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Spatial Analysis of Solar Potential in Melbourne

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Key Findings

The Australian PV Institute analysis shows that Melbourne LGA could generate more than 12% of its electricity needs from its own rooftops, with the installation of 461 MW of solar on its rooftops.

Using the average results from our 4 methods:

- There is potential to install 461MW of solar photovoltaics on City of Melbourne rooftops
- This represents a one-hundred fold increase on the existing PV deployment
- 38% of the total roof area could accommodate close to 2,000,000 solar panels
- this could generate 548GWh annually
 - meeting an estimated 12% of the LGA energy demand
 - supplying the equivalent of 112,000 Victorian households
 - avoiding 567,000 tonnes of CO₂ emissions
- Melbourne electricity customers could save up to an estimated \$112 million per year

Analysis of 3 case study buildings in the Melbourne LGA suggests potential solar PV capacities of:

960kW on Flinders St Station

2.2MW on the MCG

and 1.5 MW on Crown Casino.

Executive Summary

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 Melbourne Local Government Area (LGA). The report includes:

1. An assessment of PV Potential in Melbourne LGA
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 LGA
4. Three case studies of PV Potential on landmark buildings in Melbourne

Summary Results: Melbourne LGA

The useable area suitable for PV deployment across the Melbourne LGA was calculated using two different methods. 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 shows that 38% of the total roof area in the LGA is suitable for PV deployment. This area could accommodate over 1,840,000 solar PV panels, with a generating capacity of 461 MW.

There is an estimated 5.0MW of PV capacity currently installed on Melbourne LGA rooftops, which represents only 1% of the estimated potential capacity.

Annually, the 461MW could supply 548 GWh of electricity, approximately 12% of the estimated total electricity demand of the LGA, or the annual electricity demand of 112,000 average Victorian households.

The equivalent CO₂ emission savings are 567 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 more than \$112 million per year.

The breakdown of the solar potential across different suburbs is shown in Table 1 below.

Table 1: Summary of results categorised by suburb

Melbourne City Suburbs	PV Capacity (MW)	PV Yield (GWh)
	Average	Average
All	460.9	547.7
Carlton	29.9	35.2
Carlton Nth	1.3	1.6
CBD	34.8	39.4
CBD Nth	11.8	13.7
CBD Sth	27.9	32.6
Docklands	35.5	42.1
East Melbourne	16.6	19.1
Fishermans Bend	46.0	56.6
Flemington	12.1	14.5
Jolimont	2.9	3.5
Kensington Est	15.8	19.0
Kensington Wst	21.3	25.1
North Melbourne Est	20.2	23.8
North Melbourne Wst	31.0	37.1
Parkville	31.0	36.7
Port Melbourne	25.7	31.7
South Wharf	5.7	6.9
South Yarra	13.3	15.4
Southbank	23.6	27.3
West Melbourne	54.5	66.3

The rooftops with the largest PV potential in Melbourne have been mapped (Figure 1 below). More detailed images appear in Appendix C.

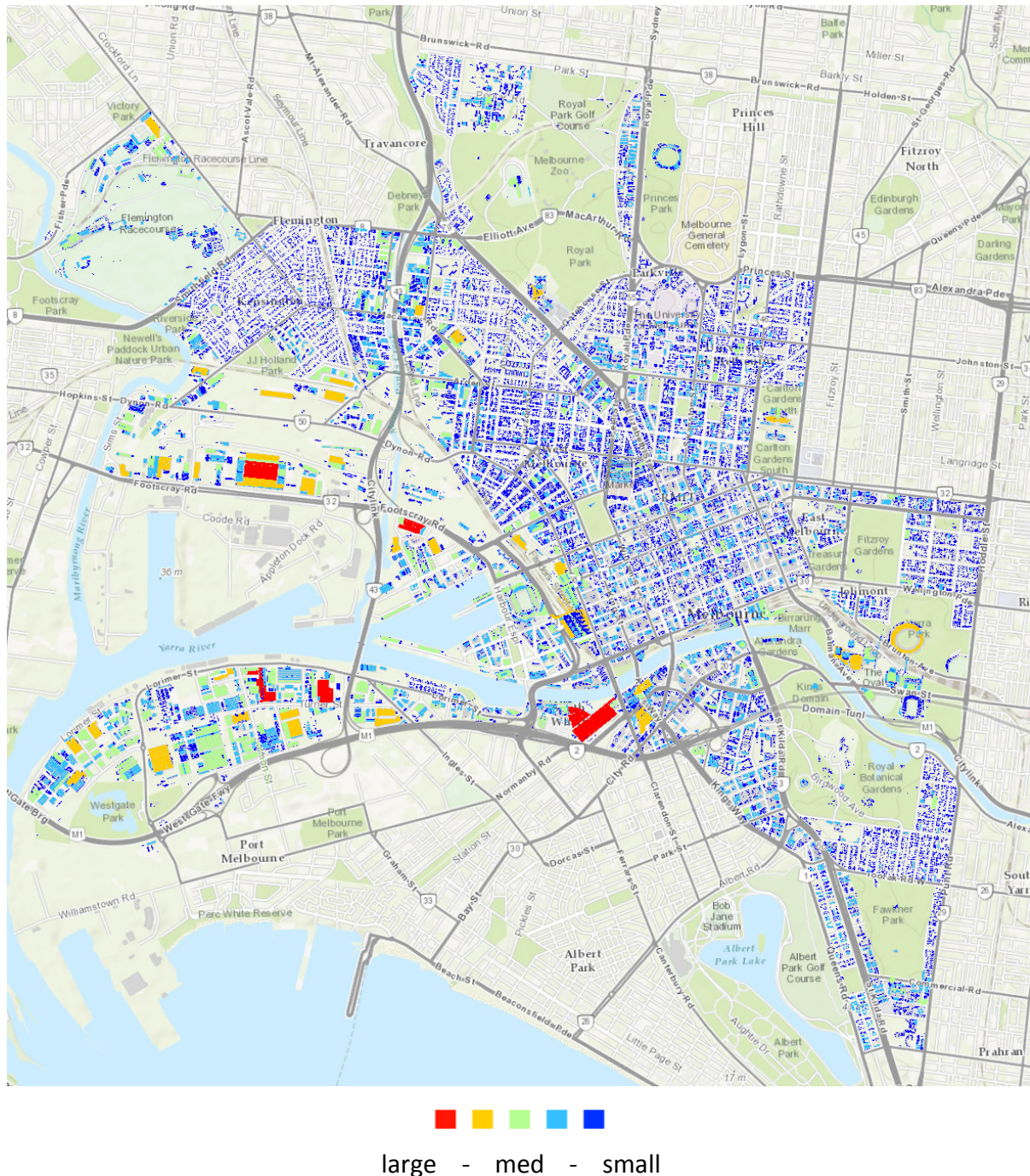


Figure 1: Rooftops with Largest PV Potential in Melbourne LGA

Summary Results: Case Study Buildings

Case studies of specific landmark buildings including Flinders Street Station, Melbourne Cricket ground (MCG) and The Crown Casino have been conducted. Table 2, based on the data and visual imagery available, shows that an area equivalent to just over a third of the total building footprint of the 3 buildings is suitable for PV arrays, based on the criteria described below. This is below average, due to the irregular structure of the roofs and, for the casino, alternative utilization of the space.

Table 2: Potential productive roof area

Site	Building Footprint (m ²)	Roof Area (m ²)	Array Area (m ²)	Array Area / Roof Area
Flinders St Station	19,000	17,220	6,144	36%
MCG	70,000	31,370	14,262	45%
Crown Casino	52,630	38,745	9,544	25%

Nevertheless, as Table 3 shows, the 3 buildings have a total capacity of 4.7MW with potential annual generation of 5.1 MWh. These are illustrated in **Figure 2-Figure 4** below.

Table 3: PV Capacity and 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)	Annual Energy Production (adjusted) (MWh/year)
Flinders St Station	960	1193	3.40	1054
MCG	2229	2822	3.47	2436
Crown Casino	1491	1891	3.47	1612

Table 4 presents the estimated carbon offsets for each system and shows that these three buildings could save an estimated 5.3 kilotonnes of carbon emissions each year and could supply the equivalent of 1040 households, based on the average 2014 electricity demand of a Victorian household (in 2014) being 4905kWh [1].

Table 4: Carbon offset and household energy equivalents

Site	Expected Annual Energy Production (MWh/yr)	Emissions Offset (Tonnes CO ₂ -e / yr)	Average VIC household equivalent
Flinders St Station	1054	1091	215
MCG	2436	2522	497
Crown Casino	1612	1668	329
Totals	5102	5281	1040

Array Illustrations

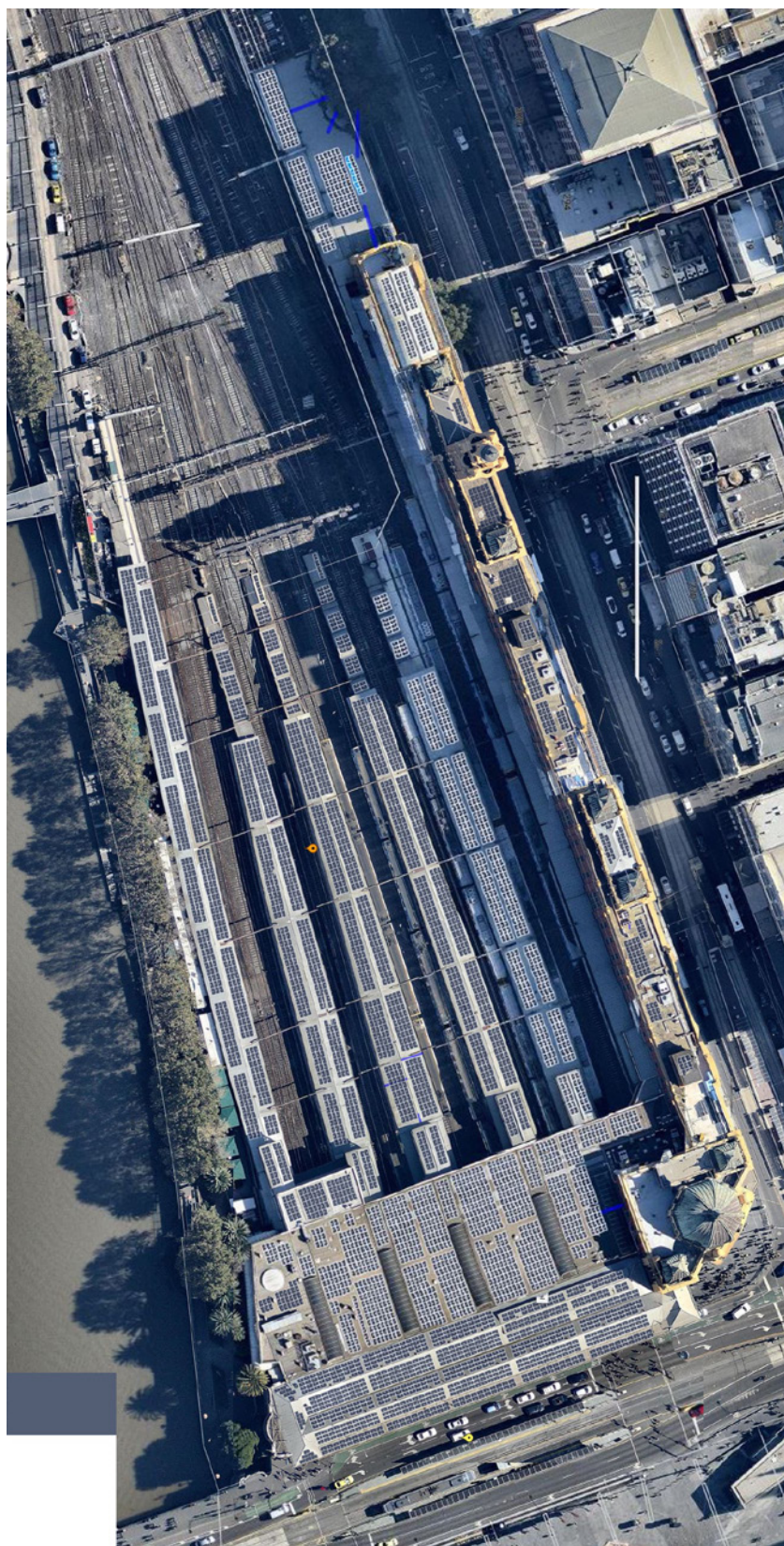


Figure 2: Potential PV Array on Flinders St Station



Figure 3: Potential PV Array on MCG



Figure 4: Potential PV Array at Crown Casino

Introduction to the Solar Potential Tool

The APVI Solar Potential Tool (SPT) 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.

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 1m² unit of surface.
3. Insolation values output by the ArcGIS model were calibrated² 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 \(SAM\)](#).

At a city level, an insolation heatmap layer (Figure 5b) allows identification of the best roofs, while the shadow layer (Figure 5c) allows the user to locate an unshaded area on a rooftop. On a specific roof surface, an estimate of annual electricity generation, financial savings and emissions offset from installing solar PV can be obtained.

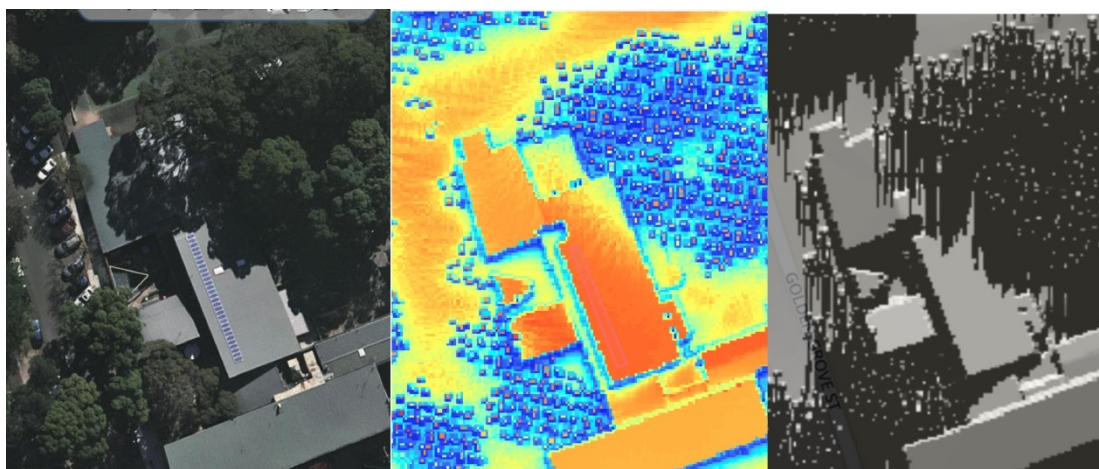


Figure 5: (a) Aerial photograph (b) Insolation heat map, (c) Winter shadow layer

This project expanded the data and methodologies behind the Solar Potential in order to estimate the Solar Potential in the City of Melbourne LGA.

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 City of Melbourne LGA

This section of the report details the methodology and the results of the geospatial analysis of PV potential across City of Melbourne LGA

Methodology

The assessment of the PV potential in City of Melbourne LGA, expanded on the initial work undertaken for the Melbourne 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 Melbourne LiDAR data – 2014 dataset sourced from the City of Melbourne GIS & Property Data Team.

The general steps in the methodology are illustrated in Figure 6. 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 2014 City of Melbourne LiDAR data covering Melbourne LGA. 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.

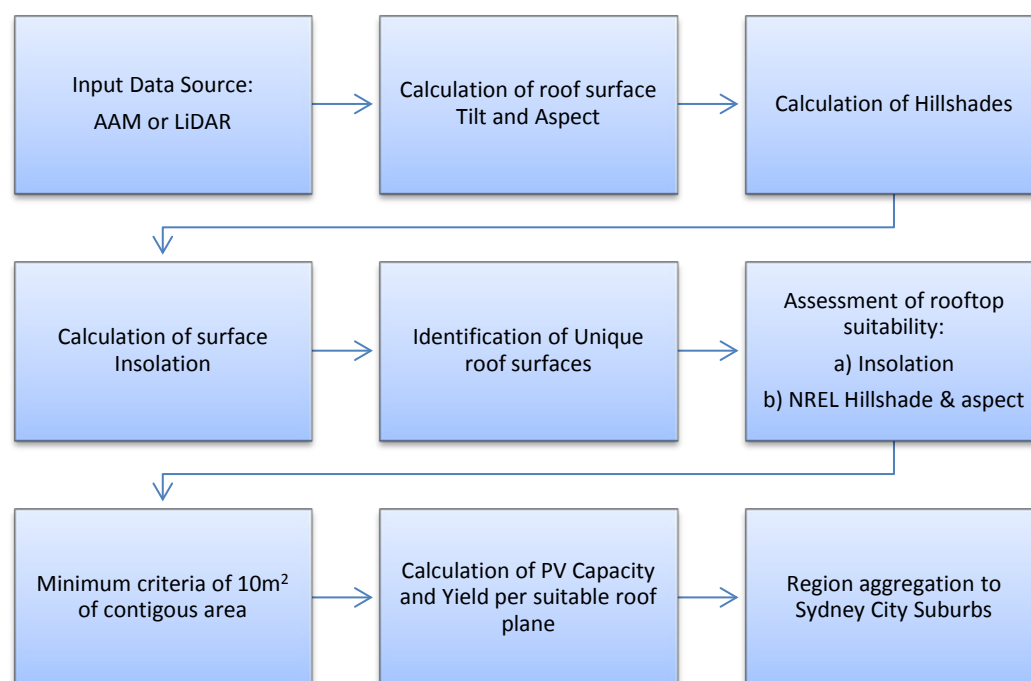


Figure 6: Major process steps for the calculation of rooftop PV potential

The regions covered by the analysis and the relevant suburbs used to classify the PV potential opportunities are shown in Figure 7.

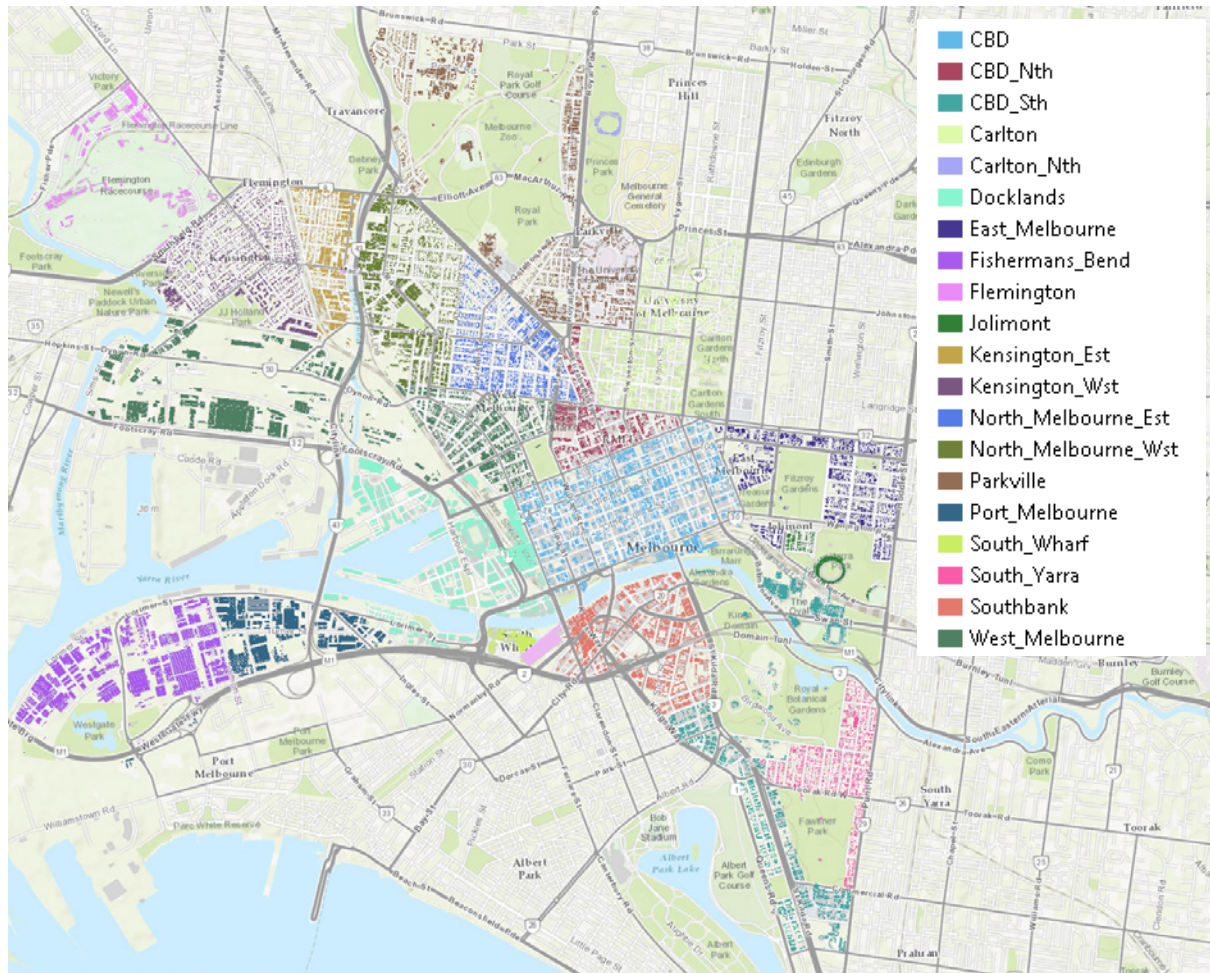


Figure 7: Melbourne LGA Regions Covered by Analysis

Assessment of Rooftop Suitability - Methods

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 **3.48kWh/m²/day**. This limit was calculated as 80% of the expected level of annual insolation for a horizontal surface in Melbourne, calculated as 4.35 kWh/m²/day, using the default TMY weather file for Melbourne 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 [2, 3].

Figure 9 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 10m² contiguous area was required for a roof plane to be determined suitable. Figure 10 presents the roof planes that were identified to meet both the insolation and 10m² contiguous area criteria for the example presented in Figure 9.

Figure 8 - Minimum distance from rooftop obstruction for 80% annual output

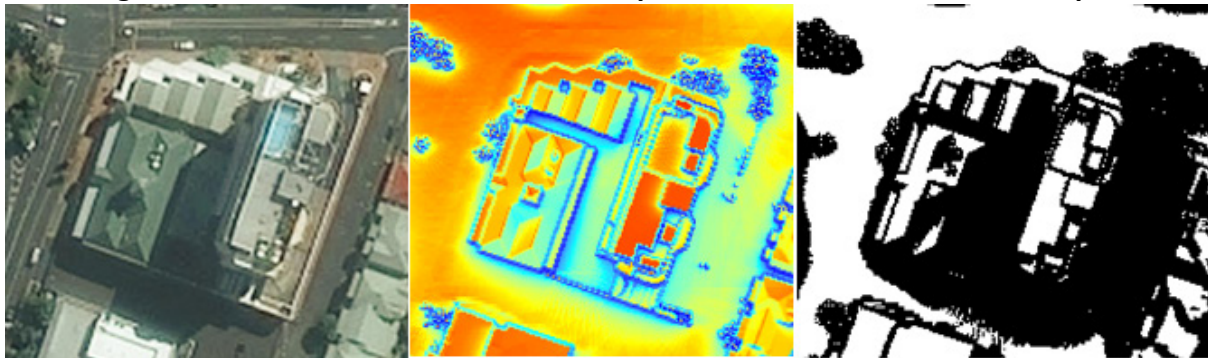


Figure 9: Example application of the Insolation limit. Areal image (left); Insolation heat map (centre); and classified Insolation layer (right)

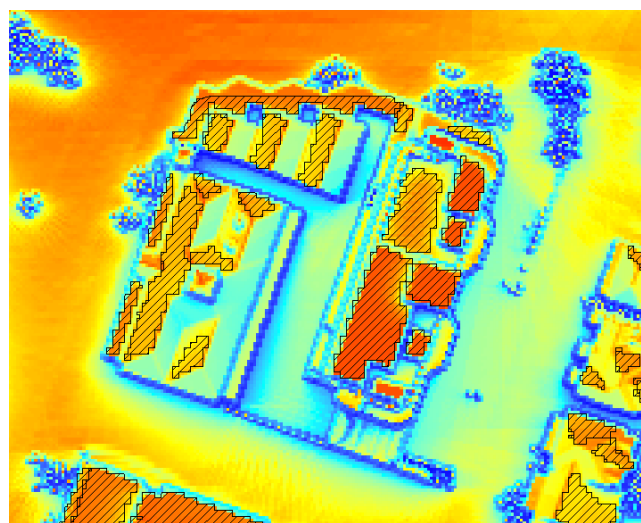


Figure 10: Example application of suitable planes (hatched areas) by the Insolation limit method.

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 [4]. 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 5.

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 [4]. For the location of Melbourne the value was determined to be 13.03 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 11. Again as for each method in this report, a 10m^2 contiguous area is also required by NREL's methodology.

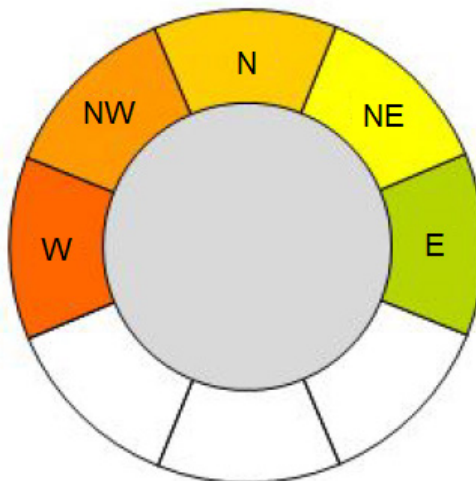


Figure 11: Rooftop azimuths included in final suitable planes for the Southern Hemisphere

Figure 12 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 10 vs Figure 12. This is not always the case as evident in the example presented in Figure 13, 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 12: Example application of the hillshade limit (left) with the suitable planes overlaid (right)



Figure 13: 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. City of Melbourne LiDAR data – 2014 dataset sourced from the City of Melbourne Smart City Office

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

Generally, Figure 14 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 14: Example of good agreement between the two input data source for large buildings. Aerial image (Left), AAM 3D buildings with Insolation limit method (centre); City of Melbourne LiDAR with Insolation limit method (Right)

Calculation of PV Capacity, Annual Yield and CO₂-e Emission Reductions

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 [2] using the DC size factor and array spacing methodologies [5]. The relevant equations for this method can be found [here](#).

Generally, the method assumes a fixed DC size factor of **156.25 W/m²** (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 15 presents the equivalent useable roof area, which is analogous to the DC size factor, for a 15 degree tilted north facing PV array in Melbourne, as a function of the tilt and orientation of the underlying roof surface. For an absolutely flat roof, Figure 15 indicates a useable area of 66%, analogous to a DC size factor of 103 W/m². 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 [4], 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.

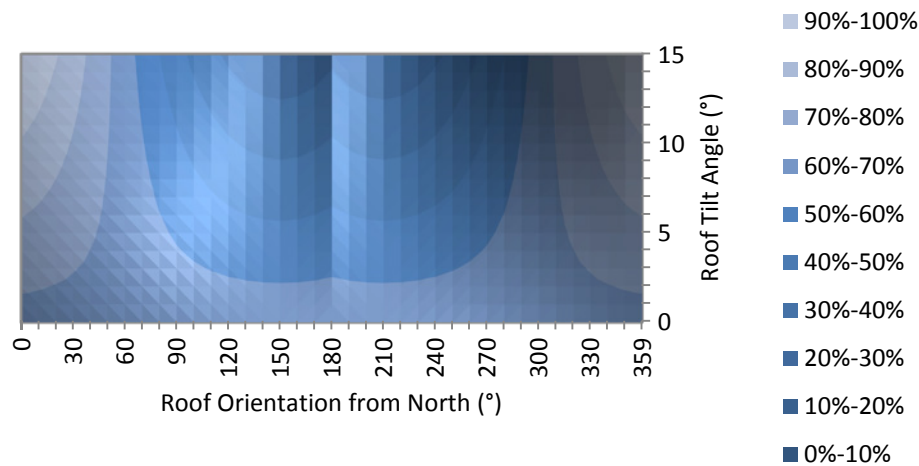


Figure 15: Percentage of useable roof area as a function of roof tilt and orientation for a 15 degree North facing array in Melbourne

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.

The potential contribution of rooftop PV generation to electricity load in the City of Melbourne LGA was estimated by comparison to the annual energy consumption seen at the zone substations located in or adjacent to the LGA. These substations and loads are listed in Table 5, and mapped in Figure 16. It must be noted that due to lack of information about which customers are connected to different feeders in the distribution network, and the radial configuration of the network, which is dynamically switched at different times to serve different customers via different substations, it is not possible to accurately estimate the load in the LGA. By including the consumption for zone substations within the LGA and 50% of the consumption for those on or adjacent to the boundary of the LGA, an estimate of the total annual demand for the area is 4,515 GWh. Although not precise, this figure can be used to give a sense of the scale of PV contribution to load in the Melbourne LGA.

Table 5: Load Data from CitiPower & Jemena Melbourne Zone Substations 2016

ZS Identifier	Network Service Provider	Zone Substation	Approx Annual Load (GWh)	Assumed % consumed in LGA	Estimated Contribution to LGA Demand (GWh)
B	CitiPower	Collingwood	132.5	50%	66.3
BQ	CitiPower	Bouverie Queensberry	229.8	100%	229.8
C	CitiPower	Brunswick	46.0	50%	23.0
DA	CitiPower	Dock Area	142.8	100%	142.8
E	CitiPower	Fishermans Bend	26.1	50%	13.1
FB	CitiPower	Fishermans Bend	107.8	100%	107.8
FR	CitiPower	Flinders/Ramsden	350.5	100%	350.5
J	CitiPower	Spencer Street	30.2	100%	30.2
JA	CitiPower	Little Bourke Street	833.2	100%	833.2
LQ	CitiPower	Little Queen	328.6	100%	328.6
MP	CitiPower	McIlwraith Place	869.1	100%	869.1
R	CitiPower	Richmond	92.2	50%	46.1
RP	CitiPower	Russell Place	34.7	100%	34.7
SB	CitiPower	Southbank	353.3	100%	353.3
SO	CitiPower	South Melbourne	164.2	50%	82.1
TP	CitiPower	Tavistock Place	11.1	100%	11.1
VM	CitiPower	Victoria Market	395.1	100%	395.1
WA	CitiPower	Celestial Avenue	85.2	100%	85.2
WG	CitiPower	Westgate	359.9	100%	359.9
FT	Jemena	Flemington	153.1	100%	153.1
Total					4,515

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 Victoria is Origin's [Small Business Peak Anytime Tariff](#) which has an energy charge of 26.7 c/kWh. . (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.) Minimum residential Feed In Tariff in Victoria is 11.3c/kWh inc GST (although this will change from July 2018) but for commercial customers, there is no minimum FIT and it would depend on a negotiation with the retailer.

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.

Financial Savings

$$= \text{Tariff}_{\text{import}} \times \text{Energy}_{\text{self-consumed}} + \text{Tariff}_{\text{export}} \times \text{Energy}_{\text{exported}}$$

Based on these estimates,

$$\text{Financial Savings} \approx (\text{Tariff}_{\text{import}} \times 60\% + \text{Tariff}_{\text{export}} \times 40\%) \times \text{Energy}_{\text{Total}}$$

$$\text{Financial Savings } (\$) \approx (0.267 \times 60\% + 0.113 \times 40\%) \times \text{Energy}_{\text{Total}}$$

Results

Table 6 presents a summary of the results of the rooftop suitability assessment for the Melbourne LGA. 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. A comprehensive breakdown of the results by method and input data source are presented in Appendix B.

The 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 31%, corresponding to 377 MW of PV potential with an expected annual yield of 451 GWh. The equivalent CO₂ emission savings are 467 kt per year. These values were calculated using the LiDAR data as the input data source in conjunction with NREL's hillshade and orientation method.

The average of the two methods indicated that an area equal to 40% of the available roof surfaces could be used to accommodate PV, corresponding to 461 MW of PV potential with an expected annual yield of 548 GWh, with corresponding potential CO₂-equivalent emission savings of 567 kt per year.

The average estimate of PV generation (548 GWh) equates to 12% of the 4,515 GWh of estimated load within the same area. There is an estimated 4.97 MW of existing PV capacity installed on Melbourne LGA rooftops, approximately 1% of the potential capacity. The electricity generation and emissions savings calculated would therefore be almost all additional. The estimated potential financial savings are \$112million, although this is highly dependent on the specific circumstances of the building occupants.

The rooftops with the largest PV potential in Melbourne have been mapped (Figure 17below). More detailed images appear within the report.

Table 6: Summary of results categorised by the Melbourne City Suburbs

Melbourne Suburb	Percentage Useable Area		Capacity (MW)		Yield (GWh)	
	Average	Std	Average	Std	Average	Std
All	37.9%	7.6%	460.9	92.2	547.7	106.4
Carlton	34.8%	7.9%	29.9	6.7	35.2	7.9
Carlton Nth	40.2%	8.7%	1.3	0.3	1.6	0.3
CBD	21.7%	9.0%	34.8	14.5	39.4	15.7
CBD Nth	29.9%	9.4%	11.8	3.7	13.7	4.3
CBD Sth	36.2%	8.7%	27.9	6.7	32.6	7.6
Docklands	36.9%	8.7%	35.5	8.4	42.1	9.7
East Melbourne	34.2%	8.0%	16.6	3.9	19.1	4.5
Fishermans Bend	54.4%	5.2%	46.0	4.4	56.6	5.2
Flemington	44.2%	7.5%	12.1	2.0	14.5	2.3
Jolimont	30.1%	10.3%	2.9	1.0	3.5	1.2
Kensington Est	44.0%	7.7%	15.8	2.8	19.0	3.3
Kensington Wst	33.2%	7.2%	21.3	4.6	25.1	5.4
North Melbourne Est	38.8%	7.9%	20.2	4.1	23.8	4.9
North Melbourne Wst	46.2%	7.3%	31.0	4.9	37.1	5.8
Parkville	36.6%	7.1%	31.0	6.0	36.7	7.1
Port Melbourne	52.5%	5.3%	25.7	2.6	31.7	3.1
South Wharf	66.4%	22.4%	5.7	1.9	6.9	2.4
South Yarra	35.9%	9.4%	13.3	3.5	15.4	4.0
Southbank	32.9%	9.5%	23.6	6.8	27.3	7.6
West Melbourne	47.6%	9.3%	54.5	10.6	66.3	12.4

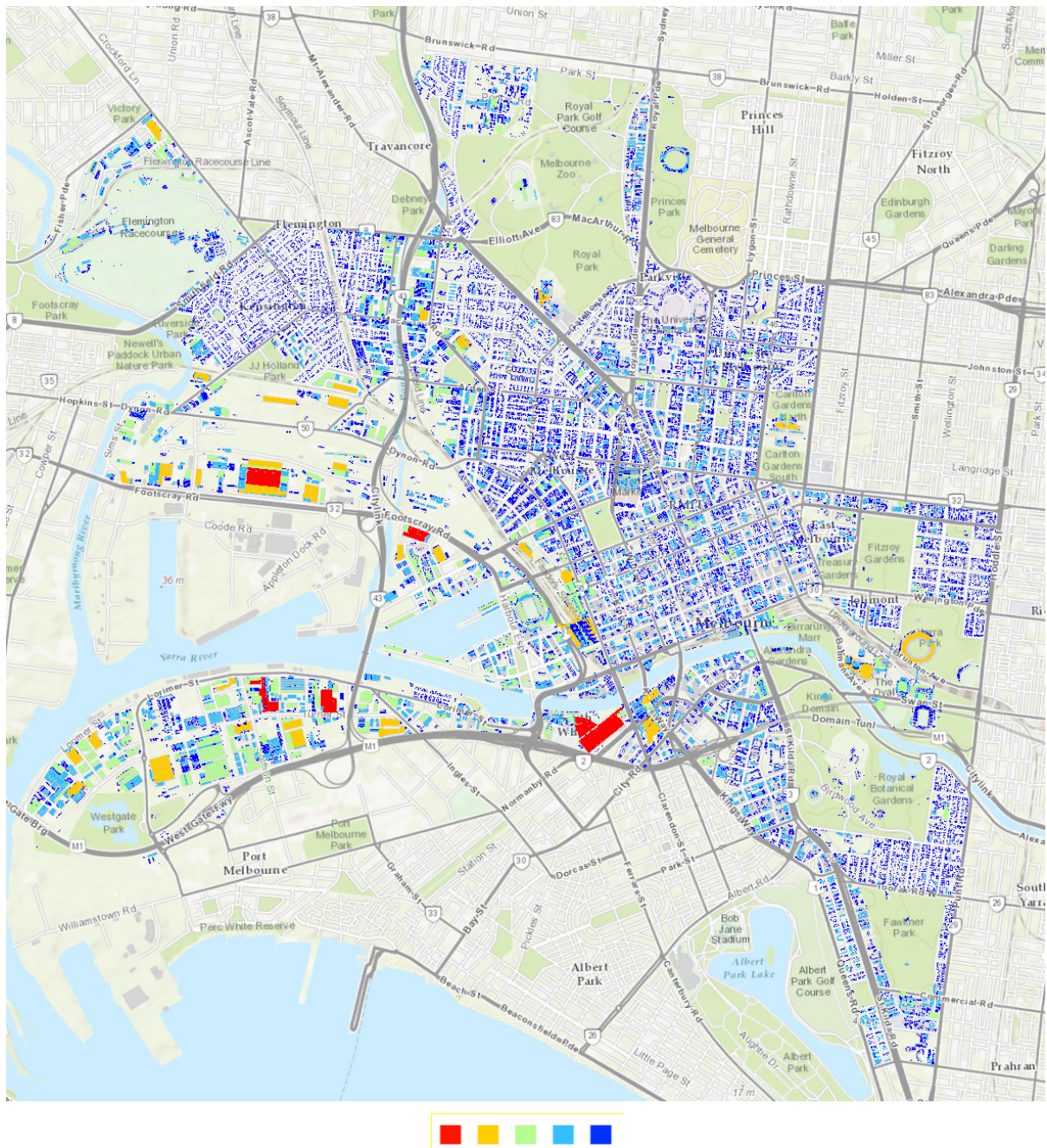


Figure 17: Rooftops with Largest PV Potential in Melbourne LGA

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 Melbourne buildings: Flinders Street rail station, Melbourne Cricket Ground (MCG) and the Crown Casino.

Methodology

The case studies were assessed by combining the GIS analysis used to assess the PV potential of Melbourne LGA with a visual assessment of the building roof profiles using aerial imagery.

Assessment of Roof Area

Firstly, Method 1 above was used to identify developable roof planes: continuous areas greater than 10m² receiving 80% of the annual insolation for an unshaded horizontal surface (3.48 kWh/m²/day).



Figure 18: Developable Planes with > 3.48 kWh/m²/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 19: 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 20)



Figure 20: 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 Melbourne (using the Melbourne RMY weather file from Energy Plus[8]) was calculated. Figure 21 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.

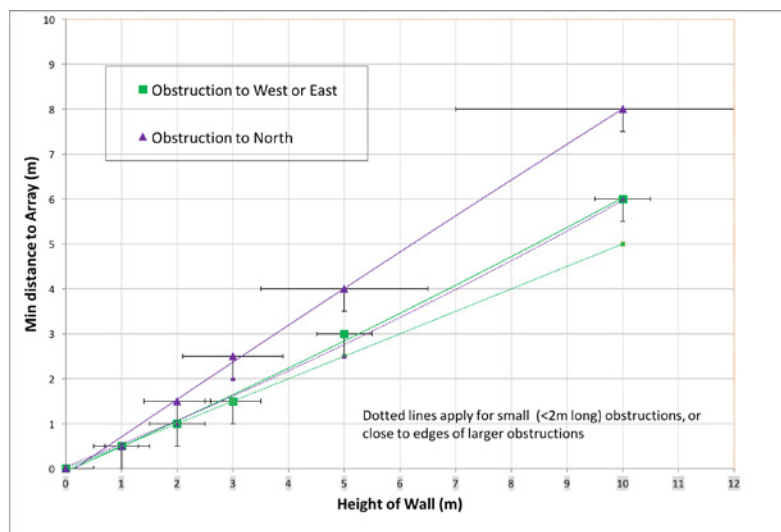


Figure 21: Nearest distance to obstruction to give 80% annual output

Nearmap's Solar Tool was then used to arrange 1.6m x 1.0m PV panels on the usable roofspace. The slope of the roof was determined from the GIS building slope layer and visual imagery. 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/m²), 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.

Calculation of Emissions Offset

The potential CO₂-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 Victoria (1.08 kg CO₂-e/kWh[6]) 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 CO₂-e /kW[7])

Results

Table 7 shows the potential roof area available for PV installation on each building, based on the data and visual imagery available, while **Table 8** shows the projected array capacity and expected annual energy production.

All three case study buildings have a below average proportion of usable roof area. Much of the roof of the Crown Casino is used as recreational space, while some of it experiences significant shading. The main building of Flinders Street Station has an irregularly shaped roof, with multiple obstacles. Nevertheless, these 2 buildings have significant solar potential and can accommodate PV arrays of 1.5MW and 0.9MW respectively. For the MCG, 45% of the roof area is theoretically usable, with potential for a 2.2MW array.³

Table 7: Available roof areas

Site	Building Footprint (m ²)	Total Roof Area (m ²)	Developable Planes (m ²)	Array Area (m ²)	Array Area / Roof Area
Flinders St Station	19,000	17,220	12,424	6,144	36%
MCG	70,000	31,370	22,732	14,262	45%
Crown Casino	52,630	38,745	15,707	9,544	25%

³ Although structural concerns are outside the remit of this report, we believe there are engineering constraints on the installation of PV on the MCG, and the owners are seeking alternative energy-sharing arrangements.[9]

The proposed PV arrays are illustrated in Figure 22 -Figure 24 below.

Table 8: Expected Annual Energy Production

Site	Array Power (kW)	Annual Energy Production (w/o shading) (MWh/year)	Average Yield across developable planes (kWh/kW/day)	Expected Annual Energy Production (MWh/year)
Flinders St Station	960	1193	3.40	1054
MCG	2229	2822	3.47	2436
Crown Casino	1491	1891	3.47	1612

Table 9 presents the estimated carbon offsets for each system and shows that these three buildings could save an estimated 5.3 kilotonnes of carbon emissions each year and could supply the equivalent of 1040 households, based on the average 2014 electricity demand of a Victorian household being 4905 kWh [1].

Table 9: Carbon offset and household energy equivalents

Site	Expected Annual Energy Production (MWh/year)	Emissions Offset (Tonnes CO₂-e / year)	Average household equivalent
Flinders St Station	1054	1091	215
MCG	2436	2522	497
Crown Casino	1612	1668	329
Totals	5102	5281	1040

Before & After Illustrations

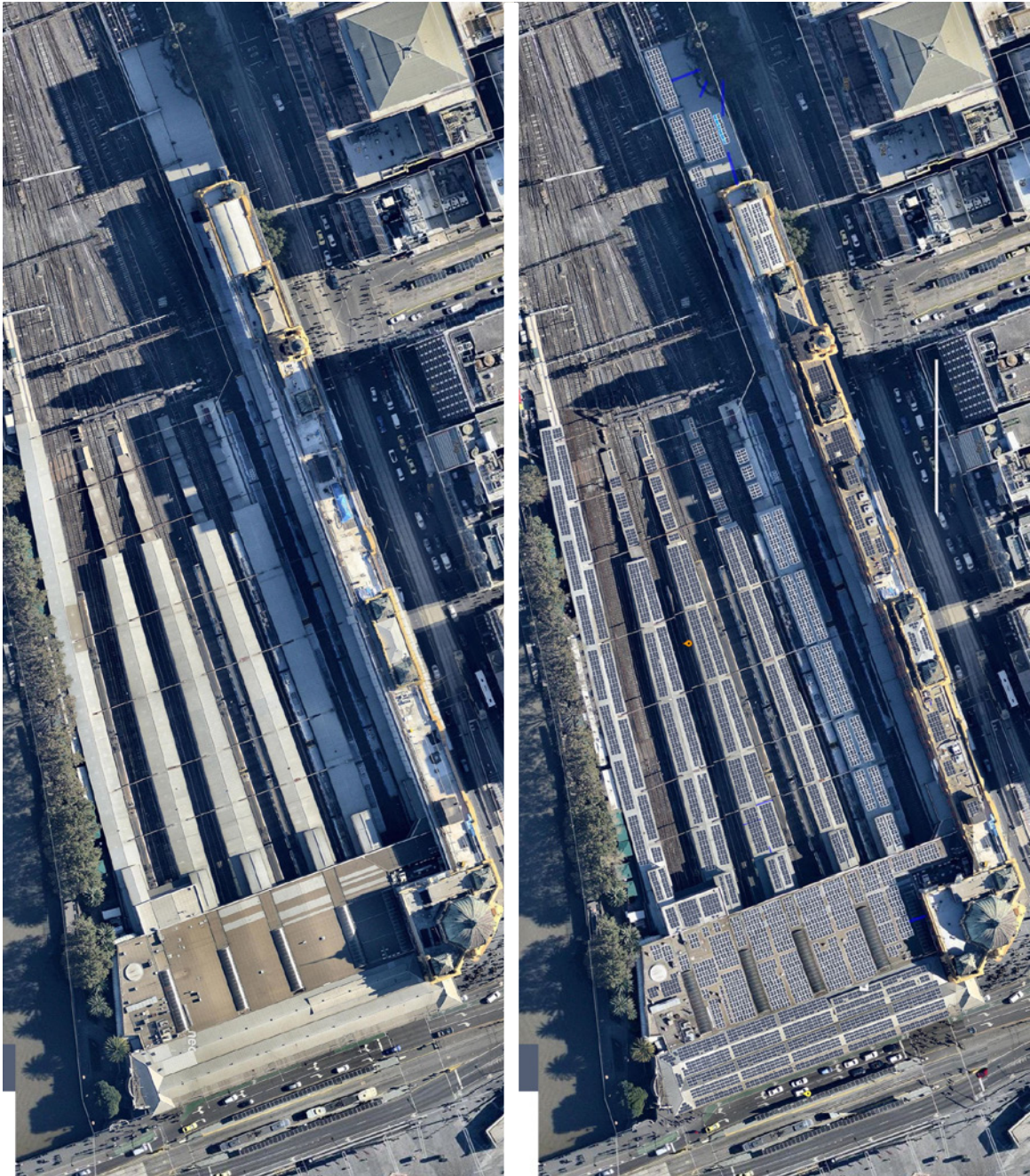


Figure 22: Flinders St Station, now and with a potential PV array



Figure 23: MCG, now and with a potential PV array

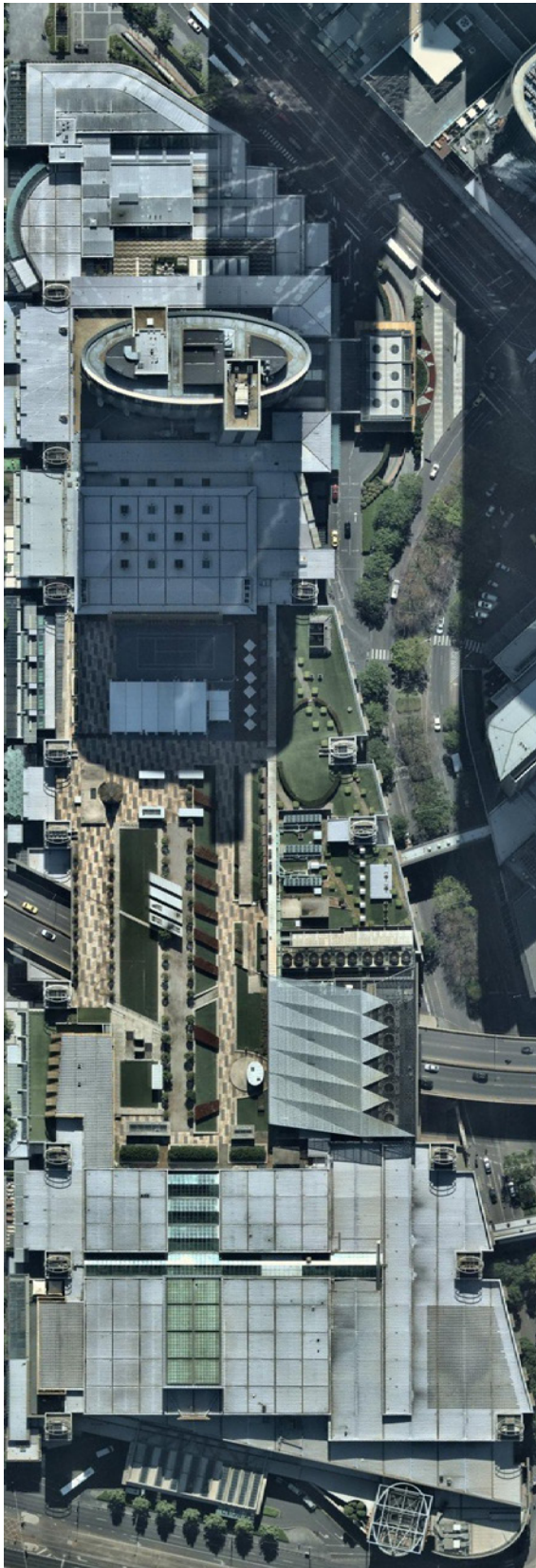


Figure 24: Crown Casino, now and with a potential PV array

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

Figure 25 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/m²/day. The simplified APVI SPT methodology enables geospatial calculation of yield for each identified roof surface.

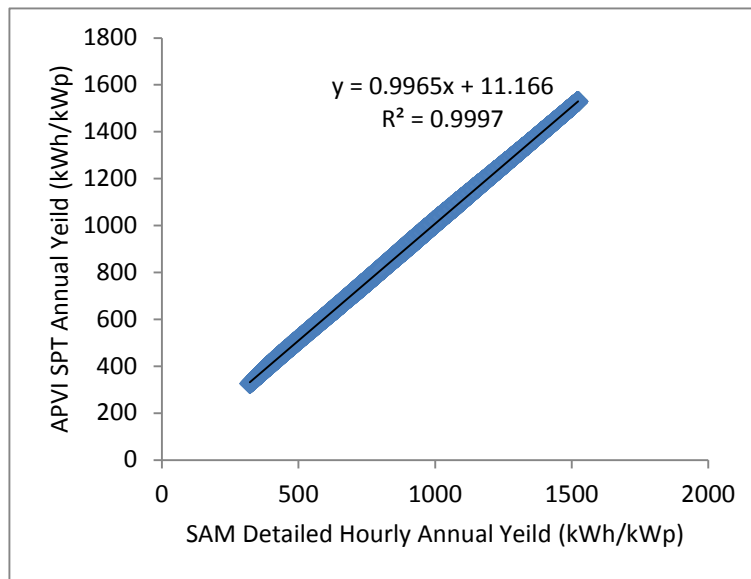


Figure 25: Correlation between APVI SPT simplified method to calculate annual yield from annual average insolation vs. detailed hourly simulations of PV performance from NREL's SAM. Results presented for each 1 degree combination of tilt (0-90°) and orientation (0-360°).

Appendix B – Assessment of Rooftop Suitability – Detailed Results

Table 10: Detailed results of rooftop suitability calculated using AAM DSM and 3D buildings

Melbourne Suburb		Method 1 - Insolation Limit (3.48 kWh/m ² /day) - 3D Buildings				Method 2: NREL Hillshade E/NE/N/NW/W (13.03) - 3D Buildings			
	Total Area (ha)	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)
All	779.24	346.95	44.5%	542.11	642.92	345.21	44.3%	539.39	636.64
Carlton	54.99	23.01	41.8%	35.95	42.30	22.74	41.3%	35.53	41.66
Carlton Nth	2.12	1.08	51.1%	1.69	2.01	0.91	42.9%	1.42	1.72
CBD	102.85	26.08	25.4%	40.74	46.89	33.52	32.6%	52.37	57.78
CBD Nth	25.31	9.48	37.5%	14.81	17.21	9.77	38.6%	15.27	17.52
CBD Sth	49.27	20.48	41.6%	31.99	37.53	22.46	45.6%	35.10	40.55
Docklands	61.56	27.28	44.3%	42.63	50.52	27.51	44.7%	42.98	50.43
East Melbourne	31.08	12.59	40.5%	19.67	22.78	12.94	41.6%	20.22	23.22
Fishermans Bend	54.21	32.42	59.8%	50.66	61.90	31.30	57.7%	48.91	60.00
Flemington	17.46	9.37	53.7%	14.63	17.42	7.98	45.7%	12.47	15.12
Jolimont	6.19	2.36	38.2%	3.69	4.52	2.46	39.7%	3.84	4.65
Kensington Est	23.00	11.94	51.9%	18.66	22.33	11.29	49.1%	17.64	21.25
Kensington Wst	41.00	16.99	41.4%	26.54	31.17	15.19	37.0%	23.73	28.21
North Melbourne Est	33.39	15.61	46.8%	24.40	28.73	14.76	44.2%	23.06	27.27

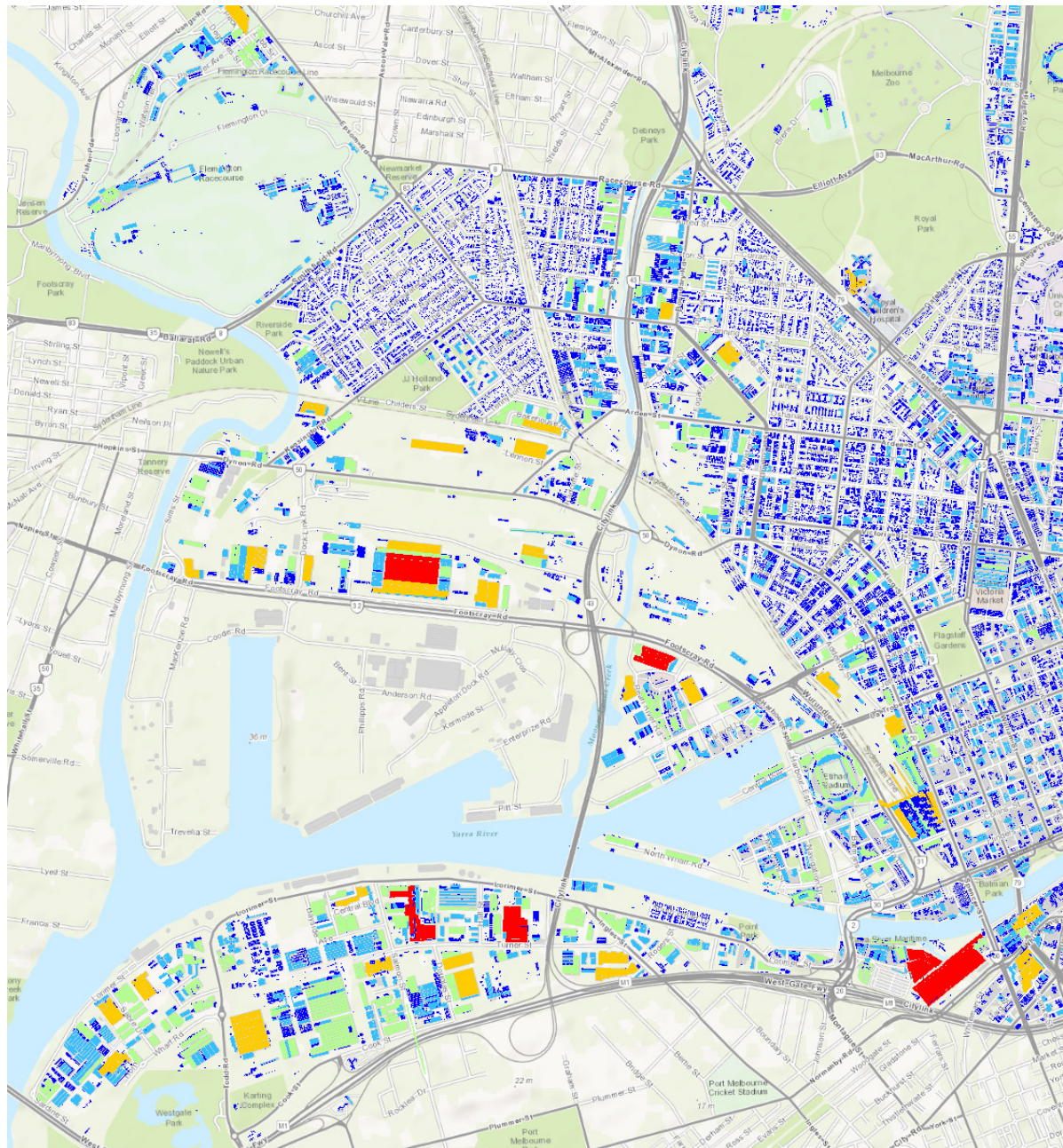
North Melbourne Wst	42.95	23.32	54.3%	36.44	43.40	21.64	50.4%	33.81	40.56
Parkville	54.30	23.39	43.1%	36.55	43.23	23.05	42.4%	36.01	42.46
Port Melbourne	31.28	17.98	57.5%	28.10	34.51	17.72	56.7%	27.69	34.17
South Wharf	5.45	2.46	45.1%	3.84	4.68	2.67	49.0%	4.17	4.98
South Yarra	23.68	10.34	43.6%	16.15	18.75	10.52	44.4%	16.44	18.97
Southbank	45.95	17.85	38.9%	27.89	32.40	19.75	43.0%	30.87	35.09
West Melbourne	73.19	42.92	58.6%	67.06	80.64	37.03	50.6%	57.86	71.03

Table 11: Detailed results of rooftop suitability calculated using Melbourne North 2013 LiDAR dataset from NSW LPI

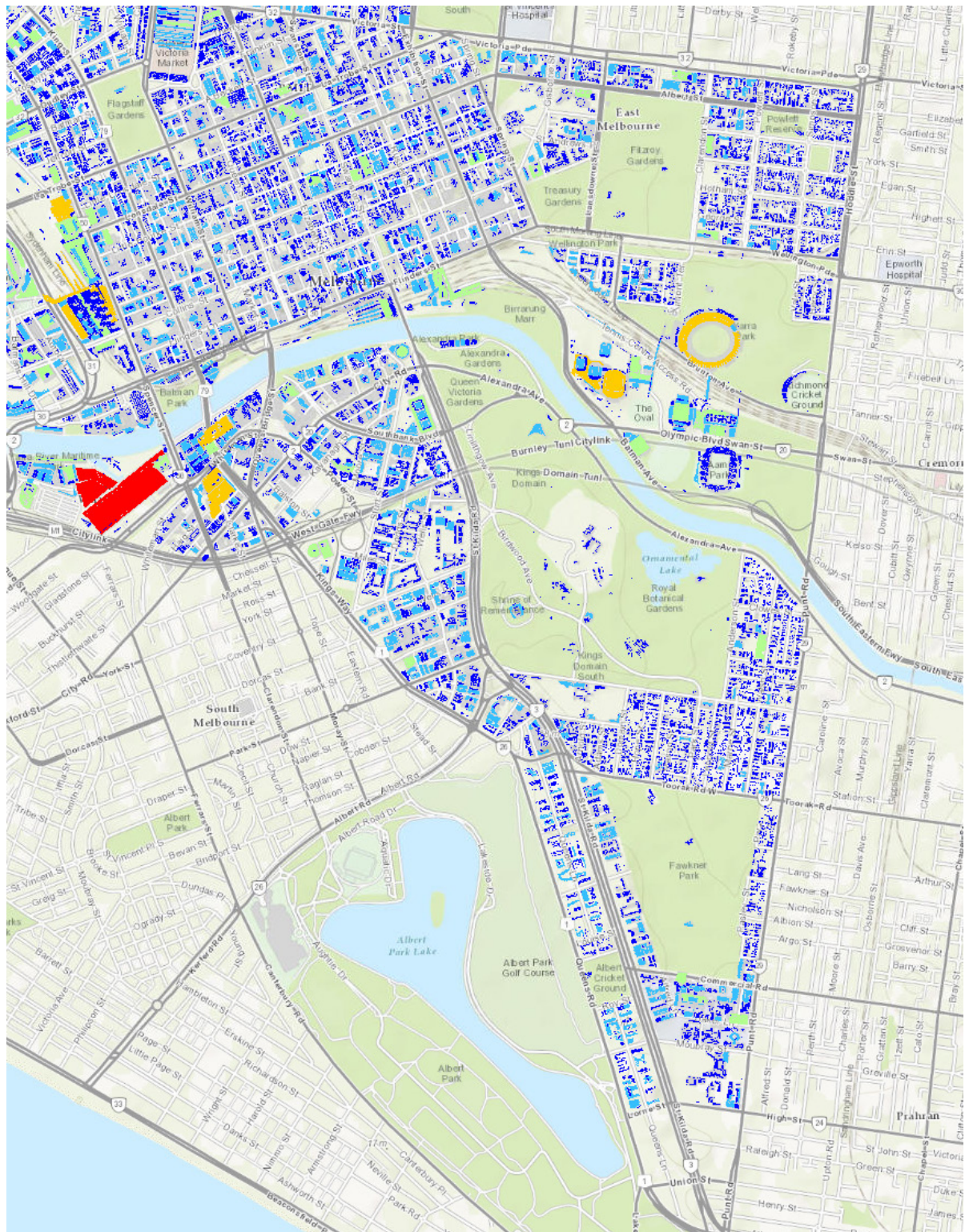
Melbourne Suburb	Method 1 - Insolation Limit (3.48 kWh/m2/day) - LiDAR				Method 2: NREL Hillshade E/NE/N/NW/W (13.03) - LiDAR			
	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)	Developable (ha)	% Useable	Capacity (MW)	Yield (GWh)
All	246.44	31.6%	385.06	460.93	241.37	31.0%	377.14	450.48
Carlton	15.41	28.0%	24.07	28.43	15.39	28.0%	24.04	28.26
Carlton Nth	0.74	34.8%	1.16	1.40	0.68	31.8%	1.06	1.29
CBD	13.04	12.7%	20.38	23.84	16.54	16.1%	25.84	29.10
CBD Nth	5.53	21.9%	8.64	10.04	5.50	21.7%	8.59	9.91
CBD Sth	13.71	27.8%	21.43	25.45	14.68	29.8%	22.94	26.84
Docklands	18.13	29.5%	28.33	33.89	18.04	29.3%	28.19	33.60
East Melbourne	8.31	26.7%	12.99	15.06	8.62	27.7%	13.47	15.46

Fishermans Bend	27.56	50.8%	43.07	53.01	26.59	49.0%	41.55	51.36
Flemington	7.24	41.5%	11.31	13.62	6.27	35.9%	9.80	12.01
Jolimont	1.24	20.0%	1.94	2.36	1.39	22.5%	2.18	2.58
Kensington Est	8.78	38.2%	13.73	16.50	8.43	36.7%	13.17	15.89
Kensington Wst	11.47	28.0%	17.93	21.18	10.78	26.3%	16.85	20.01
North Melbourne Est	11.00	32.9%	17.19	20.09	10.40	31.2%	16.26	19.06
North Melbourne Wst	17.64	41.1%	27.56	33.00	16.78	39.1%	26.23	31.54
Parkville	16.66	30.7%	26.03	30.87	16.39	30.2%	25.60	30.28
Port Melbourne	15.43	49.3%	24.10	29.81	14.61	46.7%	22.84	28.47
South Wharf	4.64	85.2%	7.25	9.02	4.70	86.3%	7.35	9.09
South Yarra	6.48	27.4%	10.13	11.87	6.69	28.2%	10.45	12.13
Southbank	10.84	23.6%	16.94	20.01	11.97	26.1%	18.71	21.68
West Melbourne	32.58	44.5%	50.90	61.49	26.90	36.8%	42.03	51.89

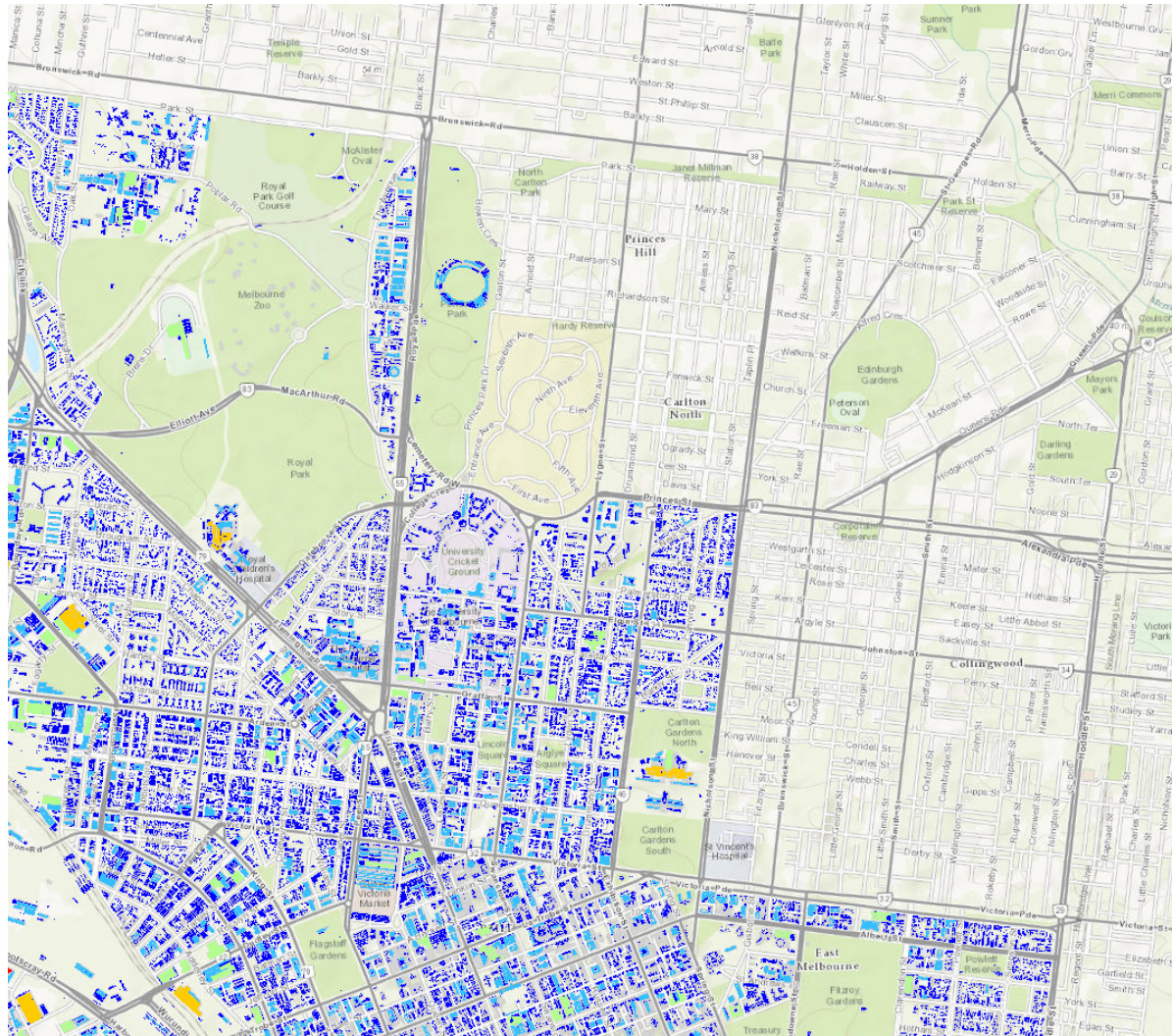
Appendix C – Detailed Maps of Rooftops with Large Solar Potential



high - med - low



high - med - low



high - med - low