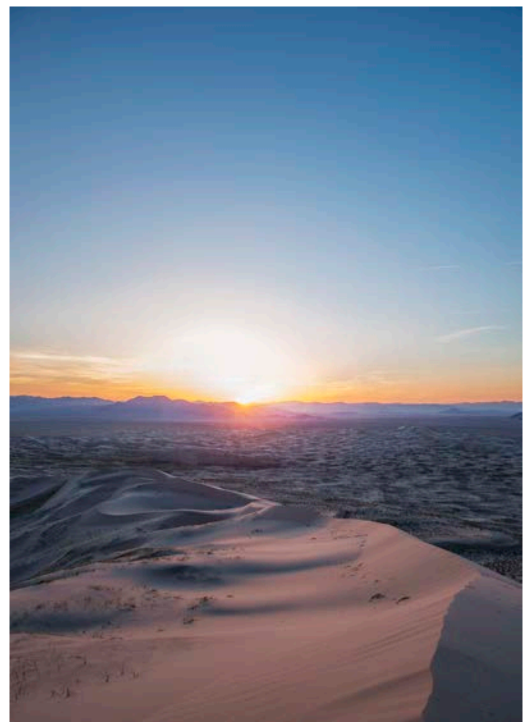
Integrating Land Conservation and Renewable Energy Goals in California:

A Study of Costs and Impacts Using the Optimal Renewable Energy Build-Out (ORB) Model



Left: Solar panels at the Fuller Star plant in Lancaster, California. Right: Kelso Dunes in Mojave National Preserve, California. © Dave Lauridsen for The Nature Conservancy

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Abstract

Currently, there is a lack of understanding of the environmental impacts and economic costs of potential renewable energy (RE) siting decisions that achieve ambitious RE targets. Such analyses are needed to inform policy recommendations that minimize potential conflicts between conservation and RE development. For these policies to be effective, they must be integrated into existing regulatory processes. The California Public Utilities Commission's (CPUC) Renewable Portfolio Standard (RPS) Calculator is a crucial first-order planning tool for RE procurement and transmission planning within the state. We developed the Optimal Renewable energy Build-out (ORB) model to generate input data for the RPS Calculator that reflects the renewable energy potential under various environmental constraints and to examine the land, conservation, water, and electricity cost impacts of the resulting environmentally constrained generation portfolios. We find that imposing environmental constraints on RE development achieves lower conservation impacts and results in development of more fragmented land areas. With increased RE and environmental exclusions, generation becomes more widely distributed across the state, which results in more development on herbaceous agricultural vegetation, grasslands, and developed & urban land cover types. More ambitious RE targets result in higher water consumption, but under more environmental exclusions, this water demand is also more geographically dispersed. We find land use efficiencies of RE technologies are relatively inelastic to changes in environmental constraints, suggesting that cost-effective substitutions that reduce environmental impact and achieve RE goals is possible under most scenarios and exclusion categories. At very high RE penetration that is limited to in-state development, cost effectiveness decreases substantially under the highest level of environmental constraint due to the over-reliance on solar technologies. This additional cost is removed once the in-state constraint is lifted. Minimizing both negative conservation impacts and electricity costs at very high RE penetration will require California to utilize a combination of in-state and out-of-state RE resources, since it is possible to achieve 50% renewable energy generation by 2030 in the WECC-wide scenario under the most stringent set of environmental constraints while incurring only a 2% cost premium.

1 Introduction

1.1 Background and Motivation

California has ambitious renewable energy targets, including a recently announced goal of 50 percent electricity derived from renewable sources by 2030. The state also has abundant undeveloped wind, geothermal, concentrating solar power (CSP) and solar photovoltaic (PV) resources. But many undeveloped landscapes with high renewable resource potential also have high conservation value, creating the potential for conflict between renewable energy development and conservation goals.

These potential conflicts matter. If renewable energy projects proceed in environmentally sensitive areas, they can unnecessarily degrade the habitat, biodiversity and other values of natural landscapes. Conversely, environmental concerns can seriously impede renewable energy development by subjecting projects to multi-year delays, major cost increases and in some cases abandonment.

Despite these high stakes, the land use and water use implications of the state's renewable energy objectives have not been well characterized quantitatively or spatially. Information about these implications would help to clarify barriers to renewable energy development, evaluate the potential effects of proposed renewable energy policies and inform long-term energy planning.

California has multiple long-term planning processes for transmission and renewable energy procurement, including the California Public Utilities Commission (CPUC) Long-Term Procurement Plan (LTPP), the California Independent System Operator (CAISO) Transmission Planning Process (TPP) and others. Although California and federal agencies have led multiple landscape-level planning initiatives to encourage environmentally-sensitive renewable energy development, the results from these studies have yet to be integrated into planning and procurement processes.

Many transmission and long-term procurement planning decisions are informed by output from the California Renewable Portfolio Standard Calculator version 6.0 (RPS Calculator). Most importantly, CAISO uses the portfolio from the RPS Calculator to prioritize transmission investments necessary to meet renewable energy goals.[a] Transmission availability is a critical factor for renewable energy developers when selecting potential project sites. Additional transmission availability through the planning of new lines or upgrades in turn encourages new generation projects in those locations. As a result, the use of the Calculator in transmission planning has direct implications on the geographic regions where renewable energy projects will be proposed and developed, and, consequently, on the land and water impacts of those projects.

The RPS Calculator receives input data on transmission availability, renewable energy resource potential, and other factors. From this information, it produces the lowest-cost portfolio of future renewable energy projects — for multiple technologies and organized by Super Competitive

[a] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/RPS+Calculator+Home.htm

Renewable Energy Zone (Super CREZ)[b] — that meets the renewable "net short" requirement, which is the difference between the RPS compliance target and the generation from existing and commercial[c] projects.

The RPS Calculator accounts for prohibitions on renewable energy development in some areas, such as national parks,[d] but it does not account for the many areas where renewable energy development will impact sensitive resources and generate significant conflict with resource agencies and environmental stakeholders, increasing the risk of project delays or failure. As a result, the RPS Calculator may overstate the potential capacity for renewable energy development in areas where projects are likely to be infeasible due to, for instance, poor alignment with land-use planning designations or biodiversity conservation priorities. By the same token, overly conservative assumptions about land availability could lead the RPS Calculator to understate the potential for low-impact renewable energy development in some areas. While the RPS Calculator helps to analyze one policy goal — increased renewable energy development — it does not provide the information needed to improve planning by avoiding impacts to important natural habitats. Incorporating environmental constraints into the Calculator would provide a more realistic estimate of the potential for renewable energy generation in each Super CREZ. It also provides a basis for analyzing how to meet multiple state goals: RE development and protection of natural resources.

1.2 Objectives and Approach

To demonstrate how land conservation values can be integrated transparently into renewable energy procurement and transmission planning and examine the environmental outcomes of scenarios, we developed the Optimal Renewable energy Build-out (ORB) model. The model generates input data for the RPS Calculator that reflects the renewable energy potential in each Super CREZ when certain lands are excluded due to their conservation value. With this input, the RPS Calculator generates portfolios of future renewable energy production using the CPUC's "least-cost, best-fit" approach, given the resource availability and other constraints in each Super CREZ.

The ORB model then takes these environmentally-constrained portfolios from the RPS Calculator and models the spatially-specific optimal locations of the utility-scale wind, PV, CSP and geothermal projects that would make up each portfolio based on each possible project's resource quality and distance to nearest transmission line or substation.[e]

From this information and the RPS Calculator's outputs, we assess the following impacts of each portfolio:

1. The relative contribution of each RE technology in resulting RPS Calculator portfolios
2. Total land area required for renewable energy development and overall land-use efficiency;

[b] Super Competitive Renewable Energy Zones are roughly county-scale energy planning units for which renewable resource potential, transmission capacity and renewable energy project costs have been estimated. The maps in this report show the Super CREZ boundaries.
[c] "Commercial" projects are those that have a CPUC-approved power purchase agreement (PPA).
[d] The full list of areas excluded from renewable energy development in the RPS Calculator has not been released for public review.
[e] By contrast, the RPS Calculator models only the total renewable generation and technology type within the boundaries of each Super CREZ; it does not specify project locations for generic future projects.

3. Land cover type, conservation value, and geographic distribution of land developed for renewable energy;
4. Spatial distribution of water demand for renewable energy generation;
5. Relative cost of electricity production compared to the RPS Calculator base case.

This report presents portfolios generated at four different levels of environmental exclusion, from least restrictive to most restrictive. The exclusion categories are based on conservation interest, management designations and legal restrictions related to energy development. Each level of exclusion is evaluated under four 2030 renewable energy build-out scenarios: 33% of generation in-state; 40% in-state; 50% in-state; and 50% generation from a combination of in-state and out-of-state sources (anywhere within the Western Electricity Coordinating Council, or WECC, region).

This study is intended to be a proof of concept for integrating environmental exclusions into renewable energy planning models and decision-making in California. In order to demonstrate how this integration could be accomplished and why it may be valuable, the study employs a tool—the RPS Calculator—that the state currently uses to inform planning and long-term procurement decision-making. As of this writing, the RPS Calculator is under public review and active revision; this report is not meant to endorse the assumptions in the version of the RPS Calculator used in this study or to imply that the build-outs generated by the ORB model represent the full suite of options for achieving California's renewable energy goals.[f]

[f] The RPS Calculator Version 6.0 does not include load outside of the CAISO balancing authority area.

2 Methods

Data and scenarios

2.1.1 Site suitability and environmental impact data

Data representing the following categories of spatial characteristics were compiled from various sources: physical (slope, elevation, water bodies), socio-economic (population centers, military zones, rail, roads, airports, mines), technical (renewable resources), agricultural (prime farmland), environmental (ecological, natural resources), and cultural (historic areas). Additionally, housing density, land cover type and water demand data were collected to estimate impacts of each build-out scenario. The sources of all exclusion and environmental impact data are listed in Appendix Table A – 1.

2.1.2 Environmental exclusions and data

In order to assess the environmental and cost impacts of excluding RE development from areas with different levels of conservation value, we developed four environmental exclusion scenarios based on categories in Wu et al. 2015.[4] The following categories increase in environmental stringency and level of administrative or legal protection, with Category 1 being the least stringent and Category 4 being the most stringent. The categories are additive in their use as exclusions levels—e.g., Category 3 Exclusion Level includes all Categories 1 and 2 lands.

> **Category 1 (Legally Excluded):** Areas where legal restrictions preclude energy development. This category strictly follows exclusions from previous planning studies (i.e., Western Renewable Energy Zones (WREZ),[5] Renewable Energy Transmission Initiative (RETI),[3] Solar Programmatic Environmental Impact Statement (SPEIS)[1]).
>
> **Category 2:** Areas with administrative and legal designations by public agencies in order to protect ecological and social values. In some cases these areas already have some restrictions on energy development. This category includes all "avoid" and "Category 2" areas identified in WREZ[5] and RETI[3] studies, respectively.
>
> **Category 3:** Lands with ecological, economic or social value, including many conservation organizations' priority conservation areas, Prime Farmland, and lands proposed for designation as Wilderness.
>
> **Category 4:** Lands with broad-scale ecological value based on regional models and studies, including contiguous high quality suitable habitat and ecologically intact lands.

Datasets and sources that compose each Environmental Exclusion Category are listed in Appendix Table A – 2.

2.2 Incorporating Environmental Constraints in the RPS Calculator

To assess cost impacts of imposing environmental constraints on RE development in California, we created environmentally-constrained RPS Calculator scenarios. To do so, we calculated the megawatts of potential installed capacity for each technology under each Environmental Exclusion Level by Super Competitive Renewable Energy Zone (CREZ) using the site suitability models (described in section 2.3.1). Super CREZs are geographic areas within which resource potential, transmission capacity, and costs have been estimated (see Appendix Figure A -1 for a reference map showing labeled locations of Super CREZs). They are also the geographic unit at which PV generic projects are selected by the RPS Calculator. For each technology, we compared the estimated environmentally-constrained potential for each Super CREZ with the base case potential (no environmental exclusions) used in the unmodified RPS Calculator (v 6.0). These potential values are tabulated for each technology in the Appendix (Tables A-4, A-5, A-6, A-7). Because the environmentally-constrained potential estimates represent *total* potential, they needed to be corrected for existing and commercial RE power plants in each Super CREZs to create "net" resource potential. To create the 2030 portfolios, the Calculator selected generic projects to meet the renewable net short from this environmentally-constrained set of "net" resource potential. As an example of how this correction was performed, consider the following: the nearly 4 GW of operational or commercial wind projects that already exist in the Tehachapi Super CREZ were removed from the estimated total potential of 6.78 GW and 5.56 GW under the Category 1 and 2 Exclusion Levels, respectively, to create a net resource potential of 2.78 GW and 1.56 GW, respectively (Table A – 4). For each Environmental Exclusion Level scenario, we modified the RPS Calculator using the lower of the environmentally-constrained and the unconstrained potential values (MW). For example, since the modeled potential under Category 4 wind exclusions (536 MW) for the Round Mountain Super CREZ was greater than the base case RPS Calculator potential (220 MW), the modified RPS Calculator Category 4 Exclusion Level scenario used 220 MW as the wind potential for Round Mountain.[g]

We generated technology-specific in-state portfolios for the following four unique 2030 RE targets in the RPS Calculator v6.0: 50% in-state, 40% in-state, 33% in-state, and 50% WECC-wide (Table 1). The RPS Calculator's least-cost, best-fit approach to portfolio creation may select different amounts of generation from each renewable energy technology, depending on its availability under different environmental exclusions. The resultant environmentally-constrained RPS Calculator portfolios (Table 1) and their contribution by Super CREZ were subsequently used as inputs for the optimal site selection process (see Figure 1 for the process flow diagram of analysis and data inputs/outputs). For assumptions and methods used in the RPS Calculator, refer to CPUC's published documentation.[h]

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[g] However, an important caveat in the way the inputs to the RPS Calculator were modified is that the lower of the potential values (the RPS Calculator default and the ORB site suitability results) were used. As such, there may be more opportunities to develop in a low conservation value area than was made available to the Calculator in the present study. As such, the results reported here may be more conservative than what is possible. To accurately assess whether more opportunities for low impact development exist, a systematic comparison of the non-environmental exclusions will need to be conducted between the RPS Calculator's default potential inputs and ORB model's site suitability results.

[h] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/RPS+Calculator+Home.htm

Table 1. RPS Calculator technology-specific generation targets (GWh)

RPS Calculator scenario	Environmental Exclusion Level	Wind	PV	CSP	Geothermal	Total
50% in-state	Base	31,288	38,656	4,095	19,231	93,270
40% in-state	Base	19,779	26,884	4,095	16,637	67,395
33% in-state	Base	18,469	21,901	4,040	8,467	52,877
50% WECC-wide	Base	30,176	34,267	4,095	19,231	87,769
50% in-state	Category 1	25,795	41,123	3,989	16,114	87,021
40% in-state	Category 1	19,650	26,540	3,989	13,431	63,610
33% in-state	Category 1	17,699	21,885	3,934	5,718	49,236
50% WECC-wide	Category 1	24,899	30,605	3,934	13,431	72,869
50% in-state	Category 2	23,198	42,818	3,989	16,073	86,078
40% in-state	Category 2	19,043	26,954	3,989	13,624	63,610
33% in-state	Category 2	17,587	21,856	3,934	5,719	49,096
50% WECC-wide	Category 2	21,340	34,210	3,989	13,624	73,163
50% in-state	Category 3	18,721	50,077	3,989	16,341	89,128
40% in-state	Category 3	16,490	29,451	3,989	13,892	63,822
33% in-state	Category 3	16,253	23,079	3,934	5,718	48,984
50% WECC-wide	Category 3	16,837	30,760	3,989	16,208	67,794
50% in-state	Category 4	16,266	50,561	18,234	8,604	93,665
40% in-state	Category 4	16,068	33,385	3,989	8,604	62,046
33% in-state	Category 4	15,235	23,502	3,989	6,146	48,872
50% WECC-wide	Category 4	15,586	27,382	3,989	8,604	55,561

2.3 Optimal Renewable energy Build-out model (ORB model)

The Optimal Renewable energy Build-out (ORB) model is a spatially-explicit site selection model that identifies installation locations for each RE technology by minimizing total generation and transmission land area given a set of technology-specific generation targets and constraints. The ORB model consists of a spatial site-suitability model that identifies all land areas appropriate for renewable energy development and a linear integer optimization problem. To anticipate possible build-outs under multiple 2030 RPS Calculator scenarios and to assess their environmental impacts, we modified the original model (Wu et al. 2015)[4] for this present study to constrain the geographic selection of sites by Super CREZ, as specified by the RPS Calculator (Figure 1), and to account for overlapping suitable areas between multiple technologies.

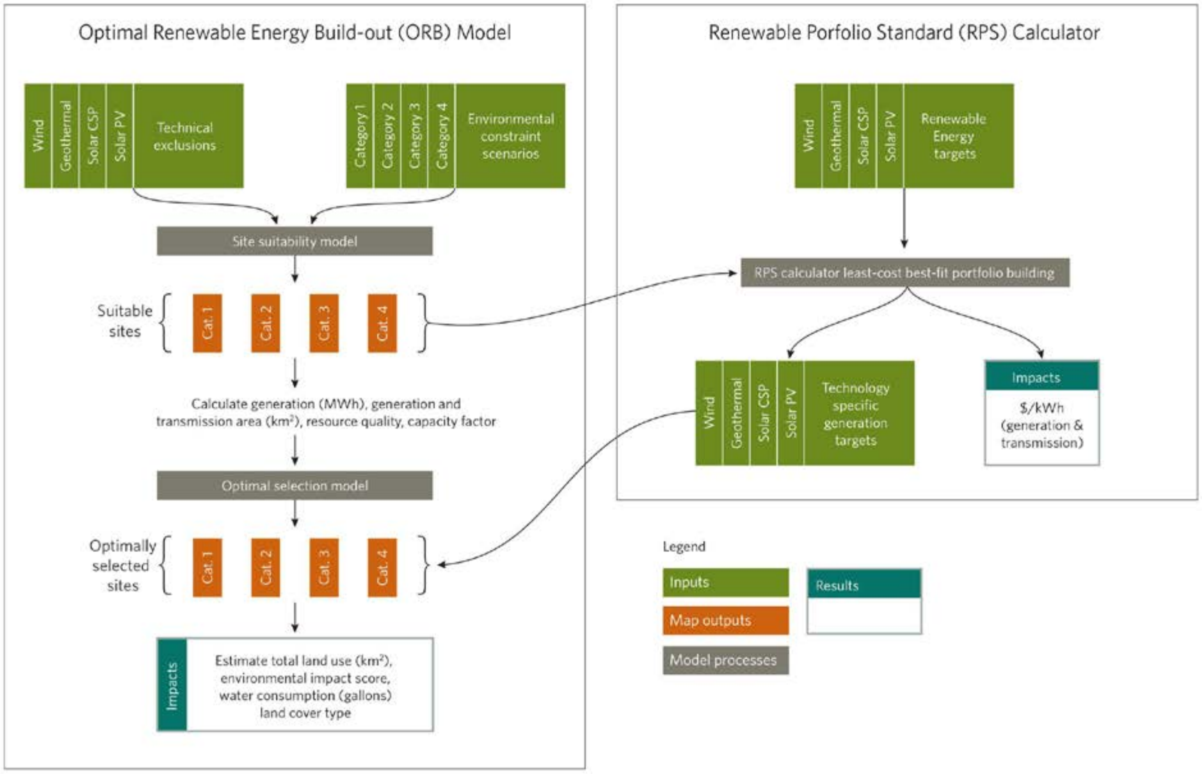

Figure 1. How the ORB model interacts with the RPS Calculator
The flowchart shows the complementary roles of the ORB and RPS Calculator models in assessing the impacts of environmental constraints on renewable energy development.

2.3.1 Site suitability model

To identify all technically possible locations for renewable energy development in California, we created site suitability models for wind, PV, CSP, and geothermal using the methods established in Wu et al. 2015.[4] Binary suitability maps were created using map algebra functions and datasets listed in Table A -2 by applying threshold and buffer specifications for each technology (Table A -3). The raster-based site suitability model was programmed in Python using the arcpy module (ESRI ArcGIS 10.2, Redlands, CA) and ran using a spatial resolution of 500 m. We created a site suitability model for each technology for each of four Environmental Exclusion Levels, generating a total of 16 model outputs. The resulting potential estimates (MW) for each Super CREZ were estimated using the land use factors in Table 2, without applying any discounts to account for unforeseen development restrictions or for areas that may already have RE development. These values are tabulated in Appendix Tables A-4 - A-7.

Development zone creation. To prepare the site suitability outputs for the site selection process, we overlaid the technology-specific site suitability areas under each Environmental Exclusion Level and determined areas where four, three, and two technologies' suitability overlapped. All non-overlapping areas were identified and designated as those suitable for only one type of generation technology. All contiguous areas suitable areas greater than 20 km^2 were divided using a 4 km x 4 km grid, and contiguous areas smaller than 2 km^2 were excluded from further analysis since these fall below minimum area specifications for utility-scale projects. We refer to the resulting areas ranging from 2 to 20 km^2 as "development zones," which serve as the spatial unit of analysis and site selection. We merged all overlapping and single-technology development zones to create a feature class of all possible development zones with attributes that indicate the technologies for which a development zone are suited.

Development zone criteria. We calculated the following criteria for each development zone and for each technology: generation land area (km^2), Euclidean distance to nearest transmission line (km), Euclidean distance to nearest substation (km), interconnection land area (km^2), total land area (km^2), area-weighted resource quality (insolation, geothermal feasibility score), capacity factor (CF; %), annual average generation (MWh). The Wind Integration National Dataset (WIND) Toolkit from the National Renewable Energy Laboratory provides direct estimates of annual average capacity factors.[i,6] See Appendix Section A – 1 for equations and details about estimating capacity factors for solar PV, solar CSP, and geothermal and estimating annual average electricity generation for each development zone and technology (Eq 4 in Appendix section A –2) using the zone and technology-specific CF and land use factor (Table 2).

Table 2. Technology-specific parameters

	Wind	PV	CSP	Geothermal
Land use factor (MW km^{-2}) – average literature values	6.1[7]	30[8]	30[8]	25.5[9]
Water demand (gal MWh^{-1}) – median literature values	0	26[10]	78[10]	135[10] (binary or ≤80% CF); 10[10] (flash or >80% CF)

Whether a development zone interconnects to the nearest substation or nearest transmission line is determined using the following heuristic: if the distance to the nearest substation is less than 37.5 km,[j] a new project would interconnect to the nearest substation; if it is greater than 37.5 km, it would connect to the nearest transmission line. Distances to either substation or transmission line were scaled up by a rule-of-thumb factor of 1.3, to account for additional length resulting from topography, and then multiplied by a line width of 0.076 km to estimate interconnection land area (km^2). To avoid systematically reducing the total land use efficiency (MWh km^{-2}) of smaller development zones as a result of a fixed interconnection area, we applied a correction factor to the interconnection area using the ratio of the development zone area (as small as 2 km^2) to the largest possible development zone area (20 km^2). This correction results in a fixed generation-to-interconnection area ratio for development zones of different sizes that are the same distance from the nearest transmission line or substation and have the same resource quality

[i] The WIND Toolkit data are in the form of point locations representing the average capacity factor of a 2 km x 2 km area around the point. To transform these data into the form usable as an input to the raster-based site suitability model, we generated a raster with 500 m cell size using inverse distance weighted interpolation of the data points.

[j] Typically the range for connecting to an existing substation is 25 – 50 km, beyond which a new line would be extended or a new substation built. The figure of 37.5 km is simply the median distance of this range. These values and the rule-of-thumb transmission line multiplication factor were provided by Jack Moore at Energy and Environmental Economics, San Francisco, California, USA.

2.3.2 Site-selection using integer linear optimization

Relaxing site suitability estimates. The installed capacity of existing and commercial RE projects in a subset of Super CREZs exceeded the estimated potential under the more restrictive Environmental Exclusion Levels. For example, no potential installed capacity of solar CSP remain in the Kramer Super CREZ under the Category 4 Exclusion Level, but 1150 GWh of solar CSP generation need to be sited in Kramer due to existing or commercial power plants that cannot be excluded from the portfolio. We chose to model the entire build-out (both existing and commercial, as well as generic) for two key reasons. First, the electricity costs estimated in the RPS calculator reflect the entire portfolio, not just the "net short" build-out. Impacts (land use efficiency, environmental impact score) modeled using the net short build-out would not correspond to the electricity costs. Second, because locations of existing and commercial projects could not be made publicly available, we could not exclude them from the site suitability models. As a result, modeling only the net short build-out (i.e., generic projects) could select sites where current existing and commercial projects may be located.

In order to model the entire build-out of an RPS Calculator portfolio, including existing or commercial projects, we relaxed the environmental exclusions only for those Super CREZs with insufficient modeled potential to meet its RPS Calculator specified generation requirements. Exclusions were relaxed to the category that would allow sufficient generation to be sited. For example, a total of eight Super CREZs under the Category 4 Exclusion Level needed to be relaxed to Category 3 and three needed to be relaxed to Category 2 Exclusion Levels, in order to model the Super CREZ-specific generation portfolio (Figure 3). We prevented any additional generation from being sited in Super CREZs where the environmentally constrained potential was less than the generation from existing and commercial projects within those Super CREZs (see section 2.2 for a description of how these environmentally constrained portfolios were generated). We excluded from the site selection process Super CREZs with minimal (<5 GWh) generation targets in the RPS Calculator scenarios and that had no potential under any Environmental Exclusion Levels based on our site suitability models. These Super CREZs include: Los Angeles County, San Diego County, Orange County, and Santa Clara County. Additionally, due to the lack of geothermal potential in our site suitability model even under the most relaxed Environmental Exclusion Level, RPS Calculator-specified geothermal targets in Lassen North, Mono County, and Owens Valley Super CREZs were not modeled in this study. The overlap of legal environmental exclusions with areas of high geothermal feasibility preclude identification of suitable sites in Owens Valley. Mono County geothermal site suitability is precluded by the slope exclusion (>1500 m).

Optimization problem construction. We constructed an integer linear optimization problem in order to optimally select development zones that meet the 2030 RE targets. Solving the optimization problem identifies both the sites and the technology for each site that minimizes total (generation and transmission) area used for electricity generation in each scenario, as shown in the objective function (1). By specifying binary decision variables ($x_{t,z}$), constraint (2) restricts the development status of each development zone to "no development" ($x_{t,z} = 0$) or "complete development" ($x_{t,z}$ = 1). Because each development zone (z) may be suitable for any combination of examined technologies (t), the optimization problem must choose to develop no more than one technology per zone, as enforced with constraint (3), while ensuring that the build-out meets technology-specific targets (d_t), as enforced with constraint (4). To align the geographic-specificity of the RPS Calculator with the ORB site selection process, constraint (5) restricts the total MWh of generation for each technology within each Super CREZ to be greater than or equal to 90% of the Super CREZ-specific RPS Calculator targets ($g_{c,t}$). We restricted development by Super CREZ using a minimum generation equal to 90% of the values specified by the RPS calculator, but imposed no maximum generation, in order to provide some flexibility to account for the following differing assumptions between the ORB model and the RPS calculator: 1) differences in capacity factors that result in differences in generation estimates, 2) the overlap of suitable sites between technologies that could not be accounted for in creating environmentally constrained potential values for the RPS calculator, which could have the effect of over-estimating the technology-specific potential in a given Super CREZ, and 3) differences in minimum project size that would prevent the ORB model from finding a solution if a maximum generation value were imposed from the RPS calculator that was less than the minimum project size in the ORB model.

We programmed the integer optimization problem in the optimization programming language (OPL) using the IBM © CPLEX Optimization Studio. We solved the optimization problem for each of the four RPS Calculator build-out scenarios (Table 1) under each Environmental Exclusion Level (Section 2.1.2). However, we only report results for maintaining the current California RPS target of 33% by 2030 and the newly announced target of 50% by 2030 for both in-state and WECC-wide.

2.3.2.1 Nomenclature

Indices:

z	development zone index where $z \in \{0 \dots Z\}$
t	technology where $t \in \{wind, PV, CSP, geothermal\}$
c	Super CREZ index where $c \in \{0 \dots C\}$

Variables:

$x_{t,z}$	selection status $\in \{0,1\}$ of development zone z, technology t

Parameters:

$a_{z,t}$	total generation and transmission area (km^2) of development zone z, technology t
$e_{z,t}$	electricity generation (MWh) of development zone z, technology t
d_t	annual generation target (MWh) for technology t from the RPS Calculator
$g_{c,t}$	annual generation target (MWh) for technology t within super CREZ c
$i_{z,c}$	assignment $\in \{0,1\}$ of zone z to super CREZ c

2.3.2.2 *Objective function and constraints*

Minimize: total (generation and transmission) land use

$$f(x_{t,z}) = \sum_{z=1}^{Z}\sum_{t=1}^{T} a_{z,t}x_{z,t} \tag{1}$$

Subject to:

$$x_{t,z} \in \{0,1\} \tag{2}$$

$$\sum_{t=1}^{T} x_{z,t} \leq 1 \qquad \forall z \in \{1,\dots,Z\} \tag{3}$$

$$\sum_{z=1}^{Z} e_{z,t}x_{z,t} \geq d_t \qquad \forall t \in \{1,\dots,T\} \tag{4}$$

$$\sum_{z=1}^{Z} i_{z,c}e_{z,t}x_{z,t} \geq 0.90g_{c,t} \qquad \forall t \in \{1,\dots,T\}, \forall c \in \{1,\dots,C\}. \tag{5}$$

2.4 Impact analysis

In addition to estimating total generation and land area characteristics of each scenario, the following impact metrics were estimated: area-weighted average environmental impact score, total water consumption by scenario (annual household-equivalents) and disaggregated by groundwater basin, average housing density (households km^{-2}), and land cover type. See Table A – 1 for sources of datasets used to estimate impacts.

Environmental impact score. We created an environmental impact scoring system by assigning each of the environmental exclusion categories a score that is the inverted value of its category (section 2.1.2), such that Category 1 areas were assigned a value of 4 and Category 4 areas assigned a value of 1. This scoring is based on the assumption that siting in areas with less legally stringent conservation values (e.g. Category 4) will be lower impact than if development occurred on land areas with more stringent values (e.g. Category 2). All areas outside of Categories 1-4 exclusions were assigned an environmental impact score of 0. Since all Category 1 areas are legally protected and excluded from all environmental scenarios, possible environmental impact scores (EIS) range from 3 to 0.

We calculated the average EIS for the build-out of an RPS Calculator portfolio by area-averaging the EIS of all selected development zones. The average environmental impact score is a measure of the ecological and social conservation value of the land developed. It ranges from 0 to 3 with a score of 3 indicating that development projects have high conservation impact. An average EIS of zero implies no development in areas of environmental concern, whereas an average EIS score of 2 implies that on average, the selected build-out occupies areas with "medium environmental impact." For example, an average EIS of 2 could result from the ORB model siting 25% of development zones on land with "high environmental conflict" (score 3), 55% on land with "medium environmental conflict" (score 2), 15% on land with "low environmental conflict" (score 1), and 5% on land with "no environmental conflict" (score 0). The environmental impact score under Category 4 Exclusion Level could never actually be zero due to the relaxations of environmental constraints for existing and commercial RE projects. Additionally, we calculated the total area (km^2) of each EIS for each scenario.

Water consumption. Total water consumption estimates rely on the literature compilation of technology-specific water consumption values reported in MacKnick et al. (2011)[10] (Table 2). Using the median value (gallons MWh^{-1}) and the annual MWh generated per technology, we estimated annual water consumption values in gallons, which were converted to annual average household water demand-equivalents (HWD_{eq}). A unit of HWD_{eq} is equal to 146,000 gallons of water, which is calculated using the average household water use of 400 gal d^{-1} (U.S. EPA: WaterSense). We report HWD_{eq} values across the entire state and spatially disaggregated for each groundwater basin.

Landscape fragmentation and land cover. Average housing density is used as a proxy for landscape and habitat fragmentation.[11] According to Radeloff et al. 2010,[11] housing growth is one of the best indicators of threat to the biodiversity and ecosystem health of protected areas in the U.S. In order to understand how habitat and vegetative communities impacted change under different sets of environmental exclusions, we used the U.S. Geological Survey's GAP land cover data, which follows the National Vegetation Classification System, to determine the area of land cover type converted under each build-out scenario.

3 Results

3.1 Site suitability and optimal build-out

The site suitability models show the spatial distribution of technically and environmentally feasible resources across the state, and the optimally selected build-outs show areas of highest resource quality and close to existing or planned transmission. As the area of environmental exclusions increase from Category 1 to 3, the area of suitable sites reduce in a spatially homogenous fashion throughout the state (Figure 2). Under the Category 4 Exclusion Level, suitable sites are largely located in the Central Valley, particularly the Westlands, Los Banos, Central Valley North, and Solano Super CREZs. Areas in Southern California with the largest areas of remaining potential under Category 4 Exclusion Level are the Riverside East, Imperial, Palm Springs, and San Bernardino Lucerne Super CREZs (see Appendix Figure A -1 for a reference map showing labeled locations of Super CREZs).

Using the relaxed site suitability areas in Figure 3, the ORB model identified selected sites to meet the Super CREZ-specific and state-wide generation targets for each technology. We constrained this site selection process in order to produce a build-out that best spatially represents the RPS Calculator portfolio within the limitations of the ORB model. That is, the ORB model attempts to spatially allocate generation to each Super CREZ according to RPS Calculator portfolio specifications. Figure 4 shows the optimally selected sites to meet the 50% in-state by 2030 target in the RPS Calculator. For selected sites of all RPS Calculator scenarios, see the accompanying layered PDF map that allows toggling of individual layers, including transmission lines and substation locations (Map A - 1). Under the Category 4 Exclusion Level in the 50% in-state, with solar PV replacing most of the reduced wind generation in the overall RE portfolio, the distribution of solar PV extends much more into the Central Valley (Carrizo North Super CREZ) and northern California (Solano, Central Valley North, and Sacramento River Valley Super CREZs) and out of the Mojave (Tehachapi, Kramer Super CREZs; Figure 4). Wind development in the Solano and Tehachapi Super CREZs remain relatively unchanged across environmental exclusion categories, but is significantly reduced in the Sacramento River Valley Super CREZ in Categories 3 and 4 Exclusion Levels. These technology-specific trends are similar for the 50% WECC-wide 2030 scenario (Map A - 1), except significantly less solar PV is required within California under Category 4 Exclusion Level (Table 1). For 33% in-state, almost no wind is sited in the Sacramento River Valley Super CREZ across all environmental exclusion scenarios, and solar PV is more widely distributed in the Central Valley region under Category 3 and 4 Exclusion Levels (Map A - 1).

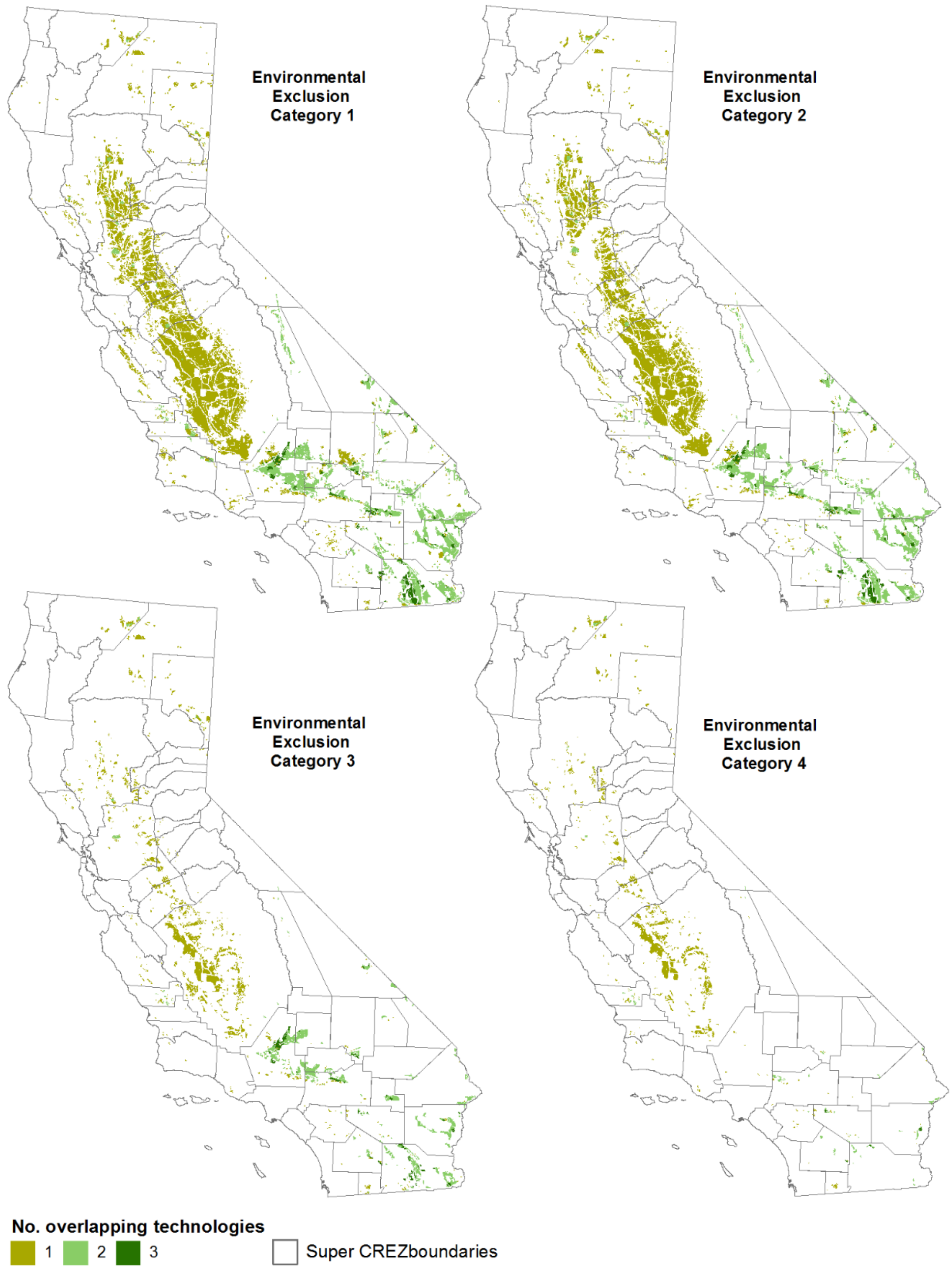

Figure 2. Suitable sites for the development of wind, solar PV, solar CSP, and geothermal.
Colors indicate the number of technologies for which an area is suitable. For example, dark green areas are those that are suitable for any possible combination of three out of the four technologies (i.e., wind, solar PV, solar CSP). The maps show suitable sites for Category 1 through 4 Environmental Exclusion Levels, with Category 1 being legal baseline exclusions and Category 4 having the most extensive exclusion criteria.

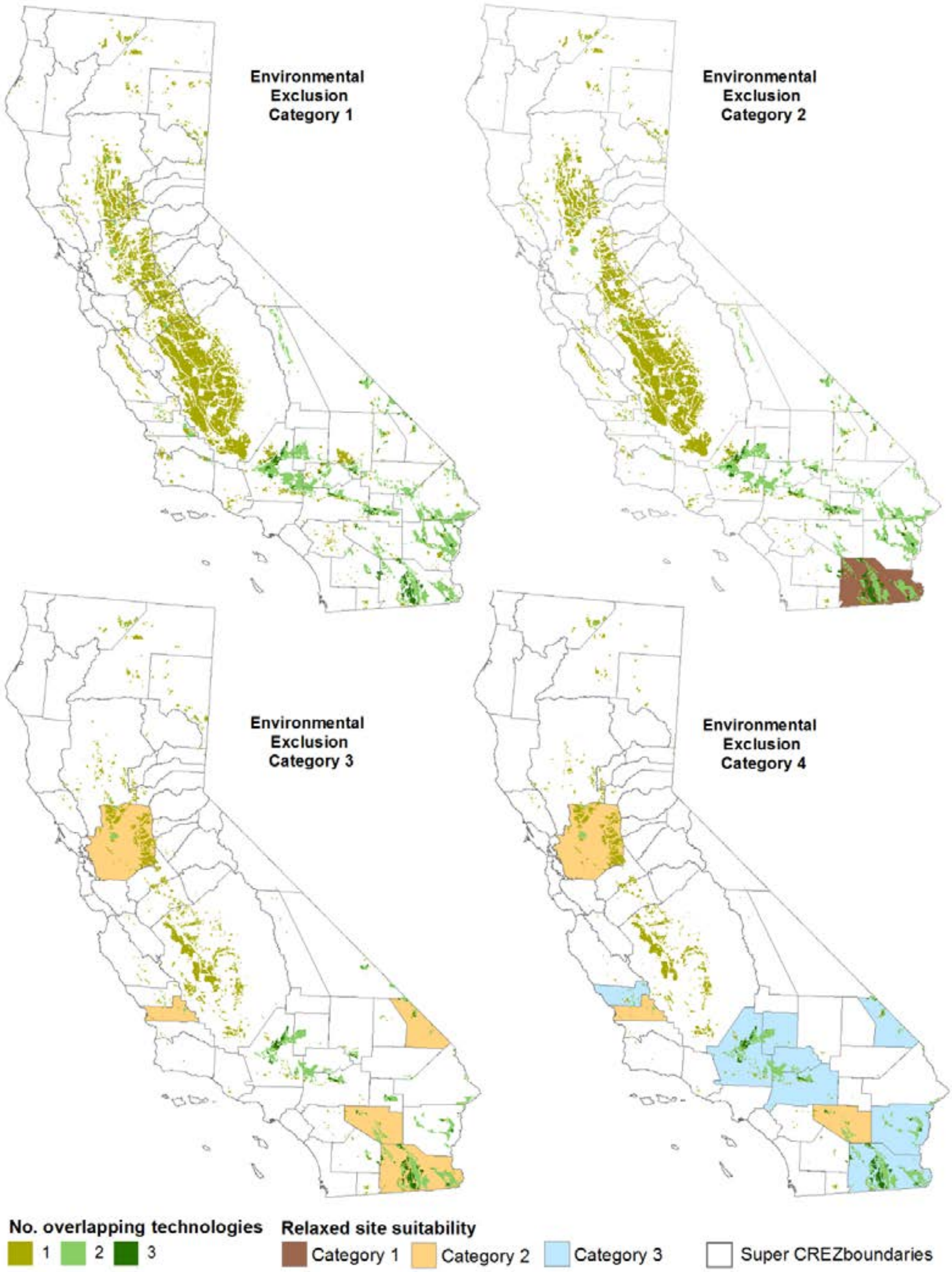

Figure 3. Suitable sites for the development of wind, solar PV, solar CSP, and geothermal under relaxed environmental exclusions.

Colors indicate the number of technologies for which an area is suitable. The maps show suitable sites under Category 1 through 4 Environmental Exclusion Levels. The difference between these maps and those in Figure 2 is the relaxation of particular Super CREZs in order to meet the generation targets of existing or commercial projects in the RPS Calculator portfolio. The color of each Super CREZ indicates the Environmental Exclusion Level to which the site suitability has been relaxed, with white fill being no relaxation. The suitable area within relaxed Super CREZs corresponds to the Exclusion Level to which it has been relaxed.

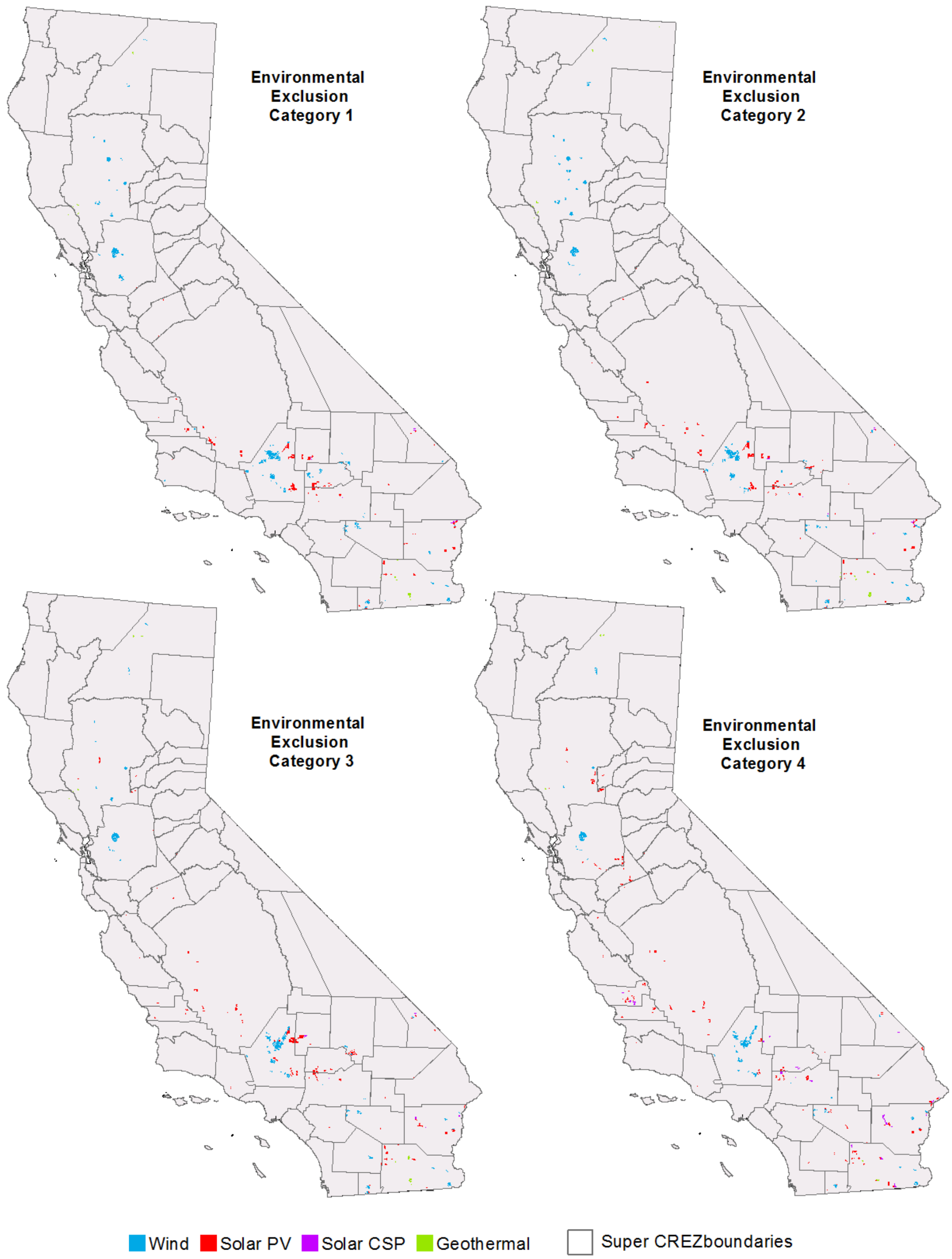

Figure 4. Development zones selected to meet the RPS Calculator's 2030 "50% in-state" renewable energy target. Maps show the optimally selected build-out for each technology using the relaxed site suitability models under the Category 1 through 4 Environmental Exclusion Levels (Figure 3). The ORB model selects development zones from the site suitability model by minimizing the total generation and transmission land area while meeting the RPS calculator portfolio's Super CREZ-specific technology generation requirements.

3.2 Electricity generation and land use efficiency

Generation mix—Overall results show that the more ambitious the RE integration target, the stronger the effect of environmental constraints on the in-state generation mix. In RPS Calculator portfolios that achieve 33% in-state RE generation by 2030, environmental constraints had little impact on the in-state electricity generation of each technology (Figure 5A). The reduction in wind generation with increasing environmental constraints is offset by a proportional increase in solar PV generation (Figure 5A). In the 50% by 2030 in-state and WECC-wide scenarios, generation portfolios change more dramatically in response to the environmental exclusions imposed. If out-of-state (WECC-wide) imports are allowed, increasing the area of environmental exclusions drives down in-state wind generation, which under the Category 2 Exclusion Level, can be addressed cost-effectively with additional in-state solar PV. Under Category 3 and 4 Exclusion Levels, out-of-state wind generation is able to compensate for reduction in in-state wind and solar PV, as observed in the drop in solar PV generation and the overall in-state generation decline (Figure 5A). If electricity must be generated within California (in the 50% in-state scenario), the same reduction in available wind generation under Category 2 and 3 Exclusion Levels must be offset by in-state solar PV. Under Category 4 Exclusion Level in the 50% in-state scenario, a dramatic increase in solar CSP generation largely compensates the reduction in both wind and geothermal generation (Figure 5A).

Land area— The total California land area needed for wind generation decreases at the higher exclusion levels, as generation mixes shift to more solar PV and CSP, and to out of state wind in the WECC-wide scenario (Figure 5C). The area in the in-state 50% scenario for solar PV increases with exclusion levels, and for CSP at the Category 4 Exclusion Level due to the need for over-development of solar technologies beyond demand resulting in solar generation curtailment (see section 3.4 for further explanation of this). However, it may be acceptable to develop more areas of lower conservation value in exchange for avoided impacts in higher quality areas.

Land use efficiency—Reductions in generation land use efficiency (GWh km^{-2}) across Environmental Exclusion Levels and RPS scenario targets are gradual and low, with a few exceptions at high RE penetration and under high environmental constraints (Figure 5C). The decrease in land use efficiency is most notable for solar PV, solar CSP, and geothermal between Category 3 and 4 Exclusion Levels in achieving 50% in-state targets. Land use efficiency for wind decreases most drastically between Category 2 and 3 Exclusion Levels to meet the 33% in-state target. The relative inelasticity of land use efficiency across combinations of RPS targets and environmental exclusion categories is in large part due to the way the RPS Calculator builds portfolios. The Calculator selects the generation mix that minimizes costs, which is directly and largely determined by a development zone's renewable resource quality and thus the zone's land use efficiency. Higher resource quality translates into higher capacity factors and more generation per unit land area (e.g., GWh km^{-2}). Despite the gradual reduction in land use efficiency for each technology as RE penetration and environmental constraints increase, the overall—"all technologies"—land use efficiency increases (Figure 5C) since solar PV generation increasingly substitutes wind generation (Figure 5A), and the land use factor (e.g., MW km^{-2}) of solar PV is significantly greater than that of wind (Table 2). However, the land use areas reported for each technology represent the "total" project land use, which represents the entire area of a wind or solar power plant, as opposed to the direct land use, which represents the land transformed or altered from its natural state due to the presence of the power plant (i.e., just the land footprint of the infrastructure). The direct land use for wind power is significantly lower than that of solar power due to the footprint of wind turbines and roads

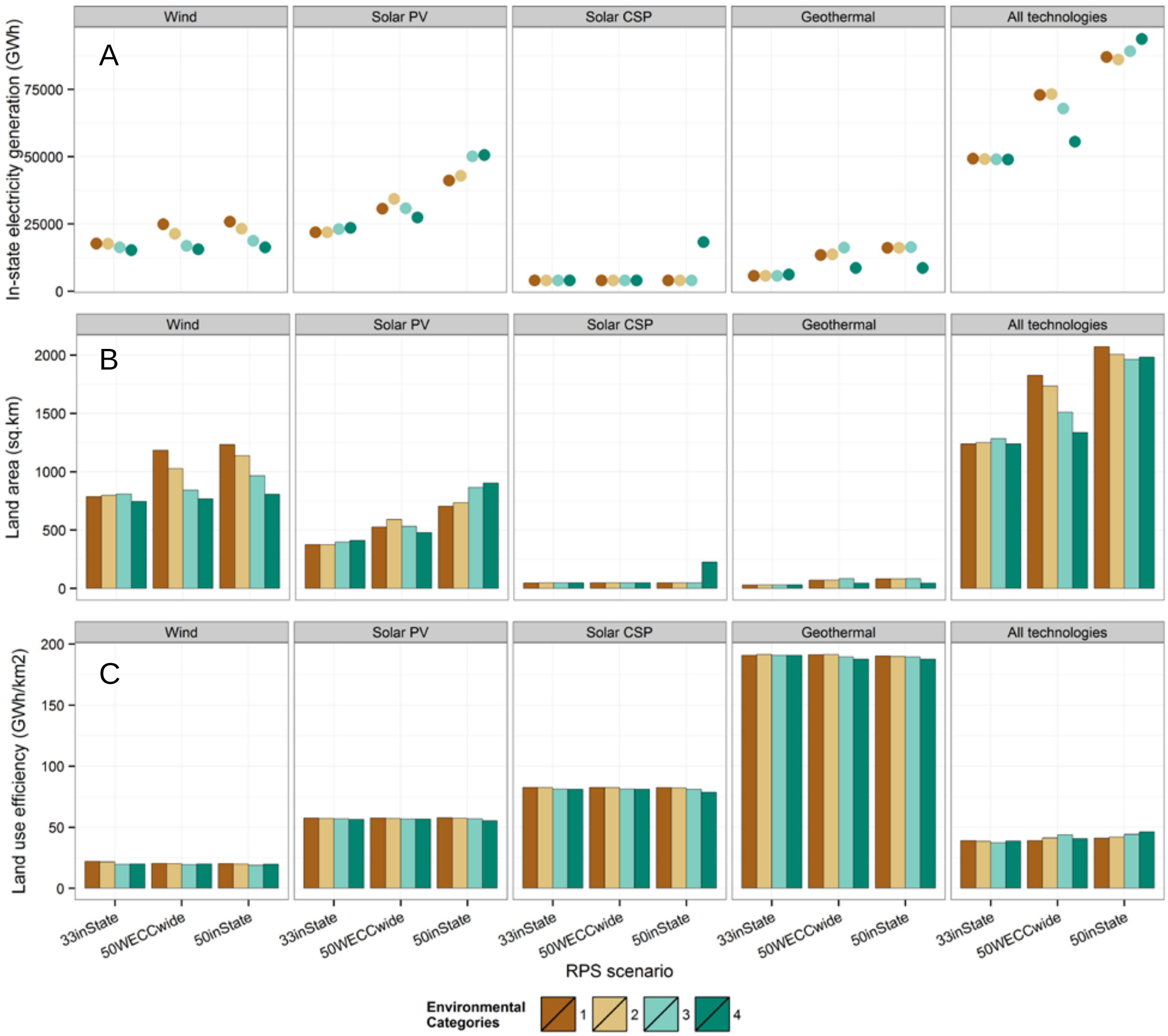

Figure 5. In-state generation and potential land area impacts of 2030 modeled build-out scenarios.
The ratio of in-state electricity generation in GWh (A) to in-state generation land area in km^{-2} (B) is the land use efficiency in GWh km^{-2} (C). These generation and land area metrics are provided for each renewable energy technology or for "all technologies" combined within a particular scenario (e.g., 33% in-state RPS target under Category 1 Environmental Exclusion Level). Generation values and land areas do not include distributed solar PV or distributed wind.

3.3 Conservation, water, and land cover impacts

Conservation impacts—To compare the conservation impacts of imposing environmental constraints on RE build-out, we developed an area-weighted average environmental impact score (EIS) and calculated the area of land falling within each EIS, where higher EIS values indicate greater conservation impact (Figure 6B, Figure 7). See methods section 2.4 for an explanation of the EIS metric. Across all generation technologies as well as an entire RPS portfolio ("All technologies"), results show a decline in average EIS with increasing environmental constraints, which suggests that fewer environmentally sensitive areas would be selected for RE development (Figure 6B). This trend is also clearly observed in the reduction of land areas rated as EISs 3, 2, and 1 with increasing environmental exclusions (Figure 7). The entire RE build-out under the Category 4 Exclusion Level to meet the 50% in-state target has less than 200 km^2 in EIS 2 areas and nearly 1000 km^2 in EIS 0 areas compared to nearly 600 and 360 km^2, respectively, under the Category 1 Exclusion Level (Figure 7).

For solar PV in particular, average EIS decreases substantially and consistently with increasing environmental exclusions, indicating that for solar PV, land impacts can be largely avoided by applying development exclusions. Under the Category 4 Exclusion Level for all RPS scenarios, more than half of all solar PV land areas are sited on land with low conservation value (EIS 0). The average EIS of a large solar PV build-out, such as in the 50% in-state scenario, can be less than that of any other RE technology. The differences in average EIS between Category 3 and 4 Exclusion Levels for wind and solar CSP are negligible, but these scores are significantly lower than those under Category 1 and 2 Exclusion Levels (Figure 6B). Solar CSP under the Category 4 Exclusion Level and in the 50% in-state scenario has a large share of development on EIS 1 land areas (due to the need to relax constraints described in section 2.3.2) but also substantially more development is sited on EIS 0 land area compared to other Environmental Exclusion Levels (Figure 7).

Environmental constraints appear to have lower impacts on geothermal resource quality compared to other technologies, as the ORB model sited geothermal in areas with lower conservation value (average EIS is less than 1) even under the more relaxed environmental constraints. This indicates that some of the highest quality geothermal resources are also in locations that have lower conservation value. The average EIS for geothermal was relatively invariant to changes in environmental constraints, until Category 4 Exclusion Level, an observation that is also consistent with a previous study.[4] Also, geothermal did not experience the same intensity of environmental constraints, since the Imperial Super CREZ, in which a large share of total in-state geothermal generation is sited by the RPS Calculator, needed to be relaxed for three of the four Environmental Exclusion Levels due to the insufficient wind and solar generation (Figure 3).

Landscape fragmentation—Trends in housing density, which is used as a proxy metric for landscape fragmentation (see methods section 2.4), are consistent with and complement trends observed in environmental impact scores (Figure 6C). Across all technologies, an increase in the area of environmental exclusions generally results in development on more fragmented land, which is consistent with environmentally sensitive or high conservation value lands as being more intact and less disturbed by human development (Figure 6C).

Water use—Water consumption is directly proportional to the amount of generation, with the exception of geothermal, which differs by sub-technology depending on the capacity factor of the site (Table 2). Total water consumption across the state will be less than 13,000 annual household-water-demand-equivalents (HWDeq) for all but the most environmentally constrained and highest RE penetration scenario (Figure 6D). Results of spatially disaggregating all technologies' water demand by groundwater basin are shown in Figure A – 2. Spatial disaggregation shows that no groundwater basin will sustain more than 3,000 HWDeq of demand from RE development. As RE penetration increases, additional basins—Salinas, Sacramento Valley, Modoc Plateau, Lucerne Valley, and Lower Mojave River Valley—may begin to experience water demand from RE generation (Figure A – 2). Due to the multi-fold increase in solar CSP generation under the Category 4 Exclusion Level in the 50% in-state generation scenario, several basins experience a significant shift in water demand, with basins like Imperial Valley, Chuckwalla Valley, San Joaquin and Upper Mojave River Valley doubling in water demand, but basins like Antelope Valley reducing water demand by 50% due to a reduction in estimated renewable energy generation in this region. However, under the 50% WECC-wide scenarios, in-state water consumption is reduced across the state, with no single groundwater basin experiencing more than 1000 HWDeq from all RE development (Figure A – 3). Though water demand increases under the Category 4 Exclusion Level in the 50% in-state scenario, the additional demand is distributed across more ground water basins (Figure A – 3).

Land cover types—Analysis of land cover types impacted in each modeled build-out shows that development of wind, solar PV, and solar CSP will predominantly be on warm semi-desert scrub and grassland (Figure 8). However, the dominance of solar PV development on warm semi-desert scrub and grassland declines gradually with increasing environmental constraints in the 33% in-state and 50% WECC-wide scenarios. This results in more development on herbaceous agricultural vegetation, Mediterranean grassland and forb meadow, and developed & urban land cover types as we exclude more areas of conservation value. Due to the increase in solar PV generation targets, solar PV in the 50% in-state scenario even more strongly demonstrates this trend of shifting spatial development patterns from highly concentrated in the southern deserts to greater state-wide dispersion as we impose more environmental constraints (Figure 9). The largest changes in land cover type for wind occur in herbaceous agricultural vegetation, Mediterranean grassland and forb meadow, and warm temperate forest, all of which experience less land transformation from wind development with increasing environmental constraints at 50% in-state and WECC-wide targets. Geothermal is largely sited in agricultural and cool temperate forest lands, which is consistent with the locations of existing geothermal projects.

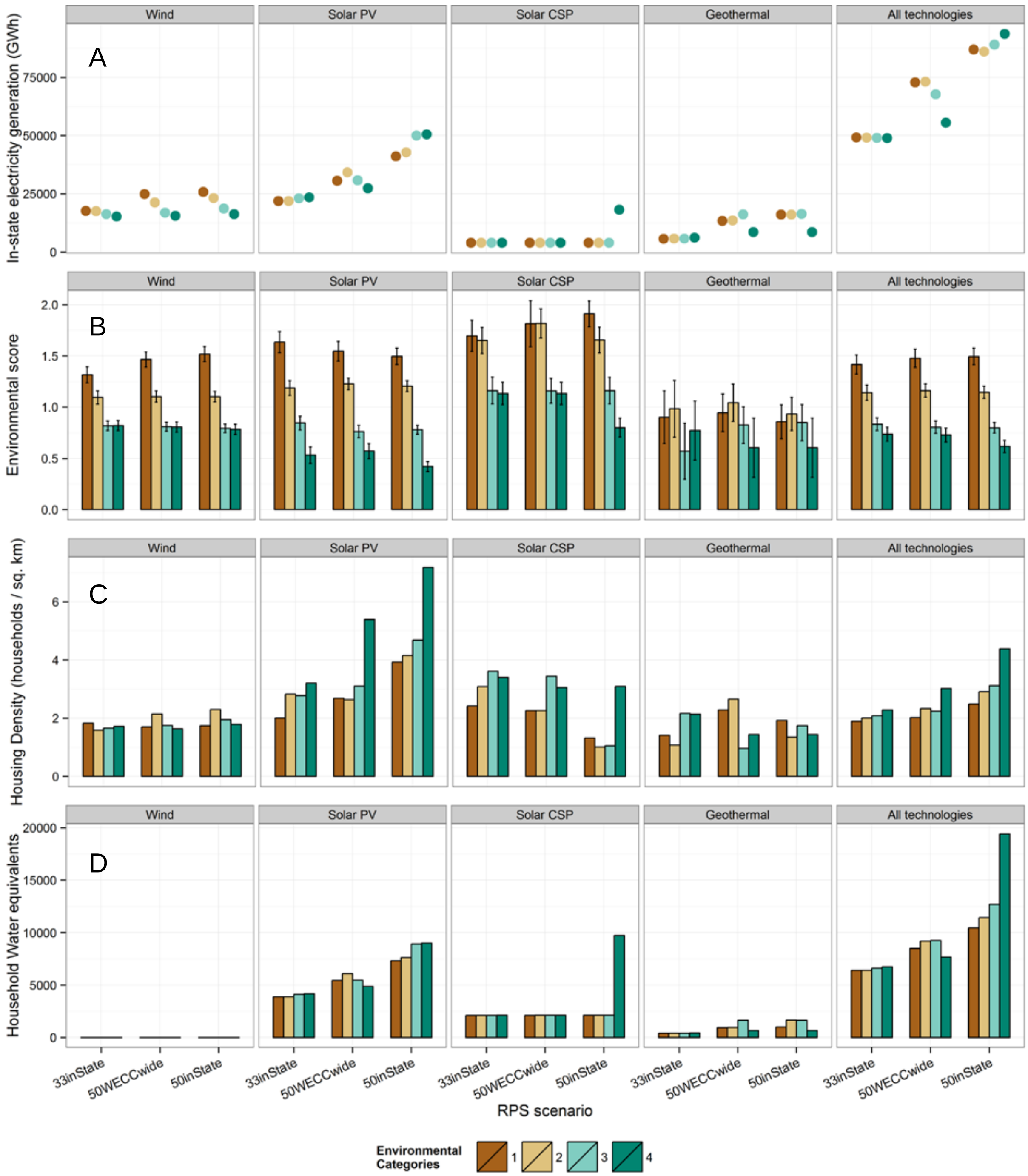

Figure 6. Environmental impacts of 2030 modeled build-out scenarios.

In-state generation (A) is provided as another possible explanatory variable for the trends observed across environmental exclusion categories, RPS scenarios, and technologies. The average environmental impact score (EIS) (B) of a build-out scenario is the area-weighted average EIS occupied by the selected development zones. Average EIS values closer to zero indicate lower conservation impact; larger values indicate higher conservation impact. Error bars show each scenario's standard deviation. Average housing density (C) is used as a proxy for the degree of fragmentation, with areas of higher housing density having greater landscape fragmentation. Household water demand equivalents (D) is the annual water consumption of an average household in the U.S., or 146,000 gal. See section 2.4 for a description of impact metrics.

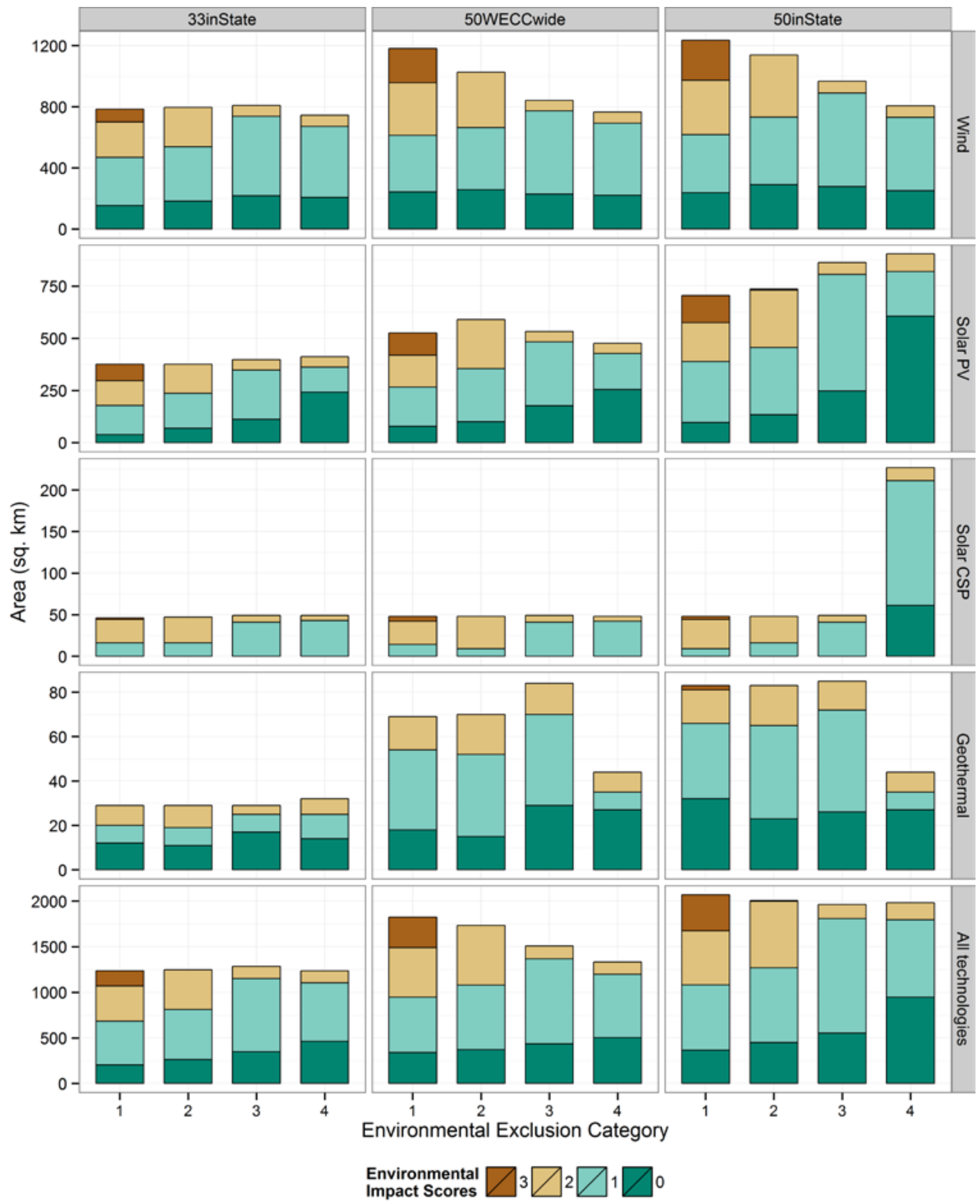

Figure 7. Environmental impact scores of 2030 modeled build-out scenarios' generation land area.
Stacked bars show the area of land falling within each environmental impact score. EIS values closer to zero indicate areas with lower conservation impact; larger values higher conservation impact. The average environmental impact score reported in Figure 6B is the area-weighted average of an entire scenario.

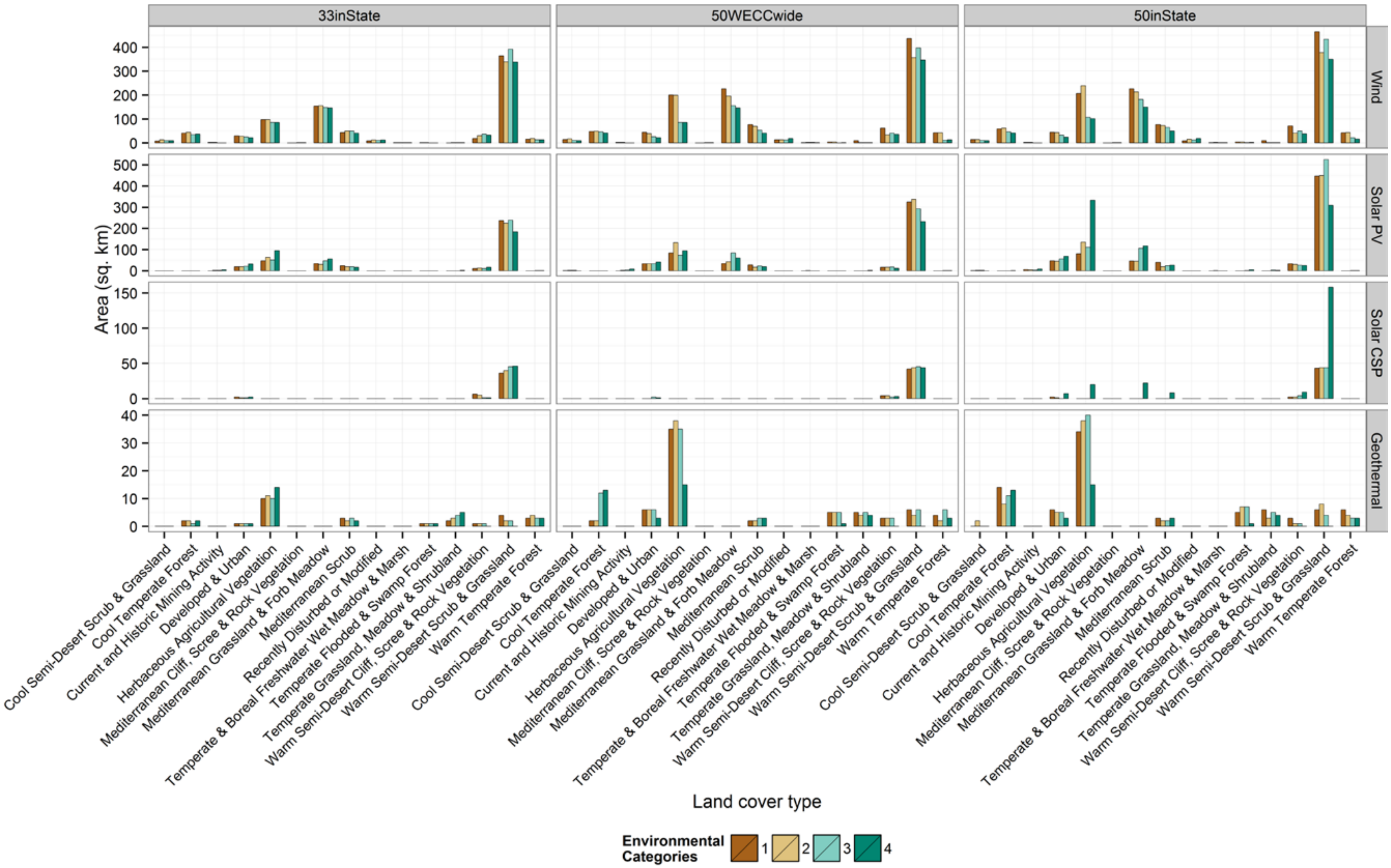

Figure 8. Area of land cover type impacted in each modeled build-out scenario.
Note that the limits of the y-axis differ between generation technologies. Land cover types follow the National Vegetation Classification System (NVCS). Figure 9 depicts the land cover types as they occur throughout California.

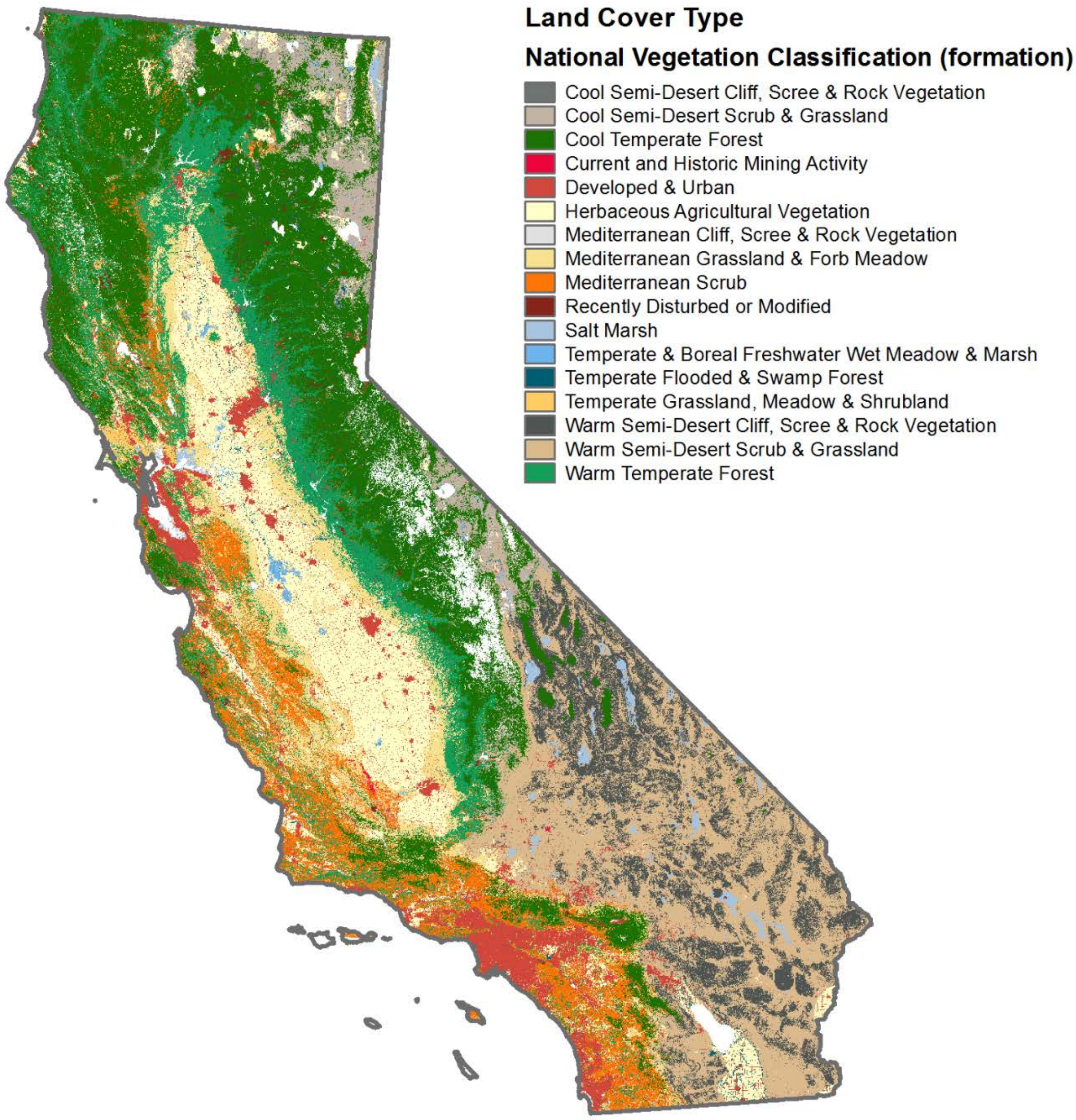

Figure 9. Land cover types in California.
This map is a reference for Figure 8. As such, it only depicts land cover types impacted by modeled renewable energy build-out scenarios.

3.4 Electricity cost impacts

Results of applying environmental exclusions in the RPS Calculator show that the level of in-state RE targets is what largely dictates the economic cost impact of increasing environmental constraints (Figure 10). As California's grid integrates more RE, the greater the electricity cost premium of applying environmental constraints becomes. Total revenue requirement is invariant to increases in environmental constraints in the 33% in-state scenario, with only a 0.2% cost premium under the Category 4 Exclusion Level. The maximum cost premium for the 50% WECC-wide scenario—

under the Category 4 Exclusion Level—is still only 2%, with Category 1 through 3 Exclusion Levels resulting in no greater than a 0.6% electricity cost increase. It is only at the most environmentally constrained and highest *in-state* RE target scenario that the cost premium increases dramatically—from 2% to 12% between Category 3 and 4 Exclusion Levels.

Changes in electricity costs, which reflect both in-state and out-of-state generation and transmission costs incurred by the utility (but do not include mitigation or permitting costs that are specific to particular sites), can be in part explained by changes in total in-state RE generation (Table 1, Figure 5A). The amount of in-state generation steadily increases in the 50% in-state scenario, as more environmental constraints are imposed. This growth is almost entirely attributed to solar PV, which comprises a larger part of the generation portfolio as a result of reduced wind generation. Under Category 4 Exclusion Level in the 50% in-state scenario, curtailment of solar PV during low-demand hours explains the need for overall generation increase to meet the same amount of demand in 2030. Additionally, distributed PV generation (i.e., small scale) contributes approx. 12,000 GWh in the Category 4 Exclusion Level 50% in-state scenario and is not included in the RE generation values reported in Table 1, Figure 5A, or Figure 6A since the ORB model was not designed to model the build-out of distributed generation. As such, the combination of adding more costly distributed solar PV generation, curtailing utility-scale solar PV generation, and large increases in more costly solar CSP generation explains the large cost premium of the Category 4 Exclusion Level, 50% in-state scenario. The 50% WECC-wide scenario avoids the need for a large build-out of solar electricity under the Category 4 Exclusion Level by taking advantage of out-of-state wind resources with higher marginal production value compared to in-state solar.

Additional transmission expansion and upgrade costs also contribute to cost increases, since the share of transmission in the total revenue requirement increases steadily from approximately 10.5% (Category 1) to 11.2% (Category 4) for the 50% in-state target. However, this rate of increase does not keep pace with the rate of increase of total electricity costs between Category 1 and 4 Exclusion Levels for the 50% in-state target. With increasing environmental constraints, transmission costs account for a smaller share of the cost differences between scenarios—it accounts for 32% of the cost difference between Category 1 and 2 Exclusion Level, 17% between Categories 2 and 3, and 16% between Categories 3 and 4.

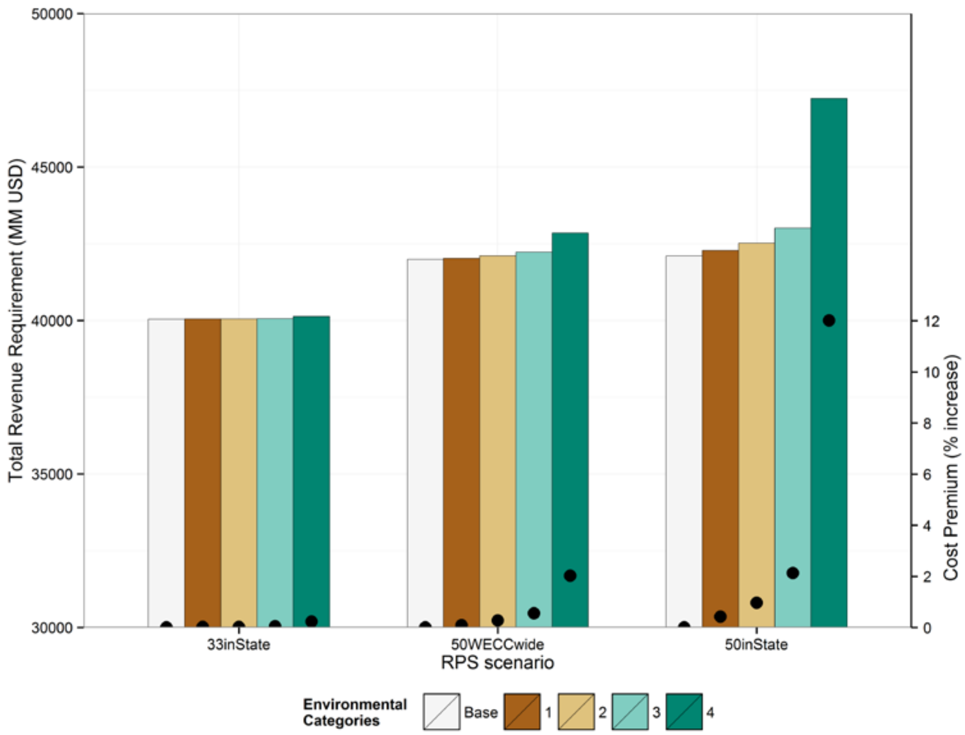

Figure 10. RPS Calculator estimated electricity costs of each Environmental Exclusion Level.
The bar plot corresponds to the primary (left) y-axis indicating the total revenue requirement (total electricity costs) of each RPS Calculator portfolio (note that the left y-axis begins at $30,000 MM USD). The x-axis shows each Environmental Exclusion Level for each RPS target scenario—33% in-state, 50% WECC-wide, 50% in-state by 2030—in increasing order of in-state RE generation. The secondary (right) y-axis and the scatterplot show the electricity cost premium (in percent increase) of imposing an environmental exclusion above the base case. The RPS Calculator's environmental base case is the unmodified Calculator v6.0, which does not incorporate environmental exclusions developed in this present study.

4 Discussion of key findings

RPS Calculator generation portfolios: The RPS target within California largely determines the extent to which the generation mix changes as a result of environmental constraints. Increasing the area of environmental exclusions reduces both the availability and cost of wind generation more consistently and substantially than any other technology examined (Figure 5).

By modifying the available potential under different tiers of environmental constraints within each Super CREZ, we created "environmentally preferred" generation portfolios within the RPS Calculator. Depending on the availability and cost of resources under each set of environmental constraints, these portfolios differ in their generation mix. The percentage target of RE largely determines the extent to which a portfolio changes as a result of environmental constraints. For the 33% in-state target, there is little variation in the generation of each technology except for wind, which consistently declines with increasing environmental exclusions. To achieve 50% in-state and WECC-wide targets, wind generation reduces in response to increasing environmental constraints. If all generation must be in-state, geothermal generation also decreases under the Category 4 Exclusion Level, with the difference largely made up by solar PV and solar CSP. The overall RE generation also increases with greater environmental constraints in this scenario due to the curtailment of solar electricity. However, if WECC-wide generation can be sourced to meet the 50% by 2030 target, in-state wind and solar PV generation that would be excluded under increasing environmental constraints would be substituted by out-of-state wind. As such, the most salient impact of imposing environmental constraints for California land areas in a 50% WECC-wide scenario is the overall reduction in within-state RE generation. This may result in a shift of environmental impact to out of state resources as creating environmentally constrained suitable sites for the entire WECC region was beyond the scope of the study. This suggests the need to coordinate land use and electricity planning at a regional scale to ensure the best climate and conservation outcomes.

Land area and land use efficiency: High renewable resource quality exists in environmentally sensitive areas, which results in a slight reduction in each generation technology's land use efficiency as more environmental exclusions are imposed. However, the relative inelasticity of land use efficiencies to additional environmental constraints suggests that cost-effective substitution of RE technologies is possible under most scenarios and environmental Exclusion Levels (Figure 5).

The general trend is a reduction in land use efficiency with increasing environmental constraints and higher electricity generation. However, the decline in land use efficiency is typically slight, which is likely an effect of the cost-minimizing method in which the RPS Calculator builds a generation portfolio, but is also importantly indicative of the ability for different RE technologies to cost-effectively substitute each other to meet RPS targets, at least until the most stringent Environmental Exclusion Level at highest RE penetration. Within a particular RPS target, the greatest decline (1 GWh km^{-2}) in total land use efficiency occurs between Category 3 and 4 Exclusion Levels for solar PV. That is, after the Category 3 Exclusion Level in the 50% in-state scenario, it becomes increasingly more costly to substitute the reduction in wind and geothermal with solar PV and CSP.

While the differences in land use efficiency have been quantified and compared, a better comparison would be of the resultant economic costs of these differences. It is otherwise difficult to meaningfully understand the impact of a 1 GWh km^{-2} loss in land use efficiency or a particular amount of additional area required to meet targets.

Conservation and land use benefits of environmental exclusions: Imposing environmental constraints on RE development achieves lower environmental impacts and results in development of more fragmented land areas (Figure 6, Figure 7).

Sites optimally selected under only legal exclusions (Category 1 Exclusion Level) are associated with higher environmental impact compared to sites selected under more environmental exclusions. Given that the RE build-outs are spatially modeled by minimizing generation and transmission land area, this result suggests that opportunities for development of high quality resources close to transmission and substations exist within environmentally sensitive areas, a finding that agrees with Wu et al.'s (2015) recent study using different sets of environmental exclusions.[4] These areas of high conservation value and high quality resources are likely to be developed if they are not actively protected. Thus, the incorporation of environmental constraints in RPS planning and siting will be necessary to achieve both conservation and clean energy goals.

Land cover types and geographic diversity: With increased renewable energy generation and environmental exclusions, generation becomes more widely distributed across the state, which results in more development on herbaceous agricultural vegetation, grassland and forb meadow, and developed & urban land cover types (Figure 8).

For solar PV and CSP, which increase in generation under more ambitious RPS 2030 targets, the general trend with increased environmental constraints is a geographic shift of modeled installations from the desert south to other parts of the state, largely northern Mojave, the Central Valley, and Northern California. This geographic dispersion of RE development is more favorable compared to spatially concentrated development from conservation, grid reliability, and system cost standpoints, since geographic heterogeneity reduces aggregate variability of generation and additional generation capable of ramping.[12] Also, a shift towards disturbed land areas (agricultural vegetation and developed and urban land cover types) reduces the burden of development on fragile and intact desert and scrubland ecosystems.

Water consumption: Since renewable energy water demand is directly proportional to increases in generation, more ambitious renewable energy targets result in higher water consumption from renewable generation. However, overall electricity water demand will likely reduce due to the substitution of natural gas combined cycle, which is a more water-intensive generation technology. Under more environmental exclusions, this demand is also more geographically dispersed (Figure 6).

Water demand for electricity generation in any single groundwater basin does not exceed the annual water demand equivalent to 3,000 households, with most groundwater basins experiencing no more than 1000 household water demand equivalents. Under the Category 4 Exclusion Level, the water demand for WECC-wide and 33% in state scenarios of any single groundwater basin does not exceed the annual water demand equivalent to approximately 1000 households. Although water requirements from the four technologies examined in this study do increase with increasing RE penetration, the total water demand from electricity generation is likely to decrease since RE displaces conventional thermal technologies such as nuclear and natural gas that are much more water intensive per MWh of generation.

Electricity costs and balancing the benefits of land conservation: Minimizing both negative conservation impacts and electricity costs at high renewable energy penetration may require California to utilize WECC-wide renewable energy resources (Figure 10).

Meeting the 50% in-state target by 2030 under the Category 4 Exclusion Level is possible and would result in a 60% reduction in average environmental impact score or a 40% reduction in development on land areas with EIS 1, 2, and 3, compared to the build-out under the Category 1 Exclusion Level. However, doing so would incur an 82% increase in water consumption and a 12% increase in costs over the Category 1 Exclusion Level case. If environmental exclusions were reduced to Category 3 Exclusion Level to achieve the same 50% in-state target, the water and cost impacts would drop dramatically—to 20% increase in water consumption and a 2% cost premium—but it would only achieve a 47% reduction in average EIS or a 17% reduction in development on EIS 1-3 land areas. If the RPS portfolio could include WECC-wide resources, it would be possible to meet the most ambitious RPS target of 50% under the most stringent set of in-state environmental exclusions for only a 2% cost premium. The 50% WECC-wide build-out under the Category 4 Exclusion Level also uses less water and achieves more than 50% reduction in average environmental impact score or a 44% reduction in development on EIS 1-3 land areas, compared to the build-out under the Category 1 Exclusion Level.

Selecting the appropriate set of environmental constraints, which may be a combination of technology-specific stringencies, will need to balance cost impacts with conservation, water, and grid benefits. Without monetary valuation of the total avoided ecosystem, ecological, and land use costs, as well as costs associated with permitting, delays, and mitigation, under each set of environmental exclusions, it is difficult to objectively determine whether the economic value of the environmental benefits justify a 2% or a 12% premium in electricity costs—i.e., whether the benefits exceed the costs in each scenario. As such, the results as they are presented in this study are inadequate for an objective decision within a traditional cost-benefit framework. Using a cost-effectiveness framework (e.g., USD per unit conservation value) could improve the tangibility of these conservation benefit vs. electricity cost comparisons.

5 References

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6 Appendix

Table A – 1. Data sources

Dataset	Source	Data type/ resolution
PHYSICAL, TECHNICAL, SOCIO-ECONOMIC		
Insolation (GHI and DNI)	National Renewable Energy Lab: Solar Maps http://www.nrel.gov/gis/data_solar.html	Feature/10km
Wind capacity factors	National Renewable Energy Lab: The Wind Integration National Dataset (WIND) Toolkit	Point feature (2 km resolution)
Geothermal favorability	USGS Geothermal Favorability Map Derived From Logistic Regression Models and Identified Moderate and High Temperature Geothermal Systems of the Western US http://certmapper.cr.usgs.gov/geoportal/rest/find/document?searchText=Geothermal&max=500&f=html&style=http://certmapper.cr.usgs.gov/geoportal/catalog/skins/themes/erp/previewlittle.css	Feature
Elevation (DEM) and slope	U.S. Geological Survey: EarthExplorer: http://earthexplorer.usgs.gov/ SRTM dataset	Raster/d90m
Minimum contiguous area	Lopez et al. (2012)[13], RETI[3], WGA[5]	Numerical values
Water bodies and rivers	Solar Energy Development Programmatic EIS (Solar PEIS): http://solareis.anl.gov/maps/gis/index.cfm	Polygon
Census urban zones	U.S. Tiger dataset: http://www.census.gov/cgibin/geo/shapefiles2011/main	Polygon
Population density (people/km^2)	Landscan 2012: http://web.ornl.gov/sci/landscan/	Raster/1km
Surface mines (hazardous facility)	U.S. Geological Survey: Active mines and mineral plants in the U.S. http://mrdata.usgs.gov/mineplant/	Point
Airports (hazardous facility)	National Transportation Atlas Database: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2013/points.html	Point
Roads	Solar PEIS and National Transportation Database: National Highway Planning Network. U.S. Tiger dataset for roads by county: http://www.census.gov/geo/maps-data/data/tiger-line.html	Polyline
Railway network	National Transportation Atlas Database: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2013/polyline.html	Polyline
Military Installations (hazardous facility)	US-PAD (see below for environmental datasets)	Polygon
ENVIRONMENTAL – See Table A – 2 for data sources		
OTHER		
Land cover types	U.S. Geological Survey National Gap Analysis Program Land Cover Data http://gapanalysis.usgs.gov/gaplandcover/data/download/	Raster/30m
Super CREZ boundaries	California Public Utilities Commission RPS Proceeding Materials Version 6.0: http://www.cpuc.ca.gov/PUC/energy/Renewables/RPS+Proceeding+Materials+Version+6.htm	Feature
Housing density	USDA Forest Service and University of Wisconsin-Madison U.S. 2010 Block Level Housing Density- Public Land Adjusted http://silvis.forest.wisc.edu/maps/blk_pla/2010/download	Raster / 30 m
ENERGY INFRASTRUCTURE		
PV plants	California Energy Commission (CEC); EIA form 860: http://www.eia.gov/electricity/data/eia860/	Geographic coordinates
CSP plants	CEC; EIA	Geographic coordinates

Wind farms	CEC; EIA	Geographic coordinates
Geothermal	CEC; EIA; Geothermal Power Plants-USA: http://geo-energy.org/plants.aspx	Geographic coordinates
Transmission lines, substations, and corridors	- California Energy Commission Siting, Transmission, and Environmental Protection Division. - planned corridors: West Wide Energy Corridor Environmental Impact Statement, section 368 corridors: http://corridoreis.anl.gov/eis/fmap/gis/index.cfm	Polyline and points

Table A - 2. Classification of environmental and ecological data into environmental exclusion categories. See legend below table for explanation of color scheme.

Category 1	Data source
National park system (parks, preserves, historic parks, historical sites, lakeshores) [all studies]	**Organization**: U.S. Geological Survey **Name**: Protected Areas of the U.S. Database, Version v3.1: **Website:** http://gapanalysis.usgs.gov/padus/data/download/ Henceforth referred to as PAD-US **Notes**: PAD-US (search for "National Park System")
National Recreation Areas [all studies]	PAD-US ("National Recreation Areas")
National Wildlife Refuges (US FWS) & state (under "Habitat and Species Mgmt Areas" in PAD-US) [all studies]	PAD-US ("National and State Wildlife Refuge")
USFS Inventoried Roadless areas (add separately to PAD-US) [all studies]	**Organization**: Solar Programmatic Environmental Impact Statement **Name**: Core final solar PEIS data files **Website:** http://solareis.anl.gov/maps/gis/index.cfm Henceforth referred to as SPEIS
Designated Federal Wilderness Areas and Wilderness Study Areas [all studies]	From multiple sources: PAD-US ("Fed Wilderness Areas and Wilderness Study Areas"), SPEIS, WSEP **Organization**: Bureau of Land Management (BLM) **Name**: BLM Western Solar Energy Plan (WSEP) **Website**: http://blmsolar.anl.gov/maps/shapefiles/ Henceforth referred to as WSEP
BLM National Conservation Areas (under "National Landscape conservation system" in PAD-US) (just King Range, Black Rock, High Rock, Headwaters Forest Reserve) [RETI]	PAD-US ("Select BLM National Conservation Areas"), WSEP, SPEIS
(NPS) National Monument	PAD-US ("(NPS) National Monument"), WSEP, SPEIS
(BLM) National Monument	PAD-US ("(BLM) National Monument"), WSEP, SPEIS
National historic and scenic trails	PAD-US –none within CA, WSEP, SPEIS
National wild, scenic and recreational rivers	PAD-US ("National Wild, Scenic, and Recreational River"), WSEP, SPEIS
BLM ROW exclusion [WREZ & WECC] - all technologies	SPEIS
BLM Special recreation management areas [WREZ & WECC] - solar	WSEP
BLM no surface occupancy restriction areas [WREZ & WECC] - solar	WSEP
BLM designated and proposed Research Natural Areas + Sikes Act Tracts [WREZ & WECC] - solar	PAD-US ("BLM Research Natural Area")
Area of Critical Environmental Concern on BLM land ONLY [all studies] - for solar	WSEP
BLM Wildlife Management Areas [WREZ & WECC] - solar	PAD-US ("BLM Wildlife Management Areas")
State Parks (CA, MT, OR, WA, WY)	PAD-US ("State Parks")

State Wilderness Areas [all studies]	PAD-US ("State Wilderness Areas and Wilderness Study Areas")
State forest [WREZ]	PAD-US ("State Forest")
DFG (now called Department of Fish and Wildlife) wildlife areas and ecological reserves [RETI] and State wildlife areas	PAD-US ("DFW wildlife areas and ecological reserves")
Existing conservation and mitigation banks under conservation easements (CA) [all studies]	**Organization**: GreenInfo Network **Name**: California Conservation Easement Database (CCED) **Website**: http://www.calands.org/cced
Existing Conservation and Mitigation Bank	PAD-US ("Conservation and Mitigation Bank"); CADFW
Lands purchased with private funds and donated to federal government [RETI] (The Wildlands Conservancy)	TNC
(State and national) wetlands [all studies]	**Organization**: US Fish and Wildlife Service **Name**: National Wetlands Inventory. **Website**: http://www.fws.gov/wetlands/Data/State-Downloads.html
Watershed Protection Areas [WREZ]	PAD-US ("Watershed Protection Areas")
Marine Protected Areas [WECC]	PAD-US ("Marine Protected Areas")
Historic/Cultural areas with Gap statuses 3,4	PAD-US ("Historic or cultural areas")
Private Conservation Land (non-conservation easements in CA) (P_Des_type in PAD-US) and other Private non-profit land [WECC]	PAD-US ("Private Conservation Land")
Category 2	**Data source**
BLM National Conservation Areas (All others)	PAD-US ("BLM National Conservation Area"), WSEP, SPEIS
BLM Visual Resource Management class I and II [WREZ]	SPEIS
BLM ROW avoidance [WREZ & WECC] - all technologies	SPEIS
BLM Special recreation management areas [WREZ & WECC] - wind and geothermal	WSEP, SPEIS
BLM no surface occupancy restriction areas [WREZ & WECC] - wind and geothermal	WSEP and SPEIS
BLM designated and proposed Research Natural Areas + Sikes Act Tracts [WREZ & WECC] - wind and geothermal	PAD-US
BLM Wildlife Management Areas [WREZ & WECC] - wind and geothermal	PAD-US
Desert Wildlife Management Areas (DWMA) [RETI] - all technologies	WSEP and SPEIS
USFS Research Natural Areas [WREZ & WECC]	PAD-US ("Research Natural Areas")
USFS Special interest areas [WREZ & WECC]	PAD-US - none exist
Area of Critical Environmental Concern on BLM land [all studies] - for wind and geothermal	WSEP and SPEIS
Area of Critical Environmental Concern on non-BLM land [all studies] - all technologies	SPEIS
State reserves (State Natural Reserves, e.g., Torrey Pines Reserve, Antelope valley poppy reserve)	PADUS ("Reserves")
Other wildlife areas and ecological reserves(BLM, county, Bureau of reclamation)	PADUS (Other wildlife areas and ecological reserves)
LA county Significant Ecological Areas - existing	**Organization**: LA County Department of Regional Planning **Name**: Significant Ecological Areas

	Website: http://planning.lacounty.gov/sea/proposed Henceforth referred to as LACSEA
Moved to Cat 2: lands precluded from development in Habitat Conservation Plans [RETI]	**Organization**: RETI GIS data **Name**: GIS data for Phase 2B **Website**: http://www.energy.ca.gov/reti/documents/index.html Henceforth referred to as RETI GIS data
Moved to Cat 2: Lands precluded from development under Natural Community Conservation Plans [RETI]	RETI GIS data
Habitat areas for listed wildlife species mapped by State, Provincial or Federal Agencies [WECC]	**Organization**: Fish and Wildlife Service (FWS) **Name**: critical habitat portal **Website**: www.criticalhabitat.fws.gov
USFWS Designated critical habitat for federally listed endangered and threatened species [RETI] (includes Desert Tortoise, Peninsular BHS, FTL)	FWS critical habitat portal Fringed Toe Lizard: BLM West Mojave Plan from California PBHS: Essential Habitat from USFWS Department of Fish and Wildlife Service (DFWS)
USFWS Upland Species Recovery Units	**Organization**: U.S. Fish and Wildlife Service **Name**: San Jose kit fox core areas **Website**: http://www.fws.gov/ecos/ajax/docs/five_year_review/doc3222.pdf
USFWS Sage Grouse Core or Priority Areas	**Organization**: CA BLM and CA Fish and Game **Name**: "GRSG Preliminary PRIORITY Habitat (PPH) GIS Data as of 3/21/2012*" **Website**: http://www.blm.gov/wo/st/en/prog/more/sagegrouse/documents_and_resources.html) Multi-source dataset: WSEP and BLM/CAFG PPH
Mojave Ground Squirrel (MGS) Conservation Areas (core areas)	BLM West Mojave Plan 2005
Category 3 (terrestrial only)	**Data source**
Land in wilderness bills [RETI] - includes Sand to Snow, (Mojave Trails national Monument) National Trails Monument	TNC and WSEP
LA county Significant Ecological Areas- proposed	LACSEA
Habitat areas for candidate wildlife species mapped by State, Provincial or Federal Agencies [WECC]	TNC (FTHL, MGS)
Prime Farmland	**Organization:** California Department of Conservation **Name:** Williamson act –Farmland Mapping and Monitoring Program (FMMP) in CA **Website**: http://www.conservation.ca.gov/dlrp/ fmmp/products/Pages/DownloadGISdata.aspx **Notes**: created a merged dataset using 2010, 2012
The Nature Conservancy Portfolio Areas	**Paper**: TNC Portfolio Areas – The Nature Conservancy, California Chapter Ecoregional Plans 1993 – 2004 Notes: Sonoran and Mojave Desert regions removed as they are superseded by other datasets
The Nature Conservancy Ecologically Core for CA deserts	**Organization**: The Nature Conservancy **Name**: Randall JM, Parker SS, Moore J, Cohen B, Crane L, et al. (2010) Mojave Desert Ecoregional Assessment. San Francisco, CA: The Nature Conservancy. 106 p. The Nature Conservancy. (2009) A framework for effective conservation management of the Sonoran Desert in California. Unpublished report. **Website:** http://www.drecp.org/meetings/2010-10-13_meeting/presentations/TNC_Mojave_Assessment.pdf Henceforth referred to as "TNC-Randall et al. 2010"

California Rangeland Conservation Coalition priority conservation areas- priority 1	Organization: California Rangeland Conservation Coalition Name: CRCC Focus Areas Website: http://www.rangelandtrust.org/index.php
Desert tortoise least cost path/ linkages - FWS Priority 1 == base (all costs considered)	**Paper**: Averill-Murray, R.C. 2013. Conserving Population Linkages for the Mojave Desert Tortoise (Gopherus agassizii). Herpetological Conservation and Biology 8(1): 1-15. **Website**: http://databasin.org/datasets/9a5f60c89e284606b3017954c1efebb1
Citizen's inventory wilderness data	**Organization**: California Wilderness Coalition **Name**: Citizen's inventory wilderness data **Website**: http://www.calwild.org/
Phil Leitner's MGS core areas	Leitner, P. 2008. "Current Status of the Mohave Ground Squirrel." *Transactions of the Western Section of the Wildlife Society* 44:11-29.
Category 3 (freshwater only)	**Data source**
Conservation value areas for freshwater species	TNC
Category 4 (terrestrial only)	**Data source**
The Nature Conservancy Ecologically Intact for CA deserts	TNC-Randall et al. 2010
California Rangeland Conservation Coalition priority conservation areas- priority 2	CRCC
Desert tortoise High quality contiguous habitat - FWS Priority 2 == binned1	See Averill-Murray et al. 2013 paper (above)
California Essential Habitat Connectivity Areas [TNC] and State wildlife corridors [WECC]	**Organization**: California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration **Name**: Essential Connectivity areas of California **Website**: https://www.wildlife.ca.gov/Conservation/Planning/Connectivity/CEHC **Report**: Spencer,W.D.,P. Beier,K. Penrod,K. Winters,C. Paulman,H. Rustigian-Romsos,J. Strittholt,M. Parisi,and A. Pettler. 2010. California Essential Habitat Connectivity Project: A Strategy for Conserving a Connected California.
Mojave Ground Squirrel (candidate species) Maxent site suitability model at 0.438 cutoff	**Paper**: Inman RD, Esque TC, Nussear KE, Leitner P, Matocq MD, Weisberg PJ, Diltd TE, Vandergast AG. (2013) Is there room for all of us? Renewable energy and Xerospermophilus mohavensis. Endang Species Res 20:1-18 **Website**:http://databasin.org/datasets/063de529c9dd4635bb9f019cd0c0ca2a
Audubon Society compiled Important bird areas (state, continental, and global) [WECC]	**Organization**: Audubon California **Name**: California Important Bird Areas **Website**: http://ca.audubon.org/california-important-bird-areas-gis-data-and-methods
Category 4 (freshwater only)	**Data sources**
Groundwater dependent ecosystems	**Paper**: Howard J, Merrifield M (2010) Mapping Groundwater Dependent Ecosystems in California. PLoS ONE 5(6): e11249. doi:10.1371/journal.pone.0011249

LEGEND
Federal land
State land
Other or mixed
Criteria differs between solar and non-solar technologies

Table A – 3. GIS exclusion criteria and buffer distances to assess suitable sites.

Criteria	Solar PV	Solar CSP	Wind	Geothermal
PHYSICAL, TECHNICAL, SOCIO-ECONOMIC				
Raw renewable resource	Global Horizontal Insolation (GHI) < 5.0† kWh m^{-2} d^{-1}	Direct Normal Insolation (DNI) < 6.75 kWh m^{-2} d^{-1}	NREL Wind toolkit resource areas	USGS geothermal class < 9 (Max: 10)
Slope	> 5%	> 5%	> 25%	> 15%
Elevation (DEM)	> 1500 m	> 1500 m	> 2000 m	> 1500 m
Contiguous area	< 1 km^2	< 5 km^2	< 2 km^2	< 1 km^2
Water bodies and rivers	EX§	EX	EX	EX
Census urban zones	EX: 0.5 km	EX: 0.5 km	EX: 1 km	EX: 1 km
Population density (people km^{-2})	> 100	> 100	>100	>100
Surface mines (hazardous facility)	EX: 1 km	EX: 1 km	EX: 1 km	EX: 1 km
Airports (hazardous facility)	EX: 1 km	EX: 1 km	EX: 1 km	EX: 1 km
Roads	EX	EX	EX	EX
Rails	EX	EX	EX	EX
Military Installations (hazardous facility)	EX: 0.5 km	EX: 0.5 km	EX: 0.5 km	EX: 0.5 km
ENVIRONMENTAL				
All Layers	EX: 0.5 km	EX: 0.5 km	EX: 0.5 km	EX: 0.5 km

† Greater than or less than values indicate thresholds for exclusion.
¥ "IN" indicates inclusion of criteria and width of buffer if applicable.
§ "EX" indicates exclusion and width of buffer if applicable.

Section A – 1. Estimation of capacity factors for PV, CSP, and geothermal development zones.

Solar PV:

$$CF = \frac{GHI}{I_{max}} d \cdot o \qquad \text{(A – Eq 1)}$$

GHI is the global horizontal insolation (average daily solar radiation) in kWh $m^{-2}d^{-1}$. I_{max} is the peak insolation or 2400 kWh $m^{-2}d^{-1}$, assuming a PV input rating and peak solar radiation of 1 kW m^{-2}. The efficiency loss factor is d and the outage rate is o; both are assumed to be 0.96 in this study.

CSP:

Assuming a no-storage system with a solar multiple of 1.3, we ran the National Renewable Energy Laboratory's System Advisor Model (SAM)[14] generic CSP model for 22 locations in central and southern California and plotted the DNI of each location against the estimated CSP capacity factor (CF; Figure A-1). The logarithmic function that was fitted to the data (A – Eq 2) was used to predict the CF of each CSP development zone resulting from the site suitability models.

Figure A -1. Capacity factor of generic CSP power plant vs. DNI.

$$CF = 24.518 \log DNI - 18.326 \qquad \text{(A – Eq 2)}$$

We assumed no storage in this analysis due to the limitations of empirical studies quantifying the land use factor (MW km^{-2}) of existing CSP plants in the U.S.[8] Only one or two CSP plants with storage were quantified, compared to more than a dozen CSP plants without storage. However, given that installed capacity and capacity factor are roughly inversely proportional, the total electricity generated of storage and no-storage system should be very similar per unit of land. This is because generator capacity of storage systems will be smaller per unit of land due to the increasing solar multiple necessary for storage systems, but the capacity factor increases since storage enables the generator to be used for many additional hours of the day.

Geothermal:

$$CF = 0.87 \cdot \frac{RQ}{10} \qquad \text{(A – Eq 3)}$$

RQ is the resource quality of geothermal and is a unit-less measure of geothermal feasibility that ranges from 1 to 10, where 10 represents the most feasible geothermal sites. 0.87 is the average capacity factor assumed for geothermal in Williams et al. 2012.[15]

Electricity generation estimation:

$$e_{t,z} = C_t \cdot a_z \cdot CF_{z,t} \cdot h \qquad \text{(A – Eq 4)}$$

The annual average electricity generation $e_{z,t}$ for zone z and technology t. C_t is the rated installed capacity per unit of land or the land use factor in units of MW km^{-2} for technology t. The land area of zone z in km^2 is a_z, the capacity factor of zone z and technology t is represented by $CF_{z,t}$, and h is the number of hours in a year, or 8760.

Table A – 4. Wind potential (MW) within each Super CREZ under each Environmental Exclusion Level.

Super CREZ	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 3 (FW[1])	Cat. 4 (FW)	RPS Calc (base)
Barstow	3445	481	399	0	399	0	208
CarrizoNorth	0	0	0	0	0	0	67
CarrizoSouth	36	0	0	0	0	0	507
CentralValleyNorth	90	90	32	0	32	0	0
Cuyama	31	31	0	0	0	0	0
Distributed	0	0	0	0	0	0	253
El DoradoCounty	0	0	0	0	0	0	0
Fairmont	0	0	0	0	0	0	
Imperial East	321	315	230	0	0	0	
Imperial South	30	0	0	0	0	0	
ImperialNorth	0	0	0	0	0	0	
Imperial_N+S+E	351	315	230	0	230	0	361
Inyokern	0	0	0	0	0	0	0
IronMountain	686	120	0	0	0	0	0
Kramer	313	141	39	0	39	0	0
LassenNorth	2532	1387	968	435	648	146	2032
LassenSouth	0	0	0	0	0	0	0
Merced	0	0	0	0	0	0	0
MountainPass	590	393	0	0	0	0	0
NonCREZ	0	0	0	0	0	0	0
OwensValley	0	0	0	0	0	0	0
PalmSprings	746	442	371	263	265	181	212
Pisgah	346	48	0	0	0	0	0
RiversideEast	1712	1034	443	180	443	180	309
RoundMountain_A	342	290	231	117	0	0	
RoundMountain_B	512	512	419	419	0	0	
RoundMountain_A+B	854	801	650	536	221	107	220
SacramentoRiverValley	1997	1968	528	240	528	231	3248
SanBernardino_Baker	670	655	56	0	56	0	0
SanBernardino_Lucerne	1949	1729	992	155	992	155	82
SanDiegoNorthCentral	279	270	176	0	168	0	168
SanDiegoSouth	414	394	394	242	394	234	399
SantaBarbara	176	0	0	0	0	0	702
Solano	2601	1493	671	221	443	104	1354
Tehachapi	6785	5865	3437	104	3201	68	1131
TwentyninePalms	942	851	150	0	150	0	124
Victorville	1027	86	0	0	0	0	1093
Westlands	153	147	0	0	0	0	0
SUM	28,725	18,740	9,531	2,374	8,206	1,404	12,471

[1] FW indicates freshwater exclusions combined with terrestrial exclusions

Table A – 5. Solar PV potential (MW) within each Super CREZ under each Environmental Exclusion Level.

Super CREZ	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 3 (FW[1])	Cat. 4 (FW)	RPS Calc (base)
Barstow	10487	7483	4973	615	4973	533	1740
CarrizoNorth	7420	5822	3773	3195	3773	3195	1519
CarrizoSouth	8800	2003	180	0	75	0	1321
CentralValleyNorth	45391	37449	6677	4392	6677	4362	1638
Cuyama	3783	2480	443	443	443	375	793
Distributed	0	0	0	0	0	0	15319
El DoradoCounty	248	248	0	0	0	0	0
Fairmont	0	0	0	0	0	0	
Imperial East	22140	18525	11325	510	0	0	
Imperial South	29700	29340	7928	0	0	0	
ImperialNorth	33517	32262	18559	2760	0	0	
Imperial_N+S+E	85357	80126	37811	3270	34687	3053	7509
Inyokern	0	0	0	0	0	0	981
IronMountain	44366	38821	7298	2260	7298	1900	3817
Kramer	21863	16864	10064	0	10064	0	2598
LassenNorth	5011	5011	4943	128	4291	128	5728
LassenSouth	0	0	0	0	0	0	0
Merced	0	0	0	0	0	0	0
MountainPass	5694	5694	1151	0	1151	0	560
NonCREZ	0	0	0	0	0	0	0
OwensValley	13068	9887	878	398	780	143	2003
PalmSprings	11989	10761	3546	2355	3546	2355	1276
Pisgah	17107	13867	829	362	829	354	470
RiversideEast	61618	57106	19047	3460	18799	3460	4691
RoundMountain_A	0	0	0	0	0	0	
RoundMountain_B	0	0	0	0	0	0	
RoundMountain_A+B	0	0	0	0	0	0	12246
SacramentoRiverValley	100624	95412	18340	12227	16356	10276	12468
SanBernardino_Baker	6566	6454	855	0	855	0	688
SanBernardino_Lucerne	23164	22976	14865	3510	14378	3158	2240
SanDiegoNorthCentral	7375	6095	4165	1808	3573	1583	991
SanDiegoSouth	459	395	395	195	395	195	268
SantaBarbara	7565	4995	345	345	158	158	1021
Solano	115899	69054	16356	9264	15666	8334	6162
Tehachapi	69833	59283	37363	360	36178	360	4888
TwentyninePalms	15864	15827	6195	83	6195	0	997
Victorville	21022	17749	10006	0	9983	0	2405
Westlands	475387	436721	146975	111733	146203	110690	13681
SUM	1,185,959	1,028,582	357,474	160,401	347,325	154,609	110,024

[1] FW indicates freshwater exclusions combined with terrestrial exclusions

Table A – 6. Solar CSP potential (MW) within each Super CREZ under each Environmental Exclusion Level.

Super CREZ	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 3 (FW[1])	Cat. 4 (FW)	RPS Calc (base)
Barstow	9006	6884	4815	420	4815	405	2800
CarrizoNorth	3330	2408	1763	1763	1763	1763	3200
CarrizoSouth	4969	1395	0	0	0	0	6000
CentralValleyNorth	0	0	0	0	0	0	0
Cuyama	1929	1124	0	0	0	0	800
Distributed	0	0	0	0	0	0	0
El DoradoCounty	0	0	0	0	0	0	0
Fairmont	0	0	0	0	0	0	
Imperial East	21495	17813	10995	510	0	0	
Imperial South	27840	27310	6281	0	0	0	
ImperialNorth	31799	30711	17181	2520	0	0	
Imperial_N+S+E	81134	75834	34456	3030	31981	2955	13740
Inyokern	0	0	0	0	0	0	4290
IronMountain	43811	38469	7088	2065	7088	1705	9600
Kramer	21653	16864	9951	0	9951	0	12370
LassenNorth	0	0	0	0	0	0	0
LassenSouth	0	0	0	0	0	0	0
Merced	0	0	0	0	0	0	0
MountainPass	5244	5244	1083	0	1083	0	1560
NonCREZ	0	0	0	0	0	0	0
OwensValley	12359	8616	563	150	563	0	10000
PalmSprings	11090	10378	2894	1687	2894	1687	0
Pisgah	16004	12802	829	362	829	212	4200
RiversideEast	61109	57016	19047	3228	18799	3228	21100
RoundMountain_A	0	0	0	0	0	0	
RoundMountain_B	0	0	0	0	0	0	
RoundMountain_A+B	0	0	0	0	0	0	0
SacramentoRiverValley	0	0	0	0	0	0	0
SanBernardino_Baker	5501	5471	780	0	780	0	6350
SanBernardino_Lucerne	21904	21799	14265	2963	13913	2745	3080
SanDiegoNorthCentral	6595	5870	3828	1733	3498	1583	0
SanDiegoSouth	0	0	0	0	0	0	0
SantaBarbara	1366	1366	0	0	0	0	0
Solano	0	0	0	0	0	0	0
Tehachapi	69295	58753	36546	0	35481	0	17990
TwentyninePalms	15864	15827	6195	0	6195	0	3610
Victorville	20212	17509	9664	0	9641	0	2400
Westlands	818	818	465	0	293	0	10000
SUM	413,193	364,446	154,231	17,400	149,566	16,282	133,090

[1] FW indicates freshwater exclusions combined with terrestrial exclusions

Table A – 7. Geothermal potential (MW) within each Super CREZ under each Environmental Exclusion Level.

Super CREZ	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 3 (FW[1])	Cat. 4 (FW)	RPS Calc (base)
Barstow	0	0	0	0	0	0	0
CarrizoNorth	0	0	0	0	0	0	0
CarrizoSouth	0	0	0	0	0	0	0
CentralValleyNorth	0	0	0	0	0	0	0
Cuyama	0	0	0	0	0	0	0
Distributed	0	0	0	0	0	0	0
El DoradoCounty	0	0	0	0	0	0	0
Fairmont	0	0	0	0	0	0	0
Imperial East	0	0	0	0	0	0	0
Imperial South	9283	9072	2724	0	0	0	0
ImperialNorth	10265	10055	4449	516	0	0	0
Imperial_N+S+E	19547	19128	7173	516	5072	363	1384
Inyokern	0	0	0	0	0	0	0
IronMountain	0	0	0	0	0	0	0
Kramer	0	0	0	0	0	0	24
LassenNorth	0	0	0	0	0	0	8
LassenSouth	0	0	0	0	0	0	0
Merced	0	0	0	0	0	0	0
MountainPass	0	0	0	0	0	0	0
NonCREZ	0	0	0	0	0	0	0
OwensValley	0	0	0	0	0	0	0
PalmSprings	1177	171	139	77	139	77	0
Pisgah	0	0	0	0	0	0	0
RiversideEast	0	0	0	0	0	0	0
RoundMountain_A	4364	3541	3277	1747	0	0	
RoundMountain_B	1785	1728	1288	1014	0	0	
RoundMountain_A+B	6149	5269	4565	2760	2187	1696	416
SacramentoRiverValley	4654	4494	2097	1995	325	325	0
SanBernardino_Baker	0	0	0	0	0	0	0
SanBernardino_Lucerne	0	0	0	0	0	0	0
SanDiegoNorthCentral	1943	1604	770	440	770	440	0
SanDiegoSouth	0	0	0	0	0	0	0
SantaBarbara	0	0	0	0	0	0	0
Solano	0	0	0	0	0	0	0
Tehachapi	0	0	0	0	0	0	0
TwentyninePalms	0	0	0	0	0	0	0
Victorville	0	0	0	0	0	0	0
Westlands	0	0	0	0	0	0	0
SUM	33,470	30,666	14,744	5,789	8,493	2,901	1,832

[1] FW indicates freshwater exclusions combined with terrestrial exclusions

Figure A - 1. Location of Super Competitive Renewable Energy Zones (CREZ), counties, and partial counties in California.

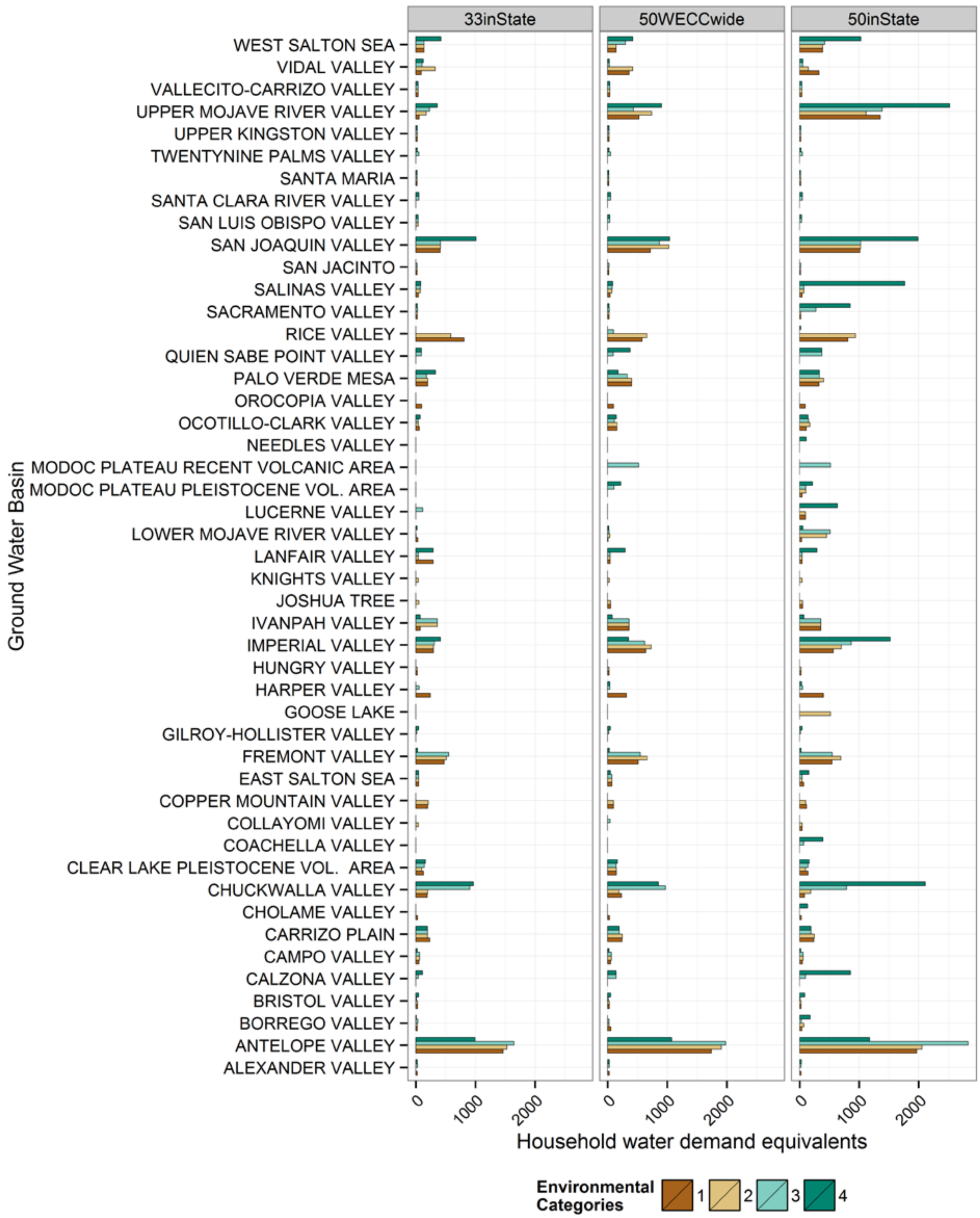

Figure A – 2. Total water demand of each 2030 build-out scenario spatially disaggregated by ground water basin. Household water equivalents is the annual water consumption of an average household in the U.S., or 146,000 gallons.

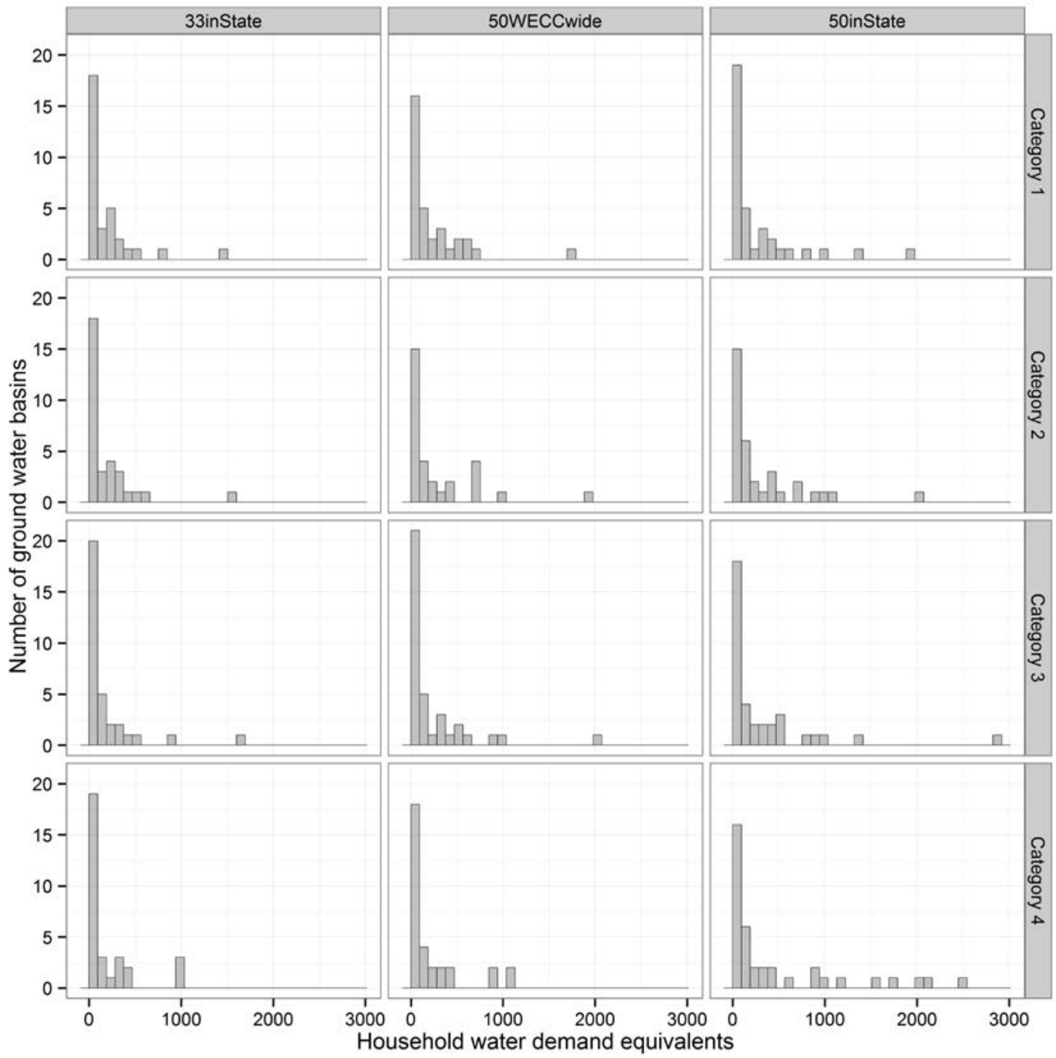

Figure A – 3. Histogram of water demand (in household water demand equivalents) for each 2030 RPS target under each environmental Exclusion Level.

Household water equivalents is the annual water consumption of an average household in the U.S., or 146,000 gallons.