

Renewable Energy In California: Solar and Wind Suitability Versus Reality

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Background: As society seeks ways to decrease carbon emissions and limit global warming, renewable energy is proving to be a growing and effective way to work towards those goals. California is leading the nation in overall solar production through large-scale photovoltaic panel projects, and is second in overall wind power production through large wind turbines. California is also a very large and diverse state in terms of people, terrain, and climate. All of this makes the state of California an incredibly interesting place to study solar and wind suitability. Additionally, as it already has many existing solar and wind power plants, it provides a great area to compare energy suitability to where plants have already been built.

Objectives:

- To run a weighted Suitability Analysis for both large Solar PV plants and Wind Farms that takes into consideration multiple factors.
- To compare the suitability scores of wind and solar to indicate which areas of California are relatively more promising for either solar or wind development.
- To examine the distribution of solar plants and wind farms throughout the state to look at patterns of clustering in terms of energy production by type, and relate their energy production to their suitability scores

Methods and Data Analysis: The first major part of this project is to create a suitability analysis for wind and solar energy. For this analysis the factors considered, as laid out in Table 1 and 2, are either wind or solar energy potential, distance to roads, distance to transmission lines, population density, slope, and special land areas. My choice of factors is based off of previous academic work on suitability analysis for wind and solar power. Each of these factors are assigned a score between 0-1, with the only exception being Special Land Areas which was given a score of -1. The higher the score the better. In order to calculate the score for solar energy potential, which ranged between 4.4-7.0 kwh/m2/day, I used fuzzy management to classify the data with a linear pattern. The reason I chose linear is because of the nature of California's climate, where even areas with relatively low solar potential were still fairly suitable overall. To calculate the score for wind potential, I again used fuzzy management, but this time with a high pattern. I chose this because the distribution of wind potential went from the lowest possible score of 1 to the highest possible score of 7, so extra weight was necessary for the higher scores because of how much more suitable they really are. Distance to roads and distance to transmission lines were both analyzed with fuzzy management, this time with a small pattern, because the closer an area is to either roads or transmission lines the better because it makes it easier to build the plant and transport the energy without additional infrastructure costs. For population density, I again used fuzzy management, but this time I used a gaussian distribution, because I determined that an area of medium level density would be most suitable. This is because an area too dense would be hard to find a place to build, but an area with low density would be able to serve less people because energy is lost during transport along transmission lines. Thus, density levels close to the median value scored the highest, and those with very high or very low density scored the lowest. In order to find special land areas, I merged layers on national parks and endangered/critical species, and set the scoring so that if an area was a special land area it received a -1, because it would be harder to build a plant there, and if it was not a special area it received a 0 because simply not being in a special land area doesn't make an area more suitable.



Conclusions and Discussion: The results of this project show that California is certainly a diverse state when it comes to renewable energy potential. Solar Suitability and Wind Suitability vary significantly throughout the state. For the most part, solar and wind plants tend to fall in places that make sense based on suitability. The major exception is near the San Francisco Bay Area, where there are many plants of both, despite relatively low suitability. However, there is a large demand for clean energy from citizens in that area which can help explain the phenomena. Although many solar plants have been built in Southern California, there are many high suitability spots left to explore. Wind power potential is more limited but there are certainly areas of high suitability scattered throughout, along with vast areas of mid suitability. Overall, Solar looks more promising than Wind for overall suitability, but comparatively the south is better for solar and there are more areas of higher probability overall for wind in the north. This visual trend is well displayed and supported by the local Moran's I analysis, which shows that there is high average suitability in areas with high-high clusters of wind or solar plants. The overall average suitability for clusters in wind plants is likely attributed to the fact there are less in total and many concentrated in the Bay Area, which has mediocre suitability scores. However, the fact that the mean suitability score for solar plants is just .01 higher than the overall mean suitability in California points to the fact that California could be targeting more suitable areas. I hope these maps can serve as a guide for future of renewable energy development in California.

Solar Plants and Wind Farms in California



Table 3: Comparing Suitability Scores to Cluster Trends

Local Moran's I Cluster Type	Mean Solar Suitability Value for Census Blocks with the Corresponding Type of Cluster	Mean Wind Suitability Value for Census Blocks with the Corresponding Type of Cluster
High-High	0.82	0.54
High-Low	0.82	0.50
Low-High	0.81	0.49
Low-Low	0.74	0.47

Table 4: Comparing Suitability Overall to Plants

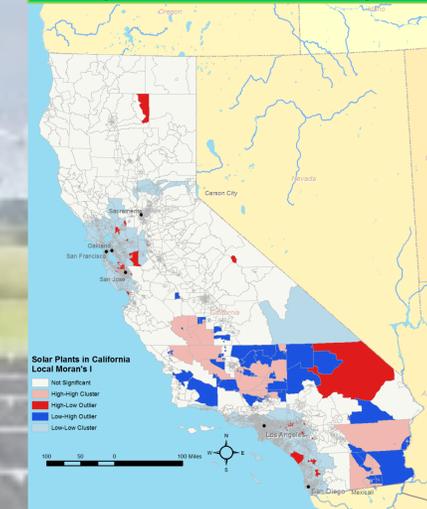
Type of Energy	Mean Suitability Score Overall	Mean Suitability for Plants	Range of Suitability for Plants
Solar	0.76	0.77	0.48-0.89
Wind	0.48	0.78	0.63-0.88

Methods and Data Analysis (cont.):

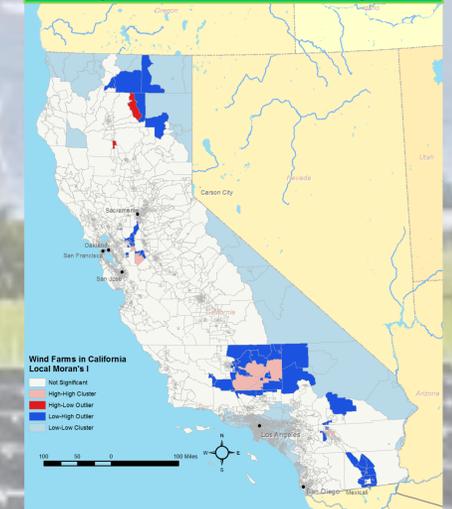
Using the raster calculator and giving each factor its appropriate weight as laid out in Table 1 and 2, I was able to calculate the overall suitability score for solar, which ranged from 0.37-0.89 and for wind which ranged from 0.22-0.83. Then, in order to take the analysis to the next step in order to produce a map that compared the two suitability scores to indicate which area of the state is relatively more promising for which type of energy, I used the raster calculator again. The input was, Solar Suitability Score + -1(Wind Suitability Score), which produced values on a scale of -.29-.45. Here, the more positive the value, the better it would be for solar, and the more negative the value the better it would be for wind. There seems to be an overall pattern that the southern part of California is better for solar and that the northern part is better for wind, but there are certainly some exceptions to the rule. I used a shapefile with California power plants to portray solar plants on top of the Solar Suitability Map, and wind plants on the Wind Suitability Map. This gives a visual representation of how well California is taking advantage of suitability while building plants, as well as being able to guide recommendations for where new plants should be constructed.

Now, looking at comparing suitability to actual generation of solar and wind power in California, I used the layer with all the power plants in California, and divided it into two separate shape files for wind and solar. In addition to just the location and type of plants, my data had the mega watts of energy produced in each plant. As there was a vast discrepancy in power produced in plants, ranging from just 1 MW to over 500 MWs, I felt that it would be more appropriate to look at distribution based on how much energy is produced by plants rather than just how many there are in an area. I used zonal statistics for solar potential onto census tracts to find data about the solar and wind potential scores in each census tract. Then, I did an attribute join from the census tract shape file to assign different energy plants to each county, resulting in a variable which represented the sum of MWs produced in each census tract. I used Local Moran's I to examine clustering of energy production between census tracts. I then had to run zonal statistics between census tracts and suitability scores. Then I ran zonal statistics as a table to look at what the average solar potential score is, as generated in my earlier analysis, in census tracts that have certain types of clusters. These same steps were repeated for wind. I was most interested in high-high and low-low clusters, with the expectation that if California was building plants based on potential, the average suitability score would be higher in high-high clusters, then low-low cluster. This was the case, with a 0.8 and 0.7 average higher score for solar and wind respectively. Finally, I ran zonal statistics as a table in order to find out information about what the average suitability score for both wind and solar plants are to see if they are above the average suitability for the state. The mean score for wind plants is 0.78, with a range from 0.63 to 0.88, while the mean overall wind suitability score for California is 0.48. The mean suitability for Solar plants is 0.77, with range .48-.89 while the mean overall solar suitability score is 0.76.

Clustering of Solar Power Generation in Megawatts



Clustering of Wind Power Generation in Megawatts



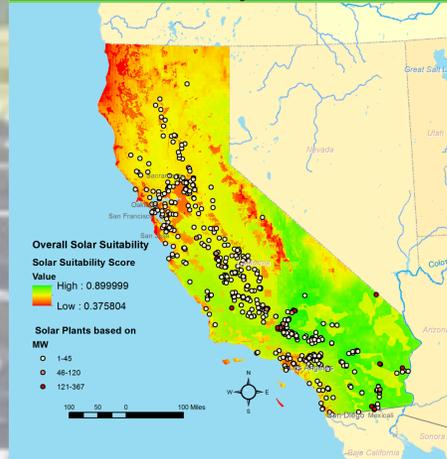
Data Sources:

- Wind and Solar Energy Potential:** National Renewable Energy Laboratory
- Population:** US Census TIGER Data
- Electrical Transmission Lines:** California Energy Commission
- Major Roads:** US Census TIGER Data
- Critical/Endangered Habitats:** US Fish and Wildlife Environmental Conservation
- National Park Boundaries:** Earth Data Analysis Center, University of New Mexico
- Elevation:** ESRI ArcGIS
- Solar and Wind Plant Sites:** California Energy Commission

Literature Cited:

- Al-Yahyai, Sultan, Yassine Charabi, Adel Gastli, and Abdullah Al-Badi. "Wind farm land suitability index using multi-criteria analysis." *Renewable Energy* 44 (August 2012): 80-87. doi:10.1016/j.renene.2012.01.004.
- Baban, Serwan M.J., and Tim Parry. "Developing and applying a GIS-assisted approach to locating wind farms in the UK." *Renewable Energy* 24, no. 1 (September 2001): 59-71. doi:10.1016/S0960-1481(00)00169-5.
- Castillo, Carolina Perpiña, Filipe Batista E Silva, and Carlo Lavallo. "An assessment of the regional potential for solar power generation in EU-28." *Energy Policy* 88 (January 2016): 86-99. doi:10.1016/j.enpol.2015.10.004.
- Charabi, Yassine, and Adel Gastli. "PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation." *Renewable Energy* 36, no. 9

Solar Suitability in California



Wind Suitability in California

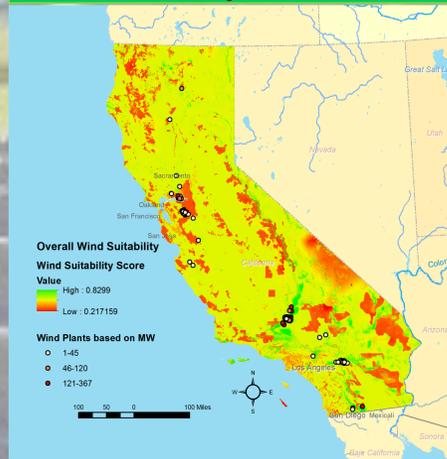


Table 1: Solar Suitability Tier System

Tier #	Feature (s)	Weight
Tier 1	Solar Energy Potential	35%
Tier 2	Slope, Population Density, distance to Electrical transmission lines	20%
Tier 3	Distance to roads, Special Land Areas	10%

Table 2: Wind Suitability Tier System

Tier #	Feature (s)	Weight
Tier 1	Wind Energy Potential	35%
Tier 2	Special Land Areas, Distance to electrical transmission lines, Distance to roads	15%
Tier 3	Slope, Population Density	10%