Mining for Solar Resources

U.S. Southwest Provides Vast Potential

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THE BAD NEWS IN ELECTRICAL ENERGY production is that prices of conventional energy sources such as natural gas and coal continue to increase. The good news, however, is that these escalating prices are spurring a renewed interest in the large-scale generation of electricity from renewable resources.

One of the primary renewable energy resources is solar energy, which is a vast, largely untapped resource, especially in the U.S. Southwest — a region deemed by some as the "Saudi Arabia of solar energy potential." Because of this potential, Congress requested the U.S. Department of Energy to research and develop an initiative to fulfill a preliminary goal of establishing 1,000 megawatts of concentrating solar power (CSP) to supply electricity to the southwestern United States. Subsequently, the Western Governors' Association (WGA) formally adopted a resolution that called for 30,000 megawatts of clean, diversified energy, including solar energy, for the western United States by 2015.

CSP technologies concentrate sunlight to provide heat to conventional power cycles such as steam-Rankine turbines, which are typical of coal-fired power plants and are most economical for large-scale installations of hundreds of megawatts. CSP is unlike other solar technologies that are based on flat-surface collectors, such as rooftop solar-electric systems and solar water heaters. In contrast, CSP requires "direct-normal" solar radiation — the component of sunlight that emanates directly from the solar disk — and excludes diffuse, or "blue-sky" radiation.

Direct-normal solar radiation values can be derived from satellite data. An analysis of these data, combined with geographical information system (GIS) data, has quantified the solar resource potential for large-scale power generation using CSP technologies. Specifically, the National Renewable Energy Laboratory (NREL), collaborating with the State University of New York (SUNY) in Albany, used this combination as an efficient, effective means for quantifying and communicating the vast solar resource potential in the U.S. Southwest. Prime locations for future solar power plants can also be identified by factoring in information on constraints on electricity transmission and access to load centers, which are the regions where electricity is consumed.

SATELLITE-DERIVED SOLAR RESOURCE DATA

Geostationary weather satellites, such as GOES (Geostationary Operations Environmental Satellite), continuously monitor the Earth's cloud cover on a time and location basis. The ground resolution approaches one kilometer for the satellite's visible-radiation sensors. This information can be used to generate solar irradiance data that are time and site specific, leading to the generation of high-resolution maps of solar radiation. Scientists have concluded that beyond 25 kilometers of ground stations, satellite-derived hourly irradiances are the most accurate data.

Researchers from the University at Albany, New York, and the University of Geneva, Switzerland, have developed a new semi-empirical model for deriving global (i.e., direct-normal + diffuse) and direct-normal solar irradiances from the visible-radiation channel of geostationary weather satellites (Perez et. al. 2002, 2003). This model evolved from the European Heliosat-1 methodology (Cano et. al. 2003), which postulates that the Earth's radiance, as seen from space, is proportional to cloud transmissivity, and hence, to the amount of solar radiation reaching the ground.

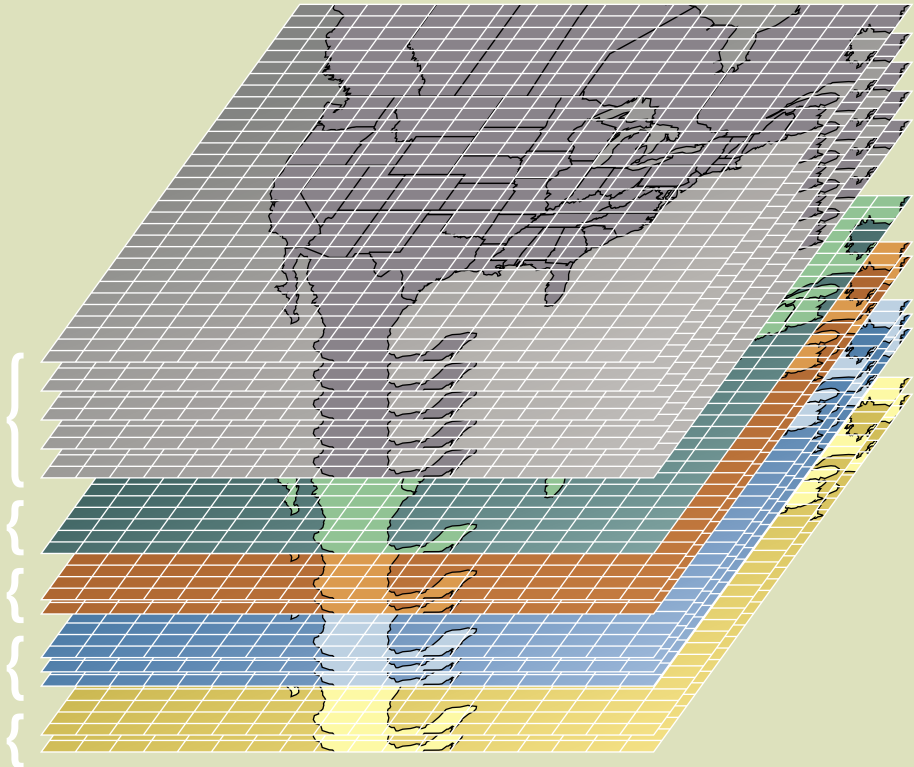


Figure 1. *This diagram illustrates all the geographically gridded data sets used in the North American model, including hourly image pixels, terrain elevation, monthly turbidity (Atmospheric Optical Depth and precipitable water), daily snow-cover updates, and the ground.*

The model consists of two main parts: (1) determining a cloud index from the satellite image, and (2) using this factor to modulate global and direct-normal clear-sky radiation envelopes. The cloud index is determined for each individualized ground location (or image pixel) being calculated from the "relative normalized pixel brightness" for a specific location. This brightness factor is the brightness of a pixel in relation to its possible maximum and minimum values at that location, where the maximum value represents cloudy conditions (or the brightness of thick cloud tops) and the minimum value represents clear conditions (or the brightness of the ground).

Because this process is individualized for each pixel, it accounts for differences in ground reflectivity over space and time and does not require an absolute knowledge of the calibration of satellite sensors. The model also accounts for site-specific characteristics for ground bidirectional (or specular) reflectance and for snow cover when present. The clear-sky radiation envelopes, which represent the upper limit of modeled irradiances, are a function of ground elevation and atmospheric transmissivity as quantified by precipitable water, ozone, and atmospheric optical depth (AOD).

The operation of the model on a geographic scale, either for preparing maps or site/time-specific time series, requires some degree of logistics and information processing. ***Figure 1*** summarizes this logistical approach and includes several layers of gridded information. The grid size of our current archive is 0.1 degree latitude-longitude, but the ultimate achievable resolution of a visible-channel GOES image can approach 0.01 degree. The gridded information layers include the following:

a. Raw satellite pixels (visible channel) — obtained via direct processing of primary GOES-EAST and GOES-WEST satellite images. Gridded raw pixel frames are archived on an hourly basis.

b. Terrain elevation.

c. Climatological AOD and water — 12 monthly layers — derived from previously gridded atmospheric optical depth data.

d. Snow cover — daily gridded frames from the National Operational Hydrologic Remote Sensing Center.

e. Specular correction factor — 216 layers (12 months by 18 hours) derived from the hourly processing of five years' worth of raw pixel data.

Table 1. *Results of satellite/GIS analysis showing area of land and associated power capacity for seven states in U.S. Southwest.*

STATE	AVAILABLE AREA (MI²)	CAPACITY (MW)*
Arizona	19,300	2,467,700
California	6,900	877,200
Colorado	2,100	271,900
Nevada	5,600	715,400
New Mexico	15,200	1,940,000
Texas	1,200	148,700
Utah	3,600	456,100
Total	**53,900**	**6,877,000**

**CSP power plants require about 5 acres of land area per megawatt of installed capacity. Solar generation can be estimated by assuming an average annual solar capacity factor of 25%-50%, depending on the degree of thermal storage used for a plant.*

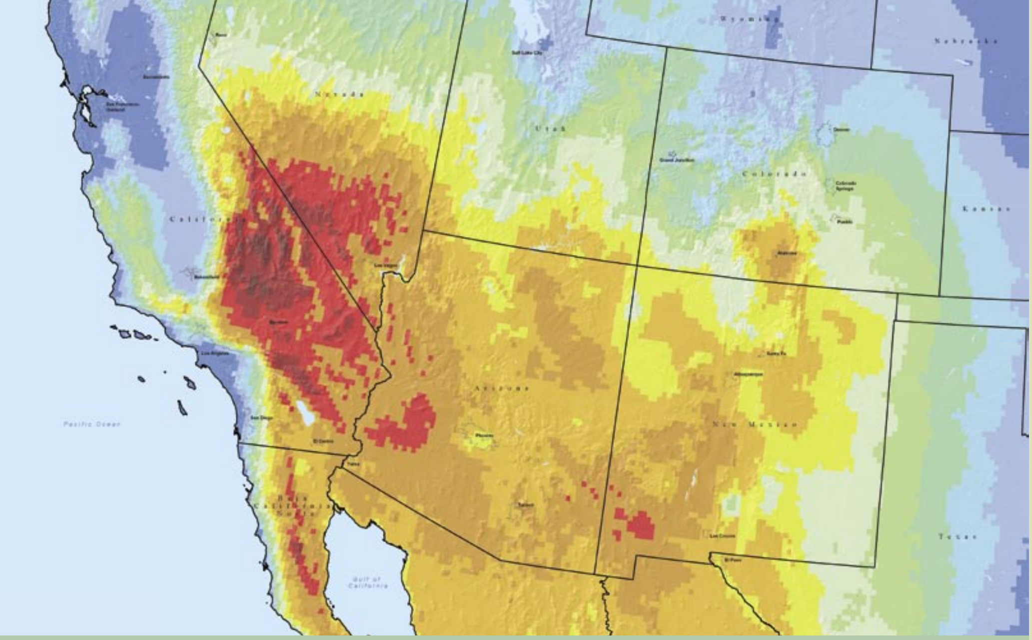


Figure 2. *Direct-normal solar radiation map is derived from 10-km resolution satellite data source. The solar resource in the southwestern United States is vast and largely untapped. Model estimates monthly average daily total radiation, averaged from hourly estimates of direct-normal irradiance over 5 years (1998-2002).*

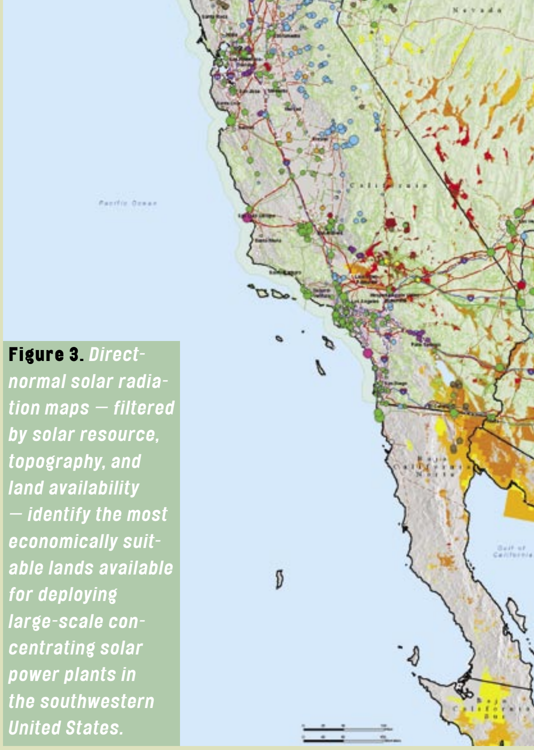


Figure 3. *Direct-normal solar radiation maps — filtered by solar resource, topography, and land availability — identify the most economically suitable lands available for deploying large-scale concentrating solar power plants in the southwestern United States.*

GIS ANALYSIS OF CSP GENERATING POTENTIAL

The direct-normal resource map shown in ***Figure 2*** was developed using the above methodology for deriving high-resolution solar resource data. However, not all the land area shown in ***Figure 2*** is suitable for large-scale CSP plants because such plants require relatively large tracts of nearly level open land with economically attractive solar resources.

To address some of the siting issues related to power plants, GIS data were applied to land type (e.g., urban, agricultural), ownership (e.g., private, state, federal), and topography. The terrain available for CSP development was conservatively estimated with a progression of filters as follows:

a. Lands with less than 6.75 kWh/m²/day of average daily direct-normal resource were eliminated to identify only those areas with the highest economic potential.

b. Lands with land types and ownership incompatible with commercial development were eliminated. These areas include national parks, national preserves, wilderness areas, wildlife refuges, water, and urban areas.

c. Lands with slope greater than 1% and with contiguous areas smaller than 10 km² were eliminated to identify lands with the greatest potential for low-cost development.

Even if we consider only the high-value resources, nearly 7 million megawatts of solar generation capacity exist in the U.S. southwest.

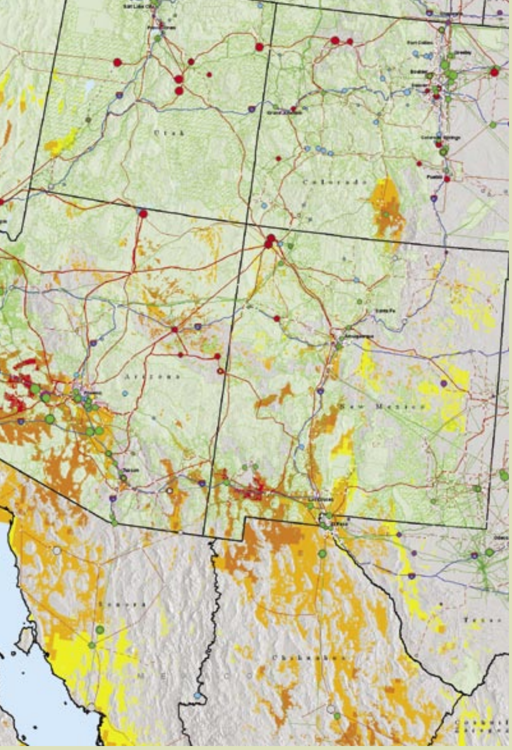
Map Key: Direct-Normal Solar Radiation

kWh/m²/day
8.00-8.25
7.75-8.00
7.50-7.75
7.25-7.50
7.00-7.25
6.75-7.00
6.50-6.75
6.25-6.50
6.00-6.25
5.75-6.00
5.50-5.75
2.75-5.50

Figure 3 shows the resulting land area when all of these filters are applied, and ***Table 1*** (on page 13) provides the resulting land area and associated CSP generation capacity. This table shows that, even if we consider only the high-value resources, nearly 7 million megawatts of solar generation capacity exist in the U.S. Southwest. According to the Energy Information Agency, in 2003 about 1 million megawatts of generation capacity existed in the entire United States. Each state in the table has sufficient land illuminated by the highest levels of solar radiation such that tapping only a small portion could generate enough electricity to meet its current needs.

CONSIDERING TRANSMISSION CONSTRAINTS AND POPULATION CENTERS

The United States is divided into a number of electricity transmission control regions. The largest region, the Western Electricity Coordinating Council (WECC), covers the western third of the United States and is essentially isolated from the rest of the nation's grid. Apart from Texas, most of which lies within the Electric Reliability Council of Texas (ERCOT) control region, the states in our assessment are part of the WECC control system and have high-voltage transmission lines that interconnect the states to move power from regions with conventional and renewable resources to population centers.



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A new solar power plant must fit into the transmission system. NREL, working with Platts Research and Consulting, has conducted a preliminary assessment that takes into account these additional transmission constraints. Ideal locations have been identified for many of the states described in ***Table 1*** (Mehos and Owens, 2004) and several potential sites were identified for each of the states of California, Arizona, New Mexico and Nevada. Future analysis will likely identify promising sites in Colorado, Texas and Utah.

To fully identify favorable opportunities for siting solar power plants, additional factors — land ownership, road access, and local transmission infrastructure capabilities and loadings — must be examined in greater detail and discussed with local experts and utility specialists. Preliminary discussions with these stakeholders and visits to potential sites have demonstrated the effectiveness of this methodology in identifying and communicating prospective locations for large-scale concentrating solar power plants.

Satellite imaging, combined with screening through GIS analysis, has proven to be a very cost-effective approach for quantifying the solar resource potential and identifying potential CSP generation sites in the U.S. Southwest. Analytical results indicate that the solar resource is enormous and largely untapped.

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