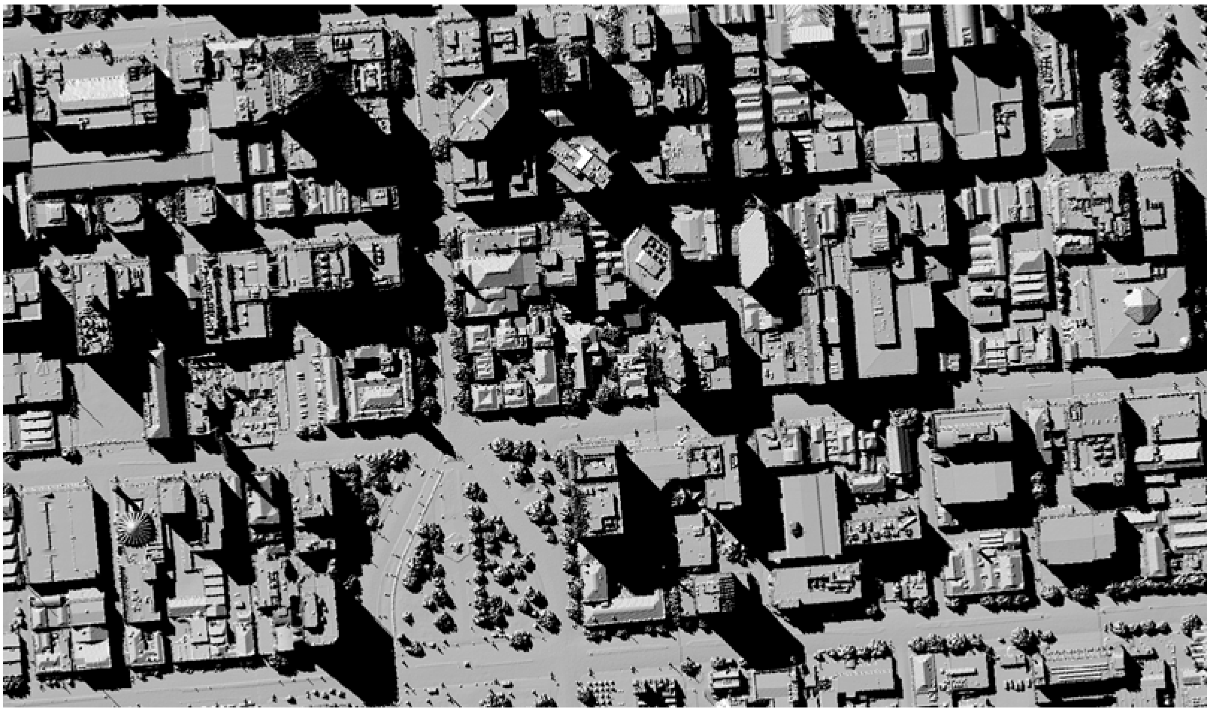
Spatial Analysis of Solar Potential in Adelaide

Prepared for the Australian PV Institute

by Jessie Copper, Mike Roberts and Anna Bruce, UNSW Sydney – April 2018



Key Findings

Our analysis shows that Adelaide CBD could generate more than 25% of its electricity needs from its own rooftops, with the installation of 129 MW of solar on CBD rooftops.

Using the average results from our 4 methods:

- There is potential to install 129MW of solar photovoltaics on CBD rooftops
- There is potential for 32 times the existing PV deployment
- 43% of the total roof area could accommodate 516,000 solar panels
- this could generate 174GWh annually
  - meeting 26% of the CBD energy demand
  - supplying the equivalent of 34,000 SA households
  - avoiding 77,000 tonnes of CO_2 emissions
- CBD electricity customers could save up to an estimated $54 million per year

Analysis of 3 case study buildings in Adelaide's CBD suggests potential solar PV capacities of:

350kW on the Centrepoint Building,

840 kW on the Central Market

and 1300 kW on the central building of Adelaide Convention Centre.

Executive Summary

Introduction

There is significant potential for rooftop solar PV in Australia. Rooftop solar PV is a key energy technology because it is leading the transition to consumer uptake of low-carbon demand-side energy technologies, which are providing new opportunities for consumer engagement and new clean energy business models to emerge. However, there is a lack of good information in the public domain about the potential for rooftop solar to contribute to low-carbon electricity generation in Australia's cities. This type of information is important for policymakers and planners, and to encourage public support for rooftop solar.

This research uses the data and methodologies behind the APVI Solar Potential Tool (SunSPoT), developed by researchers at UNSW, to estimate the Solar Potential in the Adelaide CBD. The report includes:

1. An assessment of PV Potential in Adelaide CBD
2. An estimate of the potential impact of rooftop PV on local electricity consumption and emissions
3. Identification of rooftops with the largest PV potential (area available) in the CBD
4. Three case studies of PV Potential on landmark buildings in Adelaide

Summary Results: Adelaide CBD

The useable area suitable for PV deployment across Adelaide's CBD was calculated using two different methods and two different datasets. The calculation takes account of the orientation and slope of the rooftop, as well as the average insolation and the degree of shading.

Conservative and average results are presented in the body of the report. The average of 2 methodologies applied to 2 different datasets suggests that 43% of the total roof area in the CBD is suitable for PV deployment. This area could accommodate over 516,000 solar PV panels, with a generating capacity of 129 MW.

There is an estimated 4.0MW of PV capacity currently installed on Adelaide CBD rooftops, which represents only 3% of the estimated potential capacity.

Annually, this could supply 174 GWh of electricity, approximately 26% of the total electricity demand of the CBD (higher than most other Australian capitals), or the annual electricity demand of 33820 average South Australian households.

The equivalent CO_2 emission savings are 77 kilotonnes per year.

The financial benefits of solar PV are highly specific to characteristics of the building and of the electricity demand being met, as well as to contemporary electricity retail market conditions. However, based on typical small business tariffs, we estimate the potential savings on electricity bills to be in the region of $54million per year.

The rooftops with the largest PV potential in Adelaide have been mapped (Figure 1 below, with more detailed images in Appendix B – Detailed Maps of Rooftops with Large Solar Potential

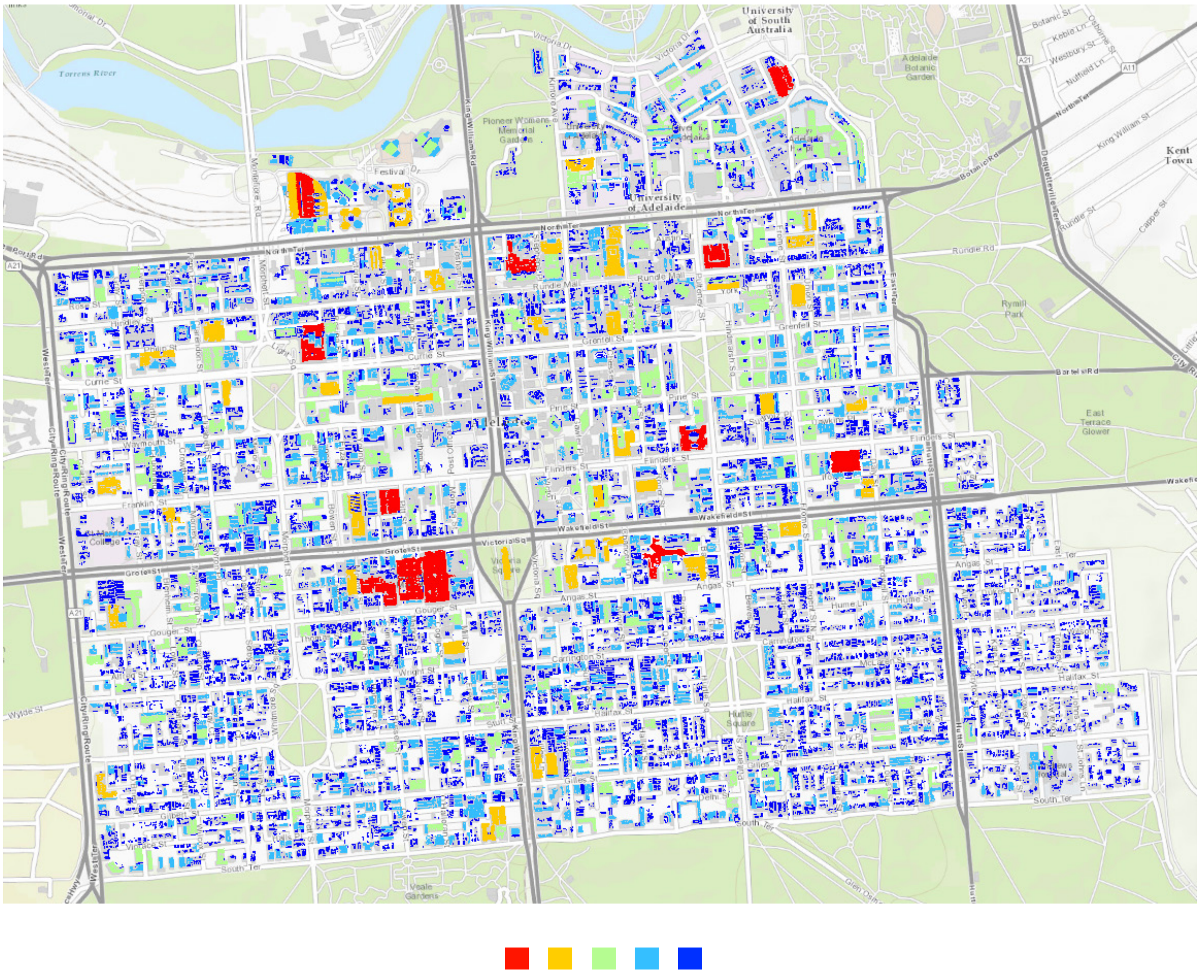


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Figure 1: Rooftops with Largest PV Potential in Adelaide CBD

Summary Results: Cities Compared

Table 1 shows a summary of our results from other Australian capital cities. Although differences in the data available in different jurisdictions mean that direct comparisons should be used cautiously, the results suggest that Adelaide has the potential to supply the greatest proportion of its CBD load from rooftop solar.

Table 1: State Capitals Compared

	Usable rooftop area	Potential Installed Capacity (MW)	Potential Annual Generation (GWh)	Estimated % of Load
Brisbane	45%	188	241	11%
Melbourne	38%	461	548	11%
Sydney	40%	619	777	22%
Canberra	50%	68	98	17%
Adelaide	43%	129	174	26%

Summary Results: Case Studies

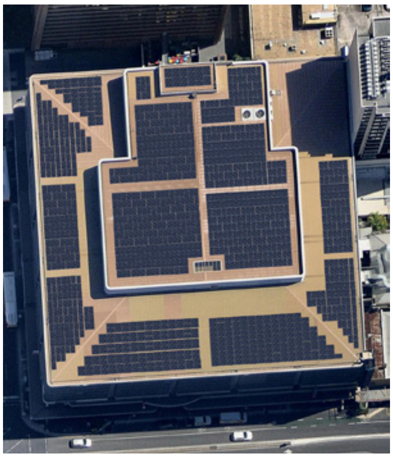
Case studies of specific landmark buildings - the Centrepoint Building, Central Market and the central building of Adelaide Convention Centre - were carried out.

Table 2 presents the potential array capacity, expected annual energy production and estimated carbon offsets for each system. The potential 2.4MW of PV generating capacity that could be accommodated on these three buildings could save an estimated 1.5 kilotonnes of carbon emissions each year and could supply the equivalent of 637 households.

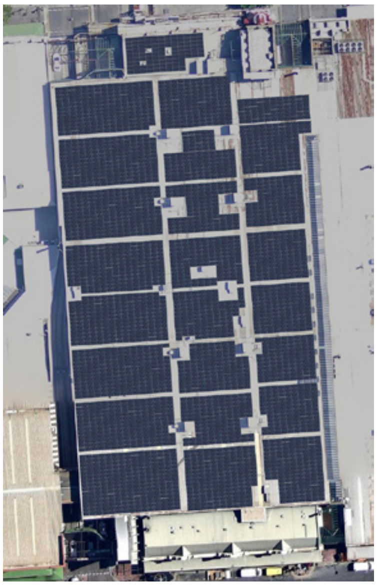
Table 2: Carbon offset and household energy equivalents

Site	PV Capacity (kW_{peak})	Expected Annual Generation (MWh)	Emissions Offset (Tonnes CO_2-e / year)	Average ACT household equivalent
Centrepoint Building	348	452	201	88
Central Market	837	1120	499	218
Convention Centre - Central Building	1303	1705	759	331
Totals	**2487**	**3277**	**1458**	**637**

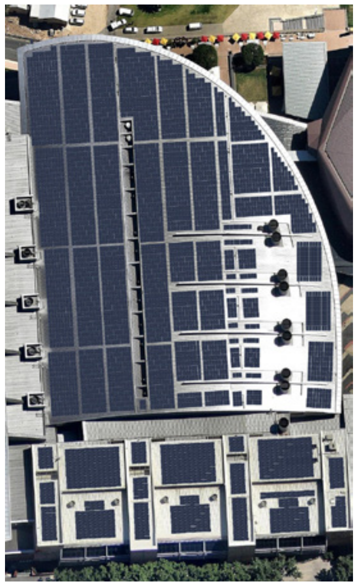
The potential PV arrays for each building are shown in Figure 2, and in Figures 20 - 22 of the main report.



(i) Centrepoint Building



(ii) Central Market



(iii) Convention Centre

Figure 2 : Potential PV arrays on Case Study buildings

Contents

Introduction

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This research uses the data and methodologies behind the APVI Solar Potential Tool http://pv-map.apvi.org.au/potential, developed by researchers at UNSW, to estimate the Solar Potential in the Adelaide CBD. The report includes:

1. An assessment of PV Potential in Adelaide CBD
2. An estimate of the potential impact of rooftop PV on local electricity consumption and emissions
3. Identification of rooftops with the largest PV potential (area available) in the CBD
4. Three case studies of PV Potential on landmark buildings in Adelaide

Introduction to the Solar Potential Tool

The APVI Solar Potential Tool (SunSPoT) is an online tool to allow electricity consumers, solar businesses, planners and policymakers to estimate the potential for electricity generation from PV on building roofs. The tool accounts for solar radiation and weather at the site; PV system area, tilt, orientation; and shading from nearby buildings and vegetation.

Figure 3 APVI Solar potential Map (SunSPoT)

At a city level, an insolation heatmap layer (Figure 4b) allows identification of the best roofs, while the shadow layer (Figure 4c) allows the user to locate an unshaded area on a rooftop. The tool allows users to select any building within the mapped area, outline a specific roof area and automatically generate an estimate of potential annual electricity generation, financial savings and emissions offset from installing solar PV.

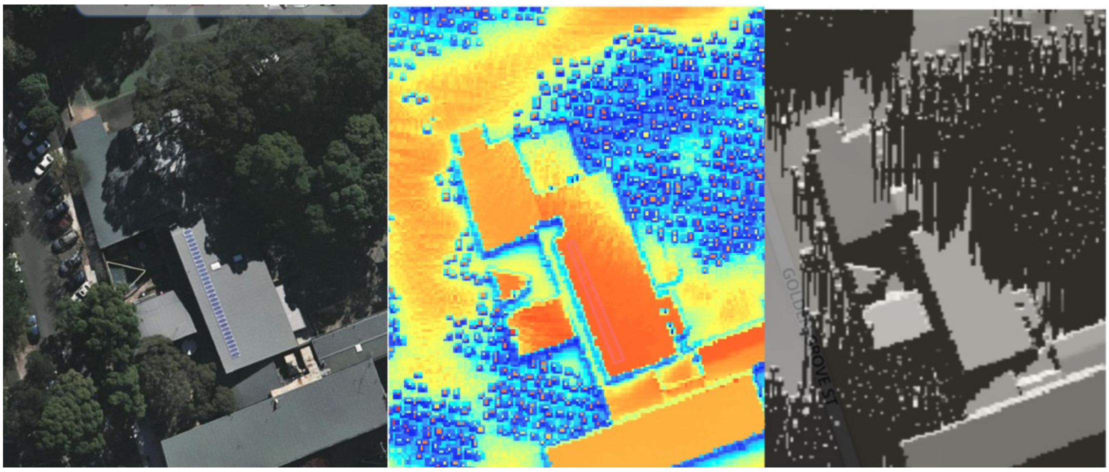

Figure 4: (a) Aerial photograph (b) Insolation heat map, (c) Winter shadow layer

The data behind the APVI SPT 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 buildings and vegetation in the areas covered by the map.
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).

This project expanded the data and methodologies behind the Solar Potential in order to estimate the Solar Potential in the Adelaide CBD region.

[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.

Assessment of the PV Potential in Adelaide CBD

This section of the report details the methodology and the results of the geospatial analysis of PV potential across Adelaide CBD.

The assessment of the PV potential in Adelaide's CBD, expanded on the initial work undertaken for the Adelaide region of APVI's SPT. The analysis made use of the following data sources:

1. The three sources of input DSMs data from AAM; and
2. City of Adelaide LiDAR data – 2010 dataset sourced from the City of Adelaide

The general steps in the methodology are illustrated in Figure 5. To test the sensitivity of the estimated PV potential two input data sources and two rooftop suitability methods were assessed. The two input data sources used to calculate the tilt, aspect, solar insolation and determine suitable roof planes were 1) the DSM and 3D building models from AAM and 2) the 2010 City of Adelaide LiDAR data covering Adelaide CBD. The two methods utilised to determine suitable rooftops were 1) based on a minimal level of surface insolation and 2) NREL's PV rooftop suitability method based on hillshade and surface orientation. Both methods also required a minimum contiguous surface area of $10m^2$ for a roof plane to be determined suitable. This limit was defined to ensure a minimum 1.5kW PV system for any plane defined as suitable.

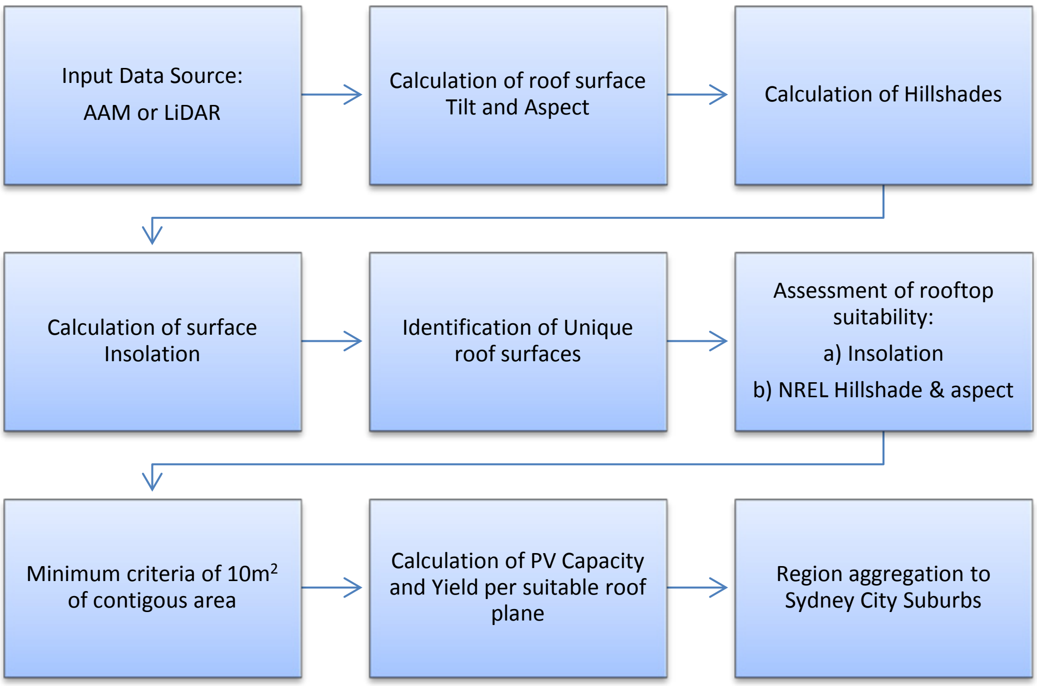

Figure 5: Major process steps for the calculation of rooftop PV potential

Method 1: Insolation Limit

The first method utilised to determine suitable roof planes was based on a minimum level of insolation. The minimum value was set at an annual average insolation of **3.99 $kWh/m^2/day$**. This limit was calculated as 80% of the expected level of annual insolation for a horizontal surface in

Adelaide, calculated as 4.98 $kWh/m^2/day$, using the default TMY weather file for Adelaide contained within the National Renewable Energy Laboratories (NREL) System Advisor Model (SAM). This limit was applied to the Solar Insolation Heat Map which was developed and calibrated as part of the APVI SPT methodology [1, 2].

Figure 6 presents an example application of the insolation limit in practice, displaying an aerial image (left), the insolation heat map (centre) and the classified insolation layer (right); classified as either above (white) or below (black) the insolation limit. As for each method in this report, a $10m^2$ contiguous area was required for a roof plane to be determined suitable. Figure 7 presents the roof planes that were identified to meet both the insolation and $10m^2$ contiguous area criteria for the example presented in Figure 6.

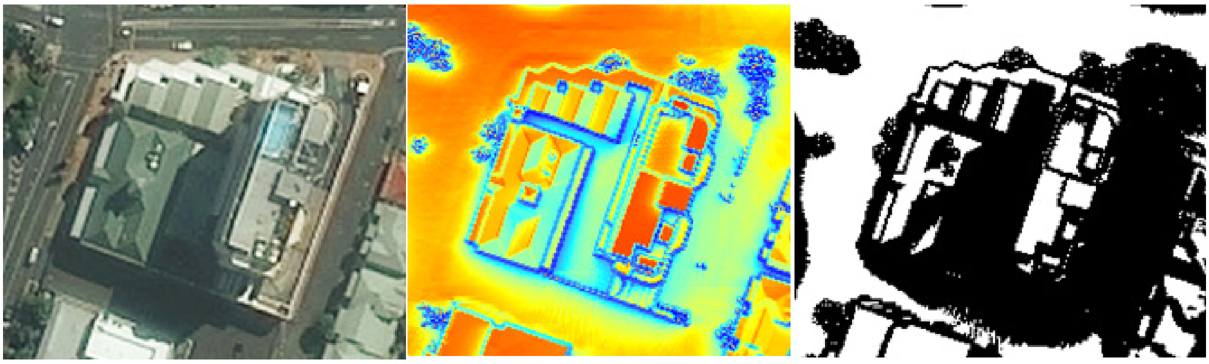

Figure 6: Example application of the Insolation limit. Areal image (left); Insolation heat map (centre); and classified Insolation layer (right)

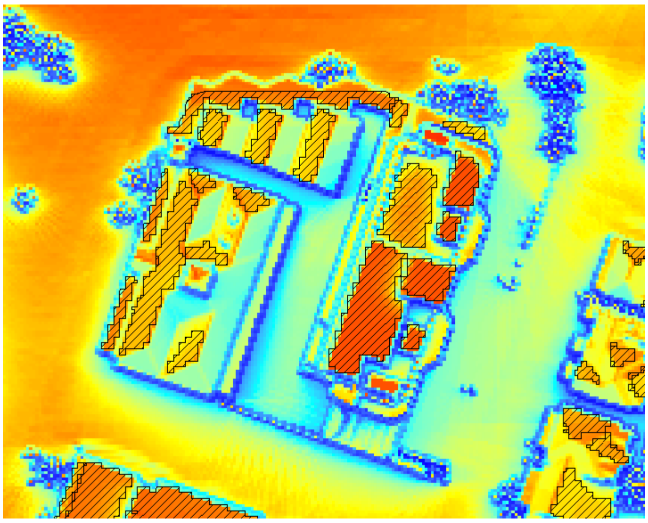

Figure 7: Example application of suitable planes (hatched areas) by the Insolation limit method.

Method 2: NREL's Hillshade and Orientation

The second method utilised to determine suitable roof planes was the method developed by NREL to assess the technical potential for rooftop PV in the United States [3]. NREL's method makes use of ArcGIS's hillshade function to determine the number of hours of sunlight received on each $1m^2$ of roof surface, across 4 representative days within a year i.e. the winter and summer solstices and the two equinoxes; similar to the shadow layers of APVI's SPT as illustrated in Figure 4.

To determine which areas met the shading criteria, NREL's method defines that roof surfaces must meet a minimum number of hours of sunlight. The limit for any location can be determined by calculating the number of hours a rooftop would need to be in sunlight to produce 80% of the energy produced by an unshaded system of the same orientation [3]. For the location of Adelaide the value was determined to be 13.69 hours across the 4 representative days.

In addition to the hillshade limit, NREL's method also excludes roof planes based on orientation. In NREL's method all roof planes facing northwest through northeast (i.e. 292.5 - 67.5 degrees for northern hemisphere locations) were considered unsuitable for PV. For southern hemisphere locations the equivalent exclusion would be orientations southeast through southwest (i.e. 112.5 – 247.5 degrees) as per Figure 8. Again, as for each method in this report, a 10m^2 contiguous area is also required by NREL's methodology.

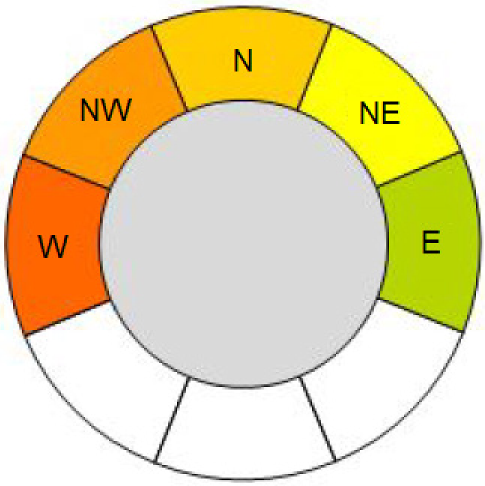

Figure 8: Rooftop azimuths included in final suitable planes for the Southern Hemisphere

Figure 9 presents an example application of NREL's hillshade and orientation limit in practice. For this particular example there is reasonable agreement between the surfaces determined as suitable for PV deployment from the two methods i.e. Figure 7 vs Figure 9. This is not always the case as evident in the example presented in Figure 10, which illustrates how the insolation limit method can define roof planes orientated southeast through southwest as suitable planes if the annual insolation meets the limit requirement.

Figure 9: Example application of the hillshade limit (left) with the suitable planes overlayed (right)

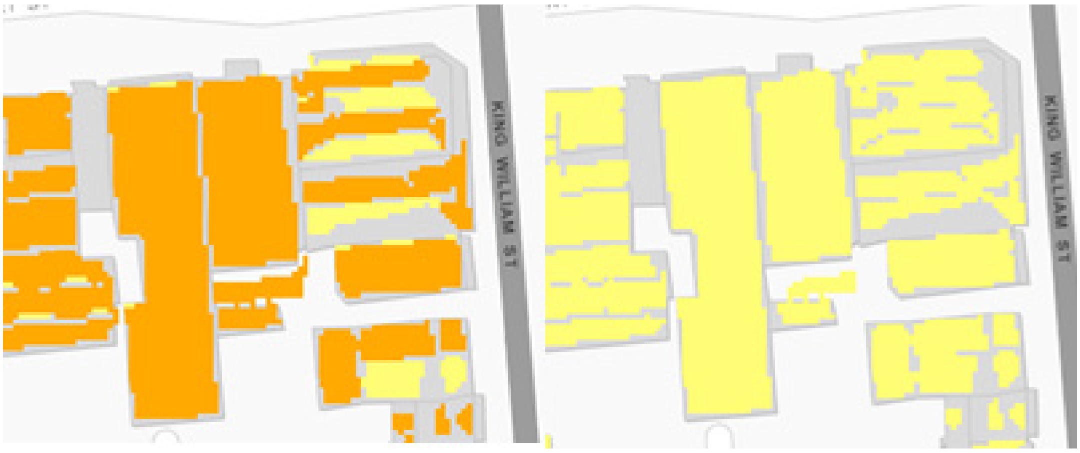

Figure 10: Comparison between roof planes defined as suitable by the insolation method (both - yellow) and NREL's hillshade and orientation method (Left – orange)

Input Data Source: AAM 3D Building Model vs. LiDAR data

The other variable that affected the sensitivity of the estimated PV potential was the input data source. Two input data sources were available for use in this analysis:

1. The DSMs and 3D building models from AAM, which were utilised to generate the APVI SPT,
2. The 2010 City of Adelaide LiDAR data dataset.

The application of the PV potential analysis was applied identically to both input data sources.

Generally, Figure 11 demonstrates that there is general agreement between the roof planes identified as suitable via the two input data sources. However, the figure also illustrates how the analyses undertaken with the LiDAR data set excludes a greater proportion of roof surfaces.

Figure 11: Example of good agreement between the two input data source for large buildings. Aerial image (Left), AAM 3D buildings with Insolation limit method (centre); Adelaide LiDAR with Insolation limit method (Right)

Calculation of PV Capacity and Annual Yield

After suitable roof planes have been identified, the PV capacity and annual yield for each roof surface can be calculated. The DC PV capacity (otherwise known as system size) was calculated as per APVI's SPT methodology [1] using the DC size factor and array spacing methodologies [4]. The relevant equations for this method can be found here.

Generally, the method assumes a fixed DC size factor of **156.25 W/m^2** (i.e. a 250W module with dimensions of 1m x 1.6m) for flush mounted arrays, and a variable DC size factor for rack mounted PV arrays. For rack mounted arrays, the DC size factor is a function of the PV array tilt and orientation and the tilt and orientation of the underlying roof surface. Figure 12 presents the equivalent useable roof area, which is analogous to the DC size factor, for a 15 degree tilted north facing PV array in Adelaide, as a function of the tilt and orientation of the underlying roof surface. For an absolutely flat roof, Figure 12 indicates a useable area of 69%, analogous to a DC size factor of 108 W/m^2. In comparison, NREL's method assumes a fixed ratio of module to roof area of 70% for flat roof surfaces.

As per NREL's method to calculate the PV potential in the United States [3], this analysis has assumed that rack mounted arrays will be installed on flat and relatively flat roof surfaces. For consistency with NREL's method, **flat roofs have been defined as roof surfaces with a tilt <= 9.5 degrees** and the **tilt angle of the rack mounted arrays were defined as 15 degrees**.

Similarly, for tilted roof surfaces > 9.5 degrees, **an additional module to roof area ratio of 0.98** was assumed in the NREL method to reflect 1.27cm of spacing between each module for racking clamps. This assumption was also applied in this study.

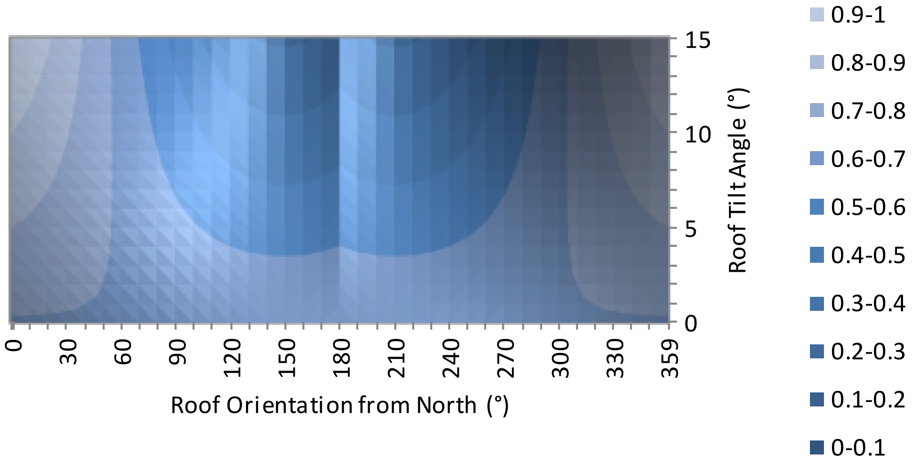

Figure 12: Percentage of useable roof area as a function of roof tilt and orientation for a 15 degree North facing array in Adelaide

The PV yield was calculated using APVI's SPT methodology as detailed here. This method multiplies the calculated DC PV capacity by the average annual level of insolation calculated on the roof surface and by a **derating factor of 0.77**. The derating factor accounts for all the typical PV losses of temperature, soiling, wiring, mismatch, manufacturing module tolerance and inverter efficiency. This simplified method shows good agreement with detailed hourly PV performance simulations undertaken in NREL's SAM as illustrated in Appendix A.

Calculation of Contribution to Total Load

The potential contribution of rooftop PV generation to electricity load in the CBD area was estimated by comparison to the annual energy consumption seen at the zone substations in SA Power networks' Adelaide Central Region (ACR) which includes the CBD area for which rooftop PV was modelled. These substations and loads are listed in Table 3, and mapped in Figure 13. The total annual demand for these substations is 674GWh, but it should be noted that these substations may feed some areas outside of the mapped CBD. Due to lack of information about which customers are connected to different feeders in the distribution network, it is not possible to accurately estimate the load in the CBD. Nevertheless, this figure can be used to give a sense of the scale of PV contribution to load in the Adelaide CBD area.

Table 3: Load Data from SA Power Networks' ACR Substations 2016-17 [5]

Zone Substation	Annual Load (GWh)
Coromandel Place 66/11kV	169
East Terrace 66/11kV	148
East Terrace 66/33kV	39
Hindley Street 66/11kV	160
Hindley Street 66/33kV	29
Whitmore Square 66/11kV	129
TOTAL ACR	**674**

Figure 13: SA Power Networks' Adelaide Central Region [6]

The annual yield was also compared to the average 2014 electricity demand of a South Australian household, being 5145 kWh [7].

Existing PV Capacity

In order to assess the potential for additional rooftop PV in the Adelaide CBD, and associated emissions reductions and electricity savings, existing PV capacity in the area was estimated. The CBD area covered by this assessment falls within the postcode area 5000 (see Figure 14). Using the Clean Energy Regulator's database of PV systems registered under the Renewable Energy Target scheme (accessed via the APVI's Solar Map[8]), which is a near complete record of PV systems installed in Australia, the installed PV capacity in this postcode area is given in Table 4. The total existing PV capacity in the CBD is therefore estimated to be around 4.0 MW.

Table 4: Existing PV Capacity in Adelaide Postcode 5000 [9]

POA	5000
PV less than 10kW (kW)	1397
PV 10kW to 100kW (kW)	2492
PV bigger than 100kW (kW)	151
Total PV Capacity (kW)	**4040**

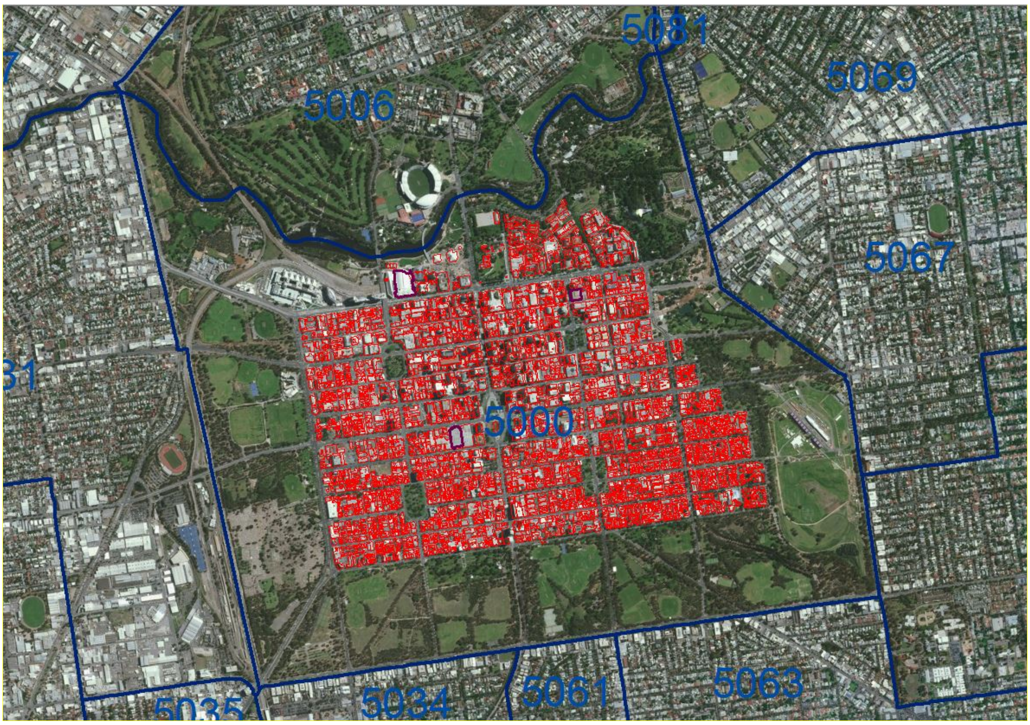

Figure 14: Adelaide CBD and Postcode Areas

Calculation of CO_2-e Emission Reductions

The annual CO_2-equivalent emission reductions are calculated by multiplying the estimated annual yield by an appropriate emissions factor for South Australia as sourced from the 2017 National Greenhouse Account Factors[9]. The relevant value for South Australia was **0.49 kg CO_2-e/kWh which is reduced by 0.045 kg CO_2-e/kWh to account for the embodied carbon emissions from the manufacture, installation, operation and decommissioning of the PV systems**. (Note that this value is lower than other jurisdictions due to the relatively high proportion of renewables in the South Australian energy generation mix.)The value of 45 g CO_2-e/kWh of electricity produced was sourced from the PV LCA Harmonization Project results found in [10], which standardised the results from 13 life cycle assessment studies of PV systems with crystalline PV modules, assuming system lifetimes of 30 years.

Estimation of Financial Savings

As well as depending on the size and orientation of the PV panels and efficiency of the PV system, the financial benefits of rooftop solar PV are highly specific to the particular energy user and to market conditions. Bill savings depend on the amount of generated electricity that is self-consumed (avoiding electricity purchase costs), the amount exported to the grid (in exchange for feed-in tariff) and on the available electricity retail tariffs for import and export. However, we are able to make some broad estimates for potential savings, based on typical values for commercial tariffs.

A standard commercial retail tariff in South Australia is Origin's SA Small Business eSaver General Supply Tariff which has an energy charge of 44.36 c/kWh with a standard solar feed-in tariff of 11c/kWh paid on exports. (It is important to note that larger businesses will pay significantly less for their electricity use, with larger charges for other components of their bill, and that FiTs up to 22c/kWh are available for some customers.)

For commercial buildings, self-consumption during the week is likely to be high due to high daytime loads, but on weekends there is likely to be significant solar export for some types of businesses, depending on the size of the PV system compared to the load. A 60% self-consumption case is therefore probably quite conservative for commercial buildings in the CBD.

$$Financial\ Savings = Tariff_{import} \times Energy_{self-consumed} + Tariff_{export} \times Energy_{exported}$$

Based on these estimates,

$$Financial\ Savings \approx \left(Tariff_{import} \times 60\% + Tariff_{export} \times 40\%\right) \times Energy_{Total}$$

$$Financial\ Savings\ (\$) \approx (0.4436 \times 60\% + 0.11 \times 40\%) \times Energy_{Total}$$

Results – PV Potential in Adelaide CBD

Table 5 shows the results of the rooftop suitability assessment for the Adelaide CBD for the two data sources and the two methods outlined above.

Table 5: Detailed results of rooftop suitability calculated using i) AAM DSM and 3D buildings and ii) Adelaide North 2013 LiDAR dataset from NSW LPI

		Method 1 - Insolation Limit (3.99 kWh/m2/day) - 3D Buildings				Method 2: NREL Hillshade E/NE/N/NW/W (13.69) - 3D Buildings			
Data Source	Total Area (ha)	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)
DSM / 3D	190.34	92.61	48.7%	144.7	196.15	96.1	50.5%	150.20	201.3
LiDAR		68.84	36.2%	107.6	146.76	72.0	37.8%	112.46	151.6

Conservative Results

The most conservative estimate suggests the useable area suitable for rooftop PV deployment (the ratio between the area of PV panels that could be accommodated and the total roof area) is 36% corresponding to 108 MW of PV potential with an expected annual yield of 147 GWh. These values were calculated using the LiDAR data as the input data source in conjunction with the Insolation method.

This corresponds to approximately 22% of the energy used in Adelaide CBD, or the average 2014 annual energy use of 28570 SA households

The equivalent CO_2 emission savings are 65 kilotonnes per year with estimated potential financial savings of $45million, although this is highly dependent on the specific circumstances of the building occupants.

Average Results

In Table 6, results are presented for the average and standard deviation (Std) of the sensitivity analysis undertaken by assessing the two input data sources and the two calculation methodologies.

Table 6: Summary of results for Adelaide CBD

Adelaide	Percentage Useable Area		Capacity (MW)		Yield (GWh)	
	Average	Std	Average	Std	Average	Std
CBD	43.3%	7.3%	128.7	21.8	173.9	28.7

The average of the two methods indicated that an area equal to 43% of the available roof surfaces could be used to accommodate PV, corresponding to 129 MW of PV potential with an expected annual yield of 174 GWh.

This corresponds to approximately 26% of the energy used in Adelaide CBD, or the average 2014 annual energy use of 33820 SA households. The equivalent CO_2 emission savings are 77 kilotonnes per year with estimated potential financial savings of $54million, although this is highly dependent on the specific circumstances of the building occupants. There is an estimated 4.0 MW of existing PV capacity installed on Adelaide CBD rooftops, approximately 3% of the potential capacity. The electricity generation and emissions savings calculated would therefore be almost all additional.

The rooftops with the largest PV potential in Adelaide have been mapped (Figure 15 below).

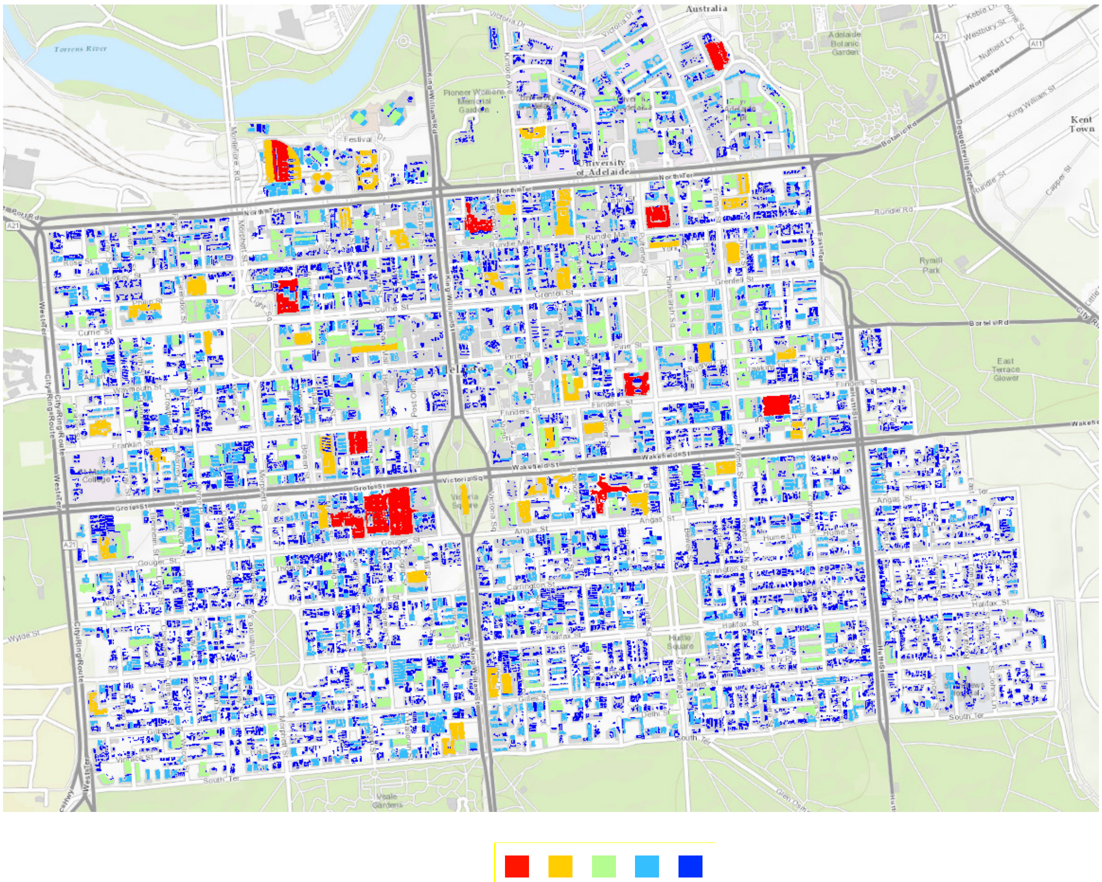

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Figure 15: Rooftops with Largest PV Potential in Adelaide CBD

Case Studies of Landmark Buildings

This section of the report details the methodology and the results for a detailed assessment of the PV potential for 3 landmark Adelaide buildings: the Centrepoint Building, Central Market and the central building of Adelaide Convention Centre. These buildings were chosen because of their high public profile and large roof areas. Note that a PV array of approximately 75kW PV was installed on the Central Market in 2011, but the roof area has much greater potential. Also, the assessment of the Convention Centre only includes the central of the three buildings, as the more recent development was not included in the dataset used for this analysis.

The case studies were assessed by combining the same GIS analysis used to assess the PV potential of Adelaide CBD with a visual assessment of the building roof profiles using aerial imagery. No structural assessment of the buildings has been carried out.

Assessment of Roof Area

Firstly, Method 1 above was used to identify developable roof planes: continuous areas greater than $10m^2$ receiving 80% of the annual insolation for an unshaded horizontal surface (3.99 $kWh/m^2/day$).

Figure 16: Developable Planes with > 3.99 $kWh/m^2/day$

The roof surfaces were then assessed visually, using imagery from multiple sources: aerial plan view images from *Nearmap* and *Google Earth,* multiple viewpoint aerial imagery from *Nearmap*, and photographs sourced from the internet. Unsuitable surfaces, including staircases, temporary structures, and public spaces (roof terraces, platforms, etc.), were identified and excluded from the usable roof area.

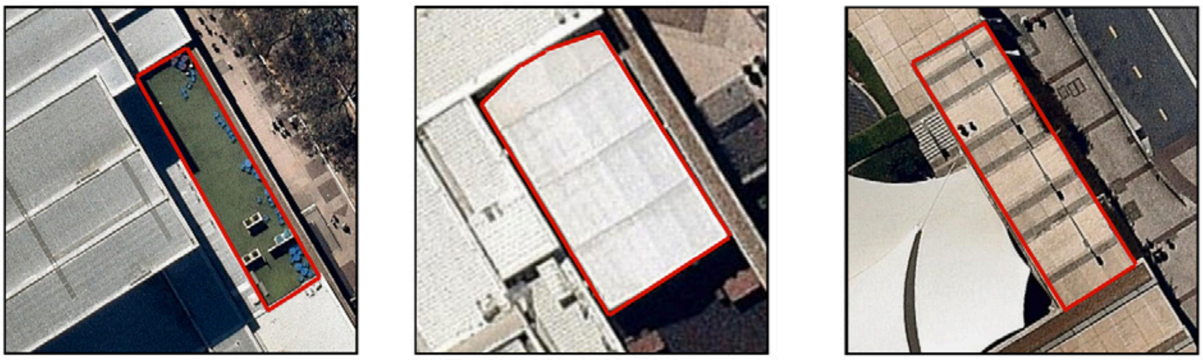


Figure 17: Examples of unsuitable surfaces (a) rooftop terrace, (b) temporary structure, (c) staircase

Small rooftop obstructions and perimeter walls below the resolution of the GIS data were also identified and their height was estimated using multiple viewpoint aerial imagery. (see Figure 18)

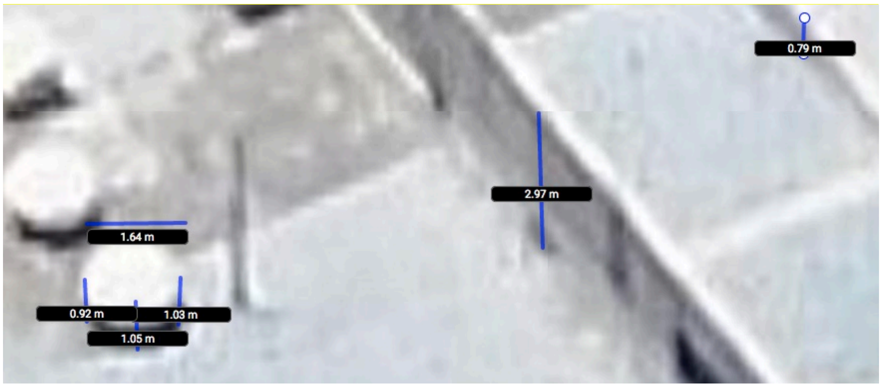


Figure 18: Estimation of rooftop obstructions

The shading on a PV module at a range of distances from obstructions of different heights was modelled using the 3D shading calculator in NREL's System Advisor Model (SAM) and the impact on annual output for a horizontal PV panel in Adelaide (using the Adelaide RMY weather file from Energy Plus[11]) was calculated. Figure 19 shows the results for a small range of distances and wall heights. Using this data, additional roof area proximate to rooftop obstructions was excluded if estimated annual output was less than 80% of an unshaded horizontal panel.

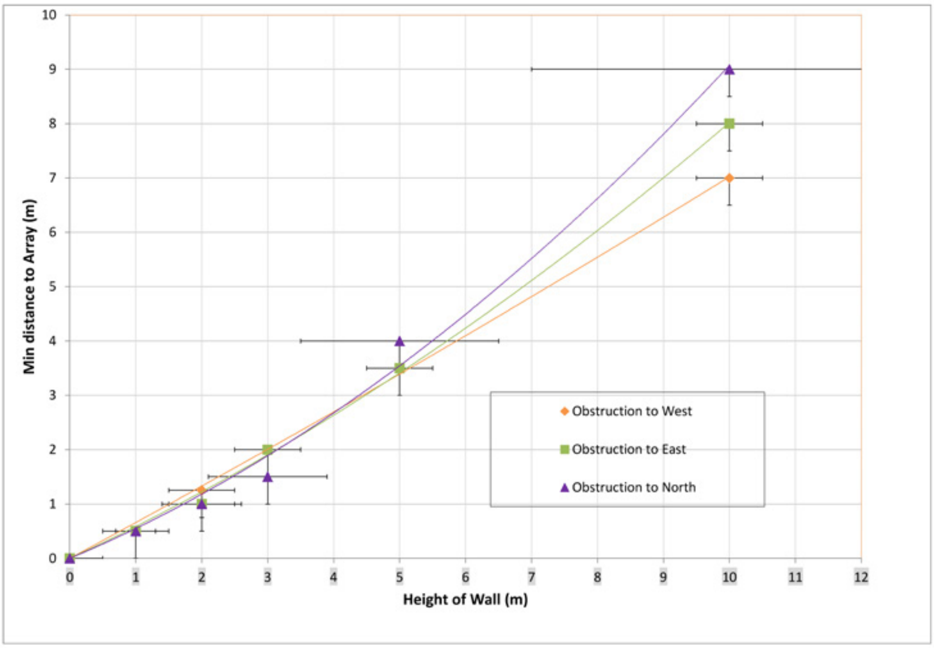


Figure 19: Nearest distance to obstruction to give 80% annual output

Nearmap's Solar Tool was then used to arrange 1.6m x 1.0m PV panels on the usable roofspace, with the roof slope determined from the GIS building slope layer. For sloping roofs, the panels were positioned flush with the roof in order to avoid self-shading and maximise generation. For flat roofs, panels were orientated towards North (i.e. between 045°and 315°) at a tilt angle of 5°.

As the assessment was carried out remotely, there may be additional physical constraints on the available roof area as well as structural restrictions on the potential array size that have not been considered here.

Calculation of PV Capacity and Annual Yield

The power capacity of the array was calculated using a nominal output of 250W per module (equivalent to a DC size factor of 156.25 W/m^2), and an initial value for the predicted annual energy output (without accounting for shading losses) was calculated for each orientation and tilt using SAM's PVWatts model and a derate factor of 0.77.

To account for shading losses, the average yield (in kWh/kW/day) was calculated using the APVI SPT method, averaged across all developable roof planes within the building footprint. This yield was then applied to the calculated array size to give a predicted annual generation accounting for shading losses. As it is outside the area of the APVI solar potential map, shading losses for Suncorp stadium were modelled using SAM's 3D Shading Model.

The annual yield was compared to the average annual electricity demand of a South Australian households, being 5145 kWh [7].

Calculation of Emissions Offset

The potential CO_2-e emissions reductions from the modelled PV systems on the 3 landmark buildings were calculated by multiplying the indirect (Scope 2) emissions factor for consumption of electricity purchased from the grid in SA (0.49 kg CO_2-e/kWh[9]) by the expected annual energy generation from the system, and subtracting the estimated embodied carbon emissions from the manufacture, installation, operation and decommissioning of the PV system (0.045kg CO_2-e /kW[10])

Case Study Results

Table 7 shows the potential roof area available for PV installation on each building

Table 7: Available roof areas

Site	Total Roof Area (m^2)	Developable Planes (m2)	Array Area (m2)	Array Area / Roof Area
Centrepoint Building	3,936	3,442	2,224	57%
Central Market	7,566	7,315	5,354	71%
Convention Centre - Central Building	15,722	13,177	8,338	53%

Table 8 shows the projected array capacity and expected annual energy production. The proposed PV arrays are illustrated in Figure 20 -Figure 22 below.

Table 8: Expected Annual Energy Production

Site	PV Capacity (kW_{peak})	Annual Energy Production (w/o shading) (MWh/year)	Average Yield per kW PV installed (kWh/kW/day)	Expected Annual Energy Production (adjusted) (MWh/year)
Centrepoint Building	348	489	3.86	452
Central Market	837	1225	4.01	1120
Convention Centre - Central Building	1303	1821	3.83	1705

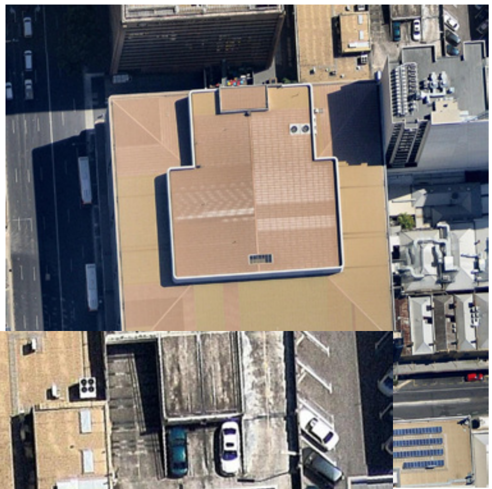
Table 9 presents the estimated carbon offsets for each system and shows that these three buildings could save an estimated 1.5 kilotonnes of carbon emissions each year and could supply the equivalent of 637 households, based on the average 2014 electricity demand of an SA household being 5145 kWh [7].

Table 9: Carbon offset and household energy equivalents

Site	Expected Annual Energy Production (MWh/year)	Emissions Offset (Tonnes CO_2-e / year)	Average ACT household equivalent
Centrepoint Building	452	201	88
Central Market	1120	499	218
Convention Centre - Central Building	1705	759	331
Totals	**3277**	**1458**	**637**

Case Study Illustrations

Figures 20-22 show the arrangements of the potential PV arrays on each of the three landmark buildings



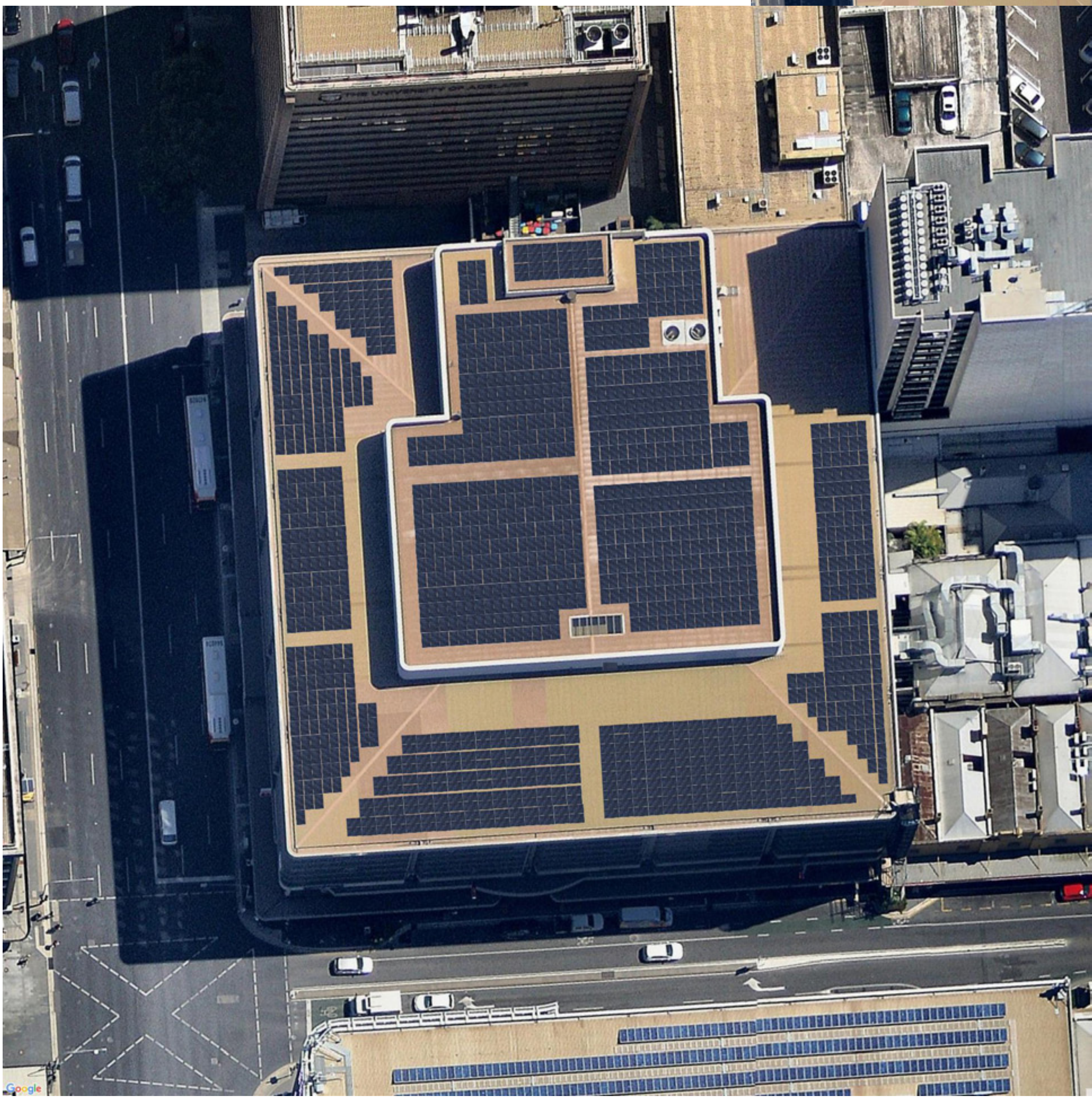


Figure 20: Centrepoint Building now (inset) and with potential 348kW PV array

Figure 21: Central Market, now (inset) and with potential 837kW PV Array

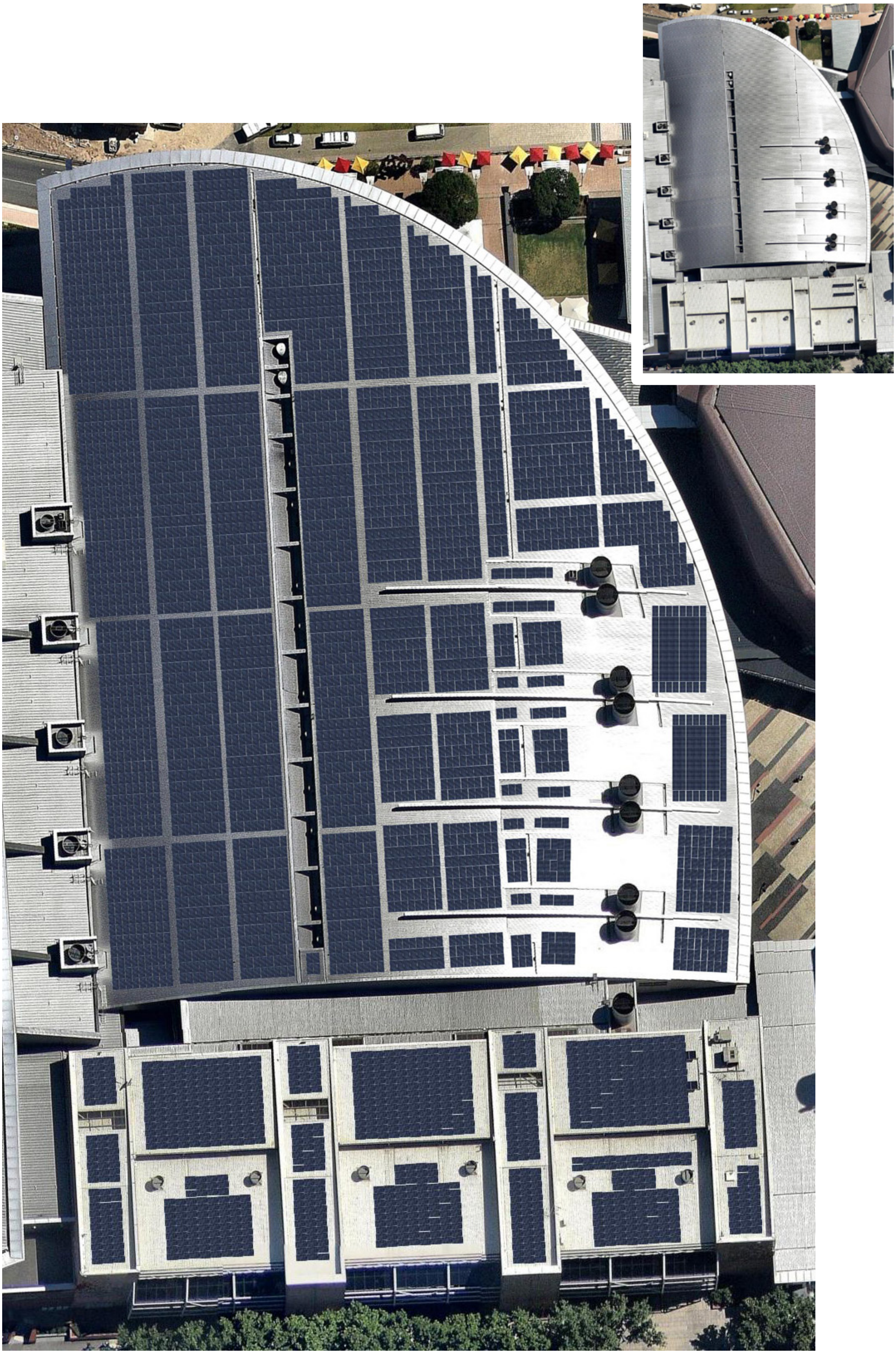


Figure 22: Adelaide Convention Centre central building, now (inset) and with potential 1.3MW PV array

References

1. Copper, J.K. and A.G. Bruce. *APVI Solar Potential Tool - Data and Calculations*. 2014 Accessed; Available from: http://d284f79vx7w9nf.cloudfront.net/assets/solar_potential_tool_data_and_calcs-2dc0ced2b70de268a29d5e90a63432d7.pdf.
2. Copper, J.K. and A.G. Bruce. *Validation of Methods Used in the APVI Solar Potential Tool*. 2014 Accessed; Available from: http://apvi.org.au/solar-research-conference/wp-content/uploads/2015/04/1-Copper_APVI_PVSystems_PeerReviewed.pdf.
3. Gagnon, P., et al. *Rootop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*. NREL/TP-6A20-65298 2016 Accessed; Available from: http://www.nrel.gov/docs/fy16osti/65298.pdf.
4. Copper, J.K., A.B. Sproul, and A.G. Bruce, *A method to calculate array spacing and potential system size of photovoltaic arrays in the urban environment using vector analysis.* Applied Energy, 2016. **161**: p. 11-23.
5. SA Power Networks. *Zone Substation Data*. 2016-2017; https://www.sapowernetworks.com.au/custom/files/zonesubreport/2016-2017/Zone%20Sub%20Report%20-%20ALL%20REGIONS%20-%2020171023.zip.
6. SA Power Networks. *Distribution Annual Planning Report 2016/17 to 2020/21*. 2016; Available from: https://www.sapowernetworks.com.au/public/download.jsp?id=28109.
7. Acil Allen Consulting. *Electricity Benchmarks final report v2 - Revised March 2015*. 2015.
8. Australian Photovoltaic Institute. *Australian PV Institute (APVI) Solar Map, funded by the Australian Renewable Energy Agency*. 2017 Accessed: 8/12/2017; Available from: http://pv-map.apvi.org.au/postcode.
9. Department of Environment and Energy. *National Greenhouse Accounts Factors July 2017*. 2017.
10. Hsu, D.D., et al., *Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation.* Journal of Industrial Ecology, 2012. **16**: p. S122-S135.
11. *Energy Plus Weather Data - Southwest Pacific Region*. Accessed; Available from: https://energyplus.net/weather-region/southwest_pacific_wmo_region_5/AUS%20%20.

Appendix A – Comparison between APVI SPT Simple PV Performance Method vs. Detail Hourly Simulation of PV Performance in NREL's System Advisor Model

Figure 23 presents a comparison between the calculated annual yields using APVI SPT simplified method versus detailed hourly simulations of PV performance using NREL's SAM PVWatts module with default settings. The results highlight the similarity in the calculated values, and demonstrate how the annual yield can be calculated using a simplified methodology, which requires as input only the annual or monthly averages of surface insolation in kWh/m^2/day. The simplified APVI SPT methodology enables geospatial calculation of yield for each identified roof surface.

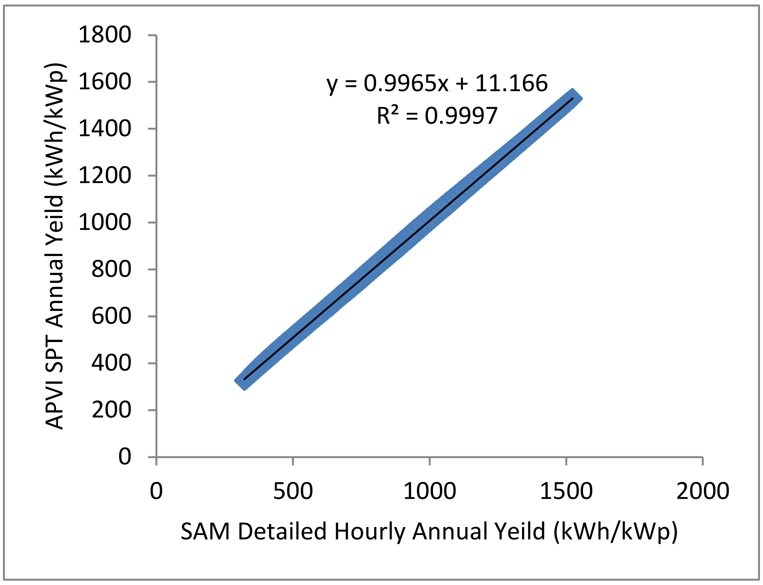
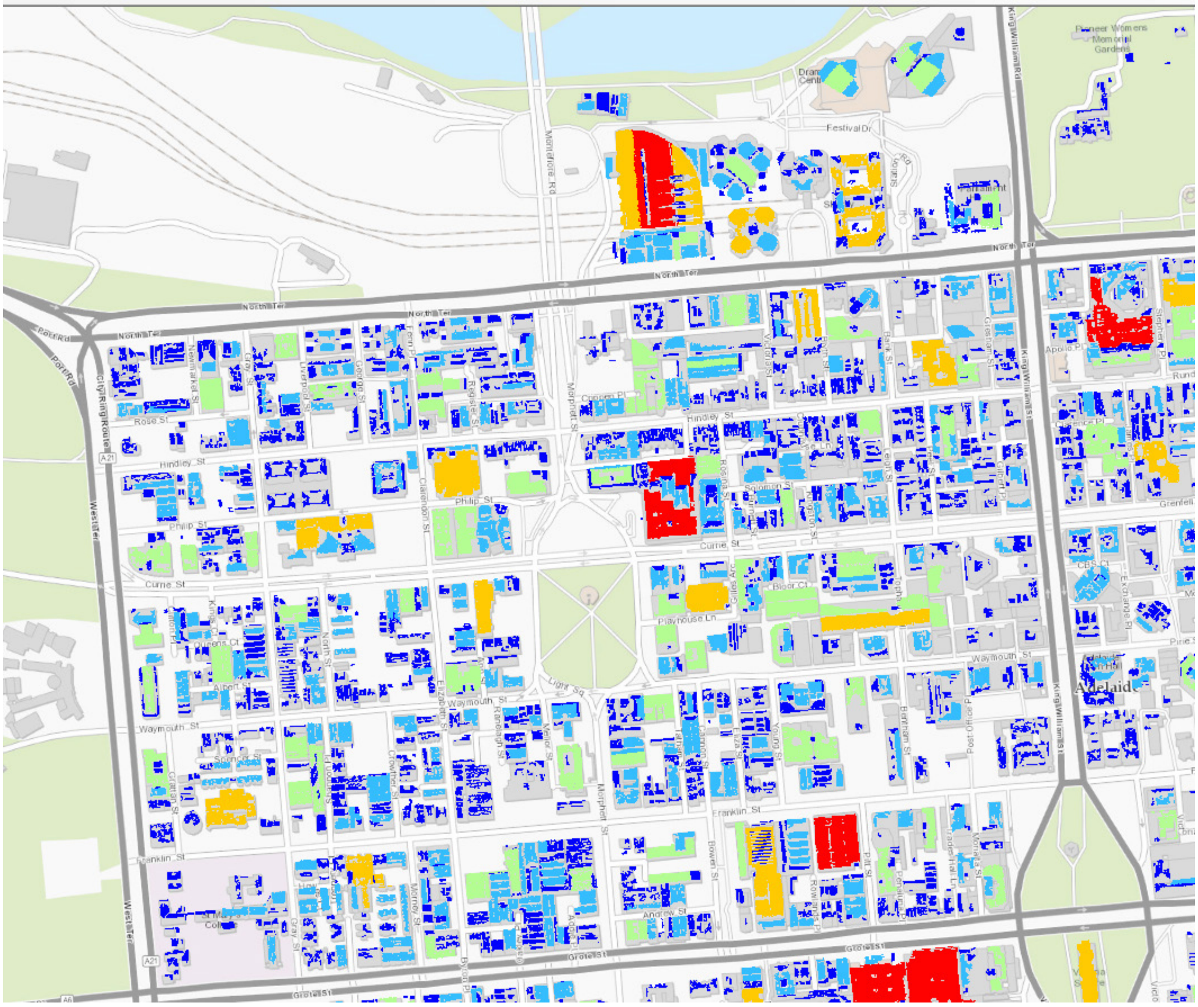
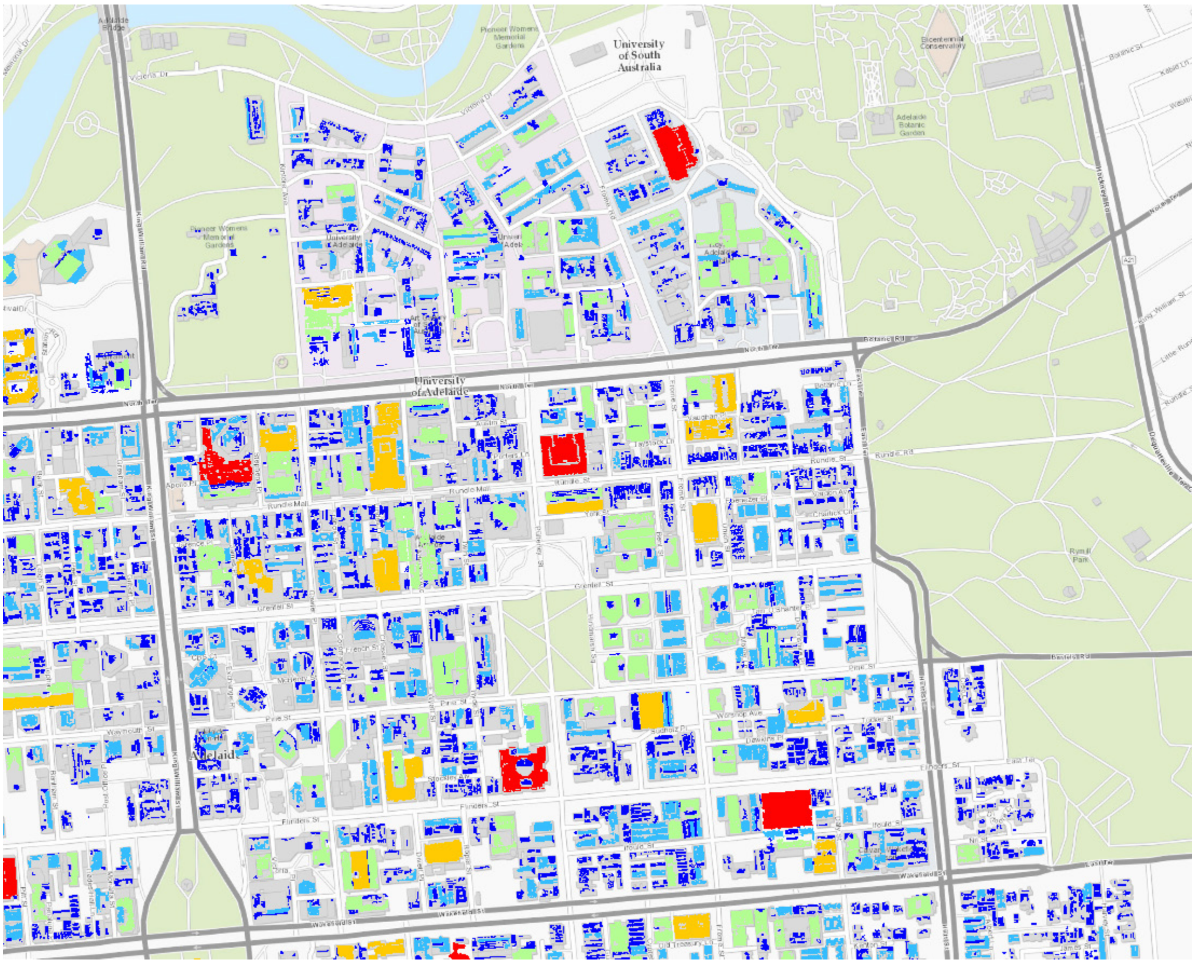


Figure 23: Correlation between APVI SPT simplified method to calculate annual yield from annual average insolation vs. detailed hourly simulations of PV performance from NREL's SAM. Results presented for each 1 degree combination of tilt (0-90°) and orientation (0-360°).

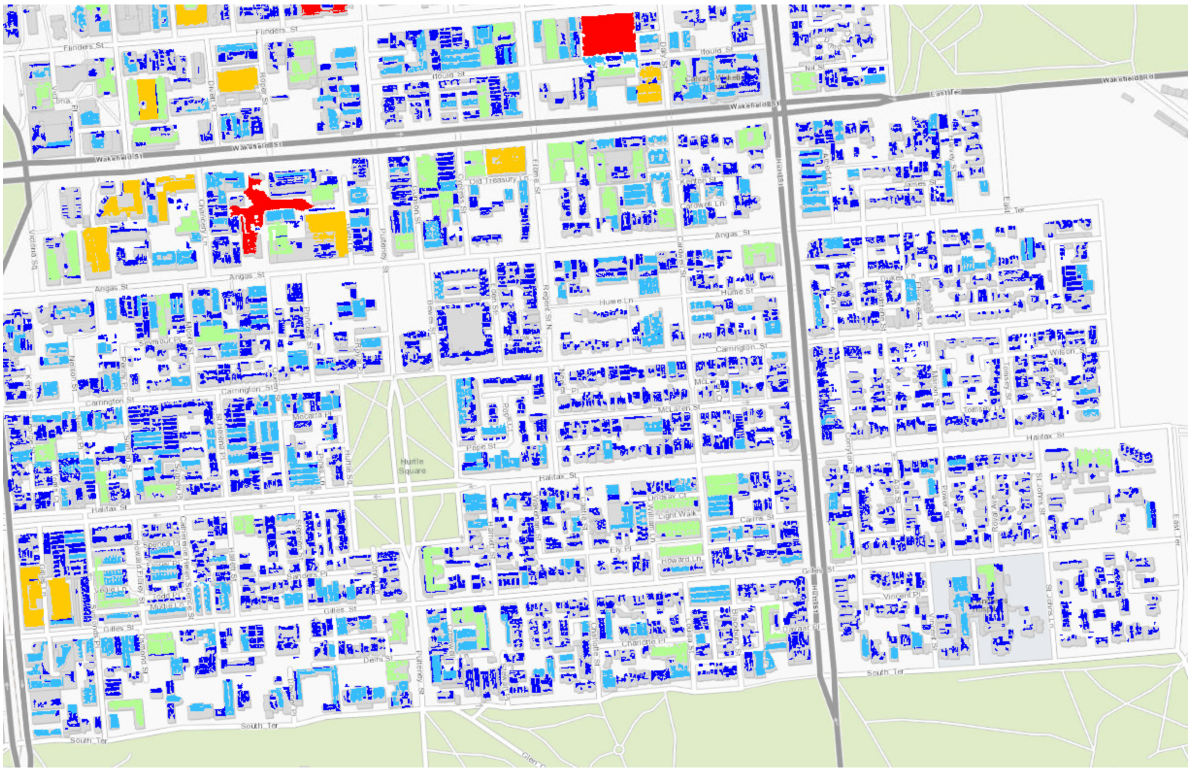
Appendix B – Detailed Maps of Rooftops with Large Solar Potential



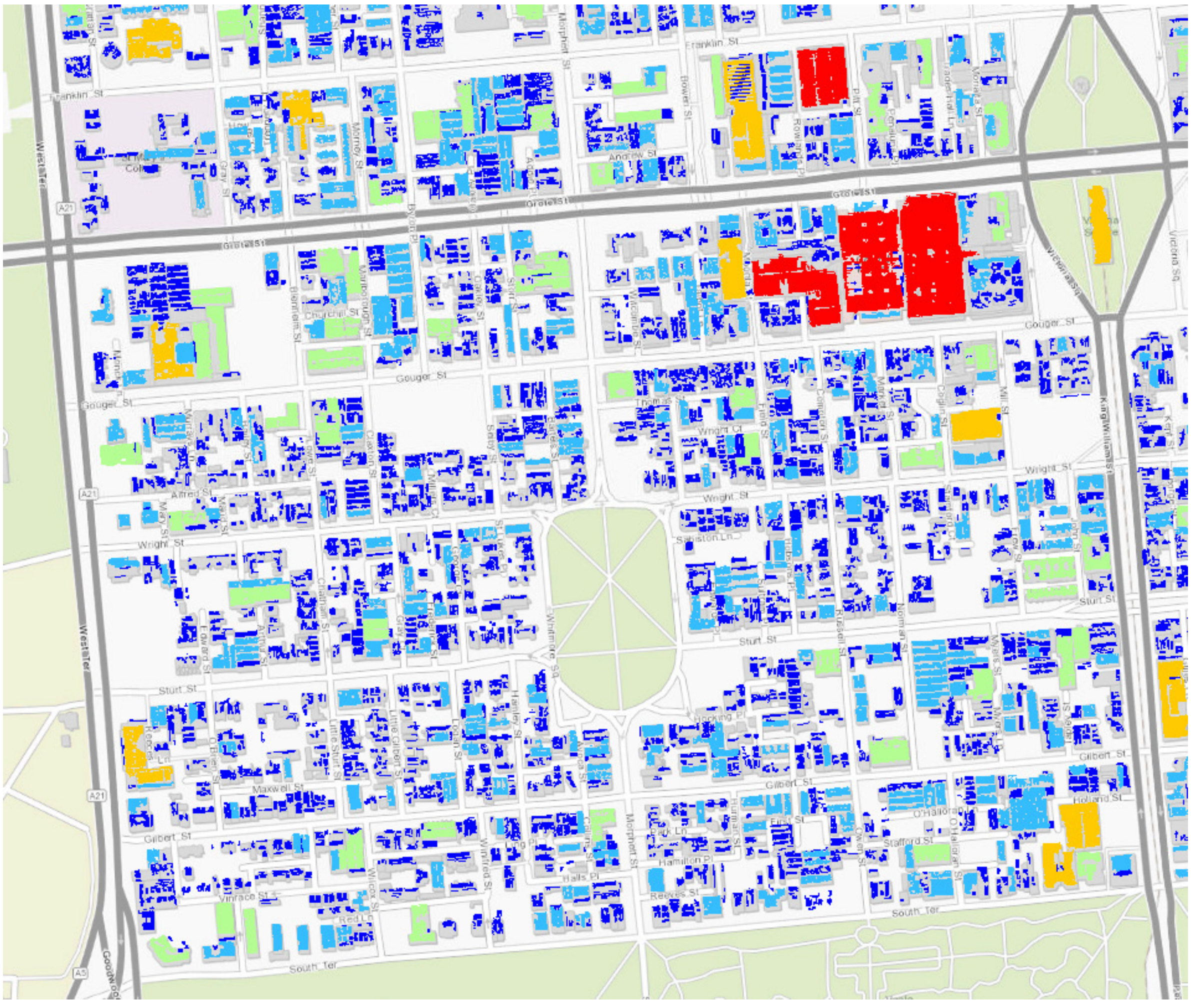
high - med - low



high - med - low



high - med - low


Franklin St
Grote St
Gouger St
Wright St
Sturt St
Gilbert St
South Ter
West Ter
Victoria Sq

high - med - low