SunSPoT Data and Calculations

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SunSPoT (the APVI Solar Potential Tool) is an online tool for estimating the potential for electricity generation from PV on building roofs in Australian cities. The tool accounts for solar radiation and weather at the site; PV system area, tilt, orientation; and shading from nearby buildings and vegetation.

SunSPoT was developed by the Australian PV Institute (APVI) as part of the APVI's Solar Mapping research project, and funded by the Australian Renewable Energy Agency.

The data behind SunSPoT were generated as follows:

1. Three types of digital surfaces models (DSMs)[1] (3D building models, XYZ vegetation points and 1m ESRI Grids), supplied by geospatial company AAM, were used to model the CBDs of Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra. Details of the data used are provided below.
2. These DSMs were used as input to ESRI's ArcGIS tool to evaluate surface tilt, orientation and the annual and monthly levels of solar insolation falling on each $1m^2$ unit of surface.
3. Insolation values output by the ArcGIS model were calibrated[2] to Typical Meteorological Year (TMY) weather files for each of the capital cities and against estimates of insolation at every 1 degree tilt and orientation from NREL's System Advisor Model (SAM), as described in detail below.

Please Note: SunSPoT has been developed as a preliminary information tool and is no substitute for an on-site assessment performed by a certified professional. The results from the tool are only an estimate and may be inaccurate due to incomplete or out of date building models and GIS data.

[1] Digital surface models provide information about the earth's surface and the height of objects. 3D building models and vegetation surface models have been used in this work. The ESRI Grid is a GIS raster file format developed by ESRI, used to define geographic grid space.

[2] Calibration was required in order to obtain good agreement NREL's well-tested SAM model and measured PV data.

Data Sources:

3D multipatch models of buildings, XYZ vegetation points and 1m ESRI ground digital elevation grids for the CBD's of Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra were supplied by AAM. The collection year of the associated AAM data sets are reported in Table 1.

Table 1: Collection year of datasets provided by AAM

Location	AAM 3D Building Model	AAM XYZ Vegetation Points
Adelaide	2009	2008
Brisbane	2011	2008
Canberra	2009	2009
Melbourne	2012	2010
Perth	2009	2011
Sydney	2013	2008/2007
UNSW	2009	2008/2007
Waverley	2009	2008/2007

Typical Meteorological Year (TMY) weather files for each capital city in Australia were sourced from the U.S. Department of Energy, Energy Simulation Software Weather Data webpage.

Calculation of Insolation, Tilt and Orientation:

ESRI's ArcGIS platform was used as the processing tool to calculate the level of insolation, tilt and orientation for each unit of surface. The resolution of the analysis was undertaken at 1 data point per square metre. Insolation was calculated using the "Points Solar Radiation" tool within ArcGIS's Spatial Analyst package.

Calibration of ESRI insolation output:

As the ESRI ArcGIS tool uses either a simplified uniform or overcast sky model with constant values for some radiation parameters throughout the year, calibration was required in order to obtain good agreement with NREL's Solar Advisor Model, which uses a typical meteorological year weather file to better reflect variation of solar radiation. SAM has been extensively tested by NREL, and was also validated for this project against measured output from PV systems in Sydney and Brisbane. The following parameters were adjusted from the default settings, as they were determined to be the combination of parameters that resulted in the best correlation with insolation calculated using SAM:

1. Time configuration : Whole year with monthly interval – Year: 2013
2. Create outputs for each interval: Checked
3. Radiation parameters – Diffuse proportion: 0.2
4. Radiation parameters – Transmittivity: 0.4

Monthly insolation outputs from ArcGIS at each 1° of tilt (between 0 and 90°) and orientation (between 0 and 360°) for an unshaded surface were tested against the expected level of insolation as calculated using SAM. The results indicated that a linear correction could be applied to the ArcGIS estimate of insolation, resulting in a Pearson correlation coefficient of 0.991 between the linear corrected ArcGIS results and insolation as reported by SAM. Detailed analysis and validation of the method are documented in: *J. K. Copper, A. G. Bruce (2014), Validation of methods used in the APVI Solar Potential Tool, Asia Pacific Solar Research Conference, Sydney, December 2014.* DOI: 10.13140/RG.2.1.2040.5925

Calculation of DC System Size (kW):

The calculation of the DC system size within the SunSPoT Tool is based on the area of the user drawn polygon/rectangle. The area of the user drawn polygon/rectangle is automatically calculated via the Mapbox[3] API rectangle and polygon drawing tools. This area is the horizontal projection (A_{flat}) of the area available on the roof. The projected roof surface area (A_{proj}) is calculated using Eqn. 1 where β is the tilt angle of the roof surface, calculated as the average tilt angle of the data points that lie within the user drawn polygon/rectangle.

The DC system size is then calculated using Eqn. 2 by multiplying the projected roof surface area (m^2) by a DC size factor (DC_{factor}) in W/m^2. This number is rounded down to the nearest multiple of modules of a chosen power rating. The chosen module power used in the SunSPoT Tool is 250 W (or 0.25 kW as used in Eqn. 2), which corresponds to a typical module sold in Australia for rooftop applications, with dimensions 1m x 1.6m.

$$A_{proj} = \frac{A_{flat}}{\cos \beta} \quad \text{Eqn. 1}$$

$$DC_{size} = round\ multiple(\frac{A_{proj} \times DC_{factor}}{1000}, 0.25) \quad \text{Eqn. 2}$$

For a flush mounted PV system the DC size factor is 156.25 W/m^2 (250W divided by $1.6m^2$). For a rack mounted PV system the DC size factor is calculated by considering:

5. The surface orientation and tilt angle
6. The user defined PV system orientation and tilt angle
7. The minimum distance required between the rows of rack mounted PV, to ensure that no shading occurs between the hours of 9am and 3pm on the Winter solstice for roughly north orientated PV systems and between the hours of 7am and 5pm on the Summer solstice for roughly south orientated PV systems.

A detailed description of the DC size factor method for rack mounted PV systems can be found in: *J. K. Copper, A. B. Sproul, A. G. Bruce (2016), A Method to Calculate Array Spacing and Potential System Size of Photovoltaic Arrays in the Urban Environment using Vector Analysis, Applied Energy 161:11-23 January 2016.* DOI: 10.1016/j.apenergy.2015.09.074

[3] Mapbox is the mapping platform used to produce the user interface and visualisations, and to integrate the data and visual layers for the SunSPoT Tool.

Calculation of monthly and annual insolation for the rack mounted configuration ($kWh/m^2/day$):

The calculation of the monthly and annual insolation in $kWh/m^2/day$ is dependent on whether the user choses the default "Flush mounted" system or investigates a "Rack mounted" system. Under the default "Flush mounted" option the insolation values are calculated simply as the average value of the parameters contained within the data points that lie within the user drawn polygon/rectangle. For the "Rack mounted" option Eqn. 3 is used to calculate the monthly and annual insolation parameters, where:

- $Dot\ point\ Insolation_{tdefault}$ is the average of the insolation parameters contained within the dot points that lie within the user drawn polygon/rectangle
- $SAM\ Insolation_{tdefailt}$ are the values of insolation at the default tilt and orientation retrieved from a lookup table of SAM outputs pre-calculated for the city under investigation at every 1° of tilt and orientation
- $SAM\ Insolation_{tuser}$ are the values of insolation from the SAM lookup table for the tilt and orientation defined by the user for the rack mounted PV system.

$$Insolation_t = \frac{Dot\ point\ Insolation_{t_{default}}}{SAM\ Insolation_{t_{default}}} \times SAM\ Insolation_{t_{user}} \qquad \text{Eqn. 3}$$

Calculation of monthly and annual AC output (kWh per annum):

The calculation of the AC output for any time period (t) is expressed by Eqn. 4, where the $Derate_{factor}$ is a fixed value equal to 0.77. This value was chosen as it is the default derate factor applied in NREL's SAM PVWatts module, which will provide a reasonable estimate of derating factor for modelling energy production from the majority of PV systems.

$$AC\ Power_t = DC_{size} \times Insolation_t \times t \times Derate_{factor} \qquad \text{Eqn. 4}$$

Calculation of the annual $CO_{2\text{-e}}$ offset (tonnes of CO_2 per annum):

The calculation of the annual $CO_{2\text{-e}}$ offset in kg is expressed by Eqn. 5, where the $Emissions_{factor}$ for each region is taken from Table 5 (Indirect emission factors for consumption of purchased electricity from the grid) of the National Greenhouse Account Factors – July 2013 report. The negative 0.045 factor in Eqn. 5 accounts for embodied carbon emissions from the manufacture, installation, operation and decomissioning of the PV system. The value of 45g $CO_{2\text{-e}}$/kWh of electricity produced was sourced from the PV LCA Harmonization Project results found in Hsu et al. (2012), which standardised the results from 13 life cycle assessment studies of PV systems with crystalline photovoltaic modules, assuming system lifetimes of 30 years.

$$CO_{2_t} = AC\ Power_t \times (Emissions_{factor} - 0.045) \qquad \text{Eqn. 5}$$

Table 2: Emission factors for use in APVI solar map sourced from the National Greenhouse Accounts report

Table 5: Indirect (scope 2) emission factors for consumption of purchased electricity from the grid

State, Territory or grid description	Emission factor kg CO_2-e/kWh
New South Wales and Australian Capital Territory	0.87
Victoria	1.17
Queensland	0.82
South Australia	0.62
South West Interconnected System in Western Australia	0.78
Tasmania	0.20
Northern Territory	0.69

Sources: National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Schedule 1)