HOW MUCH ROOFTOP SOLAR CAN BE INSTALLED IN AUSTRALIA?

PREPARED FOR:

Clean Energy Finance Corporation and Property Council of Australia

UTS Institute for Sustainable Futures

AUSTRALIAN PV INSTITUTE

UNSW SYDNEY

isf.uts.edu.au

About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures.
We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

For further information visit: **www.isf.uts.edu.au**

The School of Photovoltaic and Renewable Energy Engineering (SPREE) at the University of New South Wales (UNSW) has an international reputation for solar energy research. The SunSPoT Solar Potential Tool, which is the technical basis for the solar potential estimates in this report and a series of Solar Potential assessments published by the Australian PV Institute (APVI) for major Australian Cities, was developed and validated at SPREE for APVI to help inform and facilitate ongoing investment in solar photovoltaic (PV) systems in Australia. This work is part of a broader renewable energy systems research program at SPREE, including renewable energy resource assessment, performance analysis, modelling and mapping, renewable and distributed energy integration, and building energy modelling.

The Australian Photovoltaic Institute (APVI) is a membership organisation that exists to support the increased development and use of PV via research, analysis and information. We focus on data analysis, independent and balanced information, and collaborative research, both nationally and internationally, providing analysis to industry, regulators and government on a range of technical and policy related issues. We prepare Australia's Annual PV in Australia Report and represent Australia on the IEA's Photovoltaic Power Systems and Solar Heating and Cooling research programmes. A detailed summary of APVI projects can be sourced at our website www.apvi.org.au, as well as a range of resources including our solar mapping tool, SunSPoT. Our work is intended to be of use not only to our members but also to the broader community.

Institute for Sustainable Futures
University of Technology Sydney
PO Box 123 Broadway, NSW, 2007
www.isf.edu.au

Research team

Mike Roberts
Research Associate
University of New South Wales

Kriti Nagrath
Senior Research Consultant
Institute for Sustainable Futures

Chris Briggs
Research Principal
Institute for Sustainable Futures

Jessie Copper
Research Associate
University of New South Wales

Anna Bruce
Senior Lecturer
University of New South Wales

John Mckibben
Advisor
Institute for Sustainable Futures

Citation

Please cite as: Roberts, M., Nagrath, K. Briggs, C., Copper, J., Bruce, A., and Mckibben, J (2019) *How much Rooftop Solar can be Installed in Australia?* Report for the Clean Energy Finance Corporation and the Property Council of Australia. Sydney.

Acknowledgements

The authors thank the Clean Energy Finance Corporation and the Property Council of Australia who commissioned the research project for advancing thought leadership in the sector. We would also like to thank OMNILINK for supplying the spatial data for the analysis.

Glossary

Abbreviation	Term
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
APVI	Australian Photovoltaic Institute
AREMI	Australian Renewable Mapping Initiative
CBD	Central Business District
CER	Clean Energy Regulator
CSV	Comma-separated values file (a delimited text file type)
GW	Gigawatt (equivalent to 1000 megawatts)
GWh	Gigawatt-hour
ISF	Institute for Sustainable Futures
LGA	Local Government Area
LiDAR data	Light Detection and Ranging (remote sensing data)
MW	Megawatt (equivalent to 1000 kilowatts)
NEM	National Electricity Market
NREL	National Renewable Energy Laboratory
NSW	New South Wales
NT	Northern Territory
POA	Postal Areas
PSMA	Public Sector Mapping Agencies
PV	Photovoltaic
QLD	Queensland
SA	South Australia
SAM	System Advisor Model
SF	Shading Factor
SPT	APVI Solar Potential Tool
SWIS	South-West Inter-Connected System
TAS	Tasmania
TW	Terawatt (equivalent to 1000 gigawatts)
TWh	Terawatt-hours
UA	Useable Area
UNSW	University of New South Wales
UTS	University of Technology Sydney
VIC	Victoria
W	Watt
WA	Western Australia

Contents

Executive Summary

Over 2 million solar systems have been installed around Australia, mostly on the roofs of homes. Australia has become a world-leader in solar power.

However, rooftop solar is only just starting to take off on industrial and commercial sites. How much rooftop solar could be installed in Australia?

Using two path-breaking datasets, this study provides the first estimate for Australia:

- a top-down estimate of available roof space generated by OMNILINK using the PSMA Geoscape database – a government-owned initiative which has mapped all the buildings in Australia for the first time; and
- a bottom-up estimate of solar potential which includes a range of constraints on the available rooftop space for solar (e.g. shading, orientation) using the data from detailed studies in inner-city areas undertaken by UNSW for the APVI across five capital cities.

The estimated total potential for rooftop solar is 179 gigawatts with an annual energy output of 245 terawatt-hours.

What do these figures mean?

The potential annual output from rooftop solar is greater than current consumption in the national electricity market (just under 200 TWh per year).

Australia is currently using less than 5 per cent of the potential capacity for rooftop solar.

Where is the greatest potential for rooftop solar?

- Around half of the unused potential for rooftop solar is in residential zones.
- While most would think of dense urban centres in capital cities for rooftop solar, the second largest potential (34 GW) is in primary / rural production zones.
- Commercial and industrial zones together have the potential for 26 GW of rooftop solar.

In interpreting these results, it is important to understand that planning zones do not correspond neatly with building types. There are commercial buildings inside residential, mixed, industrial and primary production zones. Consequently, some of the capacity inside primary and rural production zones is likely to be commercial and industrial buildings.

As a first study, there will be further data that will refine this estimate in time – and beyond refinements of the APVI methods for factors such as shading there will be rooftops that are not actually suitable for solar (e.g. due to structural integrity issues).

Our study does not suggest Australia could or should source all its power from rooftop solar. But noting these caveats, our study does indicate that even with the strong recent growth, Australia has only just scratched the surface of the potential. There are still many barriers to rooftop solar which if they were to be addressed by governments, investors and communities could unlock a large volume of clean energy.

Maps of the rooftop solar potential for each Local Government Area are available on the Australian Renewable Mapping Initiative (AREMI) and APVI Map website.

1 Introduction

Australia is a world-leader in solar PV, driven primarily by household rooftop installations. There are over 2 million small scale installations around the country with an installed capacity of 8 GW (CER, 2018). In total, including large-scale solar power, Australia has installed over 10.1 GW of solar PV, capable of delivering 14.6 TWh and meeting more than 5.5 per cent of Australia's energy demand (APVI, 2018a).

2018 was a record-setting year for solar power in Australia. In September 2018, a new record for large scale solar (667 MW) was registered (APVI, 2018a). Rooftop solar on residential and commercial buildings is also growing with 200,000 new installations in 2018 (CER, 2018).

However, there is still a huge untapped potential for rooftop solar power in Australia. APVI estimates only one-fifth of all residential buildings have installed a PV system.

The growth of solar power is already reshaping the energy landscape in Australia – but just how much solar power could be installed? What is the potential for solar power in Australia?

For the first time, this report brings together two data-sets and methodologies to estimate the potential for rooftop solar power in Australia.

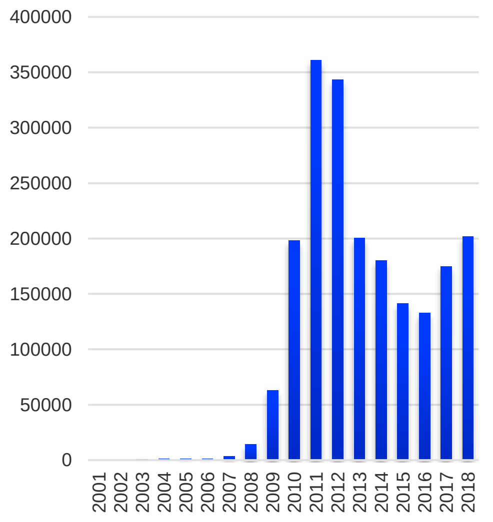
- a top-down estimate of available roof space generated by OMNILINK using the PSMA Geoscape database which has mapped over 96 per cent of Australian buildings; and
- a bottom-up estimate of solar potential using the data from detailed studies in inner-city areas undertaken by UNSW for the APVI across five capital cities.

In addition to the total potential for rooftop solar power across Australia, estimates are generated for different zones (e.g. residential, commercial), states and Local Government Areas.

2 The growth of rooftop solar in Australia

The growth of rooftop solar has been extraordinary. There was a surge in installations of rooftop solar at the beginning of this decade driven by generous state feed-in-tariff schemes. The number of installations dropped sharply as that assistance was withdrawn, but growth is now accelerating again reflecting the falling costs of PV systems and rising cost of electricity.

Figure 1 Annual Solar Installations 2001-2018



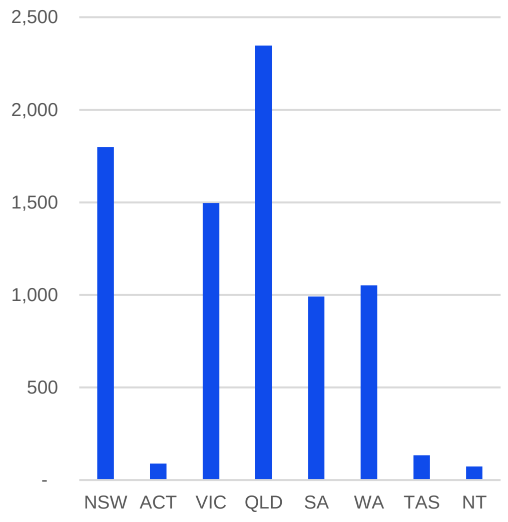
Source: (CER, 2018)

Australians have invested in over 8000 MW of rooftop PV. About one-fifth was added in 2018 alone. By the end of 2018, over 2 million small solar PV generation units were installed across Australia.

2.1 The States

The eastern states account for 70 per cent of the total installed capacity. Queensland has 600,000 installations (2.35 GW), NSW has 450,000 installations (1.8 GW) and Victoria has 380,000 installations (1.5 GW).

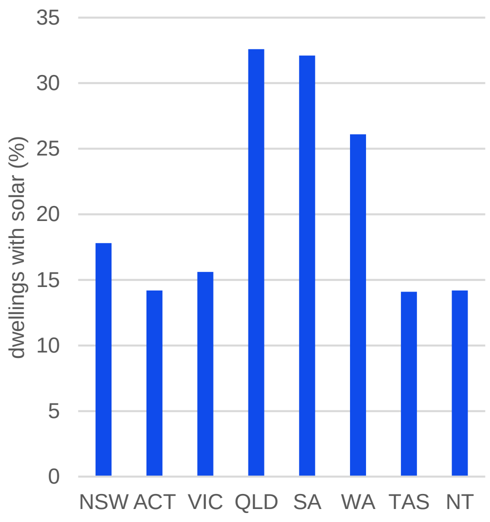
Figure 2 Solar PV, by State (MW)



Source: (CER, 2018)

The penetration of solar (the percentage of houses with solar power) is a better measure of the take-up. Solar penetration data shows Queensland, South Australia and Western Australia are the leaders. Around 1-in-3 of all houses in South Australia and Queensland have a solar PV installation.

Figure 3 Solar penetration in each state



Source: (APVI, 2018b)

2.2 The Top Solar Local Government Areas

Most of the top ten solar LGAs in Australia (number of installations) are in Queensland.

Table 1 Top Ten Solar LGAs in Australia

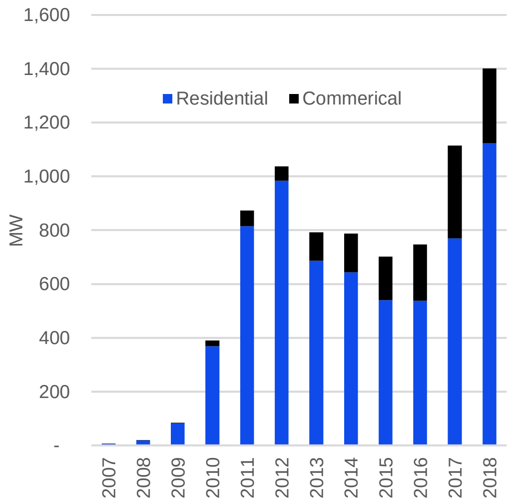
LGA	Installations	Total Capacity (MW)	% Houses
Brisbane (C), QLD	114,000	428	30.8
Moreton Bay (R), QLD	64,370	239	38.6
Gold Coast (C), QLD	61,950	242	32.1
Sunshine Coast (R), QLD	47,350	180	40.4
Logan (C), QLD	41,780	153	37.1
Onkaparinga (C), SA	26,840	94	36.6
Wanneroo (C), WA	25,310	91	33.2
Redland (C),QLD	24,630	82	42.1
Ipswich (C), QLD	24,360	88	31.9
Townsville (C), QLD	22,950	403	29.4

Source: (APVI, 2018b)
Note: (C) are Cities and (R) are Regional Councils

2.3 Residential & Commercial Buildings

While the majority of PV installations in Australia are residential, rooftop solar on commercial buildings is now growing.

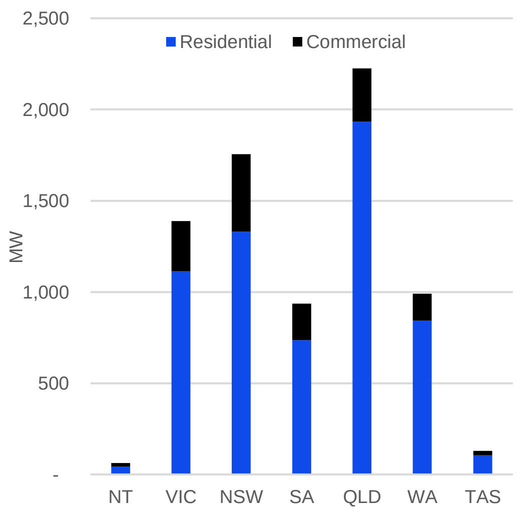
Figure 4 Solar Installations, Commercial and Residential buildings by Year (MW)



Source: (APVI, 2018b)

In the commercial space, growth is quite evenly spread. NSW leads with 400 MW followed by Queensland and Victoria which are each approaching 300 MW.

Figure 5 Solar Installations on Residential & Commercial Buildings, by State (MW)



Source: (APVI, 2018b)

3 Research Approach

The aim of this report is to produce the first estimate of the potential for rooftop solar across all Australian buildings. While other studies to date have examined solar potential for residential buildings (Roberts, Copper and Bruce, 2018) or within particular areas (Copper, Roberts and Bruce, 2017c, 2017b, 2017a, 2018a, 2018b), this is the first estimate of all rooftop solar potential in Australia. This section provides an overview of the methodology with more detailed explanations in annexes.

3.1 Methodology

The PSMA[1], an unlisted public company owned by Australia's Federal, State and Local Governments, has produced the first comprehensive census of Australia's buildings. The APVI has undertaken first-of-kind studies to generate detailed estimates of solar potential within Australian cities.

The report combines these two datasets:

- a top-down estimate of available roof space generated by OMNILINK using the PSMA Geoscape database which has mapped over 96 per cent of Australian buildings; and
- a bottom-up estimate using the data from rooftop solar potential in inner-city areas undertaken by UNSW for the APVI across five capital cities.

Top-down: estimating available roof space

A spatial analysis was undertaken to estimate the total roof area of the Australian building stock. This was categorised by postcode and primary zoning.

Existing PSMA Geoscape Building polygons were queried to extract all buildings within each state. This provided building counts and areas for each building.

The extracted building polygons were linked to the Postcode Boundaries dataset. The PSMA's Administrative Boundary dataset[2] was used to link postcodes to a Locality and then an LGA.

PSMA allocates buildings across Australia (Table 2) to one of 12 generic planning zones. State planning zones vary significantly so they are mapped against these 12 generic codes to create a uniform categorisation across the country (See Annex 6.2.2)

Table 2 PSMA generic building zones

Code	Type
0	Unknown
1	Commercial / Business
2	Community Use
3	Conservation / National Park
4	Industrial / Utilities
5	Mixed Use
6	Recreational / Open Space
7	Residential
8	Rural / Primary Production
9	Special Use
10	Transport / Infrastructure
11	Water

[1] For information on PSMA see https://www.psma.com.au/

[2] Comprehensive national collection of government boundaries, statistical boundaries, and electoral boundaries.

Each state is divided into LGAs, postcodes, localities and planning zones.

Bottom-up: estimating solar potential

APVI's analysis of solar potential in capital cities was used to derive estimates of solar potential across Australia (Copper, Roberts and Bruce, 2017c, 2017b, 2017a, 2018a, 2018b). APVI adapted the method developed for the APVI Solar Potential Tool[3] (SunSPoT) (Copper and Bruce, 2017) to assess the solar potential of building rooftops in five Australian cities (City of Sydney LGA, City of Melbourne LGA, Adelaide CBD, Canberra CBD, and Brisbane CBD).

The method uses satellite data and accounts for solar radiation and weather at the site; roof area, slope and orientation; and shading from nearby buildings and vegetation. Suitable roof planes were identified based on a threshold insolation level and a minimum contiguous roof area. Two databases and two methods were used to determine suitable roof planes (See Annex 0 for detailed methodology).

Estimating solar potential by planning zone

The solar potential maps of the urban centres were overlaid with LGA and State Planning Zones that were mapped to the 12 generic zones used by OMNILINK to categorise buildings across the country (See Annex 6.2.2).[4]

Flat and pitched usable roof surfaces were aggregated within each OMNILINK planning zone and the usable area (UA) and median shading factor (SF) were calculated.

SF = (Annual Insolation)⁄(Insolation on unshaded surface of same tilt and orientation)

Mean values for these figures were then calculated for each OMNILINK planning zone, using the two methods and two datasets, across the five mapped cities. Each planning zone has its own values for usable area and shading factor with the exception of Zone 0 (Unknown) and Zone 8 (Rural / Primary Production) which are not found in the urban areas mapped by APVI. These zones were assigned the same values as Zone 5 (Mixed).

This analysis provided average figures of percentage useable roof area and shading factor for flat and sloped roofs in each planning zone within the mapped urban areas.

Applying factors to the rest of Australia

The mean of the 5 city values for percentage of UA for each planning zone was calculated. Using sub-samples with building stock within urban areas that more closely resemble suburban and town contexts was considered. However, the variation between capital cities was found to be far more significant than between different sub-zones within a city. Consequently, an average of capital cities is more representative than a sub-sample of more suburban areas within the mapped areas of capital cities.

PSMA's Geoscape data was used to extract data on roof area, by planning

[3] The APVI Solar Potential Tool is an online tool for electricity consumers, solar businesses, planners and policymakers to estimate the potential for electricity generation from PV on building roofs.

[4] Zone allocations are aligned with state and city planning zones, rather than building types, so that, for example, not all Zone 7 buildings are residential, while residential buildings also exist in other zones.

zone. The total roof area for each planning zone in each postcode area was multiplied by the percentage of UA for each zone to determine the amount of usable roof space and an estimate made of the proportion of flat and pitched roofs in each zone. (See Annex 6.2.4).

A PV intensity of 156.25 W/m^2 (based on generic 250 W modules sized 1.6 m x 1.0 m) was applied to the usable areas to determine PV capacity for each zone and postal area (POA). These results give an estimate for the total potential rooftop PV capacity of Australian buildings.

NREL's System Advisor Model[5] (SAM) was used to estimate the annual energy generated by the potential PV capacity. The model inputs include irradiance and temperature for a reference meteorological year (derived from weather data collected at the nearest of 196 BOM weather stations), tilt and orientation (assuming 90% of usable residential roofs and 10% of other usable roofs are pitched at 25° and evenly distributed between all northerly orientations, with remaining roofs being flat) and shading characteristics from the GIS modelling, with a derating factor of 0.77 to account for electrical efficiency losses, soiling, degradation etc.

Mapping the results

This information was then plotted on QGIS maps. CSV files with the data were extracted and maps have been uploaded on AREMI and the APVI Solar Map.

Figure 6 summarises the methodology.

---

[5] https://sam.nrel.gov/

Figure 6 Research Methodology

4 The potential for rooftop solar in Australia

This study estimates the total potential for rooftop solar on Australian buildings to be 179 gigawatts with an annual output of 245 terawatt-hours.

What does this mean?

Firstly, it is greater than the current electricity consumption on the main grids in Australia. Just under 200 terawatt-hours was consumed in the National Electricity Market (NEM) and just under 20 terawatt-hours was consumed in Western Australia's grid (the South-West Inter-Connected System) in 2018.

Secondly, even with the high recent growth, Australia is using less than 5 per cent of the potential capacity for rooftop solar.

Thirdly, even under the high forecast used by the Australian Energy Market Operator for take-up to 2040, Australia would only be using 20 per cent of the technical potential for rooftop solar generation.

Table 3 Solar potential and demand

	PV Capacity (GW)	Annual Energy Output (TWh)
Existing Installations	8.1	8.1
AEMO's Forecast	21-56	31-50
Technical Potential	179	245
NEM + SWIS Consumption (2017-18)		214.5

Source: AEMO, 2018b, 2018a; CER, 2018; Department of the Environment and Energy, 2018; AER, 2019.

AEMO's high distributed energy resources case is their view on an accelerated uptake of rooftop PV (and other distributed energy and storage technologies), which projects almost 50 TWh of rooftop PV generation meeting 22 per cent of the total forecast NEM consumption in 2040 (AEMO, 2018b).

We are not suggesting Australia can or should be powered 100 per cent by rooftop solar. However, the study does highlight Australia is only using a small fraction of the potential for rooftop solar.

There a few caveats that should be noted with these figures.

- It is the first estimate combining PSMA's database and bottom-up data – as new data emerges the estimate will be refined.
- The study estimates useable roof area on the basis of slope, orientation and shading. However, it does not take into account the structural integrity of the buildings. The actual useable potential will be smaller than the estimates.
- The PSMA database has a higher number of dwellings than the Australian Bureau of Statistics because it includes other structures (e.g. sheds) on properties as well as the residence. These have been included in the estimate as these structures could host solar PV.
- This is the total potential of rooftop PV generation and includes already installed capacity as well (<5%).

This section presents the highlights of this study for states, planning zones and LGAs. The detailed maps are uploaded on the AREMI website and the APVI Solar Map.

4.1 Planning Zones

What type of buildings and zones have the most potential for rooftop solar? It is important to understand that the unit of analysis is the planning zone – the PSMA database does not identify the building use. Not all buildings in the residential zone are residences, and there are residential buildings in other zones as well.

The rooftop solar potential for different planning zones is listed in Table 4.

Table 4 Potential for rooftop solar in each planning zone

Zone	PV potential (GW)	Annual energy output (GWh)
1. Unknown	2.2	3,052
2. Commercial / Business	9.3	12,601
3. Community Use	3.9	5,371
4. Conservation / National Park	2.1	2,884
5. Industrial / Utilities	19.0	26,464
6. Mixed Use	4.0	5,584
7. Recreational / Open Space	1.7	2,346
8. Residential	96.0	1,30,153
9. Rural / Primary Production	33.9	46,680
10. Special Use	6.7	9,357
11. Transport / Infrastructure	0.6	774
12. Water	0.0	0

Over half of the potential is in residential planning zones (96 GW).

In a 2018 study, national residential solar potential was estimated to be between 43-61 GW (Roberts, Copper and Bruce, 2018). However, that study was based only on residential dwellings (as recoded in the ABS census) rather that all buildings in residential planning zones (as in this study). It may also underestimate the potential as the per-dwelling capacity was based on a study of City of Melbourne residential buildings, where average roof sizes are likely to be lower than in suburban and rural areas.

The present study applies average solar potential per square metre calculated for different planning zones in five capital cities and uses the PSMA database which covers 95 per cent of all buildings in Australia to calculate the roof area. Consequently, it is a more comprehensive study.

However, it is important to note one of the key factors in the higher figure in this study is the higher number of buildings. Roberts et. al. (2018) use ABS dwelling counts, not planning zones. The PSMA database includes all structures in the residential zones, not just residences. These have been included as these structures may also be able to host rooftop solar. In effect, the study assumes these structures have the same potential for rooftop solar as residences. There is no data on which to validate these assumptions but to the extent the actual capacity of these structures is lower, this study would be overestimating potential.

Some of these results are surprising. The potential for rooftop solar is higher in rural/primary zones (34 GW) than industrial zones (19 GW) and commercial zones (9 GW). The Rural zone covers a large range of land use ranging from Primary production (Forestry, Agriculture, Horticulture, Mining) and Rural Landscape to Residential and Industrial including Industrial buffer zones.

In the case of commercial buildings, it is likely there are significant amounts of commercial roof space in other zones (especially residential, mixed and rural/ primary production) so these figures understate the potential.

Together, commercial and industrial zones contain potential for over 28 GW of rooftop solar.

OMNILINK also undertook some analysis to determine the distribution of roof space by dwelling type - detached, duplex, townhouses and apartments. Detached houses account for just over 85 per cent of roofspace across all states. Townhouses generally account for around 5 per cent, Duplexes 5 per cent and apartments less than 5 per cent of roofspace (See Annex 6.2.1).

The data for further analysis of solar potential by dwelling type is not yet available.

4.2 The States

NSW leads the states with 49 GW of potential rooftop PV capacity and an expected output of 65 TWh. Victoria and Queensland follow with expected annual outputs of 56 TWh and 54 TWh respectively.

Figure 7 Rooftop Solar Potential, by State (MW)

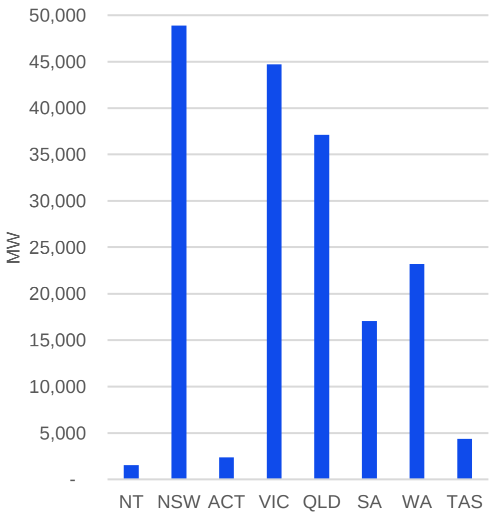


Table 5 Installed and potential capacity, by State

State	PV potential (GW)	Annual energy output (GWh)	Installed Capacity (GW)
NT	1	2,375	0.1
NSW	49	65,520	2
ACT	2	3,315	0.1
VIC	45	56,411	1
QLD	37	54,287	2
SA	17	23,516	1
WA	23	34,438	1
TAS	4	5,404	0.1

4.3 Local Government Areas

The top ten LGAs with the leading potential for rooftop solar for Australia are listed in Table 6. Most of the LGAs are in Queensland and Victoria. See Annex 6.3 for the top 10 for each state.

To find your LGA, please go to the AREMI website.

Table 6 Top Ten Solar LGAs in Australia

LGA	PV capacity (MW)	Annual Energy output (GWh)
Brisbane (C), QLD	7,075	10,330
Gold Coast (C), QLD	3,418	4,880
Moreton Bay (R), QLD	2,933	4,204
Sunshine Coast(R), QLD	2,656	3,748
Unincorporated ACT	2,368	3,313
Logan (C), QLD	2,219	3,223
Casey (C), VIC	1,896	2,272
Blacktown (C), NSW	1,861	2,415
Wyndham (C), VIC	1,826	2,309
Hume (C), VIC	1,819	2,262

4.4 States & their Capital Cities

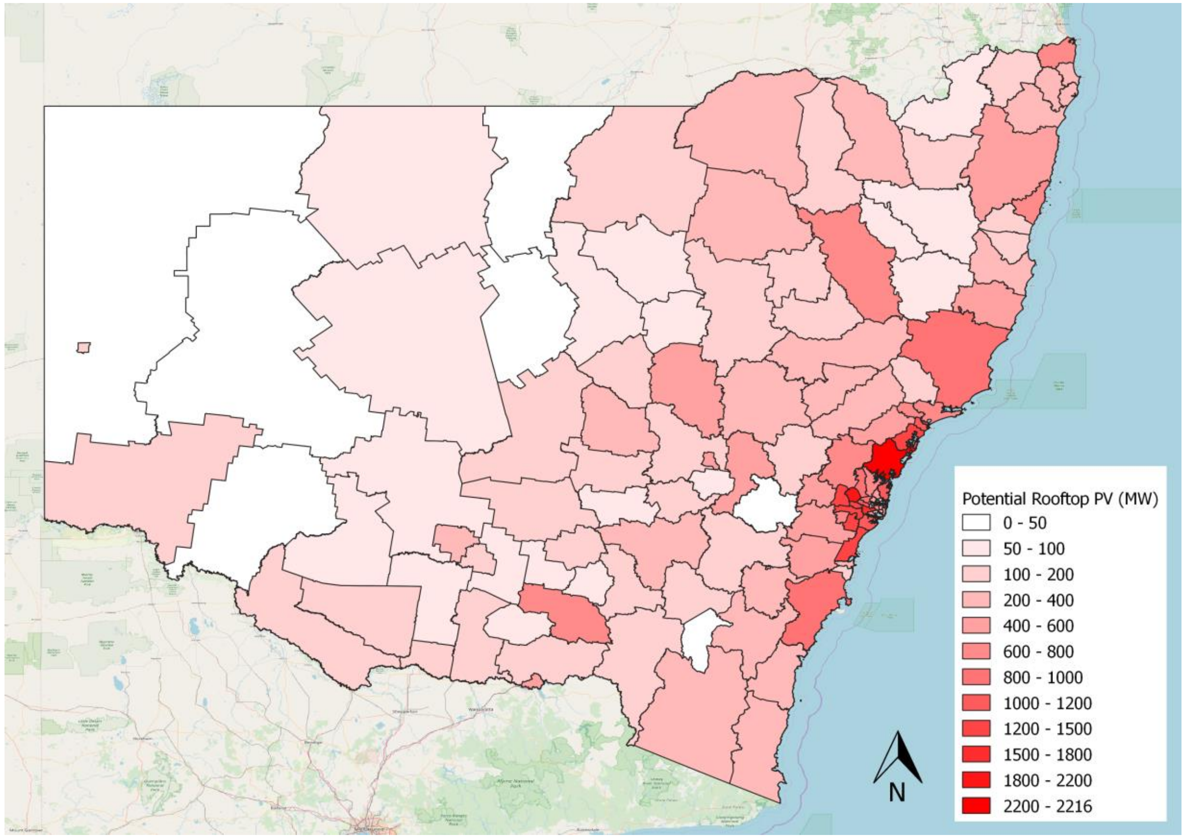
In order to see the LGA's with the greatest potential within each of the capital cities, maps have been produced for each capital city.

For more information at the LGA level, see the maps produced which are available at the Australian Renewable Energy Mapping Initiative website.

New South Wales

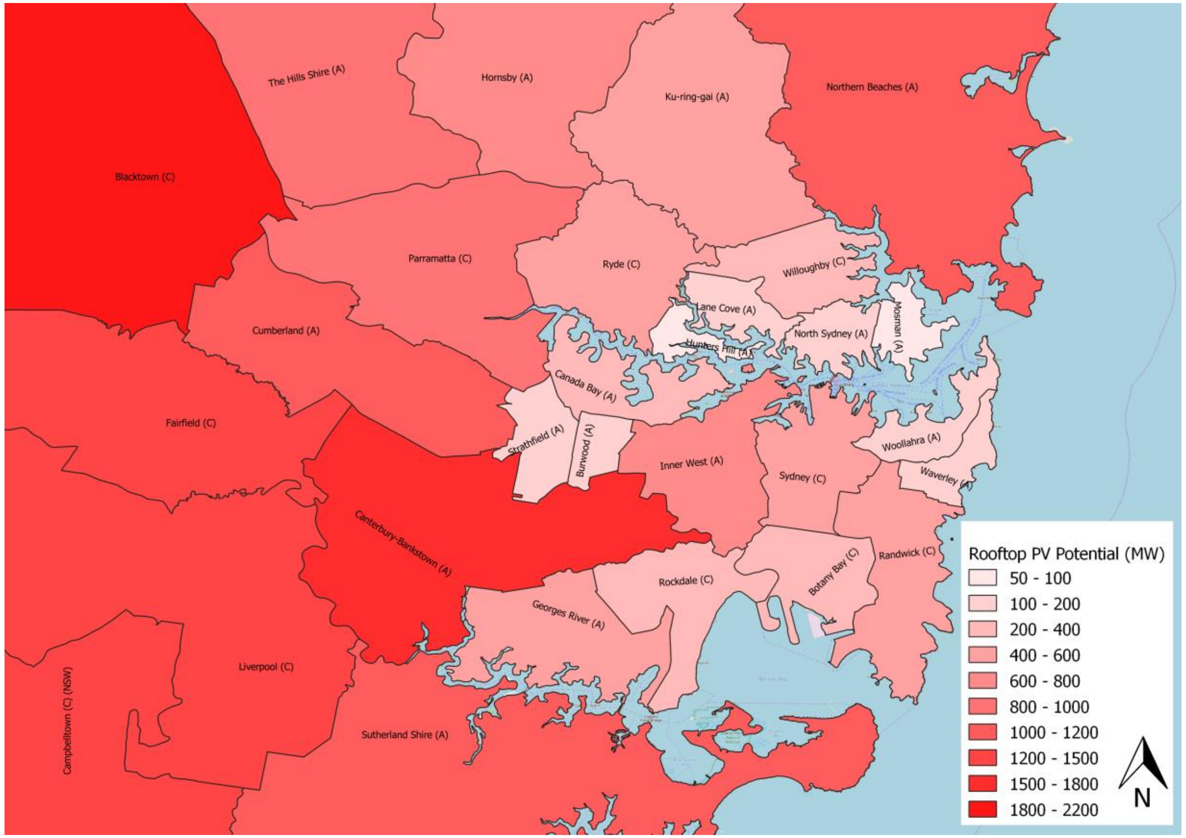
NSW has the highest rooftop solar potential in the country (49 GW), with the highest potential seen in the Central Coast LGA. The overall potential is much higher along the coast than in the interior; in particular there is a concentration in the urban areas around Sydney. This band stretches from Shoalhaven and Wollongong on the south coast to the north coast of NSW. The regional LGAs in the interior with the highest potential are Tamworth and Wagga Wagga.

Figure 8 Potential Solar PV in NSW



In Sydney, the western suburbs have the greatest potential for rooftop solar, led by the Blacktown and Canterbury-Bankstown LGAs. The Northern Beaches LGA also shows high potential. There is less potential for rooftop solar in inner-suburbs.

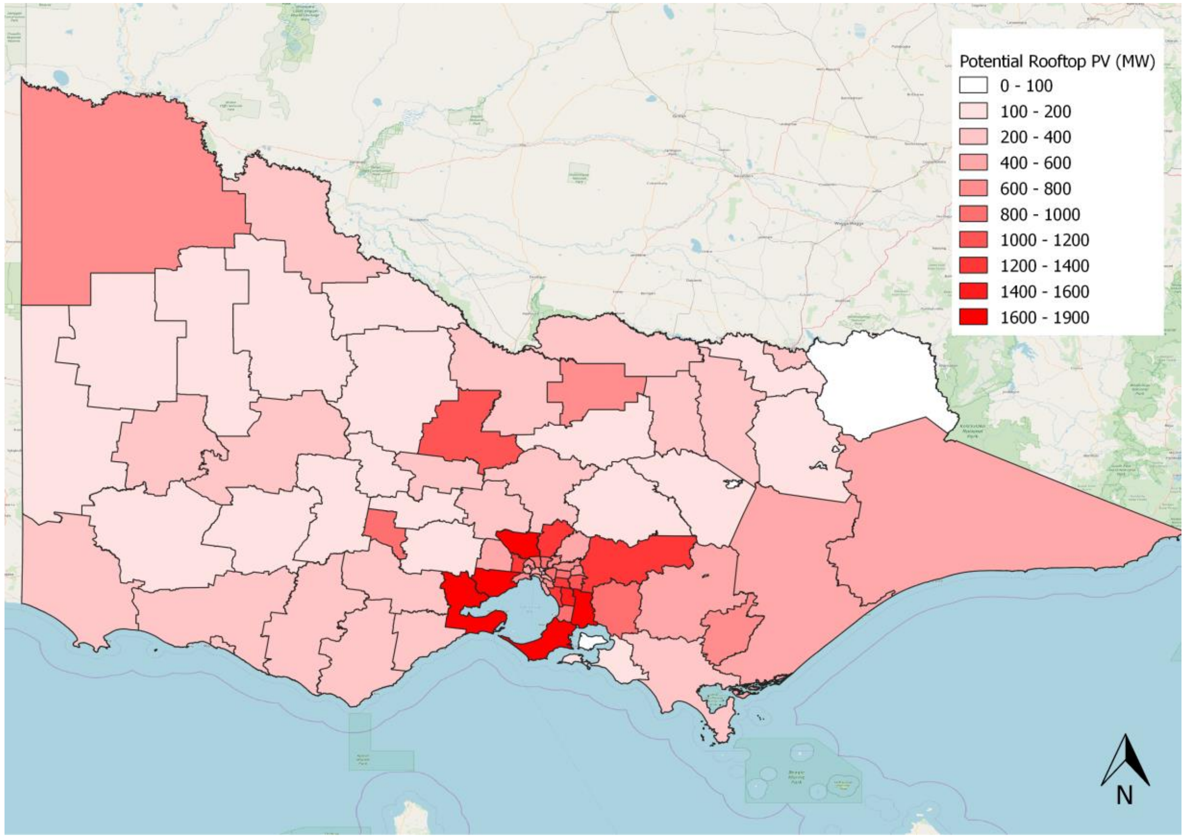
Figure 9 Potential Solar PV in Sydney



Victoria

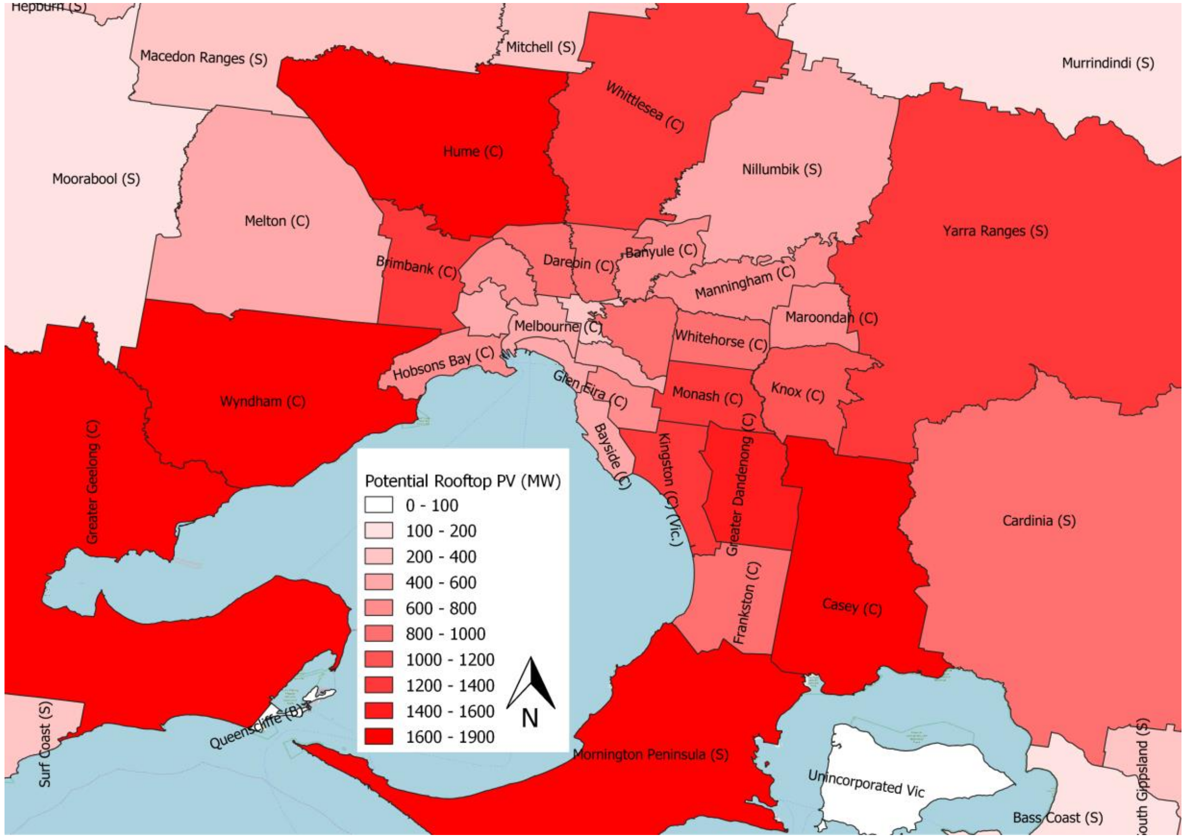
Victoria has the second highest potential in Australia (45 GW). As with NSW, the potential is concentrated along the urban areas around Melbourne, due to the higher building density in these suburbs. In regional Victoria, Greater Bendigo and Ballarat have the highest potential, followed by Grater Shepparton and Mildura.

Figure 10 Potential Solar PV in Victoria



In Melbourne, the highest potential is in Casey LGA towards the east and Wyndham and Hume LGAs on the west. Adjacent LGAs also show high potential. Again, the outer suburban LGAs in general have higher rooftop solar potential than the inner-suburbs.

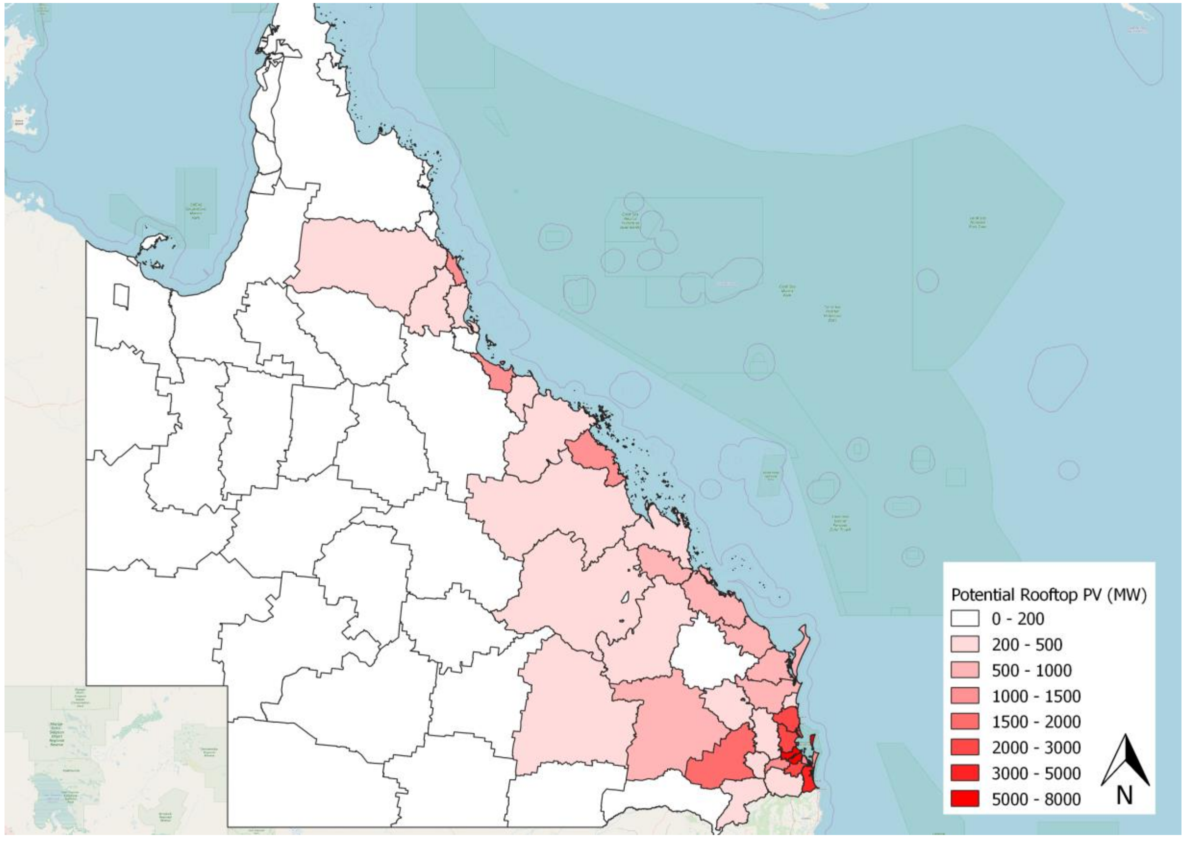
Figure 11 Potential Rooftop PV in Melbourne



Queensland

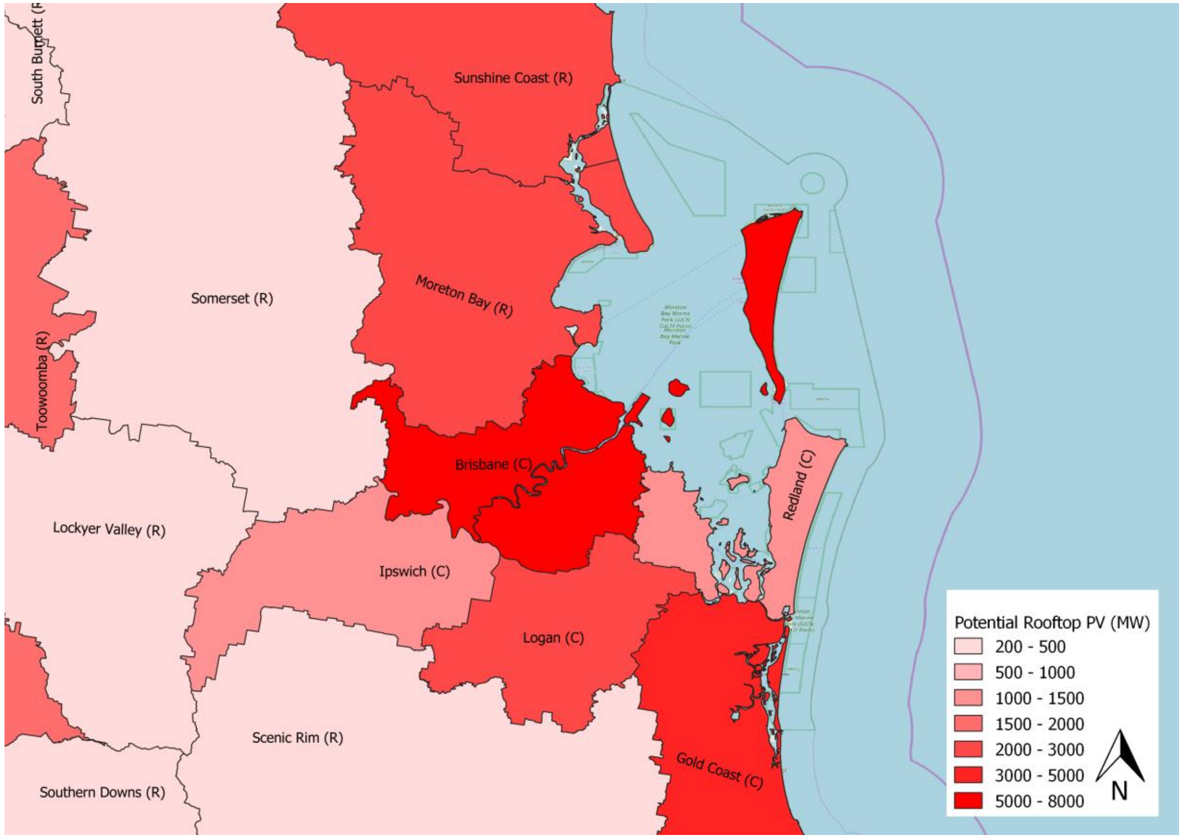
Queensland has the third highest total rooftop solar potential (37 GW). However, some of Queensland's LGAs have the highest potential in the country. Most of the potential is in LGA's along the east coast and reduces drastically as we move inland. In addition to Brisbane, some of the other coastal councils that have high rooftop solar potential include Fraser Coast, Bundaberg, Mackay, Townsville and Carins. Inland, Toowoomba shows very high potential.

Figure 12 Potential Rooftop PV in Queensland



Brisbane leads Queensland and Australia as the LGA with the highest rooftop solar potential. Gold Coast, Moreton Bay and Sunshine Coast and Logan LGAs follow next in line. Unlike NSW and Victoria, the inner and coastal suburbs have the highest potential.

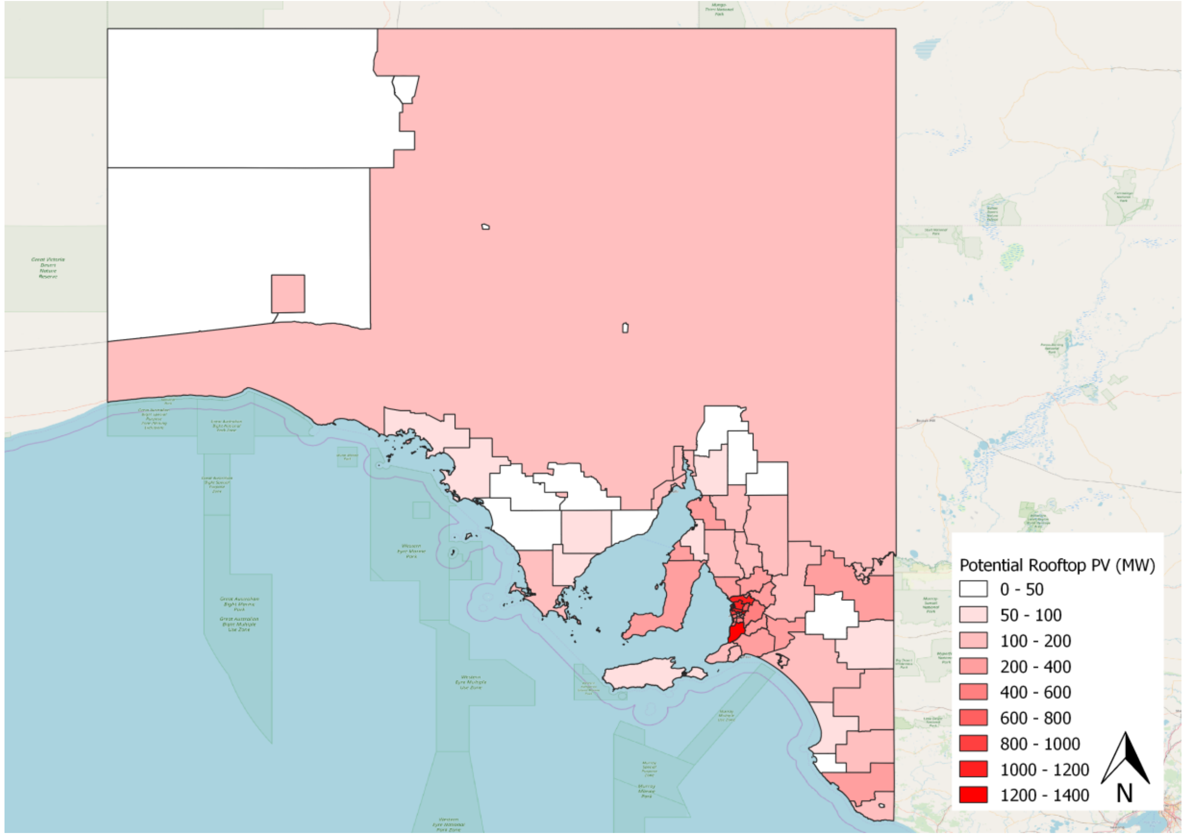
Figure 13 Potential Rooftop PV in Brisbane



South Australia

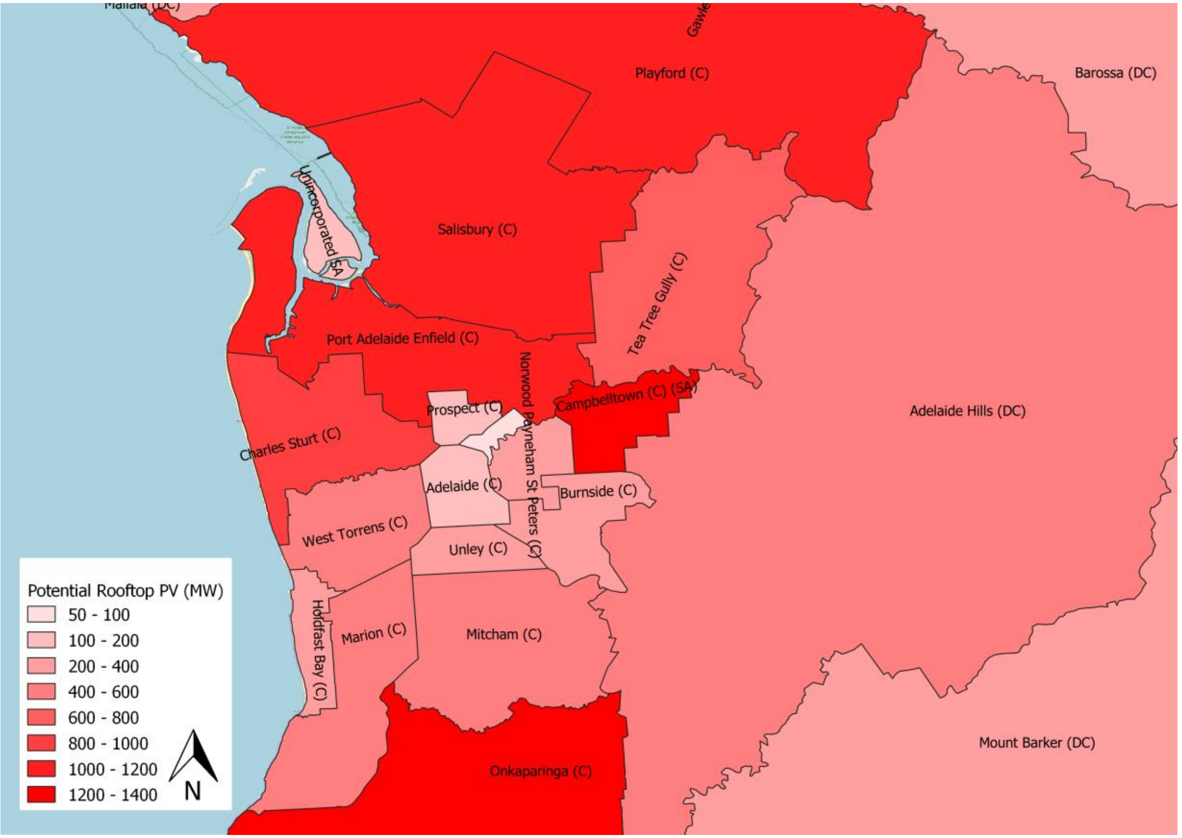
In South Australia, there is high potential for rooftop solar concentrated in LGAs around Adelaide with medium-scale potential in LGAs further north and inland. District councils like Barossa and Alexandrina show the highest rooftop potential.

Figure 14 Potential Rooftop PV in South Australia



In Adelaide, the northern suburbs in general have the highest potential for rooftop solar although Onkaparinga to the south of Adelaide leads the state. Playford, Salisbury and Port Adelaide Enfield are the LGAs north of Adelaide with the highest rooftop potential.

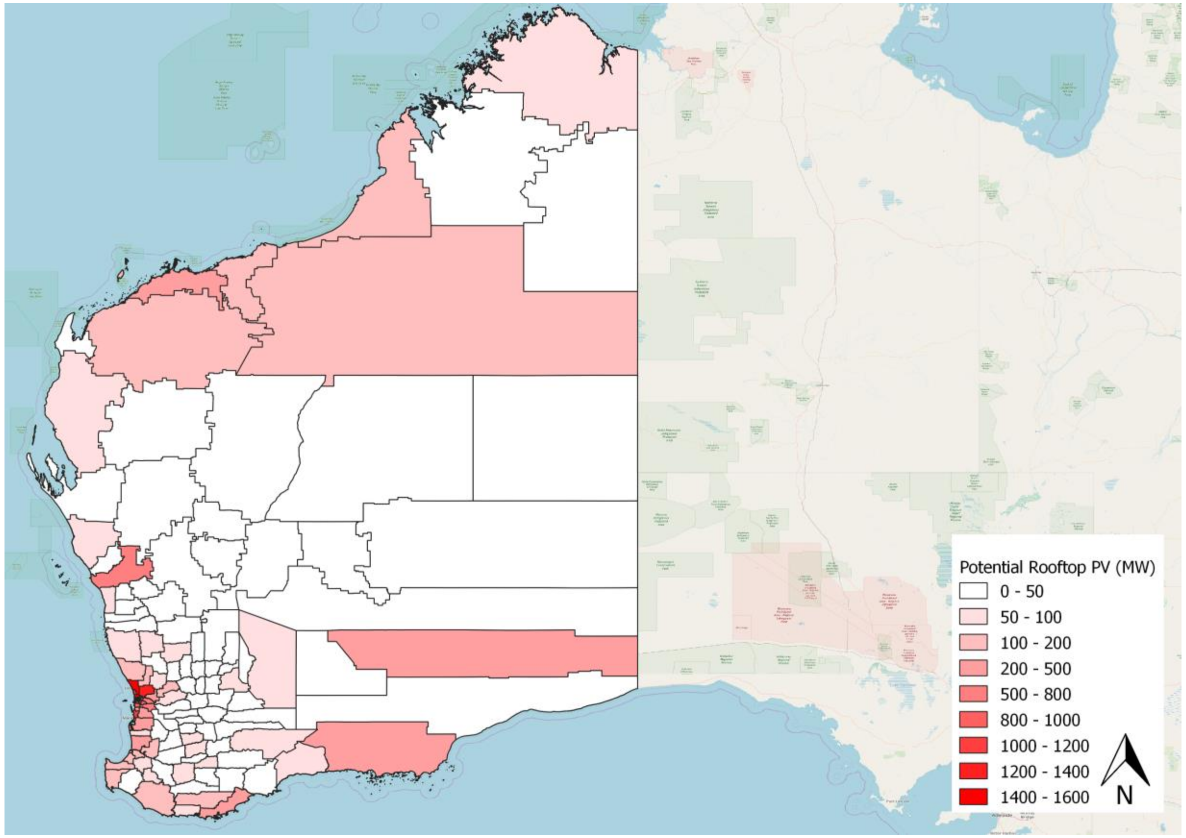
Figure 15 Potential Rooftop PV in Adelaide



Western Australia

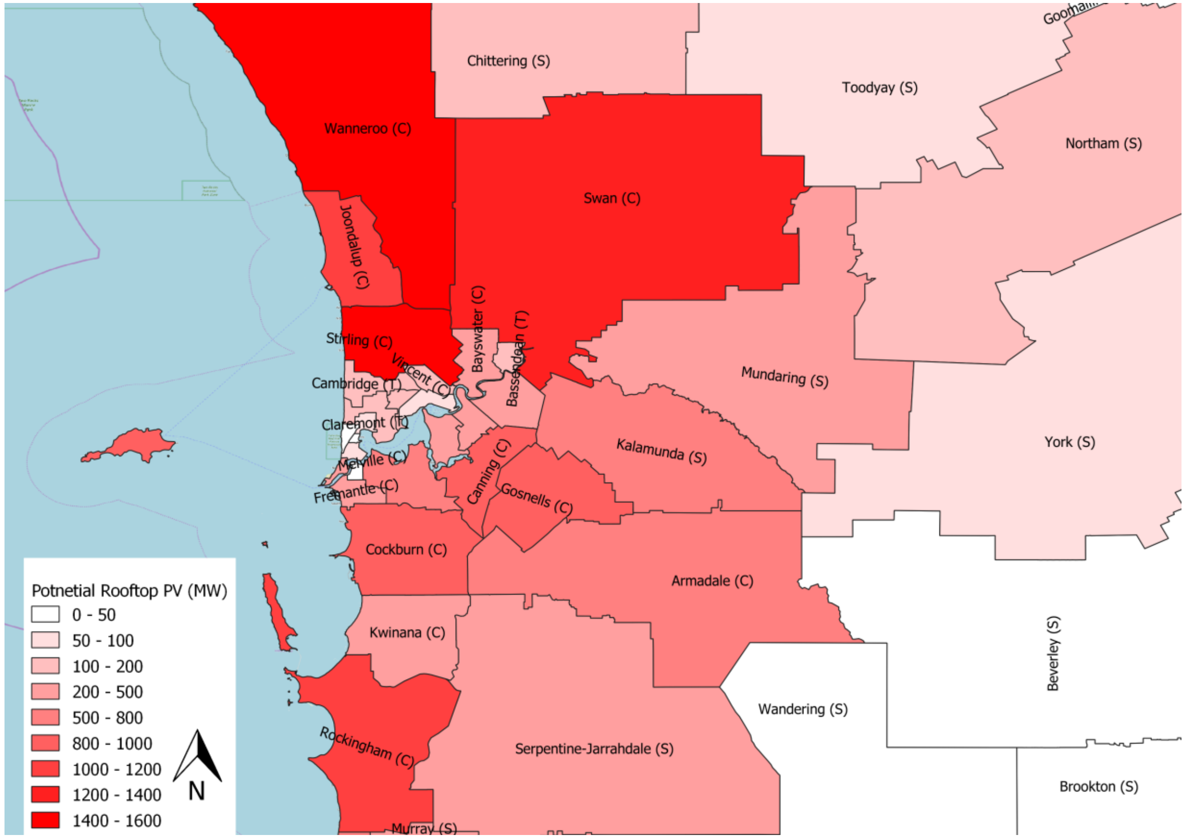
Western Australia has the fourth-highest potential for rooftop solar (23 GW). The LGAs around Perth have the highest potential. In regional areas, the Greater Geraldton and Albany LGA's show the highest potential.

Figure 16 Potential Rooftop PV in Western Australia



In Perth, the highest potential for rooftop solar is north of the city. Wanneroo, Stirling, Swan and Joondalup LGAs lead the list. In the south, the next highest potential is in Rockingham LGA. Cockburn, Gosnells and Canning are some of the other LGAS with high potential.

Figure 17 Potential Rooftop PV in Perth



Northern Territory

NT has less potential in total for rooftop solar due to the smaller number of buildings. The potential is concentrated in Darwin LGA with the highest building footprint. Other LGAs show low potential for rooftop solar.

Figure 18 Potential Rooftop PV in Northern Territory

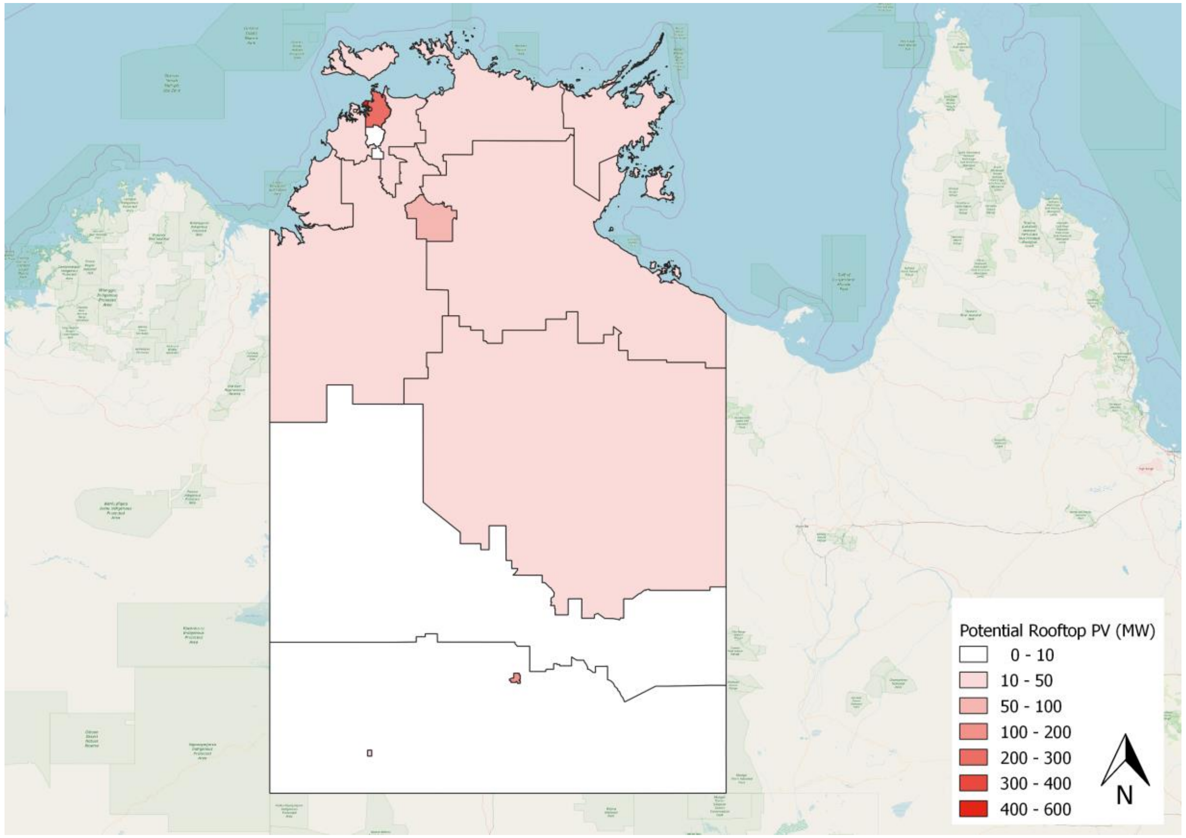
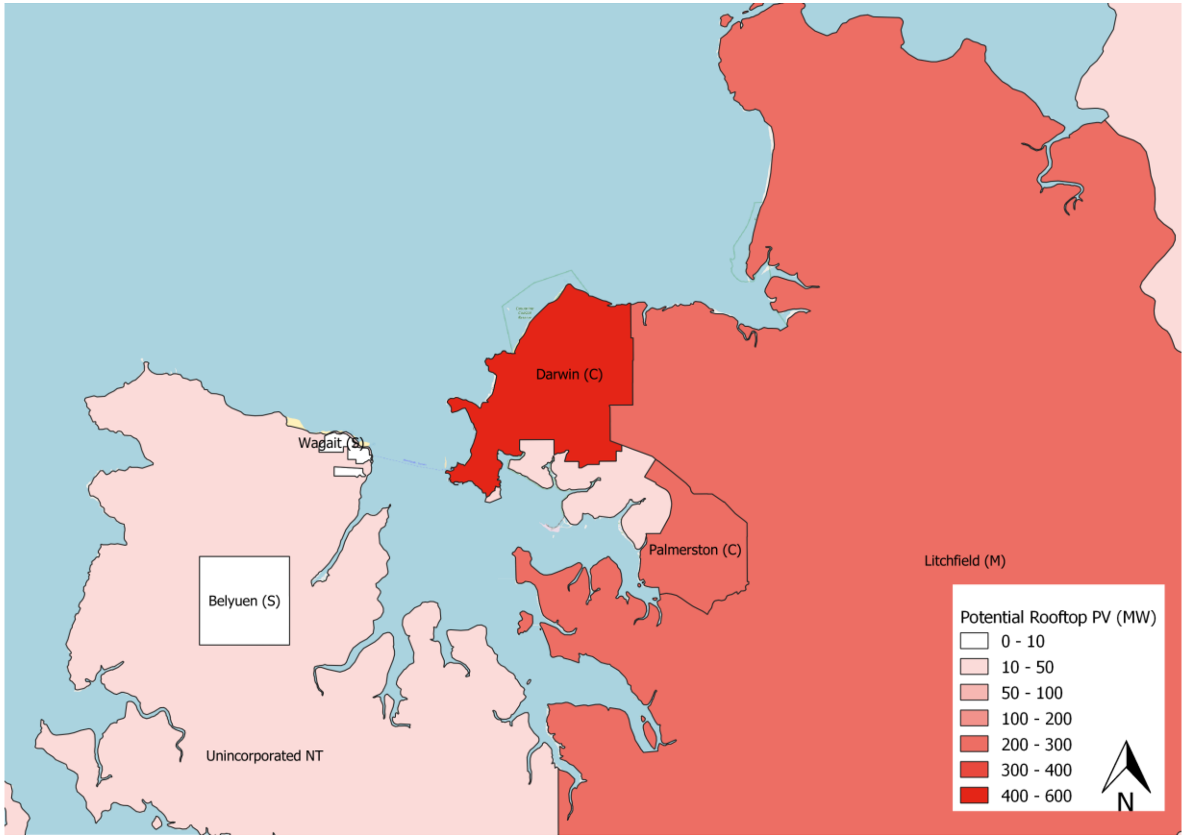


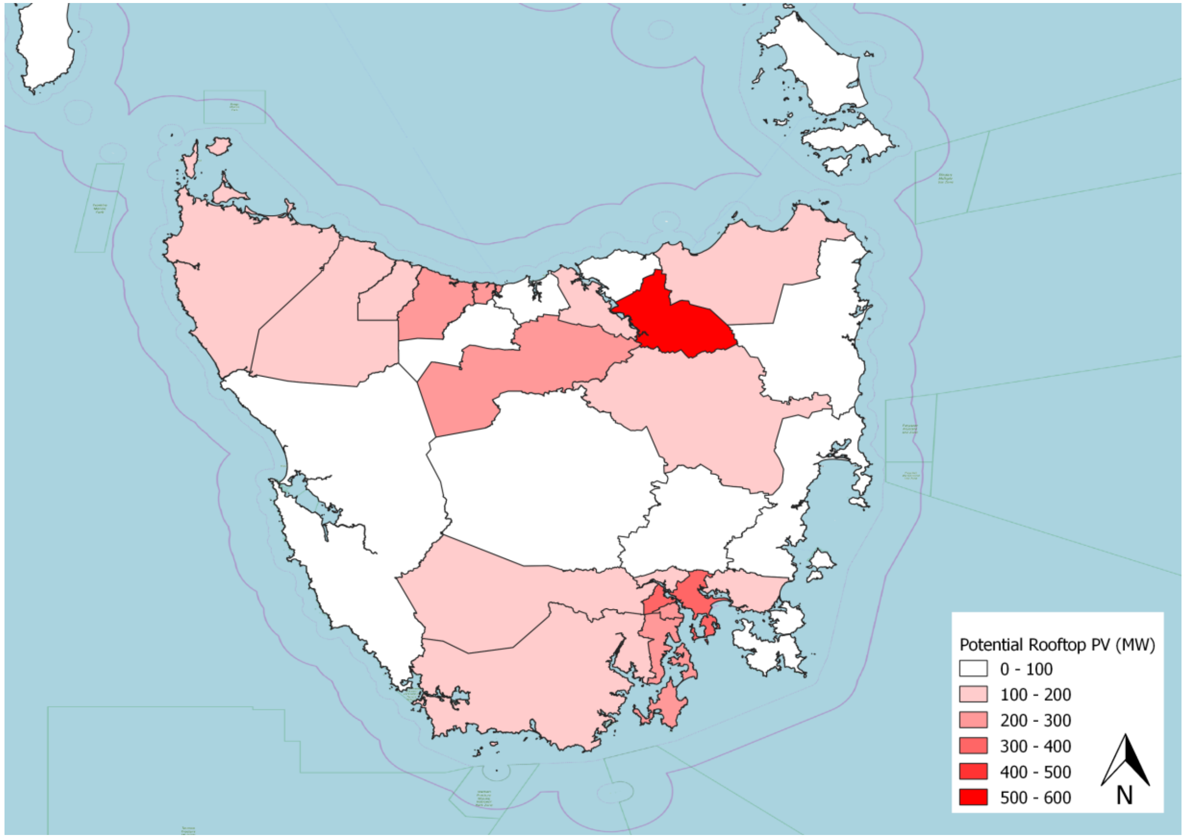
Figure 19 Potential Rooftop PV in Darwin



Tasmania

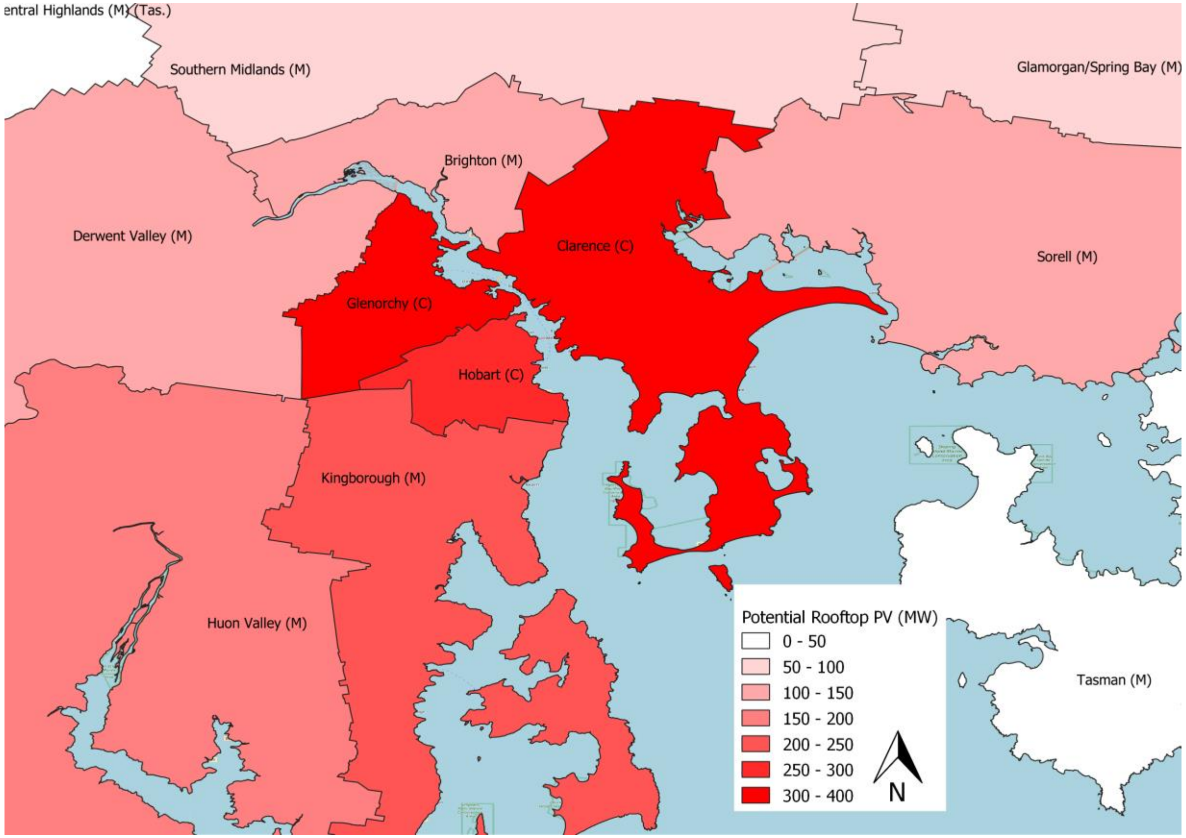
In Tasmania, Launceston shows the highest potential for rooftop solar followed by LGAs around Hobart. In regional areas, the LGAs of Meander Valley, Central Coast, Kingsborough show the highest potential.

Figure 20 Potential Rooftop PV in Tasmania



Around Hobart, the inner-suburbs have the highest potential matching the contours of development. Launceston LGA has the highest potential for rooftop solar. Hobart, Clarence and Glenorchy LGAs also show high potential.

Figure 21 Potential Rooftop PV in Hobart



5 References

AEMO (2018a) *Electricity Statement of Opportunities A report for the Wholesale Electricity Market*. Available at: https://www.aemo.com.au/-/media/Files/Electricity/WEM/Planning_and_Forecasting/ESOO/2017/2017-Electricity- (Accessed: 10 April 2019).

AEMO (2018b) *Integrated System Plan For the National Electricity Market*. Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf (Accessed: 22 January 2019).

AER (2019) *Electricity consumption (NEM)* | *Australian Energy Regulator*, *Australian Energy Regulator*. Available at: https://www.aer.gov.au/wholesale-markets/wholesale-statistics/national-electricity-market-electricity-consumption (Accessed: 23 January 2019).

APVI (2018a) *Australia hits 10GW solar*. Available at: http://apvi.org.au/wp-content/uploads/2018/10/APVI-Press-26102018_10GW.pdf (Accessed: 10 December 2018).

APVI (2018b) *Australian Photovoltaic Institute • Mapping Australian Photovoltaic installations*, *Australian PV Institute*. Available at: http://pv-map.apvi.org.au/historical#4/-26.67/134.12 (Accessed: 22 January 2019).

CER (2018) *Postcode data for small-scale installations*, *Clean Energy Regulator*. Available at: http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations (Accessed: 14 January 2019).

Copper, J. K. and Bruce, A. G. (2017) *SunSPoT Data and Calculations*. doi: 10.13140/RG.2.1.2040.5925.

Copper, J., Roberts, M. and Bruce, A. (2017a) *Analysis of Solar Potential in Brisbane for the Climate Media Centre*. Available at: http://pv-map.apvi.org.au/potential, (Accessed: 12 February 2019).

Copper, J., Roberts, M. and Bruce, A. (2017b) *Spatial Analysis of Solar Potential in Canberra*. Available at: http://apvi.org.au/wp-content/uploads/2018/03/CMC_CanberraSolarPotential_Final_lowres.pdf (Accessed: 19 March 2018).

Copper, J., Roberts, M. and Bruce, A. (2017c) *Spatial Analysis of Solar Potential in Sydney*. Available at: http://apvi.org.au/wp-content/uploads/2018/03/CMC_SydneySolarPotential_Final_Final_lores.pdf (Accessed: 19 March 2018).

Copper, J., Roberts, M. and Bruce, A. (2018a) *Spatial Analysis of Solar Potential in Adelaide*. Available at: http://apvi.org.au/wp-content/uploads/2018/04/CMC_AdelaideSolarPotential_Final.pdf (Accessed: 12 February 2019).

Copper, J., Roberts, M. and Bruce, A. (2018b) *Spatial Analysis of Solar Potential in Melbourne*. Available at: http://apvi.org.au/wp-content/uploads/2018/03/CMC_MelbourneSolarPotential_with_summary.pdf (Accessed: 12 February 2019).

Department of the Environment and Energy (2018) *Australian Energy Statistics - Table O Electricity generation by fuel type 2016-17 and 2017* | *energy.gov.au*, *Department of the Environment and Energy*. Available at: https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2016-17-and-2017 (Accessed: 31 January 2019).

Roberts, M. B., Copper, J. K. and Bruce, A. (2018) 'Analysis of Rooftop Solar Potential on Australian Residential Buildings', in *Asia Pacific Solar Research Conference*. Sydney. Available at: https://www.researchgate.net/publication/329403796_Analysis_of_Rooftop_Solar_Potential_on_Australian_Residential_Buildings (Accessed: 17 January 2019).

6 Annex

6.1 Data sources

Data Source	Data
CER time series Data (December 2019 Release)	Number of installations Installed PV capacity
APVI Data (October 2018 Release)	Postcode time series data LGA data on installations and capacity Australian PV Institute (APVI) Solar Map
PSMA Geoscape (August 2018 Release)	Building Polygons Roof Area Zoning Codes & Residential Flag Connection to PSMA Administrative Boundaries data set – Locality, LGA Connection to Address Data - GNAF
Administrative Boundaries (August 2018 Release)	State Boundaries Suburbs/ Localities Postcode Boundaries Local Government Areas (LGA)
• City Councils for Melbourne and Adelaide • ELVIS , the Elevation – Foundation Spatial Data portal for Canberra • NSW LPI for Sydney (now also available on ELVIS) • National Elevation Data Framework (NEDF) for Brisbane (now also available on ELVIS)	LiDAR data
AAM	DSMs[6] on 3D building models XYZ vegetation points
ESRI	1m ESRI Grids Rasters

[6] 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.

6.2 Methodology Assumptions

6.2.1 Dwelling Types

Extracted building polygons were appended with attributes from suburbs, postcodes and LGA datasets to determine the different dwelling types - detached, duplex, townhouses and apartments. This was based on the following assumptions:

- Detached: Building polygons (roof prints) with residential tag = "Y" and no. of addresses = 1.
- Duplex: Building polygons (roof prints) with residential tag = "Y" and no. of addresses = 2.
- Townhouse: Building polygons (roof prints) with residential tag = "Y" and where no. of addresses > 2 and roof height < 10 m.
- Apartments: Building polygons (roof prints) with residential tag = "Y" and where no. of addresses > 2 and roof height ≥ to 10 m.

The breakdown of total roof area by dwelling type for each state is listed below.

State / Dwelling Type	Detached	Townhouse	Duplex	Apartment
NSW	86%	6%	5%	4%
VIC	86%	6%	6%	2%
QLD	88%	5%	4%	2%
WA	85%	7%	7%	1%
SA	88%	5%	6%	1%
NT	86%	10%	2%	2%

6.2.2 Building Zones

PSMA developed 12 generic categories of building zones. State planning zones were categorised into these generic zones to classify the buildings in each state.

Code	Type	ACT	NSW	QLD	SA	VIC
0	Unknown					
1	Commercial / Business	ACT Zone 6	NSW Zone B5, B6, B7, B3	QLD Zone PC, MC	SA Zone I2,MS(A), MS(H)	Vic Zone 706, 711, 712, 6871, 6891
2	Community Use	ACT Zone 9		QLD Zone NC, CF	SA Zone Rb, I3, CiL, I1	Vic Zone 6926, 7161, 7162, 7165, 7166
3	Conservation / National Park		NSW Zone DM		SA Zone AH(C)	
4	Industrial / Utilities	ACT Zone 19	NSW Zone IN2, IN1			Vic Zone 1644, 1646, 7160
5	Mixed Use	ACT Zone 12	NSW Zone B4, B1, B2, B8	QLD Zone DC, MU, PDA, SBCA	SA Zone CC	Vic Zone 209, 6872 6890, 6892, 6894, 6895, 6896, 6920, 6921, 6922, 6923, 6924, 6925

6	Recreational / Open Space	ACT Zone 8,15,21	NSW Zone RE1, RE2	QLD Zone OS, SR	SA Zone PL, CF	Vic Zone 6050
7	Residential	ACT Zone 1,2,13,20	NSW Zone R4, R2, R3, R1	QLD Zone HDR, LMR, CR, MDR, EC		Vic Zone 206, 400, 401, 402, 403, 420, 421, 440, 441, 6873, 6893
8	Rural / Primary Production	Open Space/ Special Purpose: Rural A Rural: Major Utility - Timber Mill Industrial: Rural (Industry Buffer) Rural: General Farming Primary Production: Rural Landscape, Forestry, Agriculture, Horticulture, Mining Miscellaneous: Aquaculture				
9	Special Use	ACT Zone 3	NSW Zone SP1	QLD Zone SC, SP		Vic Zone 6851, 6852, 6853, 7070
10	Transport / Infrastructure	ACT Zone 5	NSW Zone SP2			Vic Zone 820, 7163, 8020
11	Water					

6.2.3 Determining roof suitability

The APVI analysis used two datasets - AAM digital surface models (DSM) and LiDAR data - to calculate the slope, aspect, hillshade and surface insolation of each unique roof surface. The key criteria for the selection of suitable roof planes were sufficient insolation and the availability of a minimum contiguous surface area of $10m^2$ to ensure a minimum 1.5kW PV system for any plane. Two methods were used to assess suitability.

- Areas receiving 80 per cent of the expected annual insolation incident on an unshaded, horizontal surface (Method 1)
- NREL's PV rooftop suitability based on hillshade and surface orientation (Method 2)

6.2.4 PV capacity and annual yield calculations

Total roof areas for each planning zone in each POA were multiplied by the percentage useable area (UA) for each zone to determine the amount of usable roof space in each zone in each POA[7]. The slope and orientation of the usable area was allocated as follows:

- Zone 7 (Residential):
  - 10per cent is flat (<10°)
  - 90per cent is pitched at 25°, orientation evenly distributed between -270° & 90°
- All other zones:
  - 90per cent is flat (<10°)

[7] However, as individual building areas were not available the minimum $10m^2$ contiguous roof area criteria could not be applied.

- 10per cent is pitched at 25°, orientation evenly distributed between -270° & 90°

A PV intensity of 156.25 W/m^2 (based on generic 250 W modules sized 1.6m x 1.0m) was applied to the pitched and flat usable areas to determine PV capacity for each zone and POA.

NREL's System Advisor Model (SAM) was used to calculate the annual yield of the potential PV capacity for each tilt and orientation at each POA using a reference meteorological year (RMY) weather file created from weather data collected at the nearest of 196 BOM weather stations. The unshaded SAM output was multiplied by the SF for the zone and POA to provide an estimate of the potential annual yield.

Various tools such as Oracle spatial, FME for ETL (Extract, Transform and Load) and python scripts were used to create a set of comprehensive lists for each state by LGAs, postcodes, localities and planning zones.

6.3 Top Ten LGAs, by State

6.3.1 NSW

LGA	PV capacity (MW)	Annual Energy output (GWh)
Blacktown (C)	1,861	2,415
Penrith (C)	1,369	1,775
Lake Macquarie (C)	1,312	1,747
Liverpool (C)	1,243	1,613
Wollongong (C)	1,238	1,636
Fairfield (C)	1,205	1,568
Gosford (C)	1,133	1,470
Wyong (A)	1,083	1,405
Sutherland Shire (A)	1,071	1,384
Newcastle (C)	1,061	1,432

6.3.2 Victoria

LGA	PV capacity (MW)	Annual Energy output (GWh)
Casey (C)	1,896	2,272
Wyndham (C)	1,826	2,309
Hume (C)	1,819	2,262
Greater Geelong (C)	1,797	2,271
Mornington Peninsula (S)	1,631	2,001
Greater Dandenong (C)	1,492	1,898
Whittlesea (C)	1,355	1,693
Brimbank (C)	1,252	1,554
Yarra Ranges (S)	1,239	1,460
Kingston (C)	1,224	1,553

6.3.3 Queensland

LGA	PV capacity (MW)	Annual Energy output (GWh)
Brisbane (C)	7,075	10,330
Gold Coast (C)	3,418	4,880
Moreton Bay (R)	2,933	4,204
Sunshine Coast (R)	2,656	3,748
Logan (C)	2,219	3,223
Toowoomba (R)	1,680	2,509
Townsville (C)	1,469	2,283
Ipswich (C)	1,335	1,859
Cairns (R)	1,245	1,813
Mackay (R)	1,087	1,643

6.3.4 South Australia

LGA	PV capacity (MW)	Annual Energy output (GWh)
Onkaparinga (C)	1,310	1,838
Salisbury (C)	1,151	1,600
Port Adelaide Enfield (C)	1,147	1,588
Playford (C)	1,085	1,511
Charles Sturt (C)	920	1,286
Tea Tree Gully (C)	674	929
Marion (C)	585	827
Mitcham (C)	493	690
West Torrens (C)	486	682
Adelaide Hills (DC)	443	609

6.3.5 Western Australia

LGA	PV capacity (MW)	Annual Energy output (GWh)
Wanneroo (C)	1,549	2,307
Stirling (C)	1,407	2,093
Swan (C)	1,301	1,936
Joondalup (C)	1,086	1,608
Rockingham (C)	1,038	1,551
Cockburn (C)	967	1,454
Gosnells (C)	885	1,326
Canning (C)	883	1,334
Mandurah (C)	743	1,107

Melville (C)	711	1,059

6.3.6 Tasmania

LGA	PV capacity (MW)	Annual Energy output (GWh)
Launceston (C)	516	651
Clarence (C)	355	417
Glenorchy (C)	317	397
Hobart (C)	287	357
Kingborough (M)	240	299
Devonport (C)	238	296
Meander Valley (M)	218	272
Central Coast (M)	210	260
Northern Midlands (M)	183	232
Burnie (C)	179	221

6.3.7 Northern Territory

LGA	PV capacity (MW)	Annual Energy output (GWH)
Darwin (C)	537	809
Litchfield (M)	236	356
Palmerston (C)	213	320
Alice Springs (T)	179	295
East Pilbara (S)	148	236
Katherine (T)	93	147
Wyndham-East Kimberley (S)	67	99
East Arnhem (S)	40	61
West Arnhem (S)	40	61
Unincorporated NT	37	57