Powering a sporting nation

Rooftop solar potential of Australian cricket

AUSTRALIAN CONSERVATION FOUNDATION

AUSTRALIAN PV INSTITUTE

UNSW SYDNEY

Contents

Cover. Australian cricketer Pat Cummins.
Photo: Sarah Reed / Newspix

Introduction

Sport is integral to Australian identity and, as our main summer sport, cricket plays a key role in our society, from physical activity at a grassroots level to the multi-million-dollar entertainment of the Big Bash T20 League.

As outlined in our previous report, Caught Behind,[1] climate change is already having a major impact on the sport. More frequent extreme temperature increases heat stress on players and audiences, with potential impacts on health and disruption to games. The severe bushfires of 2019/20 impacted the game at all levels. On December 23rd, a Big Bash game was halted as a thick cloud of smoke enveloped the pitch and play had to be abandoned, with former Australian international Peter Siddle having to be treated for smoke inhalation[2] leading to speculation that the Boxing Day Test, synonymous with the Australian holiday season, might be cancelled. Meanwhile, smoke inhalation is a growing threat to the health of the 1.77 million kids enrolled in school cricket and registered participation programs[3] across the country.

However, as well as being particularly vulnerable to the effects of climate change, Australian cricket also has an opportunity to play a role in slowing global warming and mitigating the existential threats that it faces. Decarbonisation of the energy system is one of the fastest and lowest cost routes to reducing Australia's carbon emissions, which is one of the key reasons why 1 in 4 households have installed rooftop solar and reduced their reliance on fossil fuels.[4]

The first cricket stadium to be powered from the sun was India's national cricket stadium in Bangalore, which went solar in 2015, saving an estimated 600 tonnes of CO2-e emissions annually.[5]

In Australia, solar photovoltaics (PV) now contribute to the energy needs of Queensland's Bupa National Cricket Centre, the Australian Capital Territory's recently renamed EPC Solar Park and the MCG, but there is significant potential for further deployment of solar on the stadia and other properties of Australian state and national cricket associations.

In general, the best financial returns for rooftop solar are achieved by consuming as much of the generated electricity as possible on site. In cricket stadia, powering floodlights for evening matches is challenging without battery storage, but some venues have significant daytime consumption, including lighting, heating and cooling for offices, clubrooms and other facilities. Not all commercial electricity tariffs include a feed-in-tariff (FiT) – payment for electricity exported to the grid – so solar systems on commercial properties are often designed to avoid any export. However, as Cricket ACT has shown, large commercial customers are in a strong position to negotiate a tariff structure that enables them to enjoy the full value of their solar system, exporting during the day and offsetting the export payment against their evening consumption.

1 "Caught Behind: Australian cricket not ready for challenges of climate change," ACF

2 "Peter Siddle treated for smoke inhalation after abandoned BBL match," Wisden Media

3 "2019-20 Australian Cricket Census released," Cricket Australia

4 https://pv-map.apvi.org.au/historical

5 "The world's first solar powered cricket stadium is in India," GIZ media

Australia's sports venues include diverse building styles and ages. While solar PV installation on traditional pitched and flat roofs is relatively straightforward, deployment on modern sculptural roof forms may present challenges. However, there are solutions: traditional rigid PV modules have been incorporated into the sun-dragon design of the Taiwan National Stadium in Kaohsiung,[6] while ongoing technological advances in Building-Integrated Photovoltaics (BIPV) including lightweight, flexible modules[7] will enable PV installation on previously unviable structures.[8]

Ownership and governance arrangements for major cricket stadia and headquarters vary. While some are owned and/or operated by state associations, others are owned by government, private companies or other bodies. Moreover, many are used for multiple sports and other events, so cricket associations may be one of several tenant organisations. Nevertheless, cricket's massive following in Australia gives the state associations status that could be used to influence the owners and partners of the stadia. Similar diverse arrangements exist for small community grounds and their associated buildings, which might be owned by councils or local cricket clubs, or shared with football or other sporting groups.

The national and state cricket associations form the backbone of a network of thousands of local cricket clubs at the heart of every Australian community. This gives them a unique opportunity to show leadership in communicating the risk posed by climate change to the sport, and to demonstrate one way to reduce the danger by installing rooftop solar to power their grounds.

This report explores the possibilities for solar installations on cricketing infrastructure throughout Australia, from its largest stadia to small community clubs. Case studies are presented to show the significant carbon abatement that the cricket community can achieve by wielding its significant influence in Australian society.

[6] National Kaohsiung Stadium, Taiwan | Architecture Revived

[7] "Australia invests $9.6m in 'revolutionary' Chinese solar company Sunman," David Chau

[8] The potential solar installations on stadium rooftops identified in this report are based on visual inspection of the sites using aerial imagery and do not take account of structural engineering issues.

India's solar-powered National Cricket Stadium **saves an estimated 600 tonnes of CO_2-e emissions annually**

Above. Chinnaswamy Stadium, Bangalore. *Photo*: Amith Nag

Cricket Australia

Cricket Australia's head office has been located at 60 Jolimont Street in Jolimont, Victoria, since 2001 and now houses up to 200 employees. The building roof has potential for a modest 36 kilowatt (kW) solar system (Figure 2), which could contribute to powering the organisation's offices. Investment in solar for this building is unlikely to be a priority, as the organisation is exploring options to relocate to new premises.[9] However, larger solar opportunities for Cricket Australia exist in their relationships with stadia and state associations.

The MCG, originally the Melbourne Cricket Ground and affectionately known as the 'G', was established in 1853 and saw the birth of test cricket and one-day internationals. It is owned by the Victorian government-appointed MCG trust, run by the Melbourne Cricket Club (MCC) and continues to host international cricket including test matches and men's and women's World Cup games.

In 2018, the MCG's energy consumption in September – its busiest month – was 1.65 GWh, equivalent to 4,000 Victorian households, and there have since been a number of initiatives to decrease its carbon emissions, including offsetting a month's emissions,[10] upgrading floodlights to LED technology,[11] installing 12 solar-powered light poles in the public area[12] and asking Melbourne sports fans to donate their excess solar in exchange for "VIP experiences."[13]

In 2017, the Australian Photovotaic Institute (APVI) identified potential space for a massive 2.2 megawatt (MW) solar array on the roof of the stadium [1] (see Figure 3). However, an engineering assessment of the roof structure, commissioned by the MGC, determined that much of the stadium roof would not support the weight of a traditional solar array. A smaller 99.4 kW[14] solar system has now been installed on parts of the North Stand,[15] with the generated electricity used primarily to power the MCG's water recycling facility. Further deployment may be possible with future developments in lightweight solar technology.[16]

9 "Cricket Australia looking to move from Jolimont base," Daniel Cherny

10 "Making The MCG (Carbon) Neutral Territory For September," Energy Australia

11 https://www.ausleisure.com.au/news/mcg-floodlights-being-upgraded-with-led-technology/

12 https://www.mcg.org.au/whats-on/latest-news/2019/february/solar-project-to-light-the-way-at-yarra-park

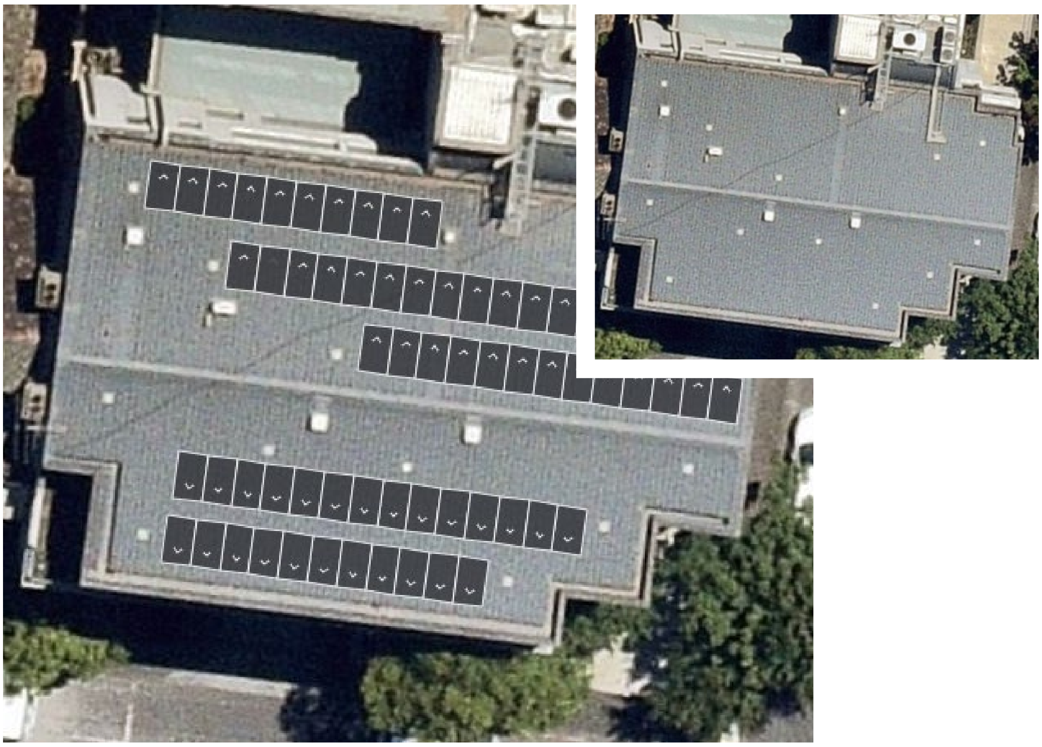
13 "People power to help light the way at the 'G'" Energy Australia

14 https://www.linkedin.com/posts/cherry-energy-solutions_power-play-mcg-goes-solar-in-climate-change-activity-6746916066280271872-TFl8

15 https://www.smh.com.au/sport/cricket/power-play-mcg-goes-solar-in-climate-change-fight-20201218-p56om7.html

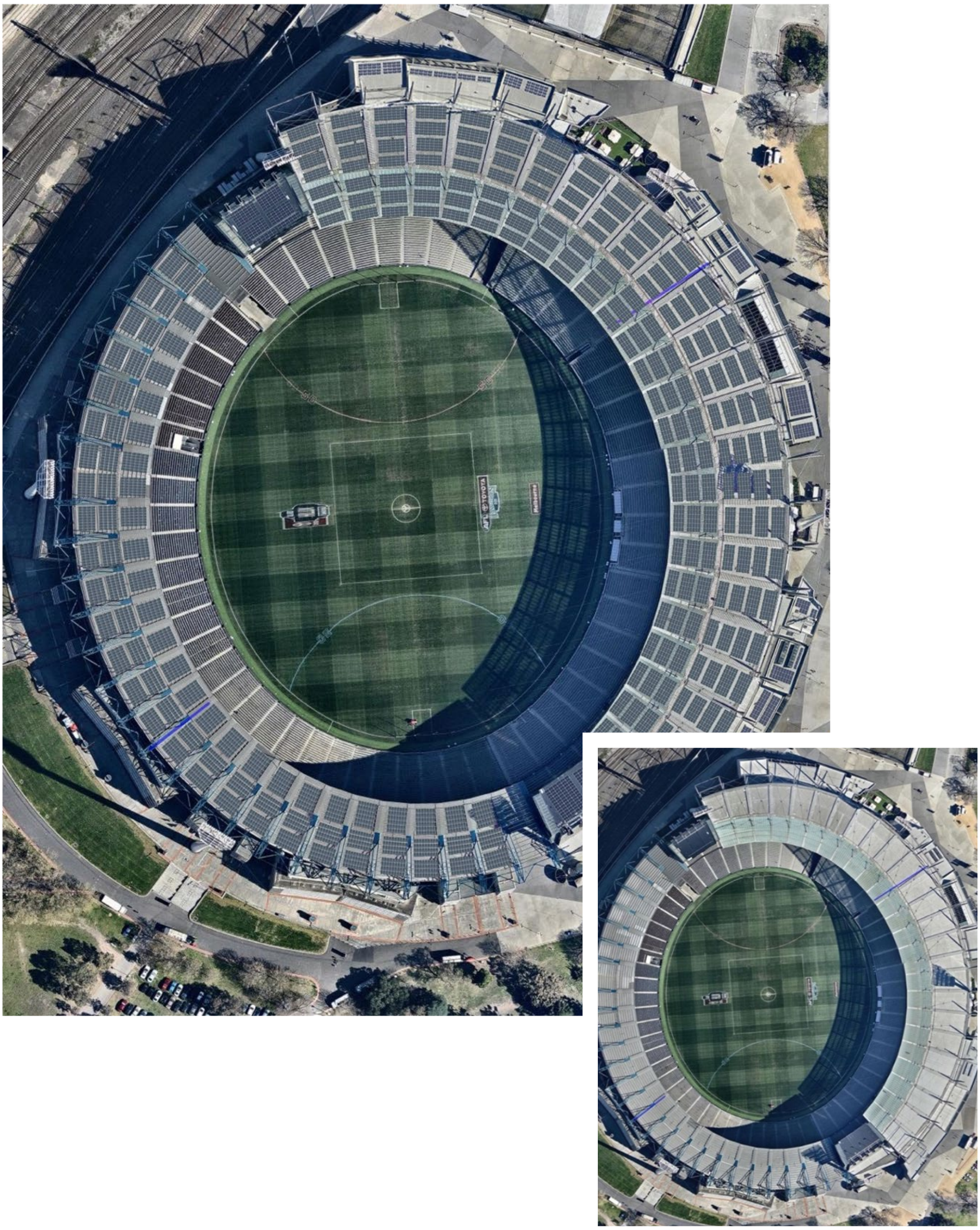
16 https://reneweconomy.com.au/sun-king-returns-to-solar-market-with-ultra-light-panels-on-maritime-museum-28176/

Figure 2 Cricket Australia's head office in Jolimont, Victoria, now (inset) and with potential 36 kW PV array



The MCG's energy consumption in September – its busiest month **equivalent to the usage of 4,000 Victorian households**

Figure 3: The MCG without solar (inset) and with a potential 2229 kW PV array [1] if engineering issues could be overcome by advances in lightweight solar technology



State associations summary results

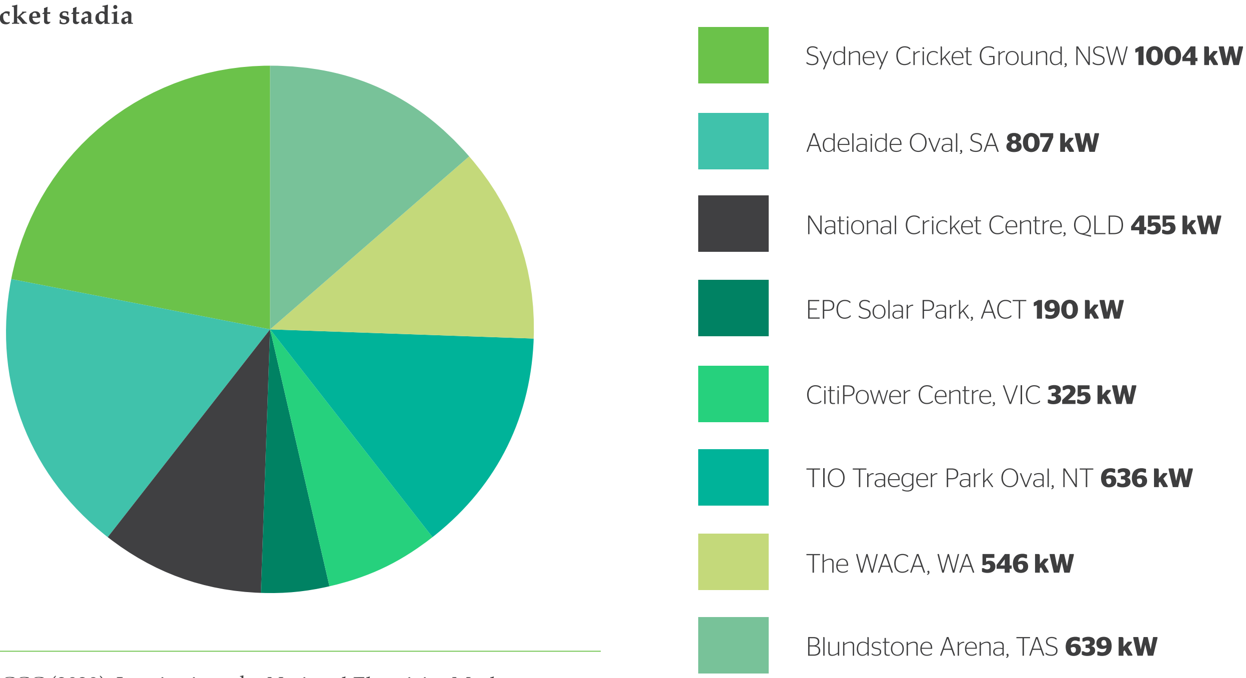
Analysis was carried out on the roof areas of the largest cricket stadium in each state to determine the size of the potential solar system that could be installed. Figure 4 is a visual representation of the solar potential on these stadia rooftops.

Table 1 shows the area and power capacity of the potential solar systems, along with the annual energy produced and estimates of the potential impacts of these systems, in terms of avoided CO2 emissions over the typical 20-year life of the system. It also includes the equivalent number of trees planted, as well as the number of typical households that could be powered by each array and the employment generated.

If solar photovoltaics were installed across the available roof area of just these nine stadia, at an estimated cost of $4.8m, enough energy would be generated to power 841 households, while approximately 83,000 tonnes of CO2 emissions would be avoided over the 20-year life of the systems.

Prices paid by commercial customers for electricity from the grid are negotiated with their retailer and vary between states, networks and customers, depending on the generation costs of the electricity, charges for transmission and distribution, and retail margins. According to the ACCC, the median price paid by small and medium enterprises in 2019 was 32.3c/kWh.[17] It its likely that some of the estimated 6,500 MWh that could be generated annually by solar systems on the major cricket stadia described in this report would be exported to the grid, and while some commercial customers negotiate to receive a feed-in tariff, others receive nothing for the export. Using a conservative assumption that half the generated energy is consumed within the facilities and that half of the exported energy attracts a typical FiT of 9.5c/kWh, the annual solar generation could save the organisations up to $1.2million annually.

Figure 4: Potential rooftop solar capacity on major cricket stadia



[17] ACCC (2020). Inquiry into the National Electricity Market - September 2020 report

Table 1: Potential PV generation and equivalent metrics for case studies completed on cricket stadia rooftops

	CitiPower Centre, VIC	Sydney Cricket Ground, NSW	EPC Solar Park, ACT	WACA Grounds, WA	Blundstone Arena, TAS	Adelaide Oval, SA	National Cricket Centre, QLD	Traeger Park Oval, NT	DXC Arena, NT	TOTALS
Seating capacity	7,000	48,601	25,011	24,500	19,500	53,500	42,000	7,200	4,500	231,812
Array area (m^2)	1,625	5020	950	2,731	3,195	4,034	2,273	3,181	1,215	24,224
PV capacity (kWpeak)	325	1,004	190	546	639	807	455	636	243	4,845
Estimated energy production (MWh/year)	383	1,293	246	799	721	1,068	686	981	353	6,530
Estimated avoided emissions (kilo tonnes-CO2-e / 20 years)	8	21	4	11	2	9	11	12	4	83
Number of average households that could be supplied from array	66	177	26	154	67	150	89	97	35	861
Equivalent trees planted over 20 years (1000 trees)	130	349	66	183	36	156	176	206	74	1,376
Estimated job-hours created	3,167	9,783	1,851	5,321	6,226	7,861	4,430	6,198	2,368	47,205
Estimated system cost ($1,000's)[18]	315	943	184	513	600	774	441	765	292	4,831

[18] System costs based on average November 2020 $/W cost of >100kW commercial systems in each state [2]. NT cost estimated at 28% higher than TAS, based on relative costs for residential system

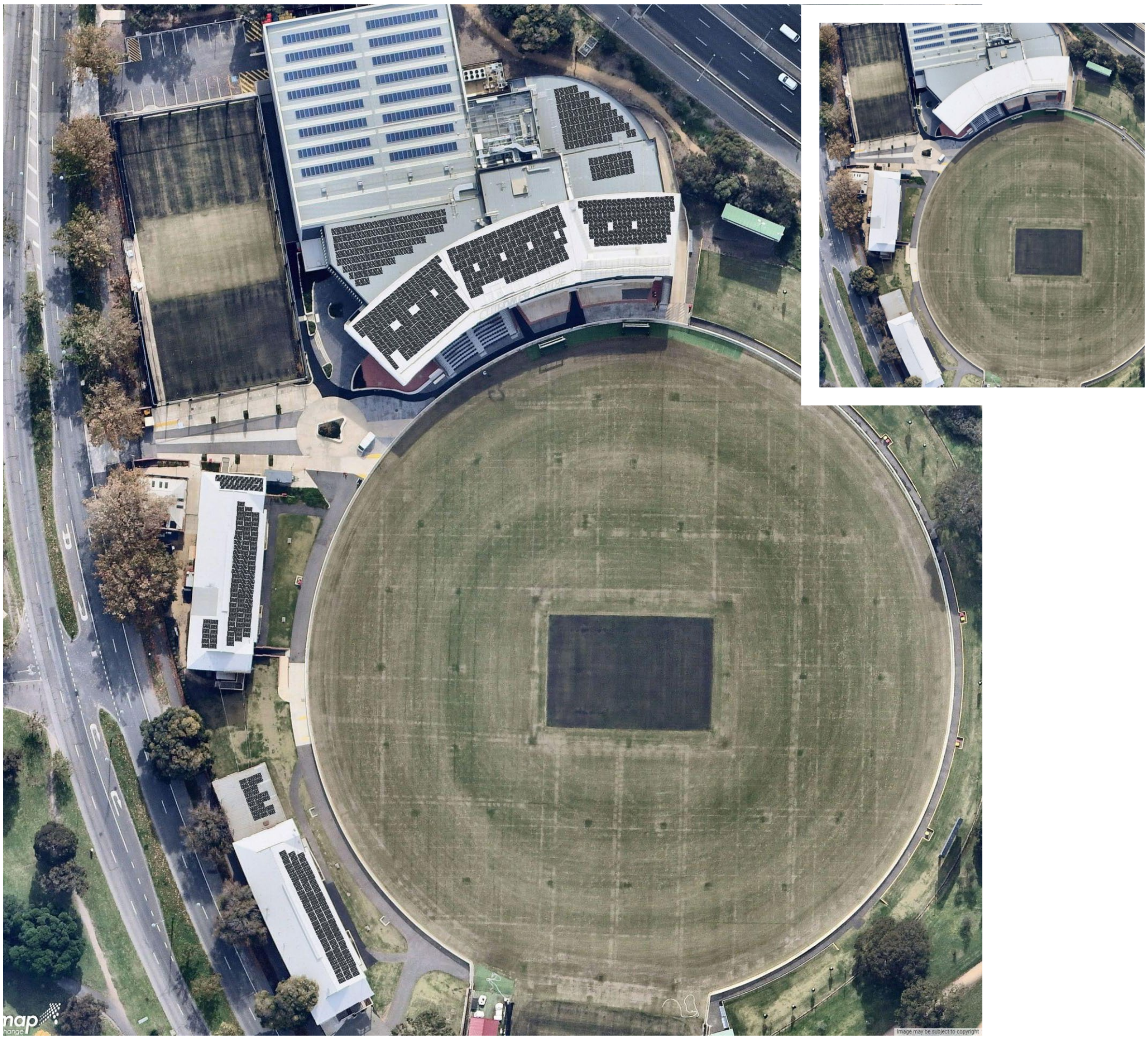
Cricket Victoria

The 7,000-seater Junction Oval[19] is the home ground of the Melbourne Stars and the Melbourne Renegades, while the CitiPower Centre, redeveloped in 2018, includes the administrative headquarters of Cricket Victoria, two outdoor practice facilities besides indoor medical and rehabilitation facilities, a gym and an aquatic centre.

Although there is a solar array on part of the headquarters building, there are further opportunities for installing panels. Figure 5 shows the CitiPower Centre as it is now (inset) and with a potential additional 325 kW solar system on the remaining roof space, excluding areas heavily shaded by the trees on the west side of the ground.

[19] Junction Oval | Austadiums (https://www.austadiums.com/)

Figure 5: CitiPower Centre now (inset) and with potential 325 kW PV array



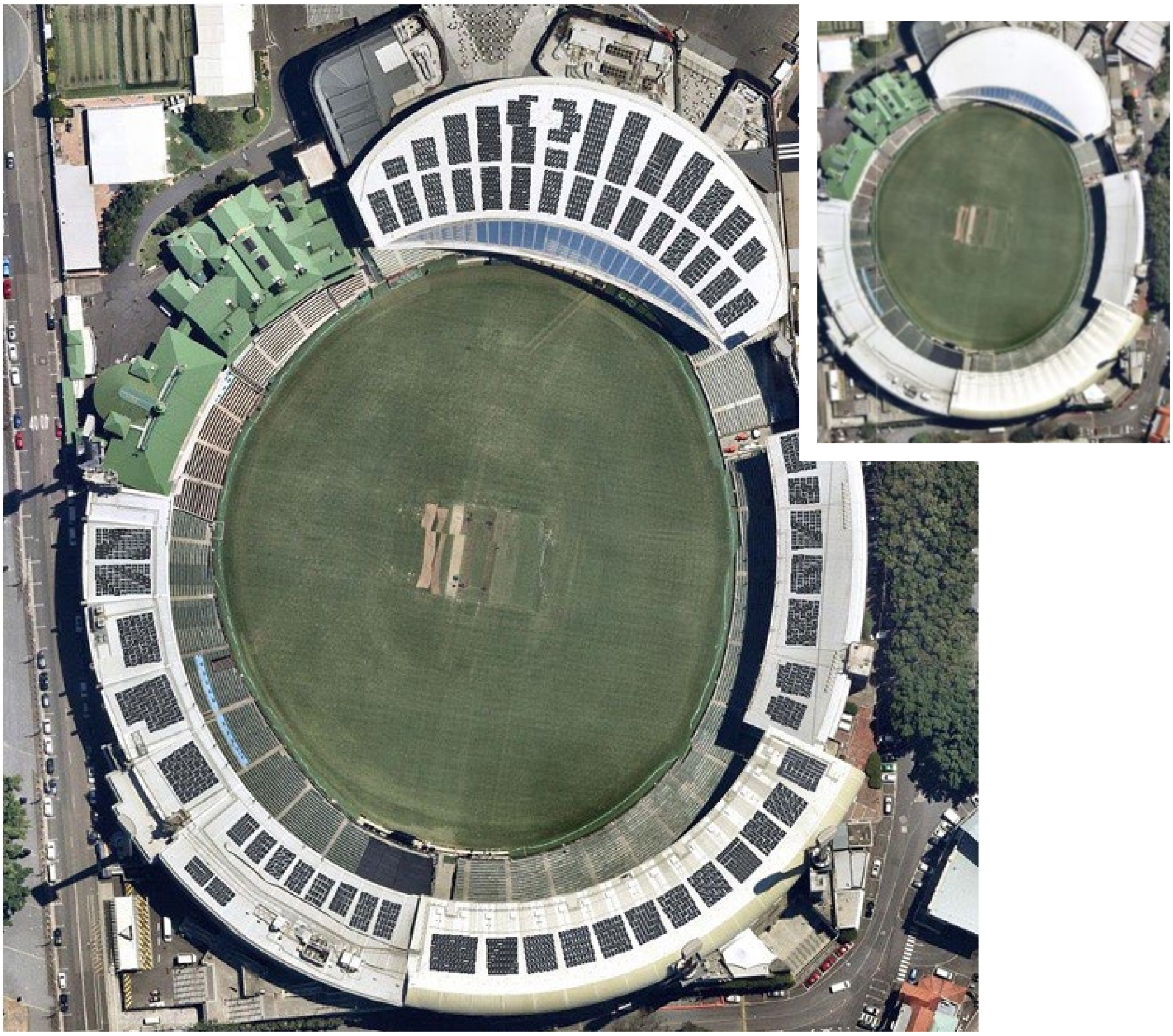
Cricket NSW

The Sydney Cricket Ground (SCG) in Moore Park is the home ground for various sports teams including the New South Wales Blues and the Sydney Sixers cricket teams, as well as Australian football leagues' Sydney Swans. The site of the 48,601[20] capacity stadium was first flattened and used as a cricket pitch by soldiers of the British army in 1851, while the latest redevelopment - including new stands - was completed in 2014. Figure 6 shows the potential 1,004 kW solar system that could be hosted on the stadium rooftops.

The slope of the roof is 10° and relatively clear of fixtures and obstructions, allowing for self-cleaning and simplifying installation. There are no major sources of shading other than the grounds' floodlights, but modelling shows they cause little reduction to the annual output of the system.

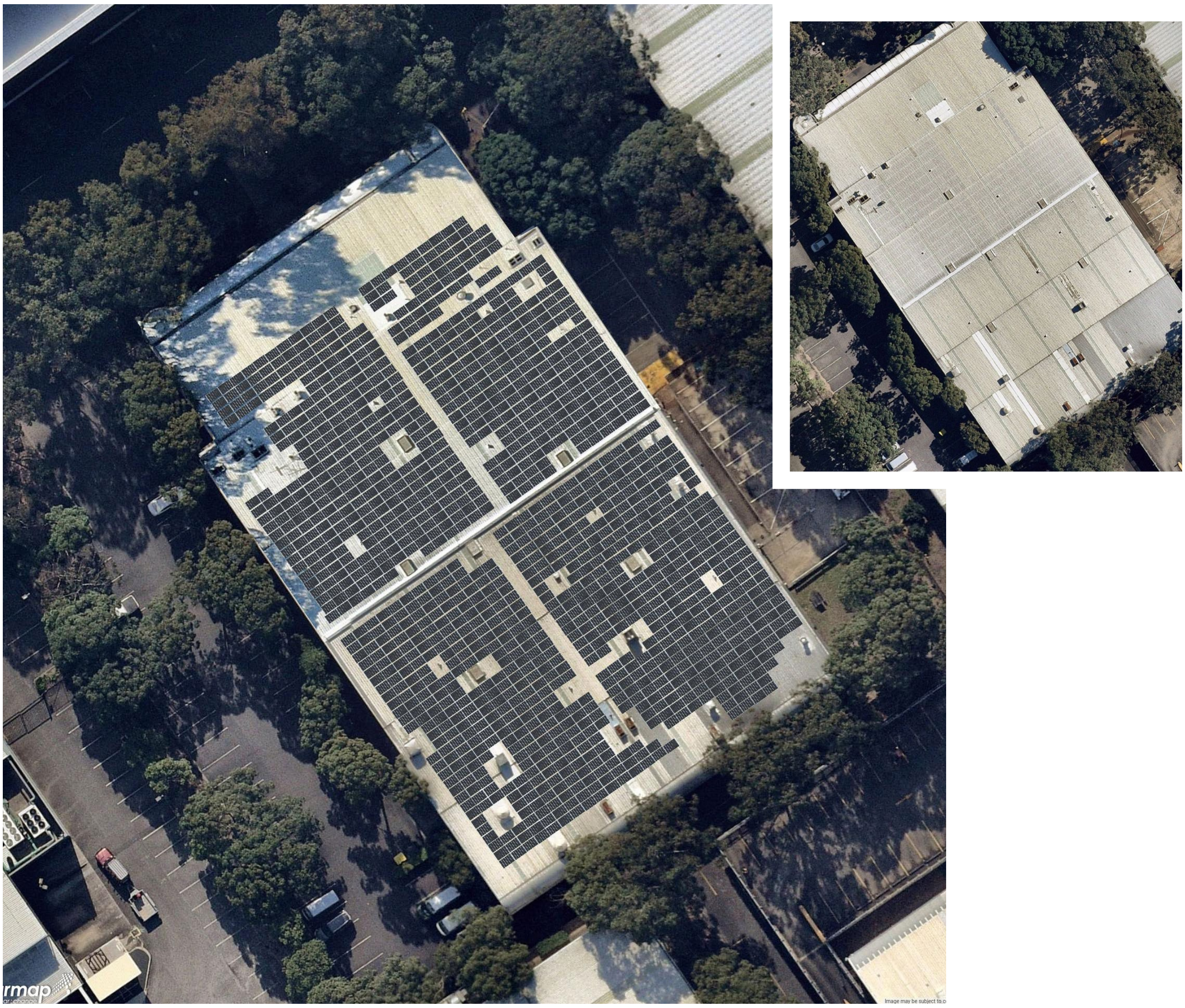
[20] Sydney Cricket Ground (SCG) | Austadiums (https://www.austadiums.com/)

Figure 6: Sydney Cricket Ground now (inset) and with a potential 1,004 kW PV array



Cricket NSW has used the 6 Herb Elliott Ave, Sydney Olympic Park site as an interim headquarters since 2019.[21] This facility is their temporary home until the new facility at Wilson Park is constructed. The building has a roof with a large surface area and slight slope (<5°). The potential 450 kW array modelled (Figure 8) is tilted at 10° to reduce the maintenance associated with cleaning the solar panels. Since this is an office building, it is likely to have significant daytime electrical consumption, thus increasing self-consumption of solar generation and reducing payback time.

Figure 7 Cricket NSW interim HQ now (inset), and with a potential 450kW PV array



[21] "Cricket NSW moves to Sydney Olympic Park," Cricket NSW Media

Cricket ACT

The headquarters of Cricket ACT underwent a $6.5 million redevelopment in 2017 and was recently renamed EPC Solar Park after the installation of a 65.6 kW solar system on its main stand.[22] The stadium complex includes offices, so has significant daytime load (averaging over 12 kW) from air-conditioning and lighting.[23] The existing solar system is installed on the north-facing roof of the southern stand and connected behind the single meter and network connection point.

This means the solar generation feeds demand across all the buildings, with excess generation being exported to the grid. Significantly for a commercial system, this export is renumerated at 8c/kWh, which helps to offset the cost of evening floodlights. Installers, EPC Solar, estimate annual bill reductions of over 40% will repay Cricket ACT's investment in just five years.[23] Figure 8 shows the existing installation (inset) and the potential for a further 190 kW of solar on the remaining roof area.

[22] "Phillip Oval Officially Renamed EPC Solar Park in New Partnership" Cricket ACT Media

[23] Information supplied by EPC Solar

Figure 8: EPC Solar Park with existing 65.6 kW array (inset) and potential additional 190 kW PV array

Cricket Queensland

The National Cricket Centre (NCC) was completed in 2013 at a cost of $29M and features state of the art indoor facilities including indoor pitches, gym and batting simulation spaces.[24] It houses the Queensland Cricket Association headquarters, is the training facility for the national Australian cricket men's team,[25] and has a seating capacity of 6,500.[26]

As shown in Figure 9 (inset), the HQ building (on the south west corner of the oval) already has a solar system that was installed in the summer of 2018/19, while the seating stands north of the HQ and the NCC building to the west have an additional solar potential of 455 kW.

[24] "Bupa National Cricket Centre," Cricket Australia

[25] "Aussie men front up at fitness camp," Dave Middleton

[26] Allan border Field | Austadiums (https://www.austadiums.com/)

Figure 9: The National Cricket Centre with existing array (inset) and potential additional 455 kW array

Western Australia Cricket Association

Named after the governing cricket association of Western Australia, the WACA is the home ground to the Western Warriors and Western Fury men's and women's cricket teams. With a seating capacity of 20,000,[27] the WACA was used as an international cricketing ground for home games until 2019 when the nearby Optus Stadium opened, and is still used for local leagues such as the Women's Big Bash League.[28] Figure 10 shows the potential 546 kW rooftop solar that could be installed on the stadium rooftops.

The six floodlight towers create some shade, however modelling shows they would have negligible impact on annual generation. Much of the roof has a slope below 10°, so a potential system would require a mounting structure providing extra tilt to allow for self-cleaning.

[27] The WACA | Austadiums (https://www.austadiums.com/)

[28] #TheFurnace | Perth Scorchers

Figure 10: The WACA now (inset) and with potential 546 kW array

Cricket Tasmania

The Tasmanian Cricket Association and the state's representative team, The Tasmanian Tigers, have called the Blundstone Arena (previously Bellerive Oval) their home ground since the early 1990s. The association's office building is also on site (southwest corner) and the oval itself has a seating capacity of 19,500.[29] Figure 12 shows the potential 639 kW solar system on the arena and office building. There is no significant shading of the arena roof, with the floodlights having a negligible effect on the annual output of the system.

The arena's roof causes partial shading of the office building roof, which has been allowed for in the analysis. The roof planes are relatively clear of fixtures and HVAC (heating, ventilation and air-conditioning) equipment, which would simplify installation.

[29] Blundstone Arena | Austadiums (https://www.austadiums.com/)

Figure 12 Blundstone Arena, Tasmania now (inset) and with potential 639 kW PV array

South Australian Cricket Association

The Adelaide Oval is a massive multi-purpose venue for several different sports, in particular cricket and AFL. With a seating capacity of 55,317,[30] the venue is home ground to the West End Southern Redbacks as well as the Adelaide Strikers. The South Australian Cricket Association also have its headquarters on site. The latest redevelopment of the oval was completed in 2014 with the expansion of the east and south stands, as well as reroofing with a Teflon-coated fibreglass material installed by Fabritecture,[31] which will not allow for a solar system to be installed.

Figure 13 Adelaide Oval, South Australia now (inset) and with potential 807kW PV array

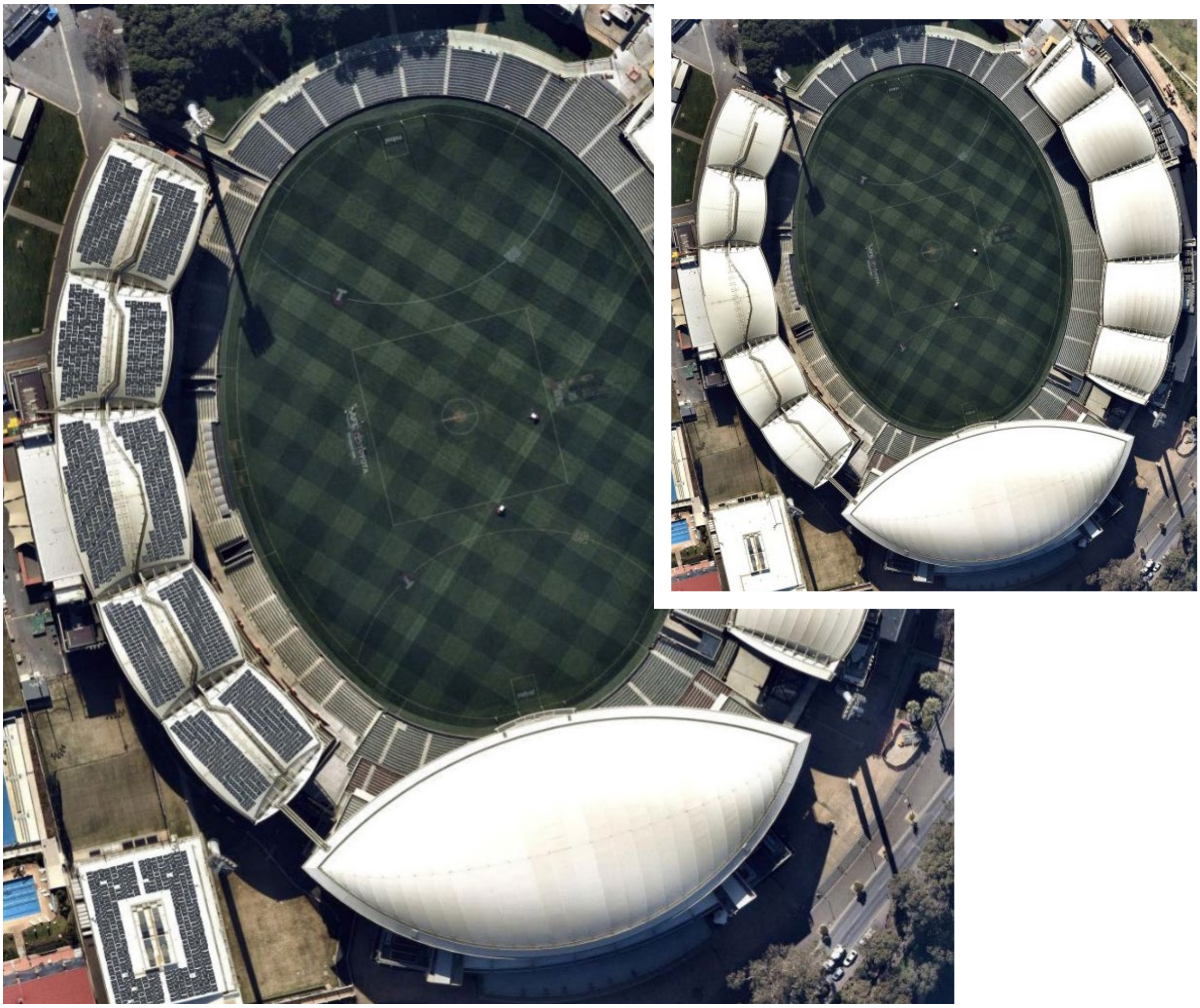


Figure 13 shows the potential 807 kW solar system on the west stand and the Favell / Dansie indoor cricket centre (bottom left). The west stand would require detailed engineering assessments to determine if the structure, shape and material can support the solar array.

[30] Adelaide Oval | Austadiums (https://www.austadiums.com/)

[31] "Fabritecture Lands $4M Contract For The Adelaide Oval Stadium Redevelopment" News Wire press release

Northern Territory Cricket

TIO Traeger Park in Alice Springs, opened in 1991, was named after engineer and inventor Alfred Hermann Traeger, best known for the "pedal radio"; a pedal powered radio transmitter-receiver which connected remote parts of Australia and helped provide access to emergency services.[32] The site has several sports facilities including tennis, basketball, hockey and baseball, as well as the 7,200-capacity[33] TIO Traeger Park Oval, dubbed "the jewel in the centre", which hosts AFL, NRL and cricket matches.[34]

Figure 14 shows the potential for a 636kW solar system, across several buildings in the park, excluding the grandstand due to the potential impact of the weight of the solar array on a cantilever roof as well as potential installation issues caused by the support cables running along the roof.

32 "The Pedal Radio of the Great Outback," Richard Begbie

33 TIO Traeger Park Oval | Austadiums (https://www.austadiums.com/)

34 "TIO Traeger Park Oval," Sporting facilities, Alice Springs Town Council

Figure 14 TIO Traeger Park Oval now (inset) and with potential 636kW PV array

Formally known as DXC Arena, the "Marrara Cricket Ground" is home to the Northern Territory Cricket Association headquarters. Located in the Marrara sports complex in Darwin, the grounds have an estimated seating capacity of 4,500,[35] where patrons mainly sit on the grass hills around the field. The rooftops of the stands and headquarters are east and west facing with slopes ranging from 15° to 45°.

They have minimal shading from surrounding trees, allowing installation flush to the roof, with enough tilt for self cleaning. Figure 15 shows the potential 243 kW solar on the roofs of the stands and headquarters building.

[35] DXC Arena/ Marrara Cricket Ground | Austadiums (https://www.austadiums.com/)

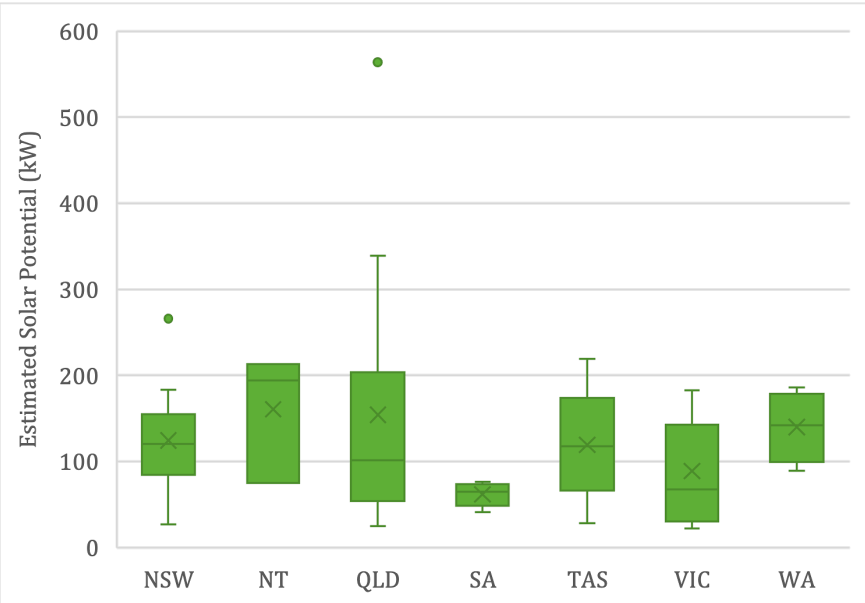
Figure 15 DXC Arena/ Marrara Cricket Ground now (inset) and with potential 243 kW PV array

Regional and community cricket

Apart from the major stadia, Australia has over 50 cricket grounds that have been used for international or first-class[36] domestic cricket matches. The infrastructure at these grounds is diverse, with roof areas ranging from under 300 m² to 7,000 m².

A conservative assumption of 40% of this roof area being suitable for solar PV deployment suggests average rooftop generation potential of 120 kW at each of these grounds, varying between 20 kW and 560 kW (Figure 15). The conservative estimate of the solar potential of these 55 grounds alone therefore exceeds 6,600 kW, with an estimated investment cost of $6.9million.[37]

Figure 15: Variability of estimated rooftop solar potential at nationally significant Australian cricket grounds



Beyond these significant cricket grounds, there are nearly 4,000 community cricket clubs across the country, with 709,957 registered participants[4]. If each of these clubs installed only a modest 10 kW PV system, they would add 40 MW to Australia's solar generation capacity, with an estimated investment cost of $47million[38], though there is likely to be capacity for more than this at many of the grounds.

As well as reducing electricity costs for community clubs (with bill savings likely to repay installation costs within a few years, particularly if a feed-in-tariff is available), these systems would contribute to the decarbonisation of the energy system and significantly help reduce emissions.

For clubs in bushfire-affected areas, the addition of a battery and hybrid, anti-islanding inverter could also provide a reliable electricity supply during grid outages caused by fires or other extreme weather events, increasing community resilience.

[36] Including List A, Twenty20, Big Bash matches

[37] Based on the national average cost of $1.05/W for commercial rooftop systems [3]

[38] Based on the national average cost of $1.18/W for small (up to 10kW) commercial rooftop systems [3]

Case study: Millewa Cricket Club

Figure 16: Millewa Cricket Club now (inset) and with potential 19 kW PV array

Having moved from the remote and grassless Morkalla cricket ground, Millewa Cricket Club (MCC) now occupies one of a cluster of five ovals in Red Cliffs, a small town of 5,000 people in North-West Victoria.

The small clubhouse is owned by the local council and shared with the local kennel club. The MCC uses the building three times a week and only consumes electricity to run lights and a small fridge (plus an extra drinks fridge used only on match days), so its electricity bill is modest.

The small north-facing section of the roof could site a 5.1kW solar PV system and the club estimates the bill savings and a 10.2c feed-in-tariff for exported electricity would pay for the system in three years.[39] The club is also keen to mount solar panels to its electric green roller. With the larger south-facing roof and adjoining outhouse, there is potential for a total of 19 kW of solar, installed using a suitable rack-mounting system (Figure 16), with an estimated 30 MWh annual energy output. This is equivalent to avoiding 612 tonnes of CO2-e emissions over a 20-year period or planting an estimated 10,210 trees.

Adding a battery and hybrid inverter would ensure a reliable electricity supply in the event of disruptive weather events or bushfires, but the cost would be significantly higher.

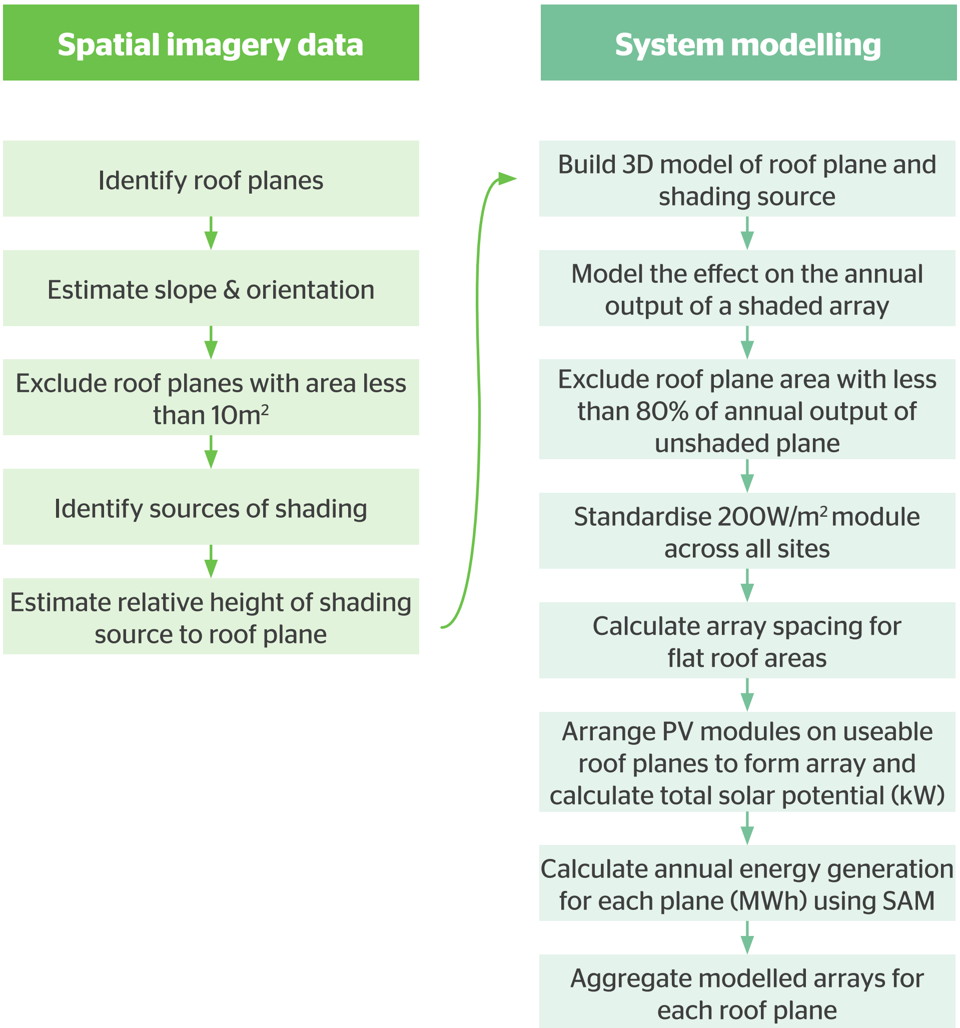
Figure 17 Millewa Cricket Club pavilion and electric roller (inset) (Image courtesy Steve Kelly)

[39] Data supplied by Millewa Cricket Club

Methodology

This section describes the method used to estimate the rooftop solar potential of the cricket stadia and associated buildings. The steps in the methodology are illustrated in Figure 18.

Figure 18: Major steps in the estimation of rooftop PV potential using visual analysis



Analysis of solar potential and energy generation

The potential solar capacity of the case study buildings was assessed visually, using multiple viewpoint aerial imagery from Nearmap [5]. Unsuitable surfaces and obstructions were identified and excluded from the usable roof area. Roof slope was estimated using the measuring tools in Nearmap's Oblique View imagery, and small rooftop obstructions and perimeter walls were also identified and their height estimated. 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 was calculated. 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.

Nearmap's Solar Tool was then used to arrange 1.7m x 1.06m PV panels on the usable roof space. On all usable roof areas with greater than 10º slope, PV arrays were assumed to be installed flush to the roof, while 'flat' roofs were assumed to have rack-mounted arrays installed at a tilt of 10º spaced to minimise self-shading. The PV capacity was calculated assuming modules of 360 watts (and a consequent DC size factor of 200 W/m2), and the annual energy output was calculated using NREL's System Advisor Model [6] and an 'ERMY' weather file [7] for the nearest Bureau of Meteorology (BOM) weather station.

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. The systems described represent the available rooftop solar potential, not a design proposal.

Carbon and equivalency metrics

The annual energy produced by potential rooftop solar PV has been compared to the average annual household energy consumption in each state (Table 2 derived from [8-10]), using data for a four-person household in the climate zone of each stadium.

Potential CO2-e emissions reductions from rooftop PV were calculated by multiplying the indirect (Scope 2) emissions factor for consumption of electricity purchased from the grid in each state (see Table 3) by the expected annual energy generation from the system over the 20-year module lifetime, and subtracting the estimated embodied carbon emissions from the manufacture, installation, operation and decommissioning of the PV system (0.045kg CO2-e /kW[11]).

Since solar is very low-maintenance, jobs created in Australia through solar deployment are predominantly in sales and installation, at an estimated 5.8 job-years (assumed equivalent to 9,744 job-hours) per megawatt of commercial solar installed [13].

The carbon uptake of trees is highly variable, depending on species and growing conditions. For our estimate of the number of planted trees that would avoid an equivalent amount of carbon emissions as the potential PV installations, we used a figure of 0.06 tonnes CO2-e per urban tree planted and allowed to grow for ten years [14]. This was divided into the estimated 20-year lifetime generation of the potential solar PV.

Table 2 Annual household energy consumption by state and climate zone

State	Zone	kWh/ year
NSW	5	7,311
QLD	2	7,682
SA	5	7,121
TAS	7	10,820
VIC	6	5,805
WA	5	5,198
NT	1	10,074
ACT	7	9,542

Table 3 Scope 2 emissions factors by state [12]

State	Emissions factor (kg-CO2/kWh)
NSW	0.81
QLD	0.77
SA	0.44
TAS	0.15
VIC	1.02
WA	0.69
NT	0.63
ACT	0.81

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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 PV Institute (APVI) is a not-for-profit, member-based organisation providing data analysis, reliable and objective information, and collaborative research to support the uptake of solar photovoltaics and related technologies. APVI promotes PV through its live solar mapping platform (http://pv-map.apvi.org.au), organises Australia's national solar research conference, and coordinates Australia's participation in two International Energy Agency programs: Photovoltaic Power Systems and Solar Heating and Cooling.

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