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Suitability modeling and the location of utility-scale solar power plants in the southwestern United States

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SUITABILITY MODELING AND THE LOCATION OF UTILITY-SCALE SOLAR POWER PLANTS IN THE SOUTHWESTERN UNITED STATES

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THESIS

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To my parents: thanks for reading to me when I was little.

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ABSTRACT

As states and regions have begun prioritizing renewable energy at the legislative level, solar energy has started to play a noticeably larger role in the energy portfolio of certain regions in the United States. Decision making concerning the siting of new solar facilities can be complicated, and GIS-based suitability modeling is often employed to determine ideal candidate sites. These suitability models seek to evaluate a comprehensive set of relevant criteria (such as insolation values, topography, access, land designation status, etc.), often at different weights, to produce a classified map of all potential sites that will facilitate decisions of site location.

This research examines the nature and reliability of this type of suitability modeling by analyzing the extent to which those regions identified as 'most suitable' in a GIS model actually match up with the locations of existing and planned solar facilities. A suitability model was developed in ArcGIS based on examples from similar research, and compared against the actual locations of photovoltaic and concentrating solar facilities in the southwestern part of the United States. The topic of land ownership is also investigated to determine its relationship to the spatial distribution of solar facilities.

The analysis indicated that although the locations of solar facilities fell mainly within those areas identified as highly suitable, this match was more noticeable for concentrating solar facilities than it was for photovoltaic facilities, indicating a need to develop separate models for these two types of facilities. Furthermore, while a high suitability classification seemed to be a prerequisite for solar facilities, the amount of highly suitable terrain in a state did not necessarily predict how many facilities would be present. Federally owned lands were also discovered to be preferable in regard to site locations. All of these results indicate the relevance of other non-spatial criteria as an explanation for the distribution of solar facilities, and the need to take into consideration the impact of such measures as state and local incentives and regulation, energy development efforts in other sectors, and other variables that have heretofore been absent in suitability models.

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Chapter One

Introduction

1.1 Background

In recent years the issue of energy has moved markedly to the forefront of American politics. As a topic with immense implications for business, government, the environment, and everyday citizens alike, solving the energy needs of current and future generations has arguably become one of the most pressing challenges of our time. Opinions vary widely, but most parties agree that efforts must be made to find ways to provide affordable and reliable energy in a way that both minimizes negative environmental impacts, and makes the US less susceptible to the economic disturbance associated with a dependence on foreign oil markets.

These conditions have led to the high profile shift to have a larger portion of our energy generated from renewable energy sources. This category broadly refers to methods of energy production that are derived from resources that are replenished naturally over time, including solar, wind, geothermal, hydroelectric, biomass, and bio-fuel energy sources. Of this group, one source has been the recipient of much attention lately because of its vast potential for large-scale installation and ability to provide electricity at increasingly competitive prices: solar energy.

The fundamentally spatial nature of the logistics involved in locating solar facilities makes the discipline of geography an ideal vantage point from which to consider this issue. The implementation of GIS technologies is particularly valuable in providing insight to questions surrounding the issue of siting new solar facilities. This type of analysis is not only useful, but essential to understanding the complex challenges associated with locating these production sites.

1.2 Goal

The goal of this research is to assess the degree to which the results of a suitability analysis correspond with the locations of actual utility-scale solar facilities in the southwestern US. This assessment enables identification of spatial and non-spatial criteria that are relevant to siting decisions but often left out of suitability models. By identifying these additional criteria, this thesis indicates how the accuracy and appropriateness of future suitability models may be improved.

1.3 Objectives

Objective One: Develop a suitability model for the southwestern US that classifies locations in terms of capacity to support utility-scale solar power facilities.

Objective Two: Obtain and map the true locations of all the existing and planned utility-scale concentrating solar and photovoltaic solar power plants in the study area.

Objective Three: Analyze the extent to which the true locations of solar facilities fall inside those regions identified in the suitability model as being “most ideal.”

Objective Four: Identify by state and/or facility type any major discrepancy between the model-derived suitability results and the actual distribution of solar power plants.

Objective Five: Investigate the relationship between land ownership and the distribution of utility-scale solar facility sites to determine whether ownership is a critical parameter in siting decisions.

Objective Six: Assess methodological weaknesses in traditional suitability modeling techniques by identifying criteria that are often overlooked in suitability analyses yet appear to explain the actual distribution of solar power plants, and discussing ways in which these criteria might be incorporated in future suitability analyses.

Chapter Two

Literature Review

2.1 General Context

The subject of renewable energy encompasses a broad array of topics and disciplines, and comprises a field of knowledge that is rapidly growing in influence in the professional and academic setting, and popular knowledge alike. In regard to solar energy in the southwestern US (which in the context of this research will refer to Colorado, New Mexico, Arizona, Utah, Nevada, California, and Texas), it is necessary to consider several topical areas. First, a general assessment of renewable energy is necessary, with a particular emphasis on the role that solar energy has within the suite of renewable energy technologies. Next, literature specific to the particular region of interest (the Southwest) will be considered to assess trends, developments, and information related to solar and other renewable energy projects in this area. With a practical set of disciplinary techniques and approaches to offer, the field of geography provides an ideal vantage point from which to examine the topic of energy, particularly since many of the logistical requirements and implications of energy development are inherently spatial in nature. Accordingly, two additional topics will be examined: the geography of energy production and transmission and the geography of facility siting. Lastly, attention will be given to methodologies and techniques employed in this field of study, focusing mainly on GIS applications in suitability modeling and decision-making.

2.2 Background of Renewables and Solar Energy

Renewable energy has recently become the focus of renewed attention, and again come to the fore in the last decade— an era when high fuel prices, concerns about climate change, and a desire to stabilize energy markets by increasing domestic production has led both policy makers and energy developers to reconsider the role that these technologies can play in the energy portfolio of the United States. While the broad category of ‘renewables’ includes many different technologies with varying potential, solar energy production—both in the form of photovoltaic (PV) technology and concentrated solar production (CSP)—has risen to the top as a means of energy production that is becoming more widely employed and inexpensive each year (Behar, 2009, Bezdek, 2007, *The Economist*, 2008, Lorinc, 2008).

Figure 1. The 8.22 MW SunEdison/Xcel Energy Photovoltaic (PV) Power Plant Outside of Alamosa, CO.

This photograph illustrates the size of utility-scale solar facilities. Image source: SunEdison, URL: http://www.sunedison.com/photos--solar-energy-pictures.php, accessed, April 6, 2010.

In fact, according to a report by *The Economist* in 2008, PV cells constitute the most rapidly growing type of alternative energy, with a sector growing by 50% a year (14).

The price of the technology is falling too. In 1982, the price of a PV module was slightly less than $20 a watt; today, PV modules cost less than $5 per watt, and experts believe technological improvements will continue to bring that price down (14).

Figure 2. Parabolic Trough Mirrors at the SEGS IV CSP Facility in Kramer Junction, CA.

Parabolic trough arrays like this one capture the sun's heat and use it to produce electricity. Image source: National Oceanic and Atmospheric Association, URL: http://www.noaanews.noaa.gov/stories2009/images/sunshade.jpg, accessed April 6, 2010.

As the costs associated with producing energy from the sun continue to decrease, the number of installed photovoltaic systems is climbing globally. In many countries including Brazil, Indonesia, Japan, Spain, Germany, and Canada to name a few, there is either an active effort to increase the amount of energy that is being domestically produced with solar, current research being done on how solar technologies can be employed more efficiently, or both (Shum and Watanabe, 2007, Dasuki, Djamin, and Lubis, 2001, Ordenes, Marinoski, and Ruther, 2007, Lorinc, 2008, Carrión et al., 2008, *Nova*, 2007). In a 2009 study by the National Renewable Energy Laboratories cited by Behar, worldwide solar investment increased from a $66 million dollar industry in 2000 to a $12.4 billion industry in 2007 (31). Within the United States, the state of California alone has plans to spend over $3 billion to incentivize solar installations for residential and business power needs (Lorinc, 2008, 40). In short, solar energy is poised to become a major player in the energy scene.

The trend of solar energy moving to a more prominent position in energy production is motivated by multiple factors, but one of the main reasons that more growth can be expected is the fact that energy demands are continuously rising. As populations grow, experts agree that providing a reliable means of meeting energy needs in the future will certainly be a priority (Pacione, 2001, Roberts, 2004, Deffeyes, 2005). In their *Annual Energy Outlook 2009 with Projections to 2030* report, the Energy Information Administration, the official source of statistics on energy use for the US government, reported that energy use across all sectors can be expected to increase .5% per year between 2007 and 2030 in the United States (Energy Information Administration, 2009, 1). A recent large-scale programmatic environmental impact statement on the designation of energy corridors for 11 western states indicates that many planners and policymakers are anticipating growth in energy production and distribution (PEIS, 2008).

Meeting these energy needs in a manner that avoids geopolitical entanglements, greenhouse gas (GHG) emissions, or other deleterious environmental impacts is a high priority as the energy infrastructure is expanded (Roberts, 2004, Fthenakis and Kim, 2007). Currently, solar power is one of just a handful of methods for energy generation with low/zero carbon output. In a recent study, Fthenakis and Kim compared the total greenhouse gas emissions of the full life-cycle of a nuclear power plant and those of a large-scale PV solar facility (2007). They found that when considering the obtainment of raw materials, construction, operation, and eventual dismantlement, PV power plants and nuclear power plants have a very similar output of carbon dioxide in terms of grams released per kWh of electricity produced over the course of their lifetime. The carbon output of solar facilities can be expected to be even lower when sites are situated in ideal locations and as advances in efficiency continue to improve their ability to harness the sun's energy.

While large-scale solar projects are not immune to their own environmental, regulatory, or social limitations in deployment, when compared to the same challenges associated with the other 'clean' alternatives such as hydroelectric, nuclear, or wind, PV projects can often avoid much of the resistance and provide a more attractive energy option (Carrión et al., 2008, Rodman and Meentemeyer, 2006). A more hospitable legal and sociopolitical view towards solar power can be a significant factor in its overall prevalence.

Unfortunately, much of the literature and research in solar energy has not been done in the peer-reviewed academic context. The majority of the information occupies the 'grey literature' category of research that has been conducted by those in the industry itself, by governments, or by journalists. While there is certainly a growing body of academic literature, there exists a real need for peer-reviewed, objective research in this area as the topic is clearly increasing in importance.

Furthermore, there is a need for more current research due to recent changes in policy, technology prices, the sociopolitical climate, increasing energy needs, and extant environmental concerns. Much good research has been done, but up to date information in a regional context is essential for providing necessary information for academics, professionals, and planners alike.

2.3 The Southwestern United States – the Region and the Role of Solar Energy

In the context of solar energy in the United States, the Southwest stands in a category of its own, principally as a result of the potential for solar energy generation in the area. A map displaying the high solar potential of the southwestern US can be seen in Figure 3.

Figure 3. Average Annual Solar Resources For a Tilt-Latitude Collector in the US.

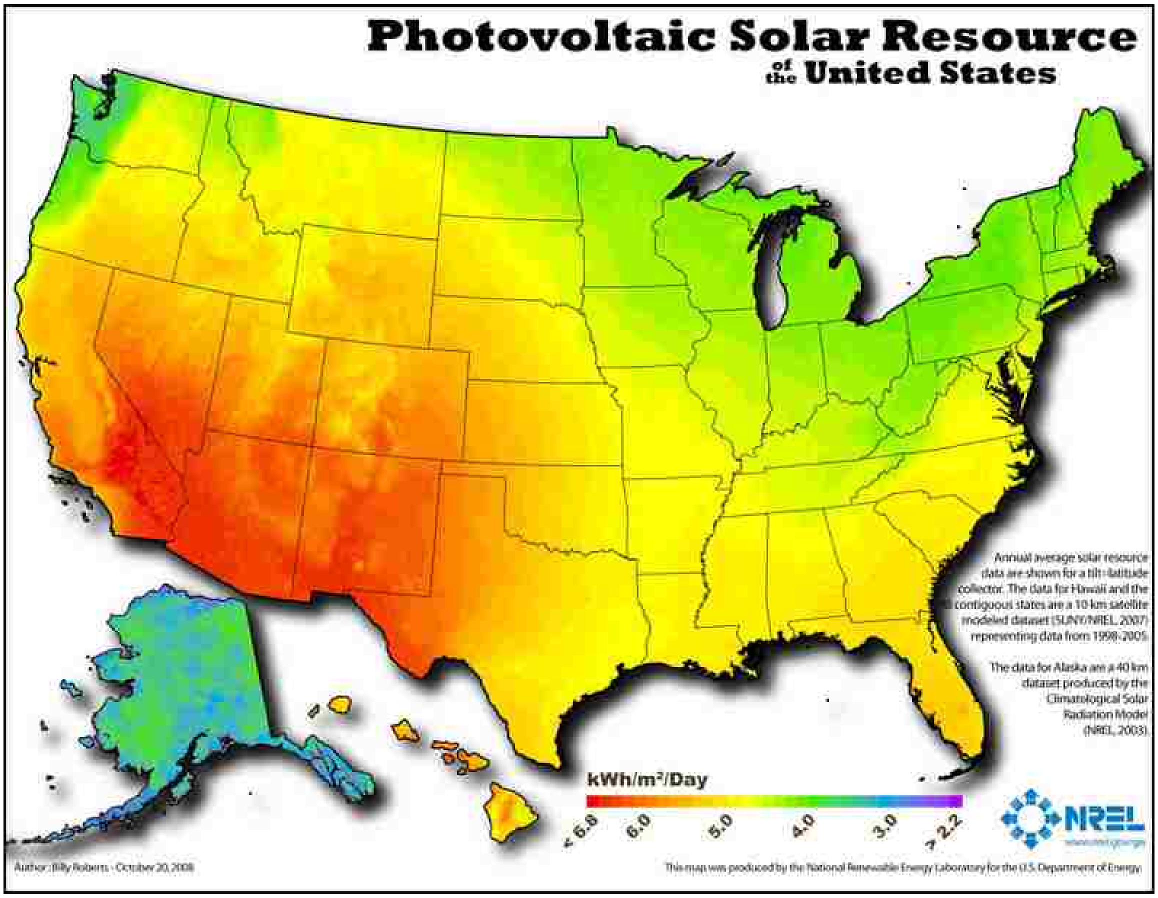


Image Source: National Renewable Energy Laboratory, URL: http://nrel.gov/gis/images/map_pv_national_lo-res.jpg, accessed April 6, 2009.

GIS data layers from the National Renewable Energy Laboratory indicate that the Southwest is unparalleled in the amount of sunlight that the area receives annually, with pockets of the highest solar potential out of the entire contiguous United States occurring in parts of California, Nevada, Arizona, New Mexico, and West Texas (National Renewable Energy Laboratory, 2009). The southern regions of Utah and Colorado also fall into this zone of high potential. This data alone points to the relevance of additional studies into the status of solar energy in the Southwest that examine both the role of solar power within these states, and its context in relation to the rest of the region. The geographical study area for this research was established primarily based on the solar potential of the selected states.

Considering the Southwest as one regional unit is fairly straightforward when discussing solar potential, but the overall pattern in much of the study, planning, and regulation of energy issues in the western states has trended toward a regional approach as well. For instance, in the *Renewable Energy Atlas of the West*, the researchers provide a comprehensive look at the status and potential of various renewable energy resources, including solar, in 11 states in the west: Washington, Oregon, California, Idaho, Montana, Wyoming, Utah, Arizona, Nevada, Colorado, and New Mexico (Nielsen et al., 2002). These same 11 states were the ones included in the government's *Designation of Energy Corridors on Federal Land in the 11 Western States* Programmatic Environmental Impact Statement made available to the public in 2008.

A regional approach becomes almost essential when considering the related issues of transmission, areas of production and use, and regulation that are part and parcel of the energy picture, whether it is produced by solar or conventional methods. A document such as the PEIS referred to above that has the specific goal of identifying strategic transmission and distribution networks on federal lands throughout the west must be regional by nature. Powerlines and gas pipelines do not conveniently end at state boundaries, nor is all the energy that is consumed in a state always produced within that state. Accordingly, the Western Renewable Energy Generation Information System—the independent agency charged with monitoring the origins and distribution of renewable energy for the western US—is also operating with a regional approach with an area of jurisdiction that encompasses 14 western states, 2 Canadian provinces, and Baja California (WREGIS, 2009).

While understanding the regional context is important, focusing on the state-wide scenario is sometimes necessary and some research has been done that focuses more specifically on solar energy within individual states. In their research, Mehos and Owen looked at the potential for concentrating solar power in Arizona, California, Nevada, and New Mexico, considering only those regions that received 6.75 kWh/square meters of insolation per day or more, had less than a 1% slope, and that did not occupy national parks, wildlife refuges, bodies of water, or developed urban areas (2004). Their results can be seen in Table 1.

Table 1. Suitable Land for CSP Plants and Associated Generation Potential

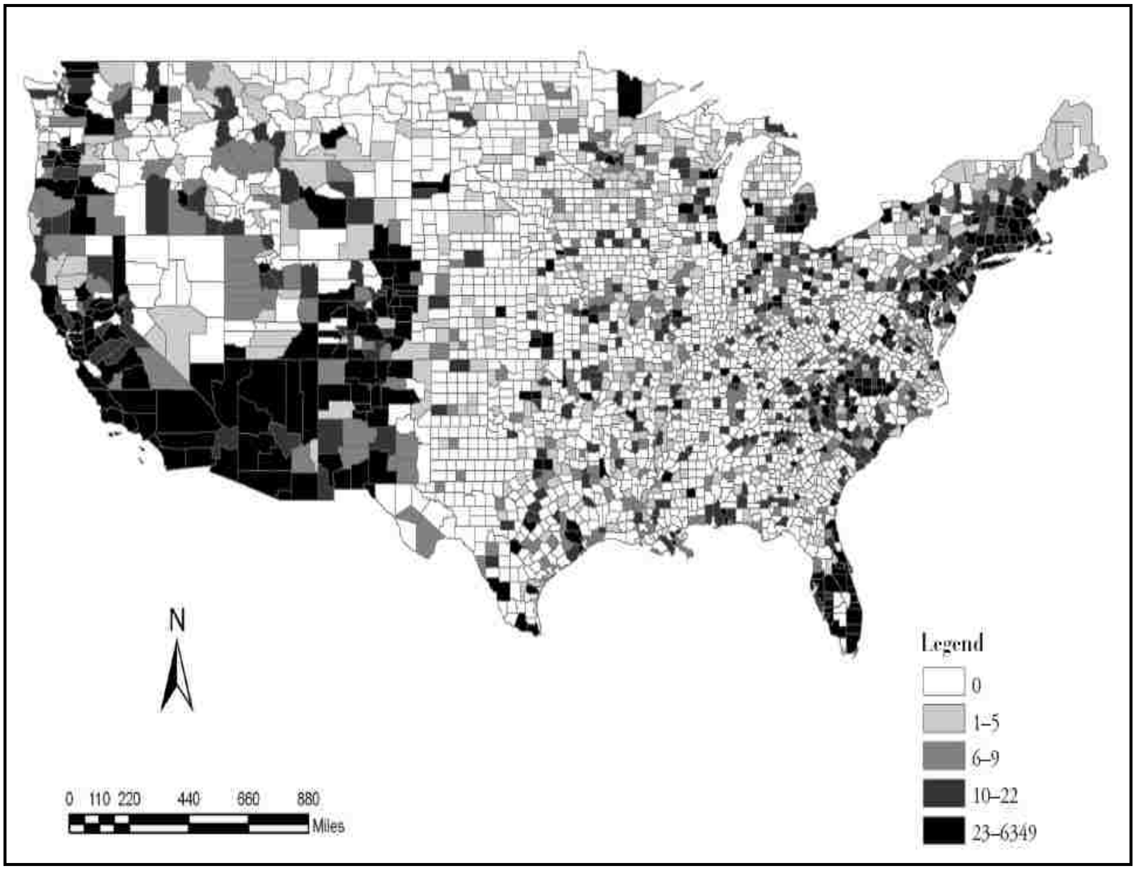
State	**Available Area (Sq. Miles)**
Arizona	25,527
California	6,421
Nevada	5,807
New Mexico	23,640
Total	61,395

(Mehos and Owen, 2004, 2).

Distance from areas of high energy consumption and access to "unconstrained transmission" were also considered (1). They found that even when considering only the highest solar resource values, "there is potential for more than 7 million MW of solar generation capacity in the Southwest" (2). Although Texas, Colorado and Utah were not even considered in their research, Mehos and Owen conclude that "the solar energy resource in the southwestern United States is largely untapped" (2). These findings demonstrate the massive potential for solar development within the region and a need to further investigate the possibility of developing these sites, as well as consider factors that might have been overlooked or excluded in previous suitability assessments.

In addition to the physical environment in the Southwest, the presence of certain socioeconomic conditions, as well as a particular political environment, makes at least certain parts of the region very well suited to the development of solar energy. Research into the prevalence of home-installed PV setups has indicated that in addition to environmental variables, certain economic conditions (median home values, degree of urbanization, etc.) and sociopolitical criteria (number of residents aged 40-49, whether a particular county voted democrat in the 2000 election, the number of environmental nonprofits within a county, etc.) correspond highly with the presence of residential solar setups (Zahran et al., 2008). The article published by these authors identified Taos county, New Mexico as the number one county in the nation for the prevalence of residential PV setups. A total of 2.84% of total households in the county (360 homes in Taos County out of 12,675) reported using solar energy for all or part of their heating needs (Zahran et al., 2008, 425). The article points out that the county “appears to have the ideal environment, sociopolitical, and economic characteristics for fostering the adoption and spread of solar thermal technologies” (Zahran et al., 2008, 425). Also of note was that more than half of all the counties in the nation leading in residential water heating with solar were located in Colorado (Zahran et al., 2008, 424). A distribution of households employing solar water heating technology can be seen in Figure 4.

Figure 4. Observed Households Heating with Solar Energy by County Quintiles



In the map above, the color of a county is based on the number of homes within it that are heating with solar energy. Image source: Zahran et al., 2008, 431.

The authors point out that a geographic pattern of residential solar use can be seen "stretching from California through Arizona and New Mexico and up through Colorado, encircling Nevada" while a relative dearth of solar use can be seen stretching from "western Texas through Kansas, Nebraska, and South Dakota, up to a stretch of counties that border Canada in Montana and North Dakota" (Zahran et al., 2008, 425). The absence of residential solar energy in western Texas is worthy of consideration when viewed in light of the distribution of solar resources in the United States (Figure 3). Even though their research looked at residential solar use rather than utility-scale solar, Zahran et al. demonstrate that the presence of high solar potential in an area alone does not necessarily correspond with an accordingly high implementation of solar technology.

Given that certain socioeconomic and political criteria are sometimes as relevant to the success of solar energy development as environmental constraints, and that these conditions appear to be more favorable in certain areas, the literature indicates the need to be aware of these other criteria as a locational factor in the development of solar power. Accordingly, as the PV sector continues to grow, it is important to recognize the high potential possessed in parts of the southwestern US to anticipate and inform planning, environmental, regulatory, and business decisions. Identifying locations within the region that are best suited for this type of development physically and socio-politically is an essential part of planning the energy future of the Southwest.

2.4 Geography and the Production and Transmission of Energy

As mentioned above, there is a precedent (and imperative) for considering the geographical context in regard to production, transmission, and regulation of energy, which is evident in the way that the western states are often considered as one energy block. Physical and political geography play a large role in the planning and implementation of energy production sites and transmission networks, and this is reflected in the literature on this topic.

One particular PV project in Indonesia focused on increasing the number of small, residential units in use throughout the country. The physical nature of the setting—many small, unconnected islands—played into the decision made to pursue a decentralized non-grid-based development approach (Dasuki, Djamin, and Lubis, 2001). Additionally, the effort was funded in large part by government aid, both foreign and domestic. This one particular case study alone highlights the relevance that physical, political, and economic geography can have in energy development projects.

Other authors have compared the way that the solar industry has been developing in Japan versus the United States. Shum and Watanabe (2007) determined that while PV development in Japan has progressed following a model akin to IT development (i.e., flexible technologies catering to a niche market), PV growth in the US has been dominated by large-scale, site-specific efforts designed to operate within the existing grid infrastructure. These authors argue that this trend has actually been an impediment to more widespread PV deployment in the US because there has been little technological development of universally installable setups that can be employed in various settings. The focus on site-specific designs in the US that they identified illustrates the role that geographical setting can have on the way that PV sector develops.

The political geography of an area can be the single-most influential factor in regard to renewable energy development such as solar. While the political climate or regulatory policies can play strongly into determining the actual location of individual facilities, a factor that will be discussed in further detail later, these criteria also have a noticeable impact on the greater picture of energy production and transmission in an area. This is probably most visible in the case of Renewable Portfolio Standards (RPS's). These RPS's are local, regional, or state-wide policies that require a minimum percentage of an area's energy to come from renewable resources.

Since 2004, New Mexico has had legislation in regard to minimum requirements and targets for renewable energy production within the state. The Renewable Energy Act of 2004, or REA, established the initial Renewable Portfolio Standard (RPS) and required investor-owned utilities to have 10% of their energy production met with renewables by 2011. According to the New Mexico Energy, Minerals, and Natural Resources Department, this policy has been responsible for considerable growth in the renewable energy economy within the state—to the tune of $500 million in capital investment since its inception (2007, 1). In March of 2007, New Mexico's REA was strengthened when Governor Bill Richardson signed State Bill 418: Enhancing the Renewable Portfolio Standard. This bill, among other things, requires public utilities companies to generate 10% of their energy with renewables by 2011, increasing to 15% by 2015 and eventually reaching 20% by 2020 (Database of State Incentives for Renewables and Efficiency, 2009).

Colorado has also passed legislation relating to the promotion of renewable energy. Effective since March 2008, House Bill 08-1160 has made it mandatory for municipal utilities companies (serving more than 5,000) to offer net-metering to their customers. In March 2007, the state also enacted a graduated RPS with House Bill 1281 that requires investor-owned utilities to have 10% of the energy they sell come from renewable energy sources between 2011 and 2014, ultimately increasing to 20% by the year 2020. Additionally, the bill requires that 4% of the renewable requirement (i.e., 0.8% percent of all energy produced in 2020) must come from solar energy (Database of State Incentives for Renewables and Efficiency, 2009).

Arizona has had a similar Renewable Energy Standard (RES) since November 2006 when the Arizona Corporation Commission established a 15% renewable requirement by 2025 for investor-owned utilities, to be introduced on a graduated scale. The RES will employ the use of renewable energy credits to ensure accurate tracking of power generation and utility compliance. Of note is the requirement that Arizona has established that requires that a percentage of the renewable energy quota to be produced using distributed technologies (30% of renewable energy, or 4.5% of all energy must be produced in this manner by 2025). This type of technology would include residential PV systems and other small-scale renewable energy generation projects. This component of Arizona's RES encourages a different mode of energy development and might be expected to visible in the scale at which utility-scale solar facilities are being deployed in the state over the next 15 years (Database of State Incentives for Renewables and Efficiency, 2009).

Utah passed similar legislation in 2008 that has been called a renewable portfolio goal (rather than a renewable portfolio standard) due to its less binding nature. Investor-owned utilities companies, municipal utilities, and electricity cooperatives will have to provide 20% of the energy they sell in 2025 with renewables, as long as it is "cost-effective." The Utah Public Service Commission is responsible for defining the measures that determine the cost effectiveness of projects. Unlike most of the renewable portfolio standards in other states that feature graduated increasing requirements, Utah does not currently have any defined interim targets (Database of State Incentives for Renewables and Efficiency, 2009).

Texas has had a Renewable Energy Mandate in place since 1999. This piece of legislation established an RPS that was strengthened in 2005 with SB 20, and now requires an additional 5,800 MW of energy to be generated from renewables by 2015 on an incrementally graduated scale. This value (5,800 MW) corresponds to about 5% of the state's energy demand. A target was established for 500 MW of this energy requirement to come from renewables other than wind, as wind power currently accounts for almost all of the renewable energy generated within the state. Provisions were made in SB 20 that allow utilities companies to recover costs associated with expanded transmission infrastructure in their rates. A renewable energy credit program has also been established to keep track of renewable energy generation and to allow for the possibility of trading as a way for utilities companies to meet the new renewable energy requirements (Database of State Incentives for Renewables and Efficiency, 2009).

Since 2002, California has also had a renewable portfolio standard in place. California's RPS is one of the more aggressive standards, with recent changes requiring that 20% of investor-owned and publicly-owned municipal utilities' retail sales come from renewables by 2010, increasing to 33% by 2020. These requirements, put in place by Executive Order S-21-09, can certainly be expected to play a significant role in the direction that energy development takes within the state in the coming years (Database of State Incentives for Renewables and Efficiency, 2009).

Lastly, Nevada has had an RPS since 1997 that requires the state utility NV Energy to supply a minimum percentage of the energy it sells with renewable resources. The requirement was revised in 2001 and again in 2009, and now a graduated increase has been instituted in the state that requires 15% of energy to come from renewables by 2012 and 25% of energy to come from renewables by 2025. Currently there is a 5% "carve out" for solar until 2015 that requires at least 5% (1/3 of the 15% renewable standard) to be produced using solar technologies (Database of State Incentives for Renewables and Efficiency, 2009).

In addition to these policies, most of the states in the study area also offer additional financial incentives in the form of tax breaks or other measures that seek to offset some of the costs associated with installing renewable energy projects. The influence that these policy measures will have in the methods of energy production within the Southwest is quite significant. The fact that these bills were passed illustrates that a favorable political climate exists, and that utilities companies will be actively seeking ways to expand their renewable energy production.

Another influential policy measure that factors heavily into the general acceptance and rate of deployment of solar installations is the institution of buyback programs. In a Nova documentary on the status of solar energy and its promising growth, the role of a government guaranteed buyback rate for energy produced on privately owned PV setups was identified as having played a critical role in the virtual explosion of solar installations throughout Germany (2007). Other research has shown that the presence of these buyback agreements, either guaranteed by the government or through arrangements with utilities companies, has been an integral part of solar development in different locations including the US, Canada, and Spain (Behar, 2009, Lorinc, 2008, Carrión et al., 2008).

Case studies in Germany have shown the role that national policies and support can have on industrial development and deployment of “renewable energy systems” (Lund, 2009). In his research, Lund looks at how these policies have shaped the roles of individual countries in the international market for products associated with renewable energy generation, pointing out that public policy will “very likely lead to new increasing industrial activities in country” (Lund, 62).

There is a need for a comprehensive approach in the planning of solar energy projects in the United States that considers local environmental concerns/constraints, the role of government involvement, sociopolitical factors, regional transmission and regulatory logistics, land issues, and other relevant criteria. The analytical power of GIS, and the advances that have been made in computer-based suitability modeling, make these two techniques well suited for this type of planning and decision making.

2.5 Geography of Solar Power Facilities

An area where the discipline of geography has perhaps the most to offer, and the focus of this research project, is the development of suitability maps that determine strategic site locations for individual solar power generation projects. As a study that concentrates on places and the dynamic, complex set of defining characteristics in those places, geography has a long history dealing with the possibility, implications, and advantages/disadvantages of dedicating land areas to a specific use.

Specifically in regard to energy geography, research in siting choices for renewable energy projects has indicated that there are similarities regarding the criteria that should be considered. For instance, in their work Rodman and Meentemeyer (2006) considered land use restrictions, available wind resources based on climatic data, and compatibility with environmental and regulatory requirements in determining suitable locations for wind farm sites in northern California. They emphasize the need to consider multiple factors and point out that targeting the most-suitable sites for development will minimize controversy and improve public perception—thus facilitating the overall process. Their rule-based modeling approach considered physical features (i.e., wind speed, obstacles, and terrain), environmental concerns (vegetation/land use—which was given the highest weight, presence of wetlands, and presence of endangered species), and the human impact element (avoiding developed areas and public parkland). Although not considered explicitly in their analysis methods, they also mentioned the importance of finding locations that were within a reasonable proximity to existing grid infrastructure.

In their work on siting solar power plants in Andalucia, Spain, Carrión et al. considered very similar criteria to determine ideal locations including environmental concerns (weather, insolation values, ruling out sites located on protected Nature Parks, etc.), land use (by choosing sites of low agricultural value), proximity to urban centers (4 km from the outer limits of city), slope (sites with a slope greater than 2% were eliminated), proximity to existing transmission lines and substations, and local opinion (*Renewable Energy,* 2008, *Renewable and Sustainable Energy Reviews,* 2008). This is similar to Mehos and Owens's (2005) research, which provided a rough assessment of potential land for solar development in the Southwest and considered insolation values, proximity to high-use areas, and access to transmission (Mehos and Owen, 2005). Furthermore, all of these researchers included GIS analysis in their methods indicating the value of this approach can have in filling the need for more analysis that considers specific factors as the Southwest moves toward a more renewable-intensive energy portfolio.

Just as political geography must be considered on the regional level, it is also relevant at the local scale. Wustenhagen et al. (2007) examined the importance of social attitudes and perceptions in the ultimate failure or success of renewable energy projects in their article, *Social Acceptance of Renewable Energy Innovation.* Although their research dealt with wind farms, they mentioned the importance of policy (such as tax laws, etc.), market concerns, and viewsheds—areas from which a physical structure or array is visible. Despite what is generally seen as wide public support for renewable energy, social acceptance is an important factor in the success of projects in local implementation. The smaller size of renewable projects tends to necessitate more sites for them than traditional sources of power generation. Establishing trust among community members, and involving and informing them of siting goals and about the nature of projects can improve community acceptance. According to the authors, major factors to consider include bridging the national-local divide, establishing a critical mass in the political system to promote solid renewable energy policy, working to promote sociopolitical acceptance through market acceptance, establishing a 'sense of ownership' or investment among locals, and considering what other factors may be critical in the acceptance of alternative technologies (including PV).

This information, considered in relation to the findings of Zahran et al. (2008) that identified parts of New Mexico as "ideal" for solar development again indicates that there is high potential within the Southwest for solar energy projects. Regarding local policy, the favorable conditions within New Mexico are also reflected in Catalina's consideration of the 1977 New Mexico Solar Rights Law (1980, 43) that declares that "'the right to use the natural resource of solar energy is a property right, the exercise of which is to be encouraged and regulated by the laws of this state. Such property right shall be known as a solar right.'"

Much of the literature indicates that solar energy projects, when planned properly, can be both well-received and financially attractive to investors. At present, there is a need for current data to help inform these types of planning decisions. The limited research that has been done in the Southwest (including *The Renewable Energy Atlas of the West* and the work of Mehos and Owen [2005]) is relatively preliminary, and increasingly outdated in the context of social and political change. An updated, comprehensive GIS-based approach to locational analysis is needed that accounts for the physical, social, legal, and political factors that shape site suitability for solar power plants. In many regards, GIS is the ideal tool/environment with which to address these issues, and the methodological approaches made possible with a GIS approach are the topic of the next section.

2.6 GIS and Suitability Modeling

Particularly in the last decade, GIS has become nearly a ubiquitous tool in suitability studies of many different types. The fundamental approach behind a GIS—that is, representing geographic information as a compilation of layers that can be manipulated both quantitatively and in their display—is very well suited to the multi-criteria style of analysis that characterizes most suitability studies. GIS platforms provide a suite of tools and analytical techniques that allow the user to investigate the nature of the distribution of nearly any geographic phenomenon. The more additional information available, in the form of data layers that are related primarily or secondarily to the presence and distribution of the phenomenon in question, the more complex and meaningful the conclusions about the topic of study can be.

The nature of suitability modeling is somewhat bi-directional in the sense that an analysis can either consider the cases of existing incidents and seek to identify the variables that explain a distribution, or a set of prioritized criteria known to be important in a locational decision-making process can be considered comprehensively to pinpoint locations that might be well-suited for or likely candidates for a particular phenomenon (i.e., organism habitat, new commercial establishments, service areas, utilities installations, etc.). Obviously these processes mutually reinforce one another and analysis in either direction works to both further the understanding of the spatial distribution of a given phenomena and improve the ability to identify likely or ideal locations for future incidents or facilities.

Much of the research in suitability modeling employs a technique known as the Weighted Linear Combination (WLC) method. In his review article, Malczewski (2000, 5) writes that the "(WLC) model is one of the most widely used GIS-based decision rules. The method is often applied in land use/suitability analysis, site selection, and resource evaluation problems." While Malczewski discusses common shortcomings in WLC applications, he points out that the method is intuitive, generally easily understandable, and thus appealing to policy and decision makers. Malczewski outlines the key steps to a WLC analysis in Table 2.

Table 2. Steps Involved in the Development of a WLC Model

Step in Model Development	**Explanation**
1. Identify the set of attribute map layers	What can and will be considered?
2. Define the set of feasible alternatives	What will possible outcomes look like?
3. Generate commensurate attribute maps	Develop appropriate classification for each variable
4. Assign attribute weights	Determine priority of variables
5. Combine attribute maps and weights	Overlay operation/summation of scores/Boolean
6. Rank the grid cells	Examine resulting combinations of grid cell scores

(Adapted from Malczewski, 2000, 9).

Regardless of the application in which a suitability model is being used, these steps (with some minor variations) are usually employed. The general idea behind the approach involves carefully choosing a set of relevant criteria input layers, developing a classification system and appropriate weight for each dataset, overlaying these layers on top of another, and considering the cumulative output. This final output can be in the form of a Boolean grid (where map areas are either "in" or "out" based on the combination of input layers), a scored grid (where the value assigned to each output area in the final map is the sum of the input layers), or some combination of both. The establishment of appropriate classifications for inputs (i.e., what will constitute a low, medium, or high ranking for a particular variable), and appropriate weights for each input (the importance/influence of each variables relative to the other variables in the model) is also critical to developing a model that performs well.

GIS-based approaches to suitability modeling that use the WLC approach have been employed in a vast array of uses including assessing land suitability for the cultivation of cherimoya fruit trees in their study area in Ecuador, producing suitability models for jaguar habitat in Arizona, mapping out regions of high risk for plague in the state of New Mexico, and developing a strategic agricultural manure application plan in Australia, to name a few (Bydekerke et al., 1998, Hatten, Averill-Murray, and van Pelt, 2005, Eisen et al., 2007, Basnet, Apan, and Raine, 2001). All of these analyses were performed in a GIS, making it possible to perform the type of overlay analysis with various factors that is fundamental to multi-criteria suitability modeling. By looking at multiple variables simultaneously, final suitability models were developed in each study with areas classified based on their ranking for each criterion.

In addition to the general approach applied in these research topics, several other techniques were implemented that are worth considering in the scope of this analysis. In their final results on Jaguar habitat analysis in Arizona, the researchers produced a series of three maps that ranged from a conservative assessment of possible habitat areas, to a more generalized map based on an adjusted set of inputs with more relaxed boundaries (Hatten, Averill-Murray, and van Pelt, 2005). This highlights the fact that even though GIS-based suitability mapping can be very powerful, it is important to be aware of the importance assigned to each of the various inputs. There can be accuracy limits for input datasets, or a level of uncertainty associated with the development of a preferred/excluded classification that should be considered when developing a suitability model.

Also of note is the way in which Eisen et al. (2007) assessed the accuracy of their map for plague risk in the state of New Mexico by comparing their final suitability map to the actual locations of recorded plague cases. In doing so, the researchers were able to assess whether outbreaks did in fact occur in those regions that they had identified as high risk zones. Ultimately, 89% of all reported human cases in the state were identified as falling within those regions the team had classified as highly suitable for plague outbreak. Investigating the degree to which their maps matched up with the real world distribution of the phenomenon under investigation allowed the researchers to assess the accuracy of their suitability model. This is an important analytical technique that will be employed in a similar fashion in this research to assess and validate the current methods of suitability mapping for solar energy.

The variety of applications in which GIS has been employed for the purposes of suitability modeling illustrates the strength of this approach and its immense utility in answering questions concerned with the explanation of a distribution or pinpointing good candidate locations for certain projects. In his review of the literature on GIS based multi-criteria decision analysis, or GIS-MCDA, Malczewski (2006, 707) discusses how widespread GIS-based multi-criteria decision analysis (GIS-MCDA) has become and how well suited it can be for a site search due to the explicitly spatial nature of the criteria being considered. He also points out that land suitability is actually the number one topic in which this method is employed; 30% of all the articles he reviewed were concerned with land suitability analysis (Malczewski 2006, 715). He points out that the "major advantage" of using GIS based MCDA in an analysis is that decision makers can incorporate value judgments (through weighting and classification) into a model, and "receive feedback on their implications for policy evaluation" (Malczewski 2006, 717). This ability to look at decision-making and how it affects policy, or alternatively, looking at policy and how it affects decision-making is very useful, and the field of energy development is certainly no exception.

GIS has now become a standard tool in suitability modeling for solar energy. The solar suitability model developed by Carrión et al. (2008) discussed earlier is a perfect example of how GIS is being employed to identify areas that are well-suited for the development of solar power. This group of Spanish researchers employed a multi-criteria overlay approach that considered land use, slope, insolation values, proximity to urban areas of high energy demand, and proximity to existing transmission infrastructure to identify suitable locations for new solar facilities (*Renewable Energy,* 2008 and *Renewable and Sustainable Energy Reviews,* 2008). Another feasibility study on concentrating solar power in New Mexico (conducted by the Black and Veatch Corporation for the New Mexico Energy, Minerals and Natural Resources Department) also used a GIS multi-criteria model that considered solar resources (insolation), the presence of adequate land and topography, transmission issues, land ownership, water resources, economic costs and benefits, environmental and permitting consideration, and social and political issues (Black and Veatch, 2005). Both of these examples considered very similar criteria, and employed a similar approach to identify suitable candidate sites.

The accuracy of certain datasets relevant to solar suitability modeling has also been improved recently through the use of GIS applications. Various research efforts have been devoted to using GIS to produce more accurate surface layers for insolation values by taking into account topography, cloud cover, difficulties associated with a low number of data collection points, and the type of technology being employed to capture sunlight (Kumar, Skidmore, and Knowles, 1997, Suri and Hofierka, 2004, Suri, Huld, and Dunlop, 2005). As these improved input datasets continue to be incorporated into suitability models, it can be expected that their overall accuracy and efficacy in locating ideal candidate sites will be increased as well.

An important consideration in the development of solar suitability models is determining whether the model will be designed for more general, regional analysis or whether it will be employed to rate different candidate sites for a small-scale, locally specific study. Malczewski (2000, 10) alludes to this when he writes that, "…the best alternative at one level does not necessarily hold at another level. It can be argued that every change in scale for which a decision problem is formulated will bring about the statement of a new set of alternatives." Studies with a more localized focus, such as the Black and Veatch report (2005) that identified several potential sites for a concentrated solar power plant in New Mexico, are often able to consider criteria that would either be impossible to obtain or too difficult to model in a larger regional study. In their report, the authors considered access to water in the ranking of candidate sites (necessary for producing steam and cooling the turbines at these types of solar facilities) by investigating the availability of water rights at each of the potential locations. The availability of water rights is obviously an important consideration for this type of localized study, but one that is impractical or nearly impossible to consider in the scope of the entire Southwest. Likewise, factors such as the price of individual land parcels are also quite relevant at an advanced stage in the planning process, usually when one final site is being selected from a narrowed-down list of several possible sites. However, this type of information is not available in a dataset for the whole Southwest, and thus cannot be considered in an analysis of this nature. Accordingly, for this research—which takes a large-scale regional focus—only those factors that are both relevant and available for the entire study area will be considered in the analysis.

The role that GIS based suitability models play in decisions relating to locating utility-scale solar facility is quite significant. The research discussed above illustrates how widespread the application of this approach is, and the underlying commonalities in design behind these suitability models. These examples will serve as a guide for the development of an original solar suitability model for the Southwest, and are a justification for the nature of this research. Ultimately, this thesis seeks to assess the accuracy of this type of analytical approach by comparing the output results of a suitability model to the actual locations of solar energy facilities, and identify ways in which future models might be improved.

Chapter 3

Research Design and Methodology

3.1 Research Design

The general approach to this research involves developing a multi-criteria suitability model that classifies the potential for the development of utility-scale solar facilities in the Southwest. After acquiring and mapping the actual locations of solar power facilities that are either built or are planned to be built, these locations will be overlaid on the results from the suitability model. In this manner, it will be possible to quantify the extent to which the true locations of utility scale solar power plants actually match up with those regions that the model classifies as “most ideal,” and identify other criteria or information that explain or factor into the observed distribution of these types of facilities. The identification, by state and/or facility type, of any major discrepancies between the model-derived suitability results and the actual distribution of solar power plants makes it possible to address methodological weaknesses in traditional suitability modeling techniques. After identifying other criteria that play a significant role in explaining the distribution of utility-scale solar power plants, ways in which future models could be improved will be discussed.

3.2 Development of the Model – Data Processing Steps

3.2.1 Data

Multiple GIS data layers were necessary for the development of a suitability model for the study area, as well as for the subsequent analysis of the accuracy of that model. It was possible to locate the majority of this information from existing sources, which facilitated the development of a robust suitability model within a reasonable timeline.

The insolation data values for the continental United States were downloaded from the National Renewable Energy Laboratories website. A layer of all the roads for the study area was acquired from the 2000 Tiger Road dataset. A layer of major power transmission lines running through the study area was also acquired from the National Renewable Energy Laboratories website. Elevation values and topography information were downloaded as a 30 meter digital elevation model (DEM) from the United States Geological Survey's Seamless website. A layer denoting the current surface management agencies of land parcels (as of 2009) was acquired from a representative of the Bureau of Land Management (BLM), and was used to determine federal and state land ownership details. This layer was also used for denoting areas to exclude from consideration based on their designation status. Due to what appeared to be incomplete coverage of the BLM layer for the state of Texas, a second layer denoting state ownership was acquired from the Texas General Land Office (GLO) website. Lastly, the location of all the existing and proposed utility-scale solar facilities (of different types) was compiled and digitized by the author. This information is represented in Table 3.

Table 3. Data by Type and Source

Data Layer	Data Type	Data Source
Solar Insolation Values	Raster, (10 m.)	National Renewable Energy Laboratories
Study Area Roads	Vector	Tiger2000 Road Dataset
Ownership/Excluded Areas	Vector	Bureau of Land Management
Texas State Ownership	Vector	Texas General Land Office Website
Study Area Powerlines	Vector	FEMA National Transmission Dataset
Hydrography Information	Vector	NationalAtlas.gov Website
Digital Elevation Model	Raster, (30 m.)	USGS Seamless Website
Existing/Proposed Solar Facilities	Vector	Compiled/Digitized by Researcher

3.2.2 Model Overview

A suitability model that classifies the land in the study area in terms of its suitability for the location of utility-scale solar power plants was developed for the southwestern United States. Both the input criteria and the relative weight that each factor ultimately has in the overall ranking of an area's candidacy were determined by considering the relevant literature and reviewing the conventional methods that have been employed in past suitability assessments of this nature. Relevant studies in this case include other suitability assessments for locating renewable energy generation sites, specific solar candidate site studies previously conducted within the study area, and other applicable GIS-based suitability assessments. In this manner, the literature serves as a surrogate for the primary collection of expert opinions, with the understanding that these opinions have already been incorporated into previous models of a similar nature and will be captured in the replication of common techniques from existing research. Furthermore, the current locations of all the existing and planned solar facilities in the Southwest were determined not by one individual or agency, but rather as a result of the goals and decisions of the multiple actors involved in energy development in the 7 different states. By developing a suitability modeling approach based on a cross section of the available research, the intention is to reproduce at a regional level the general trends that are employed in different models, as well as compensate for the unavailability of data in the decision making processes behind certain site decisions.

For this regional suitability analysis, four principal factors were considered to evaluate the suitability of land for utility-scale solar facilities: topography (slope), solar insolation values, distance to transmission lines, and distance to roads. These factors were chosen because they are routinely considered in almost all studies of this nature, and were available as datasets for every state in the study area. Additionally, while they were not ranked inputs for the suitability model, land ownership and designation status were considered in the analysis of the model output to identify potentially insightful trends in site location, and to exclude those parcels of land possessing a designation status unfit for the development of utility-scale solar.

The establishment of proper classification breakdowns for each variable, and appropriate weights for each in the overall consideration, is paramount to developing an effective suitability model. Because these parameters will ultimately be responsible for determining the final categorization of land areas, it is important to make sure that each input is classified and weighted properly in relation to its overall importance in the model. In this project, the classification of each variable is based, as much as possible, on the available examples from the literature dealing with similar suitability assessments, and the range of values present in each of the variables within the extent of the study area. For every factor except insolation values, 10 classes were established ranging from

0 to 9, with higher values representing a more desirable location within the dataset. Zero values were included to capture the fact that for some of the variables, values outside of a specific range can become insurmountably undesirable (i.e., sites with slope greater than 3% are wholly unsuitable for utility-scale development). This classification created consistent numerical scale between the layers; a prerequisite for the type of weighted sum overlay employed in this analysis. Furthermore, a 1-9 score structure was chosen to produce 3 ranked final output classes—a low, medium, and high characterization, each with a consistent internal breakdown.

The initial weights chosen for this model are based on the available information from the literature for similar suitability models, and a logical breakdown of the hierarchy of the factors in order of their importance.

3.2.3 Land Topography (Slope)

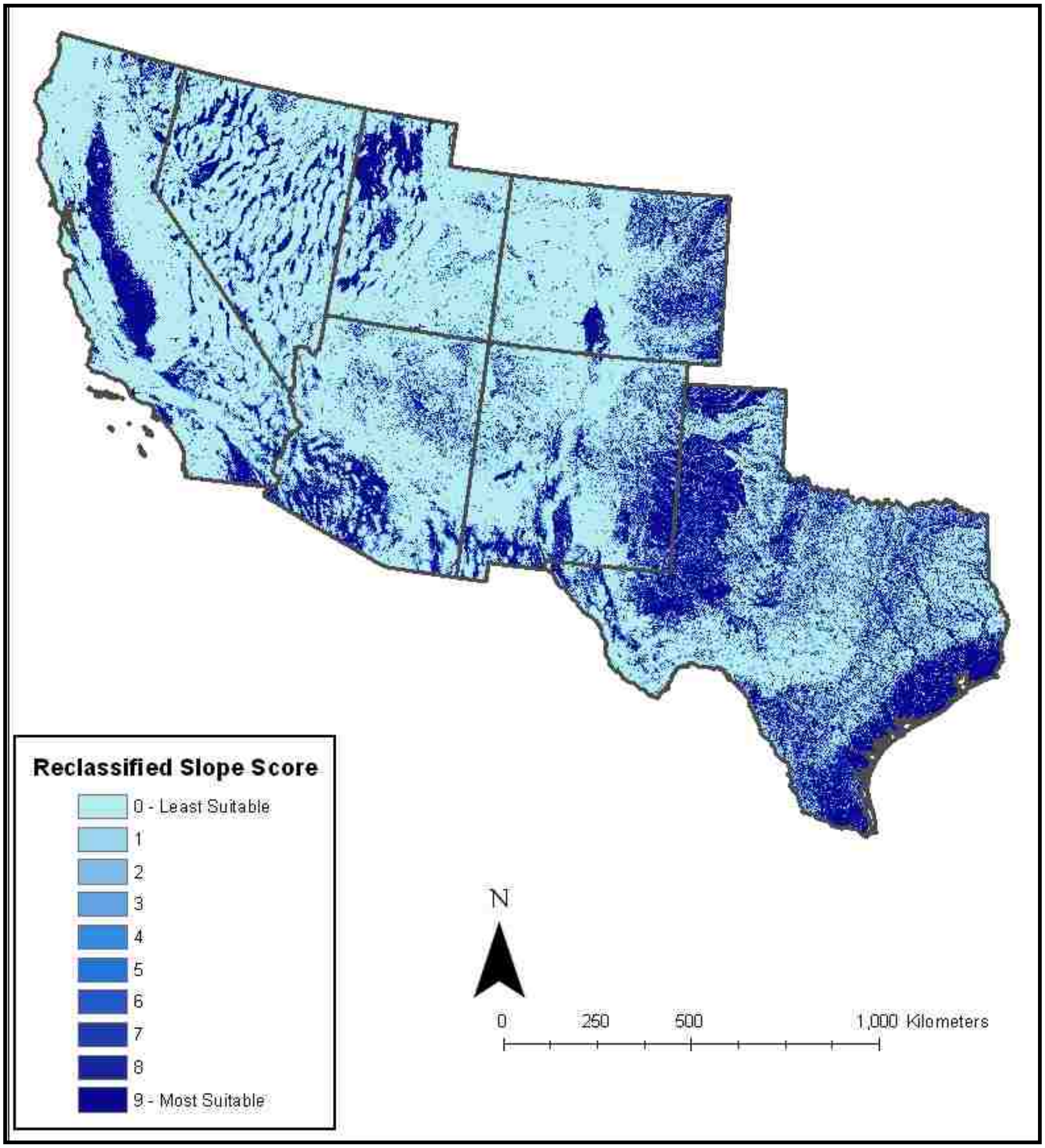
The principal factor in determining how suitable a tract of land is for solar development is the topography, specifically the slope. This is evident not only in previous suitability assessments, but logical because regardless of how good the insolation values are for a region, it is impractical to develop utility scale solar if an area is too hilly or too steep. Black and Veatch (2005, 3-1), "Parabolic trough and power tower plants require land that has a slope of less than 1 percent (i.e., 1 foot rise per 100 feet lateral distance)." In their more general regional assessment for concentrating solar, Mehos and Owen (2005, 1) write: "Lands with slope greater than 1%… were eliminated to identify lands with the greatest potential for low-cost development" (Mehos and Owen, 1). In their report on identifying suitable utility-scale PV sites, Carrión et al. (2005, 548) excluded all areas "with a slope greater than 2%," due to the fact that unless the site had a southern aspect, the shadows of the first row of solar panels would cast a shadow on those rows behind them and decrease the overall performance of the solar energy facility.

Based on this information, slope was given the highest weight in the model (40%), and was broken down into 9 classes. In the reviewed literature, no areas with slope values over 2% were considered in the various analyses. To be comprehensive, values up to 3% were considered in this analysis although slope values from 2 -3 % were assigned an output score of only 1. Slope values of 1% or less were assigned the highest value of 9, and slope values from 1- 2 % were broken down evenly into the remaining output ranks. This reclassification and the resulting map can be seen in Table 4 and Figure 5.

Table 4. Slope Reclassification Chart

Input Slope Value	**Output Rank**
0 - 1.000	9
1.001 - 1.143	8
1.144 - 1.286	7
1.287 - 1.429	6
1.430 - 1.572	5
1.573 - 1.715	4
1.716 - 1.858	3
1.859 - 2.000	2
2.001 - 3.000	1

Figure 5. Map of Reclassified Slope Rank



The slope values were obtained by downloading several hundred 30 meter DEM tiles from the USGS Seamless website, stitch these together in ArcGIS, and then running the slope operation on the study area. Flatter and thus more suitable areas appear in the map above in the darker shades of green.

3.2.4 Incoming Solar Radiation (Insolation) Values

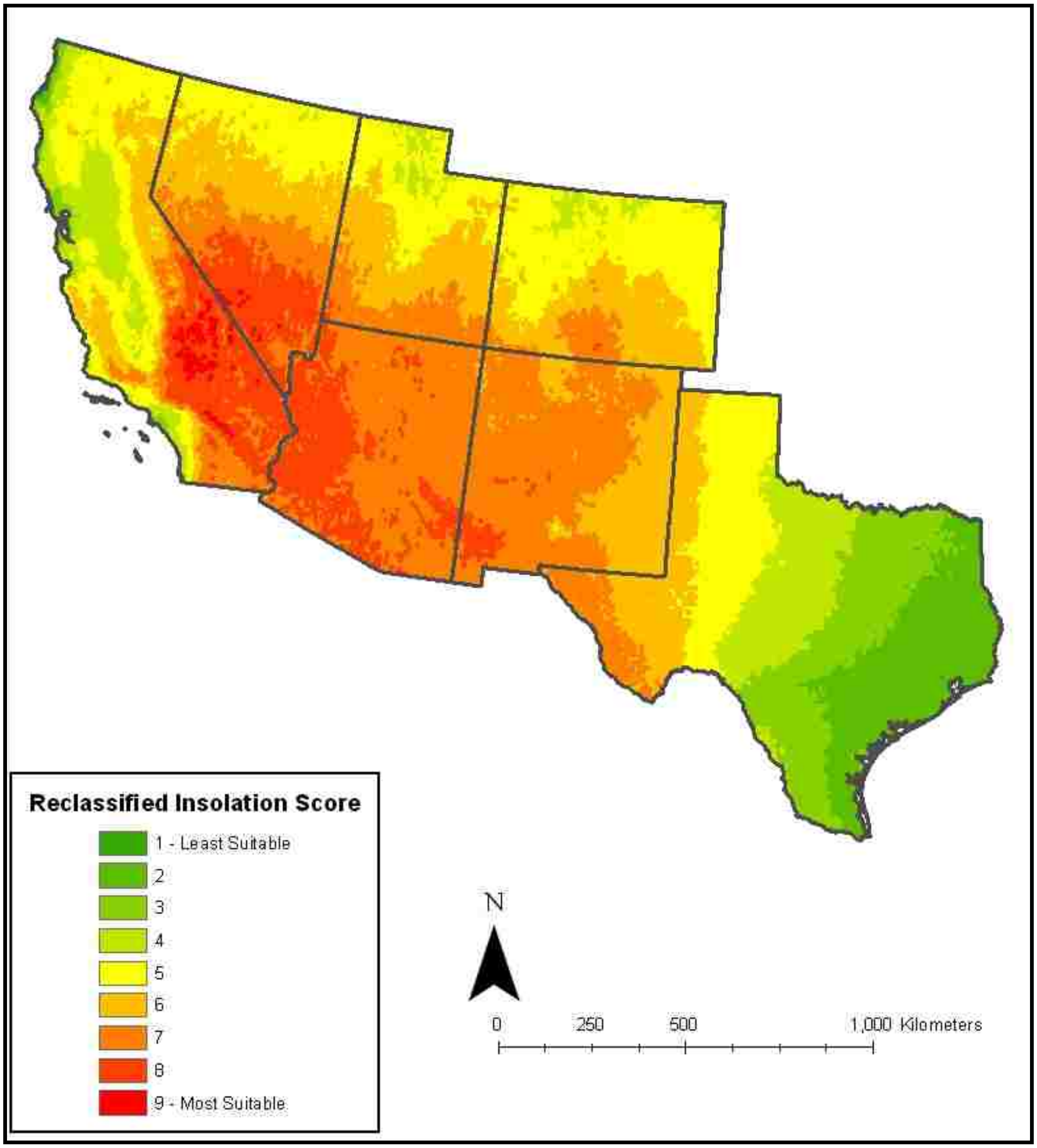
The second-most important variable in the consideration (given a 30% weight) are the incoming solar radiation (insolation) values for all of the land in the study area. Different studies have established different classifications of insolation values based on the range of values present in the study area (Carrión, 2005, Mehos and Owen, 2005, Black and Veatch, 2005). While Carrión et al. (2005) divided the insolation values into nine separate classes (with average annual insolation values greater than or equal to 4.83 kWh/m^2 /day constituting the highest ranked class), the work done by Mehos and Owen (2005) and the Black and Veatch team (2005) used fewer classes and ultimately only considered those areas with values greater than or equal to 6.75 kWh/m^2 /day. This indicates that for the Southwest, 6.75 kWh/m^2 /day or greater has been established as an ideal threshold for insolation values and will thus constitute the breakpoint for those areas with the highest ranking in the model.

Based on this information, the high class (ranks 7 – 9) in insolation values was defined as those areas with insolation values between 6.75 kWh/m^2 /day and 8.314 kWh/m^2 /day (the highest insolation values in the study area). The remaining insolation values from 3.418 kWh/m^2 /day (the lowest in the study area) to 6.749 kWh/m^2 /day were assigned ranks between 1 and 6, in an evenly distributed manner. The insolation values used for this research came from the NREL's GIS layer for incoming DNI solar radiation, defined as the "monthly average and annual average daily total solar resource averaged over surface cells 0.1 degrees in both latitude and longitude, or 10 km. in size" (NREL Metadata, 2009). This reclassification table and the resulting map for the insolation values within the study area can be seen in Table 5 and Figure 6.

Table 5. Insolation Reclassification Chart

Input Insolation Value (kWh/m^2/day)	**Output Rank**
3.418 - 3.945	1
3.946 - 4.472	2
4.473 - 4.999	3
5.000 - 5.583	4
5.584 - 6.167	5
6.168 - 6.749	6
6.750 - 7.271	7
7.272 - 7.792	8
7.793 - 8.314	9

Figure 6. Map of Reclassified Insolation Rank



3.2.5 Distance to Transmission Lines

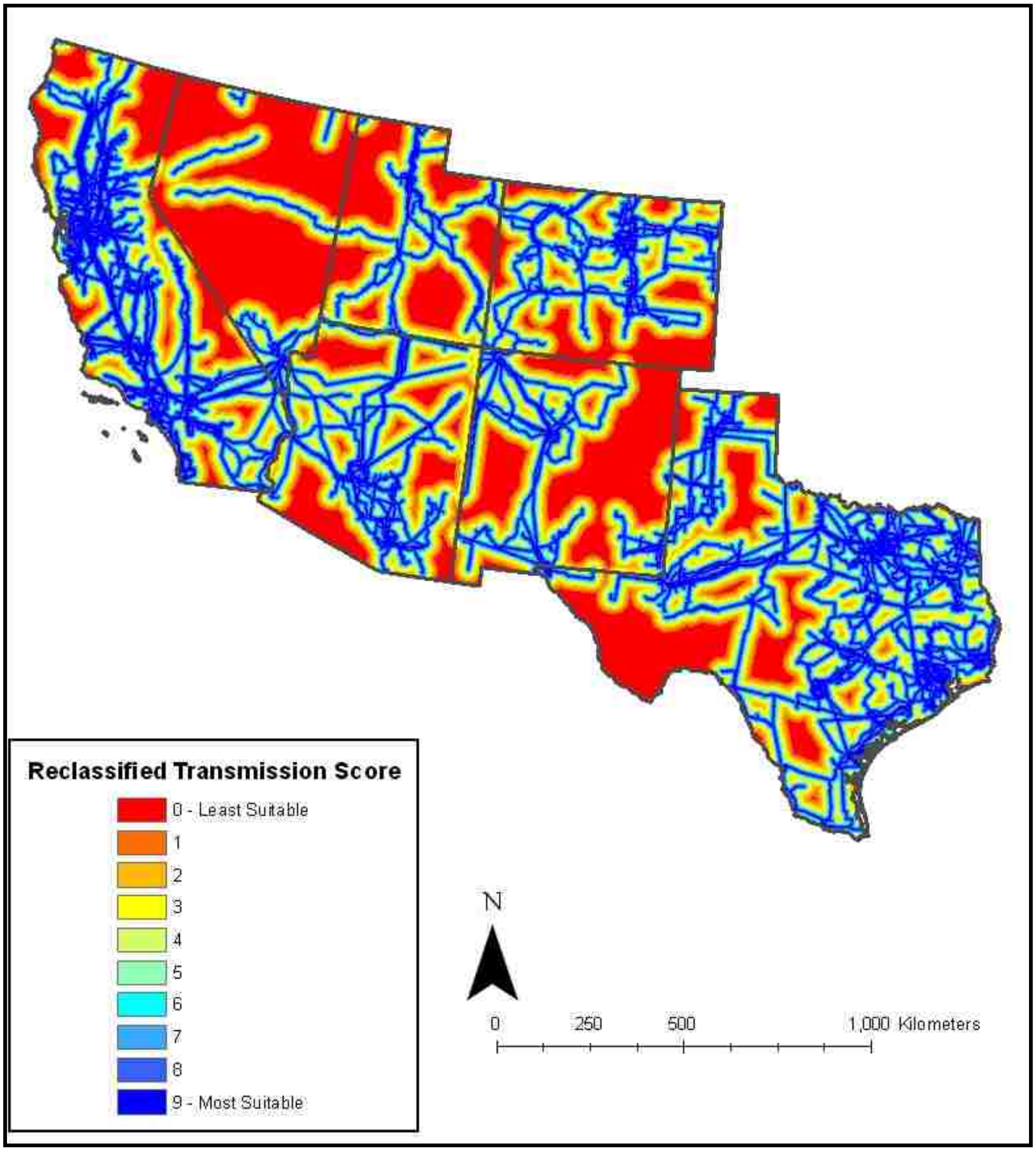
The next most relevant factor in the consideration (given a 20% weight in the model) is the distance to transmission lines. Building new transmission lines to connect a power plant to existing infrastructure can be a complicated and costly process. Minimizing the distance from a new site to existing lines is a priority in siting decisions, as many studies on siting new energy facilities point out (Mehos and Owen, 2005, Rodman and Meentemeyer, 2005, Carrión et al., 2005, Black and Veatch, 2005). Black and Veatch (2005, 3-3) specifically state that considered areas "must be within 10 miles of major transmission lines."

In the model developed for this research, transmission lines were buffered and ten classes were established, ranging from 0 to 24 miles (0 to 38,624 meters) in distance from the lines. The classification for land parcels is inversely related to their distance from the lines, with the top six ranks assigned in a decreasing manner to potential sites in increments of 1.5 miles (2,414 meters). At distances greater than 9 miles (14,484 meters), the decreasing ranks continue in increments of 5 miles (8,046 meters). Land parcels located at distances greater than 24 miles from transmission lines were considered to be undesirably distant from access to transmission and were assigned a rank of zero. The reclassification chart and the map of the reclassified distance to transmission can be seen in Table 6 and Figure 7.

Table 6. Distance to Transmission Reclassification Chart

Miles	**Input Values, Distance (m) to Transmission**	**Output Rank**
0 - 1.5	0 – 2,414	9
1.5 - 3	2,414 – 4,828	8
3 - 4.5	4,828 – 7,242	7
4.5 - 6	7,242 – 9,656	6
6 - 7.5	9,656 – 12,070	5
7.5 - 9	12,070 – 14,484	4
9 - 14	14,484 – 22,530	3
14 - 19	22,530 – 30,577	2
19 - 24	30,577 – 38,624	1
24 +	38,624 – 84,700	0

Figure 7. Map of Reclassified Distance to Transmission Rank



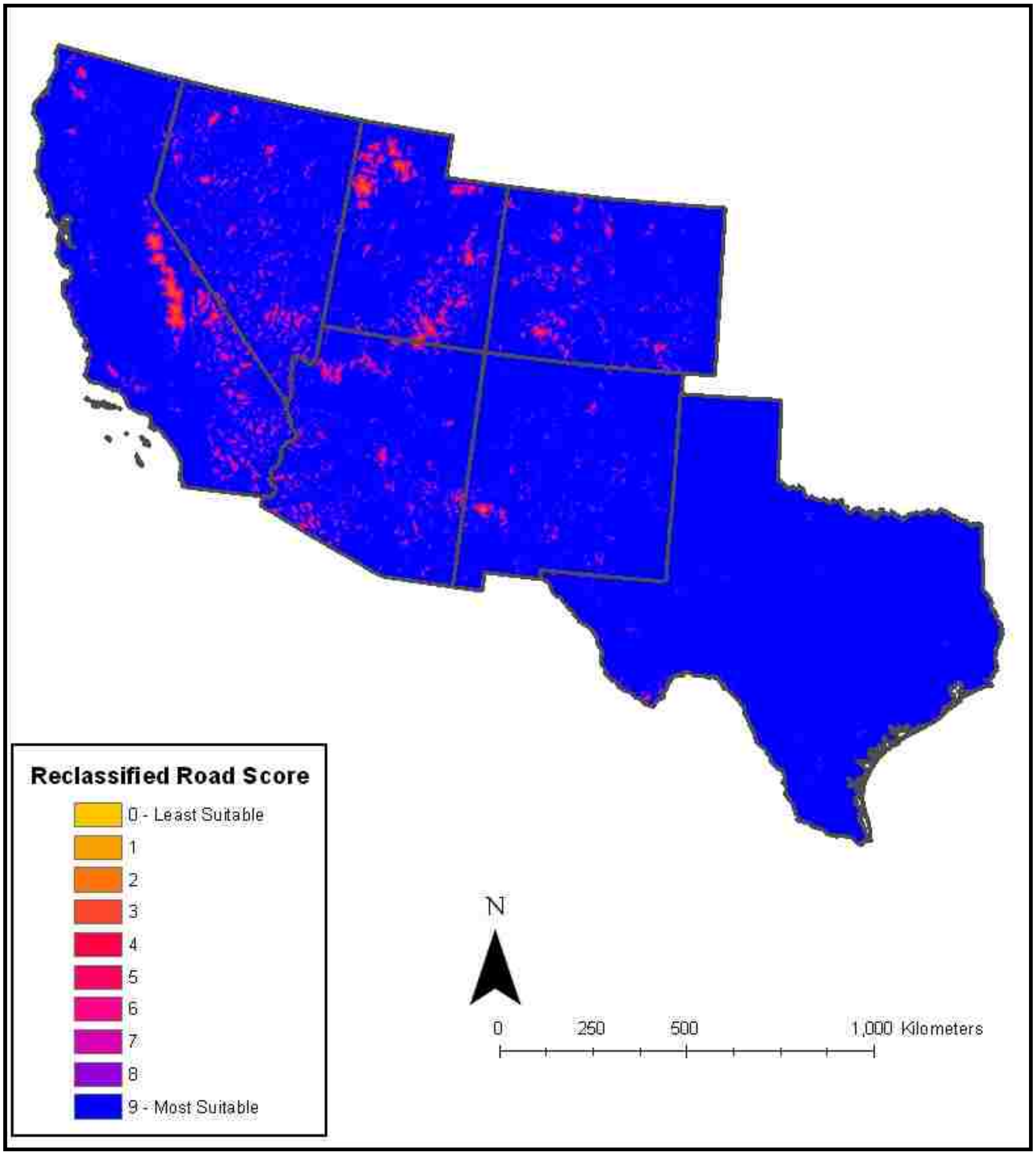
3.2.6 Accessibility (Distance to Roads)

The last factor, considered at a weight of 10% in the model, is the distance to existing roads. Accessibility is related to the cost of delivering materials to a site and the long-term maintenance of a facility. While new roads can be (and often are) built during the development of a site, minimizing the extent to which this is necessary will help keep the cost of a project down. With this in mind, a similar inverse scoring was applied to land parcels after the roads had a distance buffer applied to them. Locations at distances ranging from 0 to 21 miles (0 to 33,769 meters) from a road were considered and 10 classes were established. Regions within 0 to 1 miles of a road were given the highest rank of 9, regions in a 1 to 2 mile distance were given an 8 and so on, until a distance of 6 miles (9,656 meters) is reached. Regions between 6 and 21 miles were assigned decreasing ranks in increments of five miles, and any areas further than 21 miles from a road were assigned a rank of zero. The reclassification chart and the map of the reclassified distance to roads can be seen in Table 7 and Figure 8.

Table 7. Distance to Roads Reclassification Chart

Miles	Input Values, Distance (m) to Roads	Output Rank
0 - 1	0 - 1609	9
1 - 2	1,609 – 3,219	8
2 - 3	3,219 – 4,828	7
3 - 4	4,828 – 6,437	6
4 - 5	6,437 – 8,047	5
5 - 6	8,047 – 9,656	4
6 - 11	9,656 – 17,703	3
11 - 16	17,703 – 25,750	2
16 - 21	25,50 – 33,769	1
21 +	33,769 – 42,295	0

Figure 8. Map of Reclassified Distance to Roads Rank



3.2.7 Weighted Summation of Input Layers

The final step in the development of the suitability model involves the weighted summation of the different scores for each variable, followed by a Boolean exclusion of those regions that are ineligible for consideration as a candidate location (such as wilderness or protected areas and bodies of water). To accomplish this, the Weighted Sum function of ArcGIS was used to sum the input layers at the weights listed above for each. Table 8 shows the weights attributed to each variable.

Table 8. Weighted Sum Inputs

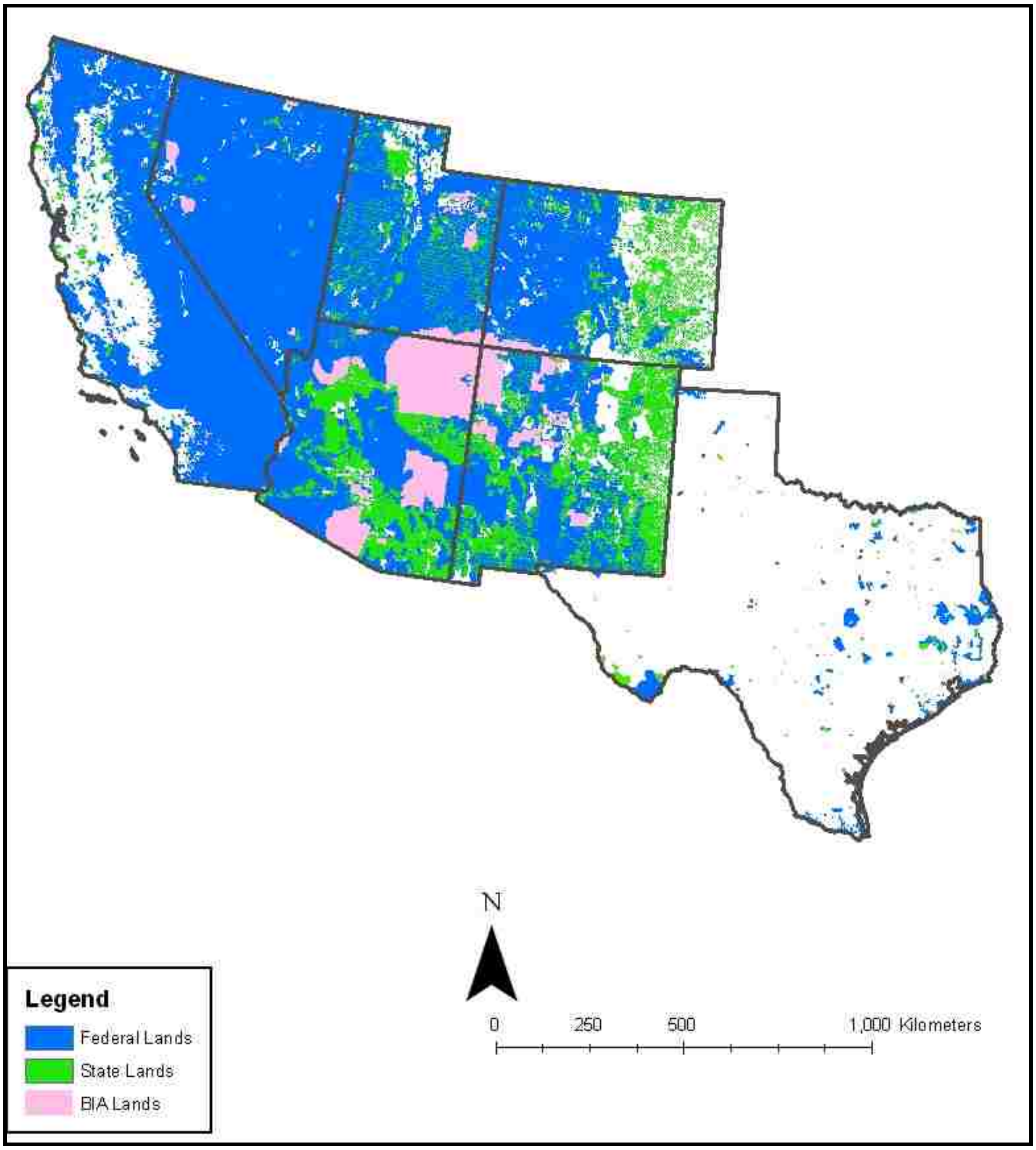
Input Criterion	Weighted Percentage
Slope	40%
Insolation	30%
Distance to Transmission	20%
Distance to Roads	10%

After processing the results, this summation resulted in a ranked output map with values ranging from 1 to 9.

3.3 Ownership and Exclusion

A key component to this analysis involves the consideration of land ownership, specifically in regard to patterns in ownership and site locations that could be useful to consider in future solar suitability analyses. The data layer acquired from the BLM contains information about all the federal and state land parcels located within the study area, and the individual agencies responsible for managing each. This information was processed to produce a layer denoting whether land parcels were under federal, state, or private ownership. While these ownership categories were not assigned a classification or preference in the suitability model, they were considered in the review of the output results to determine the relationship between site locations and ownership designation. In this research, the category of federal lands includes land parcels owned or under the management of the Department of Defense (DOD), the Bureau of Reclamation (BOR), the Department of Energy (DOE), the Bureau of Indian Affairs (BIA), the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), the Forest Service (FS), and the National Park Service (NPS). A map depicting federal and state ownership (with BIA lands displayed separately) is shown in Figure 9—lands in private ownership appear white:

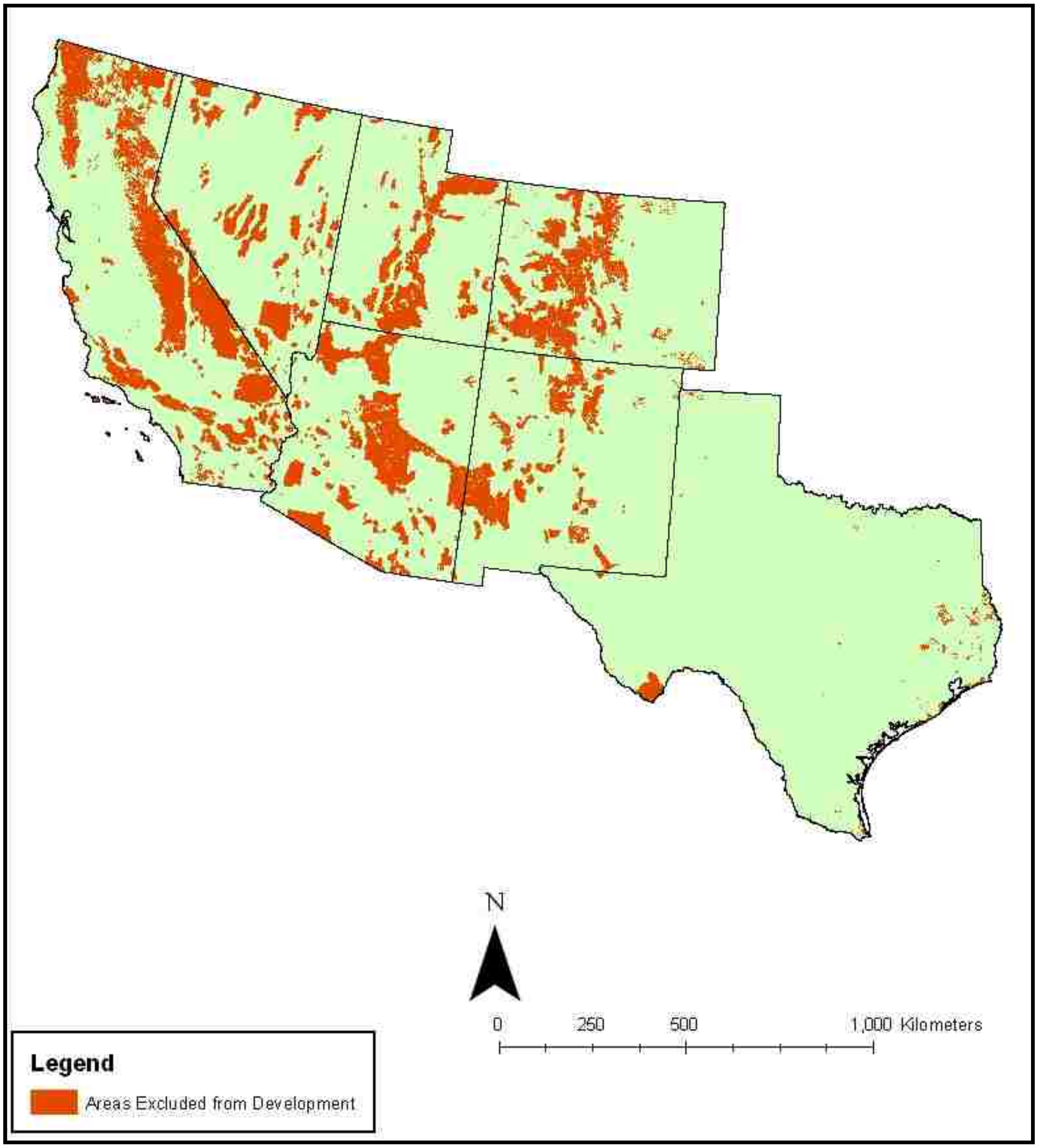
Figure 9. Land Ownership Status



These identified federal and state areas were used to delineate ownership zones, for which tabular areal tabulations were calculated identifying the amount of land in each category (federal, state, or private) classified in each of the final ranks (1-9) of the suitability output map. Areal calculations for federal land were performed twice, once on all lands with a federal designation status including BIA parcels, and a second time on all federal lands excluding BIA lands. This was done in effort to be comprehensive or broad in the definition of “federal” in terms of land ownership and management. Results for private land ownership were found by determining the difference between the total area of each state and the sum of the state and federally-owned land within that state.

To define zones of exclusion, the hydrography layer from the US National Atlas was used to locate large bodies of water that would obviously be unusable as utility-scale solar sites. These were then converted to a binary raster and multiplied against the output map to convert any water bodies to a value of zero. With the goal of creating as complete and realistic map of potential utility-scale solar sites, lands that would be precluded from this sort of energy development were also removed from the output map. The data layer from the BLM denoting the surface management agencies and land designation status of land parcels throughout the study area was used to remove ineligible areas. For this study, lands in any of the following categories were removed as potential solar development sites: wilderness areas, wildlife refuges, national parks, national preserves, national monuments, national forests, state wildlife areas, state parks, national historic parks, and national historic sites. These locations were all identified and converted into a binary raster coverage and multiplied against the output map to convert excluded areas to zero values in the output map. These results are displayed in Figure 10.

Figure 10. Areas Excluded from Solar Development



3.4 Locations of Existing and Proposed Facilities

Locating existing and proposed utility-scale solar power plants was a time-consuming process. While the list developed for this research is almost certainly not 100% comprehensive, it represents a quality representative sample of all facilities 1 MW or greater in size either built or planned within the 7 states of the study area. The 86 facilities within this sample are the end result of researching all of the facilities identified in various lists, and have been mapped with a higher degree of spatial accuracy than any other map reviewed in the course of this research. The locations were determined by reviewing the websites of state permitting agencies, press releases from energy companies and solar developers, and web searches using the Google® and Microsoft Bing® search engines. Two published lists of utility-scale solar facilities, one found on Wikipedia® and another published by the Solar Energy Industries Association (SEIA), were used as starting points to research and locate individual plants, although facilities not present on either list were also identified and mapped. Several attributes were recorded for each utility-scale solar facility and are displayed in Table 9.

Table 9. Attributes Recorded for Each Utility-Scale Solar Facility

Attribute	Description
Name of Facility	Facility name or Proposal title
Town	Town or County in which site is located
State	State in which site is located
Power Output	Actual or planned electricity output (in MW)
Status	Operational or Planned (with expected date online, if available)
Type	Parabolic Trough, Power Tower, Stirling Engine, PV, or Concentrated PV
Size	Area of site
Latitude	Latitude of site
Longitude	Longitude of site
Site Accuracy	Direct Placement, Reliable Coordinates from Documents, or Approximate
Information Source	Source documents/Proposal Info used to locate site
SEIA List	Is the site listed on the SEIA list of facilities?

The workflow for locating sites involved internet searches by individual facility to find photos and maps from permitting documents or proposed site renderings, as well as written descriptions, to ascertain the most accurate location possible for each of these facilities. These descriptions or images were then matched to specific locations using Google Maps® and Bing Maps®, since the difference in how current the aerial imagery used in either platform is sometimes made one set of images more useful than the other. After locations were identified in one or both mapping services (both of which allow for the simultaneous consideration of imagery and more traditional road networks), the corresponding locations were identified in Google Earth® to establish precise latitude and longitude coordinates for each facility. The process of locating facilities was the same for existing and proposed facilities, with the main difference being that older facilities were actually visible in the satellite imagery, while for newer sites it was often only a tract of land that could be seen. With the exception of only several facilities, it was possible to locate most installations with a high degree of certainty and very accurately. In some cases, a written description based on road intersections and nearby towns was used to identify locations, while in other cases images from proposal documents were used to locate proposed facility sites. An example of a site that was found based on an image from a proposal document (Figure 11), followed by the author identified location in Google Earth® (Figure 12), is shown below.

Figure 11. Example Image of Proposed Kingman, AZ Facility from Permitting Documents

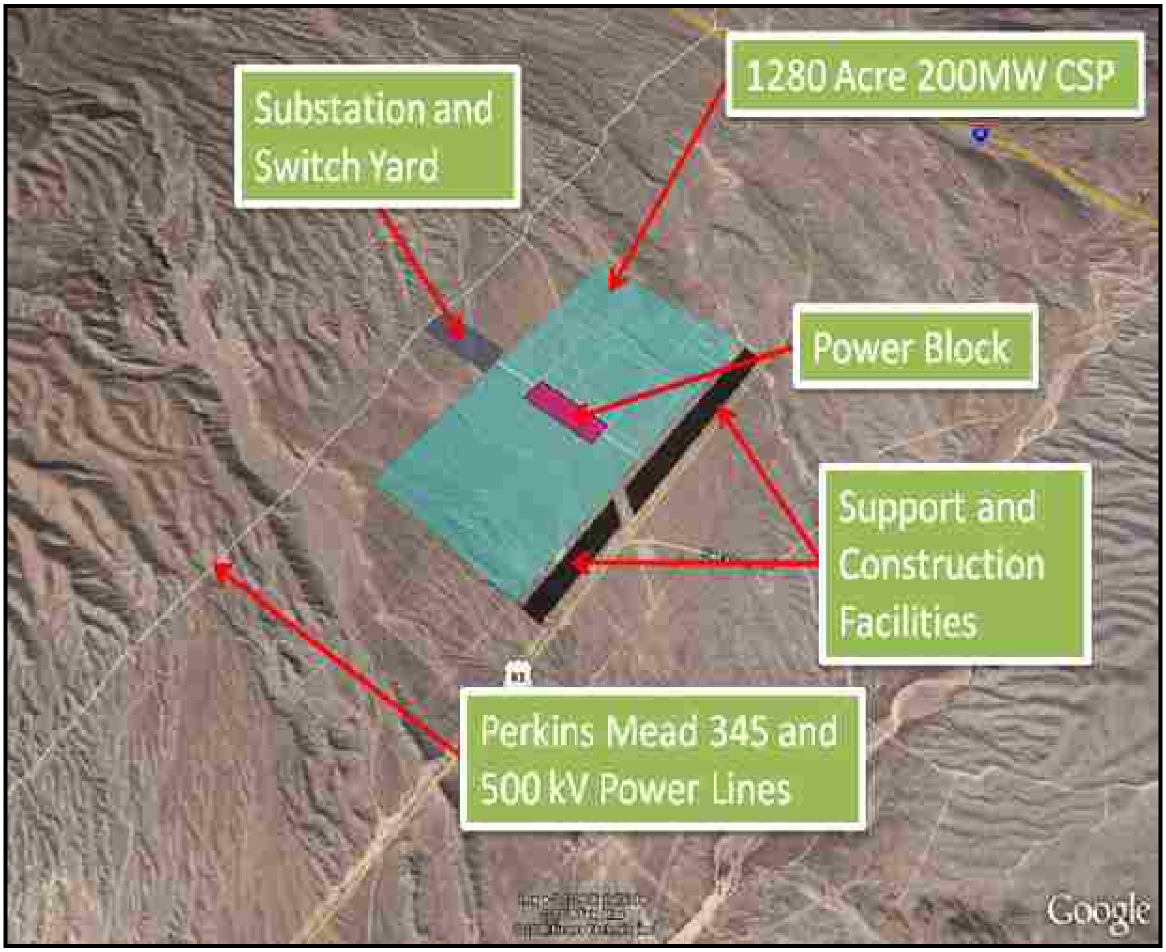


Image Source: County of Mohave Website, URL: http://resource.co.mohave.az.us/File/PlanningAndZoning/SpecialCommitteesNProjects/Hwy93_051209.pdf, accessed April 6, 2010.

Figure 12. Identified Location of Proposed Kingman, AZ Facility in Google Earth®

Image Source: Digital Globe (2010) via Google Earth® Mapping Service.

After obtaining the most accurate latitude and longitude coordinates possible for each facility, these coordinates were brought into ArcGIS and used to map the point locations of existing and planned solar power plants in the study area.

3.5 Overlaying Model Output with Actual Site Locations

The output of the suitability model was ultimately compared to the true locations of solar facilities using a GIS overlay as a way to measure the degree to which the model is able to determine truly developable sites. This comparison is done in a matrix-style assessment that characterizes the number of sites that fall into the various classifications of the suitability model. By looking at the breakdown of the site distribution by facility type, state, and the suitability class in which each power plant is located, it is possible to address objective three (analyze the extent to which the true locations of solar facilities fall into those regions identified as “most ideal”) and objective four (identify by state and/or facility type any major discrepancies between the model-derived suitability results and the actual distribution of solar facilities). Additionally, information on the ownership status (federal, state, private, etc.) of those land parcels that contain solar facilities is considered (objective five). In the following section, these results will be analyzed and the last objective is addressed, whereby methodological weaknesses in current solar suitability modeling approaches will be identified and discussed.

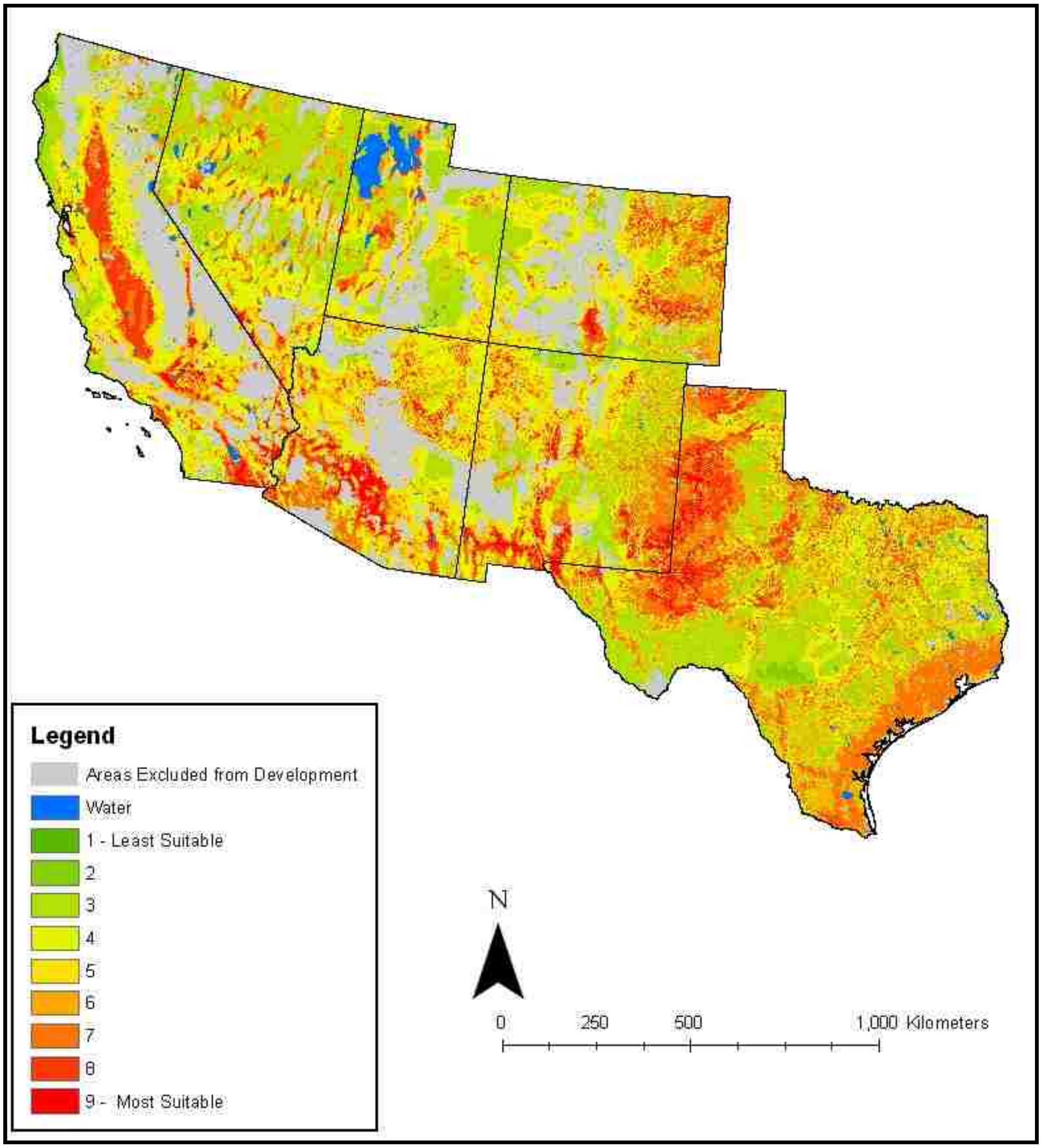
Chapter 4

Results and Discussion

4.1 Suitability Model Output

After processing, classifying, and weighting each of the 4 input layers, it was possible to produce an output map with an assignation of suitability for utility-scale solar development for every 30-by-30 meter parcel in the study area. Suitability rankings range from 1 to 9, which for the purposes of some analyses in this research is further divided into the categories of low suitability (ranks 1-3), medium suitability (ranks 4-6), and high suitability (ranks 7-9). In the final output map, areas that are unsuitable for solar development as a result of their land designation status or because they are occupied by bodies of water have been assigned zero values. The final suitability output map, complete with excluded areas and water bodies is shown in Figure 13.

Figure 13. Solar Suitability Output Map



In the above map, areas that appear in grey or blue are removed from consideration as sites for solar facilities. Regions of lower suitability are represented in green, while areas in darker shades of orange and red are the most suitable based on the parameters of the model. These areas largely correspond with those regions that have high insolation values and very minor slopes. Swaths of slightly higher values (visible in Utah and Nevada) can be explained by the presence of transmission lines in these areas, where their influence in final rank is visible.

With this map, a zonal calculation was performed to determine the amount of land classified as low, medium, or high suitability within each state. This information, as well as the total area of each state and the amount of land excluded from solar development, is displayed in Table 10.

Table 10. Areal Percentage in Each Suitability Category, By State

State	Excluded/Water	Low Suitability (Rank 1-3)	Medium Suitability (Rank 4-6)	High Suitability (Rank 7-9)	Total Area (km^2)
AZ	24.74%	3.64%	50.94%	20.68%	295,170.25
CA	34.20%	10.43%	38.33%	17.04%	408,917.19
CO	23.52%	16.35%	43.24%	16.89%	269,459.62
NM	13.40%	15.79%	47.10%	23.71%	314,875.97
NV	16.44%	33.20%	39.67%	10.70%	286,344.03
TX	2.43%	23.92%	41.08%	32.58%	685,386.91
UT	28.46%	27.41%	35.72%	8.41%	219,864.71

When the percentages above are translated into actual land areas, Texas is the clear leader in developable area, possessing over 220,000 square kilometers of land classified as highly suitable for utility-scale solar. Table 11 lists the total area in the high suitability category for each state in the study area.

Table 11. Land Area Classified as Highly Suitable, By State

State	High Suitability, km^2 (Rank 7-9)
TX	223,290.95
NM	74,671.83
CA	69,679.40
AZ	61,053.35
CO	45,521.25
NV	30,624.51
UT	18,490.39

The category of high suitability is the most noteworthy in assessing the efficacy of the suitability model, for considering trends in siting decisions, and for identifying the thresholds of the physical parameters that dictate where solar facilities can and cannot be built. With this in mind, it is useful to break apart the category listed above to more finely distinguish patterns in the distribution of highly suitable lands. Table 14 displays, by state, the amount of land categorized in ranks 7, 8, and 9 (the highest possible score in the model) with the state leader in each rank identified.

Table 12. Areal Breakdown of Highly Suitable Lands, By State and Rank

State	Rank 7 (km^2)	Rank 8 (km^2)	Rank 9 (km^2)
AZ	24,278.43	22,641.35	**14,133.58**
CA	18,840.85	43,337.87	7,500.68
CO	24,840.81	18,725.23	1,955.22
NM	42,108.71	21,423.89	11,139.23
NV	23,740.63	5,199.11	1,684.77
TX	**151,943.24**	**63,709.01**	7,638.70
UT	11,329.29	6,425.44	735.65

When considered in this manner, Arizona is the leader of the study area with over 14,000 square kilometers of land categorized in the highest rank of 9. New Mexico has the second-most amount of land in the highest category with 11,139 square kilometers in rank 9. While Texas clearly has an immense amount of land that is suitable for solar development, it is worth mentioning that the majority of the suitable land within the state does fall into the low end of the high suitability classification. However, the state is still third in the study area for land categorized as rank 9—a fact that will be revisited in the discussion of the agreement between model output and the actual locations of solar facilities.

4.2 Locations of Utility-Scale Solar Facilities

After producing the final output map of suitability within the study area, the solar power plants were mapped and overlain with the other data so that the underlying attributes of the point locations (i.e., the final suitability rank, individual input ranks, and raw input values of the land parcels containing solar facilities) could be assigned to and associated with each installation. A map of the facilities by type, is shown in Figure 14. These locations, overlaid on the results of the suitability model, are displayed in Figure 15.

Figure 14. Locations of Utility-Scale Solar Facilities

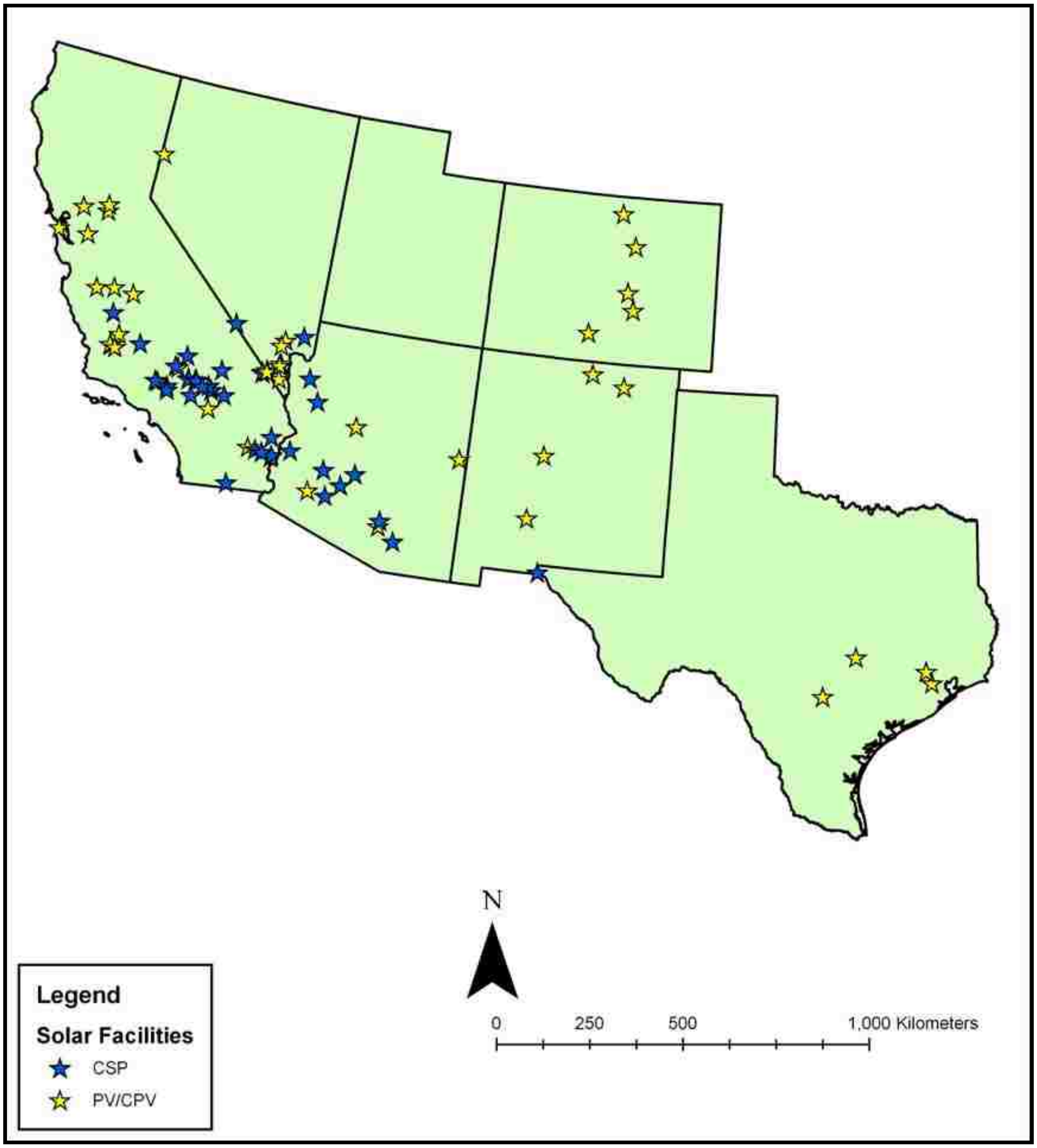
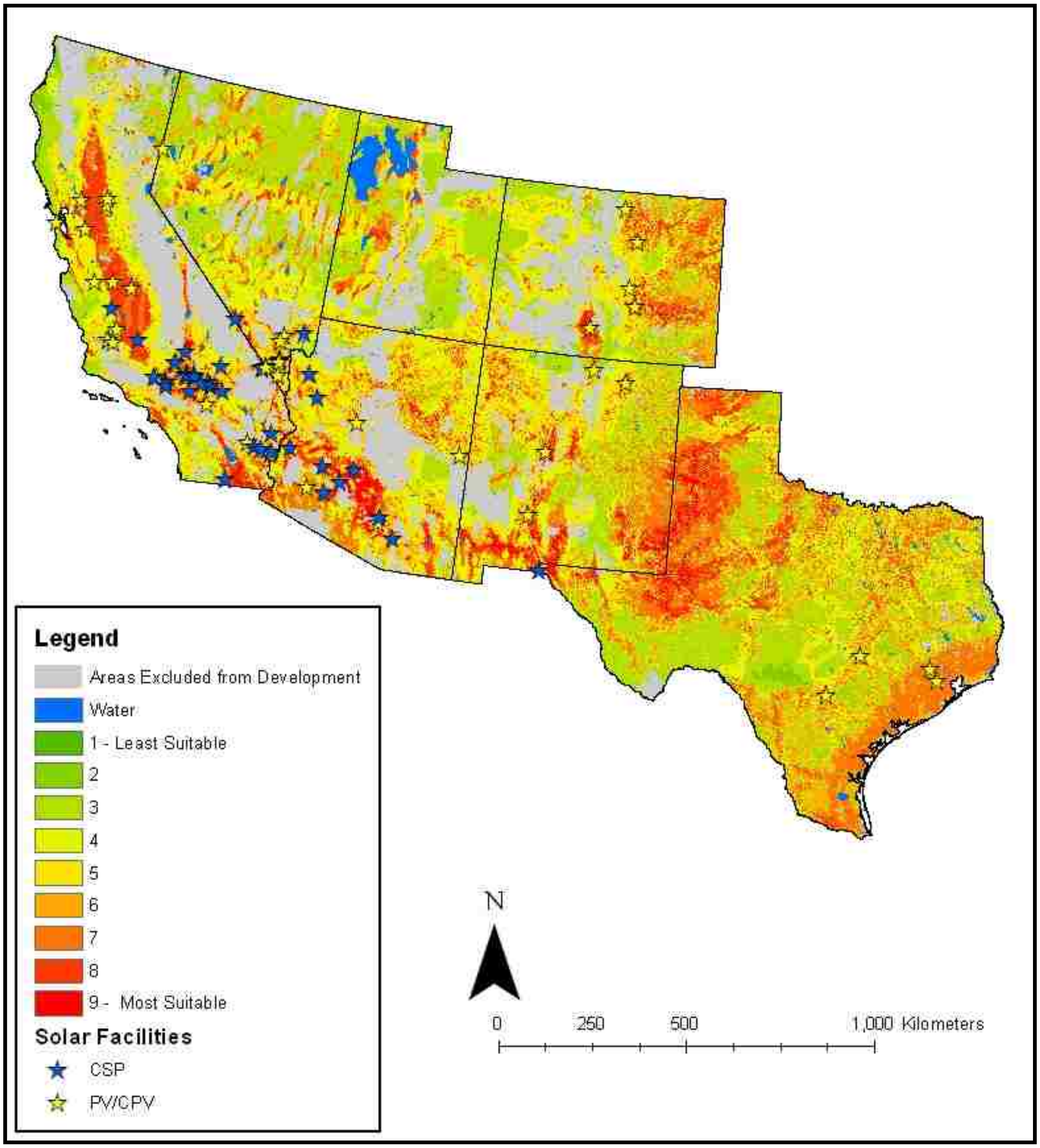


Figure 15. Utility-Scale Solar Facilities Shown With Model Output



The 86 utility-scale facilities identified and mapped for this research are listed as Appendix 1 in the appendices section of this document (the current status of each facility can also be found in the Appendix). Below, Table 13 displays the number of facilities 1 MW or greater built or planned to be built within each state:

Table 13. Number of Solar Facilities, By State

State	Number of Utility-Scale Facilities	PV/Concentrated PV Plants	CSP/Hybrid Plants
AZ	13	4	9
CA	47	17	30
CO	5	5	0
NM	5	4	1
NV	12	9	3
TX	4	4	0
UT	0	0	0
Total	86	43	43

For each facility, the type of solar technology being employed was also recorded. The plants are divided into two categories; those that employ photovoltaic (PV) or concentrated PV (CPV) technology, and those that employ concentrating solar power (CSP) thermal technology or a hybrid approach that uses CSP technology for at least part of the power generation process. The CSP category includes facilities using parabolic troughs, a power tower setup, linear Fresnel reflectors, or Stirling engine dish setups.

The list of facilities reveals that there are actually an equal number of solar plants in each of the two categories within the study area. However, in considering the overall installed output generation of each of the facility types, there is a much higher amount of solar power being produced from CSP plants (a combined total of 9,846 MW) than from PV plants (a total of 3,472.4 MW). Table 14 outlines the amount of solar power capacity installed in each state, divided by facility type and listed in order of amount per state.

Table 14. Installed MW of Utility-Scale Solar Power, By State and Type

State	Planned/Installed MW (PV/CPV)	Planned/Installed MW (CSP)	State Total MW
CA	2,177 MW	6,413 MW	8,590 MW
NV	775 MW	1,748 MW	2,523 MW
AZ	323 MW	1,593 MW	1,916 MW
NM	118 MW	92 MW	210 MW

TX	64 MW	0 MW	64 MW
CO	15.4 MW	0 MW	15.4 MW
UT	0 MW	0 MW	0 MW
Total	3,472.4 MW	9,846 MW	13,318.4 MW

These numbers are represented as percentages in Table 15.

Table 15. Percentage Breakdown of Utility-Scale Solar Power, By State and Type

State	Percent of PV/CPV in Study Area	Percent of CSP in Study Area	Percent Total of Study Area
CA	16.35%	48.15%	64.50%
NV	5.82%	13.12%	18.94%
AZ	2.43%	11.96%	14.39%
NM	0.89%	0.69%	1.58%
TX	0.48%	0.00%	0.48%
CO	0.12%	0.00%	0.12%
UT	0.00%	0.00%	0.00%
Total	26.07%	73.93%	100.00%

These tables clearly show that CSP technologies constitute the dominant mode of solar power production within the study area. They also reveal the fact that the state of California is dominating in solar power production, with over 64% of all the solar power in the entire study area being produced in this one state alone. The marginal amounts of utility-scale solar installed or planned in Texas and Colorado consist entirely of PV type facilities. At the time of this research, Utah had no utility-scale solar facilities planned or built that could be identified.

4.3 Discussion of Findings

4.3.1 Validation of Model –Agreement between Locations and Model Output

To meet the objective of determining how well the results of the suitability model match up with the actual locations of solar facilities, a spatial join operation was performed whereby each facility was assigned the attributes (in this case, the final rank) of the 30-by-30 meter pixel in which it is located in the output map. These results are displayed by facility in chart form in Appendix 2, and summarized by state in Table 16.

Table 16. Number of Facilities in Each Final Rank Category, By State

State	**Rank 4**	**Rank 5**	**Rank 6**	**Rank 7**	**Rank 8**	**Rank 9**	**Total**
AZ		3	1	1	3	5	13
CA	1	6	6	5	11	18	47
CO		3		1	1		5
NM	1	1		1	1	1	5
NV		2	4	1	2	3	12
TX	1		1	2			4
Total	3	15	12	11	18	27	86

After comparing the results of the model to the actual locations of the solar plants, 56 of the 86 facilities, or 65%, were in areas classified as highly suitable (ranks 7 through 9). The other 30 facilities, or 35% were located in areas classified as being of medium suitability (ranks 4 through 6). No facilities were located in areas that were either excluded due to their land designation status or classified as being of low suitability (ranks 1 through 3). The two highest categories, ranks 8 and 9, also contain the two largest collections of facilities by rank out of the whole group.

When we consider the performance of the model based on facility type, it appears that it performed slightly better for CSP facilities than it did for PV/CPV facilities. This conclusion is drawn from the average final rank that was assigned to land parcels containing PV/CPV facilities compared to the same measure for CSP facilities. These numbers are all the more reliable due to the fact that there happened to be the exact same number of both types of facilities in the study area. These results are shown in Table 17.

Table 17. Average, Minimum, and Maximum Final Ranks by Facility Type

Facility Type	Average Final Rank	Min. Final Rank	Max. Final Rank
PV/CPV	6.65	4	9
CSP	7.84	5	9

The model's performing slightly better for CSP facilities could be partially explained by the fact that there is a more limited set of physical conditions in which these types of facilities can be built. While these same conditions would also be good for PV/CPV facilities, the strictness of the model might have slightly 'underscored' areas that would actually be of high quality for PV/CPV installations. Overall, these results indicate that although not perfect, the results of the suitability model do seem to match the actual distribution fairly well.

Investigating the outlier sites that were assigned a rank of 4 in the model reveals an interesting pattern. All three of these sites, the EPA City of Houston Brownfield Project in Texas, the Chevron concentrated PV facility in Questa, New Mexico, and the San Francisco Recurrent Energy Project in California are all solar facilities that have been planned with an existing location already established as a site. The project in Texas is a 10 MW PV facility being planned on a contaminated tract of land designated as an EPA brownfield site (EPA, 2008). The 1 MW Chevron project in New Mexico is to be built on the tailings site of a molybdenum mine in the northern part of the state—another case where the land is essentially unsuitable for other uses or development due to its contamination with heavy metals and its current status as an EPA Superfund site (EPA, 2000). Lastly, construction on the 5 MW San Francisco Sunset Reservoir Solar Project is slated to begin later this year on the roof of the city's largest water reservoir (Recurrent Energy, 2010).

In all of these instances, it is implicitly clear that a traditional decision-making process related to a site search did not take place as these physical sites were all already established. Rather, studies were most likely undergone to determine whether the sites had at least the minimum requirements to be economically feasible, or to see if they possessed less than desirable attributes that were possible to overcome. Additionally, the benefit to public opinion that facilities located on undesirable or polluted sites might have could serve an important purpose, even if these facilities are not operating with the same output efficiency as others in more ideal locations. As such, it seems that the fact that their final suitability scores were so low indicates a need to evaluate these types of renewable energy projects in a separate category or manner from other large-scale projects. Lastly, it is worth pointing out that the main reason the sites of these facilities were assigned low ranks was because of their low input slope ranks (a rank of 2 for the San Francisco project, and ranks of zero for the other two projects), and their input insolation ranks (the Houston and the San Francisco projects received an input rank of 2). The Chevron project in New Mexico had a high rank for solar values (7) but was a low value of 2 due to its distance from transmission lines.

This brings us to several conclusions. The first is that for fixed locations that have already been identified as possible sites for utility-scale solar, the traditional parameters used to identify ideal sites do not fully apply. Some of what might be undesirable obstacles at other sites may be possible to overcome in these fixed locations, such as building a new transmission line in New Mexico if the cost is not a limiting factor, or if higher development costs and slightly lower overall output are outweighed by the benefits of using otherwise worthless land, and improving public perception about a company or municipality. Also, the low slope values assigned to all of these sites might be in part a product of the data used in this analysis. While 30 meter Landsat data is some of the best available elevation data for this part of the country, it may break down in accuracy when we are interested in fine level detail about slope information in more developed and urbanized areas. Lastly, a component of consideration is the fact that all of these facilities are employing PV technology of some kind, rather than the CSP technology (that dominates by total power generation in the study area). This indicates that these types of PV/CPV technologies probably work better in these applications, and may in fact be able to operate efficiently and profitably with less available sunlight or in areas of slightly greater slope than other types of solar technology.

Considering the overall trend in the assigned ranks of each facility, and understanding why each facility was assigned the rank it was is insightful. This information has been recorded and assembled into a list that includes each facility’s final rank, as well as its assigned rank for each of the four input variables. This list is quite large and has been included at the end of this document as Appendix 2.

4.3.2 Land Ownership and the Distribution of Utility-Scale Solar Facilities

One of the benefits of considering land ownership information in this type of analysis is being able to identify siting trends based on the ownership status of the tracts of land on which these facilities are built. Out of the 86 facilities considered in this study, none were built on state land. Exactly half of the facilities are located on private land, while the other half are located on land parcels owned or managed by various federal agencies. A breakdown of this distribution, by state, is shown in Table 18.

Table 18. Distribution Pattern of Facilities Based on Land Ownership

State	Count of Facilities on Fed. Land / Percent	Count of Facilities on Private Land / Percent
AZ	2 (15%)	11 (85%)
CA	33 (70%)	14 (30%)
CO	1 (20%)	4 (80%)
NM	1 (20%)	4 (80%)
NV	6 (50%)	6 (50%)
TX	0 (0%)	4 (100%)
Total	43 (50%)	43 (50%)

This information is most meaningful when considered in relation to the breakdown of ownership for each of the three output categories. Tables 19 – 21 show the amount of land in the high, middle, and low suitability ranks of the model, by ownership for each state. Table 22 shows the same information for those areas that were excluded from development based either on their designation status or because they are occupied by bodies of water.

Table 19. Percent of State Area Ranked High Suitability, by Ownership (Ranks 7-9)

	State	**Federal (No BIA)**	**BIA**	**Private**	**Total**
AZ	3.33%	4.66%	5.66%	7.04%	20.69%
CA	0.10%	4.86%	0.09%	12.00%	17.05%
CO	1.07%	0.31%	0.09%	15.43%	16.90%
NM	3.86%	5.57%	1.29%	12.99%	23.71%
NV	0.08%	7.97%	0.20%	2.44%	10.69%
TX	0.10%	0.12%	0.00%	32.36%	32.58%
UT	0.62%	3.49%	0.33%	3.96%	8.40%

Table 20. Percent of State Area Ranked Medium Suitability, by Ownership (Ranks 4-6)

	State	**Federal (No BIA)**	**BIA**	**Private**	**Total**
AZ	9.09%	12.42%	18.76%	10.67%	50.94%
CA	0.42%	13.78%	0.32%	23.81%	38.33%
CO	2.20%	8.08%	1.49%	31.47%	43.24%
NM	5.57%	11.91%	5.95%	23.67%	47.10%
NV	0.12%	33.45%	0.64%	5.46%	39.67%
TX	0.17%	0.21%	0.00%	40.70%	41.08%
UT	3.14%	19.45%	2.57%	10.56%	35.72%

Table 21. Percent of State Area Ranked Low Suitability, by Ownership (Ranks 1-3)

	State	**Federal (No BIA)**	**BIA**	**Private**	**Total**
AZ	0.29%	0.60%	2.48%	0.26%	3.63%
CA	0.24%	2.13%	0.23%	7.83%	10.43%
CO	0.93%	4.45%	0.01%	10.97%	16.36%
NM	2.22%	3.13%	0.82%	9.62%	15.79%
NV	0.09%	27.40%	0.63%	5.08%	33.20%
TX	0.35%	0.05%	0.00%	23.52%	23.92%
UT	2.28%	16.70%	1.44%	6.99%	27.41%

Table 22. Percent of State Area Excluded or Water, by Ownership

	State	Federal (No BIA)	BIA	Private	Total
AZ	0.22%	24.34%	0.13%	0.04%	24.74%
CA	0.08%	33.32%	0.05%	0.74%	34.20%
CO	0.18%	23.18%	0.01%	0.15%	23.52%
NM	0.03%	13.29%	0.03%	0.05%	13.40%
NV	0.06%	15.85%	0.17%	0.37%	16.44%
TX	0.22%	1.69%	0.00%	0.52%	2.43%
UT	1.49%	24.82%	0.00%	2.15%	28.46%

It is of note that although half of all the facilities are located on federally owned land parcels, less than one quarter of all the land area in the categories in which facilities are found (ranks 4-9) is under federal management. Table 23 displays the amount of land classified in ranks 4 through 9, as well as the portion of that land that is managed by the federal government.

Table 23. Breakdown of Rank Categories Containing Facilities, with Federal Percentage

State	Total Rank 4-9 (km^2)	Fed. (No BIA) Rank 4-9 (km^2)	% Fed. (No BIA) Rank 4-9
AZ	211,418.59	50,413.90	23.8%
CA	226,408.66	76,188.87	33.7%
CO	162,033.82	22,621.32	14.0%
NM	222,962.91	55,040.81	24.7%
NV	144,208.12	118,601.83	82.2%
TX	504,817.10	2,237.69	0.4%
Total	1,471,849.19	325,104.41	22.1%

The fact that half of all the facilities are on federal land, while only a little over 22% of all lands in the mid and high suitability class are actually under federal management indicates a distributional trend in the location of solar power plants. Although land ownership was not entered into the model with a classified preferential breakdown, these results indicate that certain federal lands should perhaps be considered differently in future models since, by area, they are home to a greater number utility-scale solar facilities than private land.

This trend in locating facilities on public lands can be explained in part by several factors. One factor that is not considered explicitly in this analysis is that solar sites must be affordable, available for this type of use, and in most cases must exist as large, contiguous tracts of land. It may be the case that, generally speaking, these types of land parcels are more often under the ownership of government agencies rather than in the hands of private individuals. This theory is supported in the results of this analysis by looking at the percentage of CSP facilities that are located on federal lands, versus the number of PV/CPV facilities on these lands. Of the facilities considered, 31 of the CSP facilities (72%) were located on federal lands. Contrarily, and in a coincidental inversion by the numbers, only 12 of the PV/CPV facilities (28%) were located on federal lands.

Concentrating solar power (CSP) plants that employ parabolic trough, power tower, and other technologies are often major, large-scale operations that require massive amounts of space. Not easily scaled down, it is rare to see these types of facilities in small-scale setups. Within those CSP facilities considered in this study, the average size in electricity output was 229 MW, with the largest facility in consideration possessing a planned 1200 MW output. Meanwhile, the average size of PV/CPV facilities in the study area was only 80.75 MW, with the largest facility of this type possessing only a 550 MW output. The amount of space required for these types of facilities is positively correlated with the power output of a solar power plant—correspondingly, because CSP facilities are generally larger, and because we see a visible majority of these types of facilities located on federal lands, the distribution of these sites strongly suggests that federal lands become preferable for certain facility types simply by virtue of possessing ample space.

The trend to site on public lands may also be explained in part by the fact that within the government, there have been dedicated efforts toward identifying how these lands might be used for the development of solar energy where appropriate (PEIS, 2008 and Solar Energy Development PEIS, 2008). The Solar Energy Development Programmatic Environmental Information Study specifically identifies lands owned by the Department of Interior (DOI), the Bureau of Land Management (BLM), and the Department of Energy (DOE) that are under study as regions on which to develop utility-scale solar power projects (2008). These areas were identified and considered in relation to the study area in this analysis and in fact 4 different solar projects, the 850 MW Tessera Solar One (Calico Solar Project), the 21 MW First Solar Facility, the 250 MW Solar Millenium Palen Project, and the 250 MW Genesis NextEra Solar Energy Project are all located within this federally designated area of study.

A recent news release by the U.S. Department of the Interior (2009, 1) noted Secretary of the Interior Ken Salazar's secretarial order to make "the production, development, and delivery of renewable energy top priorities for the department." Salazar's secretarial order creates a specific task force to identify public lands where the DOI can facilitate the production of large-scale renewable energy projects (including solar) by prioritizing "permitting and appropriate environmental review of transmission rights-of-way applications," and resolving "obstacles to renewable energy permitting, siting, development, and production" (Department of the Interior, 2009, 1).

In charge of one fifth of the landmass of the United States, the Department of Interior, with the Bureau of Land Management, single-handedly manages “lands with some of the highest renewable energy potential in the nation,” including over 29 million acres of land in the Southwest that possess the potential for utility-scale development (Department of the Interior, 2009, 1). This secretarial order, number 3285 (“Renewable Energy Development by the Department of the Interior”), as well as previous secretarial order number 3283 (“Enhancing Renewable Energy Development on the Public Lands”), both identify the priority that has been assigned to renewable energy development on federal land (Department of the Interior, 2009).

It is important to keep in mind that federal agencies are charged with various responsibilities in relation to the way that they manage and regulate the use to which lands are devoted—in many cases, efforts to develop utility-scale solar projects on federal lands may be met with controversy or challenges associated with the multi-use nature of certain land parcels. Even so, these efforts on the part of the government, combined with the areal requirements of these sorts of projects, indicate that in many areas of the Southwest, federal lands are well within the sights of solar developers, and may in fact constitute very desirable locations to site these facilities.

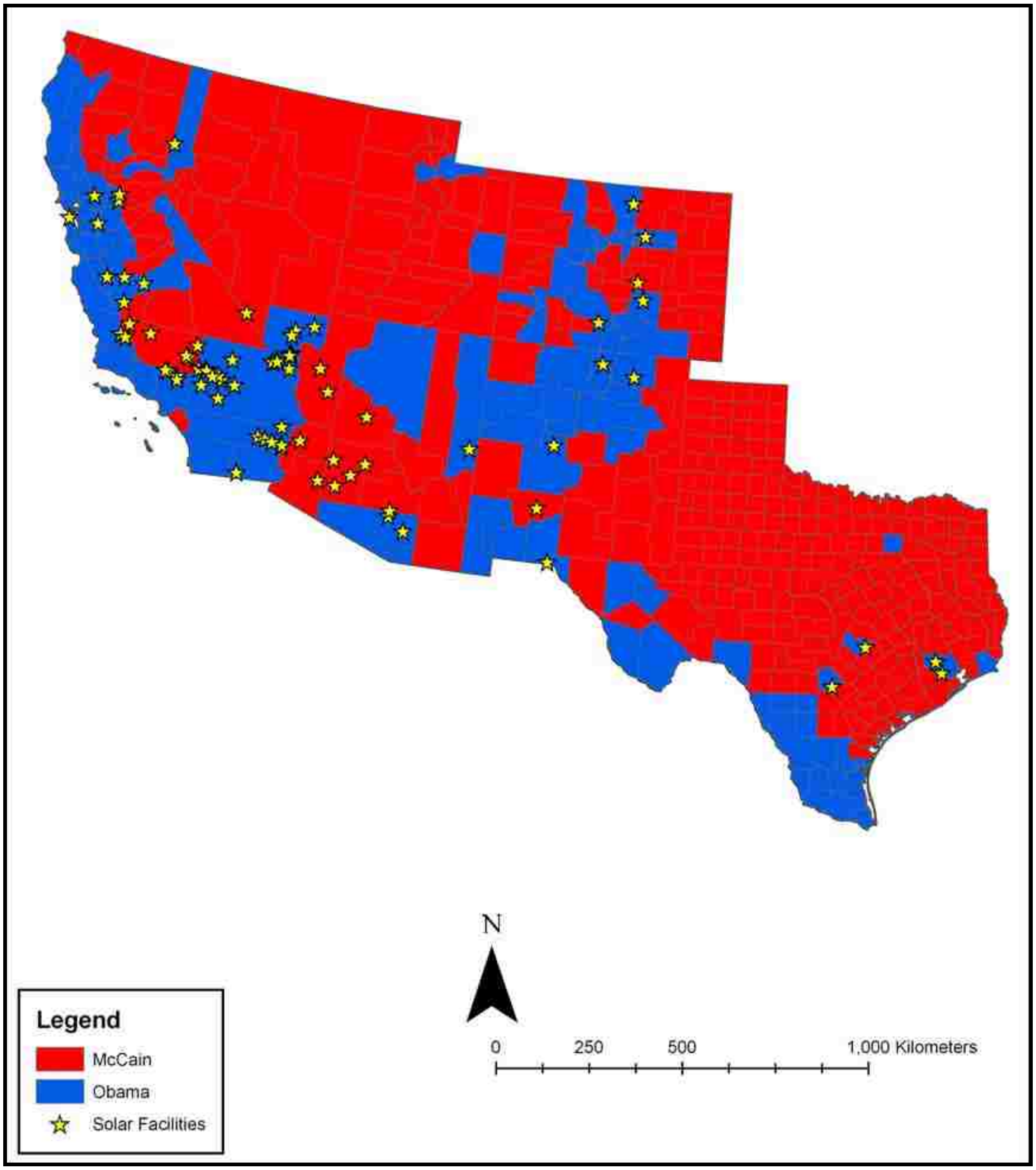
4.3.3 Socioeconomic Factors and Policy

Social and political factors play a significant role in siting decisions. While certain physical parameters must obviously be met, there are a whole host of other considerations—that are not traditionally spatially explicit—that are involved in decisions pertaining to siting solar facilities. The existence and nature of local, state, or federal requirements pertaining to renewable energy (such as the Renewable Portfolio

Standards discussed previously), local perception and attitudes towards these projects, and the general sentiment of influential persons at various levels of decision-making processes all play heavily into this issue, and are factors that are not always neatly and easily represented spatially.

Motivated by the research of Zahran et. al. (2008), which considered the relationship between voting behavior in the 2000 presidential election and the prevalence of residential solar setups, a simple consideration of the 2008 presidential election results by county in relation to the identified sites of solar facilities was performed. These results are shown in Figure 16, with counties voting Democrat shown in blue and counties voting Republican shown in red:

Figure 16. Facilities Shown with 2008 Presidential Voting Results by County



(Map data from: http://www.usatoday.com/news/politics/election2008/results.htm, 2009).

While information on county level presidential election results is only a coarse, indirect measure of these types of variables, it can be insightful to consider in relation to where solar facilities are being built. In fact, 25 out of the 36 counties (69.4 %) possessing solar facilities voted Democrat in the 2008 presidential election, a fact that might not seem too surprising considering that, in general, the democratic party has been more hospitable towards renewable energy and is often behind the type of legislation that seeks to foster its development. The results by county are shown in Table 24.

Table 24. 2008 Election Results in Counties With Utility-Scale Solar Facilities

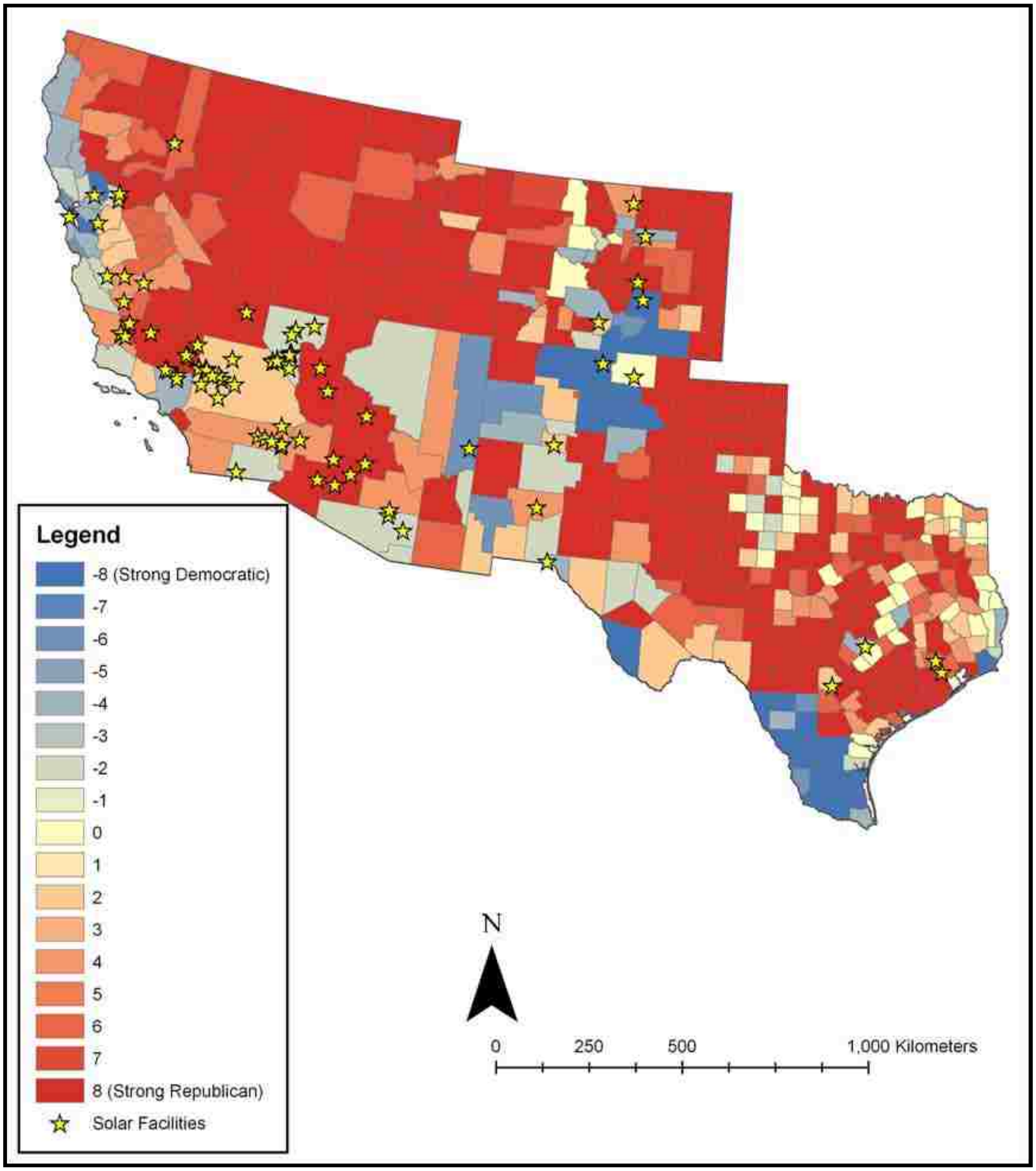
County	State	# Precincts	Obama	McCain	Other
Apache	AZ	45	15,141	8,381	292
La Paz	AZ	12	1,794	3,302	97
Maricopa	AZ	1,142	542,206	675,027	13,907
Mohave	AZ	73	21,286	42,729	1,048
Pima	AZ	417	191,465	168,670	4,244
Pinal	AZ	88	42,905	57,714	1,173
Yavapai	AZ	112	34,731	58,043	1,386
Yuma	AZ	42	17,679	23,658	440
Alameda	CA	1,041	374,922	93,372	8,818
Fresno	CA	712	94,788	94,814	2,915
Imperial	CA	108	17,791	10,850	459
Kern	CA	588	76,189	111,254	3,402
Los Angeles	CA	4,883	1,938,744	826,512	53,708
Riverside	CA	1,403	210,905	197,517	7,029
Sacramento	CA	1,330	253,581	172,431	7,956
San Benito	CA	59	5,940	3,566	172
San Bernardino	CA	1,391	237,831	214,031	9,301
San Francisco	CA	580	253,375	40,829	6,169
San Luis Obispo	CA	152	63,159	57,550	2,672
Solano	CA	214	74,340	40,755	1,864
Alamosa	CO	8	3,521	2,635	130
Denver	CO	426	195,499	60,226	3,882
El Paso	CO	387	104,670	155,914	3,823
Larimer	CO	153	84,461	68,932	2,692
Pueblo	CO	131	38,074	28,523	994
Clark	NV	1,150	379,204	256,401	13,299
Nye	NV	33	7,223	9,535	728
Washoe	NV	584	99,395	76,743	3,856
Colfax	NM	22	3,465	2,800	87
Dona Ana	NM	115	38,574	27,211	891
Sierra	NM	14	2,351	3,011	116

Taos	NM	36	13,384	2,827	202
Valencia	NM	35	15,142	13,033	393
Bexar	TX	623	275,023	245,932	3,598
Harris	TX	875	588,611	570,143	6,766
Travis	TX	211	253,278	136,671	4,915

These results are interesting, particularly in a state like Texas that has no shortage of highly suitable land for solar development, but has only a few planned solar facilities. In fact, the only 4 facilities planned in the state of Texas fall neatly into counties that voted Democrat in the 2008 election. Furthermore, these counties are in the part of the state that is much less physically desirable for solar development than the land areas in the western part of Texas—yet these more suitable areas contain no facilities. The energy picture in Texas, like all states, has its own complexities (including strong development in renewable wind energy) and while these election results hardly explain the whole story, they do seem to support to the idea that often times the socioeconomic and political factor in play can have as great an influence as the physical parameters within an area.

However, while it is convenient to consider county election results as a stand in for or a partial measure of the general sentiment towards projects of this nature, it can be more insightful to examine long term political trends to assess the relationship between presidential voting outcomes and siting decisions. To this end, the presidential election results from 1980 to 2008 were considered by county within the study area. To consider voting behavior through time, a value of -1 was assigned to a county in an election year if it voted Democrat, while a value of 1 was assigned to a county if it voted Republican. Counties that voted for an independent candidate were assigned a zero for that year. By summing these values, an index was produced for each county ranging from -8 (consistently Democrat) to 8 (consistently Republican) to classify the strength and direction of its political affiliation based on the past 8 presidential elections. These results are displayed with the locations of solar facilities in Figure 17 below.

Figure 17. Facilities Shown With County Voting Index from 1980 to 2008



When we consider these results, the correlation between solar development and voting behavior does not persist, and is in fact somewhat reversed as the mean index score assigned to counties possessing solar facilities is 1, indicating a mild republican preference. This information, which is a more robust measure of political affiliation, points to the weaknesses associated with using one political metric from a single point in time to explain trends that are intrinsically complicated. Furthermore, as the construction and planning timeframe behind the establishment of these 86 facilities has spanned almost three decades, it is important to be aware of the problems that can arise from drawing conclusions based on geographic datasets with different temporal resolutions. That is to say that although 2008 voting patterns might be relatable to recent plans to develop newer facilities such as those in Texas, they provide little information about the siting decisions for solar plants that were built in the 1980's, like several of those in California.

In sum, voting patterns are often the only metric available to quantify the social and political variables in a locale and can be very useful, but drawing conclusions directly from these results alone can be problematic. This serves as a caveat for the results presented here, as well as a potential criticism for other work (i.e., Zahran et. al., 2008) that draws conclusions from the coarse sociopolitical spatial affiliation captured in national level elections. It is intuitive that these variables do have an impact on these types of decisions and future efforts would be well directed to look at local election results over time, or even surveys of popular opinion about solar energy specifically, to understand the relationship between political attitudes and the extent of solar development in an area.

Another useful way to compare the influence of other relevant factors against physical factors is to consider the amount of land suitable for solar development in each state, and the number of solar facilities that have either been built or are planned within those states. Table 25 shows the amount of land present in categories in the mid and high range (ranks 4 through 9), the amount of land in only the highly suitable category (ranks 7 through 9), and the number of solar facilities, all by state.

Table 25. Solar Facilities and Amount of Developable Land, By Rank and State

State	**Facilities**	**Total Rank 4-9 (km^2)**	**Total Rank 7-9 (km^2)**
AZ	13	211,418.59	61,053.35
CA	47	226,408.66	69,679.40
CO	5	162,033.82	45,521.25
NM	5	222,962.91	74,671.83
NV	12	144,208.12	30,624.51
TX	4	504,817.10	223,290.95
Total	86	1,471,849.19	504,841.29

This table reveals some interesting patterns but perhaps the most visible is the fact that Texas has the most developable land in both the mid and high categories, as well as in the high suitability category alone, and yet the state possesses the fewest solar facilities out of the entire group (with the exception of Utah which has no facilities). At the same time, California has less than half of the land in ranks 4-9 than Texas has, but possesses almost 12 times the number of solar facilities. Clearly, decisions to build solar facilities are dictated by more than the mere presence of land that is physically suitable for the task.

This discrepancy brings to light a critical issue that is worthy of attention: a lack of development in solar does not necessarily imply that a state is not developing in any renewable resources, regardless of the dominant political affiliation within that state. Based on this study, California has 8,590 MW of solar energy either installed or planned while Texas has only a meager 64 MW planned to be built—an enormous gap, particularly in light of the fact that Texas has, at the very least, an amount of area suitable for solar development that is comparable to that of California. To put this in context however, one has to consider that Texas has 9,410 MW of wind energy installed, compared to California's 2,794 MW (American Wind Energy Association, 2009). While California has surged ahead as the nation's leader in solar power, Texas has assumed the same title in the category of wind.

The dearth of facilities in Texas may also point to the significance of current land use designations and the manner in which owners are using their land. While no research was identified that specifically examined the relationship of land use to solar development within the state, it is very likely that for land owners who are actively farming their land or using it for grazing, the installation of wind turbines is a preferable alternative to building a utility-scale solar facility because after the turbines are installed the land can, for the most part, still be used as it was before. Contrarily, solar technologies often require a devotion of the land that would preclude it from being simultaneously used for farmland or grazing. Unlike Texas, much of the most suitable land in California falls in desert areas that are quite arid and not actively being used for farming or grazing. This difference may factor heavily into Texas's decision to develop intensively in the wind sector as it more easily allows for mixed-use land management.

This information is critical to consider when comparing Texas's development strategy in the renewables sector, a fact that has both made Texas and California an unlikely pair in leading the way in renewable energy development, and highlights the difference that regulation and requirement strategies at the state level can have on energy development (Galbraith, 2009). Galbraith argues that the less restrictive policies toward energy development in Texas have been responsible for the increase in wind energy within the state, while California's more heavily regulated approach is at least partially responsible for the prevalence of large scale solar projects (2009). While Texas does have a goal of having 500 MW of its renewable energy generated from non-wind projects by 2025, some have argued that more aggressive requirements for solar energy, or specific 'carve outs' as they are called, will be necessary to stimulate the development of solar within the state (Database of State Incentives for Renewables and Efficiency, 2009, Hoffman, 2008). This may be the case and if so, Texas's decision, in terms of whether or not to develop their solar industry, will be one that is dictated by state priorities and policy and not, like many other states, by a lack of high-quality solar resources.

Lastly, the distribution of solar facilities is interesting to consider in relation to the state-level Renewable Portfolio Standards. Out of the seven states considered in this research, only one state (Utah) does not have a binding RPS that establishes a state-required minimum for energy production from renewable sources. That same state is also the only one that does not currently have any solar facilities 1 MW or larger either built or planned. While legislation is not the only factor to consider (Utah does have the smallest amount of physically suitable land out of the study area), these results seem to at least suggest that the difference in efficacy between state-required renewable energy levels and non-binding 'renewable energy goals' might be partly responsible for the extent of solar development within a state.

4.4 Suggestions for Future Suitability Models

A goal of this project was to identify weaknesses in conventional suitability models so that future models in solar suitability analysis might be improved. After assessing the results from this research, several areas for possible improvement were pinpointed as items to investigate and reconsider to strengthen future suitability models.

The first item to reexamine is the parameter of slope. In this study, areas with slope up to 3% were considered. This model was based on other available studies in solar suitability modeling and was also designed to have a *more* inclusive range than the studies that were reviewed. However, in analyzing the 86 facilities in this study, the average slope for study areas was 1.5% —with the maximum 7.5% percent slope in the study area belonging to a 2 MW PV facility in Fort Carson, Colorado. These results indicate that in some cases, higher slopes may actually be entirely suitable for development—either because slope can be overcome with landscaping preparation, steps taken in the design arrangement, or other measures. Excluding areas with slopes greater than 3% may result in the undesirable elimination of sites that might be developable, and one suggestion for other studies of this type is to include, in preliminary consideration at least, areas with slopes up to 5%.

A second point of consideration deals with brownfield sites or areas that might be unsuitable for other uses based on their classification as ‘contaminated’ or as remediation areas. In this study of utility-scale facilities alone, there were several instances of solar projects being developed in this category: the EPA City of Houston Brownfield Project in Texas, the Chevron PV facility at a mine tailings site Questa, New Mexico, the Fort Carson PV array on a former landfill in Colorado, and the Aerojet Solar Facility on a toxic site in Sacramento, CA. These sites are shown in Figures 18 through 21.

Figure 18. 10 MW EPA Brownfield Project Site (Houston, Texas)

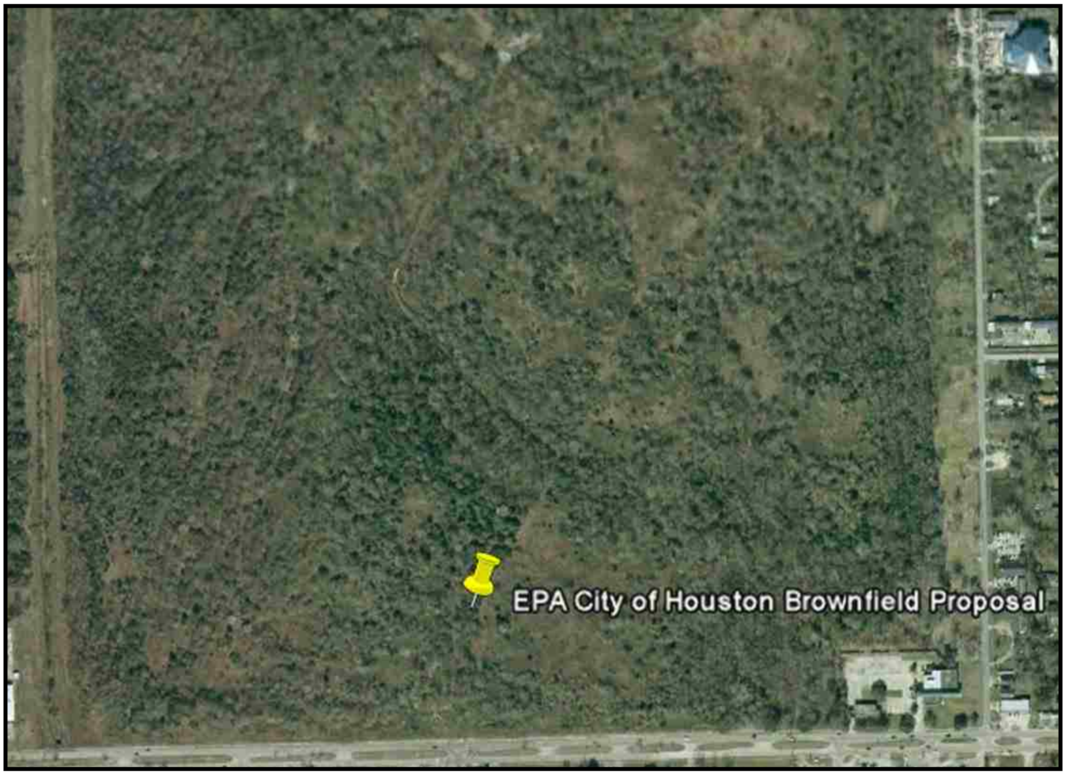


Image Source: Europa Technologies (2010) via Google Earth® Mapping Service.

Figure 19. 1 MW Chevron CPV Facility Site (Questa, New Mexico)

Image Source: NMRGIS (2010) via Google Earth® Mapping Service.

Figure 20. 2 MW U.S. Army PV Solar Array Site (Fort Carson, Colorado)

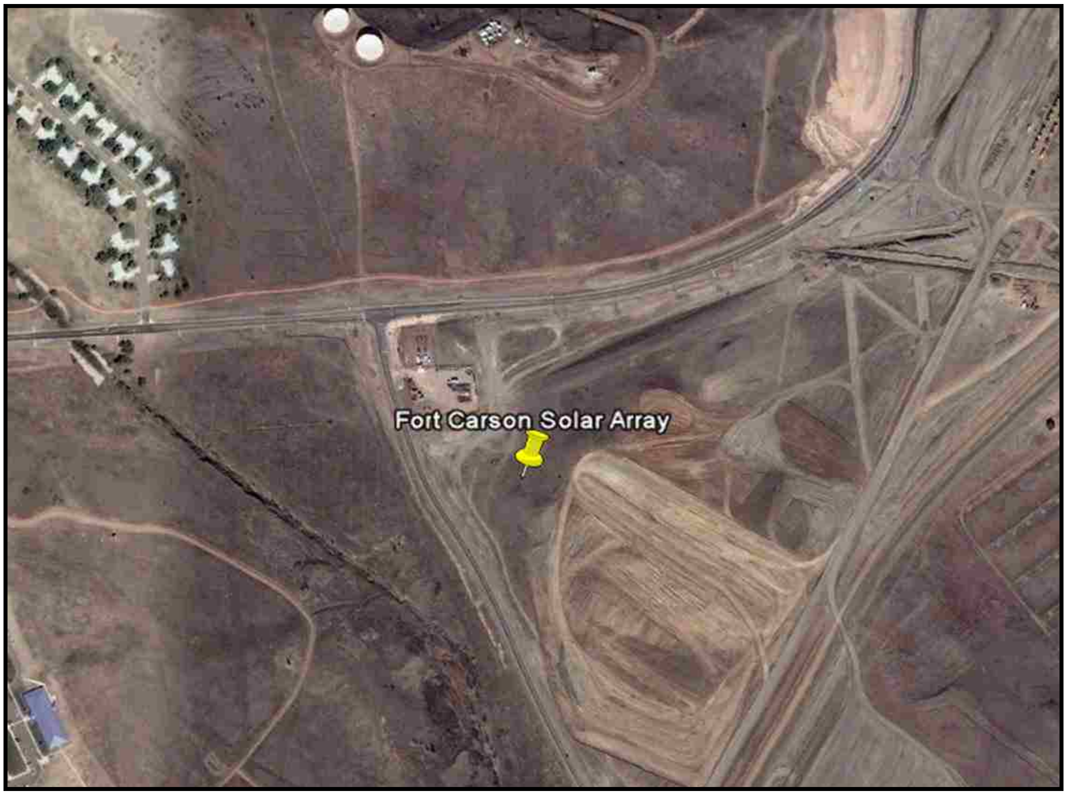


Image Source: Digital Globe (2010) via Google Earth® Mapping Service.

Figure 21. 3.6 MW PV Aerojet Project Site (Sacramento, California)

Image Source: U.S. Geological Survey (2010) via Google Earth® Mapping Service.

These 4 facilities alone generate 16.6 MW of solar energy—a significant amount of production—all off of land that was formerly unusable. Even the 10 MW San Francisco Recurrent Energy Project in California being built on formerly unused urban space (a concrete reservoir roof) could be considered in this category (shown in Figure 22).

Figure 22. 10 MW Sunset Reservoir Recurrent Energy PV Project (San Francisco, California)

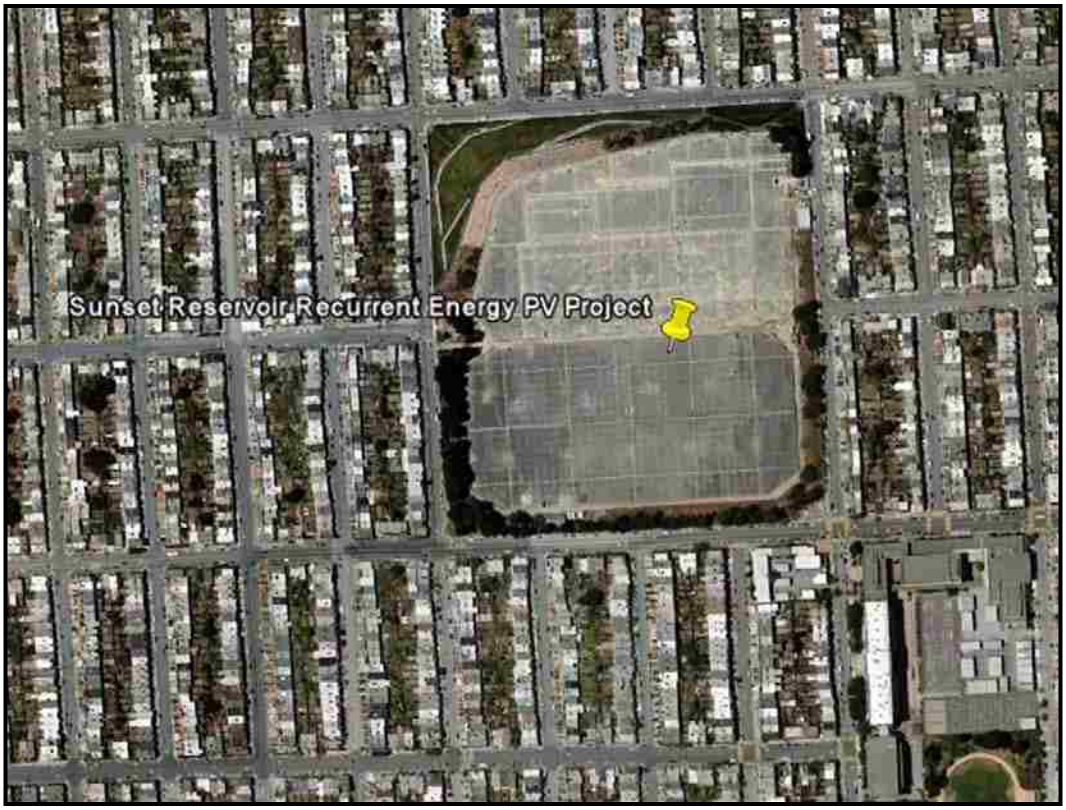


Image Source: Europa Technologies (2010) via Google Earth® Mapping Service.

These types of facilities are quite valuable. However, the development of these types of sites should be separated from other development efforts, but kept in consideration when looking for potential areas to install utility-scale solar. This would avoid potentially eliminating what might otherwise be great sites for development based on criteria that may not apply, or that could be outweighed by the benefit of converting such areas to productive use.

Another point of consideration that presented itself in this research was that, in several instances, after one facility was installed in an area, additions to that facility or new separate facilities planned within close proximity to the original seemed to be a common occurrence. This could be witnessed in the Harper Lake, Kramer Junction, and Riverside County areas in California and near the Boulder City area of Nevada. Figures 23 and 24 show these results.

Figure 23. Project Sites in Riverside County, California

Image Source: USDA Farm Service Agency (2010) via Google Earth® Mapping Service.

Figure 24. Project Sites Southwest of Boulder City, Nevada

Image Source: USDA Farm Service Agency (2010) via Google Earth® Mapping Service.

While at a certain level this would seem to be obvious—areas that are desirable for one facility would be the same for another—it was a common enough occurrence in this study to warrant investigation into whether the installation of a facility actually makes it easier to develop other facilities in the same area later (i.e., new transmission lines installed, new zoning codes established, the financial success of earlier projects making subsequent projects easier to finance and approve). While this is not necessarily easily quantified in suitability model, investigating this relationship and researching the presence of additional land near existing facilities seems like a very valuable aspect to consider in future analyses and models.

A fourth suggestion is that in consideration of sites for PV/CPV development, the parameters for acceptable or ideal insolation values be adjusted. In three PV projects in Texas, and another PV project in California, the insolation rank assigned to each site based on their insolation values was in the category of 2. This rank corresponds to insolation values ranging from 3.946 to 4.472 kWh/m^2/day, and falls into the ‘low’ suitability category. However, the fact that four different PV projects are being developed in areas with this amount of insolation indicates that although they might not be perfect, these insolation values are hardly too poor to consider for development. Future siting assessments of sites, for PV development at least, should consider expanding the range of usable insolation values.

Lastly, after reviewing this study, it is clear that future detailed studies and in-depth site investigations might do well to consider land ownership status, assigning available federal lands a higher preference than private lands. Also, efforts to map and rank the available areas of land as contiguous units would greatly facilitate future siting decisions.

Chapter 5

Conclusions

5.1 Evaluation of Research

This analysis constitutes a relevant contribution to the field of renewable energy studies—an area that is growing rapidly, and one in which current research is quite important as it plays a valuable role in helping to understand emerging trends and to plan future development efforts. As the fastest growing field within renewable energy, solar power is poised to occupy a new role in the national energy picture within the United States, particularly in the Southwest where most of the solar resources are located. By focusing on this area in particular, this research brings to light new and important information that will facilitate the efforts of solar developers, localities, and states as they plan for the future.

There were six objectives outlined in the introduction that this research project sought to achieve. The first of these was to develop a suitability model for the southwestern US that classifies regions in terms of how ideal they are for the location of utility scale solar power facilities. This was accomplished successfully using the best available data and by implementing the practices employed in other similar suitability models. The result was a valid contribution in itself as an original suitability model based on four major physical parameters for the seven states in the study area.

The second objective was obtain and map the true locations of all the existing and planned concentrating solar and photovoltaic solar power plants in the study area. This was a time consuming process but a worthwhile one as the 86 facilities identified in this research were all mapped with a degree of spatial accuracy unmatched in any of the other materials reviewed that mapped these locations. While the list of facilities produced by the Solar Energy Industries Association was the most comprehensive list of utility-scale solar facilities identified, this list only identified the town or county in which facilities were located or planned to be built (SEIA, 2010). Even the Solar Data and Mapping tool produced by the Solar Electric Power Association, a reliable source for information on solar power and another resource that was consulted in this project, provides the caveat that “mapped locations are approximate and represent either the nearest city to the project or the utility's headquarters, as applicable” (SEPA, 2010, 1). Because the third objective dealt with assessing how well the locations of facilities matched up with the suitability model results, a large amount of effort was put into mapping facilities down to their exact location in the satellite imagery of Google Earth®, so that the attributes extracted from the model and assigned to the facilities based on their locations would actually be meaningful. As a result, the list of facilities and their locations assembled for this project constitutes a significant contribution simply by offering a version of a utility-scale solar facilities map that is of a much higher accuracy than any other map readily available to the public. The details of the accuracy of each facility, and the source documents used to locate each are shown in Appendix 3. This attention to detail made it possible to address objective three, and produce insightful results about the extent to which the true locations of solar facilities actually fell inside those regions identified in the suitability model as being “most ideal.”

The fourth objective outlined in the project was to identify by state and/or facility type any major discrepancy between the model-derived suitability results and the actual distribution of solar power plants. There were several interesting patterns that were identified, including the fact that the presence of highly suitable land did not necessarily dictate the number of solar facilities that would be found, and that the necessary conditions for PV facilities seemed to be less stringent than for CSP facilities. Also, facilities built on contaminated lands, remediation sites, or areas that were attractive for solar development as a way to get more value out formerly unused space were an identifiable category in themselves, and indicate that the decision to develop these sites follows a separate type of process. These facilities also indicate that in some cases, the conventional requirements of physical parameters may not apply if there are other advantages to developing in these types of areas.

The fifth objective was to investigate the relationship between land ownership and the distribution of utility-scale solar facility sites to determine if, and to what extent, ownership is a critical parameter in siting decisions. The results of this study show that there is a clear tendency to site utility-scale solar facilities on federal land over lands that are owned privately or lands that are under state ownership. The nature of this pattern could be investigated further, but it is clear that in future siting decisions, it would behoove planners and solar developers to consider the potential advantages of locating facilities on federal lands.

This point of consideration factors directly into the last objective which was to address methodological weaknesses in traditional suitability modeling techniques by identifying other criteria that play a significant role in explaining the distribution of actual solar power plants. Several key factors were identified that had a visible impact on the distribution of solar facilities. These include non-spatial factors such as the socioeconomic and political situation potential in solar development zones, and the details about the extant energy portfolio and development plans within an area. Investigating these qualities and incorporating information about them into future suitability models would increase the accuracy of those models. Spatial factors that would be beneficial to include in future models include land ownership (with a preferential classification assigned to federal lands), current land use, a consideration of whether other solar facilities might already exist in an area, and a wider acceptable range of slope values for areas to be under consideration for development (21 of the 86 facilities, or 24%, were located on sites with slope greater than 2%).

Ultimately, all of the objectives were addressed with insightful and potentially impactful findings produced in each area of analysis. While there are a number of additional questions that are potentially raised by this research as future areas for research, this analysis constitutes a significant contribution towards quantitatively assessing the performance of solar suitability modeling in a GIS and identifying ways in which it might be improved in the future.

5.2 Limitations and Future Research

There are several limitations to this research that need to be kept in context in assessing the results of this analysis. The first is that this research only seeks to draw conclusions about utility-scale, grid-connected solar power plants producing 1 MW or more of electricity in the seven states within the study area. There are other smaller facilities, moderately sized installations at businesses and factories, and residential setups throughout the study area that this research does not address. The patterns in siting decisions discussed in this paper therefore do not apply to these other types of facilities, although future research could consider whether these smaller solar installations follow some of the same trends as the larger facilities.

Additionally, while the analysis and conclusions in this project were made using the most recent and complete information available, the complexity and intricacies of siting decisions almost certainly involve additional details and factors that were not possible to consider in the scope of this research. The cost of and availability of land parcels, as well as considerations such as access to water (via water rights), and zoning categories and restrictions are all highly relevant factors that would be worth investigating on a smaller scale, case by case basis. Determining threshold criteria for these factors would provide insight into past siting decisions and improve suitability models in the future as well. The absence of readily available, large coverage datasets that contain this information explains why these factors were not considered—compiling and organizing this type of information constitutes another area in which future research efforts would be well directed.

In addition, more research into the topic of land use and profiles of the attitudes of landowners in regard to different types of renewable energy projects (i.e., the difference between energy development in California and Texas) would be very helpful for this type of research. Compiling information about how land parcels are currently being used and investigating how this component factors into decisions regarding solar energy development could be a crucial area of investigation for future research.

Lastly, compiling a complete list of solar facilities that includes those in planning stages is inherently challenging due to the dynamic nature of such a list. While all efforts were made to list and map these facilities as comprehensively and accurately as possible, there may in fact be facilities considered in this study that may never be built or may be built in another location than the one identified in the previous documents due to last minute changes in planning decisions. Listing and mapping only those facilities that were in the final phase of planning (i.e., either through or in the later stages of permitting processes) and only those facilities for which an explicit site could be identified, does however mean that the list used in this work is as reliable as possible based on the information currently available to the public. Furthermore, this research seeks to identify general trends in siting decisions and suitability modeling—even a limited list of facilities can prove adequate and quite useful in revealing important or insightful patterns.

APPENDICES

Appendix 1. List of Utility-Scale Solar Facilities in Study Area

State	Facility	Size MW	Type	Status	Lat.	Long.
AZ	Nextlight Renewable Power Agua Caliente Project	290 MW	Photovoltaic	Proposed	32.973077	-113.489913
AZ	Fotowatio Renewable Ventures PV Facility	25 MW	Photovoltaic	Proposed	32.414605	-111.309587
AZ	Bell Independent Solar Thermal Test Site	5 MW	Parabolic Trough	Completion by May 2011	32.101797	-110.825576
AZ	Sonoran Solar Energy Project	375 MW	Parabolic Trough	Proposed	33.233411	-112.576721
AZ	Albiasa Solar Project with AZ Dept. of Comm.	200 MW	Parabolic Trough	Scheduled to be built by 2013	35.103031	-113.668746
AZ	Maricopa Solar Project (Tessera)	1.5 MW	Stirling Engine	Operational	33.557626	-112.215205
AZ	Quartzite Solar Project	100 MW	Power Tower	Proposed	33.830943	-114.202259
AZ	Saguaro (Solargenix) Power Plant	1 MW	Parabolic Trough	Operational	32.547522	-111.292516
AZ	Hualapai Valley Solar Project (HVS)	340 MW	Parabolic Trough	Construction begins Nov. 2010	35.618673	-114.014855
AZ	Starwood Solar 1	290 MW	Parabolic Trough	Construction begins 2010	33.519309	-113.139772
AZ	Solana Generating Station	280 MW	Parabolic Trough	Proposed	32.918645	-112.970396
AZ	Springerville Generating Station Solar Sytem	4.6 MW	Photovoltaic	Operational	34.296521	-109.267444
AZ	Prescott Airport Solar Power Plant	3.5 MW	Photovoltaic	Operational	34.676490	-112.405869
CA	SEGS I	13.8 MW	Parabolic Trough	Operational	34.867431	-116.825457
CA	SEGS II	30 MW	Parabolic Trough	Operational	34.862626	-116.828531
CA	SEGS III	30 MW	Parabolic Trough	Operational	35.021567	-117.564681
CA	SEGS IV	30 MW	Parabolic Trough	Operational	35.020368	-117.555585
CA	SEGS V	30 MW	Parabolic Trough	Operational	35.013434	-117.565142
CA	SEGS VI	30 MW	Parabolic Trough	Operational	35.012490	-117.555587
CA	SEGS VII	30 MW	Parabolic Trough	Operational	35.005599	-117.555781
CA	SEGS VIII	89 MW	Parabolic Trough	Operational	35.031584	-117.338052
CA	SEGS IX	89 MW	Parabolic Trough	Operational	35.031731	-117.357187
CA	First Solar Desert Sunlight Facility	250 MW	Photovoltaic	Under Review	33.725414	-115.432436
CA	First Solar Stateline Facility	300 MW	Photovoltaic	Under Review	35.532971	-115.446407
CA	Solargen Energy Project	420 MW	Photovoltaic	Proposed	36.623062	-120.892474
CA	Solon Corp. PG&E Vaca-Dixon Project	2 MW	Photovoltaic	Expected Online 2010	38.406191	-121.921599
CA	CleanTech America/Meridian CalRENEW 1 PV Facility	5 MW	Photovoltaic	Expected Online 2010	36.721196	-120.376417
CA	San Francisco Recurrent Energy PV Project	10 MW	Photovoltaic	Under Construction	37.749905	-122.483246
CA	Clear Skies Cavallo PV Project	6 MW	Photovoltaic	Under development	35.231819	-117.934741
CA	Chevron Lucerne Valley Solar Project	45 MW	Photovoltaic	Under review	34.421372	-116.810007
CA	GreenVolts GV1 Site	2 MW	Concentrated PV	Proposed	37.792952	-121.585255
CA	San Joaquin Solar 1 and Solar 2	106.8 MW	Parabolic Trough	Expected online 2011	36.134322	-120.209095
CA	Skytrough Cogentrix Demo Site	43 MW	Parabolic Trough	Proposed	34.87257,	-116.826841
CA	Mojave Solar Park	553 MW	Parabolic Trough	Expected online 2011	34.954484	-116.933308
CA	Sacramento Soleil Project (enXco)	1.25 MW	Photovoltaic	Operational	38.450122	-121.164289
CA	Paramount Farms Solar Array	1.1 MW	Photovoltaic	Operational	35.664447	-119.881018
CA	Rice Solar Project	150 MW	Power Tower	Proposed	34.064652	-114.808066
CA	Abengoa Solar (Mojave Solar)	250 MW	Parabolic Trough	Expected online 2013	35.012509	-117.318239
CA	Tessera SES Solar One (Calico Solar Project)	850 MW	Stirling Engine	Construction begins 2010	34.813996	-116.423499
CA	Tessera SES Solar Two	750 MW	Stirling Engine	Construction begins 2010	32.77605	-115.835710
CA	Kimberlina Solar Thermal Facility	5 MW	Fresnel Reflector	Operational	35.567543	-119.201559
CA	Carrizo Energy Solar Farm	177 MW	Fresnel Reflector	Proposed	35.370772	-120.048736

State	Facility	Size MW	Type	Status	Lat.	Long.
CA	Esolar Sierra Sun Tower	5 MW	Power Tower	Operational	34.731709	-118.139170
CA	Aerojet Solar Facility	3.6 MW	Photovoltaic	Operational	38.599971	-121.179115
CA	First Solar Facility	21 MW	Photovoltaic	Operational	33.586781	-114.722657
CA	Solar Millenium Blythe	1000 MW	Parabolic Trough	AFC filed 8/24/09	33.634645	-114.701647
CA	Fort Irwin Military Solar Facility	500 MW	Solar Thermal & PV	Proposed	35.398602	-116.646580
CA	Solar Millenium Palen	250 MW	Parabolic Trough	AFC filed 8/24/09	33.696959	-115.211723
CA	Ivanpah Solar Electric Generating System	400 MW	Power Tower	AFC Accepted 10/31/07	35.554035	-115.460700
CA	Beacon Solar Generating Station (NextEra)	250 MW	Parabolic Trough	Proposed completion late 2010	35.250502	-118.015075
CA	Genesis Solar Energy Project (NextEra)	250 MW	Parabolic Trough	AFC filed 8/31/09	33.664030	-115.009672
CA	Solar Millenium Ridgecrest	250 MW	Parabolic Trough	AFC filed 9/1/09	35.545469	-117.747805
CA	Nextlight Renewable AV Solar Ranch One	230 MW	Photovoltaic	Full Operation 2013	34.784634	-118.437157
CA	Customer/Community Choice Solar Farm (KCRD)	80 MW	Photovoltaic	Expected online 2011	36.682899	-119.765266
CA	City of Palmdale Hybrid Power Project	50 MW	Hybrid Combined Cycle	Expected online 2013	34.640783	-118.116174
CA	Solar Thermal Electric Hybrid (Unnamed)	59.4 MW	Parabolic Trough/Hybrid	Proposed	34.903979	-117.114888
CA	Victorville 2 Hybrid	50 MW	Parabolic Trough/Hybrid	Expected online late 2010	34.643047	-117.383776
CA	Alpine Sun Tower	92 MW	Power Tower	Expected online 2012	34.796514	-118.511652
CA	Topaz Solar Farm (First Solar)	550 MW	Photovoltaic	Construction begins 2010	35.383198	-120.066843
CA	California Valley Solar Ranch (High Plains)	250 MW	Photovoltaic	Expected online 2010	35.329284	-119.910387
CO	Colorado State Univ. PV Installation	2 MW	Photovoltaic	Operational	40.592222	-105.148749
CO	Colorado State (Pueblo) PV Installation	1.2 MW	Photovoltaic	Operational	38.312172	-104.574881
CO	Alamosa PV Plant	8.2 MW	Photovoltaic	Operational	37.687793	-105.875629
CO	Denver International Airport PV Array	2 MW	Photovoltaic	Operational	39.838085	-104.674066
CO	Fort Carson Solar Array	2 MW	Photovoltaic	Operational	38.722585	-104.779129
NM	Santa Teresa Suntower (Esolar)	92 MW	Power Tower	Work starts early 2010	31.831046	-106.623484
NM	Rancho Cielo Solar Farm	65 MW	Photovoltaic	Construction begins 2010	34.636380	-106.813196
NM	Cimarron 1 (First Solar)	30 MW	Photovoltaic	Construction begins 2010	36.464124	-104.637742
NM	BP and EnergyNovo Photovoltaic Project	22 MW	Photovoltaic	Proposed	33.100118	-107.100171
NM	Chevron Concentrated PV Project	1 MW	Concentrated PV	Proposed	36.705507	-105.613397
NV	Renewable Ventures PV Facility	26 MW	Photovoltaic	Proposed	36.395782	-114.962777
NV	Nextlight Renewable Power Boulder City Solar Project	150 MW	Photovoltaic	Proposed	35.840643	-114.960637
NV	NV Energy Searchlight PV Facility	20 MW	Photovoltaic	Proposed	35.470472	-114.929115
NV	Solar Millenium Amargosa Solar Power Project 1 and 2	484 MW	Parabolic Trough	Permitting in process	36.571957	-116.523012
NV	Nevada Solar One	64 MW	Parabolic Trough	Operational	35.800617	-114.976703
NV	Nellis Solar Power Plant	14 MW	Photovoltaic	Operational	36.261746	-115.054413
NV	Sempra Generation Photovoltaic Plant (El Dorado)	10 MW	Photovoltaic	Operational	35.787005	-114.996237
NV	Copper Mountain Solar Project	48 MW	Photovoltaic	Proposed	35.779361	-114.993462
NV	Fish Springs PV 1 Solar Ranch	100 MW	Photovoltaic	Proposed	40.107553	-119.915968
NV	Brightsource Energy Nevada Project	1200 MW	Power Tower	Expected online 2012	36.570737	-114.425732
NV	Nextlight Renewable Power Silver State North Project	140 MW	Photovoltaic	Proposed	35.618554	-115.331626
NV	Nextlight Renewable Power Silver State South Project	267 MW	Photovoltaic	Proposed	35.579059	-115.330901
TX	Blue Wing Solar Project	14-16 MW	Photovoltaic	Expected online 2010	29.306217	-98.402953
TX	Austin Energy PV Project	30 MW	Photovoltaic	Proposed	30.270995	-97.499189
TX	EPA City of Houston Brownfield Proposal	10 MW	Photovoltaic	Proposed	29.65956,	-95.376128
TX	NRG PV Wharton Project	10 MW	Photovoltaic	Proposed	29.940994	-95.542181

Appendix 2. List of Utility-Scale Solar Facilities with Final Rank and Input Ranks

Facility	Type	Size MW	FinalRank	TransLineRank	RdDisRank	InsolationRank	SlopeRank
Nextlight Renewable Power Agua Caliente Project	Photovoltaic	290 MW	7	0	9	8	9
Fotowatio Renewable Ventures PV Facility	Photovoltaic	25 MW	9	9	9	7	9
Bell Independent Solar Thermal Test Site	Parabolic Trough	5 MW	9	9	9	7	9
Sonoran Solar Energy Project	Parabolic Trough	375 MW	9	7	9	8	9
Albiasa Solar Project with AZ Dept. of Comm.	Parabolic Trough	200 MW	6	7	9	8	1
Maricopa Solar Project (Tessera)	Sterling Engine	1.5 MW	9	9	9	7	9
Quartzite Solar Project	Power Tower	100 MW	9	8	9	7	9
Saguaro (Solargenix) Power Plant	Parabolic Trough	1 MW	8	9	9	7	8
Hualapai Valley Solar Project (HVS)	Parabolic Trough	340 MW	5	5	8	7	1
Starwood Solar 1	Parabolic Trough	290 MW	8	3	9	8	9
Solana Generating Station	Parabolic Trough	280 MW	8	3	9	7	9
Springerville Generating Station Solar Sytem	Photovoltaic	4.6 MW	5	2	9	7	4
Prescott Airport Solar Power Plant	Photovoltaic	3.5 MW	5	8	9	7	0
SEGS I	Parabolic Trough	13.8 MW	9	9	9	8	9
SEGS II	Parabolic Trough	30 MW	9	9	9	8	9
SEGS III	Parabolic Trough	30 MW	9	9	9	9	9
SEGS IV	Parabolic Trough	30 MW	9	9	9	9	9
SEGS V	Parabolic Trough	30 MW	9	9	9	9	9
SEGS VI	Parabolic Trough	30 MW	9	9	9	9	9
SEGS VII	Parabolic Trough	30 MW	9	9	9	9	9
SEGS VIII	Parabolic Trough	89 MW	9	9	9	8	9
SEGS IX	Parabolic Trough	89 MW	9	9	9	8	9
First Solar Desert Sunlight Facility	Photovoltaic	250 MW	7	7	9	8	5
First Solar Stateline Facility	Photovoltaic	300 MW	6	9	9	8	0
Solargen Energy Project	Photovoltaic	420 MW	7	4	9	5	9
Solon Corp. PG&E Vaca-Dixon Project	Photovoltaic	2 MW	8	9	9	4	9
CleanTech America/Meridian CalRENEW 1 PV Facility	Photovoltaic	5 MW	8	8	9	4	9
San Francisco Recurrent Energy PV Project	Photovoltaic	10 MW	4	8	9	2	2
Clear Skies Cavallo PV Project	Photovoltaic	6 MW	5	6	9	8	1
Chevron Lucerne Valley Solar Project	Photovoltaic	45 MW	5	5	9	8	1
GreenVolts GV1 Site	Concentrated PV	2 MW	7	9	9	4	6
San Joaquin Solar 1 and Solar 2	Parabolic Trough	106.8 MW	8	8	9	5	8
Skytrough Cogentrix Demo Site	Parabolic Trough	43 MW	9	9	9	8	9
Mojave Solar Park	Parabolic Trough	553 MW	6	9	9	8	1
Sacramento Soleil Project (enXco)	Photovoltaic	1.25 MW	8	9	9	4	9
Paramount Farms Solar Array	Photovoltaic	1.1 MW	6	6	9	5	6
Rice Solar Project	Power Tower	150 MW	6	3	9	7	4
Abengoa Solar (Mojave Solar)	Parabolic Trough	250 MW	9	9	9	8	9
Tessera SES Solar One (Calico Solar Project)	Sterling Engine	850 MW	6	9	9	8	1
Tessera SES Solar Two	Sterling Engine	750 MW	5	3	9	7	3
Kimberlina Solar Thermal Facility	Fresnel Reflector	5 MW	8	9	9	5	9

Facility	Type	Size MW	FinalRank	TransLineRank	RdDisRank	InsolationRank	SlopeRank
Carrizo Energy Solar Farm	Fresnel Reflector	177 MW	8	8	9	6	9
Esolar Sierra Sun Tower	Power Tower	5 MW	9	8	9	7	9
Aerojet Solar Facility	Photovoltaic	3.6 MW	8	8	9	4	9
First Solar Facility	Photovoltaic	21 MW	9	8	9	7	9
Solar Millenium Blythe	Parabolic Trough	1000 MW	9	9	9	7	9
Fort Irwin Military Solar Facility	Solar Thermal & PV	500 MW	5	5	8	8	1
Solar Millenium Palen	Parabolic Trough	250 MW	6	9	9	8	2
Ivanpah Solar Electric Generating System	Power Tower	400 MW	5	8	9	8	0
Beacon Solar Generating Station (NextEra)	Parabolic Trough	250 MW	9	9	9	8	8
Genesis Solar Energy Project (NextEra)	Parabolic Trough	250 MW	9	9	8	8	9
Solar Millenium Ridgecrest	Parabolic Trough	250 MW	7	8	9	9	4
Nextlight Renewable AV Solar Ranch One	Photovoltaic	230 MW	8	9	9	6	7
Customer/Community Choice Solar Farm (KCRD)	Photovoltaic	80 MW	8	9	9	4	9
City of Palmdale Hybrid Power Project	Hybrid Combined Cycle	50 MW	7	9	9	7	4
Solar Thermal Electric Hybrid (Unnamed)	Parabolic Trough/Hybrid	59.4 MW	9	7	9	8	9
Victorville 2 Hybrid	Parabolic Trough/Hybrid	50 MW	9	8	9	8	9
Alpine Sun Tower	Power Tower	92 MW	8	8	9	6	9
Topaz Solar Farm (First Solar)	Photovoltaic	550 MW	8	8	9	6	9
California Valley Solar Ranch (High Plains)	Photovoltaic	250 MW	5	9	9	6	1
Colorado State Univ. PV Installation	Photovoltaic	2 MW	7	8	9	4	6
Colorado State (Pueblo) PV Installation	Photovoltaic	1.2 MW	5	8	9	6	1
Alamosa PV Plant	Photovoltaic	8.2 MW	8	7	9	7	9
Denver International Airport PV Array	Photovoltaic	2 MW	5	9	9	5	0
Fort Carson Solar Array	Photovoltaic	2 MW	5	9	9	6	0
Santa Teresa Suntower (Esolar)	Power Tower	92 MW	5	9	9	7	0
Rancho Cielo Solar Farm	Photovoltaic	65 MW	9	9	9	7	9
Cimarron 1 (First Solar)	Photovoltaic	30 MW	7	8	9	7	4
BP and EnergyNovo Photovoltaic Project	Photovoltaic	22 MW	8	5	9	7	9
Chevron Concentrated PV Project	Concentrated PV	1 MW	4	2	9	7	0
Renewable Ventures PV Facility	Photovoltaic	26 MW	7	9	9	8	4
Nextlight Renewable Power Boulder City Solar Project	Photovoltaic	150 MW	9	9	9	7	9
NV Energy Searchlight PV Facility	Photovoltaic	20 MW	6	8	9	8	1
Solar Millenium Amargosa Solar Power Project 1 and 2	Parabolic Trough	484 MW	9	7	9	8	9
Nevada Solar One	Parabolic Trough	64 MW	9	9	9	7	9
Nellis Solar Power Plant	Photovoltaic	14 MW	6	9	9	7	1
Sempra Generation Photovoltaic Plant (El Dorado)	Photovoltaic	10 MW	8	9	9	7	8
Copper Mountain Solar Project	Photovoltaic	48 MW	8	9	9	7	6
Fish Springs PV 1 Solar Ranch	Photovoltaic	100 MW	6	0	9	5	9
Brightsource Energy Nevada Project	Power Tower	1200 MW	5	7	9	7	0
Nextlight Renewable Power Silver State North Project	Photovoltaic	140 MW	6	9	9	7	1
Nextlight Renewable Power Silver State South Project	Photovoltaic	267 MW	5	9	7	7	0
Blue Wing Solar Project	Photovoltaic	14-16 MW	6	9	9	3	5
Austin Energy PV Project	Photovoltaic	30 MW	7	8	9	2	9
EPA City of Houston Brownfield Proposal	Photovoltaic	10 MW	4	9	9	2	0

Facility	Type	Size MW	FinalRank	TransLineRank	RdDisRank	InsolationRank	SlopeRank
NRG PV Wharton Project	Photovoltaic	10 MW	7	9	9	2	9

Appendix 3. List of Facilities and Sources Used to Identify Locations

On SEIA List	Name of Facility	Lat./Long.	Comments	Information Source	More
Yes	Nextlight Renewable Power Agua Caliente Project	32.973077, -113.489913	Direct Placement	http://www.nextlight.com/docs/UPDATE_%20PG&E,%20Energy%20Capitals%20NextLight%20Sign%20290%20MW%20Solar%20Power%20Deal.pdf	http://www.aguacalientesolarproject.com/secondary.asp?id=1
Yes	Fotowatio Renewable Ventures PV Facility	32.414605, -111.309587	Reliable Approx Coordinates from Description	http://www.renewableventures.com/news/20090916-pressrelease-tep.html	http://www.tucsonaz.gov/aar/rfeb1710.pdf
Yes	Bell Independent Solar Thermal Test Site	32.101797, -110.825576	Direct Placement	http://www.uatechpark.org/images/article/Solar%20Zone%20%201-19-10.doc	Will utilize thermal storage
Yes	Sonoran Solar Energy Project	33.233411, -112.576721	Direct Placement	http://www.nexteraenergyresources.com/pdf/sonoran.pdf	BLM Land
Yes	Albiasa Solar Project with AZ Dept. of Comm.	35.103031, -113.668746	Direct Placement	http://resource.co.mohave.az.us/File/PlanningAndZoning/SpecialCommitteesNProjects/Hwy93_051209.pdf	private land
Yes	Maricopa Solar Project (Tessera)	33.557626, -112.215205	Direct Placement	http://www.srpnet.com/environment/solar/maricopasolar.aspx	http://www.stirlingenergy.com/pdf/2009_8_19.pdf
No	Quartzite Solar Project	33.830943, -114.202259	Direct Placement	http://www.wapa.gov/transmission/Quartzsite/Newsletter1_508.pdf	
Yes	Saguaro (Solargenix) Power Plant	32.547522, -111.292516	Direct Placement	http://www.aps.com/_files/renewable/SP017SaguaroSolarTrough.pdf, http://www.chiefengineer.org/content/content_display.cfm/seqnumber_content/2594.htm	
No	Hualapai Valley Solar Project (HVS)	35.618673, -114.014855	Direct Placement	http://www.hualapaivalleysolar.com	http://www.slideshare.net/MitchellDong/mohave-sun-power-340-mw-hualapai-valley-solar-project-september-2009
No	Starwood Solar 1	33.519309, -113.139772	Reliable Coordinates from Google Earth and Map on website	http://www.starwoodsolar.com/, http://www.starwoodsolar.com/images/Newsletter_Map_Reduced.pdf	Will utilize salt storage
Yes	Solana Generating Station	32.918645, -112.970396	Reliable Coordinates from Google Earth and Map on website	http://www.solanasolar.com/default.cfm, http://www.aps.com/main/green/Solana/facts.html, http://www.solanasolar.com/misc/Solana.pdf	Will utilize salt storage
No	Springerville Generating Station Solar Sytem	34.296521, -109.267444	Direct Placement	http://www.tucsonelectric.com/Green/GreenWatts/SolarStats/SolarDescr.asp	
No	Prescott Airport Solar Power Plant	34.676490, -112.405869	Direct Placement	http://www.aps.com/my_community/Solar/Solar_22_ARCHIVE.html	http://www.aps.com/_files/renewable/SP002PrescottAirport.pdf
Yes	SEGS I	34.867431, -116.825457	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=28	
Yes	SEGS II	34.862626, -116.828531	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=29	
Yes	SEGS III	35.021567, -117.564681	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=30	
Yes	SEGS IV	35.020368, -117.555585	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=31	
Yes	SEGS V	35.013434, -117.565142	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=32	
Yes	SEGS VI	35.012490, -117.555587	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=33	
Yes	SEGS VII	35.005599, -117.555781	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=34	
Yes	SEGS VIII	35.031584, -117.338052	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=35	
Yes	SEGS IX	35.031731, -117.357187	Direct Placement	http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=36	
Yes	First Solar Desert Sunlight Facility	33.725414, -115.432436	Reliable Approx Coordinates from Description	http://www.greenbiz.com/news/2009/08/18/sce-and-first-solar-team-sunny-partnership	http://www.sce.com/NR/sc3/tm2/pdf/2391-E.pdf

On SEIA List	Name of Facility	Lat./Long.	Comments	Information Source	More
Yes	First Solar Stateline Facility	35.532971, -115.446407	Reliable Approx Coordinates from Description	http://www.greenbiz.com/news/2009/08/18/sce-and-first-solar-team-sunny-partnership	http://www.sce.com/NR/sc3/tm2/pdf/2391-E.pdf
Yes	Solargen Energy Project	36.623062, -120.892474	Reliable Coordinates from Google Earth	http://www.mercurynews.com/breaking-news/ci_14050919?nclick_check=1	
Yes	Solon Corp. PG&E Vaca-Dixon Project	38.406191, -121.921599	Reliable Coordinates from Google Earth and Map/Info on website	http://www.next100.com/2009/07/pge-selects-solon-corp-for-pv.php	
Yes	CleanTech America/Meridian CalRENEW 1 PV Facility	36.721196, -120.376417	Reliable Approx. Coordinates from Google Earth, available documents	http://www.cleantechamerica.com/media/CalRENEW-1FactSheet.pdf	http://www.meridianenergy.co.nz/NR/exeres/C506B3B5-6EAA-45CC-AA50-7396D8B40C31.htm
Yes	San Francisco Recurrent Energy PV Project	37.749905, -122.483246	Direct Placement	http://www.recurrentenergy.com/resources/sfsunset.php	
Yes	Clear Skies Cavallo PV Project	35.231819, -117.934741	Approx. Coordinates from available description	http://www.ecoseed.org/en/general-green-news/green-business-news/latest-deals-a-ventures/4141-clear-skies-solar-cavallo-energy-in-us-20-million-solar-project-in-california	http://globalsolartechnology.com/index.php?option=com_content&task=view&id=3848&Itemid=9
Yes	Chevron Lucerne Valley Solar Project	34.421372, -116.810007	Direct Placement	http://www.blm.gov/ca/st/en/fo/barstow/chevron_energy_solutions.html	http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/cdd.Par.66057.File.dat/Draft_EIS_CDCA_Plan_Lucerne_Valley_Solar_Project-Volume-I.pdf
Yes	GreenVolts GV1 Site	37.792952, -121.585255	Direct Placement	http://www.acgov.org/cda/planning/GreenVoltsMND_InitSt.pdf	
Yes	San Joaquin Solar 1 and Solar 2	36.134322, -120.209095	Direct Placement	http://www.energy.ca.gov/sitingcases/sjsolar/index.html	supplemented with biomass
Yes	Skytrough Cogentrix Demo Site	34.87257, -116.826841	Reliable Coordinates from Google Earth, available documents	http://social.csptoday.com/news/sunray-energy-signs-agreement-skyfuel	
Yes	Mojave Solar Park	34.954484, -116.933308	Reliable Approx Coordinates, based on SEIA map	http://www.energy.ca.gov/siting/solar/, http://cleantech.com/news/1522/pg-e-solel-in-553-mw-solar-deal	http://cleantech.com/news/1522/pg-e-solel-in-553-mw-solar-deal
Yes	Sacramento Soleil Project (enXco)	38.450122, -121.164289	Direct Placement	http://www.kcra.com/video/16775851/index.html	http://www.enxco.com/pdf/SacramentoSoleilProject%20Profile10-2008FINAL.pdf
No	Paramount Farms Solar Array	35.664447, -119.881018	Direct Placement	http://www.paramountfarms.com/pdf/press/Solar_Release_May_16.pdf	
Yes	Rice Solar Project	34.064652, -114.808066	Direct Placement	http://www.energy.ca.gov/sitingcases/ricesolar/index.html	http://www.energy.ca.gov/sitingcases/ricesolar/documents/applicant/2009-11-19_Applicant_Data_Adequacy_Supplement_TN-54204.pdf
Yes	Abengoa Solar (Mojave Solar)	35.012509, -117.318239	Direct Placement	http://www.energy.ca.gov/sitingcases/abengoa/notices/2009-12-09_notice_hearing.html	
Yes	Tessera SES Solar One (Calico Solar Project)	34.813996, -116.423499	Direct Placement	http://www.energy.ca.gov/siting/meetings/2010-01-22_meeting/presentations/Tessera_Solar-Solar_Projects_2010-01-22.pdf	
Yes	Tessera SES Solar Two	32.776055, -115.835710	Direct Placement	http://www.energy.ca.gov/siting/meetings/2010-01-22_meeting/presentations/Tessera_Solar-Solar_Projects_2010-01-22.pdf	
Yes	Kimberlina Solar Thermal Facility	35.567543, -119.201559	Direct Placement	http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=12066 And http://en.wikipedia.org/wiki/Kimberlina_Solar_Thermal_Energy_Plant and http://www.nytimes.com/external/venturebeat/2008/10/23/23venturebeat-ausras-first-solar-thermal-plant-starts-up-99529.html?pagewanted=print	http://www.ausra.com/pdfs/KimberlinaOverview.pdf
No	Carrizo Energy Solar Farm (Proposed generation by 2010)	35.370772, -120.048736	Direct Placement	http://en.wikipedia.org/wiki/Carrizo_Energy_Solar_Farm, http://www.energy.ca.gov/sitingcases/carrizo/index.html	http://www.energy.ca.gov/sitingcases/carrizo/index.html
Yes	Esolar Sierra Sun Tower	34.731709, -118.139170	First commercial solar tower in US	http://www.esolar.com/our_projects/, http://www.marcgunther.com/wp-content/uploads/DSC_0737.JPG	http://www.alternativeenergy.com/profiles/blogs/esolars-sierra-suntower-named

On SEIA List	Name of Facility	Lat./Long.	Comments	Information Source	More
No	Aerojet Solar Facility	38.599971, -121.179115	Reliable Approx Coordinates from Description	To be built on land used for toxic waste…	http://www.newsreview.com/sacramento/content?oid=1030253
Yes	First Solar Facility	33.586781, -114.722657	Direct Placement	http://www.rcaluc.org/filemanager/agenda/agendas/archive/2008/10_09_08_sr/sr_4.1.pdf	
Yes	Solar Millenium Blythe	33.634645, -114.701647	Reliable Coordinates from Google Earth, available documents	http://www.energy.ca.gov/sitingcases/solar_millennium_blythe/index.html	
Yes	Fort Irwin Military Solar Facility	35.398602, -116.646580	Approx. Coordinates of Fort Irwin from Google Earth	http://www.army.mil/-news/2009/08/07/25621-army-on-track-to-power-fort-irwin-with-sunshine/	Clark Energy Group and Acciona Solar Power
Yes	Solar Millenium Palen	33.696959, -115.211723	Direct Placement	http://www.energy.ca.gov/sitingcases/solar_millennium_palen/index.html	http://www.energy.ca.gov/sitingcases/solar_millennium_palen/documents/applicant/afc/2.0%20Project%20Description.pdf
Yes	Ivanpah Solar Electric Generating System	35.554035, -115.460700	Direct Placement	http://www.energy.ca.gov/sitingcases/ivanpah/index.html	http://www.energy.ca.gov/sitingcases/ivanpah/documents/figures/project_description/Fig3.pdf
Yes	Beacon Solar Generating Station (NextEra)	35.250502, -118.015075	Reliable Coordinates from Google Earth and Map on website	http://www.energy.ca.gov/sitingcases/beacon/index.html, http://www.energy.ca.gov/sitingcases/beacon/documents/2008-03-24_BEACON_VICINITY+LOCATION_MAPS.PDF	
Yes	Genesis Solar Energy Project (NextEra)	33.664030, -115.009672	Reliable Coordinates from Google Earth and Description on website	http://www.energy.ca.gov/sitingcases/genesis_solar/index.html	Wet cooling
Yes	Solar Millenium Ridgecrest	35.545469, -117.747805	Direct Placement	http://www.energy.ca.gov/sitingcases/solar_millennium_ridgecrest/index.html	http://www.energy.ca.gov/sitingcases/solar_millennium_ridgecrest/documents/applicant/afc/2.0%20Project%20Description.pdf
Yes	Nextlight Renewable AV Solar Ranch One	34.784634, -118.437157	Reliable Coordinates from Google Earth, available documents	http://www.avsolarranchone.com/secondary.asp?id=15, http://www.nextlight.com/docs/AVSR1%20AV%20Press%20Solar%20Plant%20for%20farmland%20site_5-11-09.pdf	
No	Customer/Community Choice Solar Farm (KCRD)	36.682899, -119.765266	Approx. Coordinates from available description	http://www.reuters.com/article/environmentNews/idUSN0642961120070708	
Yes	City of Palmdale Hybrid Power Project	34.640783, -118.116174	Reliable Coordinates from Google Earth and Map/Info on website	http://www.energy.ca.gov/sitingcases/palmdale/index.html	
No	Solar Thermal Electric Hybrid (Unnamed)	34.903979, -117.114888	Reliable Approx Coordinates from Description	http://www.altenergymag.com/news_detail.php?pr_id=3361	Will make use of heat storage
Yes	Victorville 2 Hybrid	34.643047, -117.383776	Reliable Coordinates from Google Earth and Description on website	http://www.energy.ca.gov/sitingcases/victorville2/index.html	Natural Gas and Solar Thermal
Yes	Alpine Sun Tower	34.796514, -118.511652	Reliable Coordinates from Google Earth and Map/Info on website	http://www.pge.com/nots/rates/tariffs/tm2/pdf/ELEC_3481-E.pdf	Excellent, original info document
Yes	Topaz Solar Farm (First Solar)	35.383198, -120.066843	Reliable Approx Coordinates from Description, found in Google Maps	http://en.wikipedia.org/wiki/Topaz_Solar_Farm, http://www.slocounty.ca.gov/planning/environmental/EnvironmentalNotices/optisoloar.htm	
Yes	California Valley Solar Ranch (High Plains)	35.329284, -119.910387	Reliable Coordinates from Google Earth, available documents	http://www.californiavalleysolarranch.com/Fact_Sheet.pdf, http://www.slocounty.ca.gov/planning/environmental/EnvironmentalNotices/sunpower.htm, http://en.wikipedia.org/wiki/California_Valley_Solar_Ranch	

On SEIA List	Name of Facility	Lat./Long.	Comments	Information Source	More
No	Colorado State Univ. PV Installation	40.592222, -105.148749	Direct Placement	http://www.news.colostate.edu/Release/4725	
No	Colorado State (Pueblo) PV Installation	38.312172, -104.574881	Direct Placement	http://www.colostate-pueblo.edu/Communications/Media/PressReleases/2009/Pages/20090103.aspx	
Yes	Alamosa PV Plant	37.687793, -105.875629	Reliable Approx Coordinates from Description, available data	http://denver.bizjournals.com/denver/stories/2006/03/27/daily45.html, http://www.sunedison.com/uploads/pr/14/121607-alamosa.pdf,	
No	Denver International Airport PV Array	39.838085, -104.674066	Reliable Coordinates from Google Earth and Map/Info on website	http://www.metrodenver.org/news-center/metro-denver-news/DIA-solar-dedicated.html, http://images.google.com/imgres?imgurl=http://www.sincerelysustainable.com/wp-content/uploads/2009/08/DIA-Solar-Field.jpg&imgrefurl=http://www.sincerelysustainable.com/renewable-energy/solar-renewable-energy/denver-airport-expanding-its-solar-usage-significantly&usg=__OWIfzpglGnDFUYc1kaHERm6FcdA=&h=434&w=654&sz=83&hl=en&start=14&um=1&tbnid=NX-9dD25JMCQcM:&tbnh=92&tbnw=138&prev=/images%3Fq%3Dphotovoltaic%2Bfacility%2BDIA%26hl%3Den%26sa%3DN%26um%3D1	
No	Fort Carson Solar Array	38.722585, -104.779129	Direct Placement	http://www.wapa.gov/newsroom/NewsFeatures/ftcarsonsolar.htm	http://sems.carson.army.mil/environmental/p2/P2Dec07.pdf
Yes	Santa Teresa Suntower (Esolar)	31.831046, -106.623484	Reliable Approx Coordinates from Description on website, Wikipedia	http://www.democracyfornewmexico.com/democracy_for_new_mexico/2009/06/new-mexico-suntower-gov-bill-richardson-announces-construction-of-states-first-solar-thermal-power-p.html, http://www.bizjournals.com/albuquerque/stories/2009/06/08/daily65.html?ana=from_rss	
No	Rancho Cielo Solar Farm	34.636380, -106.813196	Reliable Approx Coordinates from Description, available data	http://www.governor.state.nm.us/press/2008/dec/121608_01.pdf, http://www.loopnet.com/property/15830625/Rancho-Cielo/	
Yes	Cimarron 1 (First Solar)	36.464124, -104.637742	Direct Placement	http://www.tristategt.org/NewsCenter/NewsItems/First-Solar-Cimmaron-I-Announcement.cfm	
Yes	BP and EnergyNovo Photovoltaic Project	33.100118, -107.100171	Approx. Coordinates from available description	http://solar.energy-business-review.com/news/bp_solar_energynovo_partner_to_build_22_mw_solar_plant_in_new_mexico_us_090901/	http://www.krqe.com/dpp/news/business/business_ap_elephant_butte_solar_plant_planned_200909011122
No	Chevron Concentrated PV Project	36.705507, -105.613397	Reliable Coordinates from Google Earth, available documents	http://www.triplepundit.com/2010/02/chevron-acts-to-reclaim-contaminated-land-with-sunshine/	http://www.epa.gov/superfund/sites/npl/nar1599.htm
Yes	Renewable Ventures PV Facility	36.395782, -114.962777	Direct Placement	http://www.renewableventures.com/news/20090813-pressrelease-nvenergy.html	http://www.cityofnorthlasvegas.com/MeetingsAndAgendas/PDFs/PlanningCommission/Agendas/2009_10_14/Items/P009.pdf
Yes	Nextlight Renewable Power Boulder City Solar Project	35.840643, -114.960637	Reliable Coordinates from Google Earth	http://www.bouldercitysolar.com/secondary.asp?id=7	http://www.bcnv.org/Finance/mediavault/RFP%20Solar%20Energy.pdf
Yes	NV Energy Searchlight PV Facility	35.470472, -114.929115	Reliable Approx Coordinates from Description	http://www.accessclarkcounty.com/depts/administrative_services/Town_Services/Documents/SearchMinutes09May12.pdf	http://www.lasvegassun.com/news/2009/jun/11/nv-energy-buy-power-searchlight-solar-plant/
Yes	Solar Millenium Amargosa Solar Power Project 1 and 2	36.571957, -116.523012	Direct Placement	http://www.basinandrangewatch.org/Amargosa-SolarMillenium.html	Will utilize salt storage, wet cooling
Yes	Nevada Solar One	35.800617, -114.976703	Built by Acciona Solar Power (Solargenix)	http://en.wikipedia.org/wiki/Nevada_Solar_One	Facility # : (702) 617-1096
Yes	Nellis Solar Power Plant	36.261746, -115.054413	Reliable Coordinates from Google Earth	http://en.wikipedia.org/wiki/Nellis_Solar_Power_Plant	Largest PV plant in N. America
Yes	Sempra Generation Photovoltaic Plant (El Dorado)	35.787005, -114.996237	Reliable Coordinates from Google Earth	http://www.sempragenereration.com/eds.htm, http://investor.firstsolar.com/phoenix.zhtml?c=201491&p=irol-	Additional 48 MW to be built

On SEIA List	Name of Facility	Lat./Long.	Comments	Information Source	More
				newsArticle&ID=1238556&highlight	
Yes	Copper Mountain Solar Project	35.779361, -114.993462	Direct Placement	http://www.swrec.org/documents/powerpoints/utility_scale_wind&solar_sahagian_swrec2009.pdf	
Yes	Fish Springs PV 1 Solar Ranch	40.107553, -119.915968	Direct Placement	http://guntherportfolio.com/2010/01/fish-springs-pv-1-solar-project-moves-forward/	
Yes	Brightsource Energy Nevada Project	36.570737, -114.425732	Direct Placement	http://cleantech-israel.blogspot.com/2008/08/brightsource-energy-planning-1200-mw.html	http://www.blm.gov/pgdata/etc/medialib/blm/nv/energy.Par.69807.File.dat/1-20-2009%20Status%20of%20Nevada%20Solar%20Energy%20Workload%20updated.pdf
Yes	Nextlight Renewable Power Silver State North Project	35.618554, -115.331626	Direct Placement	http://www.wildnevada.org/index.php?option=com_content&view=article&id=544:fast-track-silver-state&catid=89	
Yes	Nextlight Renewable Power Silver State South Project	35.579059, -115.330901	Direct Placement	http://www.basinandrangewatch.org/NextLightPrimm.html	http://www.basinandrangewatch.org/NextLight-Scoping.html
Yes	Blue Wing Solar Project	29.306217, -98.402953		http://www.juwisolar.com/blue-wing-solar/	
Yes	Austin Energy PV Project	30.270995, -97.499189	Direct Placement	http://www.geminisolar.com/portfolio/Austin-Energy/AustinSolarFactSheet.pdf	
No	EPA City of Houston Brownfield Proposal	29.65956, -95.376128	Direct Placement	http://www.epa.gov/brownfields/sustain_plts/factsheets/houston_solar.pdf	
Yes	NRG PV Wharton Project	29.940994, -95.542181	Direct Placement	http://houston.bizjournals.com/houston/stories/2009/09/21/daily42.html	http://www.reuters.com/article/idUKN2445821820090924

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