SunShot
U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY

PVMapper:
Final Progress Report
DE-EE0005351

November 26, 2014

BOISE STATE UNIVERSITY

BYU
BRIGHAM YOUNG UNIVERSITY

Idaho National Laboratory INL

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Executive Summary

The period of performance for the Department of Energy funded project, *Sunshot: Development of an Open Source Utility Scale Solar Project Siting Tool* (DE-EE005351), ran from September 2011 through September 30, 2014. The outcome of the project exceeded the Statement of the Project Objectives, which included the following:

- To develop the tool on an open-source platform;
- To integrate the appropriate data sets and layers;
- To include a measure of social risk and public acceptance;
- To enable customization of variable weights;
- To provide a free and accessible platform to download the tool; and
- To provide a sustainability plan to ensure future relevance of the tool.

The project team consisted of members from Boise State University, the Idaho National Laboratory, Brigham Young University, and the University of Idaho. Through extensive consultation and meetings with a Project Steering Committee and industry input, the team created ***PVMapper*** and *PVMapper* ***Site Designer***. The open source tools provide an extensible, customized siting comparison software suite from the macro- (comparison of selected sites and land area for utility-scale facilities - *PVMapper*) to the micro-scale for individual site layouts (*PVMapper Site Designer)*. Both tools are available at http://*PVMapper*.org/.

PVMapper is an open source GIS application for utility-scale PV project siting that optimizes site comparisons for specific users based on their own customizations of weights for specific data layers, distance, and social integration and risk tools. Social preference data in regard to proximity and intersection with specific, mappable land features is integrated at the 95% confidence level from a series of three annual surveys with over 1,300 respondents, enabling users to identify potential opposition and areas that may incur costly delays in permitting or result in project termination. Users can also customize distance and scoring functions to eliminate sites based on one criterion or screen sites based on items such as ground slope or a given proximity to certain power infrastructure. From a single application, *PVMapper* provides the most relevant GIS data layers and a "scoreboard at-a-glance" interface for users to simultaneously compare multiple sites. With the simple click of the mouse, *PVMapper* also provides both summary and detailed reports of siting analysis that detail scoring and the source of specific data layers and functions for easy reference. Interfacing with the System Advisor Model and PVWatts, *Site Designer* quickly provides the option of designing a specific site, and calculating solar insolation and potential power production.

From the applications, developers save significantly on soft costs in two areas. First, a developer's use of *PVMapper* saves weeks of development and analytical costs by narrowing down many sites to the select few that can justify much more expensive interconnection studies. At the same time, the social tools demonstrate areas of potential public concern or public assurance in regard to sites, helping developers target the areas with the most opportunity for success based on their own business plans and strategy. Use of the social tools may also save significant government and public effort in permit and site review through the selection of less controversial sites and site layouts. Besides solar developers, *PVMapper* and *Site Designer* will also be of use to Authorities Having Jurisdiction (AHJs), investors, financiers, software developers, environmental consultants,

utilities, public utilities commissions, and non-governmental organizations. Energy developers may also extend the suite of tools to apply to other generation technologies.

As part of the sustainability plan, *PVMapper* and *Site Designer* will be hosted for at least five more years on servers at Brigham Young University. The project website (http://*PVMapper*.org/) provides access to the software by free download, user registration, source code, documentation, software license, the team, training videos, and publications. In addition, a User Advisory Board was also formed and consists of representatives from SunEdison, Terracon, Aspen Environmental Group, Brigham Young University, Boise State University, and the Idaho National Laboratory. The Board develops protocols for software updates and completed its first software "push" successfully with the addition of the 95% confidence intervals from the final analysis of project survey data. As part of its charge the User Advisory Board is continuously recruiting project partners.

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Introduction

PVMapper is an open source GIS application for utility-scale PV project siting that optimizes site comparisons for specific users based on their own customizations of weights for specific data layers, distance, and social integration and risk tools. The software's purpose is to reduce the soft costs associated with business development and permitting for utility-scale solar photovoltaic (PV) developers. In order for the software to be the most accessible and with little limitation for use, the team chose a New BSD License (https://*PVMapper*.codeplex.com/license). Because the software is open source and emphasis was put on users not needing to purchase a license, the software was built from the ground-up, requiring an intensive and time consuming effort in development, as well as Alpha and Beta testing. From its inception, the project was developed in close collaboration with a Steering Committee, comprised of industry representatives from large and small solar developers, environmental consultants, data and renewable forecasting firms, and the National Renewable Energy Laboratory and Argonne National Laboratory.

The project website (http://*PVMapper*.org/) provides access to the software by free download, user registration, source code, documentation, software license, the team, training videos, and publications.

PVMapper uses a standard GIS tool interface familiar to users. Once registered, individual users can draw and select polygons for individual sites to score them comparatively or on an individual basis. Alternatively, users can import a site from their own .kml files or add layers that *PVMapper* can automatically score as a distance tool. Sites and any proprietary data are stored on the user's machine and not on the server, providing industry the assurance that their data is internally secure. *PVMapper* utilizes well-documented data in approximately 25 layers, including land administration, soil type, irradiance, power infrastructure, brownfields, and

Table 1. Organizational participation in *PVMapper*.

Project Activity	Organizational Participants
Semi-Structured Interviews	juwi Solar First Solar Tenaska Solar
Project Steering Team	juwi Solar Tenaska Solar First Solar 3Tier Terracon Panorama Environmental, Inc. Pacific Gas & Electric The Louis Berger Group Stantec National Renewable Energy Laboratory Argonne National Laboratory
Software Design Reviewers	juwi Solar Tenaska Solar Argonne National Laboratory
Beta Testers	Abengoa Solar Tetra Tech Faze1 Schletter National Rural Electric Cooperative Association Aspen Environmental Group AquaSoli Solar Electric Power Association Solar Energy Industry Association AWS Truepower National Renewable Energy Laboratory
Voluntary Review Committee	SunEdison Aspen Environmental Group Terracon *Idaho National Laboratory *Brigham Young University *Boise State University

*Original Project Partner

wetlands, among others. A *Scorecard* is generated for each site, listing individual and category scores based on technical details such as direct-normal irradiance, slope, and soil type; distance from certain features such as power infrastructure; or proximity with given land types and uses such as agriculture or wildlife. There are five categories of scoring tools, and 16 individual tools. Six of the tools are related to social preferences and distance. The lowest score and weighted average score constitute an additional category, based on direct input from the project Steering Committee. Through the utility score function that maps each score value, users can customize individual tools to match optimized cases for a developer's individual business strategy. As examples, users can set parameters to score given distance ranges higher, set optimal ranges for slope, or identify intersection with certain land types as project killers. The Steering Committee and industry users rated this function as crucial to the project's success because the business cases varied widely among different developers, depending on their size, type, and market niche.

Social Acceptance (6 Tools)								
Agriculture Proximity	10	There was no agricul...	100	20.1% ± 3.9% of p...	67	20.1% ± 3.9% of p...	67
Existing Solar Proximity	10	70.05% ± 4.65% of...	91	There was no existin...	100	72.25% ± 4.55% of...	92
Historic Proximity	10	41.7% ± 4.7% of p...	83	There was no histori...	100	There was no histori...	100
Recreational Proximity	10	41.7% ± 4.7% of people would accept a site built 3.5 mi - 4 mi away from a historic landmark (95% confidence interval).		19.25% ± 5.25% of...	66	19.25% ± 5.25% of...	66
Wetland Proximity	10	The nearest historic landmark is Ryan Ranch, 3.65 mi away.		10.85% ± 2.85% of...	54	10.85% ± 2.85% of...	54
Wildlife Proximity	10	6.55% ± 2.55% of ...	49	6.55% ± 2.55% of ...	49	6.55% ± 2.55% of ...	49
Social Acceptance (average):			78		73		71
Totals (2 Tools)							
Lowest Score		Wildlife Proximity	49	Wildlife Proximity	49	Wildlife Proximity	49
Weighted Average Score		Average	78	Average	73	Average	71

Figure 1. Social Acceptance Tools in *PVMapper*.

As with other proposed energy infrastructure projects, solar PV facilities sometimes engender strong responses from the public that can slow or even result in the rejection of needed approvals from AHJs. As part of the project, the team developed measures of social risk and site preferences based on quantifiable data from a series of three telephone surveys. The surveys elicited attitudes toward utility-scale solar and its proximity or intersect location from given types of land features. In addition, the surveys asked about attitudes toward solar power in general, renewables in relation to other sources of energy such as fossil or nuclear, and attitudes about climate change. The team binned distance and intersect responses at the 95% confidence level to provide quantifiable measures of social risk toward a selected site location. For example, once a site is drawn, a tool (line item in the scoreboard) seeks out the distance to a feature such as historic landmarks, scores it, and reports that "41.7% ± 4.7% of US residents would accept a site built 3.5-4 mi away from a historic landmark. The nearest historic landmark is Ryan Ranch, 3.65 miles away; Score = 83."

PVMapper generates both Summary and Site Detail Reports for the user with a click of the mouse. At-a-glance Summary Reports provide an overall score by highlighting the few areas that cause a site to rate

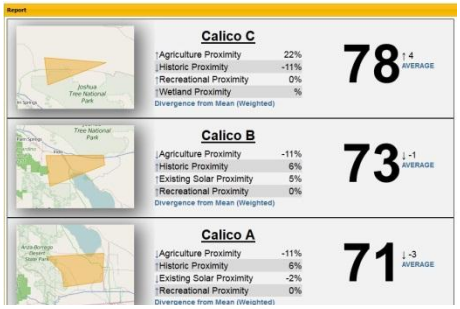

Figure 2. Summary Report from *PVMapper*.

higher or lower than the other(s) by divergence from the mean (weighted); these are useful to the user in quickly comparing sites and possibly refining custom utility scoring functions or redrawing sites. Site Detail Reports provide an image of the site drawn on a map and a detailed rundown of how the site scored for each measure, why it was scored that way, and references for the data sources. The Site Detail Reports are useful to developers for making the business case, both internally to the company and externally to investors or financiers, to down-select to only a few high-potential sites for expensive and lengthy interconnection studies that cost in the hundreds of thousands of dollars for each one.

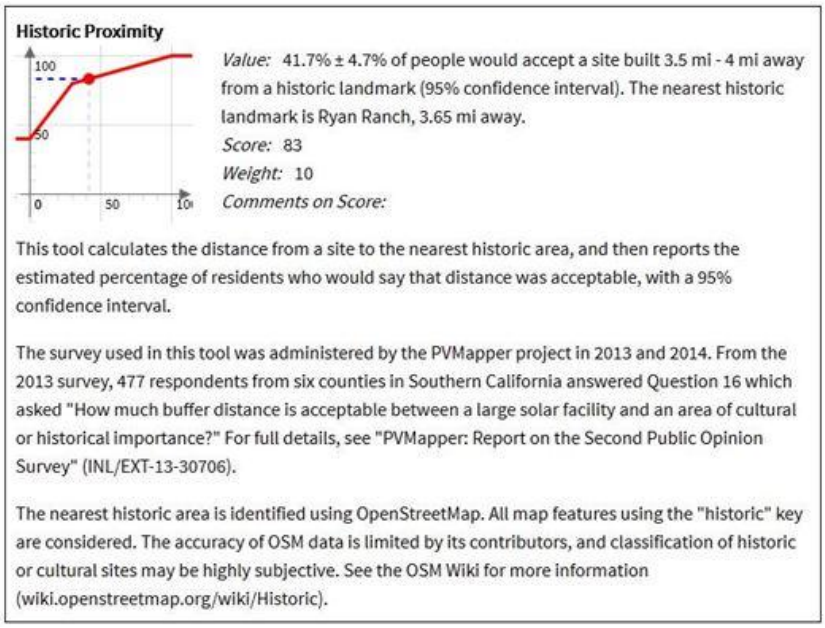

Figure 3. Detailed Report excerpt from *PVMapper*.

As part of the internal business case, the user also has the option of using *Site Designer* to provide an informative and quick design and layout of a specific site based on topography and land cover, which also calculates solar insolation and potential power production. The site layout includes panel orientation and obstructions such as buildings and different species of trees. *Site Designer* is available as an open source download from the *PVMapper*.org website.

To ensure sustainability, the team and industry have formed a User Advisory Board to institute procedures to keep the software updated, add new features if applicable, and to market the software to user groups and software developers. The UAB held its first meeting and successful update of the software, through agreed upon procedures, in October 2014. In addition, team partner Brigham Young University is hosting the software for at least the next five years on its servers.

Finally, the Department of Energy, industry, NGOs, and AHJs should pay close attention to respondents' preferences about utility-scale solar facility location as well as broader attitudes toward solar as an electric generation technology. Surveys were administered annually for three years, using a national sample with oversampling in the southwest where utility-scale PV is most likely to be developed on a wide scale. Oversampled states in areas with high solar potential included Arizona, California, Nevada, and Utah. In general, respondents indicate support for large solar developments in the vicinity of former industrial areas, military bases, privately-owned land, and existing solar facilities. There is consensus against these developments in the vicinity of wildlife habitat, wetlands, and historical or cultural areas. These findings are consistent across question types examining buffer distances between facilities and these features, and when respondents are asked to identify their most and least preferred land features from a list. In contrast, respondents are mixed in their assessment of building near agricultural areas lands, public lands, recreation areas, and residential areas.

Overall, respondents overwhelmingly demonstrate support for solar as a technology and either increasing or maintaining its production. About 7 in 10 respondents are convinced of climate change's seriousness while the remaining do not consider it a problem or rate it as a slight concern. In terms of the factors that respondents consider most important in energy, cost was by far the most important, with job opportunities and where it is produced the least important among seven choices—others included environmental impact, safety, whether it is renewable, and reliability.

The remainder of this report is structured as follows. The next section discusses the software architecture and user customization for *PVMapper* and then *Site Designer*. Data sets and layers are then described. Following those sections, survey and social risk integration in the tool are discussed, paying close attention to items that users need to understand, including limitations and further research needs. The concluding sections detail publications and presentations from project efforts.

Software Architecture[1]

Frameworks

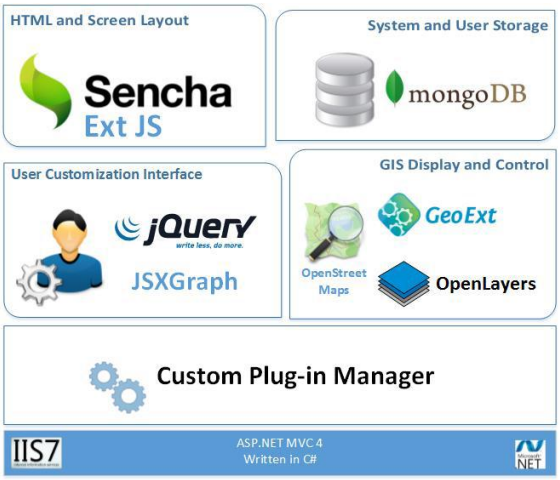

Figure 4. Framework for *PVMapper* Architecture.

PVMapper uses Microsoft's open source MVC 4.0 framework and is coded in C# on the server side. Much of *PVMapper*'s functions run on the client's computer instead of a central server. Similar to most browser-centric applications, the client side uses JavaScript as its programming language. *PVMapper* utilizes several well-established frameworks in JavaScript in order to calculate and render the page to the client. Figure 1 pairs these different frameworks with specific application uses. For example, Ext JS was selected as the HTML and screen layout. In this capacity, Ext JS enables *PVMapper* to essentially become a single page application. Similarly, *PVMapper* depends on the OpenLayers platform to process map data and display it on the screen. OpenLayers is used as a JavaScript GIS engine. While the JavaScript engine is not fully featured when compared to server side systems, it is still very powerful and runs completely on the client. This was a design goal of *PVMapper* to provide user proprietary data security assurance and to allow the system to handle many simultaneous users. Finally, GeoExt is community code that helps in the setup of OpenLayers objects into Sencha Ext JS controlled windows.

Modularity through Plug-ins

Separating the mapping and decision-making functions adheres to well-known software development patterns that require business logic to be organized separately from data processing. This separation simplifies changing business rules (e.g., solar site selection rules) without disturbing code associated with processing map layers or calculating site properties, thus users can change their site selection preferences quickly and easily.

PVMapper's modules and module application programming interface provide the interface between map-based data processing and the *PVMapper* decision analysis structure. Modules are created as part of the initial development effort, but they also can be added at any time in the future, aiding the sustainability of the open

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[1] The section on *PVMapper* and the web-based software is largely reproduced from Peery, B., Alessi, S., Lee, R., Vang, L., Brown, S., Ames, D, and Solan, D. (2014). *Enhancing User Customization through Novel Software Architecture for Utility-Scale Solar Siting Software.* International Environmental Modeling and Software Society (iEMSs) 7th International Congress on Environmental Modeling and Software, San Diego, CA, USA. Available at http://www.iemss.org/sites/iemss2014/papers/iemss2014_submission_292.pdf . The section on *Site Designer* is largely reproduced from Ames, D.P., Pinthong, K., Scott, M., Khattar, R., Solan, D., and Lee, R. (2014). *Open source map-based software for photovoltaic system layout design*. International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software, San Diego, CA, USA. http://www.iemss.org/society/index.php/iemss-2014-proceedings .

source code. The modules are simply algorithms contained in JavaScript. The JavaScript is written to conform to the plug-in architecture of the system following the definitions of the application programming interface. This process is simple enough that someone with very little JavaScript experience could successfully write a module that pulls data from a data source, displays a map on the application map window, and calculates a score based on their data that would be automatically pulled into the scoreboard for each site.

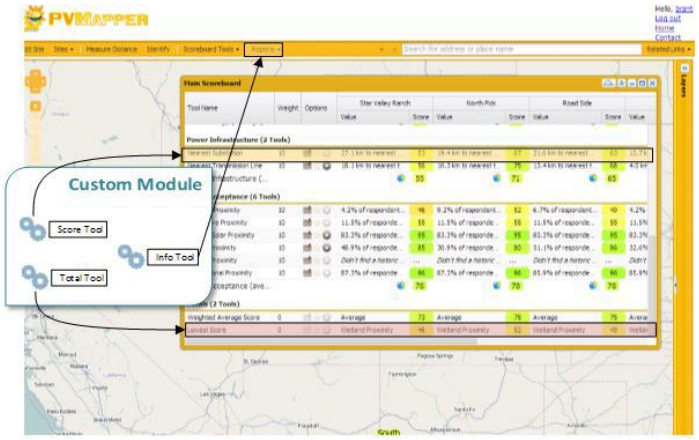


Figure 5. Tool Uses.

Each custom module has one or more tool objects that will interact with the system. Currently, there are three types of tools:

1. ScoreTool, calculates scores for the scoreboard for each site.
2. InfoTool, used to add functionality to the system.
3. TotalTool, used to change the scoreboard summary statistics.

Using one of these types of tools, a programmer can customize almost any part of the system without having to re-write base code. Many of the features in the current version of *PVMapper* are Idaho National Laboratory- and Brigham Young University-developed plug-in modules. Figure 3 provides an example of the minimal code that has to be written to enable a module that will score all sites that would be called "ThisTool" in the scoreboard.

```
1     var mytool: IScoreTool = {
2         title: "ThisTool",
3         description: "My super sweet score thingy",
4         init: null,
5         destroy: null,
6         activate: null,
7         deactivate: null,
8         updateScoreCallback: (score: pvMapper.Score) => {
9             score.updateValue(1);
10        },
11        onSiteChange: null,
12        onScoreAdded: function (context: any, event: EventArg, score: pvMapper.Score) => void {}
13    };
14
```

Figure 6. Example module code (TypeScript).

By virtue of the module manager, the programmer does not have to worry about how the module will interact with the system. The programmer simply has to supply the needed properties and event handlers in the module code and the plug-in framework connects everything automatically. The controller for the *PVMapper* module handles recalculation of values for all user-created sites for each of the activated ScoreTools when needed. Using this technique, a module can be written that uses a unique data set, a unique map display, and unique data calculations. It could also provide derived values from its data in any way it needs to without the constraint of predesigned limits. This framework also allows the module to provide a configuration window for the user to further customize the tool to the user's preferences. For example, the "Distance to a Power Line" tool uses a custom window to ask which type and rating of power line the user would like to use to calculate distance. The tool provides the custom algorithm and the user provides the business logic without modifying code. This modular approach creates an environment where loosely coupled tools can be added to the system throughout

the software's life without having to change base code. This enhances the sustainability of the software, because it is easier to maintain and it can grow easily with new functionality. This open approach invites collaboration by the software users and ensures that *PVMapper* will stay relevant for the years to come.

Site Comparison through Multi-Objective Comparison

Solar site selection is a multi-objective decision analysis problem, because no single site property can be used to determine the best sites for solar development. Levels of solar insolation, access to roads and transmission lines, distance from sensitive wildlife habitat and residential areas, and so forth all influence site selection decisions. Many mathematical techniques (such as optimization, decision trees, simulation, and goal programming) of varying level of mathematical sophistication are available for comparing, contrasting, and ranking such decisions. Over time, *PVMapper* may incorporate multiple techniques; however, to begin, *PVMapper* has adopted a simple-to-understand, straightforward approach that has been used in many areas for decision making.

The approach, which is a type of multi-attribute utility theory[2] and is entitled the Scoring Function Approach, has been used for general engineering decision analysis (Wymore, 1993), automotive energy technology (Burns et al., 2004), natural resource ranking (Yakowitz et al, 1993), environmental quality (French et al., 1998), soil quality assessment (Karlen and Stott, 1994, Andrews and Carroll, 2001), and health care (Ruland, 2002). One educational website[3] states "One of the first applications of multi-attribute utility theory involved a study of alternative locations for a new airport in Mexico City in the early 1970s. The factors that were considered included cost, capacity, access time to the airport, safety, social disruption and noise pollution."

The scoring function multi-objective approach is useful because it is easy for users to follow how numbers are transformed from site properties to dimensionless scores and weighted and rolled up into overall site comparisons. This numerical transparency facilitates interpretation and helps users to have more confidence in the comparisons produced.

This approach allows users to quantify their site preferences through the scoring function shape and location. Then, the scoring function maps the numeric property values that the user has deemed important for site comparison into a score value between 0 and 1. Because all dimensional property values are mapped on a 0 to 1 dimensionless scale and are thereby normalized, properties with widely varying dimensional scales can be compared. The score is then multiplied by a weight assigned by the user and the product summed over all properties included in the overall site comparison scoring hierarchy.

$$Score(Site) = \sum_{x \in S} f(x) \; where \; f(x) = (Weight(x) * ScoreFunction(Sitevalue(x)) \quad (1)$$

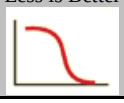
Scoring Functions

Table 2 shows example scoring function weightings and parameterizations. Simple increasing and decreasing curves are used, which are defined by the following six parameters: weight, scoring function, minimum value, target value, maximum value, and slope. The target value is the site parameter value for which the user prefers a middle score of 0.5. The minimum value is the smallest site value where the score reaches a limit of 0 or 1, depending on the scoring function form. The maximum value is the largest site value where the score reaches a

[2] http://wiki.ece.cmu.edu/ddl/index.php/Multiattribute_utility_theory
[3] http://www.hsor.org/what_is_or.cfm?name=mutli-attribute_utility_theory

limit of 0 or 1, depending on the scoring function form. Slope controls how rapidly or gradually the curve increases or decreases. The scoring function's shapes are often described by their name; for example, "Less is Better" is a curve transitioning from 1 to 0, "More is Better" is a curve transition from 0 to 1, "Center is Best" is a bell-shaped curve, and "Small and Large are Better" is an upside down bell-shaped curve. Scoring functions can take on many shapes[4] to represent stakeholder preferences.

Table 2. Example site selection preferences parameters and values.

Decision Category	Weight	Scoring Function	Scoring Function Parameters
Environment: Road Access Distance	40%	Less is Better 	Minimum: 0 miles Target: 2 miles Maximum: 20 miles Slope: -20
Environment: Habitat Buffer	60%	More is Better 	Minimum: 0.5 miles Target: 5 miles Maximum: 15 miles Slope: +20
Energy: Net Annual Energy	70%	More is Better 	Minimum: 30 MkW Target: 35 MkW Maximum: 40 MkW Slope: +20
Energy: Intermittency	30%	More is Better 	Minimum: 35% Target: 55% Maximum: 60% Slope: +20
Social: Public Perception	100%	More is Better 	Minimum: 80% Target: 98% Maximum: 100% Slope: +20

The scoring functions are designed to take a value that is produced by a module tool and translate that value into a dimensionless normalized value between 0 and 1. The functions in Table 2 show how this can be accomplished when the tool provides numeric values. To normalize textual values, *PVMapper* utilizes a user-configurable star rating system illustrated in Figure 7. Default ratings are provided by the module, giving the developer of the tool a way to present sane defaults. The user can reconfigure the ratings to match their preferences, which will affect the value that is used in the selected score function. In this way, a textual value can be transformed into a numeric value that then is normalized through the same method as the other tools.

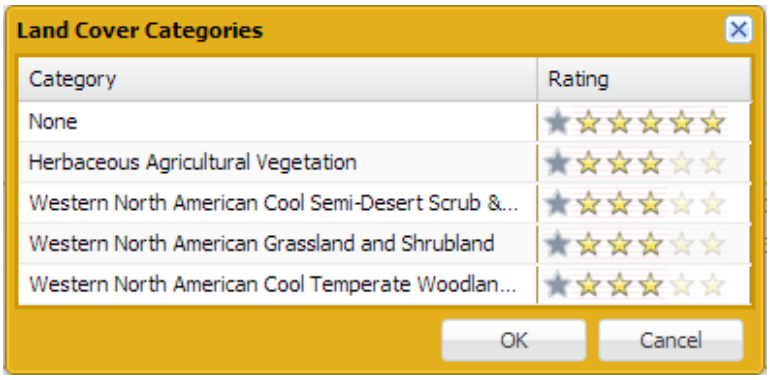


Figure 7. Example star rating in *PVMapper*.

[4] Many additional scoring functions can be used. Wymore (1993) lists 12 types, which include bell shapes, step shapes, and asymptotic forms.

Scoring Calculation Plug-in Architecture

The available scoring functions in the function collection can be modified using *PVMapper*'s plug-in architecture. Using the native strengths of JavaScript to enhance an object through object injection, an author could create an InfoTool plug-in that adds or overrides a function to the system. All object and properties of the utility function system can be overridden by independently created code. By using loosely coupled utility function code, the software is able to morph and grow to fit the exact needs of the user.

The utility functions also are changeable by the user without the need for code. The calculations are run in a parameterized function, which allows the user to modify the parameters to more closely match their desired scenario. For example, if a user wanted a "more is better"-type function to become a "more is better up to a point" (say 30) and then the desirability of the site drops off quickly to 50 but is always somewhat desirable, a function could be modified by the user from the default.

Summary

PVMapper is designed to help utility-scale solar development companies make siting decisions. In addition to a basic GIS capability, *PVMapper* has added an independent site comparison analysis framework. The two components interact to provide users with information on the properties of the sites, as well as scores that represent a convolution of site properties and user-oriented site comparison preferences. These site comparison preferences can consist of a combination of predefined regulatory-oriented and user-oriented preference choices.

In the current and initial version of *PVMapper*, scores are calculated using the scoring function approach. In future versions of *PVMapper*, additional decision analysis tools could be added. The scoring function approach is attractive because of its simplicity and easy user interpretability. An overview of the modular plug-in architecture is given in regard to the user interface, map data aggregation and value extraction, and utility scoring functions and their respective graphical user interfaces. The modular approach creates an excellent opportunity for *PVMapper* to grow with the user's needs. The architecture is open, thus it is more sustainable into the future. *PVMapper* is designed to meet the broad needs of various users who will be interacting with the software in different ways.

Site Designer

Introduction

In this era of growing energy challenges, there is value in simplifying the process of designing, and ultimately implementing, photovoltaic systems. Previous studies have presented methods to estimate solar radiation and potential solar power production. Hofierka (2009) presents a method for the assessment of photovoltaic potential in urban areas using open-source solar radiation tools and a 3-D city model implemented in a GIS. Hofierka (2009) uses the solar radiation model r.sun (Šúri and Hofierka 2004) which is a tool for the estimation of solar radiation for clear-sky and overcast atmospheric conditions. Šúri et al. (2005) developed an application that estimates electricity generation for a chosen PV configuration. It also calculates optimal inclination and orientation of a PV module for a given location. This paper presents the design and development of *PVMapper* Site Designer (PVMSD), an open source geographic information system (GIS) based PV system layout designing software. Unique to PVMSD is the layout design of a PV system combined with optimization of panel orientation and estimation of energy generation. Its GIS interface provides an intuitive and relatively easy method to define parameters such as PV arrangement, nearby objects, weather data and PV panel parameters. Based on these inputs it generates various PV layout alternatives giving an idea of variations in energy production and investment cost.

Methods

PVMSD is a GIS application for PV system layout design; it uses the free and open source DotSpatial tools (Cao and Ames, 2012) for core GIS components. The two functions of PVMSD are site data specification and PV system layout design, the second consisting of rooftop design and site design. Site design tools are provided for building spatial datasets – primarily using the Esri shapefile specification – including a time-zone map, weather stations, buildings, trees, and a raster digital elevation model (DEM). PVMSD can import these datasets or create them (except for the DEM) and overlay them on the same map using a common projection. Spatial outputs show the effective area (no shading area) for PV system layout design. The second major functionality, PV system layout design for site and rooftop, allows a user to specify panel locations for site design. The user can specify a site boundary, or create a custom alignment. Also a user can create a rooftop layout design by identifying the ridge and eaves of a roof as the array boundary and specifying the pitch of roof. Both design types require user to choose panel spacing and size (from a set of prescribed models). PVMSD uses that data, including site data to create panel locations as a point shapefile. Next, PVMSD uses the panel location data to create a PV panel array as a polygon shapefile and a Collada file used for 3D visualization in SketchUp software. A user can verify the designed layout by an overlap check, shading check, and as a three dimensional (3D) visualization with SketchUp. PVMSD will calculate energy production by using SAM Simulation Core (SSC) software development kit (SDK). The PVMSD work flow is shown in Figure 8.

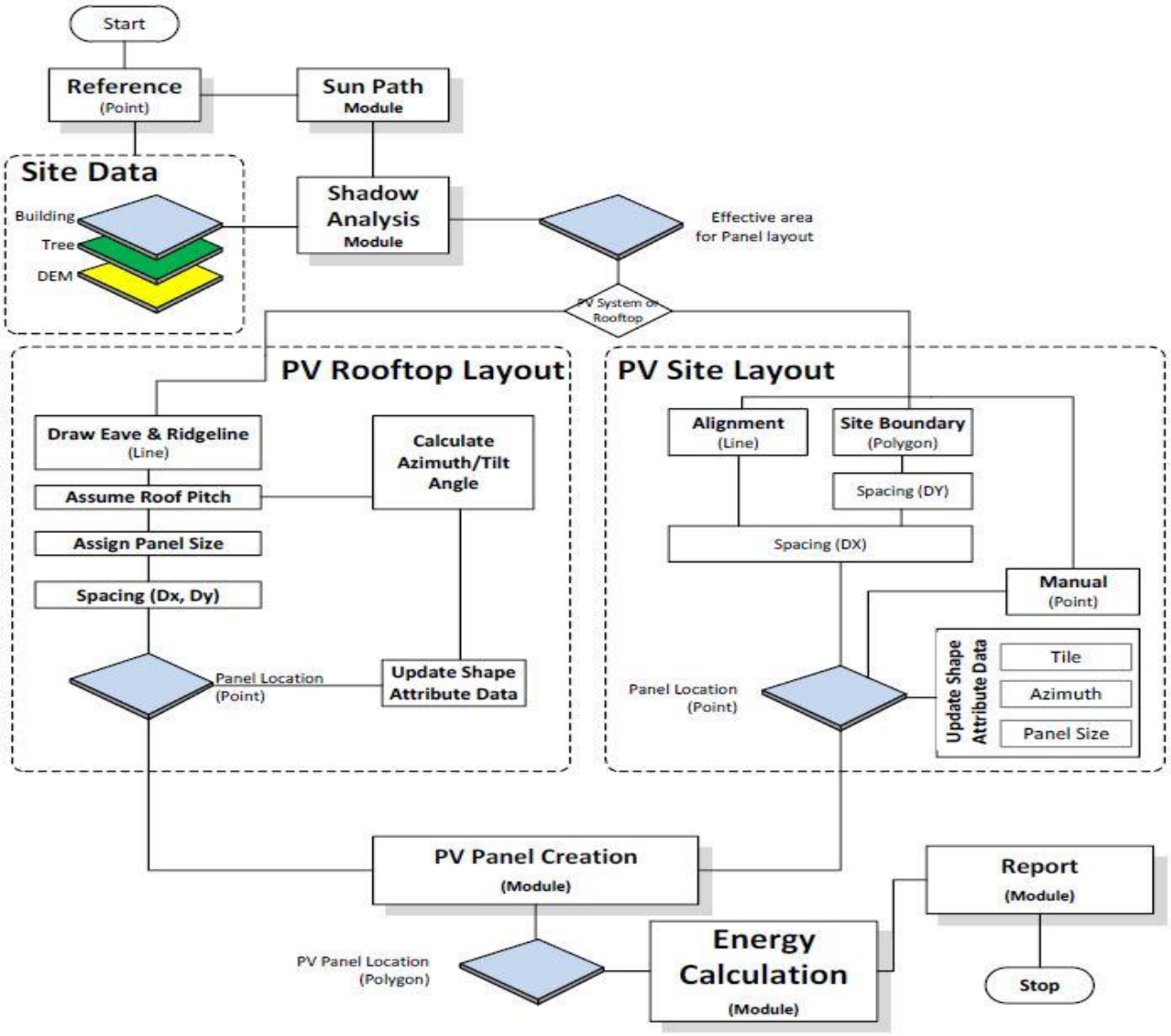


Figure 8. PVMSD Flowchart.

Design Data

The site data dataset refers to a PV layout site location and consists of the following 6 data types: site reference point, time zone, solar obstruction objects, panel locations, PV panels, and a DEM layer, described as follows: 1) The site reference point (latitude and longitude) is used for sun path calculation, time zone selection, and weather station selection. The site reference point can be selected by inputting a location in text or directly clicking on a location on the map. 2) A time zone polygon shapefile is installed with PVMSD and is used to identify the time zone of the current site location. 3) Solar obstruction object data is optional data that can be

loaded from a shapefile or created in the software to indicate locations of buildings and trees around the construction site. 4) The PV panel location dataset is a point shapefile that is created by the PVMSD panel location creation tool and indicates locations of poles or panel center points as defined by a system alignment layer (lines) or site boundary layer (polygon). The 5) PV panel's shapefile creation is similar to that of the PV panel location shapefile (combining the panel location with user indicated panel properties). 6) DEM data is optional data used to define terrain variability. If the user does not have DEM data, PVMSD will assume the site terrain is flat and set site elevation equal to zero at mean sea level.

Sun Path Analysis

A sun path analysis tool allows the user to compute hourly altitude and azimuth angles of the sun throughout year. Solar radiation amounts depend on site location (site reference) and time. The general solar energy of a site can be shown with a solar rose diagram (SRD), as shown in Figure 9. An SRD is a diagram that shows day-long light levels for each combination of the sun's altitude and azimuth. PVMSD displays the SRD as a shapefile with the reference point at the center. The SRD helps a user visualize the direction (altitude and azimuth) from which the site receives the most solar radiation. For example, a south facing panel at 20-30 degrees tilt angle will receive 124 hours of direct sunlight per year.

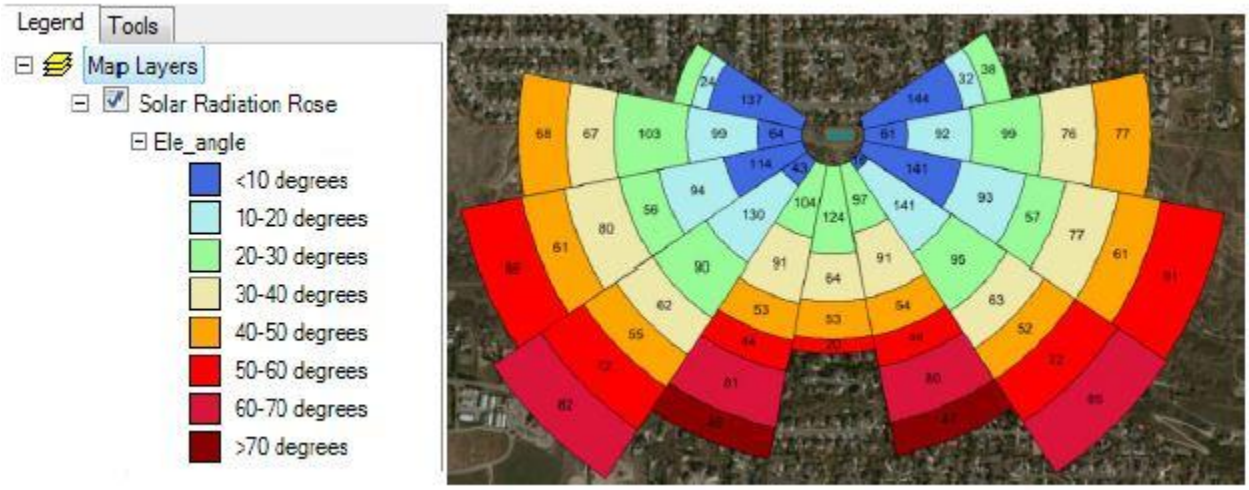


Figure 9. Sun Rose diagram.

Shadow Analysis

A model has been developed to determine the exact shadow projected onto surfaces over the study area. PVMSD can store information about buildings and trees as solar obstruction objects. Buildings only need a height value assigned; however, trees need three important parameters: height, diameter and type of tree. Ten tree shapes were prepared for PVMSD: spreading, pyramidal, round, oval, conical, vase, columnar, open, weeping, and irregular. Each tree type has a total of 20 vertexes on a vertical plane with locations proportional to its diameter. That plane is rotated throughout the shadow calculation process to remain perpendicular to the sun's azimuth.

The equations to calculate the shadow of an obstruction object (Equation 2, Equation 3) depend on location of light source or sun position. PVMSD uses two parameters (altitude angle and azimuth angle) for representing the

sun position as shown in Figure 10. Altitude and azimuth angles are calculated over one year in one hour increments then used as input data for the shadow calculation process.

$$dx = \frac{h \sin(Azi)}{\tan(Alt)} \quad (2)$$

$$dy = \frac{h \cos(Azi)}{\tan(Alt)} \quad (3)$$

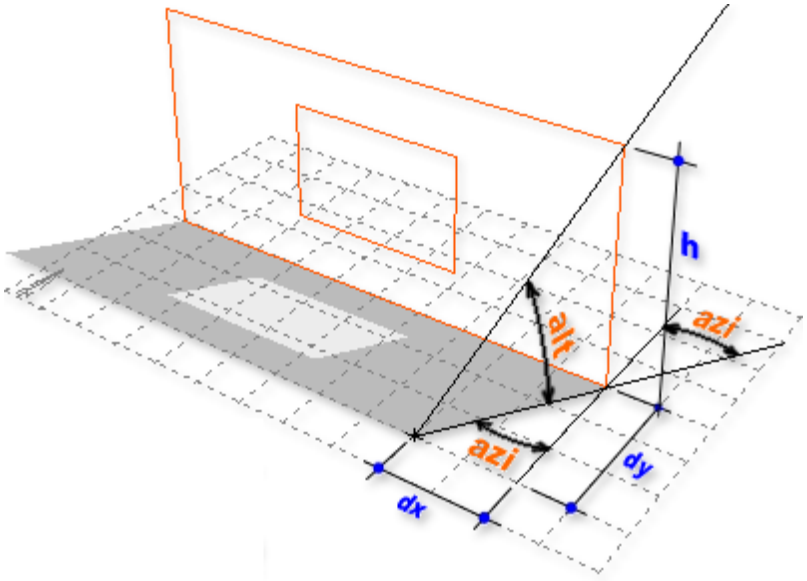


Figure 10. Shadow to building location relationships.

Source: http://wiki.naturalfrequency.com/wiki/Shading/Overshadowing

The calculation outputs are coordinates of vertexes of the solar obstruction object on the reference plane. For example a solar obstruction object having 4 vertexes will result in 4 vertexes per hour of sunlight or 40 vertexes in a day with 10 hours of sun. A boundary is then created so that the area within the boundary contains all vertexes. The convex hull algorithm (Graham 1972) is used to select a list of vertexes that make up the shadow boundary.

Photovoltaic Site Layout Design

For the case when user does not have panel location data, this tool was developed to create a panel location data layer. PVMSD offers two methods to create panel location data. The default method is based on alignment assignment and the optional method is by area assignment. PVMSD uses line shapefiles and panel spacing to create the panel location shapefile. Set spacing is determined not in the x or y directions but along the specified lines. If the user already has pole data, this step can be skipped.

Photovoltaic Rooftop Layout Design

The layout of panels for a rooftop design uses the same data types and shapefiles but the way in which the needed data is retrieved varies from the site designer. The tilt and azimuth of PV panels are determined by the pitch and azimuth of the roof. There are 3 fields of input needed for such calculations: ridge line, eave line, and pitch. To calculate the azimuth of the roof a line is calculated that is the shortest distance between the ridge and the eave line. This line from ridge down to the eave is the azimuth used in later PV panel production calculations. For rooftop design the ridge line and eave line make up a plane. With user indicated horizontal and vertical spacing the panel position layer is created within the plane. Beyond this point both the rooftop and site design processes are the same.

Photovoltaic Panel Properties

With PV panel location known the next step is to select properties of the PV panels. A user populates four fields including the width, height, azimuth, and tilt of each panel. If using the rooftop designer, the azimuth and tilt are instead determined by the azimuth and pitch of the roof. PVMSD then generates the PV panel shape file which contains the panel locations and exactly where the panels are facing and finally how much surface area they have.

Energy Production Calculation

The next step of the process is to use solar site data, location data, and panel properties stored in the attribute tables of the shapefiles created during the site/rooftop creation process for the calculation of the PV power production. If both site designer and rooftop design is used at the same site their energy production is calculated and presented separately. To calculate energy production PVMSD uses Sam SDK. The SAM Simulation Core (SSC) software development kit (SDK) is a collection of developer tools for creating renewable energy system models using the SSC library. The SDK allows user to create your own applications using the SSC library (Gilman 2004).

Results

PVMSD is intended to support efficient and timely design of the layout of a PV system. Tests have shown that one can use the system to build and test a utility scale (5-500 MW) PV project in less than ten minutes. While we have not tested using the software to model existing sites, we anticipate conducting these studies in the near future.

Application Development Results

PVMSD was created for ease of use with a basic GIS interface. The result is a relatively simple layout allowing user to navigate through the PV system design process. Users can click directly on the base-map to select site location, identify buildings and trees, design alignment of PV array, and identify the ridge and eave of roofs. The user can move through each ribbon from left to right as the process progresses. Users familiar with other GIS software such as Esri ArcGIS will be very comfortable using PVMSD as the use of layers, shapefiles, attribute tables, and navigation tools closely compare.

Calculation Results

PVMSD provides several tables, figures, and graphics throughout the creation process and well as the main table of PV production at the final step. Included are: solar-rose diagram as previously described, sun rose table, sun

path calculations table, and PV production table. 1) The sun rose table represents specific values for the number of hours the sun is at each altitude and azimuth for one calendar year. The altitude is in 10 degree increments and the azimuth angles are the 16 points of direction on a compass i.e. N, E, NE, and NNE. 2) Sun path calculations table presents precise solar data for any given calendar day including sunrise and sunset time, sun declination, sunlight duration, approximate atmospheric refraction, along with a large amount of other fields of solar data. 3) The final PVMSD output, PV production table presents the number of kilowatt hours produced monthly by the PV array.

In comparison to PVWatts, a program produced by the National Renewable Energy Laboratory that calculates PV energy production, PVMSD's numbers match almost exactly. This comparison to a reliable resource is important to the success of PVMSD however it must also be tested on an existing site to compare PVMSD calculations with actual production of a major solar production plant for concrete proof of PVMSD's accuracy.

Conclusion

With the continual increase in the necessity of renewable energy, cost continues to be an important factor. *PVMapper* – Site Designer is a new software tool intended to reduce the cost of large scale solar energy production by being able to reduce the time and effort required to design a PV system layout. By including weather station data, solar data, location, terrain, solar obstructions, and the orientation of the PV panels in its calculations, PVMSD provides accurate estimates of energy production. In addition, the common GIS interface provides a simple and user-friendly platform to easily navigate the application. By having resources like PVMSD available, the cost of the design of a major PV system can be decreased making solar energy production more feasible and ultimately decreasing our dependency on non-renewable resources.

Data sets and Layers

PVMapper uses approximately 25 data layers for the mapping and scoring functions of the software. Table 3 lists the category, specific data layer, and its description. The team uses layers that do not require a license and are robust, transparent, and most apt to be maintained. At the same time, it is important to note that data must be maintained and updated for *PVMapper* to continue to be relevant beyond the short-term timeframe extending to five years.

Table 3. Data sources for *PVMapper*.

Category	Data Layer	Description
Base Map	ESRI Street Map	World-wide street map overlaid on shaded relief imagery.
	OpenStreetMap	Free editable map of the world.
	Shaded Relief	Portrays surface elevations as a shaded relief.
	USGS Topo	Electronic version of USGS Topographic Maps at all scales.
	World Imagery	Imagery from various sources at 1 meter or better for many parts of the world.
Tool Data	Direct-Normal Irradiance 10km	Monthly and annual average daily total solar insolation from a clear sky direct normal model.
	Global-Horizontal Irradiance 10km	Monthly and annual average daily total solar insolation from a satellite radiation model.
	Land Administration	Map showing land ownership/management.
	Land Cover	Map of land cover (e.g., vegetation, crop, urban, etc.).
	Power Infrastructure	Map of power lines and substations from OpenStreetMap.
	REPowering Mapper Solar Landfills	Map of EPA landfills suitable for solar energy development.
	Sensitive Species Habitat	Map of habitat essential for conservation of listed species from USFWS.
	Soil Type	USDA/NRCS Soil Survey Geographic showing soil taxonomy.
	Tilted Flat-Plate Irradiance	Monthly and annual average daily total solar insolation for a tilted flat plate array.
	Wetlands	USFWS National Wetlands Inventory - areas classified as wetlands.
Reference	Cities	Cities of the U.S. derived from OpenStreetMap.
	Counties	County boundaries in the U.S. derived from OpenStreetMap.
	Dams	Dams in the U.S. derived from OpenStreetMap.
	EPA Brownfield Sites	Map of EPA Brownfield sites.
	Indian Reservations	
	Railroads	Railroads in the U.S. derived from OpenStreetMap.
	Rivers	Rivers/streams in the U.S. derived from OpenStreetMap.
	Roads	Roads in the U.S. derived from OpenStreetMap.
	Solar Energy Zones	BLM prioritized solar energy zone in the southwestern U.S.
	States	States boundaries of the U.S. derived from OpenStreetMap.

PVMapper GIS Layer Descriptions

Base Maps

Esri Street Map http://services.arcgisonline.com/ArcGIS/rest/services

This worldwide street map presents highway-level data for the world. Street-level data includes the United States; much of Canada; Mexico; Europe; Japan; Australia and New Zealand; India; South America and Central America; Africa; and most of the Middle East. This comprehensive street map includes highways, major roads, minor roads, one-way arrow indicators, railways, water features, administrative boundaries, cities, parks, and landmarks, overlaid on shaded relief imagery for added context. The map also includes building footprints for selected areas. Coverage is provided down to ~1:4k with ~1:1k and ~1:2k data available in select urban areas. The street map was developed by Esri using Esri basemap data, DeLorme basemap layers, U.S. Geological Survey (USGS) elevation data, Intact Forest Landscape (IFL) data for the world; HERE data for Europe, Australia and New Zealand, North America, South America and Central America, Africa, and most of the Middle East; OpenStreetMap contributors for select countries in Africa; MapmyIndia data in India; and select data from the GIS user community. For more information on this map, including the terms of use, visit us online.

OpenStreetMap http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Shaded Relief http://services.arcgisonline.com/ArcGIS/rest/services

This map portrays surface elevation as shaded relief. This map is used as a basemap layer to add shaded relief to other GIS maps, such as the ArcGIS Online World Street Map. It is especially useful in maps that do not contain orthoimagery. The map resolution (cell size) is as follows: 30 Meters for the U.S. 90 Meters for all land areas between 60° north and 56° south latitude. 1 KM resolution above 60° north and 56° south. The shaded relief imagery was developed by Esri using GTOPO30, Shuttle Radar Topography Mission (SRTM), and National Elevation Data (NED) data from the USGS. For more information on this map, including the terms of use, visit us online.

USGS Topo
http://basemap.nationalmap.gov/ArcGIS/rest/services/USGSTopo/MapServer/tile/${z}/${y}/${x}?blankTile=true

The USGS Topo base map service from The National Map is a combination of contours, shaded relief, woodland and urban tint, along with vector layers, such as geographic names, governmental unit boundaries, hydrography, structures, and transportation, to provide a composite topographic base map. Data sources are the National Atlas for small scales, and The National Map for medium to large scales.

World Imagery http://services.arcgisonline.com/ArcGIS/rest/services

World Imagery provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide. The map includes 15m TerraColor imagery at small and mid-scales (591M down to 72k) and 2.5m SPOT Imagery (288k to 72k) for the world, and USGS 15m Landsat imagery for Antarctica. The map features 0.3m resolution imagery in the continental United States and 0.6m resolution imagery in parts of Western Europe from Digital Globe. In other parts of the world, 1 meter resolution imagery is available from GeoEye IKONOS, i-cubed Nationwide Prime, Getmapping, AeroGRID, IGN Spain, and IGP Portugal. Additionally, imagery at different resolutions has been contributed by the GIS User Community. For more information on this map, including the terms of use, visit us online.

Tool Data

Direct-Normal Irradiance 10km http://maps.nrel.gov/

This data provides monthly average and annual average daily total solar resource averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size. This data was developed using the State University of New York/Albany satellite radiation model. This model was developed by Dr. Richard Perez and collaborators at the National Renewable Energy Laboratory and other universities for the U.S. Department of Energy. Specific information about this model can be found in Perez, et al. (2002). This model uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the hourly total insolation (sun and sky) falling on a horizontal surface. Atmospheric water vapor, trace gases, and aerosols are derived from a variety of sources. A modified Bird model is used to calculate clear sky direct normal (DNI). This is then adjusted as a function of the ratio of clear sky global horizontal (GHI) and the model predicted GHI. Where possible, existing ground measurement stations are used to validate the data. Nevertheless, there is uncertainty associated with the meteorological input to the model, since some of the input parameters are not available at a 10km resolution. As a result, it is believed that the modeled values are accurate to approximately 15% of a true measured value within the grid cell. Due to terrain effects and other microclimate influences, the local cloud cover can vary significantly even within a single grid cell. Furthermore, the uncertainty of the modeled estimates increases with distance from reliable measurement sources and with the complexity of the terrain.

Global-Horizontal Irradiance 10km http://maps.nrel.gov/

This data provides monthly average and annual average daily total solar resource averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size. This data was developed using the State University of New York/Albany satellite radiation model. This model was developed by Dr. Richard Perez and collaborators at the National Renewable Energy Laboratory and other universities for the U.S. Department of Energy. Specific information about this model can be found in Perez, et al. (2002). This model uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere. Atmospheric water vapor, trace gases, and aerosols are derived from a variety of sources. Where possible, existing ground measurement stations are used to validate the data. Nevertheless, there is uncertainty associated with the meteorological input to the model, since some of the input parameters are not available at a 10km resolution. As a result, it is believed that the modeled values are accurate to approximately 15% of a true measured value within the grid

cell. Due to terrain effects and other microclimate influences, the local cloud cover can vary significantly even within a single grid cell. Furthermore, the uncertainty of the modeled estimates increases with distance from reliable measurement sources and with the complexity of the terrain.

Land Administration

http://dingo.gapanalysisprogram.com/ArcGIS/rest/services/PADUS/PADUS_owner/MapServer/

The Protected Areas Database of the United States (PAD-US) is a national database of federal and state conservation lands. It contains the most current information about publicly held conservation lands (with conservation measures available) in the U.S. It was first published for delivery to the UNEP-World Conservation Monitoring Center's (WCMC) World Database for Protected Areas (WDPA) in April 2009 by USGS GAP, on behalf of the PAD-US Partnership. Data in this layer includes a combination land owner, land manager, management designation or type, parcel name, GIS Acres and source of geographic information of each mapped land unit.

Land Cover

http://dingo.gapanalysisprogram.com/ArcGIS/rest/services/NAT_LC/1_NVC_class_landuse/MapServer/

This dataset combines the work of several different projects to create a seamless data set for the contiguous United States. Data from four regional Gap Analysis Projects and the LANDFIRE project were combined to make this dataset. In the Northwestern United States (Idaho, Oregon, Montana, Washington and Wyoming) data in this map came from the Northwest Gap Analysis Project. In the Southwestern United States (Colorado, Arizona, Nevada, New Mexico, and Utah) data used in this map came from the Southwest Gap Analysis Project. The data for Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Mississippi, Tennessee, and Virginia came from the Southeast Gap Analysis Project and the California data was generated by the updated California Gap land cover project. The Hawaii Gap Analysis project provided the data for Hawaii. In areas of the county (central U.S., Northeast, Alaska) that have not yet been covered by a regional Gap Analysis Project, data from the Landfire project was used. Similarities in the methods used by these projects made possible the combining of the data they derived into a single seamless coverage. They all used multi-season satellite imagery (Landsat ETM+) from 1999-2001 in conjunction with digital elevation model (DEM) derived datasets (e.g. elevation, landform) to model natural and semi-natural vegetation. Vegetation classes were drawn from NatureServe's Ecological System Classification (Comer et al. 2003) or classes developed by the Hawaii Gap project. Additionally, all of the projects included land use classes that were employed to describe areas where natural vegetation has been altered. In many areas of the country these classes were derived from the National Land Cover Dataset (NLCD). For the majority of classes and, in most areas of the country, a decision tree classifier was used to discriminate ecological system types. In some areas of the country, more manual techniques were used to discriminate small patch systems and systems not distinguishable through topography. The data contains multiple levels of thematic detail. At the most detailed level natural vegetation is represented by NatureServe's Ecological System classification (or in Hawaii the Hawaii GAP classification). These most detailed classifications have been crosswalked to the five highest levels of the National Vegetation Classification (NVC), Class, Subclass, Formation, Division and Macrogroup. This crosswalk allows users to display and analyze the data at different levels of thematic resolution. Developed areas, or areas dominated by introduced species, timber harvest, or water are represented by other classes, collectively referred to as land use classes; these land use classes occur at each of the thematic levels. Six layer files are included in the download packages to assist the user in displaying the data at each of the Thematic levels in ArcGIS.

Power Infrastructure (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

REPowering Mapper Region Solar on Landfills

http://www.epa.gov/renewableenergyland/maps/REPowering_Mapper_Region_Solar_Landfills.kmz

The U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) Center for Program Analysis (CPA) initiated the RE-Powering America's Land Initiative to demonstrate the enormous potential that contaminated lands, landfills, and mine sites provide for developing renewable energy in the United States. EPA developed national level site screening criteria in partnership with the U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL) for wind, solar, biomass, and geothermal facilities. While the screening criteria demonstrate the potential to reuse contaminated land for renewable energy facilities, the criteria and data are neither designed to identify the best sites for developing renewable energy nor all-inclusive. Therefore, more detailed, site-specific analysis is necessary to identify or prioritize the best sites for developing renewable energy facilities based on the technical and economic potential.

Sensitive Wildlife Habitat

https://ecos.fws.gov/arcgis/rest/services/crithab/usfwsCriticalHabitat/MapServer/export

The Critical Habitat portal is an online service for information regarding Threatened and Endangered Species final Critical Habitat designation across the United States. Not all of the critical habitat data designated by the U.S. Fish & Wildlife Service (USFWS) is available from this portal. Critical habitats are areas considered essential for the conservation of a listed species. Federal agencies are required to consult with the U.S. Fish and Wildlife Service on actions they carry out, fund, or authorize to ensure that their actions will not destroy or adversely modify critical habitat. These areas provide notice to the public and land managers of the importance of these areas to the conservation of a listed species. Special protections and/or restrictions are possible in areas where Federal funding, permits, licenses, authorizations, or actions occur or are required.

Soil Type http://services.arcgisonline.com/ArcGIS/rest/services

USDA/NRCS SSURGO: This layer shows the Soil Survey Geographic (SSURGO) by the United States Department of Agriculture's Natural Resources Conservation Service. SSURGO digitizing duplicates the original soil survey maps. This level of mapping is designed for use by landowners, townships, and county natural resource planning and management. The user should be knowledgeable of soils data and their characteristics. The soil units are symbolized by Esri to show the dominant condition for the 12 soil orders according to Soil Taxonomy. Dominant condition was determined by evaluating each of the components in a map unit; the percentage of the component that each soil order represented was accumulated for all the soil orders present in the map unit. The soil order with the highest accumulated percentage is then characterized as the dominant condition for that unit. If a tie was found between soil orders, a "tie-break" rule was applied. The tie-break was based on the

component's "slope_r" attribute value, which represents the Slope Gradient – Representative Value. The slope_r values were accumulated in the same fashion as the soil order attributes, i.e., by soil order, and the order with the lowest slope_r value was selected as dominant because that represented the lower slope value, and therefore we assumed the soils were more likely to be staying in that area or being deposited in that area. USDA/NRCS STATSGO This layer shows the U.S. General Soil Map of general soil association units by the United States Department of Agriculture's Natural Resources Conservation Service. It was developed by the National Cooperative Soil Survey and supersedes the State Soil Geographic (STATSGO) dataset published in 1994. It consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. The soil units are symbolized by Esri to show the dominant condition for the 12 soil orders according to Soil Taxonomy. Dominant condition was determined by evaluating each of the components in a map unit; the percentage of the component that each soil order represented was accumulated for all the soil orders present in the map unit. The soil order with the highest accumulated percentage is then characterized as the dominant condition for that unit. If a tie was found between soil orders, a "tie-break" rule was applied. The tie-break was based on the component's "slope_r" attribute value, which represents the Slope Gradient – Representative Value. The slope_r values were accumulated in the same fashion as the soil order attributes, i.e., by soil order, and the order with the lowest slope_r value was selected as dominant because that represented the lower slope value, and therefore we assumed the soils were more likely to be staying in that area or being deposited in that area. USDA/NRCS GLOBAL SOIL REGIONS This layer shows the Global Soil Regions map by the United States Department of Agriculture's Natural Resources Conservation Service. The data and symbology are based on a reclassification of the FAO-UNESCO Soil Map of the World combined with a soil climate map. The soils data is symbolized to show the distribution of the 12 soil orders according to Soil Taxonomy. For more information on this map, including the terms of use, visit us online.

Tilted flat-plate Irradiance http://maps.nrel.gov/

This data provides monthly average and annual average daily total solar resource averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size. This data was developed using the State University of New York/Albany satellite radiation model. This model was developed by Dr. Richard Perez and collaborators at the National Renewable Energy Laboratory and other universities for the U.S. Department of Energy. Specific information about this model can be found in Perez, et al. (2002). This model uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the hourly total insolation (sun and sky) falling on a horizontal surface. Atmospheric water vapor, trace gases, and aerosols are derived from a variety of sources. A modified Bird model is used to calculate clear sky direct normal (DNI). This is then adjusted as a function of the ratio of clear sky global horizontal (GHI) and the model predicted GHI. Where possible, existing ground measurement stations are used to validate the data. Nevertheless, there is uncertainty associated with the meteorological input to the model, since some of the input parameters are not available at a 10km resolution. As a result, it is believed that the modeled values are accurate to approximately 15% of a true measured value within the grid cell. Due to terrain effects and other microclimate influences, the local cloud cover can vary significantly even within a single grid cell. Furthermore, the uncertainty of the modeled estimates increases with distance from reliable measurement sources and with the complexity of the terrain.

Wetlands http://107.20.228.18/ArcGIS/services/FWS_Wetlands_WMS/mapserver/wmsserver?

The U.S. Fish and Wildlife Service (Service) is the principal Federal agency that provides information to the public on the extent and status of the Nation's wetlands. The Service's strategic plan for our vast national wetland data holdings is focused on the development, updating, and dissemination of wetlands data and information to Service resource managers and the public. The development of the Wetlands Master Geodatabase is in direct response to the need to integrate digital map data with other resource information to produce timely and relevant management and decision support tools. Wetlands provide a multitude of ecological, economic and social benefits. They provide habitat for fish, wildlife and a variety of plants. Wetlands are nurseries for many saltwater and freshwater fishes and shellfish of commercial and recreational importance. Wetlands are also important landscape features because they hold and slowly release flood water and snow melt, recharge groundwater, act as filters to cleanse water of impurities, recycle nutrients, and provide recreation and wildlife viewing opportunities for millions of people.

Reference Layers

Cities (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Counties (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Dams (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many

more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

EPA Brownfield Sites http://mapsdb.nrel.gov/geoserver/geothermal_prospector/wms?

This layer is hosted by NREL on the Geothermal Prospector GIS tool (http://maps.nrel.gov/gt_prospector). Brownfields are real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant. Cleaning up and reinvesting in these properties protects the environment, reduces blight, and takes development pressures off green spaces and working lands.

Indian Reservations http://www.openstreetmap.org/

Railroads (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Rivers (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Roads (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Solar Energy Zones

http://solarmapper.anl.gov/ArcGIS/rest/services/SEZ_Map_Service_SDE/MapServer

Maps and information about the 17 Solar PEIS solar energy zones (SEZs). These are the priority development areas for utility-scale solar energy facilities identified in the Solar PEIS Record of Decision.

An SEZ is defined by the BLM as an area well-suited for utility-scale production of solar energy where BLM will prioritize solar energy and associated transmission infrastructure development. A discussion of the criteria used to identify SEZs is provided in Chapter 2 (Volume 1 of the Final Solar PEIS). Modifications to the originally proposed SEZs and SEZs dropped from further consideration are described in Chapters 8 through 13 of the Final Solar PEIS (Volumes 2 through 5).

States (OpenStreetMap) http://www.openstreetmap.org/

Collaborative project inspired by Wikipedia to create a free editable map of the world. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world. OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the user diaries, community blogs, and the OSM Foundation website.

Public Preferences and Integration of Social Risk in *PVMapper*

A main soft cost challenge for utility-scale PV developers is to move from site identification and selection through permitting and initial construction. As with any industrial infrastructure, public concerns are often raised in regard to the project's location and its intersection or proximity with certain land uses or features. *PVMapper* addresses these concerns early in the process when developers are comparing many options for sites, which may not be near each other or even within the same state or region. In a scientific manner, *PVMapper* quantitatively delineates public preferences in regard to a site the software user draws as a polygon, using the most up-to-date and publicly available datasets and layers. This provides a very robust check for a site by scoring the site using several social risk tools. The user is provided very clear flags as to whether a site may run into significant opposition due to its location. The user can then use the information to re-draw the site or optimize in the location, choose another location, or plan to use more extensive human resources down the line to engage the public. The tool is designed to avoid situations where developers did not account for public preferences in regard to land uses and land features, which the team has documented in some test cases [Calico reference].

Because studies are very inconsistent and based on limited data in regard to public opposition to energy infrastructure, the team chose to administer a set of three surveys over three years to provide the most robust treatment of quantifiable data to date, specifically focusing on alignment between public attitudes, industry input as to how it would use the data, and mappable features and data availability. Most studies are based on overall support for solar in large samples (REFS), or at the opposite end of the spectrum there are those that rely on very small samples in regard to specific projects already in the queue, and they measure distance from respondents' property (REFS). In contrast, the *PVMapper* team undertook first of its kind surveys that measured distance or intersects based on the location of hypothetical proposed facilities from the land features, not from the respondents own property. The surveys were national but the team did oversample in areas where projects have been proposed or are most likely so that respondents would likely be more educated or affected personally from utility-scale PV projects. Also, the team administered more general questions to measure support for utility-scale solar "near where you live" and "within your county", and those responses compared to the distance responses indicated no social gap effect where respondents claimed to support proximate projects but then provided distances that were not congruent. In other words, overall responses were consistent between the general questions about proximity and providing distance measures from or on specific land features. This approach is groundbreaking because it provides quantifiable and reliable data to inform developers about public preferences in regard to sites that have yet to be optioned, rather than relying upon limited expert opinion, anecdotal feedback, or guesses.

PVMapper uses distance tools to integrate social risk into decision making based on proximity and respondents stated distance preferences from different types of land features. It also uses intersect preferences—the overlay of a proposed facility sited on a specific land feature—as part of its suite. From the three surveys and their oversamples, the distance tools use 95% confidence levels in regard to distance ranges from specific land features. The 95% confidence intervals indicate the probability that the data being examined—distance from a given land use or feature—is contained within the range. The 95% confidence levels are given as approval preferences in ranges as a percentage plus or minus an error range as percentage, such as 60.7% ± 6.1%, for a tool based on the type of land feature and response rate. Therefore, the 95% confidence intervals and ranges

will not be the same for each tool nor within a given tool, depending on if the distance is substantially different. Users must be aware that the distances stated are based on responses and data analysis, and respondents distance perceptions against actual distance measurements have yet to be scientifically addressed in any study to date. What the data does demonstrate clearly is the public's comfort or discomfort in regard to proximity for certain land uses. Users should also note, based on the response rates for specific questions that those who support solar were more likely to answer social tool-related questions than non-supporters, that the ranges given for the 95% confidence levels should be regarded as on the more optimistic side—the minimum acceptable distances are slightly more likely to have come from those who strongly support solar. Therefore, these distances should be very much regarded as minimum distances, and anything closer is not a conservative estimate. In sum, the social tools are meant to inform users but are neither warranted nor meant to be used as hard and fast rules. Instead, they provide a very robust check in regard to intersects and proximity to certain land features. The team has published journal articles on some of the more general findings from Years 1 and 2 of the survey (Carlisle, Kane, Solan, and Joe 2014; Carlisle, Kane, Solan, and Joe forthcoming 2015), and it is submitting an article for publication that rolls up the most significant findings from all three survey years.

PVMapper Publications and Presentations

Peer-Reviewed Publications

Joe, J., Hendrickson, K., Wong, M., Kane, S., Carlisle, J., Solan, D., Ames, D., Beazer, R., and Koehler, D. 2015. "The relationship of political efficacy and familiarity with attitudes toward transmission lines". (Under review, *Journal of Environmental Psychology*).

Carlisle, J., Kane. S., Solan, D., Bowman, M., and Joe, J. 2015."Public attitudes regarding large-scale solar energy development in the U.S. (revised and resubmitted) *Renewable and Sustainable Energy Reviews*.

Carlisle, J.E., Kane, S.L., Solan, D., and Joe, J. 2014. "Support for solar energy: examining sense of place and utility-scale development in California. *Energy Research and Social Science* 3, 124-130.

Ames, D.P., Pinthong, K., Scott, M., Khattar, R., Solan, D., and Lee, R. 2014. "Open source map-based software for photovoltaic system layout design". International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software, San Diego, CA, USA. http://www.iemss.org/society/index.php/iemss-2014-proceedings.

Peery, B., Alessi, R.S., Lee, R.D, Vang, L., Brown, S., and Solan, D. 2014. "Enhancing user customization through novel software architecture for utility-scale solar siting software." International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software, San Diego, CA, US. http://www.iemss.org/society/index.php/iemss-2014-proceedings.

Other Publications

Kuiper, J., Ames, D., Koehler, D., Lee, R., & Quinby, T. (April 2013). Web-Based Mapping Applications for Solar Energy Project Planning. Conference Proceedings, American Solar Energy Society SOLAR 2013: Boulder, CO.

Presentations

Ames, D.P., Pinthong, K., Scott, M., Khattar, R., Solan, D., and Lee, R. *Open source map-based software for photovoltaic system layout design.* Paper presented at the International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software; San Diego, CA, June 2014.

Bowman, M., Carlisle, J., and Kane, S. *Public Attitudes Towards Large-Scale Solar Energy Development in the U.S.* Presentation at the International Symposium on Society and Resource Management; Estes Park, CO, June 2013.

Carlisle, J., Kane, S., Solan, D., and Joe, J. *Place Attachment and Public Support for Solar Development in Southern California.* Paper presented at the Western Political Science Association; Seattle, WA, April 2014. *__Winner of *Charles Redd Award* for Best Paper on the Politics of the American West.__

Carlisle, J., Bowman, M., and Kane, S. *Public Attitudes towards Large-Scale Solar Energy Development in the U.S.* Presentation at the Workshop on Energy, Transportation, and Water Infrastructure: Policy and Social Perspectives; Ames, IA, July 2013.

Carlisle, J., and Bowman, M., 2013, *Green on Green: Public Perceptions of Solar Energy Siting in the U.S. Southwest.* Presentation at the Western Political Science Association Annual Meeting; Hollywood, CA, March 2013.

Kane, S., Carlisle, J., and Bowman, M., 2013, *Solar Energy Development and Land-Use Preferences.* Presentation at the International Symposium on Society and Resource Management; Estes Park, CO, June 2013.

Kuiper, J., Ames, D., Koehler, D., Lee, R., & Quinby, T. *Web-Based Mapping Applications for Solar Energy Project Planning.* Paper presented at the American Solar Energy Society's SOLAR 2013 conference; Baltimore, MD, April 2013.

Peery, B., Alessi, R.S., Lee, R.D, Vang, L., Brown, S., and Solan, D. *Enhancing user customization through novel software architecture for utility-scale solar siting software.* Paper presented at the International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software; San Diego, CA, June 2014.

Solan, D., Ames, D., and Lee, R. *PVMapper: An Open-Source GIS Application for Utility-Scale PV Project Siting.* Poster presentation at the SunShot Grand Challenge Summit; Anaheim, CA, May 2014.

Solan, D. *Development of an Open-Source GIS Utility Scale Siting Tool.* Presentation at Edison Electric Institute's & National Rural Electric Cooperative Association's Utility Siting Workshop; Madison, WI, October 2012.

Solan, D. *The Development of Government-Funded Open Source Software Decision Support Tools and Databases: Lessons Learned from Energy Infrastructure Siting Projects.* Paper presented at the Northeast Conference on Public Administration; November, Newark, DE, November 2013.

References

Ames, D.P., Pinthong, K., Scott, M., Khattar, R., Solan, D., and Lee, R. (2014). Open source map-based software for photovoltaic system layout design. International Environmental Modeling and Software Society, 7th International Congress on Environmental Modeling and Software, San Diego, CA, USA. http://www.iemss.org/sites/iemss2014/papers/iemss2014_submission_152.pdf .

Andrews, S.S., Carroll, C.R., 2001. Designing a decision tool for sustainable agroecosystem management: Soil quality assessment of a poultry litter management case study. Ecol. Applic. 11 (6), 1573–1585.

Burns, J.W., Cors, T., Knight, B., and Thelen, B., 2004. Evaluating advanced automotive energy technologies: A multivariate contribution metric. Intl. J. of Energy Technol. and Policy 2(3), 262–271.

Cao, Y. and Ames, D.P. 2012, A Strategy for Integrating Open Source GIS Toolboxes for Geoprocessing and Data Analysis, Proceedings of the International Congress on Environmental Modelling and Software, Sixth Biennial Meeting, Leipzig, Germany, July 2012. http://www.iemss.org/society/index.php/iemss-2012-proceedings. ISBN: 978-88-9035-742-8. R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.), pp. 1505-1511.

Carlisle, J.E., Kane, S.L., Solan, D., and Joe, J. 2014. Support for solar energy: examining sense of place and utility-scale development in California. Energy Research and Social Science 3(2014), 124-130.

Carlisle, J.E., Kane, S.L., Solan, D., and Joe, J. forthcoming 2015. Public attitudes regarding large-scale solar energy development in the U.S.. Renewable and Sustainable Energy Reviews (forthcoming).

Environmental Protection Agency, United States. 2012. Solar energy, Energy & climate change. http://www.epa.gov/region1/eco/energy/re_solar.html (last accessed 11.3.14) Gilman, P., 2004. SAM simulation core SDK, System Advisor Model (SAM). https://sam.nrel.gov/content/sam-simulation-core-sdk (last accessed 7.3.14)

French, S., Simpson, L., Atherton, E., Belton, V., Dawes, R., Edwards, W., Hämäläinen, R., Larichev, O., Lootsma, A., Pearman, A., and Vlek, C., 1998. Problem formulation for Journal of Multi-Criteria Decision Analysis: report of a workshop, Journal of Multi-Criteria Decision Analysis 7(5): 242–262.

Graham, R. L., 1972, An efficient algorithm for determining the convex hull of a finite planar set, Information processing letters, 1, 132-133.

Hofierka, J., 2009. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools, Renewable energy, 34, 2206-2214.

Karlen, D.L., Stott, D.E., 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. SSSA, Inc., Madison, Wisconsin, USA.

Marion B., Anderberg M., 2000, PVWATTS-an online performance calculator for grid-connected PV systems, Proceedings of the solar conference, American solar energy society, American institute of architects, 119-124.

Peery, B., Alessi, S., Lee, R., Vang, L., Brown, S., Ames, D, and Solan, D., 2014. *Enhancing User Customization through Novel Software Architecture for Utility-Scale Solar Siting Software.* International Environmental Modeling and Software Society (iEMSs) 7th International Congress on Environmental Modeling and Software, San Diego, CA, USA. http://www.iemss.org/sites/iemss2014/papers/iemss2014_submission_292.pdf

Ruland, C., 2002. Patient Preferences in Health Care Decision Making. http://people.dbmi.columbia.edu/~cmr7001/sdm/html/definitions.htm#multi.

Šúri, M., Hofierka, J., 2004, A New GIS-based Solar Radiation Model and Its Application to Photovoltaic Assessments, Transactions in GIS, 8, 175–190.

Šúri, M., Huld, T., Dunlop E, 2005 PV-GIS: a web-based solar radiation database for the calculation of PV potential in Europe, International journal of sustainable energy, 24, 55-67

Wymore, W., 1993. Model-Based Systems Engineering, CRC Press, Boca Raton.

Yakowitz, D.S., Stone, J.J., Lane, L.J., Heilman, P., Masterson, J., Abolt, J., Imam, B., 1993. A decision support system for evaluating the effects of alternative farm management systems on water quality and economics. Water Sci. Technol. 28 (3-5), 47-54.