Solar PV Site Suitability: Using GIS Analytics to Evaluate Utility-Scale Solar Power Potential in the U.S. South West Region

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Project report submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

Solar PV Site Suitability: Using GIS Analytics to Evaluate Utility-Scale Solar Power Potential in the U.S. South West Region

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Determining socially acceptable and economically viable locations for utility-scale solar projects is a costly process that depends on many technical, economic, environmental and social factors. This paper presents preliminary results from a GIS-based spatial multi-criteria solar siting assessment study done in the South Western United States. Proximity raster layers were derived from features such as roads, power lines, and rivers then overlaid with 10x10m raster terrain datasets including slope and potential irradiance to produce a high resolution map showing solar energy potential from "Poor" to "Excellent" for high potential counties across the South Western United States. A second identical map was also produced adding social acceptance data collected from a series of surveys taken by the PVMapper/Sunshot Initiative project shows the potential public resistance that can be expected in areas of "Excellent" solar energy suitability. The maps produced can significantly reduce time, money, and resources currently allocated toward finding and assessing areas of high solar power suitability.

Keywords: Justin Robert Brewer, photovoltaic, suitability, public attitudes
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1 INTRODUCTION AND BACKGROUND

Energy demand is determined primarily by population growth rates, industry and geographic distribution, whereas the amount of people that can be supported at an acceptable quality of life relies heavily on the availability, costs, and efficiency to which energy is produced (Holdren, 1991). Extensive, overuse of fossil fuels has been argued to be responsible for excessive levels of carbon dioxide and resulting ecologic, social, and, economic impacts (Coyle, 2014). This recognition drives much active research in renewable energy.

The expanded use of renewable energy is expected to increase global energy production at levels that would forego use of the world’s finite resources and reduce the human impact on the environment. Photovoltaic (PV) energy has received much attention as a potential alternative/renewable energy source in the past decade with clear advantages for regions where grid connected power is inconvenient or expensive. PV energy production has also shown to produce enough power to compete in large scale markets. Though, in spite of recent efforts to expand solar energy production, solar power presently contributes only a small percentage of total U.S. energy supply.

In recent years, advanced solar panel manufacturing practices have led to a dramatic drop in costs and solar energy production has been shown to compete in price with conventional sources in some U.S. markets. (Drury, Brinkman, Denholm, Margolis, & Mowers, 2012). As the PV market grows, manufacturers will continue to standardize designs and system installation and
share efficient practices to further reduce costs associated with PV energy production (Goodrich, James, & Woodhouse, 2012). Paired with the falling cost of PV hardware and technology, the viability of PV utility-scale power production has the potential to take a large share of the energy market.

Today only 3% of the global energy market is produced by PV, however countries that have made renewable energy a priority demonstrate meeting more than 30% of electricity demand with wind and solar (Nichols, 2014). Historically, major concerns regarding the long term sustainable use of solar power were the costs related to variable energy integration into the grid and the cost-to-efficiency ratio regarding the variability of solar irradiance. Today these concerns have considerably decreased due to advances in panel-to-grid integration technology. Advancements in almost every aspect of PV technology have led to solar energy cost competitiveness. As physical technology prices continue to fall, a greater share of the cost of PV deployment is associated with preliminary site selection and other so called, "soft costs." A survey conducted by the National Renewable Energy Laboratory (NREL) found that non-hardware balance-of-system soft costs account for an increasing portion of PV systems by an average of 50% to 64% of total installed price (Ardani et al., 2012).

The Department of Energy’s SunShot Initiative, seeks to make solar energy cost-competitive with other forms of electricity by the end of the decade—including through the reduction of soft costs. The stated goal of the SunShot Initiative is to reduce the total installed cost of solar energy systems to $.06 per kilowatt-hour (kWh) by 2020. According to the energy.gov web site:
SunShot has achieved 60% of its goal, only three years into the program's ten year timeline. Since SunShot's launch in 2011, the average price per kWh of a utility-scale photovoltaic (PV) project has dropped from about $0.21 to $0.11.\(^\text{1}\) (Energy.gov, 2013)

Many of these goals are carried out through public and freely accessible web-based mapping applications to aid in analyzing solar energy project siting decisions. Examples of such web mapping applications include:

- **PVMapper** ([http://pvmapper.org](http://pvmapper.org)) is an open-source geographic information system (GIS)-based web application, currently under development, that will provide utility-scale solar developers with tools and data for site selection and screening of potential PV solar energy plants.

- **The Eastern Interconnection States Planning Commission (EISPC) Energy Zones Mapping Tool** ([https://eispctools.anl.gov](https://eispctools.anl.gov)) facilitates planning for clean energy zones and provides and extensive library of energy resources and other siting factors as mapping layers, models to map the suitability for solar energy and other technologies, and region-specific reports.

- **Solar Energy Environmental Mapper** ([http://solarmapper.anl.gov](http://solarmapper.anl.gov)) concentrates on the southwestern United States and was developed to share information relevant to siting utility-scale solar projects in the six southwestern states included in the scope of the Solar Energy Development Programmatic Environmental Impact Statement.

Another application that proves to be valuable in suitability analysis is Landscape Modeler, a web mapping application by ESRI. Though this product is not freely available to the public, it reduces the time and technical knowledge needed to conduct an in depth suitability analysis. This application specifies the environmental and cultural factors considered important to decision
making, selects the appropriate data layers, weights them and uses geoprocessing tools to filter the criteria and identify the best locations. Applications such as this allow for the use of raster services to visualize information such as critical habitats, development risk, fire potential, and solar power potential across the U.S.

With soft costs quickly becoming the limiting factor behind solar energy production, location siting is one of the most important factors to address. Finding a suitable location for solar energy development affects purchase price, solar power efficiency, environmental impacts, and public opinion (Kuiper, Ames, Koehler, Lee, & Quinby, 2013). The factors contributing to the success of solar development siting include physical characteristics such as slope, road and water proximity, land ownership and use, potential environmental impacts, and grid connectivity. Much of the data related to these factors are freely available.

This paper presents an approach to develop large-scale high resolution site suitability maps of potential utility-scale PV installation locations to help further reduce PV soft costs. By modeling public sentiments toward potential solar PV development locations we hope to reduce the potential economical pitfalls associated with social resistance. While our overarching goal is to build and make freely available such maps for the entire United States, this paper presents initial methods and results for the South West Region of the United States.
2 METHODS

Solar energy resource analysis for utility-scale development is affected by factors that can be divided into four categories: technical, economic, environmental and social. Technical, economic and environmental factors depend on the physical terrain, existing infrastructure proximity, geographic location, and land use restrictions. The fourth category, "social," is variable over time based on popular or cultural beliefs and perceived aesthetics regarding environmental issues. To develop a site suitability map that adequately addresses the four main categories, we assessed and processed available datasets using ArcGIS software. We chose the southwestern region of the U.S. due to the substantial growth of commercial PV in the region, the availability of potential lands with "excellent" suitability, and the ability to test results against many existing PV sites.

The technical, economic and environmental limiting factors for preliminary PV solar siting and this study were derived from discussions and decisions made by the PVMapper steering committee. Preliminary terrain and proximity siting requires the consideration of existing infrastructure that affect the direct cost of utility-scale PV solar power development and potential solar irradiance that directly impacts the efficiency of an operating site. Vehicle access to a developing site is essential for constructability and maintenance. Due to the high cost of road construction, proximity to existing roads is essential during preliminary siting. Proximity to national grid transmission lines affects construction and development costs while proximity to a stable water source is needed for suitable maintenance. Flat terrain is essential for both solar exposure and constructability while a high daily annual solar irradiance is needed for plant
efficiency and stability. Given these factors the siting parameters we chose for this study are: distances to roads, river, and power lines along with low maximum slopes combined with high average daily annual solar irradiance values.

2.1 Preliminary Boolean Map

2.1.1 Limiting Factors

The commencement of this project required data for currently operating PV projects within the study area. SEIA (Solar Energy Industries Association) provided their national database of all ground-mounted solar projects, 1 MW capacity and above, that are either operating, under construction or under development. This data was collected by SEIA from public announcements of solar projects in the form of company press releases, news releases, and in some cases conversations with individual developers. Data were edited to show only PV sites in operating status within the south west region of the U.S. The top 100 capacity sites in the region were selected to determine optimum proximity to specific features as well as slope and solar irradiance values for currently operating PV power plants. To extract this data, we determined PVMapper to be the best tool for geospatial location analysis.

Each selected site was processed by PVMapper to analyze the maximum slope, minimum irradiance value, and distance to nearest river, road, and major grid power line. The PVMapper score card tool uses GIS layers to give an overview of the site terrain slope, soil, solar irradiance potential and land cover as well the distance to such features as the nearest transmission lines, rivers, and roads. Data provided by PVMapper are presented in a report for each site. Site data extracted from PVMapper reports were added to a spreadsheet giving each site a row with columns representing distance to feature values, maximum slope and minimum irradiance values for a flat
plate tilted solar collector. The values for each column were analyzed and the 85th percentile value was selected to represent limiting values for the Boolean map to be built. Limiting values extracted are shown below in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>85th Percentile Distance (km)</th>
<th>85th Percentile Irradiance (Kwh/m2/day)</th>
<th>85th Percentile Max Slope (Degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Proximity</td>
<td>.56</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>River Proximity</td>
<td>17.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Power Line Proximity</td>
<td>32.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Irradiance (Tilted Flat Plate)</td>
<td>-</td>
<td>6.53</td>
<td>-</td>
</tr>
<tr>
<td>Slope</td>
<td>-</td>
<td>-</td>
<td>3.07</td>
</tr>
</tbody>
</table>

### 2.1.2 Description of Data and Sources

Terrain data are used to model the potential solar exposure loss due to the poor slope and aspect characteristics of the land. Also a high-resolution digital terrain model can predict constructability issues associated with steep slopes. Digital Elevation Model (DEM) data, or a digital representation of a terrain surface, were extracted from the National Map Viewer managed by the USGS National Geospatial program (NGP). Data were extracted in ten-meter by ten-meter cell size (10 m) raster format and converted to slope raster data, shown in Figure 1.

Infrastructure proximity layers used for this analysis were derived from OpenStreetMap (OSM); a collaborative editable map of the world where data is imported from digitization of aerial photography and other user-contributed sources. We chose roads and major electrical grid towers to represent the necessity for nearby grid connections and/or substation conversion.
potential and site accessibility. We extracted these polyline and point shapefiles from the study area extent and edited to dismiss outlier data and produce accurate results during analysis, shown in Figure 1.

Solar irradiance data were derived from solar maps provided by the NREL online data repository. Data values represent, the solar energy resource available to a flat plate collector, such as a photovoltaic panel, oriented due south at an angle from horizontal to equal the latitude of the collector location (http://www.nrel.gov/gis/solar.html). According to NREL, this is a typical practice for PV system installation, although other orientations are also used. The data provide, monthly average daily total solar resource information on grid cells of approximately 40 km by 40 km in size (NREL, 2013) This map was developed from the Climatological Solar Radiation (CSR) Model. The CSR model was derived using three parameters including cloud cover, horizontal surfaces, and trace gasses together with water vapor. Eight years of data were used to define cloud cover as monthly average percent cover per 40 km grid cell (Maxwell, 1998). The 40 km data format was extracted as a polygon feature class containing the annual daily average irradiance values in kwh/m²/day, shown in Figure 1.
2.1.3 Data Preparation

The goal of a Boolean map is to demonstrate geospatial areas that fit within given limitations of various GIS layers. The resulting map is presented in the form of a single shapefile representing the area that overlaps every layer's acceptability parameters. The area of study for this project required the infrastructure proximity layers be edited to contain the southwestern region of the U.S. We processed the road polyline data for the area of study to create a shapefile layer representing the acceptable area for PV development according to the 85th percentile values shown in Table 1. This was done using the buffer function in ArcMap that produced a polygon
layer representing all area within .56 kilometers of an existing road. We used a similar process to produce polygon layers representing the acceptable areas for development near existing rivers and power lines.

The process to prepare the slope and solar irradiance rasters required the conversion of rasters to polygons. We then selected the polygons containing acceptable values using a simple SQL expression to query the area containing the acceptable values shown in table 1. The road, river, power line, slope, and solar irradiance layers were then intersected. The intersect tool, a part of ArcMap's analysis toolbox licensing, computes a geometric intersection of the input features which overlap in all layers. The output produces a shapefile representing the areas that fit within the limitations of each parameter, shown in Figure 2.

![Figure 2: Map Showing Acceptable Areas for PV Development](image-url)
2.1.4 Zonal Statistics

The Boolean map shown in Figure 2 is a representation of suitable land for the development of utility-scale PV solar power. The five suitability factors used were determined by the PVMapper steering committee. We derived the parameters for each factor from the analysis done on the 100 highest capacity currently operating PV sites in the study area. We used the 85th percentile values as limiting values for each factor to produce. The Boolean map we created was used for visual suitability analysis and to assess the highest concentration of area suitable for PV development. Using ArcGIS and this map, we calculated the zonal for each county in the southwestern U.S. The results of this analysis are shown below in Table 2.
Table 2: Results of the Zonal Statistical Analysis Showing Percent and Total Suitable Area

<table>
<thead>
<tr>
<th>STATE</th>
<th>County</th>
<th>Total Area (Km²)</th>
<th>Suitable Area (Km²)</th>
<th>Percent Suitable Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>Apache</td>
<td>43123</td>
<td>21010</td>
<td>49%</td>
</tr>
<tr>
<td>Arizona</td>
<td>Navajo</td>
<td>38463</td>
<td>16146</td>
<td>42%</td>
</tr>
<tr>
<td>Arizona</td>
<td>Maricopa</td>
<td>34074</td>
<td>15411</td>
<td>45%</td>
</tr>
<tr>
<td>Arizona</td>
<td>Pinal</td>
<td>19609</td>
<td>9352</td>
<td>48%</td>
</tr>
<tr>
<td>Arizona</td>
<td>Cochise</td>
<td>22466</td>
<td>9223</td>
<td>41%</td>
</tr>
<tr>
<td>California</td>
<td>Modoc</td>
<td>19422</td>
<td>8309</td>
<td>43%</td>
</tr>
<tr>
<td>California</td>
<td>Lassen</td>
<td>21057</td>
<td>12424</td>
<td>59%</td>
</tr>
<tr>
<td>California</td>
<td>Merced</td>
<td>7954</td>
<td>5618</td>
<td>71%</td>
</tr>
<tr>
<td>California</td>
<td>Butte</td>
<td>7251</td>
<td>4041</td>
<td>56%</td>
</tr>
<tr>
<td>California</td>
<td>Stanislaus</td>
<td>6348</td>
<td>3356</td>
<td>53%</td>
</tr>
<tr>
<td>California</td>
<td>Nevada</td>
<td>4214</td>
<td>2875</td>
<td>68%</td>
</tr>
<tr>
<td>Colorado</td>
<td>Kit Carson</td>
<td>9359</td>
<td>7436</td>
<td>79%</td>
</tr>
<tr>
<td>Colorado</td>
<td>Elbert</td>
<td>7866</td>
<td>6160</td>
<td>78%</td>
</tr>
<tr>
<td>Colorado</td>
<td>Arapahoe</td>
<td>3481</td>
<td>2827</td>
<td>81%</td>
</tr>
<tr>
<td>Colorado</td>
<td>Alamosa</td>
<td>2892</td>
<td>2180</td>
<td>75%</td>
</tr>
<tr>
<td>Colorado</td>
<td>Denver</td>
<td>683</td>
<td>675</td>
<td>99%</td>
</tr>
<tr>
<td>Nevada</td>
<td>Pershing</td>
<td>26836</td>
<td>10898</td>
<td>41%</td>
</tr>
<tr>
<td>Nevada</td>
<td>Eureka</td>
<td>18313</td>
<td>7818</td>
<td>43%</td>
</tr>
<tr>
<td>Nevada</td>
<td>Lyon</td>
<td>8762</td>
<td>4082</td>
<td>47%</td>
</tr>
<tr>
<td>Nevada</td>
<td>Storey</td>
<td>1136</td>
<td>579</td>
<td>51%</td>
</tr>
<tr>
<td>Nevada</td>
<td>Carson City</td>
<td>695</td>
<td>358</td>
<td>51%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>San Juan</td>
<td>22203</td>
<td>12936</td>
<td>58%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Chaves</td>
<td>22647</td>
<td>11213</td>
<td>50%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Guadalupe</td>
<td>11606</td>
<td>5874</td>
<td>51%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Valencia</td>
<td>4218</td>
<td>2877</td>
<td>68%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Bernalillo</td>
<td>4476</td>
<td>2438</td>
<td>54%</td>
</tr>
<tr>
<td>Utah</td>
<td>Uintah</td>
<td>19982</td>
<td>9104</td>
<td>46%</td>
</tr>
<tr>
<td>Utah</td>
<td>Duchesne</td>
<td>14451</td>
<td>6510</td>
<td>45%</td>
</tr>
<tr>
<td>Utah</td>
<td>Sanpete</td>
<td>6784</td>
<td>3137</td>
<td>46%</td>
</tr>
<tr>
<td>Utah</td>
<td>Carbon</td>
<td>6722</td>
<td>2987</td>
<td>44%</td>
</tr>
<tr>
<td>Utah</td>
<td>Rich</td>
<td>4750</td>
<td>2240</td>
<td>47%</td>
</tr>
</tbody>
</table>

Table 2 shows 5 counties in each state with the highest concentration of suitable area in order of most total suitable area as defined by the Boolean map and the zonal analysis we
prepared using ArcMap. This preliminary breakdown returned the counties in the southwestern region of the U.S. that are most suitable for further analysis. We selected the top two counties in each state with highest total suitable area for high density suitability analysis including social factors.

2.2 Solar PV Site Suitability Analysis

A GIS suitability analysis is a process used to determine the appropriateness of a given area for particular use based on a calculated raster values. The basic principle behind a suitability analysis for the purposes of this project is to determine the degree to which each area is suitable for solar PV development on a utility-scale. Suitability is determined through a multi-factor analysis of the different aspects of existing terrain. The factors we chosen to assess suitability were derived from the original parameters provided by the PVMapper steering committee. These factors are, as mentioned earlier in this paper, proximity to exiting features such as roads, rivers, and power lines along with slope and solar irradiance values. Suitability status is displayed as one of three categories labeled "Poor", "Good", and "Excellent". Categorical status was calculated using a simple weighted sum equation based on weighted importance in suitability for this project.

2.2.1 Model

Preparation of data layers required a high level of computing power to produce high density10m raster layers for each suitability parameter. Proximity to feature layers were converted from the vector format provided by OSM to 10m raster data layers using ArcGIS. Each 10m raster layer created was built to snap directly to the 10m slope layer for ease in layer calculations performed at a later stage.
PV site suitability analysis, using raster layer parameters, can be conducted using map algebra (Tomlin, 1990). For the purposes of this paper, map algebra procedures were simplified using local class operations. Cell to cell math was performed using the data layers presented above to produce a map showing areas of high suitability while also eliminating areas that would be detrimental to the constructability, cost effectiveness, and efficiency of a solar power plant. We built and organized these operations using a visual programming application called ModelBuilder included in Esri’s ArcGIS software package. ModelBuilder allows processes to be organized together in sequences of geoprocessing tools, linking the output of one tool into another tool as input as shown in figure 3.

In order to evaluate each area according to its distance to a specific infrastructure feature, we derived a euclidean distance raster was derived from each road, river, and power line raster using the Euclidean Distance tool in ArcMap to evaluate proximity. The output of this process is then used as the input for a reclassify function that groups distance values into 9 blocks and gives each block an integer ranging from 1 to 9. For example the Euclidean distance values representing distance from existing roads between 0 and 250 meters is reclassified or replaced with a 9. In this way a new output raster is created containing only integer values from 1 to 9, each representing a step scale of distances to existing roads. We defined the distribution of categories for each parameter based on common maximum distances for each infrastructure feature. For roads, the 9 categories were reclassified from a range of 0 km to 6 km, rivers ranged from 0 km to 45 km, and power line distances ranged from 0 km to 85 km. The ModelBuilder model interface showing this process for the proximity to feature parameters is shown below in figure 3.
When classifying distances to features it is important to expand the processing extent to include features just beyond the county borders. Figure 3 shows the county mask feature buffered by 1 km to include nearby features just outside county boundaries. The buffered shape was then used as the extent to which processing occurred. To restore the raster extent to the area of study, a mask of the original county shape was applied during map algebra calculations.

Slope and solar irradiance data were also reclassified to create 10m raster layers containing integers ranging from 1 to 9. Solar irradiance values were redefined by 9 evenly distributed categories from 3 to 8 kwh/m²/day. We also assigned reclassified values to slope characteristics into 9 evenly distributed categories ranging from 0 to 90 degrees. Cells with a value of 9 represent area of flat terrain or high irradiance value. Cells with a value of 1 represent terrain containing steep slopes and areas of low solar exposure. Figure 4 below shows the
processes used in ModelBuilder to prepare and reclassify these layers. The input county shape serves as the processing extent for both layers.

![ModelBuilder Workflow Showing Slopes and Solar Irradiance Reclassification](image)

**Figure 4: ModelBuilder Workflow Showing Slopes and Solar Irradiance Reclassification**

At this point in the model each parameter of the suitability analysis is represented with a raster layer containing integer values ranging from 1 to 9 representing the suitability inside each layer. The next process run allows each parameter to be weighted based on the value each parameter brings to PV development and operational costs. This study required a cost analysis comparison to determine weighted values. Using the 85th percentile values shown in Table 1, we compared the cost to construct .56 km of road was to the cost to install 17.3 km of water line and 32.7 km of power line. A comparison shows that the needed power line and water line construction cost are similar and about 80 percent of the cost of building the needed road length. The cost associated with the constructability issues that arise from steep slopes is largely unknown and hard to weight the value of flat terrain for development, so we chose the weighted value for this parameter to be equal to that of building a .56 km stretch of road. The value of
solar irradiance is also hard to determine due to future advancements in technology, but because solar exposure affects plant efficiency for the entire design life of the facility, we chose to weight it 10 percent higher than road construction. These weighted values are shown below in Table 2.

Table 3: Table Showing Weighted Values Used to Determine Suitability

<table>
<thead>
<tr>
<th>Weighted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Road Proximity</td>
</tr>
<tr>
<td>Existing Power Line Proximity</td>
</tr>
<tr>
<td>Existing Water Source Proximity</td>
</tr>
<tr>
<td>Slope</td>
</tr>
<tr>
<td>Solar Irradiance</td>
</tr>
</tbody>
</table>

We determined a weighted sum model or multi-criteria decision analysis was the best method for analysis since each layer has been evaluated cell by cell with an integer value from 1 to 9 that denotes the benefits of each parameter. This model multiplies the weighted value by each raster layer value that sums each corresponding cell. The result is a raster containing values anywhere from 4.7, the lowest possible product, or 42.3, the highest possible product of the weighted sum model. The weighted sum model result was then reclassified again to categorize each area as Poor, Good, or Excellent suitability. Suitability status was determined from the limitations shown below in Table 3.
Table 4: Suitability Status Ranges

<table>
<thead>
<tr>
<th>Weighted Sum Values</th>
<th>Reclassified Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7 – 26</td>
<td>Poor</td>
</tr>
<tr>
<td>26 – 32</td>
<td>Good</td>
</tr>
<tr>
<td>32 – 42.3</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

The ModelBuilder workflow linking the weighted sum analysis to the reclassify tool is shown below in Figure 5. The weighted sum tool was restricted to process only within the confines of the original county boundary. This ensures that final map results show only suitable area inside the area of study, but still include the distance to features outside the extent.

Figure 5: ModelBuilder Model Showing Final Stages of Suitability Workflow
2.3 Public Acceptance Model

2.3.1 PVMapper Survey

Included in the scope of the PVMapper project is the formal integration of socio-political attitudes and economical solar site suitability designed from data retrieved from a specially designed public opinion survey. Part of the public opinion survey was designed to gage the public's preferred distances or buffers, between solar facility and a variety of land features including residential areas, agricultural lands, cultural resources, wildlife breeding grounds, recreation areas, and existing solar facilities. The survey questions defined 4 categories of distances for response: less than a mile, 1-5 miles, 6-10 miles, and more than 10 miles. These categories define the minimum acceptable distance between the land feature and a potential solar facility. For example, if a respondent chooses less than a mile, the minimum acceptable distance between the feature and the solar generation facility can be less than a mile, and any distance greater is also acceptable.

Figure 6 shows the results representing minimal acceptable distances from each feature to solar power plant construction. For residential areas, a solar power plant built more than 6 miles away is supported by 72% of those surveyed. For breeding or nesting sites, a large majority of respondents believe that only 10 or more miles away is suitable for PV development and about 49% of those surveyed believe a solar development location needs to be at least 6 miles away from recreational areas. Sixty-five percent of the public believe solar power development within 5 miles of agricultural land is acceptable.
The PVMapper survey allows for site suitability based on technical, economical, and environmental factors to be analyzed according to the potential social acceptance as a function of feature proximity. The method used to locate areas of high suitability with high percentage of public acceptance was to build a public acceptability layer. The goal of a public acceptance model is to build a raster that contains the lowest percentage of potential social acceptance in each cell according to the proximity of the five features of study outlined by the PVMapper survey. This model was designed to produce a high density result that matches the suitability raster already created. This was done specifically to overlay the suitability layer and social acceptance layer to demonstrate areas of high suitability and high social acceptance contrast to areas of high suitability and potential public resistance.
2.3.2 Model Details

Data used to define locations of residential area and agricultural area were derived from land use raster data retrieved from the U.S. Department of Agriculture's National Agricultural Statistics Service. We extracted cells containing values that represent residential areas and agricultural areas to create a residential data layer and an agricultural data layer. Breeding and Nesting location data was defined by the U.S. Fish and Wildlife Service's Geospatial Services and was extracted as polygon shape files. Recreational Boundaries were defined by the U.S. Department of the Interior Bureau of Land Management. The National Register of Historic Places containing geographical locations of registered historic sites was downloaded from the U.S. National Park Service.

We built the social acceptance model using ModelBuilder within the area of study defined for this project as the Southwestern U.S. We used each feature layer collected to create 5 euclidean distance rasters with 10m cell size and snapped to site suitability raster. The distance rasters were reclassified to represent the categorical public acceptance percentages for each cell. For example, we reclassified the distance from residential areas such that all cells within 1 mile of a residential area were replaced to a value of .21 to represent 21% of respondents that feel areas of 1 mile or less to be acceptable for solar site development. Similarly, all areas between 1 and 5 miles of residential areas are represented with a .57 to show that 57% of people believe 5 miles or less to be acceptable area for solar power development, this was continued for the other values.

After reclassification there were five raster datasets that represent the public acceptance percentage according to proximity to each respective feature. We then combined these datasets into one layer using the minimum value of acceptance for each location as the output. This
means that for any location in the area of study there is a value representing the least accepted area for all five input factors. Figure 6 shows the flow of processing we built using ModelBuilder.

Figure 7: Workflow for Social Acceptance Model

The completed Social acceptance model represents the minimum percentage of public acceptance for each area according to the proximity to certain features such as endangered species habitat and nesting sites, historical landmarks, residential area, agricultural area and recreational area. This model is useful in combination with the suitability model developed. The goal is to analyze the social acceptance of areas with high geographical and economical suitability for solar PV plant development. This goal was satisfied by using simple map algebra to multiply the weighted sum value data produced by the suitability workflow by the social acceptance percentage before categorizing suitability according to Table 4. For example, if an area suitability value was calculated to be 42, a high suitability value, it was then multiplied by
its social acceptance percentage value of .4 or 40% to be equal to 16.8. In this way an area of high suitability with low percentage of acceptability becomes an area of low suitability. The resulting map produced can help developers find suitable areas while avoiding areas that could produce public push back or general social disapproval.
3 RESULTS AND DISCUSSION

3.1 PV Suitability Results

The PV site suitability model and map product defines the areas of the South West U.S. region that satisfy the technical, economical, and environmental goals of this study. The weighted values of potential irradiance, slope considerations, and necessary existing infrastructure show areas with high potential output potential as they relate to constructability and cost efficiency. Weighted values produced based on this model were further broken down into three categories to facilitate a visual representation of the results. Because a cell size of 10mx10m was used for all processing, the resulting maps allow for a high definition visual map shown in Figure 8. Users can examine map products from this model at a zoomed in scale that more accurately represents the boundaries of suitable area. Without such a high density dataset, values and boundaries can become fuzzy and less representative of current terrain causing potential constructability issues. The maps in Figure 8 do not include social acceptance factors.
Figure 8: County Site Suitability for Arizona and California
3.2 Social Acceptance Model Results

The lasting implications of this study reside in the dynamic of predicting public acceptance or, more accurately, potential resistance. The social acceptance model described in section 2.3 of this report is believed to have accurately attached values representing the absence of public resistance to visually definable geographical coordinates. The PVMapper survey used as the underlying source for this model was designed to capture American sentiments toward solar development in general, however, this study was directed specifically at the proximity of suitable land to areas of high environmental controversy. The value of this model is in the identification of the seemingly excellent potential in any siting model that may intrude on areas that can spark public resistance. Public attitudes toward solar development are essential to cost efficiency of PV production and to gain momentum in the continuing battle for energy market share. The map shown below in Figure 9 shows the gradient of expected public resistance values.
3.3 Resulting County Overlay

The table in Section 2.1.4 of this report provides counties with high suitability density and total area. These counties were the subject of further analysis for this project. For each selected county, the suitability data were extracted and multiplied by the public acceptance factor as defined in section 2.3 of this paper. The result of this operation reports the potentially suitable area for solar PV development that has the least risk of producing public resistance. The distinction between high economic, environmental, and technical potential and that same potential demonstrated with limited negative public attitudes is essential to the financial success of solar power production. The maps below show the high percentage of economically suitable area that should be avoided to appease public opinion. The social acceptance factor is believed to be very conservative as to avoid the unpredictable culture of public opinion. In this way the models outlined in this paper lead to defining areas carrying all the criteria stated with a high degree of confidence.
Figure 10: Suitability Including Social Factors
4 CONCLUSION

This goals of this study included determining acceptable and economically viable locations for utility-scale solar projects. In depth preliminary siting analysis allows for the avoidance of solar development from areas that can cause constructability and public issues. These issues hamper the solar PV industry with both added cost and decreased efficiency. This paper presented the method and results from a GIS-based spatial multi-criteria solar siting assessment study done for the southwest U.S. region. Suitability was assessed through economic, technical, environmental, and social factors to determine areas of the study region that contain both excellent terrain with proximity to features that reduce the cost of construction and are in harmony with the environmental sentiments of the public. Using this model developers will understand the limitations associated with current social opinion regarding environmental issues. Avoiding unforeseen public resistance will overall reduce the soft costs associated with solar development.
REFERENCES


