Sunny side up: how schools, prisons and libraries can power Queensland's renewable future

AUSTRALIAN CONSERVATION FOUNDATION

AUSTRALIAN PV INSTITUTE

UNSW SYDNEY

Installing rooftop solar panels.
Photo: James Thomas Photo (Claude Raschella).

Key **findings**

The significant potential for deployment of solar photovoltaics (PV) on rooftops of Queensland's government and public-sector buildings presents an opportunity. Queensland can increase the supply of clean, low-cost electricity to contribute to the daily energy demand of schools, hospitals and other essential services.

This report looks at the solar rooftop opportunities on public buildings in five diverse local government areas (LGAs) — Brisbane, Cairns, Logan, Gladstone and Townsville — and provides a case study for each.

Key findings:

- The energy generated each year by these potential PV installations could power 44,000 average Queensland households.
- These PV installations could generate an estimated 844 job-years* of employment in the solar installation business.
- 152,000 tonnes of CO_2 emissions could be avoided, equivalent to leaving 1,353,000 tonnes of coal in the ground or planting 51 million trees.

Of the 150 megawatts (MW) of solar potential identified on public buildings, just over half is on public schools with public hospitals and correctional centres providing further opportunities.

- 77 MW of PV potential on public schools
- 28 MW on public hospitals
- 14 MW on correctional centres

As expected, of the five LGA's considered, Brisbane has the highest potential with 91 MW on its public buildings, while Townsville has 22 MW, Cairns 16 MW, Logan 10 MW and Gladstone 6 MW of potential.

There is an estimated additional 233 MW of capacity on other community buildings, including private schools and hospitals, universities and colleges, sports clubs, community centres and aged-care facilities across these LGAs.

These findings point to a major opportunity for Queensland government at all levels to deploy rooftop solar PV on their buildings, creating financial value for taxpayers and supporting employment in the renewable energy industry. It also would contribute to the Queensland government's targets of 50% renewable energy by 2030 and 30% cut in emissions by 2030, as well as to Australia's Paris emissions reduction commitments.

The analysis behind this report combines a digital surface model (DSM) of Queensland, derived from LiDAR data, with a dataset of building footprints to map the scale of this opportunity in the five identified diverse LGAs.

*A job-year is a measure of the labour required to develop and construct a project and represents a single person employed full time over a year.

152,000 tonnes of CO_2
emissions could be avoided

Figure 1: Map of solar potential opportunities

Authors

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 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. The tool 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 (pv-map.apvi.org.au). APVI also 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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Contents

Introduction

Although 32% of Australia's 17.5 gigawatts (GW) of solar photovoltaics (PV) is installed in Queensland, nearly half of it is on the roofs of 672,000 solar households.[1] Commercial-scale rooftop PV is a relatively new market — with only 5% of Queensland solar installations in this category — and it offers major opportunities, including on public buildings, where large roof areas meet significant daytime electricity consumption.

As in other Australian jurisdictions, deployment of solar photovoltaics (PV) in Queensland prior to 2018 was largely driven by households installing rooftop solar, initially motivated by high feed-in tariffs. While the state now leads Australia and the world for residential PV penetration, with over 38% of houses generating their own solar energy,[1] the past two years have seen a surge in deployment of utility-scale PV as well as an increase in commercial rooftop systems of between 10 kilowatts (kW) and 100 kW capacity. The combination of rising electricity costs, increasing PV efficiencies and falling capital costs now make the installation of PV particularly attractive where it can be used to meet on-site consumption. Nevertheless, despite generating more solar energy than any other state, Queensland now lags behind New South Wales in both the number and capacity of monthly PV installations.[2]

Government, at all levels, is uniquely placed to effect an increase in rooftop PV deployment through its ownership of a large portfolio of diverse buildings in rural and urban locations. Not all rooftops are suitable for PV installation. Poor orientation, shading by buildings or trees, obstructions such as heating, ventilating and air conditioning systems (HVAC) or other infrastructure, and multifaceted roof-forms can decrease deployment opportunities. The proportion of usable roof surfaces also varies between 35% and 75% across building types and locations.

This report presents an analysis of the rooftop solar potential of government and public buildings in five diverse Queensland Local Government Areas (LGAs), along with detailed rooftop analysis and PV system design for five case-study buildings.

Government, at all levels, is uniquely placed to effect an increase in rooftop PV deployment

Energy generated each year by these potential PV installations **could power 44,000 Queensland households**

Previous page. Facility manager, Warwick Solar Farm, QLD.

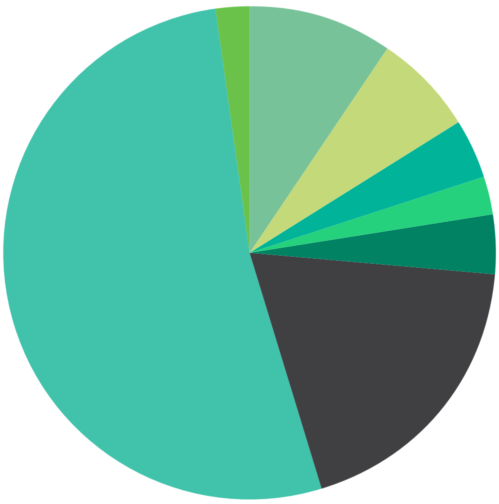
Results

Summary: public and government buildings

Table 1 shows the estimated rooftop capacity for solar PV installation on public and government buildings in five Queensland LGAs, while Figure 2 shows distribution of PV capacity by building category. These are buildings owned or operated by branches of federal, state and local government, including the following categories:

- Public schools
- Public hospitals
- Correctional centres
- Emergency services / defence buildings
- Government or council offices and depots
- Other public building (libraries, arts centres, etc.)
- Post offices
- Public utility buildings

Figure 2: Potential PV capacity on public buildings across five LGAs by building category



Public school **77 MW**

Public hospital **28 MW**

Correctional centre **14 MW**

Emergency services/defence **10 MW**

Government or council building **6 MW**

Public building **5 MW**

Post office **4 MW**

Public utility **3 MW**

Over half the potential rooftop capacity is on public schools. Hospitals and correctional centres also have significant generating potential, as well as daytime energy demand likely to ensure high proportion of on-site consumption of the energy generated. However, the smaller categories are not insignificant. For example, the roofs of post offices in these five LGAs alone could provide close to 4 MW of generating capacity.

Table 1 illustrates some of the potential benefits of utilising this rooftop solar potential, which could generate enough electricity to power over 44,000 average Queensland homes. In the process, this could avoid 152,000 tonnes of CO_2 emissions, equivalent to leaving 1,353,000 tonnes of coal in the ground or planting 51 million trees, as well as providing 844 job-years of employment in the solar industry.

Figure 3: Solar PV capacity by LGA totalling 146 MW

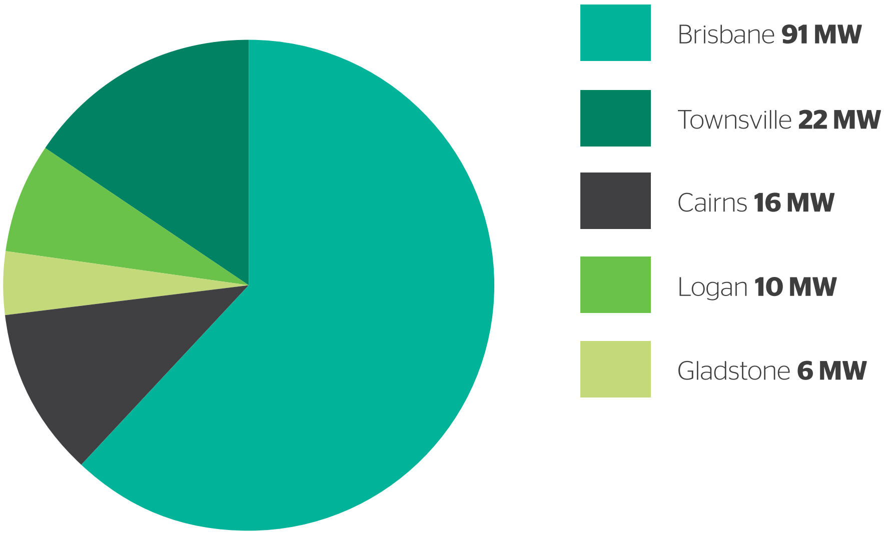


Table 1: Possible PV generation and equivalent metrics for public and government buildings

	Brisbane	Cairns	Gladstone	Logan	Townsville
# Buildings	592	101	56	63	125
PV capacity (kW)	90,700	16,400	6,500	9,900	22,100
Annual energy (MWh)	121,800	22,500	7,900	13,300	33,500
Equivalent QLD household consumption	27,100	5,000	1,800	3,000	7,400
Avoided CO_2 emissions (kilotonnes /20 years)	93	17	6	10	26
Displaced coal (kilotonnes/20 years)	828	153	54	91	228
Job-years	526	95	38	57	128
Trees equivalent (1000's for 20 years/generation)	31,066	5,736	2,011	3,397	8,539

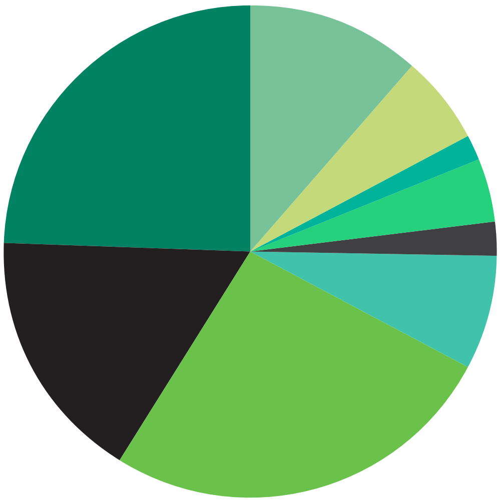
Other public community **buildings**

In addition to buildings owned and operated by branches of federal, state and local government, there are large numbers of buildings that play an important community or public role and, in many cases, receive significant public funding.

This provides an opportunity for governments to incentivise and support PV deployment on these buildings. Categories of buildings include:

- Private schools
- Tertiary institutions
- Sports and community clubs and facilities
- Aged-care facilities
- Private hospitals
- Airport buildings
- Medical centres
- Other educational buildings
- Childcare centres

Figure 4: Additional building categories (Total potential capacity is 234 MW)



Brisbane

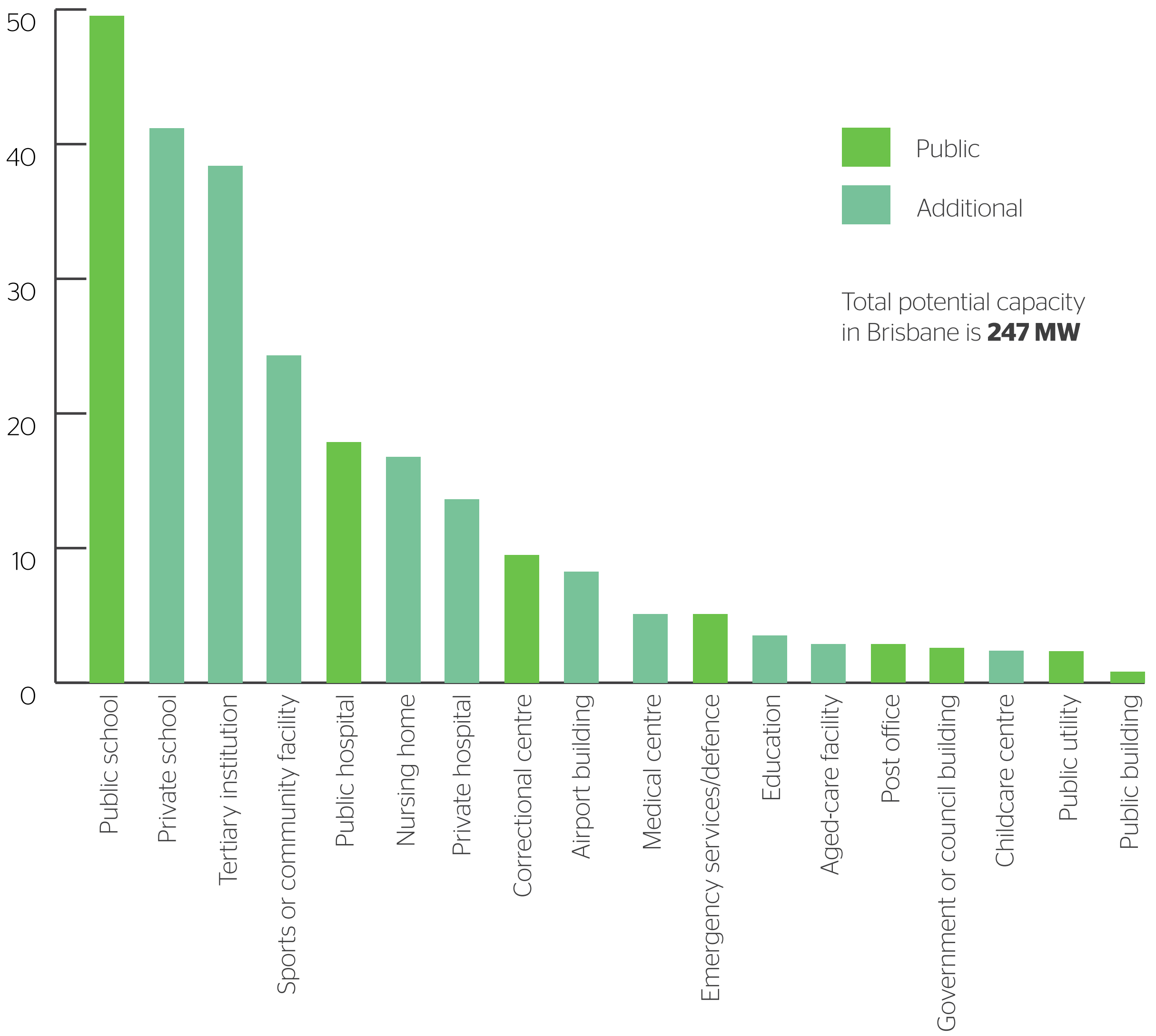
As you can see in Table 2 for the Brisbane LGA, the 406 public school buildings provide more than half of the solar potential. If you include the 62 public hospital buildings, these categories provide just under three-quarters of the solar potential. Adding in other buildings that aren't necessarily publicly owned but which house important community spaces and services increases the solar potential of the Brisbane LGA over 2.5 times as seen in Figure 5. Private school buildings and the buildings of tertiary institutions have the most solar potential in this category.

Table 2: Solar potential of government buildings by category — Brisbane LGA

	# Buildings	PV capacity (kW)	Annual energy (MWh)
Public school	406	49,535	66,546
Public hospital	62	17,882	24,076
Post office	20	2,861	3,873
Other public building	3	824	1,115
Public utility	9	2,353	3,196
Correctional centre	46	9,499	12,711
Emergency services/ defence	29	5,112	6,881
Government or council building	17	2,612	3,431
TOTAL	**592**	**90,677**	**121,829**

Brisbane

Figure 5: Solar PV capacity all public and community buildings in Brisbane (MW)



Total potential capacity in Brisbane is **247 MW**

Case study:
Kenmore South State School

Figure 6: Kenmore South State School, now (inset) and with potential 629 kW PV array

Table 3: Kenmore South State School — PV metrics

Total roof area (m2)	6,346
Array area (m2)	3,019
Array area/roof area (%)	48
PV capacity (kW peak)	629
Estimated energy production (MWh/year)	913
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	14.0
Equivalent QLD households	203
Equivalent avoided coal use (kilotonnes/ 20 years)	6.2
Equivalent trees planted (20 years)	232,815

Cairns

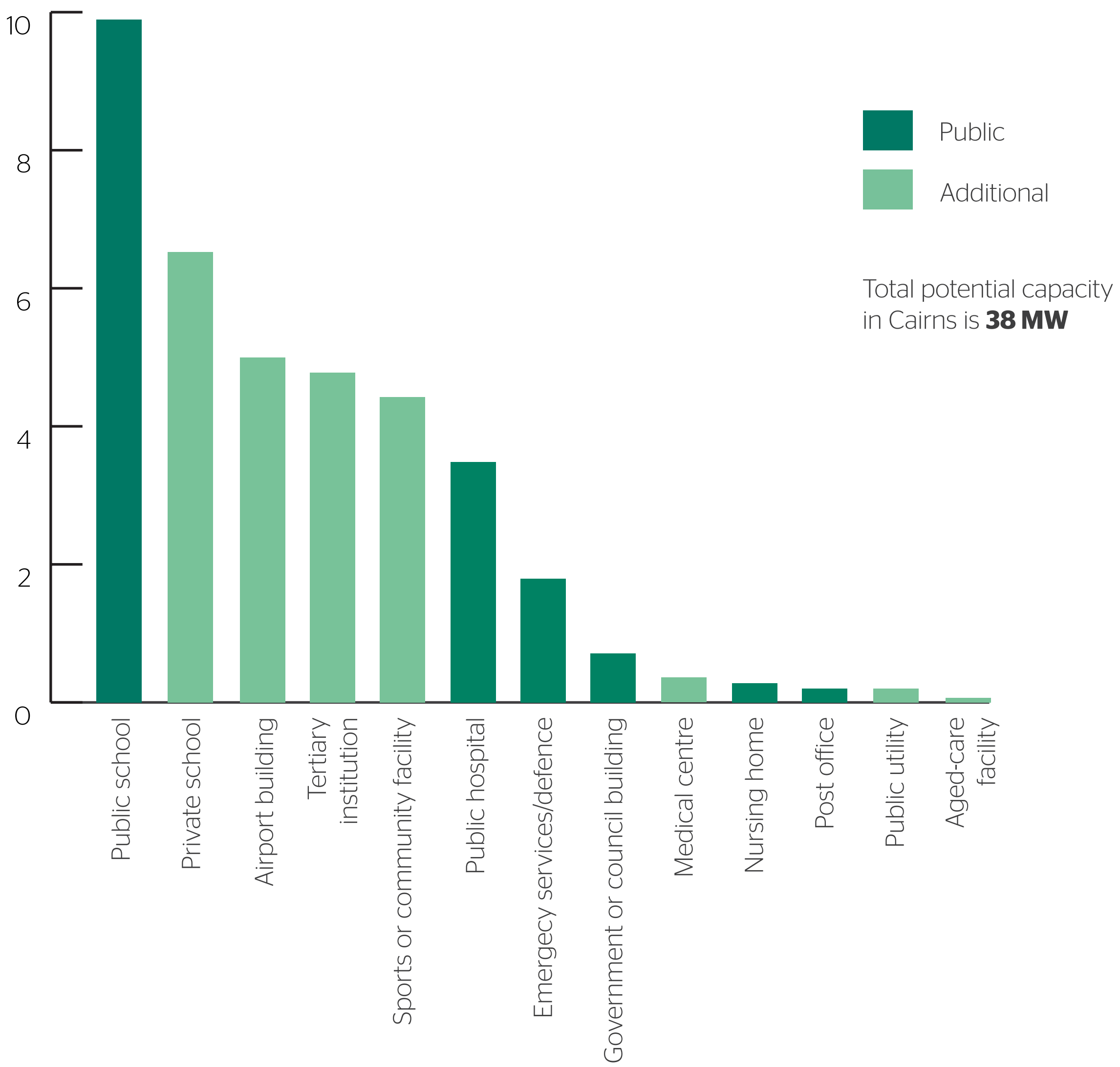
Similar to the Brisbane LGA, public school and hospital buildings provide the biggest potential opportunity for solar PV. The addition of other community-based buildings more than doubles the potential of solar PV in Cairns, with private schools, airport buildings and tertiary education buildings showing the greatest potential.

Table 4: Solar potential of government buildings by category — Cairns LGA

	# Buildings	PV capacity (kW)	Annual energy (MWh)
Public school	77	9,895	13,586
Public hospital	6	3,485	4,788
Post office	1	277	388
Other public building	-	-	-
Public utility	2	201	280
Correctional centre	-	-	-
Emergency services/ defence	13	1,794	2,462
Government or council building	2	708	992
TOTAL	**101**	**16,360**	**22,496**

Cairns

Figure 7: Solar PV capacity all public and community buildings in Cairns (MW)



Total potential capacity in Cairns is **38 MW**

Case study:
Cairns State Special School

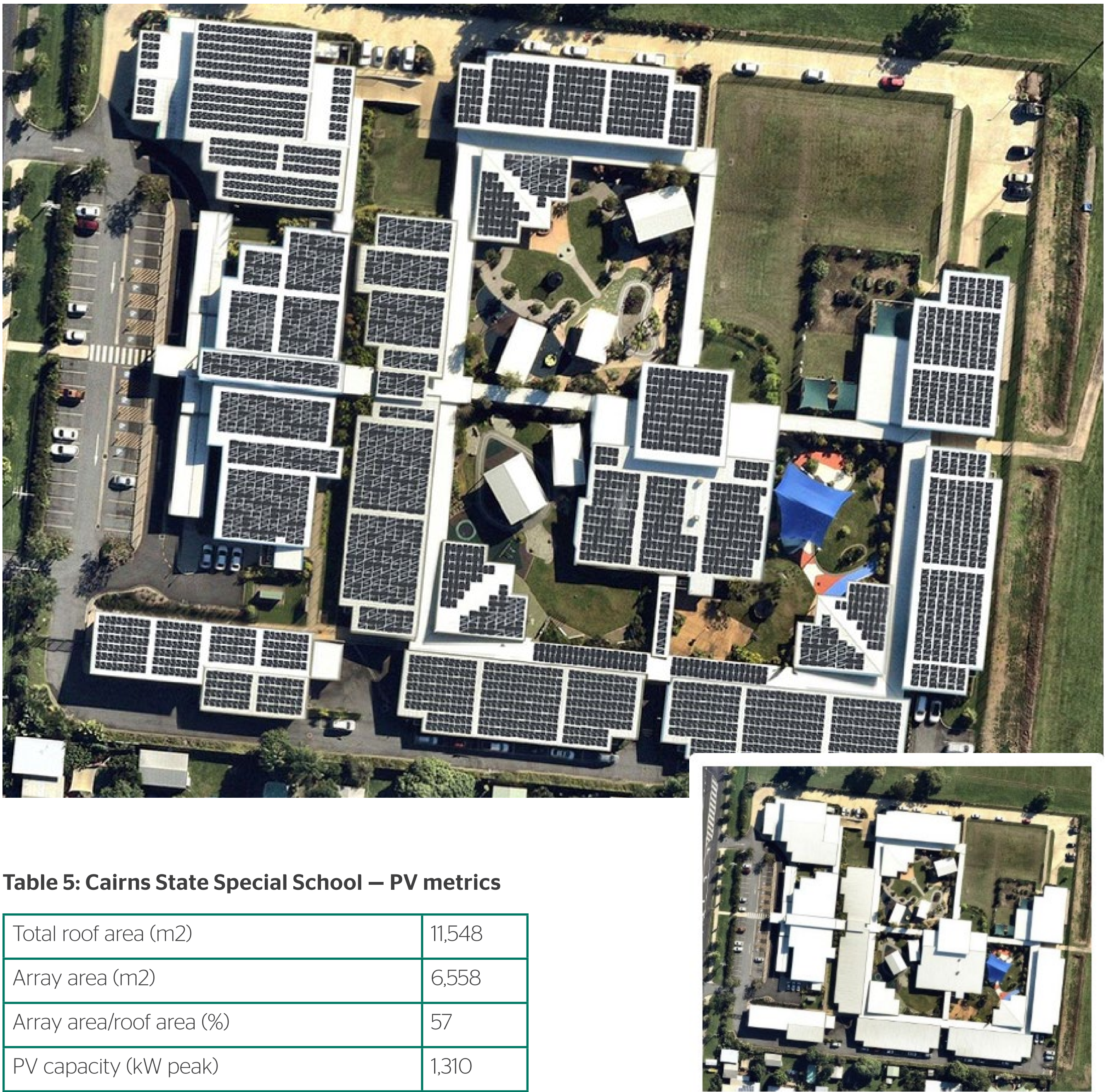


Figure 8: Cairns State Special School, now (inset) and with potential 1.3 MW PV array

Table 5: Cairns State Special School — PV metrics

Total roof area (m2)	11,548
Array area (m2)	6,558
Array area/roof area (%)	57
PV capacity (kW peak)	1,310
Estimated energy production (MWh/year)	1,914
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	29.3
Equivalent QLD households	425
Equivalent avoided coal use (kilotonnes/ 20 years)	13.0
Equivalent trees planted (20 years)	488,000

Coal mine near Leard State Forest. Photo: Dean Sewell.

1,353,000 tonnes of coal could be kept in the ground

Gladstone

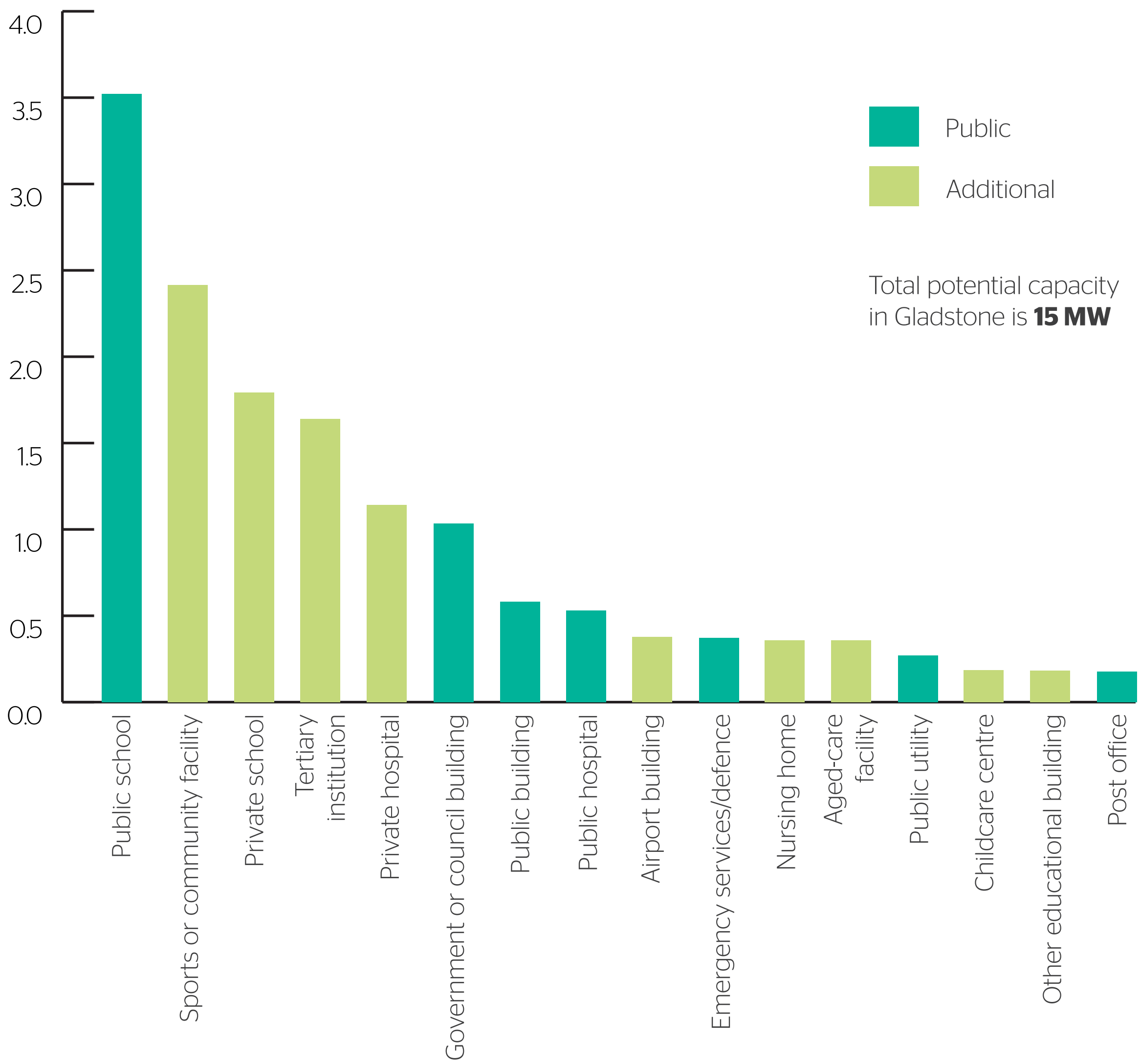
Gladstone public school buildings provide the biggest opportunity in the LGA with over half potential capacity found on these buildings. Including other community based buildings more than doubles the potential PV capacity in the Gladstone LGA.

Table 6: Solar potential of government buildings by category — Gladstone LGA

	# Buildings	PV capacity (kW)	Annual energy (MWh)
Public school	36	3,521	4,287
Public hospital	2	529	645
Post office	2	176	213
Other public building	4	581	697
Public utility	2	271	336
Correctional centre	-	-	-
Emergency services/ defence	3	371	449
Government or council building	7	1,034	1,258
TOTAL	**56**	**6,484**	**7,885**

Gladstone

Figure 9: Solar PV capacity all public and community buildings in Gladstone (MW)



Total potential capacity in Gladstone is **15 MW**

Case study:
Gladstone Hospital

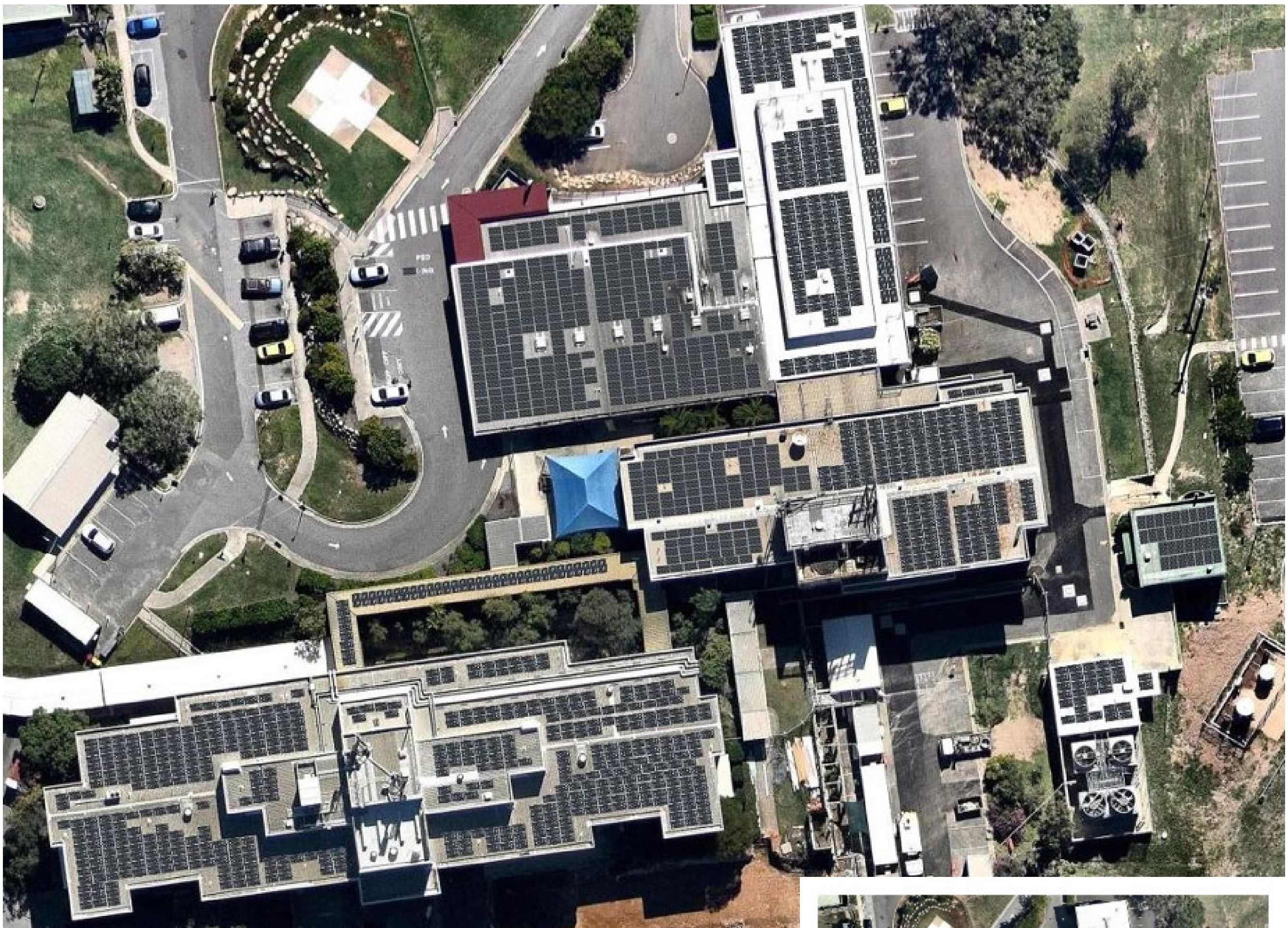


Figure 10: Gladstone Hospital, now (inset) and with potential 518 kW PV array

This case study used the building footprint prior to the opening of the new Gladstone hospital emergency department.

Table 7: Gladstone Hospital — PV metrics

Total roof area (m2)	4,940
Array area (m2)	2,484
Array area/roof area (%)	50
PV capacity (kW peak)	518
Estimated energy production (MWh/year)	781
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	11.9
Equivalent QLD households	173
Equivalent avoided coal use (kilotonnes/ 20 years)	5.3
Equivalent trees planted (20 years)	199,155

Logan

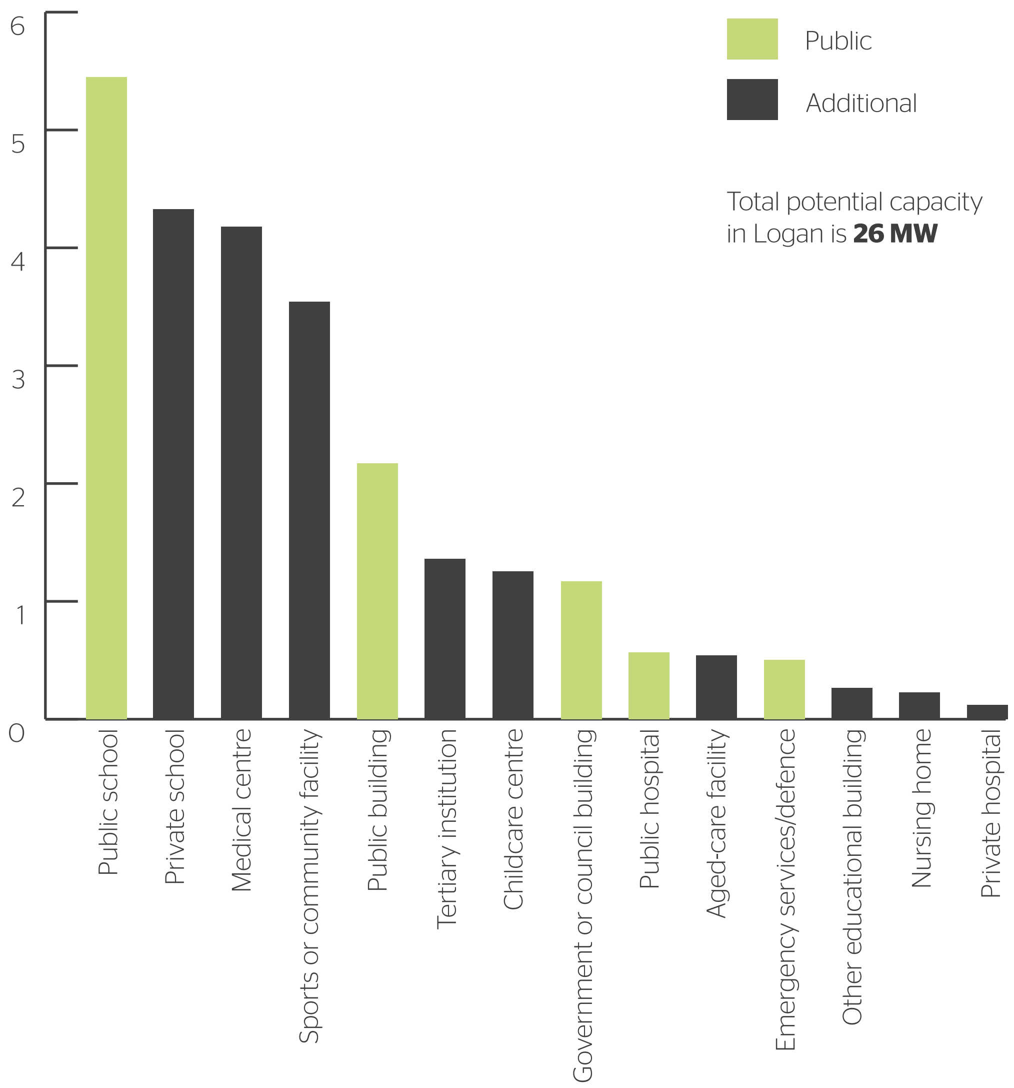
In the Logan LGA, public school buildings and other public buildings — in this case six libraries — make up almost 80% of the solar potential, while adding in additional buildings triples the amount of solar potential in Logan with private schools and medical centres making the largest contribution. The Griffith University Campus in Logan also provides an opportunity for solar PV as outlined in the case study below.

Table 8: Solar potential of government buildings by category — Logan LGA

	# Buildings	PV capacity (kW)	Annual energy (MWh)
Public school	48	5,448	7,284
Public hospital	1	566	785
Post office	-	-	-
Other public building	6	2,172	2,977
Public utility	-	-	-
Correctional centre	-	-	-
Emergency services/ defence	4	503	679
Government or council building	4	1,169	1,595
TOTAL	**63**	**9,857**	**13,321**

Logan

Figure 11: Solar PV capacity all public and community buildings in Logan (MW)



Total potential capacity in Logan is **26 MW**

Case study: Griffith University, Logan Campus

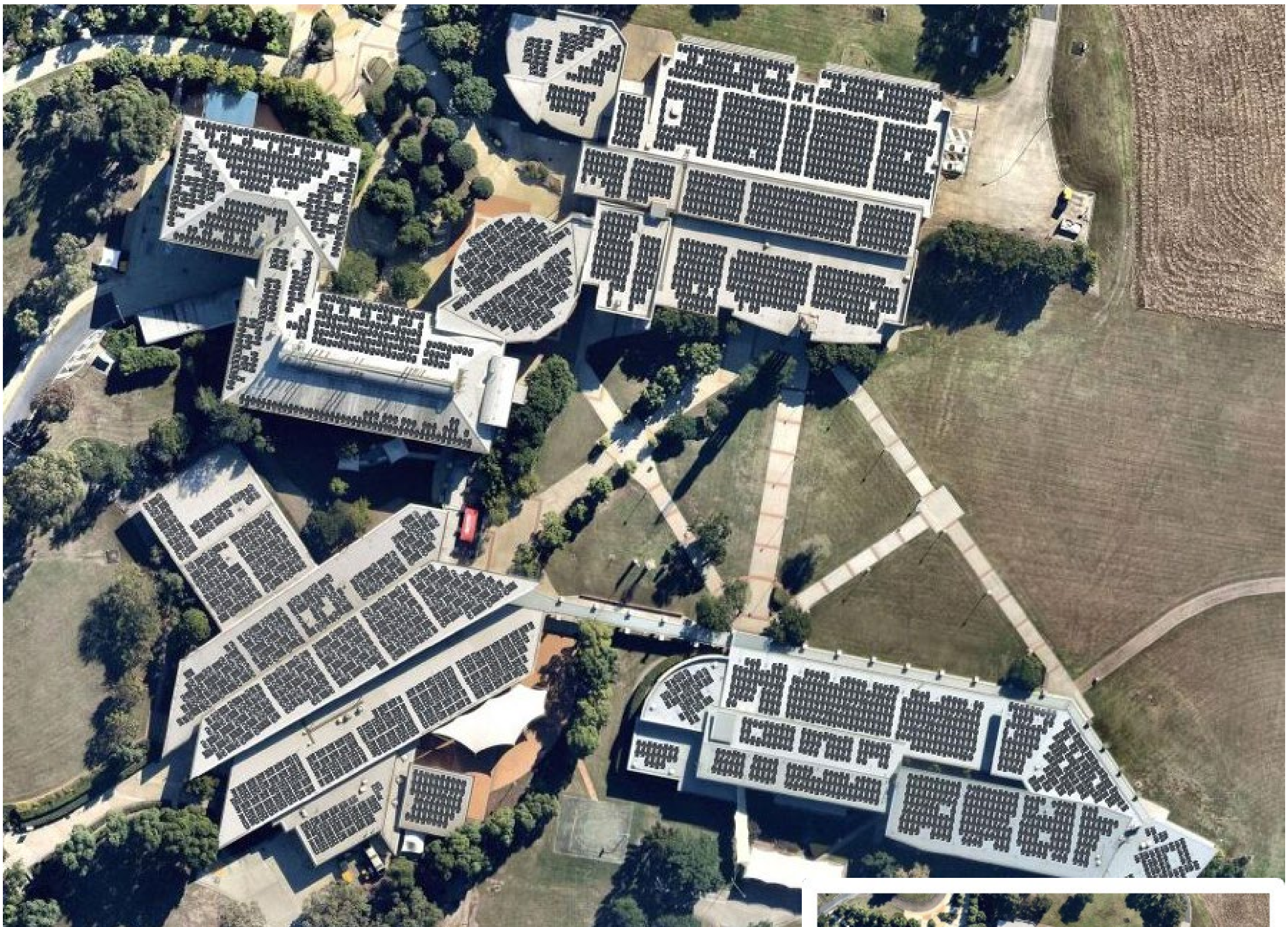


Figure 12: Griffith University, Logan Campus now (inset) and with potential 1.36 MW PV array

Table 9: Griffith University, Logan Campus — PV metrics

Total roof area (m2)	12,506
Array area (m2)	6,807
Array area/roof area (%)	54
PV capacity (kW peak)	1,360
Estimated energy production (MWh/year)	1,977
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	30.2
Equivalent QLD households	439
Equivalent avoided coal use (kilotonnes/ 20 years)	13.4
Equivalent trees planted (20 years)	504,135

Townsville

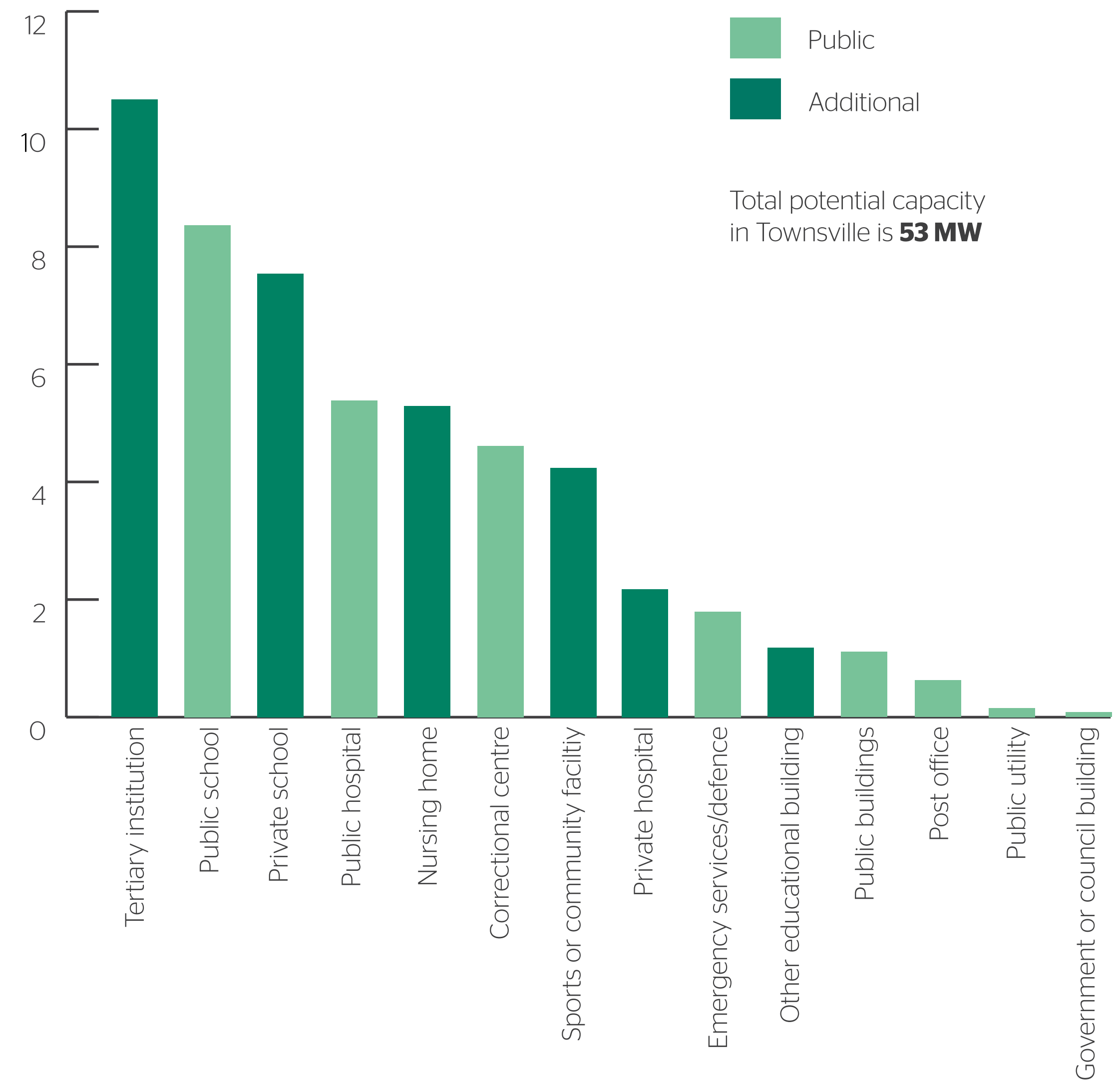
In the Townsville LGA, public schools and hospitals make a large contribution. Correctional centre buildings, such as the Townsville Correctional Centre (see case study below), and tertiary institution buildings — particularly from James Cook University — also provide further opportunities for solar PV.

Table 10: Solar potential of government buildings by category — Townsville LGA

	# Buildings	PV capacity (kW)	Annual energy (MWh)
Public school	66	8,366	12,558
Public hospital	6	5,382	8,292
Post office	4	627	966
Other public building	4	1,111	1,680
Public utility	2	157	238
Correctional centre	30	4,612	6,899
Emergency services/ defence	12	1,796	2,728
Government or council building	1	85	127
TOTAL	**125**	**22,137**	**33,488**

Townsville

Figure 13: Solar PV capacity all public and community buildings in Townsville (MW)



Total potential capacity in Townsville is **53 MW**

Case study:
Townsville Correctional Centre

Figure 14: Townsville Correctional Centre, now (inset) and with potential 1.84 MW PV array

Table 11: Townsville Correctional Centre — PV metrics

Total roof area (m2)	16,123
Array area (m2)	8,814
Array area/roof area (%)	55
PV capacity (kW peak)	1,837
Estimated energy production (MWh/year)	2,845
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	43.5
Equivalent QLD households	632
Equivalent avoided coal use (kilotonnes/ 20 years)	19.3
Equivalent trees planted (20 years)	725,475

Case study
Summary results

Table 12: Possible PV generation and equivalent metrics for case study buildings

	Cairns State Special School	Gladstone Hospital	Kenmore South State School	Griffith University	Townsville Correctional Centre
Total roof area (m2)	11,548	4,940	6,347	12,506	16,123
Array area (m2)	6,558	2,484	3,019	6,807	8,814
Array area/roof area (%)	57	50	48	54	55
PV capacity (kW peak)	1,310	518	629	1,360	1,837
Estimated energy production (MWh/year)	1,914	781	913	1,977	2,845
Estimated avoided emissions (kilo tonnes-CO_2-e/20 years)	29.3	11.9	14.0	30.2	43.5
Equivalent QLD households	425	173	203	439	632
Equivalent avoided coal use (kilotonnes/20 years)	13.0	5.3	6.2	13.4	19.3
Equivalent trees planted (20 years)	488,000	199,000	233,000	504,000	725,000

Table 13: Potential PV capacity and annual generation on other public and community buildings

		Aged-care facility	Airport building	Childcare centre	Sports or community facility	Private hospital	Medical centre	Nursing home	Private school	Tertiary institution	Other educational building	**Total**
Brisbane	Buildings	18	2	16	9.2	51	16	64	309	203	28	799
	PV capacity (MW)	2.9	8.3	2.4	24.3	13.6	5.1	16.8	41.2	38.4	3.5	156
	Annual energy (GWh)	3.8	11.2	3.2	33.0	18.2	7.0	22.5	55.3	51.6	4.7	211
Cairns	Buildings	2	6	1	28	–	4	1	40	19	–	101
	PV capacity (MW)	0.2	5.0	0.1	4.4	–	0.5	0.4	6.5	4.8	–	22
	Annual energy (GWh)	0.3	7.0	0.1	6.1	–	0.7	0.5	9.0	6.6	–	30
Gladstone	Buildings	2	2	2	15	2	–	1	14	10	1	49
	PV capacity (MW)	0.4	0.4	0.2	2.4	1.1	–	0.4	1.8	1.6	0.2	9
	Annual energy (GWh)	0.4	0.5	0.2	2.9	1.4	–	0.4	2.2	2.0	0.2	10
Logan	Buildings	3	–	12	14	1	22	1	41	5	4	103
	PV capacity (MW)	0.5	–	1.3	3.5	0.1	4.2	0.2	4.3	1.4	0.3	16
	Annual energy (GWh)	0.7	–	1.7	4.8	0.2	5.7	0.3	5.8	1.9	0.3	21
Townsville	Buildings	–	–	–	17	9	–	22	60	70	10	188
	PV capacity (MW)	–	–	–	4.2	2.2	–	5.3	7.5	10.5	1.2	31
	Annual energy (GWh)	–	–	–	6.5	3.3	–	8.0	11.4	16.0	1.8	47

There are large numbers of buildings that play **an important community or public role**

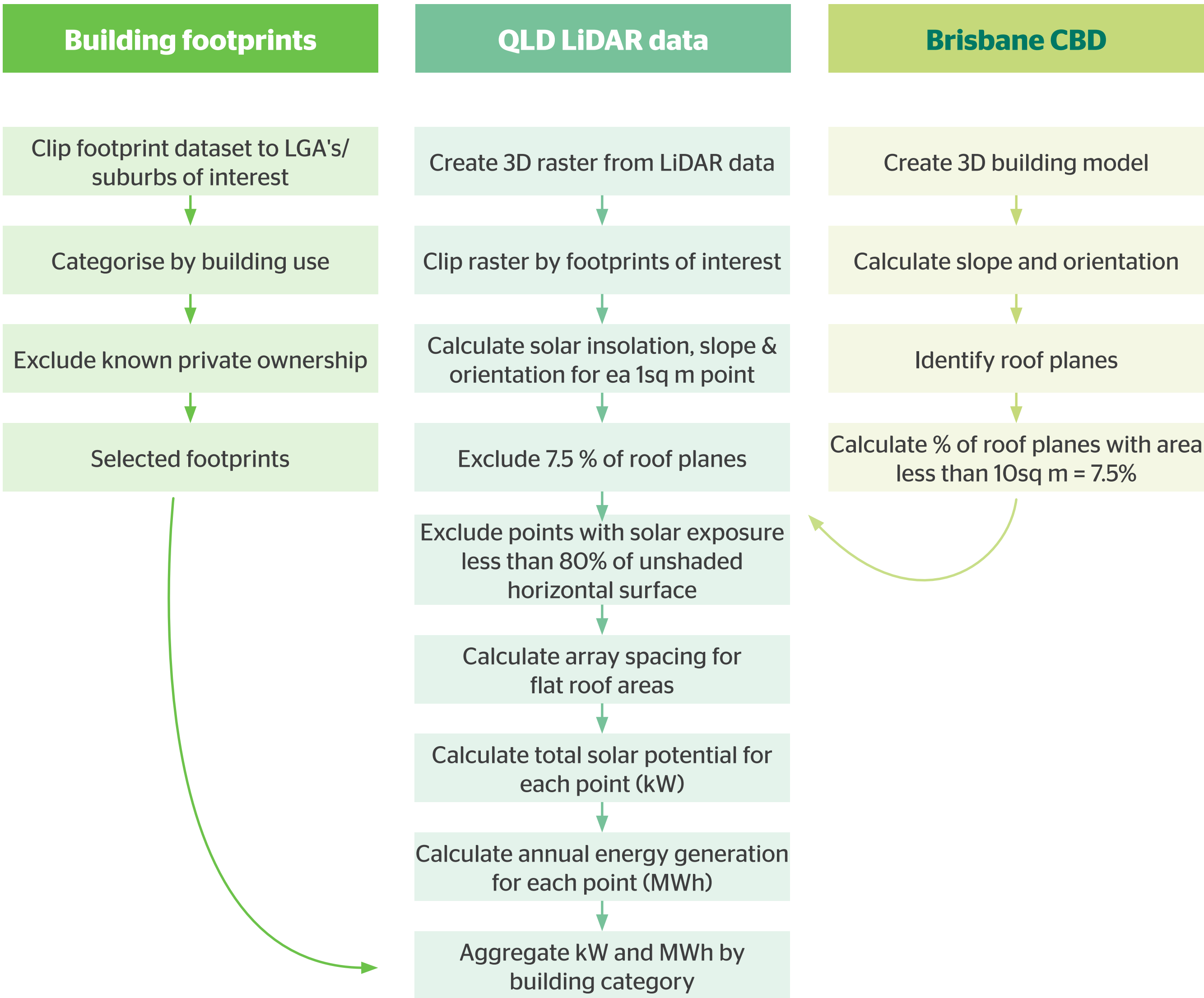
These PV installations could generate an estimated **844 job-years of employment in the solar installation business**

Installing rooftop solar panels.
Photo: James Thomas Photo (Claude Raschella).

Methodology

This section describes the method used to estimate the rooftop solar potential of government/public buildings in five Queensland Local Government Areas (LGAs). The steps in the methodology, which is based on the method underlying the APVI's SunSPoT tool, [3] are illustrated in Figure 15.

Figure 15: Major steps in the calculation of rooftop PV potential



Data sources

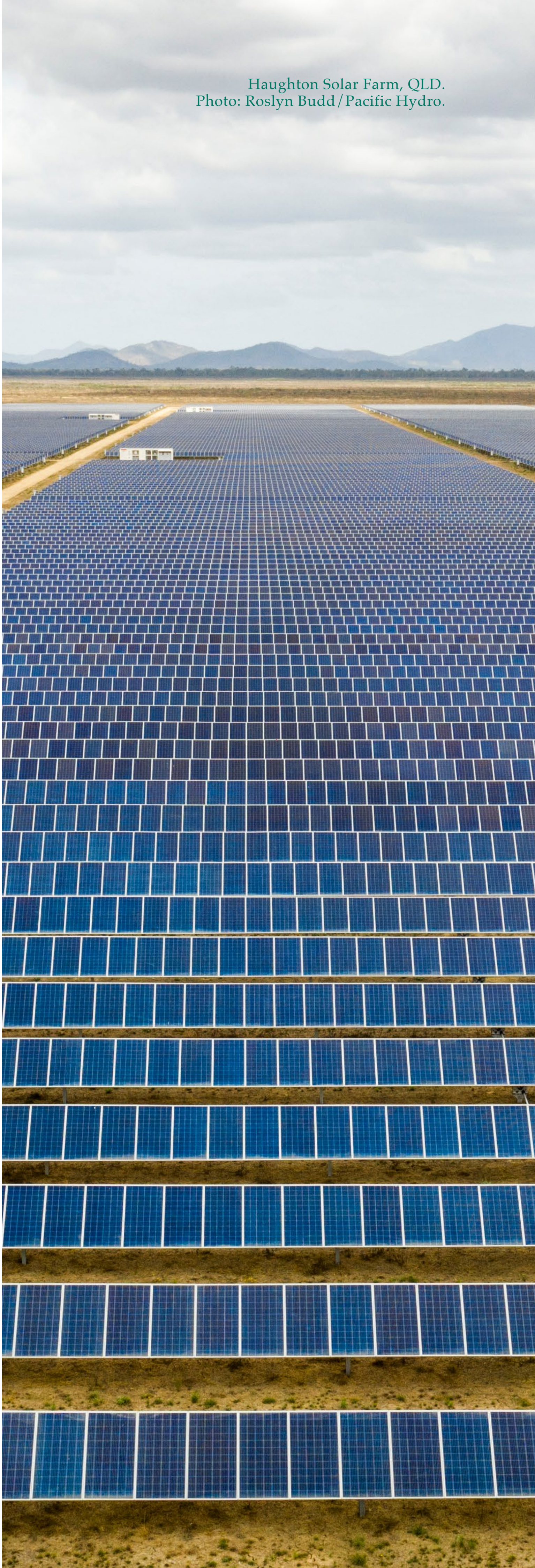
This analysis is primarily based on the following data sources:

- Building Areas — Queensland[4] dataset, which includes building boundaries for buildings with footprints greater than 625m,^{2} along with some limited metadata including names and building function.[2]
- Queensland LiDAR data, point cloud dataset available through ELVIS[5], collected between 2009 and 2014.

Additionally, the calculation of percentage usable roof area includes analysis of digital surface models (DSMs), including 3D building models and XYZ vegetation points, for Brisbane CBD, supplied by geospatial company AAM.[6]

The calculation of energy generated by the potential arrays on case study buildings uses long-term solar and weather data (1990–2017) provided as ERMY weather files for various QLD locations by Exemplary Energy Partners.[7]

Any omissions in these datasets will affect the accuracy of the analysis in this report. In particular, the analysis is constrained by the spatial accuracy of the datasets and excludes recent developments and changes in building use.



Haughton Solar Farm, QLD.
Photo: Roslyn Budd / Pacific Hydro.

Solar potential **assessment**

The QLD LiDAR data for each LGA was first converted to a 1m-resolution DSM elevation raster using ArcGIS[8] and clipped to include only the building footprints greater than 625m,[2] plus a threshold distance of 1 kilometre on every side to enable assessment of shading from surrounding objects.

The ArcGIS Area Solar Radiation tool was used to calculate the annual solar exposure for each point on the surface, and calibrated using coefficients generated using NREL's System Advisor Model[9] and an 'ERMY' weather file[7] for the nearest Bureau of Meteorology (BOM) weather station. The dataset was then clipped again to include only the building footprints and the adjusted annual solar exposure, orientation and slope for each 1m^2 area of surface was calculated.

The proportion of building roof area that is suitable for solar PV installation depends on the roof form, the presence of obstructions (e.g. air-conditioning units, aerials, lift housings) and the level of solar exposure. To estimate the proportion of suitable building roofs, we used the methodology in the APVI's Analysis of solar potential in Brisbane[10] and other solar potential reports.[11] This involves excluding roof points which receive less than 80% of the annual solar exposure of a horizontal, unshaded plane. Additionally, analysis of high-resolution DSM for Brisbane CBD was used to determine the proportion of roof area in planes of less than 10m^2 area, and this proportion of the roof points was also excluded.

The method assumes a fixed DC size factor of 200 W/m2 (e.g. a 320W module with dimensions of 1m x 1.6m). On all usable roof areas with greater than 10º slope, PV arrays were assumed to be installed flush to the roof and to cover 98% of the usable area (to allow for fixing clamps between each module), while 'flat' roofs were assumed to have north-facing, rack-mounted arrays installed at a tilt of 15º. The rack-mounted arrays were spaced to avoid self-shading, using the methodology developed by Copper et al.[12]

The energy yield was calculated using the method used for the APVI SunSPoT tool.[10] The calculated DC PV capacity is multiplied by the average annual level of insolation 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.

Metadata associated with the building footprint dataset, including building type, function and name, were used to categorise the footprints and the PV capacity and energy output were aggregated across each building category.

Note that the methodology does not account for existing PV installations on these roofs but, unlike on houses, the proportion of roof space in this sector already occupied by PV is low.

Carbon and equivalency **metrics**

The annual energy produced by potential rooftop solar PV has been compared to the average annual household energy consumption in Queensland, which is approximately 4,502 kWh.[13]

Potential CO_2-e emissions reductions from rooftop PV was calculated by multiplying the indirect (Scope 2) emissions factor for consumption of electricity purchased from the grid in Queensland (0.81 kg CO_2-e/kWh[14]) 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 CO_2-e/kW[15]).

The amount of displaced coal was calculated using the energy content of bituminous coal (27.0 GJ/t [14]) and the average heat rate of coal-powered generation in QLD (9.18 GJ/MWh) to give displaced coal of 0.34 tonnes/MWh of generation, which was applied to the estimated PV generation over the 20 year module lifetime.

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 per MW of commercial solar installed.[16]

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 CO_2-e per urban tree planted and allowed to grow for 10 years.[17] This was divided into the estimated 20-year lifetime generation of the potential solar PV.

Case studies

The potential solar capacity of the case study buildings were assessed visually, using multiple viewpoint aerial imagery from Nearmap.[18]

Unsuitable surfaces and obstructions were identified and excluded from the usable roof area. Small rooftop obstructions and perimeter walls were also identified and their height estimated using multiple viewpoint oblique aerial imagery. 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 1.6m x 1.0m PV panels on the usable roof space, using Nearmap oblique images to estimate roof slope. The PV capacity was calculated assuming modules of 320W, and the annual energy output calculated using NREL's System Advisor Model[9] 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 here. The systems described represent the available rooftop solar potential, not a design proposal.

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