

# Open Source Map Based Software for Photovoltaic System Layout Design

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**Abstract:** This paper presents the design and development of an open source map-based software package, PVMapper – Site Designer (PVMSD), for designing large scale photovoltaic (PV) systems. PVMSD uses numerous factors to reflect the characteristics of landscape specific to the area including site location, time zone, sun path, nearby weather station data, tilt and azimuth angle of the solar panels, and nearby objects such as trees and buildings that may obstruct or cast shadows over the panels. PVMSD enables the design of solar panel layout, assesses solar shade that could reduce the efficiency of the layout design, and calculates the optimal energy production obtained from the layout design. The program uses the System Advisor Model (SAM) software development kit (SDK) together with data from nearby weather stations to compute the potential power production of a specific layout design. Power production estimates from PVMSD were validated and compared with PVWATTS – PV software developed by the National Renewable Energy Laboratory. Results are shown to be comparable with PVWATTS, while the map-based interface and design tools of PVMSD provide extensive additional capabilities not in PVWATTS. Potential applications of PVMSD are also discussed.

Keywords: photovoltaic; design; solar energy; geographical information system

**Software availability:** PVMapper – Site Designer software and documentation can be accessed at <https://pvdesktop.codeplex.com/>. Source code and additional documentation for PVMSD can be accessed at the PVMSD code repository website <https://pvdesktop.codeplex.com> and its source code are released under the New Berkeley Software Distribution (BSD) License which allows for liberal reuse of the software and code.

## 1. 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.

## **2. 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 1.

### **2.1. 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.

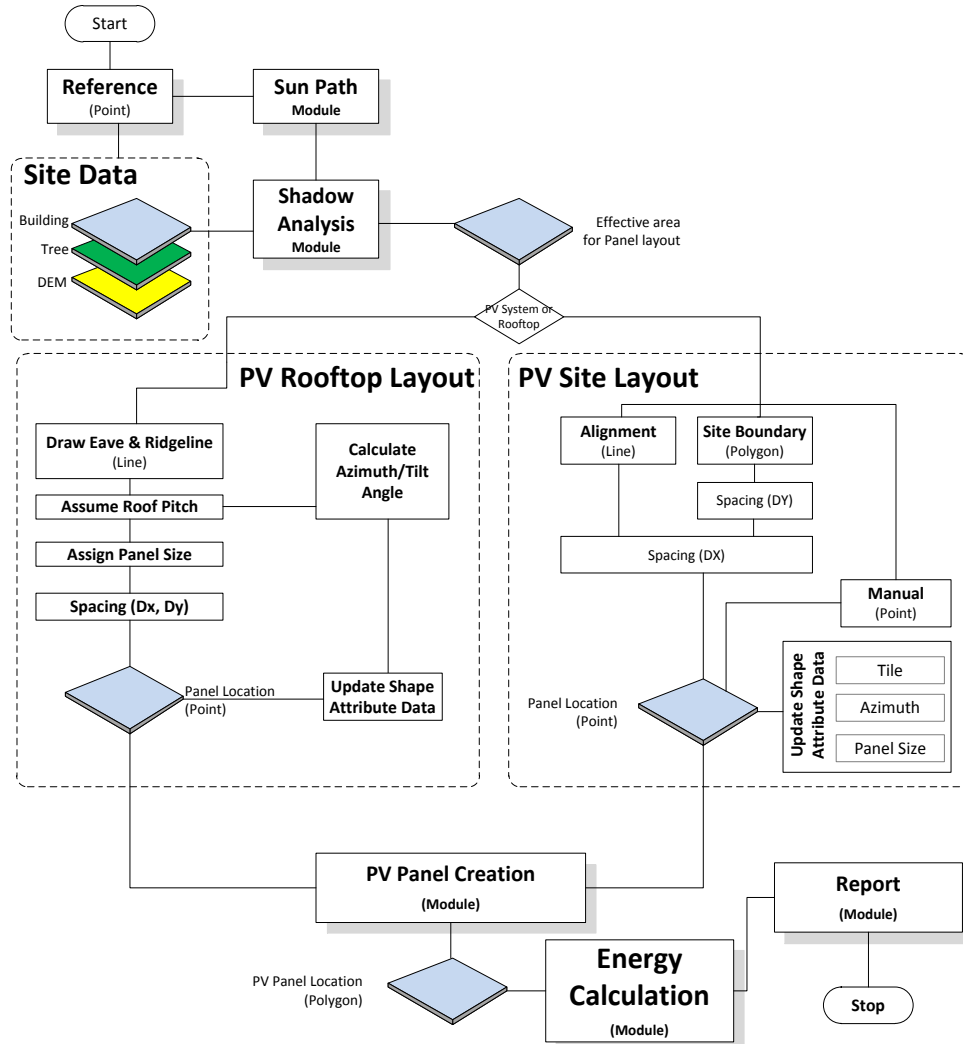


Figure 1 – PVMSD Flowchart Diagram

## 2.2. 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 1. 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, in Figure 2, a south facing panel at 20-30 degrees tilt angle will receive 124 hours of direct sunlight per year.

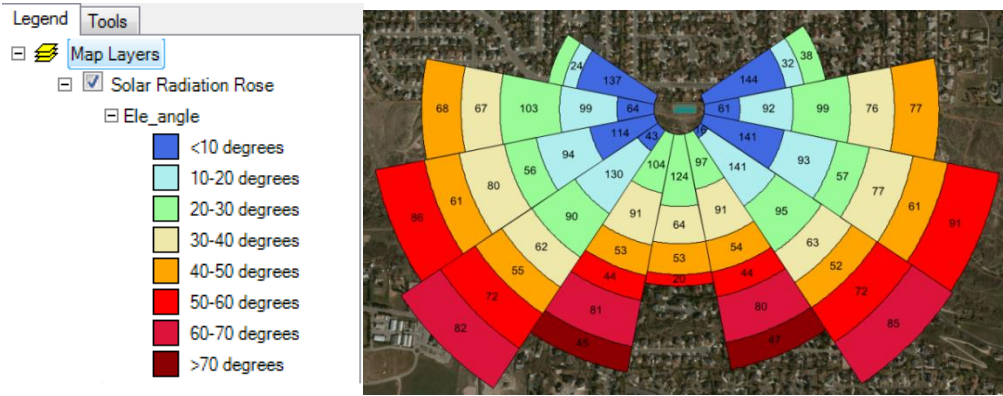


Figure 2 – Sun Rose Diagram

### 2.3. 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 1, Equation 2) 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 3. Altitude and azimuth angles are calculated over one year in one hour increments then used as input data for the shadow calculation process.

$$dx = \frac{h \sin(Azi)}{\tan(Alt)} \tag{1}$$

$$dy = \frac{h \cos(Azi)}{\tan(Alt)} \tag{2}$$

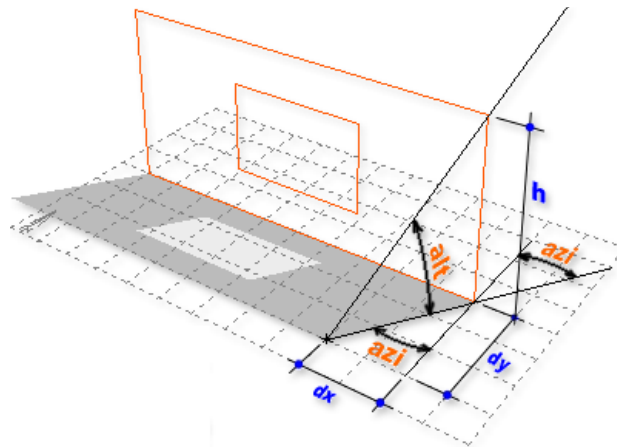


Figure 3 - Shadow to building location relationships  
 Figure from: <http://wiki.naturalfrequency.com/wiki/Shading/Overshadowing>

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.

#### 2.4.1 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 (Figure 4) 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.



Figure 4 - Panel position alignment process

#### 2.4.2 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.

### 2.5 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.

## 2.7 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).

## 3. 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.

### 3.1. 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. See Figure 5.

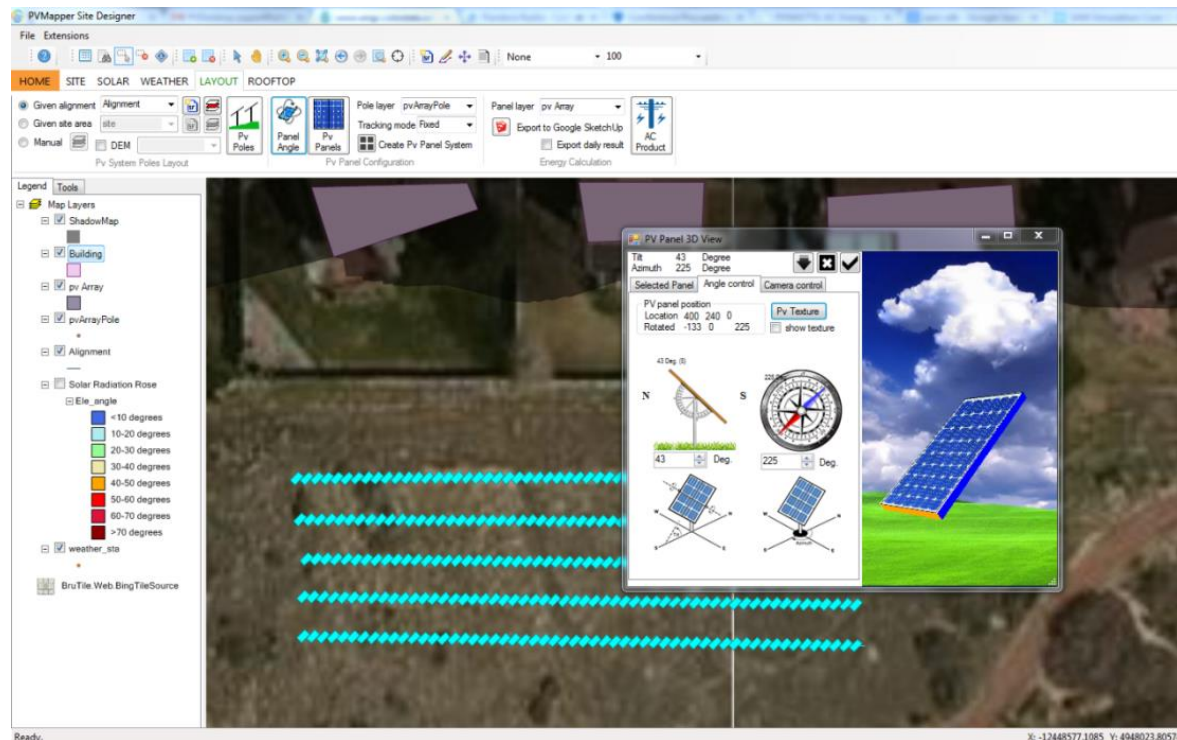


Figure 5 - PVMapper - Site Planner interface



### 3.2. 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 as seen in Figure 6. 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.

### 4. 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.

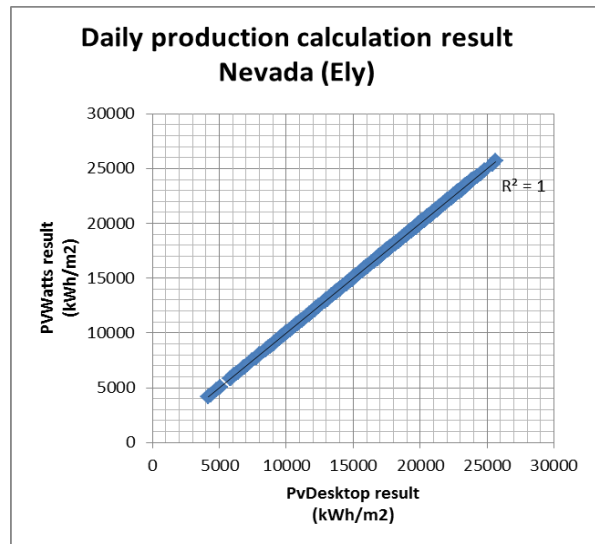


Figure 6: PVMSD Calculations compared with PVWatts

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