), there are six critically-overdrafted, high priority subbasins across Fresno, Kings, Tulare, and Kern counties.[11] These include Westside (5-022.09), Kings (5-022.08), Tulare Lake (5-022.12), Kaweah (5-022.11), Tule (5-022.13), and Kern County (5-022.14) (Figure 1). There are also two medium priority basins in the region - Pleasant Valley (4-006) and White Wolf (5-022.18). The high priority basins were required to submit GSPs as of January 2020.[12]

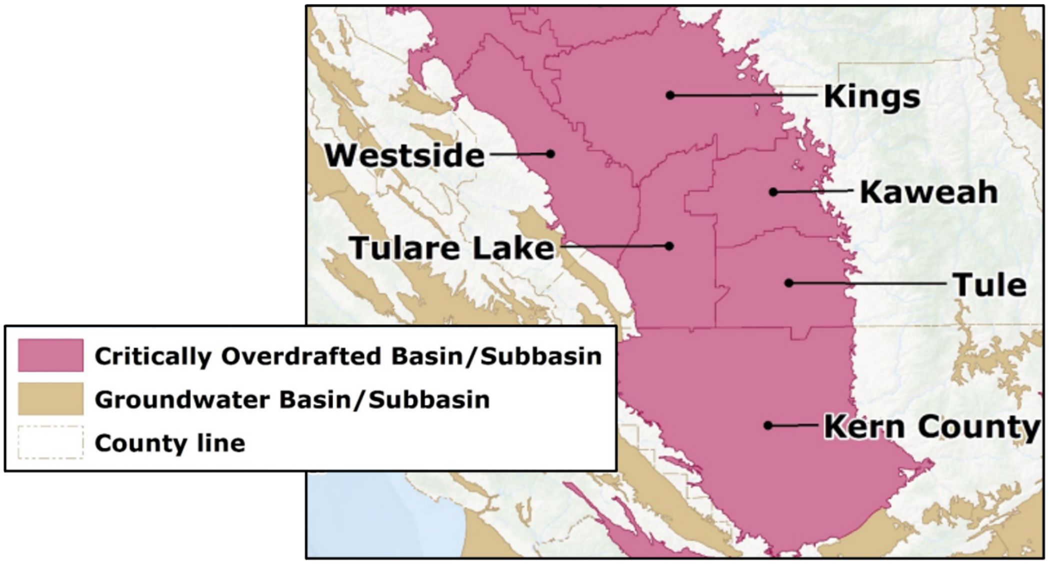


Figure 1. Critically overdrafted groundwater basins in the southern San Joaquin Valley. Adapted from a map produced by the California Department of Water Resources (2020).

GSPs provide a detailed outline for how to achieve groundwater sustainability, defined by SGMA as “management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing adverse results.”[10] These adverse results include: 1) the drawdown of groundwater to unacceptably low levels, 2) the reduction of storage in an aquifer, 3) the degradation of water quality, 4) allowing seawater intrusion, 5) causing land to subside, or 6) using groundwater in ways that reduce other people’s surface water or harm ecosystems.[13]

The region suffers from poor groundwater quality, especially in lower-income, rural communities. In some places, groundwater has become unsafe to drink due to nitrate contamination stemming from heavy agricultural fertilizer use; in other places, wells have dried up altogether.[14]

2.1.3 Agricultural and Economic Implications of SGMA

Hanak et al.[7] explore approaches for addressing key water challenges in the SJV. Without significant water trading rights, the southern region of the SJV, especially agricultural lands in Kern County, will be disproportionately impacted by SGMA. With only local trading, approximately 750,000 acres would need to be fallowed; the southeastern SJV may see losses around $840 million (14% of total crop revenue) and Kern County may lose nearly $790 million (20% of total crop revenue). These losses, combined with others throughout the region, result in a total loss of $2 billion across the entire Valley. The best approach to spread out losses in crop acreage and decrease losses in revenue includes a Valley-wide water trading program. Under this scenario, the expected total annual crop revenue losses drop to $1.3 billion. This scenario would also result in an overall increase in farm profits by $225 million; farmers in the northwest where farming is less profitable would gain from selling water and those in the Kern Basin would gain from keeping more cropland in production. Overall, acreage losses would drop by only 25,000 acres for a total of 725,000 acres of land requiring fallowing, but the losses would be considerably more balanced across the region and crop revenue losses would be much smaller.

Infrastructure advancements, improving groundwater recharge, and increasing efficiency of water use technologies can significantly improve the outlook across the SJV. With a combined portfolio of strategies, land fallowing drops to 535,000 acres from 750,000 acres, losses from all agricultural sectors fall 26% from $5.3 billion to $3.9 billion, annual declines in gross domestic product drop 36% from $2.1 billion to $1.3 billion, and job losses drop 40% from 21,000 to less than 13,000.[7]

2.1.4 Solar Development in the San Joaquin Valley

Solar developers are increasingly siting solar farms in the SJV.[15] In 2018, Senate Bill 100 (SB-100) was signed into law to ensure that California achieves 100% clean energy by 2045.[16] The interest of solar companies in buying or leasing land to site USSE presents a potentially profitable opportunity for landowners, while potentially providing a funding source to restore habitat in the Valley through on-site mitigation or off-site habitat protection/restoration. The California Farm Bureau, which promotes directing solar development away from productive farmland and important habitat, illustrates the different views of stakeholders.[17,18] A recent estimate predicts 235,000 acres of irrigated SJV farmland may be converted to USSE development.[19] Practices on solar development sites such as land grading, vegetation management, and other activities can make the areas minimally suitable for species.[20,21] However, there is also growing evidence that solar can be co-sited with agriculture, grazing, pollinator habitat, and other compatible and beneficial uses.[22]

i. Regulatory, Technical, and Economic Constraints

Solar implementation in the SJV faces regulatory review, in addition to economic and technical constraints. A lengthy permitting process can be expensive, through direct costs for staff time, labor scheduling, capital investments, and indirectly by introducing uncertainty to partners and investors. Additional economic considerations include proximity to transmission, ability to obtain a power purchase agreement, permitting factors, predetermined zones for solar development, electricity costs, and land prices. Solar electricity costs in California have been dropping as solar is expanding; the average installed prices for utility-scale and commercial projects in 2010 and 2017 were $4.50/watt and $1.56/watt, respectively.[23] The size of the solar project will also influence its costs. Projects that are over 20 megawatts (MW) generally have higher costs because of environmental review, mitigation, and transmission upgrades.[24]

At the state level, environmental permitting requirements are primarily dependent upon the California Environmental Quality Act (CEQA) and, where federal land is concerned, the National Environmental Policy Act (NEPA).[24] The CEQA analysis for a solar development project requires an Environmental Impact Report (EIR), mitigated negative declaration (MND), or negative declaration to disclose the significant environmental impacts of a proposed project and how those impacts will be minimized.[25] Additional entities with permitting requirements may include: the California Public Utilities Commission (CPUC) or publicly owned utilities (POU) Board of Directors for approval of required transmission or distribution equipment; the U.S. Fish and Wildlife Service (USFWS) for a Federal Endangered Species Act (ESA) Habitat Conservation Plan (HCP) and Incidental Take Permit or Biological Opinion and Incidental Take Statement; the California Department of Fish and Wildlife (CDFW) for a California ESA Incidental Take Permit or Natural Communities Conservation Plan (NCCP); and/or the California Independent System Operator (CAISO) for an interconnection agreement.[25] The permitting process at the local level for large USSE projects can be a major impediment as it is often lengthy, complicated, and expensive.[26,27] Streamlining this process is recommended and can be accomplished by adopting clear standards and providing straightforward guidelines for the solar industry to follow to make the approval process more predictable.

Solar development has also been affected by the Williamson Act, a California law that allows local governments to sign ten-year contracts with private landowners; landowners receive lower property tax assessments in return for restricting their land for agricultural use or open space. Many proposed solar developments in the southern SJV are on lands contracted under the Williamson Act, yet solar projects typically are not compatible with the requirements of the Act. In the past, to implement solar on these lands, the contract would have to be canceled at a high fee. Thus in 2011, new legislation was enacted, reducing the cancellation fee if a landowner allowed a solar use easement.[9] The easement must be located on land with reduced agricultural productivity and cannot be sited on land designated as prime farmland. A similar type of agreement, known as a Farmland Security Zone contract, has a minimum initial term of 20 years. Land restricted by a Farmland Security Zone contract is valued for property assessment purposes at 65% of its Williamson Act-restricted valuation, or 65% of its Proposition-13 valuation, whichever is lower.[28]

One of the technical constraints facing solar development is the lack of adequate transmission in the SJV.[9] Site selection is highly dependent on distance to transmission, as project developers are especially concerned with economically-feasible access as well as sufficient capacity to carry the generated power.[29] Hence, identification of least-conflict land for solar without consideration of the availability of future transmission may be ineffective. Transmission is expected to increase given that current renewable energy planning is based on the predicted expansion of solar.[19] Some large-scale solar development projects, such as Westlands Solar Park (http://www.westlandssolarpark.com), are installing transmission corridors to support their projects. Reactive installation of transmission, however, can cause duplicative infrastructure; hence, it is recommended that transmission siting and planning be driven by policy.[29] Further recommendations for improving transmission planning and capacity include: developing a centralized portal with current and projected transmission-capacity information that is available to local governments; comprehensive regional planning among local governments for a more cohesive approach to processing and permitting solar energy facilities; and urging CAISO, which is responsible for managing transmission planning for the state, to prioritize new transmission lines and upgrades.[29]

ii. Overlap with Suitable Habitat

An important consideration in the siting of renewable energy is identifying when optimal land for solar development overlaps with suitable habitat for special status species. A study conducted by The Nature Conservancy (TNC) in the western SJV found that many of the proposed solar development projects, as well as those that were under construction, were situated within remnant SJV ecosystems.[17] Based on the habitat loss in the region, TNC noted that the remaining habitat was crucial for species and recommended limiting the amount of solar development that should occur within the western SJV. However, within the 5.7-million-acre study area, TNC was able to identify approximately 400,000 acres of low conservation value where solar could be developed. In the southern SJV, the optimal solar land is often agricultural land, which provides a promising opportunity for developing solar projects on retired agricultural land in this region and the potential to use mitigation offsets or other mechanisms for habitat conservation.[29]

iii. Mitigation and Additional Costs

When solar projects cause environmental harm (i.e., developing on land that provides habitat to endangered or threatened species), the project design must include mitigation measures per environmental law (i.e., CEQA, CESA, etc.).[24] Mitigation ratios dictate the amount of land to be conserved for each unit (i.e., acre/hectare) of land developed. A mitigation ratio is determined based on species and habitat type, among other factors. While a large ratio would protect more land, it may also disincentivize solar developers. Dashiell et al.[23] calculate the mitigation ratio used for low biodiversity land to be 0.13 versus a 2.95 ratio for high biodiversity land. The same study finds the average time to secure a permit on low biodiversity sites to be 13 months versus 35 months on high biodiversity sites; however, permitting times vary and can be much longer if a framework such as an HCP is involved.[23] Mitigation ratios may vary as the development of these ratios involves negotiations with counties, the CDFW, the USFWS, and/or the Army Corps of Engineers. Ultimately, mitigation can be a complicated and costly process, which may be improved by coordination between federal, state, and local agencies, and by reducing mitigation requirements for projects on least-conflict lands.[9]

Although conservation through mitigation is cited as a potential way to leverage solar development to protect habitat, this may not be a viable option for retired agricultural lands. EIRs for 27 different solar projects that were recently approved in Fresno County did not reveal any final decisions requiring compensatory mitigation. Many lesser mitigations were imposed on the projects, such as conducting preconstruction and seasonal surveys for endangered and threatened species, restricting lighting, erecting wildlife-friendly fencing, minimizing rodenticide and herbicide use, capping all vertical pipes, avoiding and creating buffers around active nests and burrows, banning pets, and, in some instances, relocating species (i.e., burrowing owls).[30] The condition common to the sites was that the land was previously disturbed agriculture, which describes much of the land in the SJV. Despite the presence of endangered species on some of the sites, the regulatory authorities believed the levels of impact on the species would not be significant, thus illustrating the weakness of protections afforded by existing regulations.

iv. Land Costs

Land prices are a major factor in guiding the placement of solar facilities. In 2018, the average price of farmland in the SJV was $9,000/acre, with irrigated cropland commanding $11,740/acre, non-irrigated cropland bringing in $4,900/acre, and pastureland being valued at $2,700/acre. Water rights strongly influence the values.[23] Recently, some of the best farmland such as irrigated almond groves could be sold for $30,000/acre.[31] By contrast, starting an almond farm from scratch, provided water is available, can cost about $14,000/acre ($6,000/acre to purchase bare farmland plus $8,000/acre in establishment costs). Once established, the farmers can expect to earn $12,000/acre/yr.[31] Such land will likely stay productive farmland, and solar will be steered to less expensive sites. Solar companies often find that leasing private land is cheaper than purchasing it, and both are cheaper than leasing U.S. Bureau of Land Management (BLM) land.[23] The Sacramento Bee reported on a case in which a solar company leased farmland for $1,000/acre/yr, which the farmer claimed was 10 times the income earned from planting wheat.[32]

2.1.5 Conservation and Habitat Restoration

The SJV has been historically classified as a perennial grassland; however, Germano et al.[4] maintain that many parts resembled desert, with sparse native grasses, shrubs, and forbs. As mentioned, up to 535,000 acres will likely have to be fallowed in the Valley due to SGMA; the same report predicts 80,000 acres of San Joaquin desert, 20,000 acres of SJV intermittent wetlands, and 20,000 acres of SJV riparian and floodplain habitat could be restored through active management.[7] For context, the SJV covers 7.1 million acres within which 2.5 million acres could be suitable habitat for at least one listed species, 1 million acres within five kilometers (km) of an existing protected area could support at least one listed species, and 100,000 of the 1 million acres that were fallowed more than once between 2011 and 2015 (due to extreme drought conditions in the area) could be restored to suitable habitat in close proximity to existing protected areas.[33] Estimates of acreage needed to restore enough habitat to delist 11 federally endangered/threatened species varies; Williams et al.[34] arrive at 80,300 acres, which is consistent with TNC's goal of conserving 50,000 to 80,000 acres of upland habitat in the SJV.

i. Endangered and Threatened Species

Williams et al. refer to the following 11 species: the blunt-nosed leopard lizard (*Gambelia sila*), San Joaquin kit fox (*Vulpes macrotis*), Fresno kangaroo rat (*Dipodomys nitratoides*), Tipton kangaroo rat (*Dipodomys nitratoides nitratoides*), giant kangaroo rat (*Dipodomys ingens*), Bakersfield cactus (*Opuntia basilaris* var. *treleasei*), San Joaquin woolly-threads (*Monolopia congdonii*), Hoover's woolly-star (*Eriastrum hooveri*), Kern mallow (*Eremalche kernensis*), palmate-bracted bird's-beak (*Cordylanthus palmatus*), and California jewelflower

(*Caulanthus californicus*). Subsequently, more species have been federally listed, such as the riparian woodrat (*Neotoma fuscipes riparia*), riparian brush rabbit (*Sylvilagus bachmani riparius*), and Buena Vista Lake shrew (*Sorex ornatus relictus*).[35–38] California lists more species as endangered, including the Bakersfield smallscale (*Atriplex tularensis*) and San Joaquin Valley Orcutt grass (*Orcuttia inaequalis*).[39] If a site has endangered or threatened species, different stipulations must be met. If the species is federally listed, the developer must work with the USFWS to determine mitigation ratios and other requirements. If the species is listed at the state level, the developer needs to work with the CDFW to do the same. Not all mitigation actions require habitat restoration. For example, relocating individuals of a species is often a mitigation action.[30] Likewise, not all habitat restorations are in response to mitigation requirements.

Multiple considerations for habitat conservation and restoration must be made given the specific needs of each species of interest. Some restoration actions are less expensive, such as simply allowing natural regeneration. Often, grazing can be used to keep out invasive grasses and still provide good habitat value. In 2004, habitat protection costs for the San Joaquin kit fox were $150-$900/acre.[40] The San Joaquin kit fox, which requires about 600 hectares as a home range, inhabits grassland, scrubland, oak woodland, alkali sink scrubland, vernal pool areas, alkali meadows, oil fields, and wind turbine facilities. Kit foxes are less abundant in row crops, irrigated pastures, orchards, vineyards, and grazed annual grasslands. They prefer loose soil but are adaptable, and they eat rodents, lagomorphs, birds, and insects. The species will use man-made dens and prefers dens in flat, well-drained open areas with grass or scattered brush, avoiding thick brush. The nocturnal giant kangaroo rat is found in the western SJV on fine sandy loam with sparse grass/forb vegetation. It occupies only 2% of its former range due to cultivation, rodenticides, and crushing by cattle.[41] The Tipton kangaroo rat is found in Kern, Tulare, and Kings Counties and prefers the arid valley floor in sparse woody shrubland. The riparian woodrat prefers dense riparian shrub cover; the only known current population is found on 250 acres at Caswell Memorial State Park.[42] The riparian brush rabbit is also only found at Caswell Memorial State Park.[43] The Fresno kangaroo rat historically had a range of about 888,000 acres, which had contracted in 2010 to 371 acres in Kings County.[44] The Buena Vista Lake shrew occupies only 5% of its historic range in the Tulare Basin.[45] Only 41,300 acres of acceptable habitat remain in the SJV for Nelson's antelope squirrel. Blunt-nosed leopard lizards require 500 hectares to support a sustainable population.[46] This species is found in the southern SJV and adjacent western and southern foothills, occupying only 15% of its historic range.[47]

ii. Identifying Areas to Preserve/Restore

Lortie et al.[46] state that habitat restorations should aim to increase habitat area, improve connectivity, increase native plant species, and decrease exotic plants, especially focusing on controlling exotic grasses. Considering the various factors, it may be more beneficial to direct mitigation activities off-site to expand existing protected areas and create corridors to connect valuable habitat. High biodiversity areas may include wetlands, important habitat to kit foxes and other listed species, Carrizo Plain mitigation areas, land within the Grasslands Ecological Area, or land within one km of the San Joaquin River. Identifying the areas of most favorable habitat that coincide with the lands most likely to be leased or sold by landowners is critical to allow conservation organizations to focus protection efforts.

Likewise, locating the lowest value habitat that coincides with areas of highest solar industry interest allows governments and organizations to target incentives for siting USSE on those parcels.[17]

iii. Other Policies, Incentives and Conservation Tools

Beyond the policies mentioned in Section 2.1.4, additional policies and incentives that affect stakeholders may include the Migratory Bird Treaty Act, the SJV Upland Species Recovery Plan, the Federal Clean Water Act, and county general plans, such as the Kern County General Plan, which guide solar to disturbed lands that do not support state or federal protected species. Some funds for habitat can be obtained from California's Proposition 68, which provides $200 million to restore Central Valley rivers.[48] The Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentives Program (EQIP) both provide funds to idle land and decrease the need for irrigation.[49,50]

If an Initial Study, required by CEQA, finds substantive evidence of potentially significant environmental effects of a project, an MND or an EIR must be conducted; an EIR can take over a year to complete. If an HCP or NCCP is prepared, the red tape and delays can be managed in large projects because local negative impacts are allowable as long as the overall project protects the species of interest; due to the expense, these are not good for smaller projects.[7,51] Two projects, the Maricopa Orchards Solar Project and the Kern Water Bank, make use of HCPs. Both an HCP and an NCCP were established for the Kern Water Bank where the restoration of 17,000 acres of cropland provided habitat for upland and wetland species and another 3,000 acres was set aside as a conservation bank managed by the CDFW.

Of the SJV's 202 agricultural and urban water suppliers, a quarter of them had recharge facilities on their lands in 2017 and expressed interest in developing a similar approach to the Kern Water Bank to expand their water supply/storage and enhance habitat. Furthermore, the Kern Water Bank project developed a vegetation management system utilizing grazing of exotic grasses to control non-native species, pests, and to improve air quality while expanding habitat for San Joaquin desert species. The CDFW's Regional Conservation Investment Strategy (RCIS) has been established as an expedited alternative to NCCPs but does not provide regulatory insurance for species takes. The Habitat Restoration and Enhancement Act of 2014 limits the CDFW evaluation and permitting timeline to 60 days for small projects, and over 24 restoration projects were approved under this regulation by 2016.[7]

Another tool to facilitate the development of lands supporting or likely to support threatened and endangered species is the Safe Harbor Agreement (SHA), a voluntary agreement between a private or non-federal property owner and the USFWS (or NOAA in the case of marine species or anadromous fish). If the agreed-upon actions of the landowners contribute to the recovery of an ESA listed species, the government will not require additional or different management without the landowner's consent. At the end of the SHA, original management practices are restored but a net conservation benefit must result. States, non-governmental organizations (NGOs), soil conservation districts, and other local entities often act as intermediaries so the USFWS does not have to be closely involved in every agreement.[52]

There are three major conservation tools that land trusts and agencies can employ to protect land in concert with landowners. First, land can be purchased outright from a landowner (this is known as a fee simple). Second, a landowner can sell some development rights, retain other rights and ownership of the land. In this case, the sale will preclude the landowner from claiming a charitable donation income tax deduction. Finally, a landowner can donate a conservation easement that stipulates which rights are being donated. The donation allows the landowner to receive an income tax deduction on the decrease in value of the encumbered land, as determined by qualified appraisal. The landowner does not receive a payment from the land trust or agency. In all cases, the conservation organization or agency is responsible for monitoring the property and ensuring the land is protected in perpetuity. These tools offer interesting possibilities to landowners in the SJV as they decide how to manage their parcels, factoring in the potential to lease land to solar developers.[53–56]

2.1.6 Environmental Justice & Health Implications

The expected fallowing and retirement of 535-750K acres of cropland has major implications for human and environmental health. Without coordination across the SJV from all stakeholders, lost opportunities to minimize airborne dust and other particulates could lead to increased health concerns that are a major problem for residents who already experience respiratory illnesses at rates much higher than the rest of the state's population.[57] In fact, the death rate from Chronic Lower Respiratory Diseases (CLRDs) in the SJV is 12 times higher, and one in every 37 residents of Kern County died from CLRD between 2013 and 2016.[58] Agricultural practices like disking and the spraying of herbicides contribute to poor local air quality. Disking still occurs on fallowed properties because it makes the land undesirable for endangered and threatened species; if these species inhabited the land, it would restrict future land use. A coordinated management approach for retired lands that includes land stewardship (i.e., cover crops, compost, grazing), temporary and permanent land conservation, and species-focused restoration could provide the region with multiple benefits (i.e., ecosystem services) such as improved air and water quality, water recharge, and carbon sequestration.[2] Actions by solar developers to minimize land disruption and dust production can also improve conditions in the SJV.

2.1.7 Literature Review Takeaways

SGMA's implementation will have widespread impacts on land use throughout the SJV. The USSE industry is siting projects within the Valley, though it faces several regulatory, technical, and economic demands. Development of large-scale solar projects may trigger mitigation requirements for habitat conservation, benefiting the several listed species of concern in the Valley. However, these measures may be insufficient if a facility is located on previously disturbed agricultural land. Coordinated efforts for land repurposing are important for ensuring that landowners benefit from converting their land, that renewable energy and conservation goals are met, and that harm to human and environmental health is minimized.

As SGMA-imposed groundwater limitations take effect over the next 20 years, many landowners will be faced with difficult decisions about transitioning irrigated agricultural land to alternative land uses. These decisions will involve several considerations, including the evaluation of financial benefits from alternative land uses compared to those from continued farming. Alternative land uses that would provide revenue to landowners may include conservation and/or restoration of habitat for endangered species and USSE. These options respectively improve natural lands that produce a range of public benefits and help advance the state's ambitious renewable energy goals.

Our initial literature review and examination of case studies did not reveal many instances where solar developments on formerly irrigated agricultural lands in the SJV were required to provide off-site mitigation for habitat loss. To further explore this trend, and to gain additional insight into opportunities for promoting both conservation and USSE development in the Valley, we conducted a series of stakeholder interviews.

2.2 Stakeholder Interviews

We conducted 29 stakeholder interviews to help accomplish our first objective of understanding the viability of solar and conservation on retired agricultural land, as well as our second objective of assessing potential strategies for TNC and other conservation organizations to leverage new solar development to achieve upland species conservation goals. These stakeholders consist of landowners, solar developers, environmental consultants, NGOs, researchers, state agencies, county planners, and water districts. We gather three key takeaways from these interviews:

1. **Solar development is viable on retired agricultural lands, but limited transmission availability is a major hurdle to solar expansion.** Across all stakeholder groups, there was support for siting solar on farmland that must come out of production due to SGMA, particularly if it steers development away from undisturbed lands. Solar developers believed retired land requiring repurposing will present further opportunities for development. One of the main obstacles to siting solar in the Valley today is transmission availability; expansion of suitable transmission for USSE is crucial to meet the state's renewable energy goals.

2. **Solar development on retired agricultural lands does not require significant compensatory habitat mitigation.** One of the TNC's interests was leveraging CEQA-required mitigation from placing solar on agricultural fields to facilitate and fund habitat conservation. However, stakeholders agreed that these highly disturbed lands have little biological value, and thus solar development on such lands would require minimal compensatory mitigation, if any (with the exception of particular species like the Swainson's hawk or burrowing owl).

3. **There is interest from developers in creating habitat on solar sites.** Developers expressed interest in returning lands to their natural conditions and making solar more habitat-friendly; however, due to regulatory pressures, they currently feel discouraged from doing so. If developers were to create more wildlife-friendly solar, they noted that it would need to be profitable and that they would require incentives such as expedited issuance of permits, reduced mitigation costs, and Safe Harbor Agreements.

2.3 Moving Forward: Spatial-Economic Model

Given these findings, this project conducts a spatial-economic analysis to determine, of the agricultural lands that are most likely to be retired in the next 20 years, which may be converted to USSE and which may be conserved for species habitat. The analysis is used to offer proposals which may help TNC protect the 50,000 to 80,000 acres they suggest are needed to give long term protection to threatened and endangered upland species in the SJV.

3. Methods

3.1 Overview

We create a spatial-economic model to forecast how predicted retired agricultural land will be repurposed. Specifically, we aim to establish whether there is a stronger financial incentive to convert land to utility-scale solar energy (USSE) or conserve it for habitat. Ultimately, it is up to the landowner to determine future land use. Hence, we calculate the net present discounted profit that a landowner would receive from leasing their land for USSE, as well as the net present discounted profit they would receive from selling the development rights for the placement of a conservation easement. We assume that the landowner will select the more profitable option.

We complete this analysis in five key steps:

1. Identify agricultural land predicted to be retired in the Valley.
2. Determine the net present discounted profits that a landowner would receive from a solar lease.
3. Determine the net present discounted profits that a landowner would receive from the sale of a conservation easement.
4. Compare profit results from solar and conservation land uses to obtain a landowner's decision.
5. Conduct sensitivity analyses on variables influencing solar and habitat profit.

3.2 Identification of Predicted Retired Agricultural Land

To begin our analysis, we first identify which agricultural lands are likely to be retired in the next 20 years as SGMA takes effect. Bryant et al.[2] claim that approximately 86,000 hectares, or almost 213,000 acres, of existing irrigated agricultural land will be permanently retired by 2040. The study, conducted in conjunction with TNC, also provides spatial data identifying potential parcels of land that would be retired based on five overlaid retirement scenarios. The study notes that a pixel is considered retired if any agricultural land within the pixel is retired, which could only be a fraction of the total pixel area; this may provide an overestimate of retired land. To ensure these predicted retired lands are indeed currently used for agriculture, we crop this spatial layer to the 2018 agricultural lands layer from the California Department of Water Resources (CADWR) Statewide Crop Map.[59]

The total number of predicted retired acres using all five retirement scenarios is 505,871, which far exceeds Bryant et al.'s projection for permanent retirement of approximately 213,000 acres. Therefore, we select all parcels where at least two scenarios overlap, which decreases the retirement acreage to approximately 214,009, more closely matching the Bryant et al. projection (Figure 2). We conduct all further analyses within these land pixels predicted to be retired.

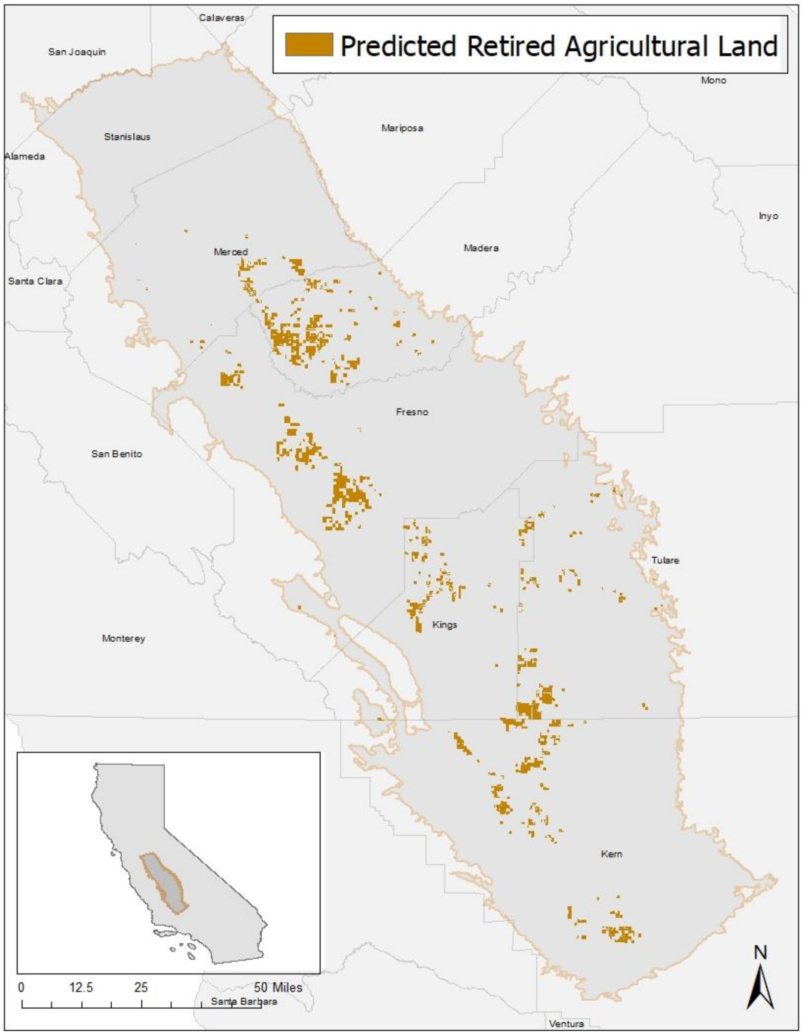


Figure 2. Predicted retired agricultural land in the SJV. Areas of agricultural land, displayed per pixel (approximately 15.4 acres) and totaling approximately 214,000 acres, that are expected to be permanently retired by 2040. Data Source: Bryant et al. (2020).

3.3 Landowner Profits from Solar

To obtain the solar profit component of our spatial-economic model, we calculate the dollar value, in net present value (NPV) terms, that a solar developer would receive if they chose to develop USSE (specifically, a single-axis tracking system) on a pixel of land. We assume that solar developers operate competitively such that this NPV equates to the value that a landowner would receive if they were to lease their land to a solar developer. The revenue obtained is dependent upon the wholesale electricity price and capacity factor in the region. From the revenue, we subtract costs, which are made up of the cost of development and the cost of connecting to a transmission line. This is shown in equation 1, with revenue and cost variables detailed below.

Equation 1. Solar profit

$$Solar\ profit = \left(\left(\sum_{t=0}^{T=25} \frac{p * f_i * 24 * 365}{(1+\delta)^t}\right) - c\right) * m - (r * d_i)$$

p	Wholesale electricity price ($/MWh)
f_i	Capacity factor (%) *
δ	Discount rate (%)
c	Development cost ($/MW)
m	Density multiplier coefficient (MW/pixel)
r	Transmission connection cost ($/km)
d_i	Distance to transmission (km) *

**Cropped to retired agricultural land layer.*
Note: i denotes a spatial layer (per 250 m x 250 m pixel).

Wholesale electricity price (*p*, $/MWh): For our equation, we identify a wholesale electricity price for solar photovoltaic (PV) technology of $100 per megawatt hour (MWh), which represents the California average wholesale price in 2019.[60] The national average wholesale electricity price for solar PV in the same period was $83/MWh.

Capacity factor (f_i, %): Capacity factor is a value used for evaluating the performance of electricity generation. It is representative of the generation in a typical year, as a percent of the maximum theoretical generation that could be produced if the facility were operating at maximum capacity at all times. We reference a spatial layer from Wu et al.[19] for continuous capacity factor that includes all candidate project areas, or areas that are suitable for solar based on spatially-explicit techno-economic exclusions for development (Figure 3).[19] These areas are also subdivided into smaller utility-scale project-sized areas (typically 50-100 MW) and exclude all lands with existing legal restrictions against energy development.[19]

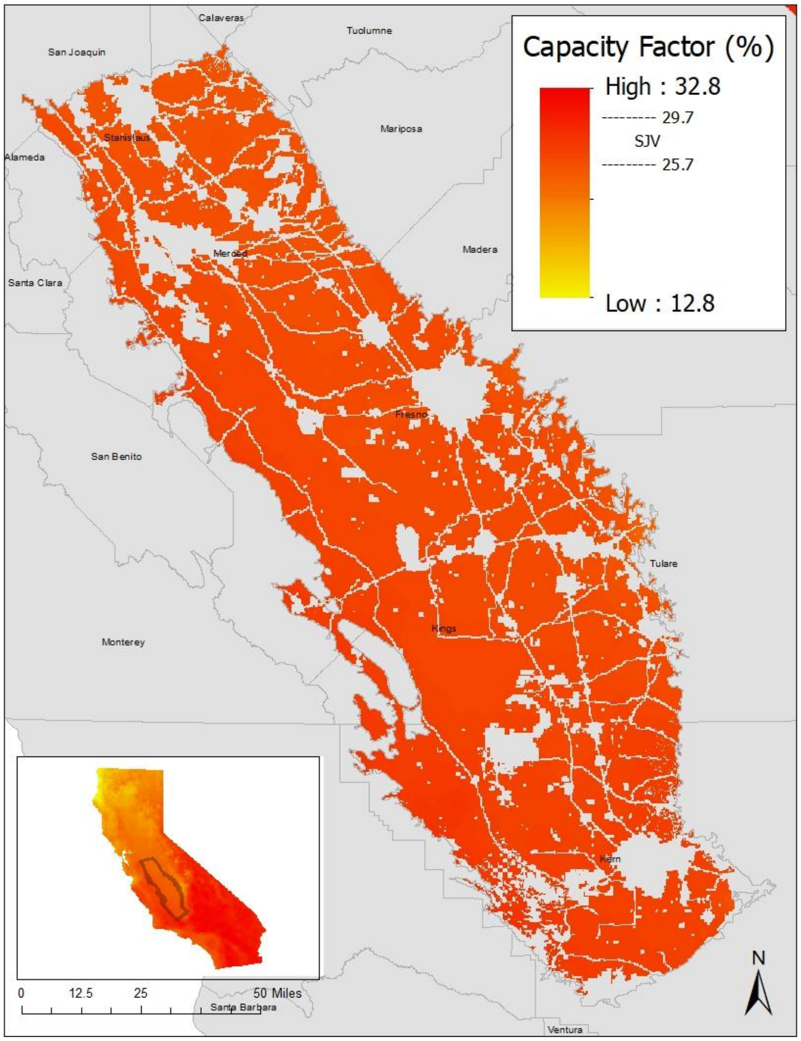
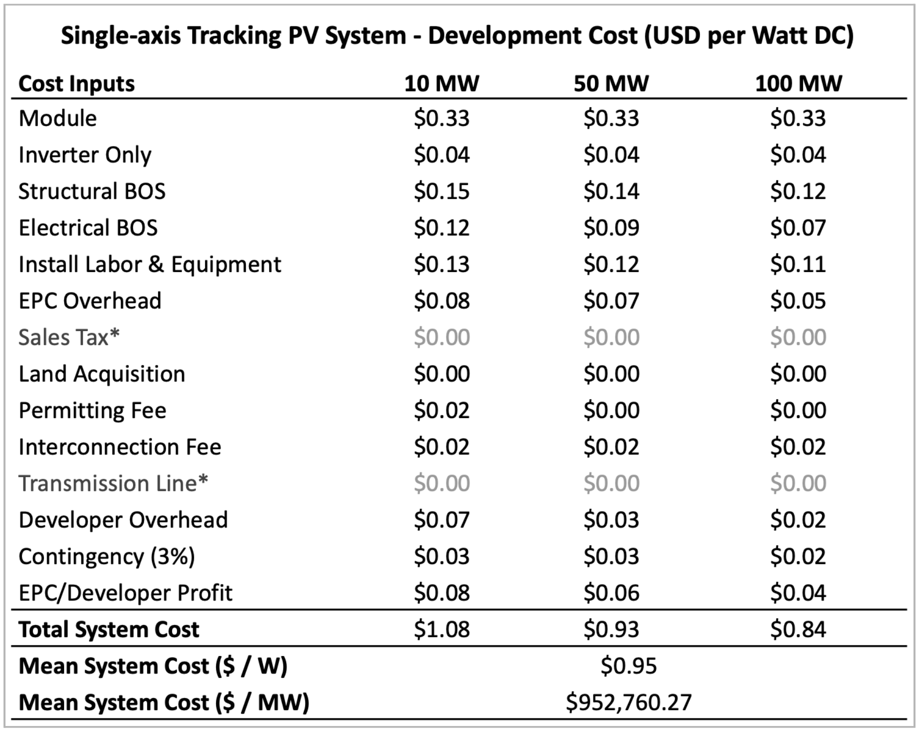


Figure 3. Solar capacity factor in the SJV. Capacity factor, expressed here as a percentage, is used to evaluate the performance of electricity generation. Capacity factor is displayed per pixel (approximately 15.4 acres) for all areas where there is potential for solar development. Note that the full range of values (12.8 to 32.8) represents capacity factor across the entire state, and the SJV falls within the range of 25.7 to 29.7. Data Source: Wu et al. (2019).

Discount rate (δ, %): We calculate revenue for a single year and discount it over a 25-year period, which is approximately the lifespan of a solar facility. We calculate NPV using a fixed discount rate of 5% over the 25-year lifespan of the project. This rate reflects the mean of values forecasted annually between 2019 and 2035 for the weighted average cost of capital (WACC nominal). To calculate NPV, solar projects developed by for-profit organizations, such as Independent Power Producers, should use a discount rate equal to nominal weighted average cost of capital.[61,62] This mean value comes out to 0.05136 or 5% rounded.

Development cost (*c*, $/MW): Development cost accounts for the total upfront capital needed to develop utility-scale PV systems as incurred by the engineering, procurement, and construction (EPC) entity and the solar developer. In our equation, we focus on energy-only (no storage) single-axis tracking systems for which the calculated base cost is $0.95/watt DC ($952,760/MW) (Table 1). The cost inputs we calculate are built from bottom-up model results used to quantify U.S. national costs in the first quarter of 2021.[63] We tailor cost input values to meet the needs of our analysis.

Table 1: Breakdown of cost inputs calculated for utility-scale PV systems. Adapted from Vignesh et al. (2021).



Single-axis Tracking PV System - Development Cost (USD per Watt DC)

Cost Inputs	10 MW	50 MW	100 MW
Module	$0.33	$0.33	$0.33
Inverter Only	$0.04	$0.04	$0.04
Structural BOS	$0.15	$0.14	$0.12
Electrical BOS	$0.12	$0.09	$0.07
Install Labor & Equipment	$0.13	$0.12	$0.11
EPC Overhead	$0.08	$0.07	$0.05
Sales Tax*	$0.00	$0.00	$0.00
Land Acquisition	$0.00	$0.00	$0.00
Permitting Fee	$0.02	$0.00	$0.00
Interconnection Fee	$0.02	$0.02	$0.02
Transmission Line*	$0.00	$0.00	$0.00
Developer Overhead	$0.07	$0.03	$0.02
Contingency (3%)	$0.03	$0.03	$0.02
EPC/Developer Profit	$0.08	$0.06	$0.04
Total System Cost	$1.08	$0.93	$0.84
Mean System Cost ($ / W)		$0.95	
Mean System Cost ($ / MW)		$952,760.27	

**Sales tax exemption on components in California until 2030*
**We instead calculate transmission connection cost using $/km (see Equation 1) using spatial data*

We calculate development cost using U.S. national data published by the National Renewable Energy Lab.[63] Our cost of development includes: modules, inverters, structural and electrical balance of system (BOS) components, labor, permitting, interconnection fees, EPC and developer overhead, and a 3% contingency to estimate markup on EPC costs. We modify these published values to suit our analysis by removing: 1) costs associated with transmission lines, as this cost is calculated at the pixel level using spatial data and distance calculations (see *Transmission connection cost* below); and 2) component sales tax costs because current California state policy provides a 100% tax exemption through at least 2030. Lastly, we take the mean of the total system costs for 10 MW, 50 MW, and 100 MW capacity solar facilities. Our analysis does not evaluate development cost based on facility capacity or size; however, we do omit reported costs for systems under 10 MW from this mean calculation as we do not consider less than 10 MW to be "utility-scale." We do not include the costs incurred by the Operations and Maintenance (O&M) entity, including the cost of land acquisition (long-term land leases), property taxes, cleaning, and repairs.

Transmission connection cost (r, $/km): Transmission connection cost is a constant dollar value, which is multiplied by the distance that a pixel is to existing transmission (see *Distance to transmission* below). Connecting a USSE site to a transmission line requires the construction of an additional transmission line called a generation-tie (gen-tie). This cost is influenced by the distance between the solar site and the nearest main transmission line; the greater this distance, the more expensive the connection will be.

We obtain this value, in dollars per kilometer (km) using the Black & Veatch transmission line capital cost calculator from the Western Electricity Coordinating Council.[64] For a 230 kilovolt (kV) single circuit line, we arrive at a cost of $522,140 per kilometer. The following input costs are associated with connecting new utility-scale PV solar facilities to the grid: voltage class, conductor type and age, structure, approximate length, and overhead costs.

Distance to transmission (d_i, km): To evaluate the cost of connecting to a transmission line from each pixel, we include a spatial layer that represents the distance between each pixel in our study area and the nearest transmission line (Figure 4). We calculate this distance from a spatial layer of existing transmission.[65] From this spatial layer, we remove all transmission lines that cannot support USSE (i.e., all lines under 230 kV). The distance to transmission layer is restricted to the same candidate project areas as the capacity factor layer.[19]

Density multiplier coefficient (m, MW/pixel): We include a density multiplier coefficient of 3.71 MW/pixel to ensure that all units in our solar profit equation are in dollars per pixel.[66]

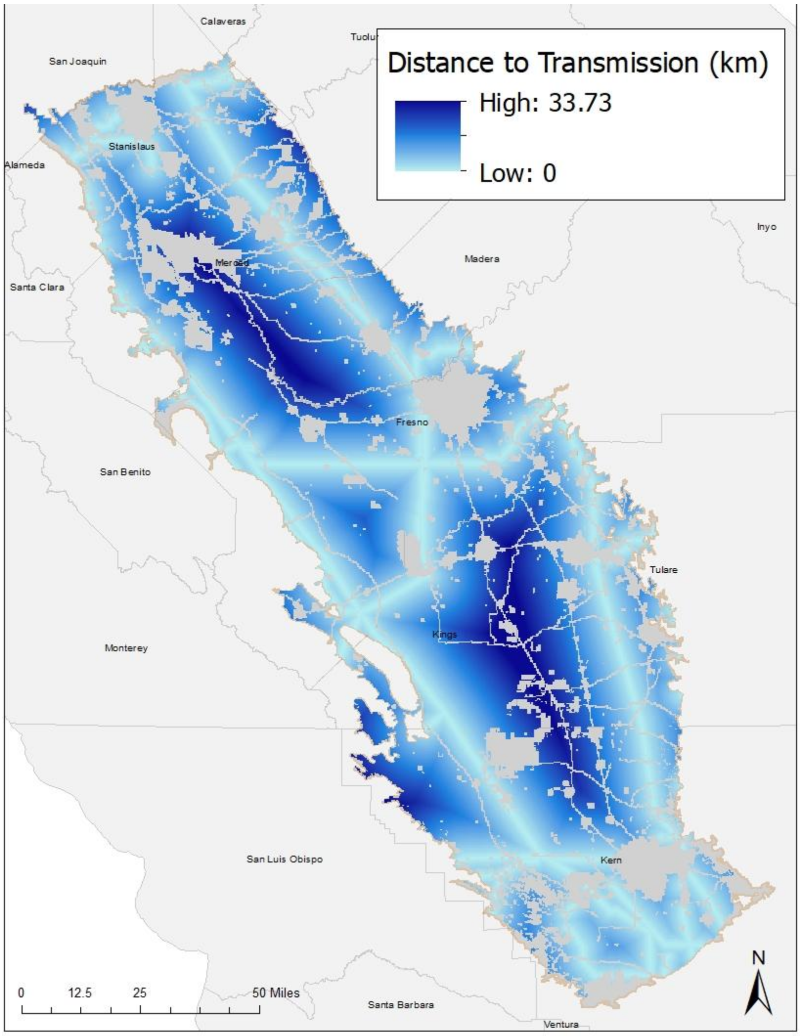


Figure 4. Distance to transmission (kilometers) in the SJV. Distance from areas of potential solar development (see also Figure 1) to transmission lines per pixel (approximately 15.4 acres). Data Source: Oak Ridge National Laboratory et al. (2021).

3.4 Landowner Profits from Conservation

We calculate the dollar value of a one-time payment that a landowner would receive if they were to sell a conservation easement on their land. Based on the value of their land and whether the land is considered suitable habitat for target species, a landowner will be able to sell the development rights of that land for the placement of a conservation easement. This is captured in equation 2, with the variables used in this analysis detailed below.

Equation 2. Habitat profit

$$\textit{Habitat profit} = v_i * s * h_i$$

v_i	Land value ($) *
s	Compensation for conservation (%)
h_i	Suitable habitat *

**Cropped to retired agricultural land layer.*
Note: i denotes a spatial layer (per 250 m x 250 m pixel).

Compensation for conservation (s, %): For conservation easements in which landowners sell the development rights of their land to a land trust or other entity, landowners typically receive approximately 40-60% of the land's value.[67] We choose this method of protecting land for our analysis, as opposed to an outright sale of the land or donation of development rights in exchange for income tax deductions, since landowners can retain ownership of their land (similar to the lease of land for solar), and it is more feasible to quantify a one-time payment to landowners based on land value than it is to calculate the amount saved via income tax deductions. Therefore, to determine the payment a landowner would receive, we multiply the land value in each pixel by 60%.

Land value (v_i, $): This spatial layer represents estimated fair market value of private properties in the SJV (Figure 5).[68]

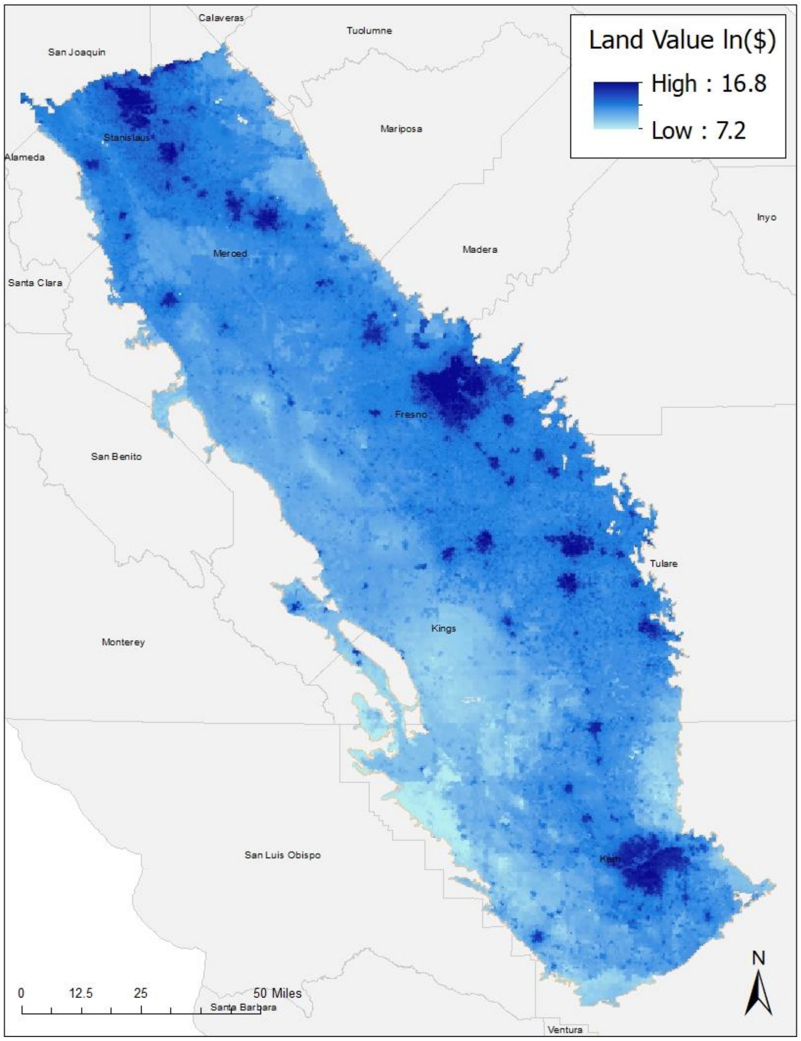


Figure 5. Land value in the SJV. Value of land in natural log dollars or ln($) per pixel (approximately 15.4 acres). Data Source: Nolte et al. (2020).

Suitable habitat (h_i): We evaluate habitat profit only in areas of suitable habitat. Suitable habitat is defined as areas that are suitable for at least one or more of TNC's target umbrella species (San Joaquin kit fox, blunt-nosed leopard lizard, giant kangaroo rat, and San Joaquin woolly-thread) within 5 km of a protected area. We combine individual species suitability layers into one layer to determine where they overlap. We obtain protected area data from both the Protected Area Database (PAD) and California Conservation Easement Database (CCED).[69] These data encompass state and federally protected areas, conservation easements, and land protected by non-governmental entities (i.e., TNC). We remove city-owned lands as those are typically public parks. We buffer protected areas to 5 km and crop the combined species suitability layer to this buffer to create our suitable habitat spatial layer (Figure 6A). We also create a spatial layer for suitable habitat for two or more of TNC's target species (Figure 6B). These lands may be even more valuable from a conservation perspective and represent areas where TNC is more inclined to focus resources to conserve habitat.

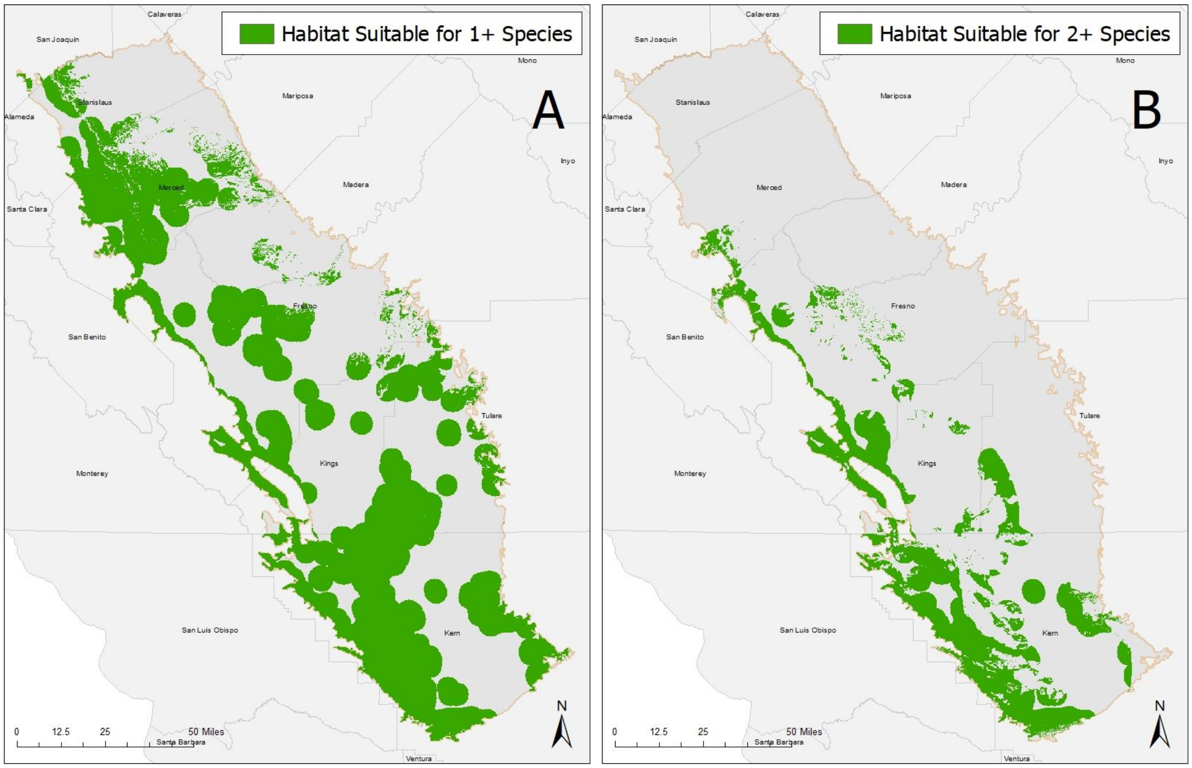


Figure 6. Habitat suitability in the SJV. Suitable habitat within a 5 km distance of a protected area for at least one (A) or two (B) of the following species: San Joaquin kit fox, blunt-nosed leopard lizard, giant kangaroo rat, and the San Joaquin woolly-thread. Data Source: The Nature Conservancy.

3.5 Solar and Habitat Profit Comparison

We determine that a landowner chooses to lease their land for USSE, instead of selling development rights to protect their land for habitat, if the inequality in Equation 3 is satisfied (that is, if solar profit for a pixel of land exceeds habitat profit). If the reverse is true and habitat profit exceeds that of solar, then the landowner would choose to sell to an entity placing a conservation easement rather than to a USSE developer.

If both solar profit and habitat profit for a single pixel are less than or equal to zero, this indicates that neither land repurposing option is profitable to the landowner. Thus, the landowner will not choose to convert to either land use option.

Equation 3. Comparison of solar profit and habitat profit.

$$\left(\left(\sum_{t=0}^{T=25} \frac{p * f_i * 24 * 365}{(1+\delta)^t}\right) - c\right) * m - (r * d_i) > v_i * s * h_i$$

3.6 Sensitivity and Scenario Analyses

We conduct sensitivity and scenario analyses to 1) complete diagnostics checks and 2) identify the most important variables driving the overall value of each option, solar or habitat. We alter the spatially-fixed variables one at a time, holding all other variables constant at their base values. These altered variables include wholesale electricity price (p), development cost (c), transmission connection cost (r), discount rate (δ), and compensation for conservation (s). The base values for each are defined as follows:

- p = \$100/MWh
- c = \$952,760/MW
- r = \$522,140/km
- δ = 5%
- s = 60%

To check the robustness of the model and ensure proper functionality, we change each of these base values to zero one by one. We also input different values for these variables to represent alternative scenarios. For the wholesale electricity price (p), we run the model with the average wholesale price for solar PV in the U.S. (\$83/MWh), as well as a forecasted wholesale price for solar in California as of 2046 (\$34/MWh).[70] For the discount rate (δ), we run the model with other feasible rate values a solar developer might use when considering a project (4% and 10%). For the development cost (c), we run the model with a value that includes component sales tax costs to represent the expiration of the California state policy providing a 100% tax exemption (\$992,860/MW). We run the model with an estimated future value for the transmission connection cost (r), which is calculated using the rate at which the total cost of construction to connect to transmission fell between 2018 and 2019 (\$472,140/km). Finally, for compensation for conservation (s), we run the model with a value representing the low end of the range for the fraction of land value that a landowner would see in exchange for a conservation easement (40%). We also run the model with a value representing outright purchase of a property (100%).

4. Results

4.1 Overview

Our model provides us with predictions of the profit a landowner would theoretically obtain from converting their retired agricultural land to either USSE or to habitat via the sale of a conservation easement. This allows us to evaluate and compare these profit values and identify the potential spatial distribution of USSE and habitat. We present results for the predicted distribution of solar and habitat throughout the landscape using a model run with habitat suitability for one or more species and a model run with habitat suitability for two or more species. We compare our results to California's energy goals and TNC's habitat goals. Lastly, we assess the results of our sensitivity analysis to determine the impacts of these variables on landowners' decisions to select solar or habitat. Sections 4.2 and 4.3 show results when the model is run with values.

4.2 Distributions of Solar and Habitat Profits

Solar profit values range from approximately -$7.3 million to nearly $10 million (Figures 7 & 8). Solar development will not occur on pixels where profit values are zero or negative, as these are unprofitable areas for development. The majority of high profit solar pixels are located along existing transmission infrastructure.

To test whether the assumption of perfect competition among solar developers reflects conditions in the Valley, we compare the solar profit to real-world land lease values. Land lease values in the SJV for solar projects range from $200 to $2,000 per acre per year.[67] We discount these values over a 25-year period to determine the range of profit that a landowner may receive after leasing to a solar developer; these profits range from $42,846 to $428,456. We cap our model's solar profit values at the maximum land lease value ($428,456) and run the comparison analyses again to understand how the breakdown of pixels selected for solar versus habitat changes. Our results of solar and habitat distribution throughout the landscape do not change, which supports our use of the original values under the perfect competition model. We proceed with the uncapped data for all further analyses.

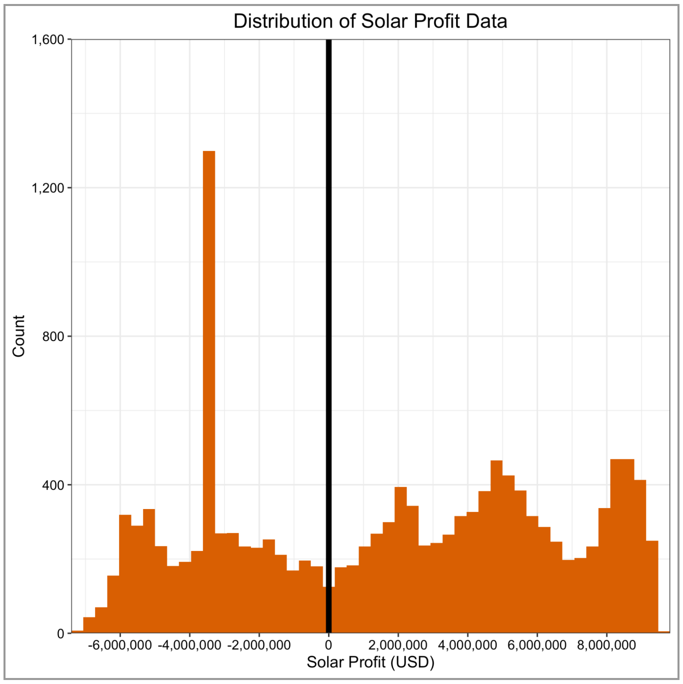


Figure 7. Distribution of solar profit values when variables are set at base values (p = $100/MWh, δ = 5%, c = $952,760/MW, r = $522,140/km). The spike of clustered negative values represents the pixels where solar is not feasible (i.e., where capacity factor is 0).

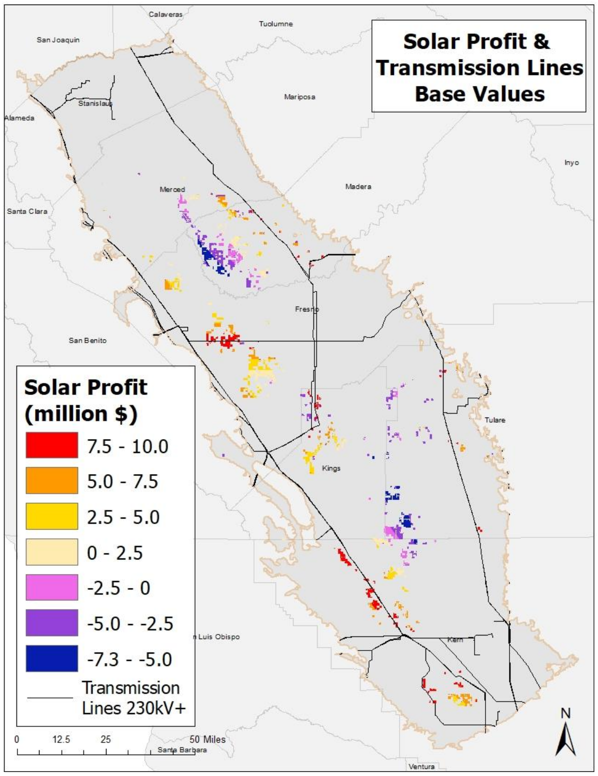


Figure 8. Spatial distribution of solar profit values when input variables are set at base values (p = $100/MWh, δ = 5%, c = $952,760/MW, r = $522,140/km). Transmission lines 230kV or greater are represented.

Habitat profit values under the single-species scenario range from zero to approximately $5 million, though they largely do not exceed $200,000 (Figures 9A & 10A). Habitat profit values under the dual-species scenario range from zero to approximately $550,000, though they largely do not exceed $75,000 (Figures 9B & 10B).

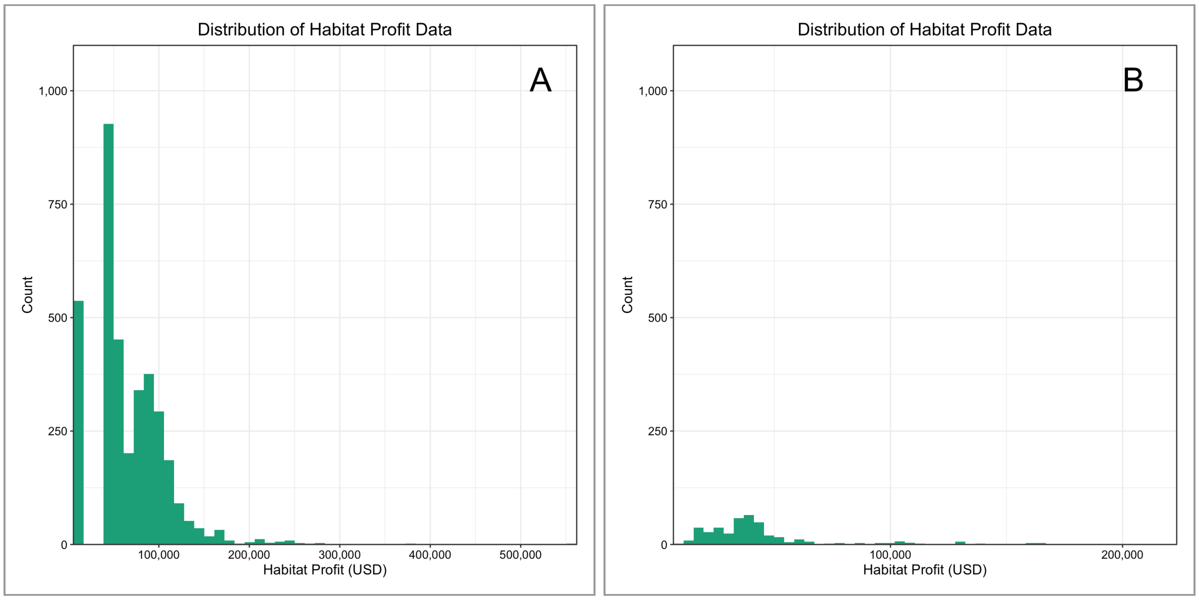


Figure 9. Distribution of habitat profit values with habitat suitability for one or more species (A) and two or more species (B) when compensation variable is set at the base value (s = 60%). For ease of visualization, the data for the one-species scenario is truncated at $550k, the data for the two-species scenario is truncated at $250k.

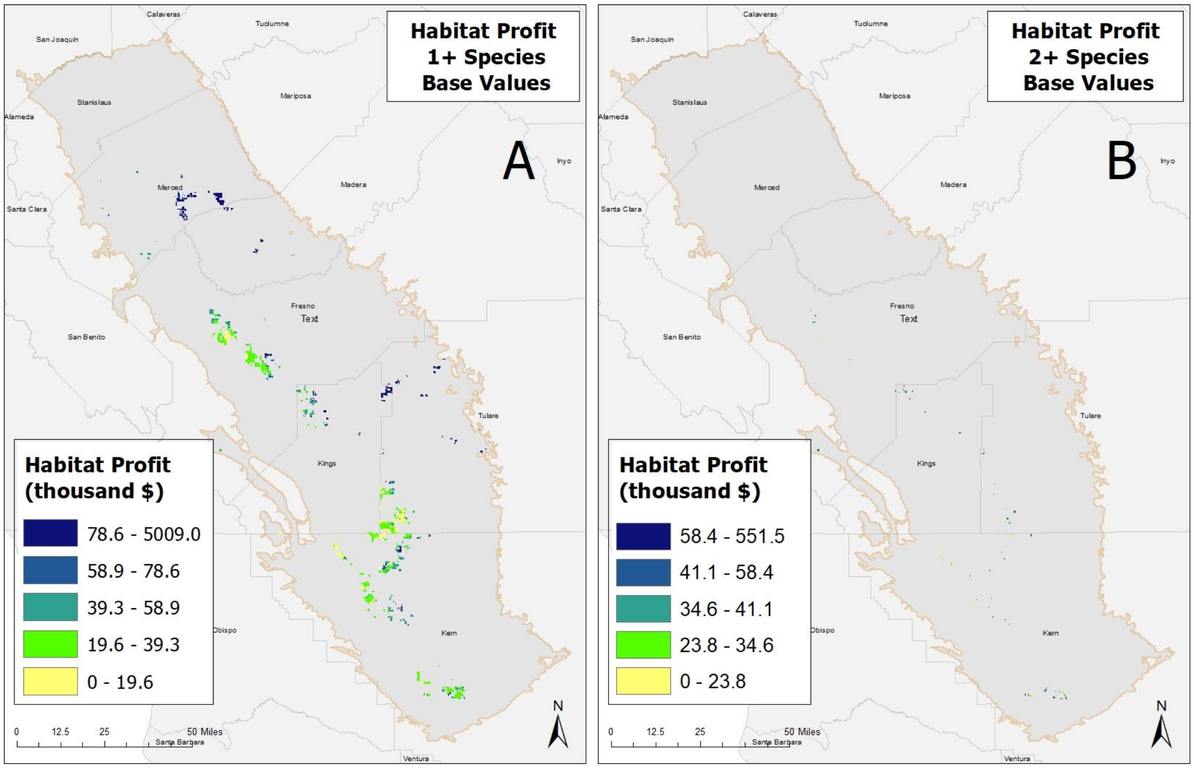


Figure 10. Spatial distribution of habitat profit values with habitat suitability for one or more species (A) and two or more species (B) when compensation variable is set at the base value (s = 60%).

4.3 Model Selection: Solar versus Habitat

When the solar equation profits are compared to the habitat equation profits, landowners will either choose USSE, a conservation easement, or neither option (Figure 11). Neither is used to represent areas not selected for USSE or habitat conservation because neither option provides the landowner any value. Most pixels are selected for USSE, and these lands are predominantly on the western side of the Valley. Fewer pixels of land are selected for habitat conservation when habitat suitability for two or more species is evaluated compared to one or more species. More land is selected for neither when habitat suitability for two or more species is considered.

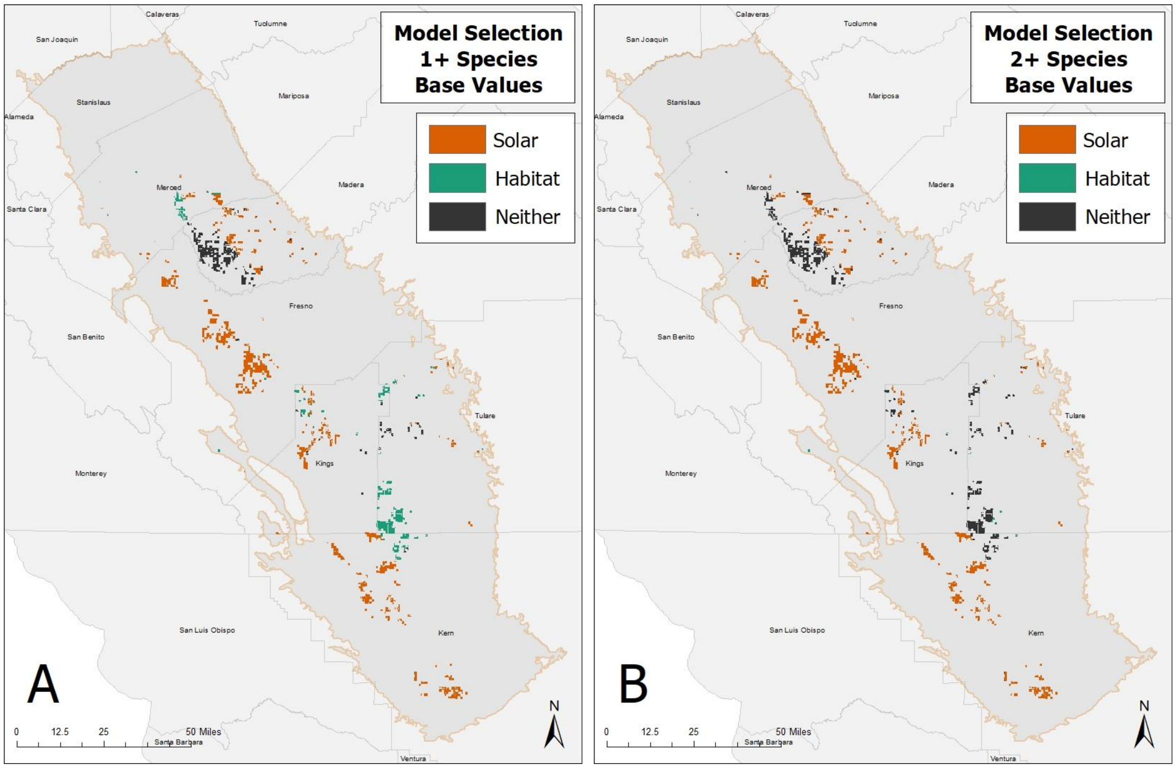


Figure 11. Model selection with habitat suitability for one or more species (A) and two or more species (B) when input variables are set to base values (p = \$100/MWh, δ = 5%, c = \$952,760/MW, r = \$522,140/km, and s = 60%).

When solar development is more profitable than habitat conservation for a given pixel, we evaluate the degree to which it is more profitable; we term this solar profitability (Figure 12). Solar profitability across the landscape ranges from a couple thousand dollars to nearly $9.5 million. The range of solar profitability does not vary with the change of habitat suitability layers. As with solar profits, areas of high solar profitability are located primarily along the western side of the Valley.

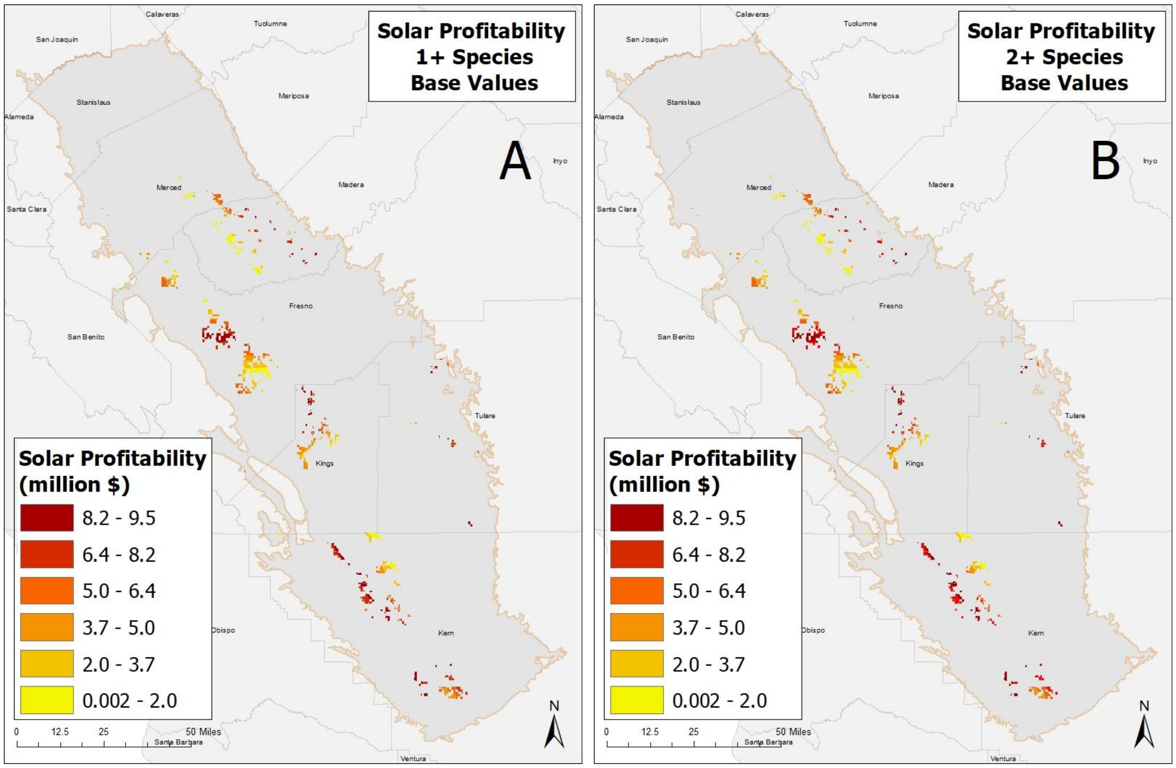


Figure 12. Degree to which solar is more profitable than habitat conservation with habitat suitability for one or more species (A) and two or more species (B) when input variables are set to base values (p = \$100/MWh, δ = 5%, c = \$952,760/MW, r = \$522,140/km, and s = 60%). We use quantile classification to display the results.

The degree to which habitat conservation is more profitable than USSE for a single pixel is termed habitat profitability (Figure 13). The profitability ranges from approximately $5,000 to $5 million when considering habitat suitability for one or more species. When habitat suitability is changed from one or more species to two or more, fewer parcels of land are selected for habitat and the range of profitability is reduced ($10,700 - $551,500).

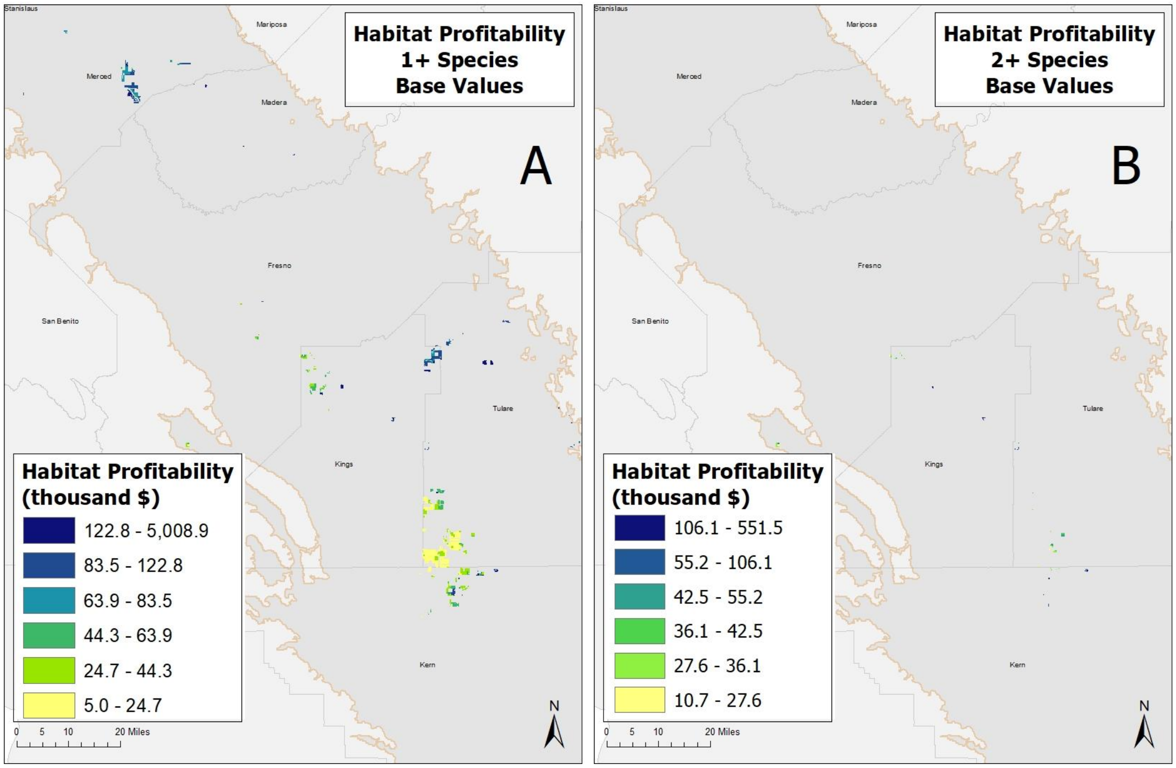


Figure 13. Degree to which habitat is more profitable than solar with habitat suitability for one or more species (A) and two or more species (B) when input variables are set to base values (p = $100/MWh, δ = 5%, c = $952,760/MW, r = $522,140/km, and s = 60%). We use quantile classification to display the results.

When compared to California energy goals and TNC habitat goals, our model indicates neither will be fully achieved solely on predicted permanently retired agricultural lands. Our model predicts 44.64% of the SB-100 solar capacity goal and 50.70-81.11% of TNC's habitat goal will be achieved (Table 2).

Table 2. Model results compared to California solar goals and TNC habitat goals.

	Goals	**Model Results**	**Results as % of Goals**
SB-100 Solar Capacity	70 GW	31.25 GW	44.64%
TNC Upland Habitat	50,000 - 80,000 ac	40,556 ac	50.70 - 81.11%

4.4 Sensitivity Analyses

By changing the values of spatially-fixed variables, including wholesale electricity price (*p*), cost of development (*c*), percent compensation for conservation (*s*), transmission connection cost (*r*), and discount rate (δ), we can analyze how each of these variables affects the share of pixels selected for solar development, habitat conservation, or neither of those land uses. For base values and habitat set to one or more species, about 19% of pixels (~ 41,000 acres) are selected for habitat conservation, 61% of pixels (~ 130,000 acres) are selected for solar development, and 20% of pixels (~ 43,000 acres) are selected for neither category. For base values and habitat set to two or more species, about 1% of pixels (~ 2,000 acres) are selected for habitat conservation, 60% of pixels (~ 129,000 acres) are selected for solar development, and 39% of pixels (~ 83,000 acres) are selected for neither category.

When the price of electricity is given a zero value, a maximum of approximately 53% of all pixels are selected for habitat conservation under the one-species suitability scenario and a maximum of about 3% of all pixels are selected under the two-species scenario (Figure 14). Increasing the price of electricity greatly decreases the share of pixels selected for habitat conservation under both habitat scenarios and increases the share of pixels selected for solar.

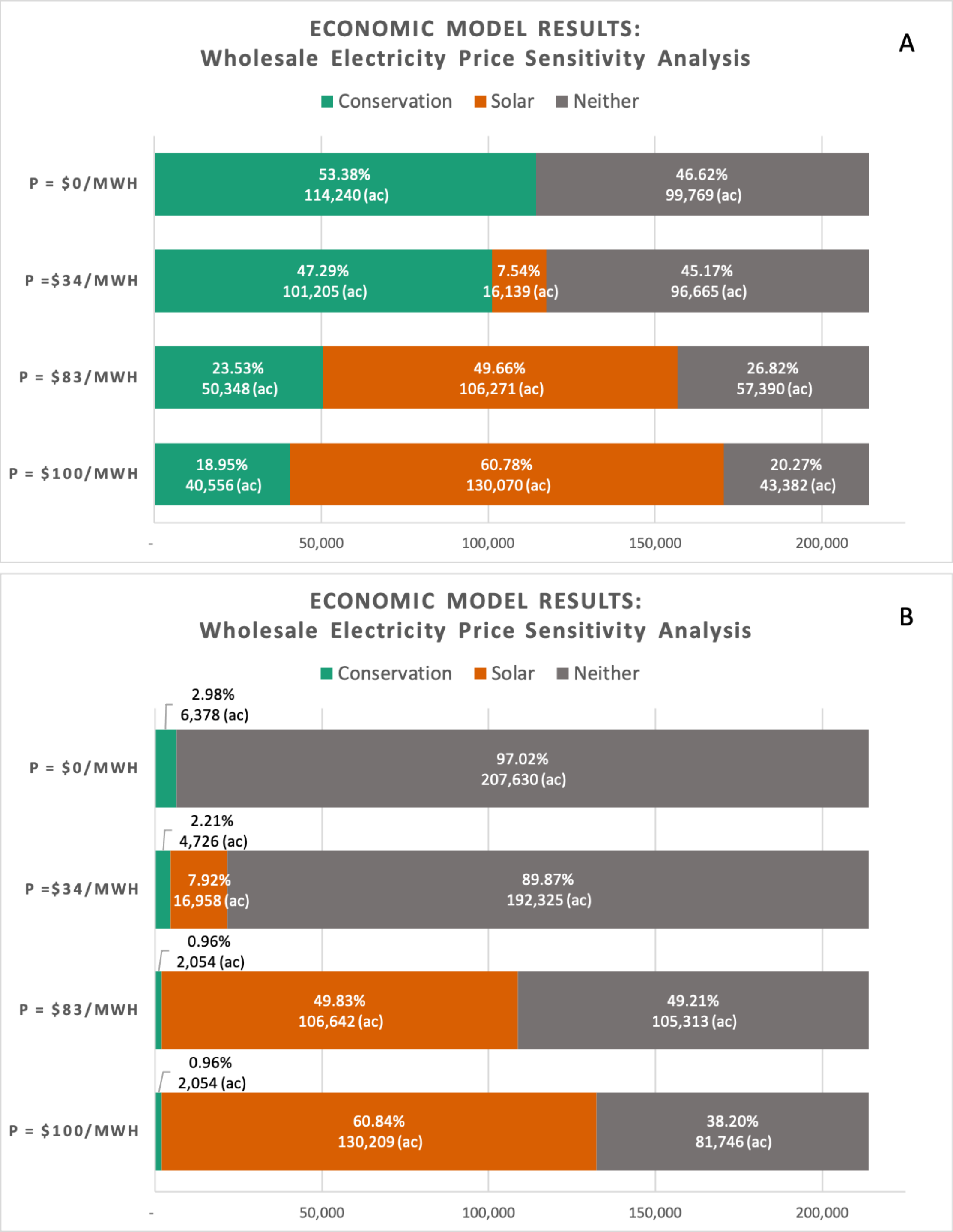


Figure 14. Share of pixels selected for solar, habitat conservation, or neither when wholesale electricity price is varied and habitat is set to one or more species (A) and two or more species (B). p = $100/MWh is the base value.

Changes in the cost of solar development have only a small effect on the share of pixels going to habitat conservation versus solar under both habitat scenarios (Figure 15).

Figure 15. Share of pixels selected for solar, habitat conservation, or neither when development costs are varied and habitat is set to one or more species (A) and two or more species (B). c = $952,760/MW is the base value.

We observe that increases in compensation for conservation have little effect on the number of pixels selected for habitat and solar under both habitat scenarios (Figure 16). When the value of conservation compensation is zero, a maximum of about 61% of pixels are selected for solar under both habitat scenarios.

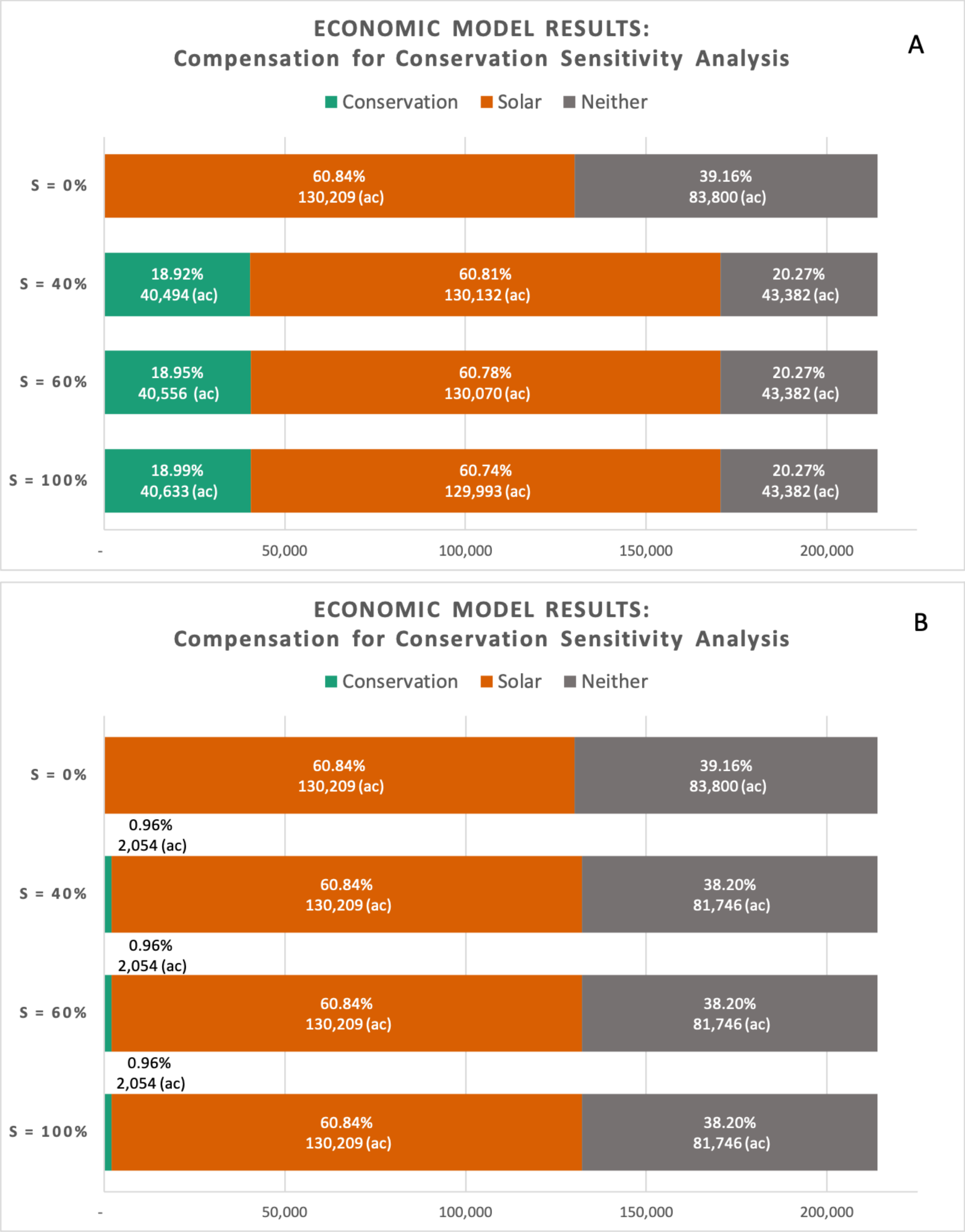


Figure 16. Share of pixels selected for solar, habitat conservation, or neither when percent compensation for conservation via an easement is varied and habitat is set to one or more species (A) and two or more species (B). s = 60% is the base value.

The cost of connective transmission lines has a marked impact on the number of shares selected for solar under both habitat scenarios (Figure 17). When the cost of transmission connection is given a value of zero, nearly 93% of all pixels are selected for solar under both habitat scenarios.

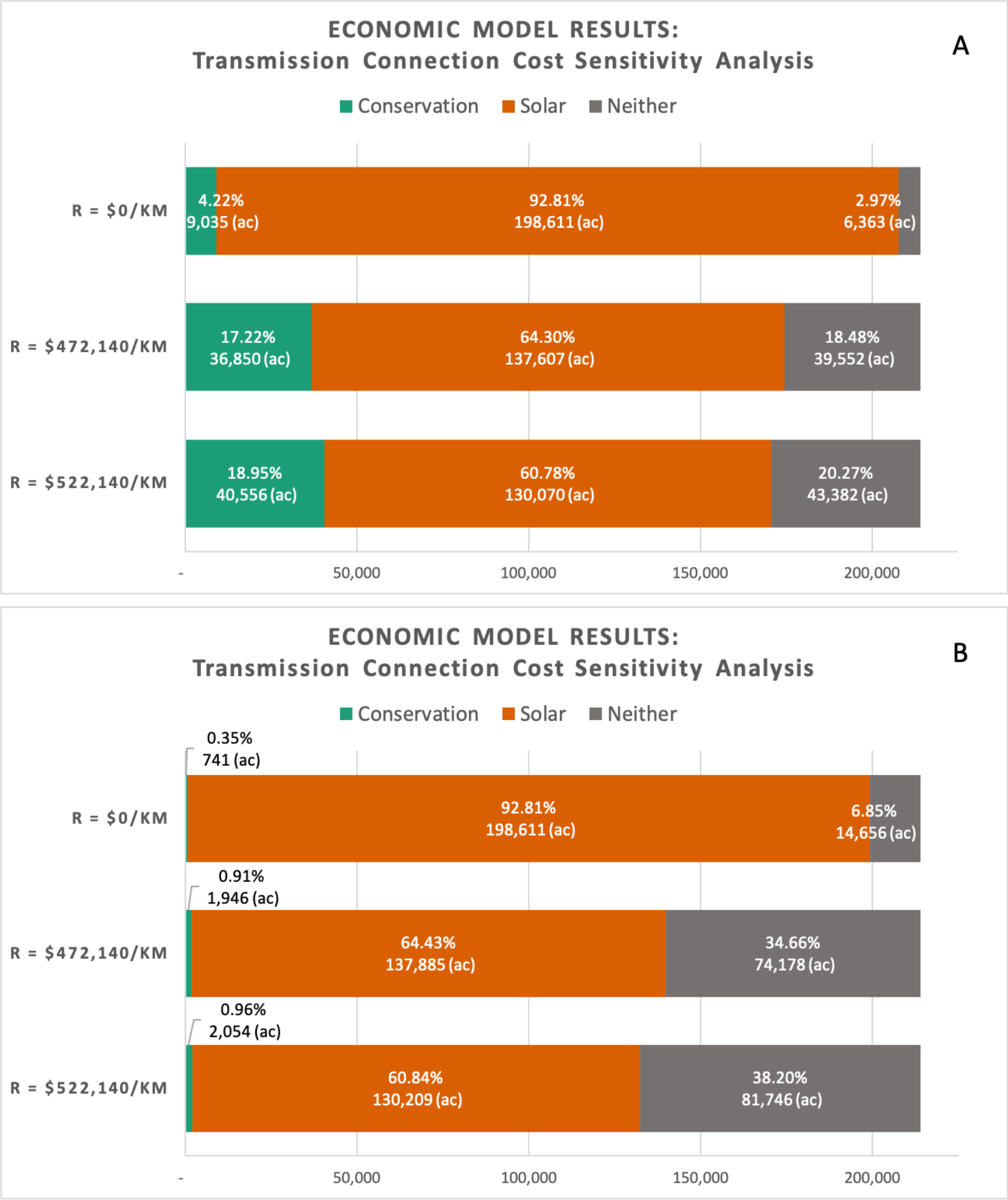


Figure 17. Share of pixels selected for solar, habitat conservation, or neither when transmission cost is varied and habitat is set to one or more species (A) and two or more species (B). r = $522,140/km is the base value.

The discount rate used when calculating solar profits has a substantive influence on model outcomes under both scenarios (Figure 18). We see that an increase in the discount rate corresponds with a decrease in the share of pixels selected for solar. Under the single-species scenario, this decrease corresponds to an increase in the share of pixels selected for habitat conservation.

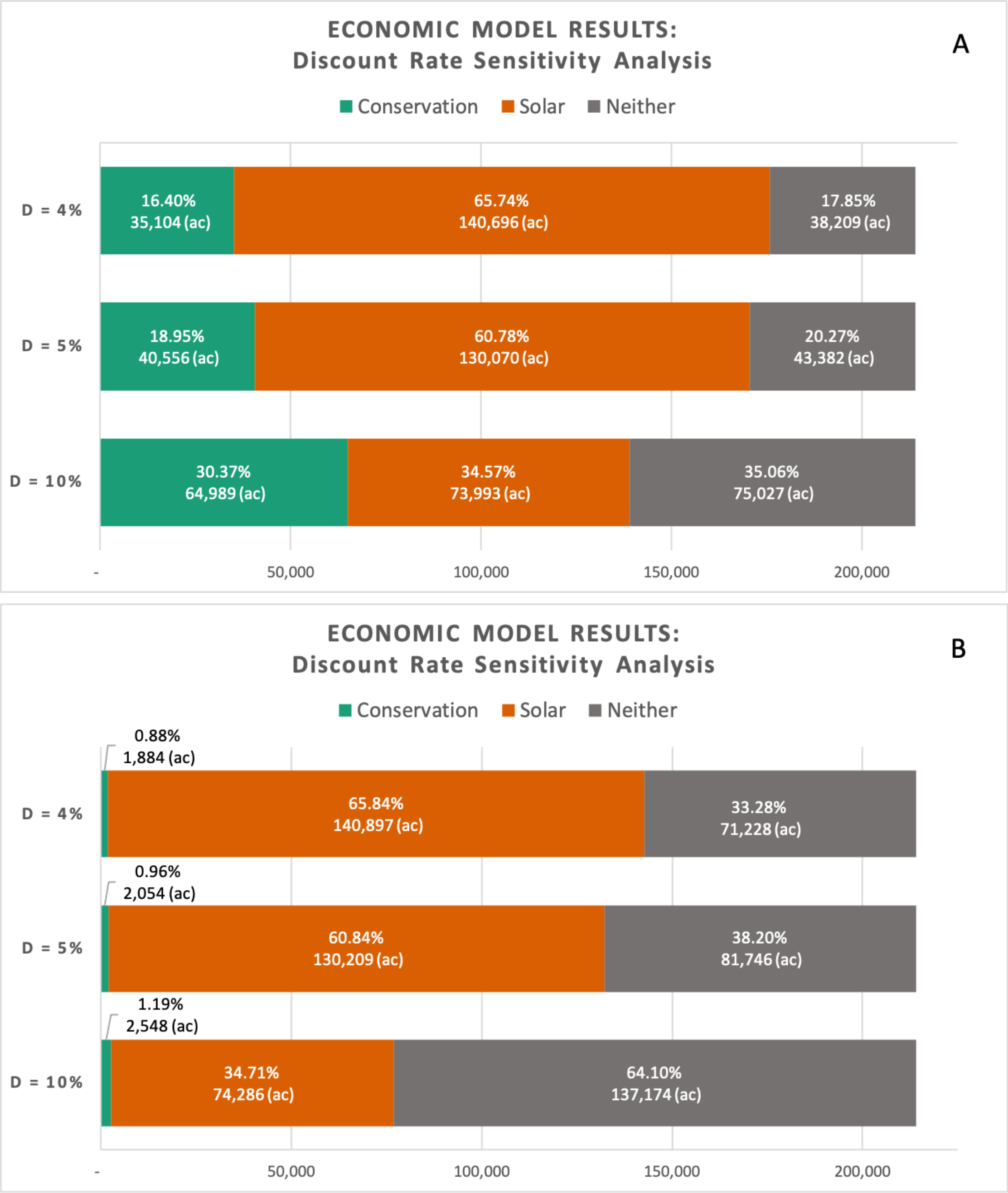
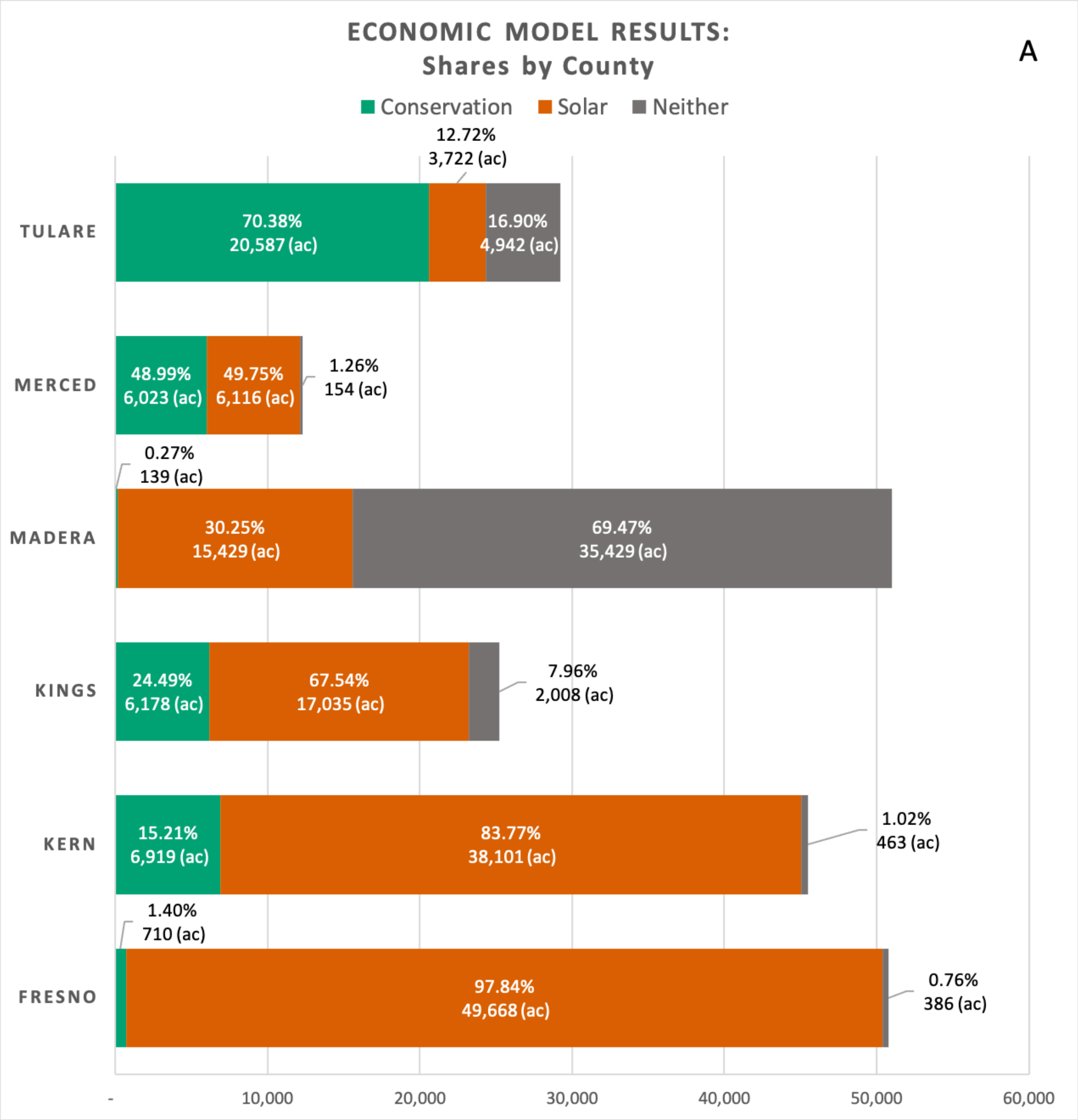


Figure 18. Share of pixels selected for solar, habitat conservation, or neither when discount rate (δ) is varied (denoted here as D) and habitat is set to one or more species (A) and two or more species (B). δ = 5% is the base value.

The breakdown of pixels selected for solar development, habitat conservation or neither of those land uses varies widely across the six counties in the study area (Figure 19). Across both species scenarios, we see the largest number of acres selected for solar in Kern and Fresno Counties, followed by Kings and Madera counties. Under the one-species scenario, we see the greatest number of acres selected for habitat conservation in Tulare County, followed by Kern, Kings and Merced Counties. We also see the largest number of acres selected for neither land use in Madera County under both scenarios. Additionally, very few or no pixels are selected for habitat conservation in Madera County.



(Figure Continued Below)

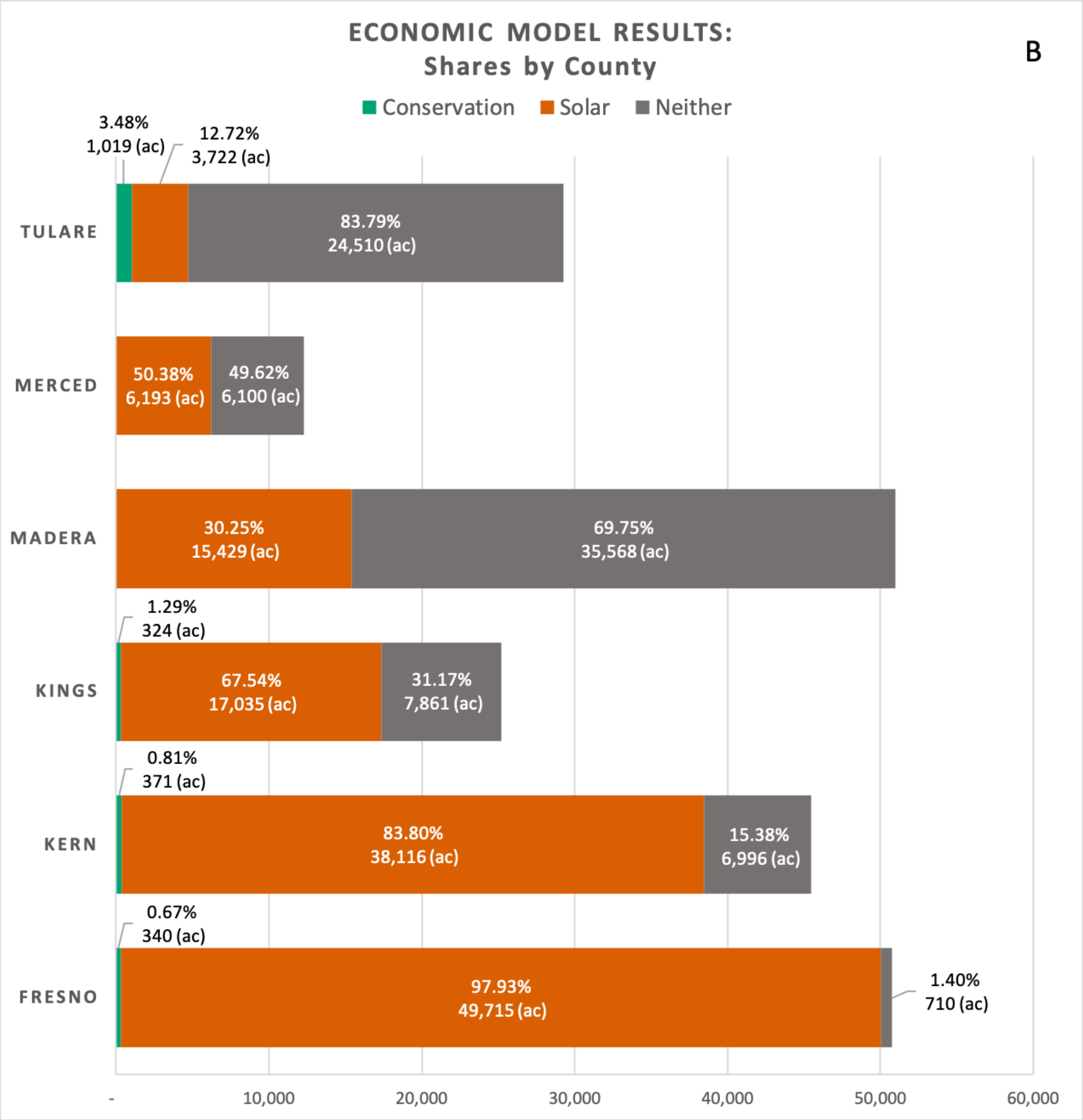


Figure 19. Share of pixels selected for solar, habitat conservation, or neither by county when habitat is set to one or more species (A) and two or more species (B). Input variables are set to base values (p = $100/MWh, δ = 5%, c = $952,760/MW, r = $522,140/km, and s = 60%).

5. Discussion

5.1 Revisiting Objectives

This study aims to analyze the viability of new solar development and habitat conservation in the SJV considering anticipated land use changes. It also aims to assess potential strategies to achieve solar and upland species conservation goals. Results show both USSE and habitat conservation are viable on predicted retired agricultural lands, but the scale at which both are implemented may not be enough to achieve California's renewable energy goals or TNC's habitat goals. Implications of this, and potential strategies to achieve these goals, are discussed below.

5.2 Summary

Solar projects are being proposed and constructed throughout the SJV and it is important to ensure that these developments do not cause environmental harm through habitat destruction. Instead of siting USSE on prime habitat, which can disrupt and harm endangered species, an alternative is to place it on agricultural land that has gone out of production. Tens to hundreds of thousands of acres of currently irrigated agricultural land in the SJV are predicted to be retired due to groundwater restrictions imposed by SGMA. Along with the expansion of USSE in the SJV, organizations like TNC are looking to conserve additional habitat for upland species; such goals may also be met in part through the use of retired agricultural land. These repurposements have the potential to financially aid landowners having to retire productive farmland, as well as advance renewable energy and conservation goals.

5.3 Solar and Conservation Viability on Retired Agricultural Lands

Based on our qualitative assessment via stakeholder interviews and our quantitative spatial-economic analysis, we conclude that solar and habitat conservation are viable alternative uses for landowners. Our spatial-economic analysis allows us to determine that solar development could be a profitable option on the majority of the agricultural pixels that are predicted to retire from agriculture. Profits obtained from USSE development on retired lands benefit landowners by providing them with a source of income on a piece of land that can no longer be used for irrigated agriculture due to groundwater limitations. Additionally, since land retirement provides USSE development with additional opportunities that may steer development away from natural lands, this could benefit conservation organizations like TNC. What's more, additional solar development in the Valley aids the state in achieving its renewable energy goals. We also find that there are parcels where landowners could profit from conserving their property. Similar to solar, this will provide financial support to landowners as well as aid TNC in achieving its upland habitat conservation goals. These results regarding the viability of solar and habitat conservation on retired agricultural lands are supported by information obtained in our stakeholder interviews.

The results of our solar profitability calculations demonstrate that many landowners have a high financial incentive to convert to solar. The exact profit they might see is not precisely represented by these results, however. Our perfect competition assumption may not fully capture true market conditions. We will note that it is not improbable that as solar development continues to expand, demand may indeed reach levels where developers must pay landowners several million dollars for leases in the future. The timing of these land use changes is important and addresses nuances that could not be captured by our model. For instance, due to the current lack of transmission infrastructure limiting solar development, landowners may be more likely to consider habitat conservation. Though there is the potential for transmission, and thus USSE, to expand within the next 25 years, which could lead to large revenue streams for landowners, the landowners may not want to wait that length of time to make decisions about their land. By contrast, conservation easements are a permanent decision, unlike solar in which the land is typically leased and has an end date. This may steer landowners away from conservation easements if they hope to utilize their land in the future.

The results of our habitat profitability calculations demonstrate more precisely, for each pixel where habitat is selected, how much more a landowner could make by converting to habitat as opposed to solar. Conversion to habitat is largely profitable where solar development is not (and thus not selected by the model), so those profitability results paint a reasonably accurate picture of how much it would cost to conserve those lands. These results do not reflect any other forms of value from conservation outside of the fraction of land value derived from the sale of a conservation easement that we include in our model. Ecosystem service benefits and potential public health benefits stemming from land management for habitat were intentionally not incorporated when scoping this project because the landowner may not directly receive these benefits. Though we considered sources like funding from mitigation/conservation banks that might have helped incorporate value from some of those benefits, we required data for our habitat conservation valuation that varied spatially.

5.4 Sensitivity and Scenario Analyses

We see in the sensitivity analysis results that when the wholesale electricity price variable (p) is given a zero value, rendering solar unprofitable, still only about half of all pixels are considered suitable for habitat conservation according to the parameters of our model. This has implications for what other land uses a landowner might choose outside those considered in this assessment, as well as what incentives might be impactful. For example, the $50 million land repurposing program funded by AB-170 incentivizes a variety of alternative land uses like groundwater recharge, pollinator habitats and cattle grazing.[71] Some of these land uses are more permanent than others.

Additionally, the fact that this electricity price variable has such a marked impact on solar profits could have implications for solar expansion. The more solar goes on the grid, the less valuable it becomes. This is a point of concern demonstrated by the scenario run with a forecasted future wholesale price of electricity ($34/MWh). We will also note that rather than simply running a scenario with a predicted future wholesale electricity price, the analysis could be improved by instead varying that input to reflect the likely changes that would occur over the 25-year period considered.

Results from our sensitivity analysis for the development cost (c) indicate that the variable does not heavily influence whether a pixel is selected for solar. Though the value of development cost will change (likely decreasing) over time, the costs are incurred up front, and thus we do not attempt to vary the value over the 25-year project period. We can improve this analysis by including a scenario with forecasted future development costs.

Changes made to the compensation for conservation variable (*s*) have little effect on the amount of land chosen for habitat. This can be at least partially explained by the fact that the distribution of profits from habitat protection is much smaller than the distribution of profits from solar development. Even full land values are, on average, much smaller than the potential profit derived from converting to solar. We can also infer that selection for solar is largely influenced by variables other than compensation for conservation; when the fraction of land value is increased from 0 to 40%, all of the pixels selected for habitat are drawn from the Neither category. In other words, the share of solar pixels remains fairly constant regardless of the compensation.

The results of our sensitivity analysis for transmission connection cost (*r*) strongly support the hypothesis that transmission is one of the biggest drivers of solar profitability. This is reflective of what we find in the literature and through stakeholder interviews. Transmission remains a significant barrier to siting solar in the Valley, and it may negatively impact habit conservation goals for the region if USSE development is driven toward undisturbed lands that are near existing transmission.

Modifying the discount rate (δ) reveals the extent to which solar developers' own assessments and judgment can influence where solar might be built in the Valley. While land might seem suitable by all other measures, the degree to which potential profits are discounted will heavily influence a developer's willingness to invest in a project in the Valley.

5.5 Spatial Distribution of Results Across the Landscape

The model selection results provide context to the spatial distribution of data at the pixel level. Each pixel represents 15.4 acres of the land surface. The arrangement of pixels resulting from this spatial-economic model is inherently dependent on the distribution of permanently retired agricultural lands over the course of SGMA implementation. As such, Bryant et al.'s forecasted land retirement layer developed using the Statewide Agricultural Production (SWAP) model for economic optimization considering various inputs like crop prices and water resources heavily influences the specific placement of solar and habitat across the landscape.[72] By utilizing this modeled retirement scenario, noticeable patterns and trends are observed that provide insight into which spatial variables have the greatest economic impact on land repurposing.

For the purposes of clearly visualizing these spatial patterns, we primarily discuss the distribution of pixels under the single-species scenario. Solar dominates the western side of the SJV, meaning landowners may see higher potential profits for solar development than habitat conservation across Kern, Kings, Fresno, and Madera Counties. The arrangement of solar profits follows the path of major transmission lines across the Valley. In the northern counties (Merced, Madera, and Fresno), solar is distributed to the west and east, likely due to the proximity of existing transmission infrastructure.

Selection for solar and habitat conservation appears evenly distributed in Merced County. The majority of pixels selected for retirement under the one-species scenario in the county are adjacent to lands identified by TNC as having high conservation value, which suggests that a potential conservation strategy or policy initiative focused on the region might be worthwhile. There is also a large concentration of pixels selected for neither land use in Madera County. This points to a need for strong incentives for an alternative beneficial land use.

The spatial distribution of habitat pixels across the landscape is more sparse than that of solar pixels in most counties. However, there are notable clusters where conservation easements may be more profitable than solar development, particularly in Tulare County. Habitat results are heavily concentrated in the southwest corner of Tulare County at the borders of Kings and Kern Counties. In this same region, solar pixels make up a large portion of retired lands. Both are found either overlapping with, or in close proximity to, TNC's priority restoration regions and areas of high conservation value (Figure 20).[73] Both land repurposing options help to achieve important environmental goals but one may be more desirable over the other depending on the location. For instance, in certain locations it may be important to prioritize habitat conservation where pixels are adjacent to lands with high conservation value.

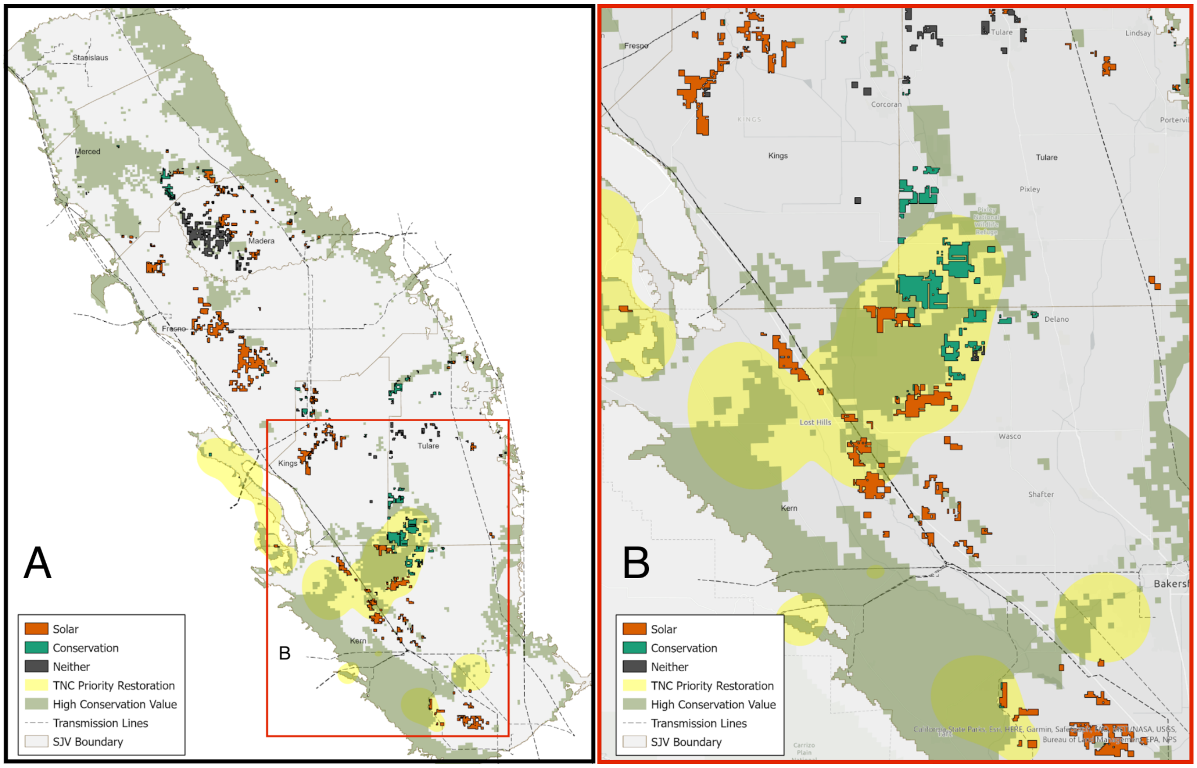


Figure 20. Spatial distribution of pixels using base input values with habitat suitability for one or more species across the entire San Joaquin Valley (A) and zoomed in on the border of Kern, Kings, and Tulare (B). Model results are displayed with modern spatial layers (2021) for transmission line infrastructure, and The Nature Conservancy's highlighted areas for priority restoration and high conservation value.[73]

For conservation, overlap with or proximity to ecologically valuable areas is a desirable outcome and is likely to result in higher quality protected habitat than would exist in more disturbed regions. Siting solar in high conservation areas is much more challenging for developers as projects will likely face strict regulations, high mitigation costs, and social pressure from the public and NGOs.[23]

Within the TNC Priority Restoration area (highlighted in yellow in Figures 20 and 21), the model run using base values identifies 23,660 acres for solar, 20,680 acres for habitat conservation, and 463 acres for neither land use. Large-scale development of solar, such as that suggested by the model results, could present a significant challenge for conservation priorities within this region. The most potentially challenging area is a grouping of solar pixels adjacent to pixels selected for habitat conservation that are positioned between the Kern National Wildlife Refuge and the Pixley National Wildlife Refuge (Figure 21). This 3,660-acre grouping selected for solar development is positioned in a unique part of the landscape that, if developed, would limit the opportunity to expand contiguous protected space around the Kern Refuge and hinder overall connectivity between the Kern and Pixley National Wildlife Refuges.

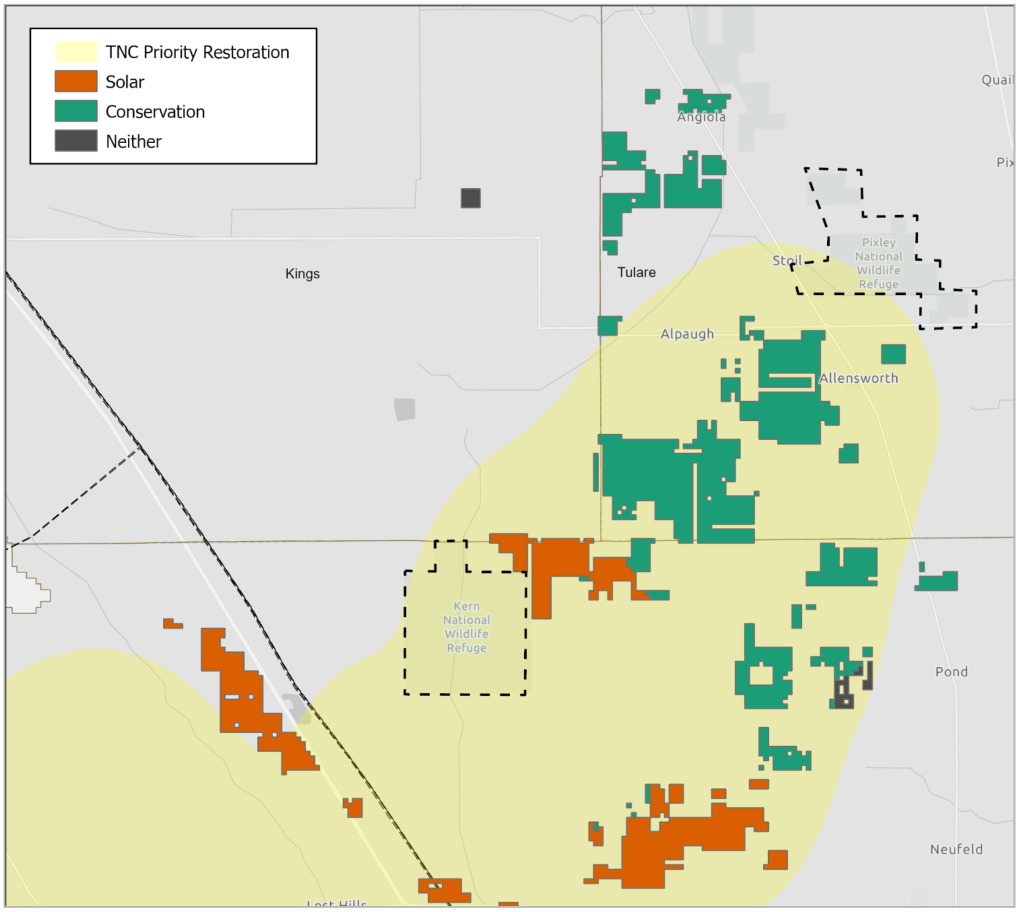


Figure 21. A closer look at model results within the TNC Priority Restoration area at the intersection of Kings, Tulare, and Kern Counties, highlighting where solar may be in direct conflict with conservation priorities – specifically the solar pixels between Kern National Wildlife Refuge and Pixley National Wildlife Refuge.

Under the two-species scenario, the spatial trends discussed here remain much the same. However, there is considerably less selection for habitat conservation, and the majority of the pixels selected for habitat under the single-species scenario instead go to neither land use (see Figure 11B).

5.6 Land Requirements & Planning Implications

We make the assumption that each pixel, approximately 15.4 acres, constitutes a separate USSE development or its own conservation easement. This, however, may not reflect reality. When analyzing pixels selected for solar repurposing, it is beneficial to convert acres to an energy specific size unit to compare economic implications and renewable energy portfolio goals. With respect to the objectives of this study, to assess viability of new USSE development and supportive policy options, we find it most useful to present the spatial results in terms of capacity. The optimized power density per acre (0.24 MWDC) scaled to the pixel level is 3.707 MWDC. According to standard references to capacity minimums by researchers and regulatory agencies, a "utility-scale" facility is that which is greater than 5-10 MW in capacity – for our purposes we use 10 MW as the minimum threshold.[74] Furthermore, the cost to develop USSE in terms of $/MW is reduced overall as capacity increases. If a developer wants to produce larger USSE projects, they will likely consider large areas of land, or groups of pixels of our current size. A similar situation may arise for conservation easements. Typically, conservation strategies place more value on larger contiguous areas of habitat compared to smaller fragmented areas. Thus, from the perspective of a developer or conservation organization, it is important to note that any one pixel on its own is likely not suitable for either repurposing option given its size. For conservation easements, however, we do attempt to specifically consider areas that would improve existing habitat by only assessing pixels within 5 km of a protected area.

In order to develop USSE, groupings of at least 3 adjacent retired land pixels (or non pixel-scale dependent area > 41.66 acres) are needed to reach a capacity >10 MW. Given the current distribution of cells, this effectively reduces the developable solar area by ~1,992 acres (1.5%). At this reduced area, solar capacity constructed in the most optimal way spatially using current power density rates could reach over 30 GW. Grouped adjacent pixel area distributions skew to the right with several very large outliers. The mean area for grouped solar pixels is 540 acres – this is an area capable of supporting a large PV USSE system (~ 130 MW capacity). To reach the 30 GW capacity potential across the SJV with systems this size, it would take 1,000 total new facilities. The solar grouping with the largest area is 16,988 acres with a potential capacity for ~ 4.1 GW of new solar. For scale, the largest PV USSE plant in California is rated at 550MW capacity.[75] Reaching 30 GW with large facilities like this would require very large areas of land of around 2,300 acres and would require working with numerous landowners.

Conservation also benefits from large contiguous pieces of land, and specific goals also have size requirements. For example, a kit fox requires a roughly 1,500-acre home range. Additionally, a viable population needs access to other kit foxes who also require land for home ranges.[46] Adjacent grouped pixels selected for habitat conservation also have a skewed distribution of areas, with an average of 372 acres, and a maximum of 8,200 acres. Though the habitat pixel results of this analysis do not meet the needs of species like the kit fox as individual groupings, there are several large pixel groups clustered around high priority habitat for five focal species (Tipton kangaroo rat, giant kangaroo rat, blunt-nosed leopard lizard, San Joaquin woolly-thread, and San Joaquin kit fox) in the border region of Tulare, Kings, and Kern. As a network of conservation easements, this could in time provide over 20,000 acres of new habitat in an area that has positive implications for restoration such as proximity to protected habitat, suitability for important umbrella species, and minimal adverse effects to agriculture.[72,73]

Given the uncertainty of exactly where and when retirements will happen, the success of repurposing these lands to meet either goal will be dependent on strategic plans to help optimize retirement and new development. Coordinated regional efforts that cross county lines should place emphasis on specific size requirements to reach high capacity for solar or greater ecological returns for conservation efforts. Consideration for the arrangements of dependent variables for solar like proximity of transmission lines or protected/intact habitat for conservation will also be important. The development of new transmission lines is likely to have the greatest impact on how a future San Joaquin Valley landscape may look. As solar is by far the more profitable model result on retired lands near transmission, it is foreseeable that without timely intervention, protecting certain high priority conservation areas will not be an option indefinitely.

5.7 Additional Limitations and Assumptions

While our spatial-economic model serves as a useful starting point for evaluating land use change in the SJV, there are several limitations and assumptions that are important to address. Those not previously addressed are outlined below.

This model does not consider strategic planning and placement of USSE developments and conservation easements. Strategic planning for both the developer and the conservation organization would involve additional considerations related to key stakeholders, resource allocation, specific land prioritization, etc. This model would be most useful in combination with strategic planning from TNC for lands targeted for conservation.

Finally, solar technology is improving; this study looks at single-axis tracking solar, but other technologies should be evaluated. Furthermore, as of the writing of this report, the impact of SGMA has not been fully realized by landowners in the Valley; as water access becomes more limited, additional constraints and variables may need to be considered.

6. Conclusion

6.1 Takeaways

We are able to draw a few key conclusions from our model results, including the following:

1. Solar and habitat conservation are viable and profitable on retired agricultural lands, with solar largely dominating the landscape.

2. There is overlap between high priority restoration regions identified by TNC and the pixels selected for both solar and habitat conservation by our model.
3. Predicted retired agricultural lands, if converted according to our model selections, will not provide enough USSE to meet California's state-wide solar energy goals or enough habitat for TNC's upland species goals.

These takeaways speak to the need for incentivizing dual-use projects, where habitat and renewable energy goals can be achieved synchronously. Further, approximately 20-40% of the land likely to be retired does not have a clear incentive to convert to either solar or habitat. This takeaway leaves the door open for a multitude of policy incentives to help drive land-use change in a positive direction.

6.2 Recommendations

If all predicted permanently retired agricultural lands are converted as our model predicts, California will be able to meet a fraction of its goal for expanded solar capacity (31GW of 70GW under SB-100) and TNC will be able to meet a portion of its habitat goals (40.5K of 50-80K acres). USSE may need to expand onto lands of higher quality habitat to make up the difference at further detriment to TNC's goals.[17] TNC has expressed interest in identifying policies to direct USSE onto retired agricultural lands and finding ways to make land parcels dual-use (USSE and habitat compatible). The following recommendations are developed with the goal of meeting multiple stakeholder needs:

1. Safe Harbor Agreements should be applicable to permanently retired agricultural lands with USSE to eliminate penalties to landowners and solar developers that create/allow habitat on their parcels.[52] Without this, developers and landowners are disincentivized to maintain habitat on a solar development. The use of Safe Harbor Agreements could also expedite solar permitting, making dual-use of the land more favorable for solar developers.

2. The Internal Revenue Service and California Department of Revenue should allow landowners who have leased land for USSE to establish permanent conservation easements and claim an upfront charitable income tax deduction on the reduction in land value from market value to restricted value, as determined by qualified appraisal, if the solar company signs an agreement with the government or TNC to create and maintain habitat under elevated panels on permanently retired agriculture parcels during the term of the lease. In return, the solar companies will receive favorable lease extension terms. Unlike the method of conservation easements considered in our spatial-economic model, where development rights are sold for a percentage of the land value, this method of setting up an easement is by landowner donation. The landowner will not receive a one-time payment for the sale of development rights, but rather an income tax deduction with carry forwards to subsequent tax years to capture the greatest value from the donation. This will offset some of the solar lease income. This method of placing an easement on the land also comes at less of an expense to TNC since the organization will not be purchasing development rights. Further, the landowners will be able to retain valuable water rights to use elsewhere or sell.[53,76]

Before this method is utilized, habitat under panels needs to prove effective. Initially, the use of Safe Harbor Agreements should be implemented. Habitat on dual-use lands should be studied to understand the impacts of this system on species.[77] If habitat under panels does prove successful, then conservation easements should be placed on dual-use lands.

3. Survey findings indicate that local governments, agricultural groups, and conservation organizations want to preserve prime farmland and high-quality habitat. Thus, stakeholders should collaborate and pressure CAISO and decision-makers to prioritize new transmission lines and upgrades to concentrated areas of permanently retired agricultural lands.[9,29]

   To meet state renewable energy goals under SB-100, CAISO began a 20-year planning process that will facilitate the development of new high voltage transmission lines and substations to accommodate over 50 GW of new USSE. The plan identifies ~ 20 GW of new USSE resource capacity expansion throughout Central Valley transmission zones, of which the majority (more than 12.5 GW) is allocated to zone SPGE_Z1_Westlands.[78]

   The CAISO transmission expansion plan also identifies upgrades and development of new interstate connections to adapt the grid to renewable energy technology dynamics. Conservation organizations should monitor this planning process to ensure new high voltage lines avoid sensitive habitat and minimize impacts to species.[78]

4. A local vision for renewable energy in the region can help create momentum and political support. Local stakeholder engagement and the presentation of various planning tools could be considered to prioritize multiple land uses throughout the area including conservation, solar, water recharge, etc. Planning tools that could be considered include a CDFW Regional Conservation Investment Strategy (RCIS) or a TNC greenprint. It is important that an RCIS has one driving principle to help prioritize development – one possibility is new transmission lines to incentivize renewables. A greenprint may layer in more land considerations (i.e., aesthetics) directly related to environmental review processes under CEQA and NEPA.

   In developing this local vision and momentum using a planning tool like RCIS, landowners facing permanent retirement (i.e., the Westlands Water District, farmers, etc.) would be included as stakeholders who may lease land for USSE development and transmission/substation construction. Where restoration/conservation priorities are identified (i.e., near the Ciervo-Panoche SJV kit fox core area), retired farmland can facilitate development of advanced mitigation credits.[79,80] Furthermore, the RCIS could identify construction guidelines for new USSE facilities and transmission projects that help advance habitat conservation such as wildlife friendly fencing, artificial dens, native vegetation, and pollinator habitat.[81]

5. Local land trusts could create water cooperatives where farmers contribute funds to buy land for fallowing and then receive the surface water and pumping rights

associated with the land, minus an allocation for habitat. The shares would be tradeable so farmers could buy and sell water rights while the land trusts manage the land.[6]

6. GSAs could purchase tracts of land and the water tied to them, which could be used elsewhere in the district. These lands could potentially then be leased to solar companies.

6.3 Future Steps

Potential next steps could include updating the model with variables that more accurately represent changes in market conditions over time. One way to do this would be to discount over 30 years instead of 25. This time horizon may more realistically reflect those used by some solar developers when considering a solar development project.[62] It would also be useful to consider the impacts of Renewable Energy Credits (RECs) on solar profit. Further, it would be interesting to make comparisons using the levelized cost of electricity (LCOE).

The assessment could also be refined so that only parcels where value could be derived from both habitat and solar are evaluated. In order to get a snapshot of what it would cost today to steer land use away from solar in these locations, solar profits could be capped at the total discounted profits seen from today's peak solar lease values to reflect the current market (calculated above as ~ $428k). Quantifying how much investment might be required to incentivize conservation on prime habitat could help inform conservation strategy.

Additionally, it would be helpful to consider the timing of the model results in the context of SB-100 buildout benchmarks. This could be achieved by ranking pixels selected for solar from highest to lowest by profit and using this ranking to project what development could look like, assuming the most profitable sites are developed first.

As when considering the viability of dual-use where habitat for species can coexist with solar development, it is important to assess the regulatory barriers in place and pinpoint more policy changes needed to facilitate the creation of more dual-use projects.

Finally, the loss of agricultural land in the SJV will have significant impacts on many stakeholder groups, particularly the farming community. Over the next two decades, regional- and ground-level coordination combined with novel ideas and initiatives will be necessary to facilitate meeting the needs and goals of all stakeholder groups in the Valley.

References

1.Williams, A. P. *et al.* Large contribution from anthropogenic warming to an emerging North American megadrought. *Science* **368**, 314–318 (2020).

2. Bryant, B. *et al.* Shaping Land Use Change and Ecosystem Restoration in a Water-Stressed Agricultural Landscape to Achieve Multiple Benefits. *Front. Sustain. Food Syst.* **4**, (2020).

3. Semerdjian, A. E., Butterfield, H. S., Stafford, R., Westphal, M. F. & Bean, W. T. Combining Occurrence and Habitat Suitability Data Improve Conservation Guidance for the Giant Kangaroo Rat. *J. Wildl. Manag.* **85**, 855–867 (2021).

4. Germano, D. J. *et al.* The San Joaquin Desert of California: Ecologically Misunderstood and Overlooked. *Nat. Areas J.* **31**, 138–147 (2011).

5. Harter, T. *Addressing Nitrate in California's Drinking Water*. (2012).

6. Kelsey, R., Hart, A., Butterfield, H. & Vink, D. Groundwater sustainability in the San Joaquin Valley: Multiple benefits if agricultural lands are retired and restored strategically. *Calif. Agric.* **72**, 151–154 (2018).

7. Hanak, E. *et al. Water and the Future of the San Joaquin Valley*. (2019). doi:10.13140/RG.2.2.24360.83208.

8. Wilson, T. S., Sleeter, B. M. & Cameron, D. R. Future land-use related water demand in California. *Environ. Res. Lett.* **11**, 054018 (2016).

9. Pearce, D., Strittholt, J., Watt, T. & Elkind, E. A Path Forward: Identifying Least-Conflict Solar PV Development in California's San Joaquin Valley. (2016).

10. SGMA Groundwater Management. https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management.

11. USGS Water Resources: About USGS Water Resources. https://water.usgs.gov/GIS/huc.html.

12. SGMA Basin Prioritization Dashboard. https://gis.water.ca.gov/app/bp-dashboard/final/.

13. California Legislative Information. Water Code - WAT. https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=WAT&sectionNum=10721.

14. Keeler, B. *et al.* The social costs of nitrogen. *Sci. Adv.* **2**, (2016).

15. Phillips, S. & Cypher, B. *Solar Energy Development and Endangered Upland Species of the San Joaquin Valley: Indentification of Conflict Zones*. https://esrp.csustan.edu/publications/pdf/phillips_cypher_2015_solarspeciesconflict.pdf (2015).

16. California Legislative Information. Senate Bill No. 100 Chapter 312. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100 .

17. Butterfield, H. *et al. Western San Joaquin Valley least conflict solar energy assessment*. (2013).

18. Gamper, J. *Solar and the San Joaquin Valley: Identification of Least-Conflict Lands*. (2015).

19. Wu, G. C. *et al.* Power of Place: Land Conservation and Clean Energy Pathways for California. 89 (2019).

20. Dhar, A., Naeth, M. A., Jennings, P. D. & Gamal El-Din, M. Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems. *Sci. Total Environ.* **718**, 134602 (2020).

21. Dr. Scott Butterfield, personal communication. (2021).

22. Barron-Gafford, G. A. *et al.* Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nat. Sustain.* **2**, 848–855 (2019).

23. Dashiell, S., Buckley, M. & Mulvaney, D. *Green Light Study: Economic and Conservation Benefits of Low-Impact Solar Siting in California*. https://www.scienceforconservation.org/products/green-light-study/ (2019).

24. Snellings, T. *et al. Solar Energy Facility Permit Streamlining Guide*. 44 (2012).

25. Williams, C. & Goodman, M. *Integrating Solar PV and Distributed Renewable Energy Policies and Programs into California City and County General Plans*. 55 (2014).

26. Hernandez, R. R. *et al.* Environmental impacts of utility-scale solar energy. *Renew. Sustain. Energy Rev.* **29**, 766–779 (2014).

27. Hu, J., Harmsen, R., Crijns-Graus, W. & Worrell, E. Barriers to investment in utility-scale variable renewable electricity (VRE) generation projects. *Renew. Energy* **121**, 730–744 (2018).

28. *Farmland Security Zones: Questions and Answers*.

29. Kelly, K. & Delfino, K. *Smart From the Start: Responsible Renewable Energy Development in the Southern San Joaquin Valley*. 20 (2012).

30. Verrips, B. *Westlands Solar Park Master Plan and WSP Gen-Tie Corridors Plan*. 136 (2017).

31. Yaghmour, M. *et al.* Sample costs to establish an orchard and produce almonds San Joaquin Valley South. *Univ. Calif. Agric. Nat. Resour. Coop. Ext. Agric. Issues Cent.* (2016).

32. Kasler, B. ‘Farming the sun:’ As water goes scarce, can solar farms prop up the Valley?

The Sacramento Bee (2019).

33. Butterfield, H. *et al. Identification of potentially suitable habitat for strategic land retirement and restoration in the San Joaquin Desert*. 23 (2017).
34. Williams, D. *et al.* Recovery Plan for Upland Species of the San Joaquin Valley, California. https://esrp.csustan.edu/publications/recoveryplan.php (1998).
35. U.S. Fish & Wildlife Service. Species Profile for Riparian woodrat (=San Joaquin Valley)(Neotoma fuscipes riparia). https://ecos.fws.gov/ecp/species/6191.
36. U.S. Department of Agriculture. Vanished Rabbit Reappears on Central California's Dos Rios Ranch. https://www.usda.gov/media/blog/2014/12/02/vanished-rabbit-reappears-central-californias-dos-rios-ranch (2017).
37. Department of the Interior. *Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for Buena Vista Lake Shrew*. (2013).
38. CSU Stanislaus. Endangered Species Recovery Program. https://esrp.csustan.edu/publications/pubhtml.php?doc=sjvrp&file=chapter01A01.html.
39. California Natural Diversity Database. State and Federally Listed Endangered, Threatened, and Rare Plants of California. 25 (2022).
40. Haight, R. G. *et al.* Optimizing reserve expansion for disjunct populations of San Joaquin kit fox. *Biol. Conserv.* **117**, 61–72 (2004).
41. U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office. Giant Kangaroo Rat - Mammals, Endangered Species Accounts. *U.S. Fish & Wildlife Service* https://www.fws.gov/sacramento/es_species/Accounts/Mammals/giant_kangaroo_rat/ (2017).
42. U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office. Riparian Woodrat Species Account. *U.S. Fish & Wildlife Service* https://www.fws.gov/sacramento/es_species/Accounts/Mammals/Documents/riparian_woodrat.pdf (2008).
43. U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office. Riparian Brush Rabbit Recovery. *U.S. Fish & Wildlife Service* https://www.fws.gov/sacramento/es/Recovery-Planning/Riparian-Brush-Rabbits/ (2017).
44. U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office. Fresno Kangaroo Rat Species Account. *U.S. Fish & Wildlife Service* https://www.fws.gov/sacramento/es_species/Accounts/Mammals/Documents/fresno_kangaroo_rat.pdf (2010).
45. U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office. FAQ's on the Buena

Vista Lake Shrew (Sorex ornatus relictus) Proposed Revised Critical Habitat. *U.S. Fish & Wildlife Service* https://www.fws.gov/sacramento/outreach/2012/07-10/Documents/QA-BVLS-pCH-2012Jul05%20FINAL.pdf (2012).

46. Lortie, C., Filazzola, A. & Miguel, M. F. A synthesis of dryland restoration lessons relevant to the San Joaquin Valley. (2020) doi:10.32942/osf.io/agw34.

47. *Maricopa sun solar complex habitat conservation plan*. (2014).

48. California Legislative Information. Bill Text - SB-5 California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access For All Act of 2018. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB5 (2017).

49. Reimer, A. P., Gramig, B. M. & Prokopy, L. S. Farmers and conservation programs: Explaining differences in Environmental Quality Incentives Program applications between states. *J. Soil Water Conserv.* **68**, 110–119 (2013).

50. O'Neal, B. J., Heske, E. J. & Stafford, J. D. Waterbird Response to Wetlands Restored Through the Conservation Reserve Enhancement Program. *J. Wildl. Manag.* **72**, 654–664 (2008).

51. Cylinder, P., Bogdan, K. & Zippin, D. Understanding the Habitat Conservation Planning Process in California. 79.

52. U.S. Fish & Wildlife Service. Endangered Species | For Landowners | Safe Harbor Agreements. https://www.fws.gov/endangered/landowners/safe-harbor-agreements.html (2020).

53. Fishburn, I. S., Kareiva, P., Gaston, K. J. & Armsworth, P. R. The Growth of Easements as a Conservation Tool. *PLOS ONE* **4**, e4996 (2009).

54. Parker, D. P. Land Trusts and the Choice to Conserve Land with Full Ownership or Conservation Easements. *Nat. Resour. J.* **44**, 483–518 (2004).

55. Horton, K., Knight, H., Galvin, K. A., Goldstein, J. H. & Herrington, J. An evaluation of landowners' conservation easements on their livelihoods and well-being. *Biol. Conserv.* **209**, 62–67 (2017).

56. Land Trust Alliance. Income Tax Incentives for Land Conservation. *Land Trust Alliance* https://www.landtrustalliance.org/topics/taxes/income-tax-incentives-land-conservation.

57. Meng, Y.-Y. *et al.* Outdoor air pollution and uncontrolled asthma in the San Joaquin Valley, California. *J. Epidemiol. Community Health* **64**, 142–147 (2010).

58. Perez, N. Despite decades of cleanup, respiratory disease deaths plague California county. *EHN* https://www.ehn.org/chronic-respiratory-disease-california-2621765230/pollution-per

sists (2018).

59. California Natural Resources Agency. i15 Crop Mapping 2018. https://data.cnra.ca.gov/dataset/i15-crop-mapping-20181.

60. U.S. Energy Information Administration. Solar photovoltaic generators receive higher electricity prices than other technologies. https://www.eia.gov/todayinenergy/detail.php?id=45436 (2020).

61. Vimmerstedt, L. 2021 Annual Technology Baseline (ATB) Cost and Performance Data for Electricity Generation Technologies. (2021) doi:10.25984/1807473.

62. Equations & Variables | Electricity | 2021 | ATB | NREL. https://atb.nrel.gov/electricity/2021/equations_&_variables.

63. Vignesh, R., Feldman, D., Margolis, R. & Desai, J. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2021*. 76 https://www.nrel.gov/docs/fy22osti/80694.pdf (2021).

64. WECC - Western Electricity Coordinating Council. https://www.wecc.org:443/Pages/home.aspx.

65. Oak Ridge National Laboratory, Los Alamos National Laboratory, Idaho National Laboratory & National Geospatial-Intelligence Agency Homeland Security Infrastructure Program Team. Electric Power Transmission Lines. https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about (2021).

66. Bolinger, M. & Bolinger, G. Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density. *IEEE J. Photovolt.* 1–6 (2022) doi:10.1109/JPHOTOV.2021.3136805.

67. Environmental Defense Fund. *Advancing Strategic Land Repurposing and Groundwater Sustainability in California: A guide for developing regional strategies to create multiple benefits*. https://www.edf.org/sites/default/files/documents/EDF_AdvancingLandRepurposing_March2021_0.pdf (2021).

68. Nolte, C. High-resolution land value maps reveal underestimation of conservation costs in the United States. *Proc. Natl. Acad. Sci. U. S. A.* (2020) doi:https://doi.org/10.1073/pnas.2012865117.

69. GreenInfo Network. California Conservation Easement Database - California Natural Resources Agency Open Data. https://data.cnra.ca.gov/dataset/california-conservation-easement-database (2021).

70. *NREL Cambium*. (National Renewable Energy Laboratory, 2021).

71. Multibenefit Land Repurposing Program. https://www.conservation.ca.gov/dlrp/grant-programs/Pages/Multibenefit-Land-Repu

rposing-Program.aspx.

72. SWAP Model | Center for Watershed Sciences. https://watershed.ucdavis.edu/project/swap-model.

73. Kelsey, R., Butterfield, H., Hart, A., Redmond, R. & Bigda-Peyton, H. *Roadmap for Restoration*. (2020).

74. Renewable Energy: Utility-Scale Policies and Programs. *Energy.gov* https://www.energy.gov/eere/slsc/renewable-energy-utility-scale-policies-and-programs.

75. Topaz Solar Farm, California. https://earthobservatory.nasa.gov/images/85403/topaz-solar-farm-california (2015).

76. Bernstein, J. & Mitchell, B. A. Land trusts, private reserves and conservation easements in the United States. *Parks* **15**, 48–60 (2005).

77. Cypher, B. *et al. Response of San Joaquin Kit Foxes to Topaz Solar Farms: Implications for Conservation of Kit Foxes*. (2019).

78. *CAISO 20-Year Transmission Outlook*. 79 http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf (2022).

79. Wilbert, T. R. *et al.* Distribution, fine-scale subdivision, and population size of San Joaquin kit foxes in the Ciervo-Panoche Natural Area, California. *Conserv. Genet.* **20**, 405–417 (2019).

80. Regional Conservation Investment Strategies Program. https://wildlife.ca.gov/Conservation/Planning/Regional-Conservation.

81. Sinha, P., Hoffman, B., Sakers, J. & Althouse, L. Best Practices in Responsible Land Use for Improving Biodiversity at a Utility-Scale Solar Facility. *Case Stud. Environ.* **2**, 1–12 (2018).

82. *The Protected Areas Database of the United States (PAD-US)*. https://www.usgs.gov/programs/gap-analysis-project/science/pad-us-data-overview (2021).

83. United States Geological Survey. PADUS by GAP Status - ScienceBase-Catalog. https://www.sciencebase.gov/catalog/item/56bba50ce4b08d617f657956.

Appendices

Appendix A. Spatial Data Processing

We use ArcMap 10.8.1 to ready spatial data. We list the data processed and their uses in Table A1. We project all data to NAD 1983 California Teale Albers, resample the pixel size of all layers to 250m x 250m (the smallest of our data), and clip the layers to predicted permanently retired agricultural lands. Lastly, for all spatial inputs, we convert NA values to zero so that the model computes every pixel.

Table A1. Data processed in ArcMap and their uses.

Data Processed	**Use**
Fallowed lands (Bryant et al., 2020)	Predicted retired agricultural lands
Agricultural lands (CropMapper, 2021)	
San Joaquin kit fox habitat suitability (TNC)	Habitat suitability layer
Blunt-nosed leopard lizard habitat suitability (TNC)	
Giant kangaroo rat habitat suitability (TNC)	
San Joaquin woolly-threads habitat suitability (TNC)	
PAD protected lands (United States Geological Survey et al., 2021)	
CCED protected lands (GreenInfo Network, 2020)	
Solar capacity factor (Wu et al., 2019)	Solar capacity factor layer
Solar siting region (Wu et al., 2019)	
Transmission lines (Oak Ridge National Laboratory et al., 2021)	Transmission distance layer
Land value (Nolte et al, 2020)	Land value layer

Predicted Permanently Retired Agricultural Lands:

Predicted retired lands from Bryant et al. are broken into five classes based on the number of times Bryant et al. selects each pixel for retirement. We add this layer as a raster file, project it using the Raster Project tool, and resample it to a smaller pixel size of 250m x 250m using the Resample tool. Next, we use the Int tool to create an attribute table. We calculate the acreage of each class and sum it to find the value closest to the Bryant et al. estimate of permanently retired farmland. We select classes two through five.

We add agricultural lands from CropMapper as a shapefile and project the shapefile using the Project tool.

We clip the predicted retired lands to the agricultural lands to ensure all land predicted to be retired is actually farmland. We then reclassify this new layer using the Reclassify tool so that retired lands of classes two through five are given a value of one. We assign No Data to class one values.

Solar Capacity Factor

We add a continuous capacity factor raster from Wu et al. to ArcMap and project the raster using the Raster Project tool. This data has the smallest cell size of all layers, so it does not need to be resampled and it determines the pixel size of all other data.

We add sites suitable for solar (candidate project areas of solar siting level 1), as determined by Wu et al., as a shapefile, project it using the Project tool, and rasterize it using the Polygon to Raster tool with a cell size set at 250m x 250m.

Next, we clip the capacity factor layer to the extent of the suitable solar sites using the Extract by Mask tool. The Raster Calculator converts capacity factor percents to decimals by dividing the layer by 100. Finally, we clip the solar capacity factor layer to the predicted permanently retired agricultural lands using the Extract by Mask tool.

Distance to Transmission

We add a transmission line layer from Oak Ridge National Laboratory et al. to ArcMap as a shapefile. We filter lines for voltages greater than or equal to 230 kV. We use the Euclidean Distance tool to create a raster layer containing 250 m x 250 m pixels with values for the shortest distance (in meters) from each to the closest transmission line. Next, we clip the transmission distance layer to the predicted permanently retired agricultural lands using the Extract by Mask tool. Once the data is loaded into R, we convert it from meters to kilometers.

Habitat Suitable for One or More Species

We add four habitat suitability raster files from TNC to ArcMap. They show suitable habitat for four umbrella species (San Joaquin kit fox, San Joaquin woolly-thread, blunt-nosed leopard lizard, and giant kangaroo rat). We project these layers using the Project Raster tool and resample them to 250m x 250m using the Resample tool. Next, we use the Mosaic to New Raster tool to combine the four layers into one using sum as the mosaic operator (i.e., any pixel where two habitat suitability layers overlap is given a value of two, etc.). We feed this new output into the Reclassify tool and give all classes, one through four, the value of one.

We add protected lands from the Protected Area Database (PAD) to ArcMap as a shapefile and project (Project tool).[82] PAD lands are made up of: state and federally protected areas, conservation easements, and land protected by non-governmental entities. We filter these so that all parcels owned by cities are removed. This eliminates city parks that are too small to function as effective habitat.

We also add conservation easement lands from the California Conservation Easement Database (CCED) as a shapefile and project it using the Project tool.[69]

Next, we use the Union tool to combine the PAD lands and CCED lands into one layer containing all protected lands. We remove any lands that have a GAP status of four because they are not protected from conversion for anthropogenic uses.[83] The Euclidean Distance tool creates a 5 km buffer around protected areas. Next, the Extract by Mask tool clips the habitat suitability layer to areas within the 5 km buffer of protected areas. Reclassify changes all values to one and missing values are assigned No Data. Extract by Mask clips the suitable habitat layer to the predicted permanently retired agricultural lands. Once the habitat layer is read into the R script, we change No Data pixels to zero.

Habitat Suitable for Two or More Species

To create the habitat suitability layer for two or more species, we repeat the same steps used for the one or more species habitat suitability layer. The difference comes when reclassifying with the Reclassify tool. A value of one is assigned where two or more species exist instead of where one or more species exist.

Land Value

We add land value data from Nolte et al. to ArcMap in raster format, project it using the Raster Project tool, and resample it to a cell size of 250 m x 250 m using the Resample tool. The data is in ln dollars per hectare format and we convert it to dollars per pixel. We do this by first using the Exp tool to obtain dollars per hectare and then by using the Raster Calculator to multiply each pixel by 6.25. This value is used because 62,500 m^2 (the area of a 250 m x 250 m pixel) equals 6.25 hectares.

Appendix B. Economic Model Details

We use R code organized in a Markdown document to evaluate which parcels of land would be selected for habitat conservation or USSE development. The spatial datasets processed in ArcMap are first read into R. These include habitat suitability for one or more and two or more species, distance to transmission, solar capacity factor, land value, and predicted retired land.

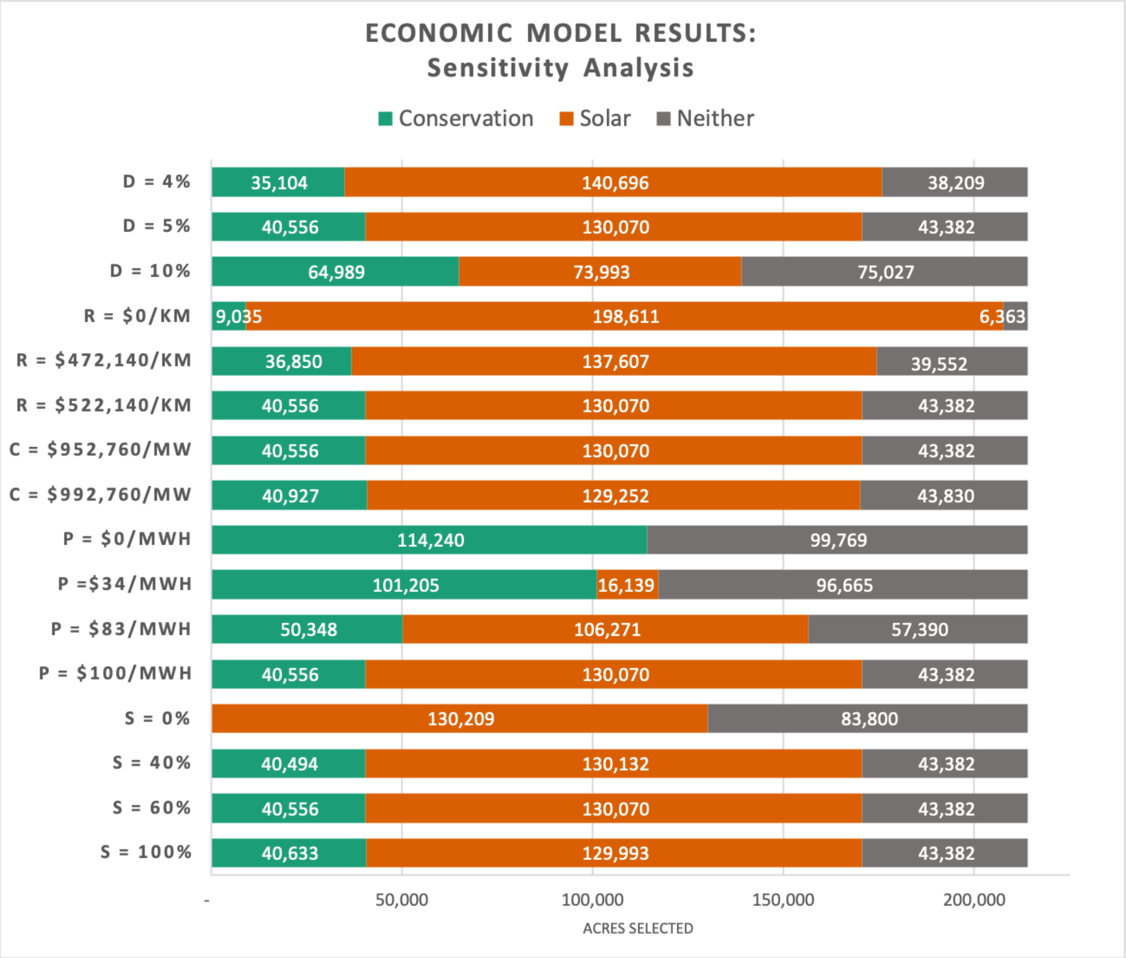
First, we prepare these spatial data layers for assessment by the model. For the purpose of our analysis, we convert NA values in each layer to zeros to ensure every pixel is assessed by the model functions. Then we crop the habitat suitability, distance to transmission, capacity factor and land value layers to the predicted retired land layer. Finally, we set each spatial layer to the same extent and stack them.

Next, we apply two functions representing equations 1 and 2, which respectively calculate solar and habitat profits. These functions pull values from the spatial layers for two variables in equation one (solar capacity factor (f_i) and distance to transmission (d_i)) and two variables in equation two (land value (v_i) and habitat suitability (h_i)). The functions also incorporate defined values for the spatial-fixed variables in each equation. For equation 1, those variables include wholesale electricity price (p), cost of development (c), and transmission connection cost (r); for equation 2, the only spatially-fixed variable is the percent compensation for conservation (s).

The functions generate new spatial data layers containing unique results in each pixel. We run the function for equation 2 twice, each time with a different habitat suitability layer. The resulting layers represent habitat profits under the one- and two-species scenarios. We convert any negative values in the solar profit layer to zeros. Finally, we stack the solar and habitat profit layers and feed them into a third equation comparing which profit is greater in each pixel, assigning one of three values:

- 1 if solar profit is greater,
- 2 if habitat profit is greater or,
- 3 if neither land use is profitable.

Appendix C. Sensitivity Analysis Results



(Figure Continued Below)

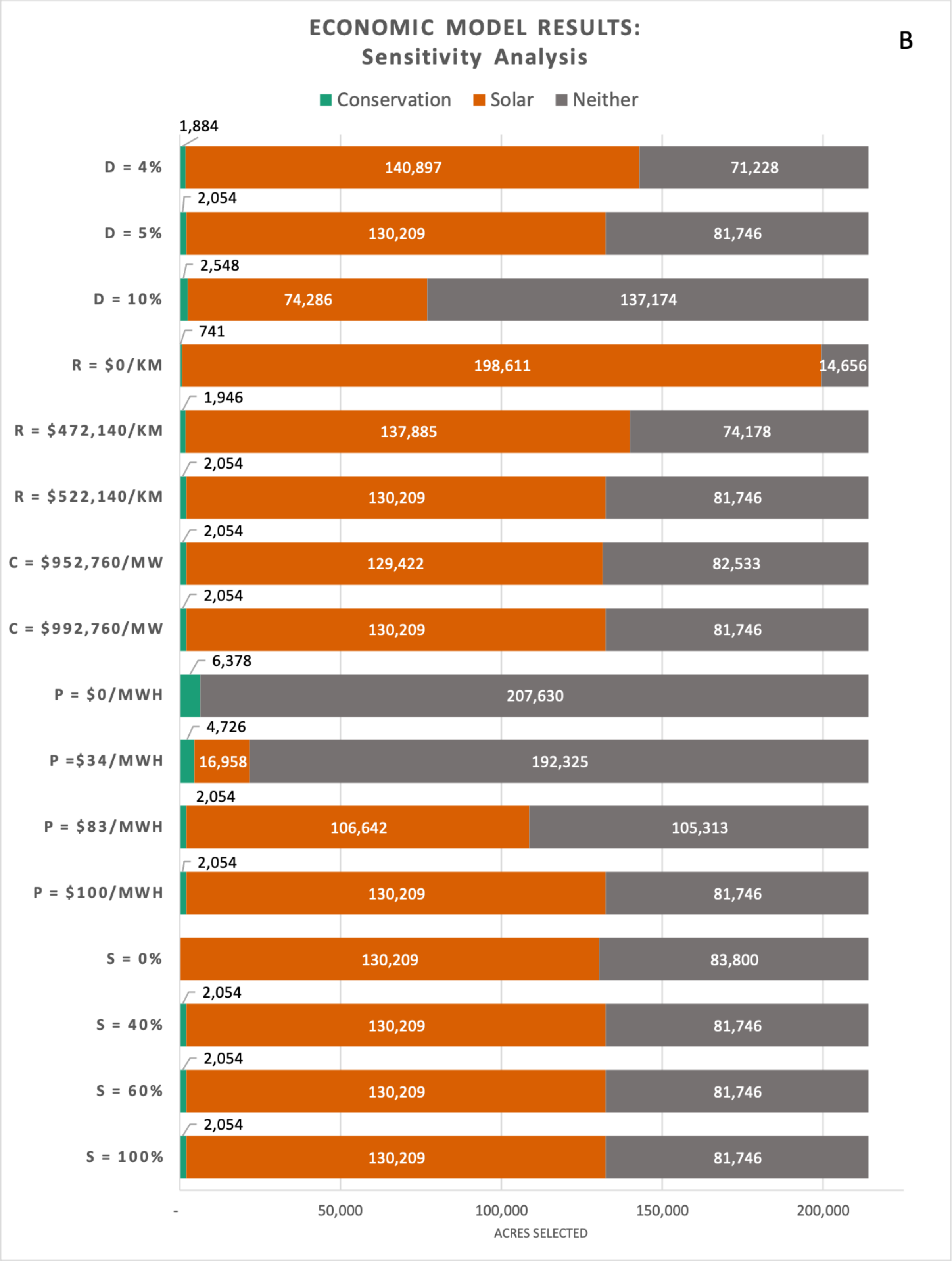


Figure C1. Model selection, summarized in total acres, with habitat suitability for one or more species (A) and two or more species (B). Note: here D represents the input variable for the discount rate, δ.

Wholesale Electricity Price ($/MWh) (*p*)

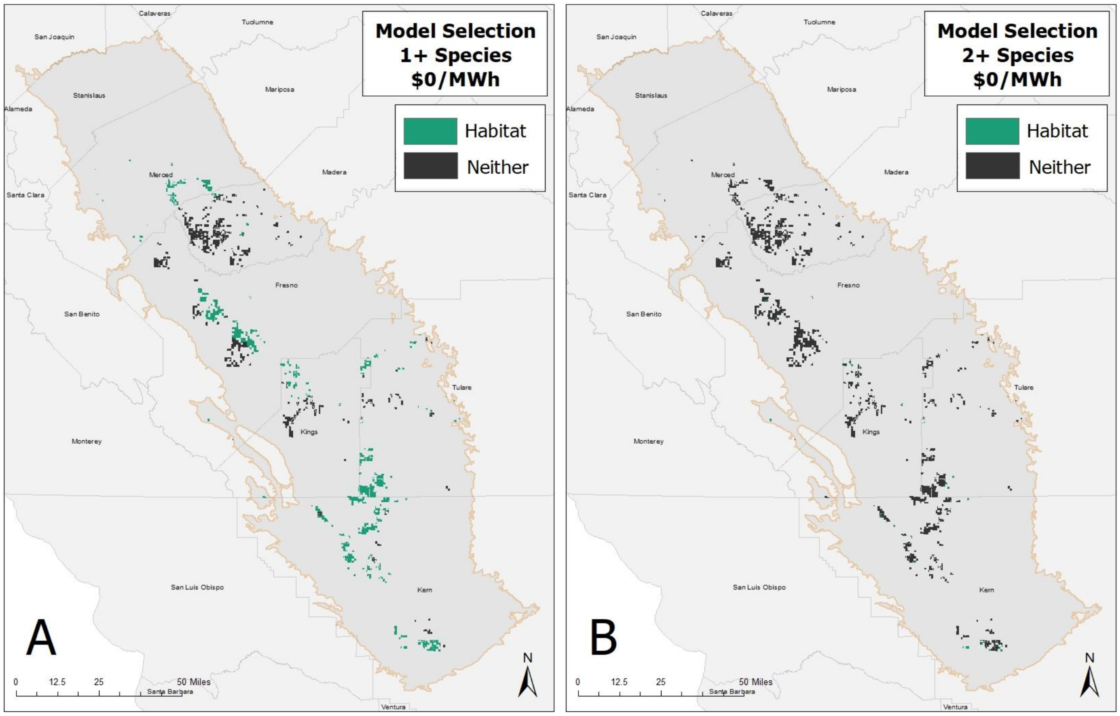


Figure C2. Model selection with habitat suitability for one or more species (A) and two or more species (B) when wholesale electricity price (p) is $0/MWh and other variables are set to base values (δ = 5%, c = $952,760/MW, r = $522,140/km, and s = 60%).

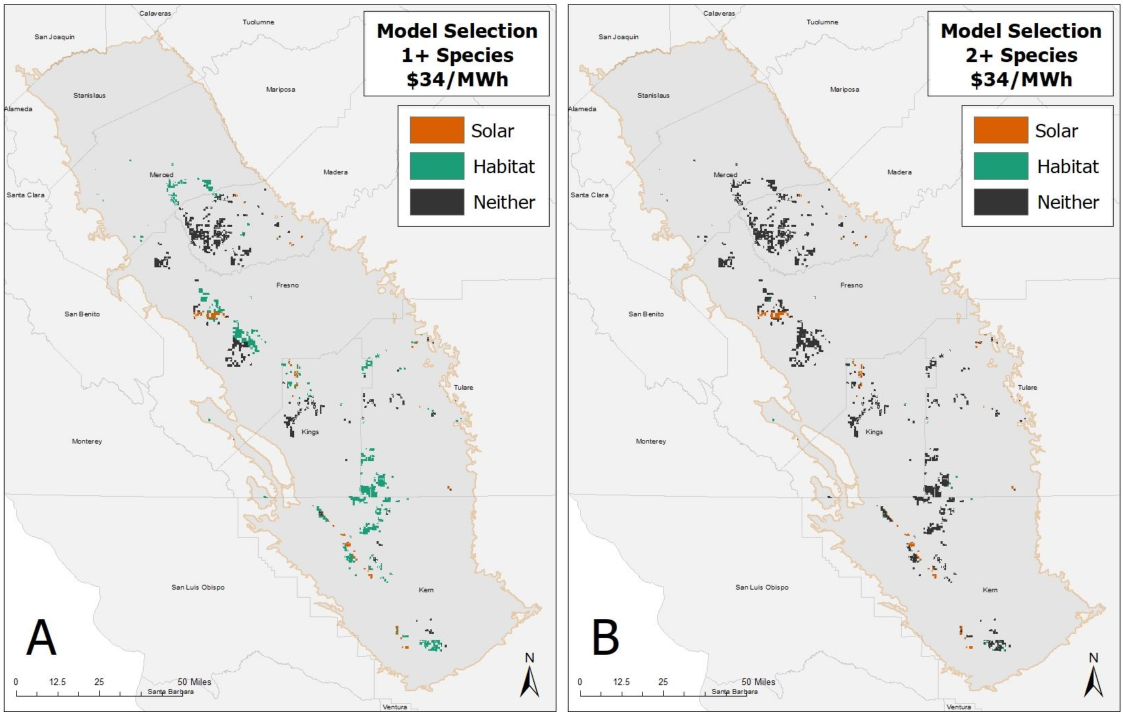


Figure C3. Model selection with habitat suitability for one or more species (A) and two or more species (B) when wholesale electricity price (p) is $34/MWh and other variables are set to base values (δ = 5%, c = $952,760/MW, r = $522,140/km, and s = 60%).

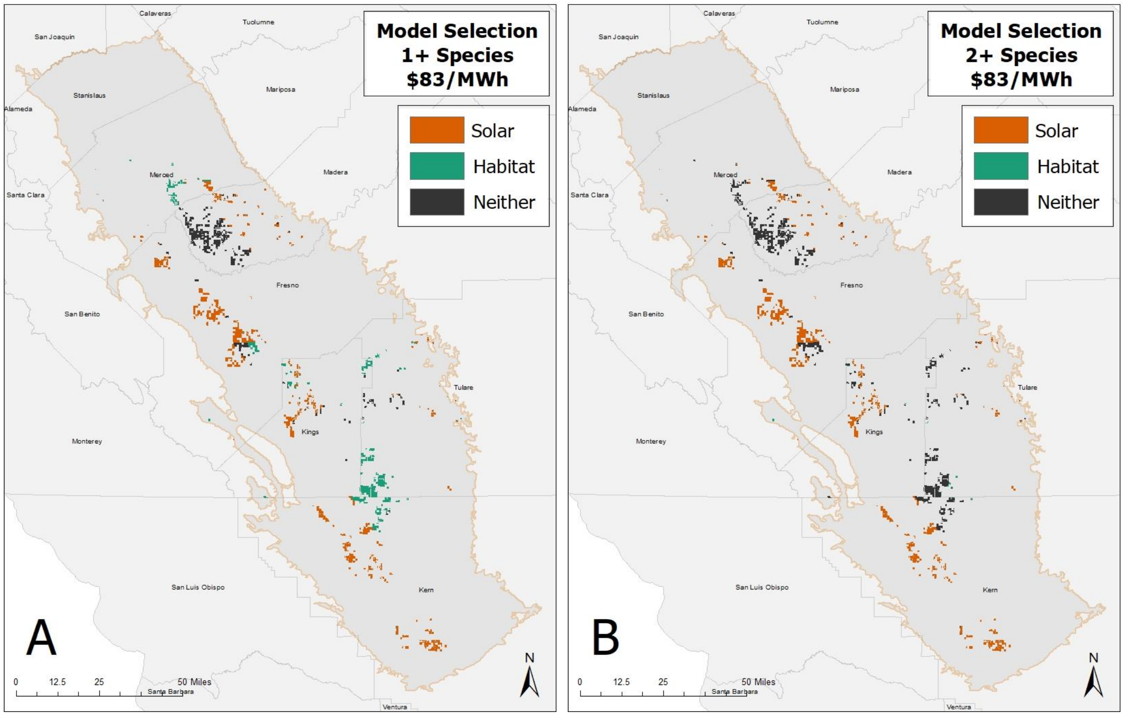


Figure C4. Model selection with habitat suitability for one or more species (A) and two or more species (B) when wholesale electricity price (p) is $83/MWh and other variables are set to base values (δ = 5%, c = $952,760/MW, r = $522,140/km, and s = 60%).

Discount Rate (%) (δ)

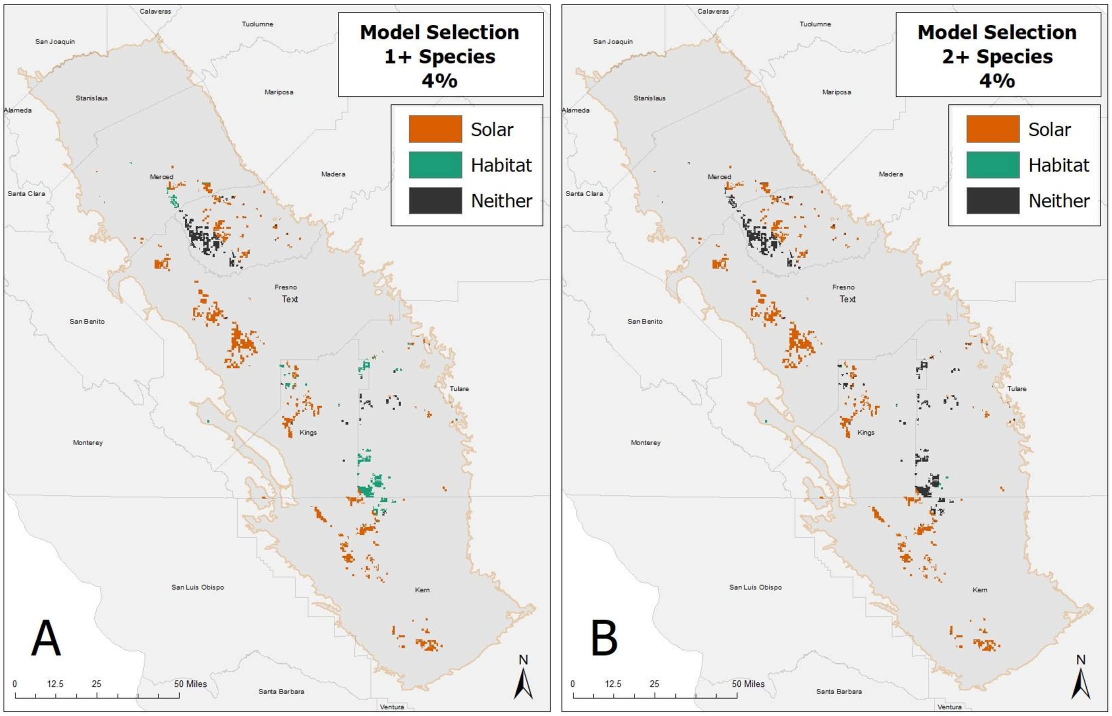


Figure C5. Model selection with habitat suitability for one or more species (A) and two or more species (B) when the discount rate for solar profit is 4% and other variables are set to base values (p = \$100/MWh, c = \$952,760/MW, r = \$522,140/km, and s = 60%).

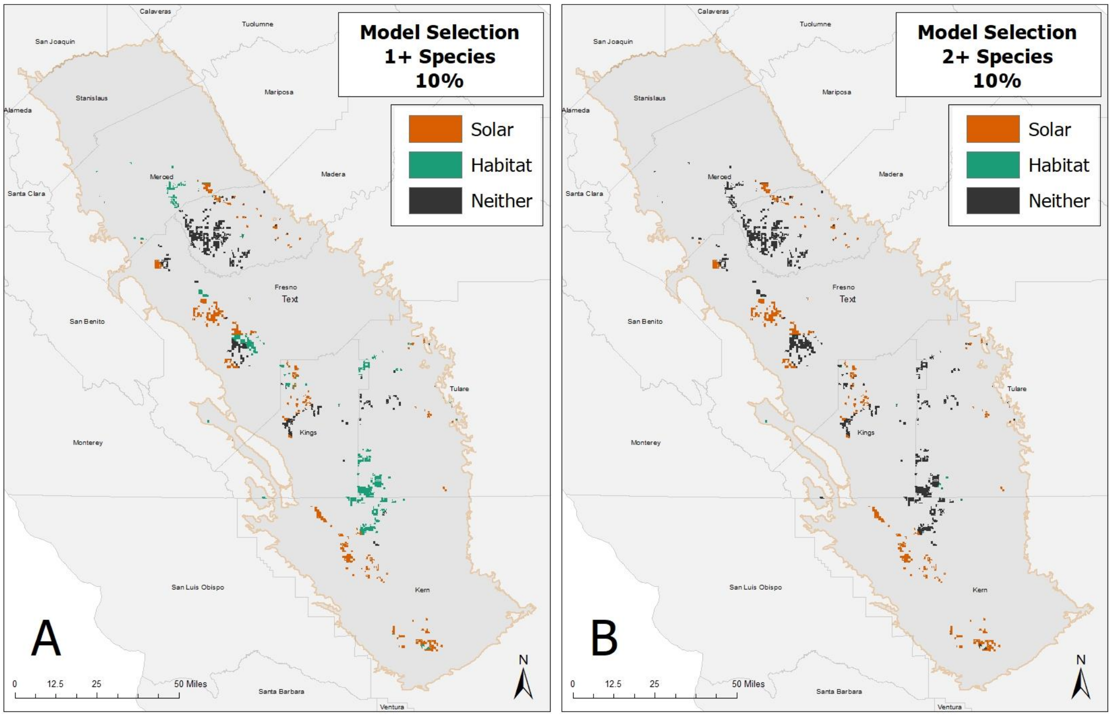


Figure C6. Model selection with habitat suitability for one or more species (A) and two or more species (B) when the discount rate for solar profit is 10% and other variables are set to base values (p = \$100/MWh, c = \$952,760/MW, r = \$522,140/km, and s = 60%).

Development cost ($/MW) (*c*)

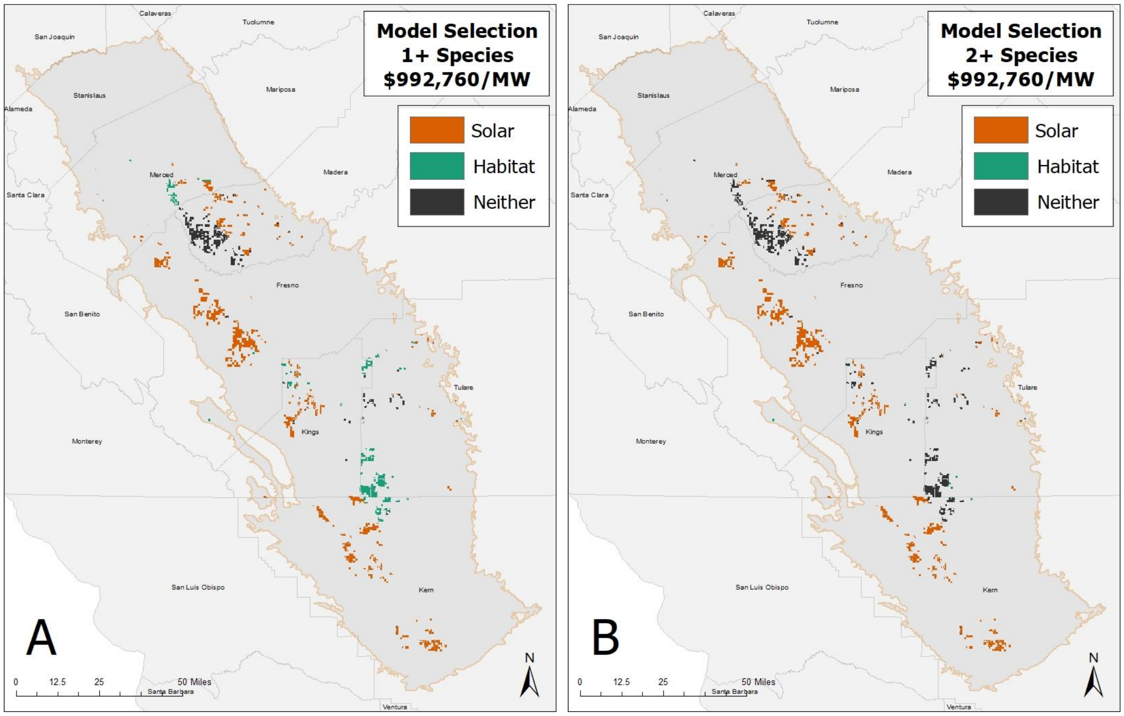


Figure C7. Model selection with habitat suitability for one or more species (A) and two ors more species (B) when development cost (c) is \$992,760/MW and other variables are set to base values (p = \$100/MWh, δ = 5%, r = \$522,140/km, and s = 60%).

Transmission Connection Cost ($/km) (*r*)

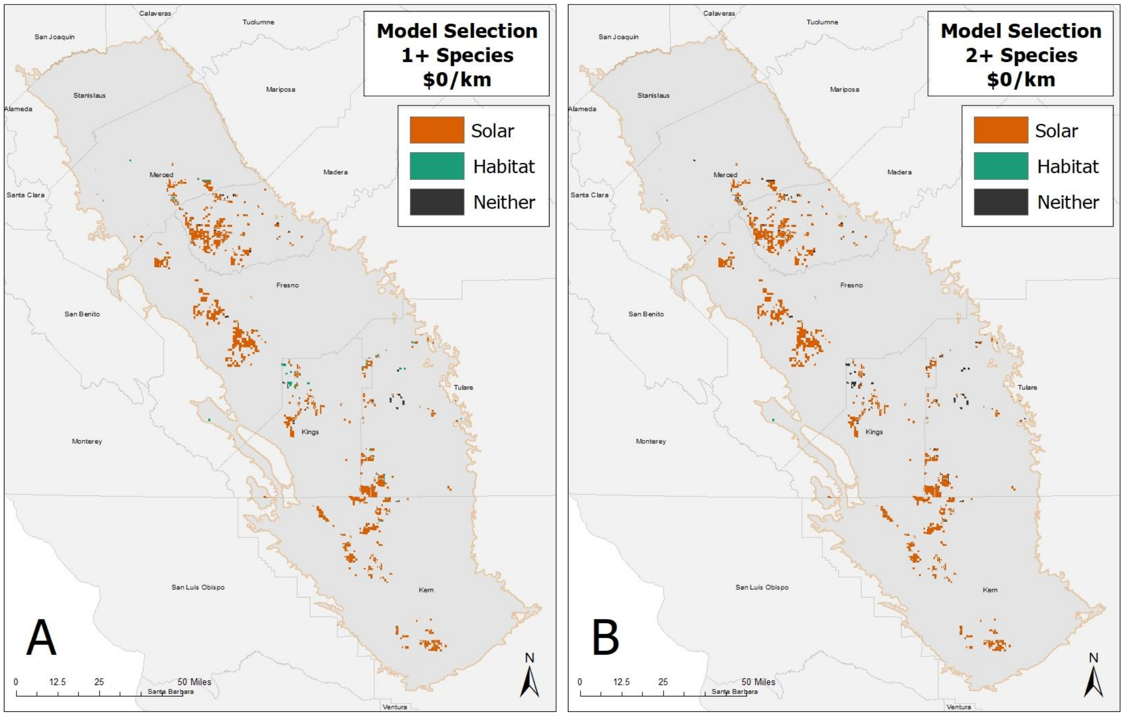


Figure C8. Model selection with habitat suitability for one or more species (A) and two or more species (B) when transmission connection cost (r) is $0/km and other variables are set to base values (p = $100/MWh, δ = 5%, c = $952,760/MW, and s = 60%).

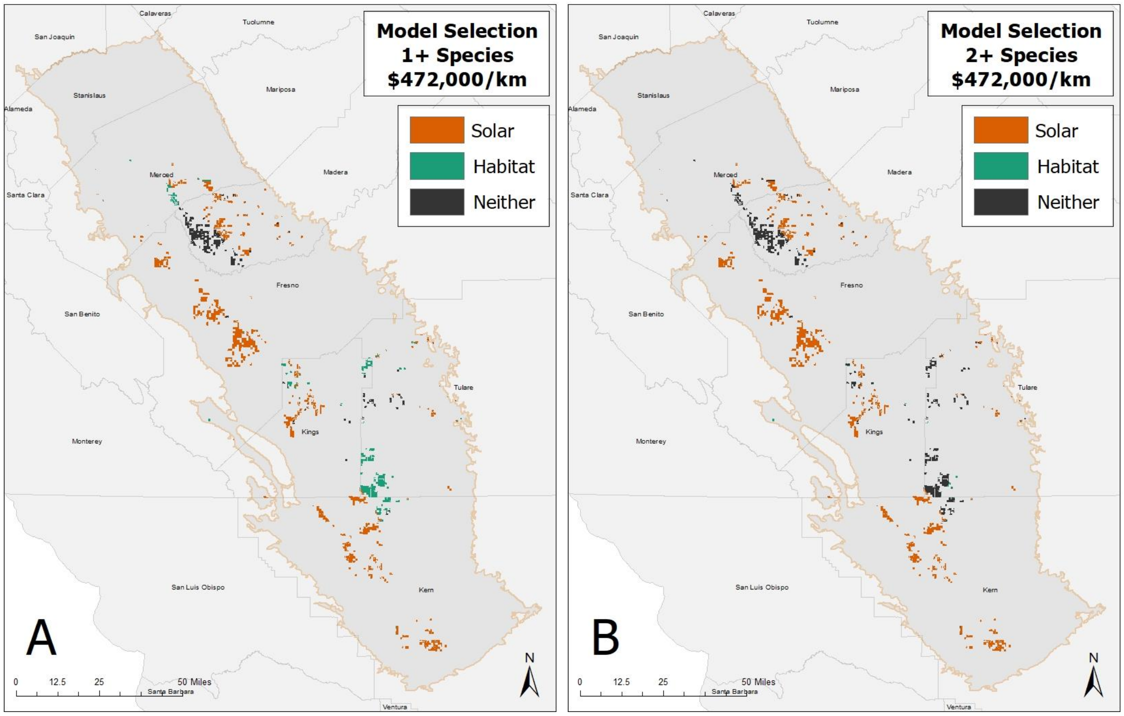


Figure C9. Model selection with habitat suitability for one or more species (A) and two or more species (B) when transmission connection cost (r) is $472,000/km and other variables are set to base values (p = $100/MWh, δ = 5%, c = $952,760/MW, and s = 60%).

Land Value (\$) (v_i)

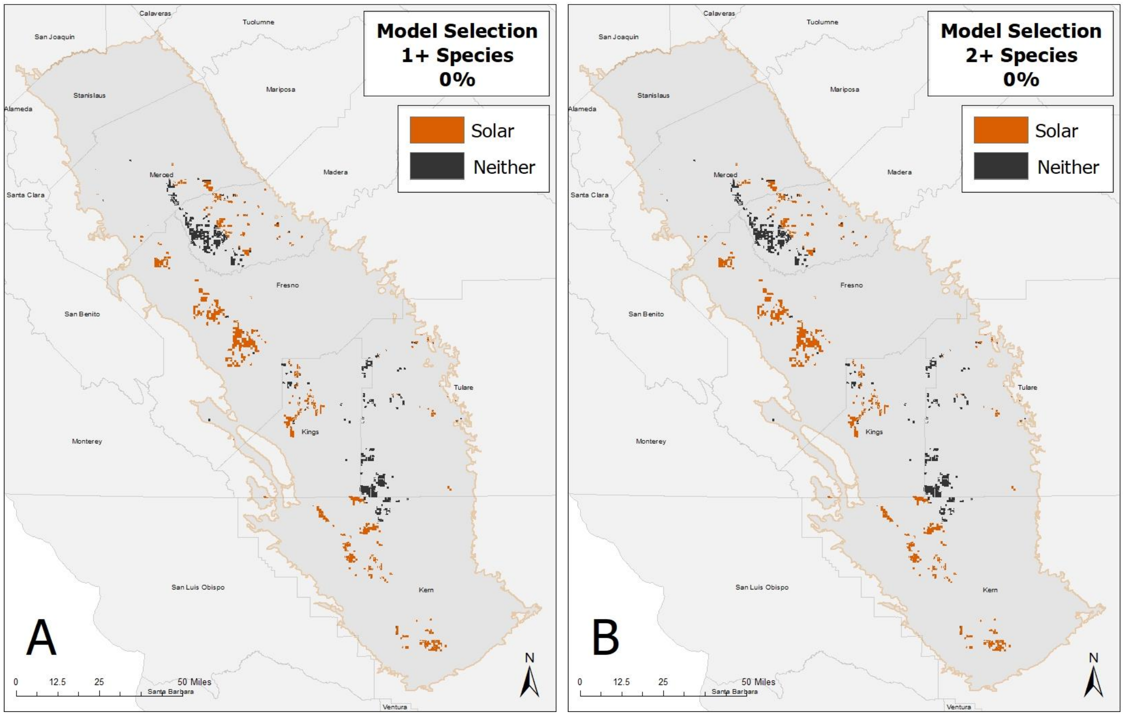


Figure C10. Model selection with habitat suitability for one or more species (A) and two or more species (B) when compensation for restoration (s) is 0% and other variables are set to base values (p = \$100/MWh, δ = 5%, c = \$952,760/MW, and r = \$522,140/km).

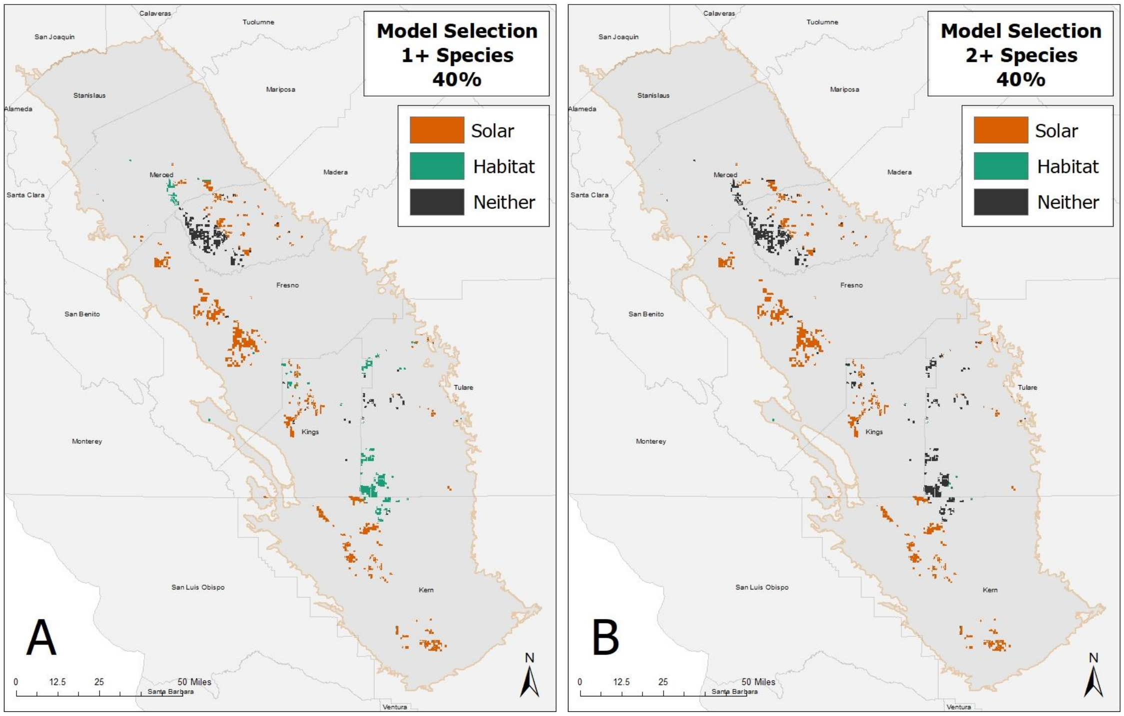


Figure C11. Model selection with habitat suitability for one or more species (A) and two or more species (B) when compensation for restoration (s) is 40% and other variables are set to base values (p = \$100/MWh, δ = 5%, c = \$952,760/MW, and r = \$522,140/km).

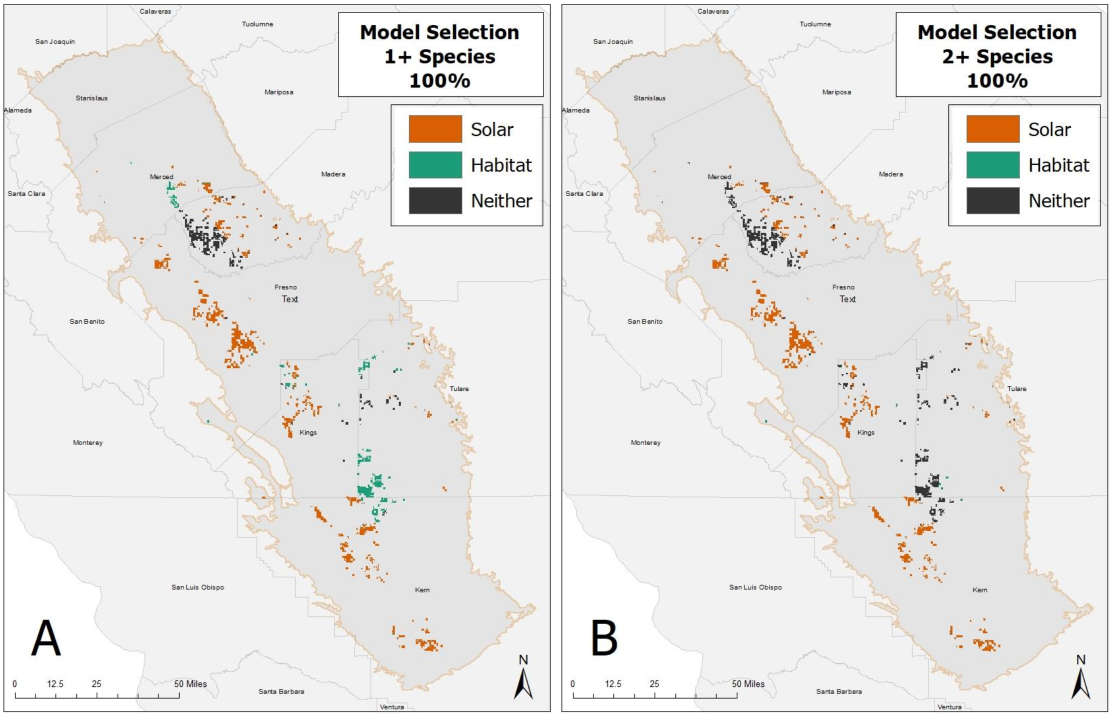


Figure C12. Model selection with habitat suitability for one or more species (A) and two or more species (B) when compensation for restoration (s) is 100% and other variables are set to base values (p = \$100/MWh, δ = 5%, c = \$952,760/MW, and r = \$522,140/km).