CLEAN ENERGY COUNCIL

AUSTRALIAN GUIDE TO AGRISOLAR FOR LARGE-SCALE SOLAR

For proponents and farmers

March 2021

ACKNOWLEDGEMENTS

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ABOUT THIS REPORT

This guide has been developed to share knowledge and learnings from agrisolar practices around Australia and the world, to assist proponents of utility-scale solar, and the landholders and farmers who work with them, to integrate agricultural activities into solar farm projects.

As solar grazing is the dominant form of agrisolar for utility-scale solar, this guide has a strong focus on sharing the knowledge and learnings from Australian projects that have integrated solar grazing practices to date, providing:

- case studies from solar farms currently employing solar grazing
- information on the benefits of solar grazing for proponents and farmers
- practical guidance for both farmers and proponents considering solar grazing (see Sections 2 and 3).

A further aim is to contribute to the local knowledge of trends and research from international markets about a broader range of agrisolar models which could be considered for the Australian context. An overview of these practices are discussed in Sections 1 and 4.

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Front cover photo: Sheep at Finley Solar Farm (merinos and merino-cross dorsets) rest in the shade of solar panels. / ESCO Pacific

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FOREWORD

KANE THORNTON
CHIEF EXECUTIVE
CLEAN ENERGY COUNCIL

Since the early days of the renewable energy sector in Australia, project proponents and farmers have worked hand-in-hand to harness the power of the wind and sun.

Proponents have benefited from access to cleared land near the electricity transmission network, and rural landholders have benefited from the opportunity to supplement their agribusiness income and ride through the ups and downs of commodity cycles and weather events.

With the emergence of utility-scale solar in Australia in the mid-2010s, which has a more dense footprint than wind farms over a smaller area, there is growing interest in exploring and promoting new models for complementary solar energy and agricultural production.

Agrisolar has quickly taken off in Australia in the form of 'solar grazing', which is now the predominant form of land co-use, both here and internationally. This guide has been designed to share the learnings of the solar grazing experience to date to encourage more proponents and farmers to take up the highly successful practice.

Importantly, however, the guide also aims to accelerate our understanding of the immense opportunities for solar projects to support a wide range of other food and fibre growing activities and biodiversity outcomes, from horticulture and viticulture to cropping and beekeeping.

We look forward to the partnership between the clean energy and farming sectors going from strength-to-strength as we embrace new, innovative ways to maximise land productivity in Australia and support the long-term success of renewable energy in regional communities across the country.

SECTION 1: AGRISOLAR OVERVIEW

Grazier Ken Ikin and BJCE Asset Manager Leo Pearce inspect pasture on Gullen Solar Farm before the reintroduction of sheep. / BJCE Australia

1.1 INTRODUCTION

Since the mid-2010s, Australia has seen the development of many solar farms in regional areas, reflecting the sharp fall in the cost of solar photovoltaic (PV) technology, making it now the lowest-cost form of electricity.

As the sector grows, there is increasing interest in exploring and promoting new models for complementary solar energy and agricultural production. This coupling is known by a range of interchangeable terms including 'agrisolar' (used in this guide), 'agrivoltaics', 'agrophotovoltaics (APV)' and 'solar sharing'.

Utility-scale solar (generally considered to be greater than 5 MW) typically requires access to relatively flat or gently sloping land in sunny areas within proximity to electricity transmission networks, where biodiversity impacts can be avoided or minimised. This often means that land which has been previously cleared or zoned for agricultural use is well-situated to host solar farm developments.

Many companies working within the Australian utility-scale solar sector have committed to minimising the impacts on highly productive agricultural land (see the Clean Energy Council's Best Practice Charter for Renewable Energy Developments in Appendix 1) and exploring opportunities to integrate continued agricultural production into projects.

Where solar farms are proposed and developed, there is increasing interest in exploring the opportunities for complementary agricultural activities which can benefit from a number of the valuable characteristics of solar arrays, including:

- the provision of partial shading and weather protection (including sun, rain, hail and wind)
- protection from predators for sheep
- improved soil moisture retention, which can lead to improved vegetation growth for some crops beneath the panels, as shown in international studies.[1]

Agrisolar was first proposed in Germany in 1981.[2] Since then, local and international trials and research, particularly in the past five years, have shown that solar energy and agricultural production can be highly compatible and mutually beneficial. Government funding programs across the world have led to a rapid increase of agrisolar from 5 MW installed capacity in 2012 to at least 2.8 GW in 2020.[3]

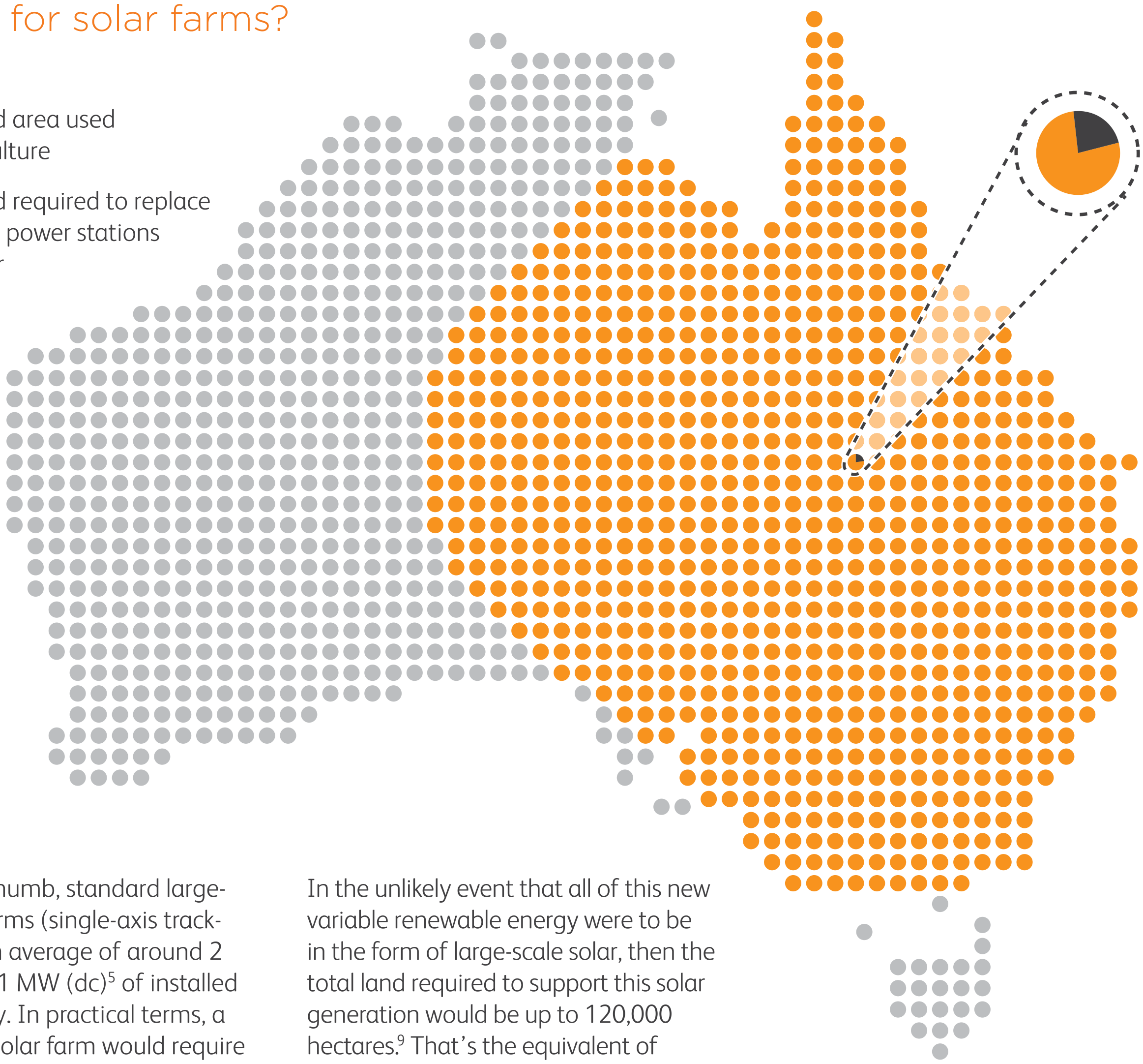
With the deployment of large utility-scale solar farms commencing in Australia from around 2015 onwards, the local experience of agrisolar practices is still developing and currently dominated by the practice of sheep grazing on solar farms. The first known Australian solar farm to implement agrisolar practice was the Royalla Solar Farm which began grazing sheep in 2015. Since then, there have been over a dozen solar farms that have introduced grazing, and it has proved to be an effective partnership for both solar farm proponents and graziers. 'Solar grazing', as it is known, is the most prevalent form of complementary land use for utility-scale solar farms. At present, where other forms of agrisolar are being pursued in horticulture, viticulture, aquaculture and cropping, it is typically at a much smaller (ie. non-utility) scale.

Solar grazing is the most prevalent form of complementary land use for utility-scale solar farms.

Replacing all of Australia's coal-fired power stations due to retire by 2040 with solar farms would require less than 0.016 per cent of Australia's total land area.[4]

BOX 1

How much land is needed for solar farms?



As a rule of thumb, standard large-scale solar farms (single-axis tracking) utilise an average of around 2 hectares per 1 MW (dc)[5] of installed solar capacity. In practical terms, a 100 MWdc[6] solar farm would require access to approximately 200 hectares of land. (The land area needed for every megawatt of installed capacity is expected to decline as solar modules become more efficient.)

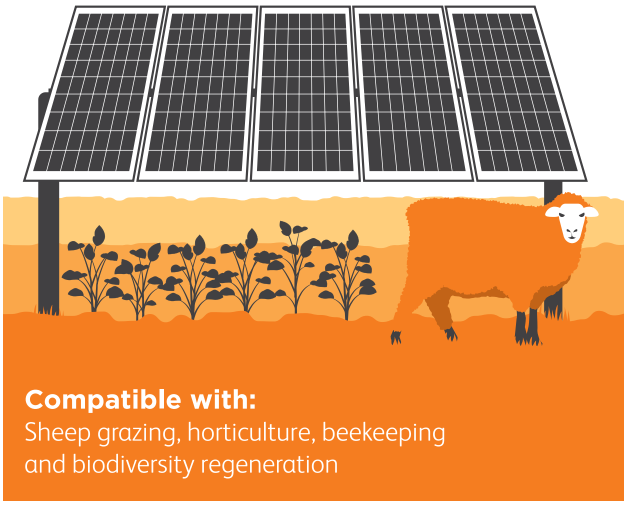
The Australian Energy Market Operator has estimated that up to 50 GW[7] of 'variable renewable energy' (wind and solar power) capacity will need to be installed between 2020 and 2040 to replace Australia's retiring coal-fired power stations.[8]

In the unlikely event that all of this new variable renewable energy were to be in the form of large-scale solar, then the total land required to support this solar generation would be up to 120,000 hectares.[9] That's the equivalent of less than 0.016 per cent of Australia's total land area, or 0.027 per cent of Australia's total land currently used for agricultural production.[10] By contrast, Australian agriculture currently accounts for 58 per cent of Australian land use. The impacts of the relatively small percentage of cleared rural land required to support new solar power projects in Australia can be further minimised by pursuing integrated land uses with other sectors.

1.2 WHAT IS AGRISOLAR?

Agrisolar refers to co-developing the same area of land for both solar PV power as well as for agriculture. Several forms of agrisolar have been developed around the world, with a wide range of innovative approaches emerging in recent years.

FORMS OF AGRISOLAR



GROUND-MOUNTED PV PANELS

Ground-mounted PV is the most common form of utility-scale solar. In solar farms today, panels are typically connected in long rows (arrays) and mounted on steel frames above the ground so that when tilted, the clearance between the panels and the ground can be as low as 20 cm and up to 3 m on the high side.[11]
These arrays can be fixed in one direction or can track the sun throughout the day, powered by a motorised tracking system.

The height of the panels above the ground usually allows sufficient space for animals such as sheep to graze underneath, or for plants and crops to be cultivated for horticultural purposes or biodiversity reasons. Existing fixed array systems (which do not track the sun) may be unsuitable for some agrisolar practices if the solar panel rows are sited too close together with minimal solar penetration between the arrays.

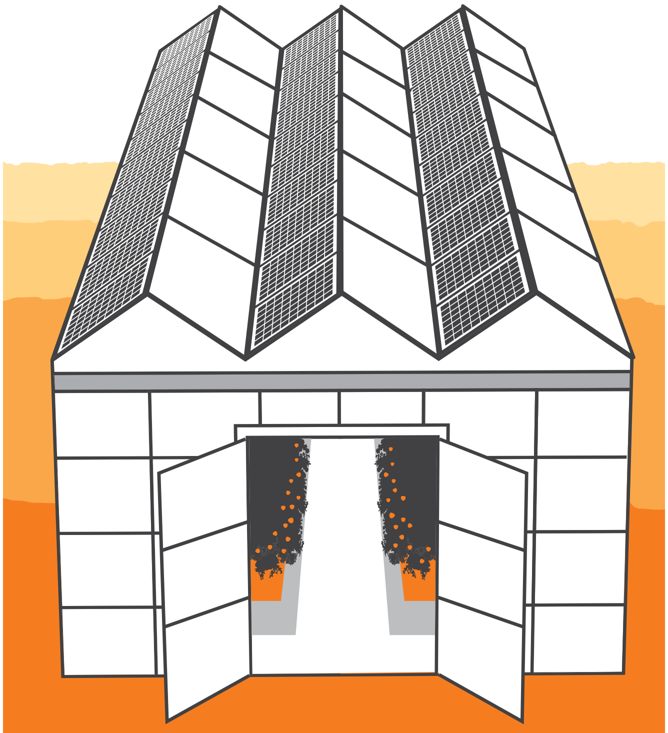
ELEVATED PV PANELS

In land-scarce regions, interest has increased in the deployment of elevated solar panels enabling crops to be grown and harvested beneath panels, such as fruit trees, grapes and cereals. In this model, the panels are raised on stilts or reinforced structures from 2.5 - 5 m high. Initially developed in Japan by engineer Akira Nagashima in 2003, there are several smaller-scale sites and trials in Asia, Europe and South America.

In this model, the PV panels can be spaced to allow sufficient sunshine to filter through to the plants below to allow sunlight to pass through. The distance between structures and the height of the panels may also be wide enough for people, planting and harvesting machinery.

Elevated PV plants developed to date have tended to be used in smaller-scale applications rather than utility-scale solar developments (>5 MW) largely due to the taller and more complex structures, as well as the larger area of land required and increased equipment costs. However, there are examples of large-scale PV installations co-located with crops, including a 700 MW installation over berry crops on the edge of the Gobi Desert in China.[13]

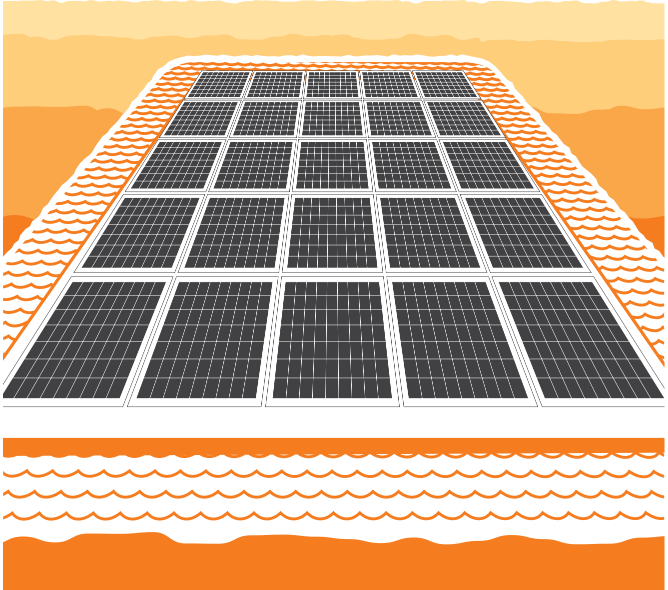
FORMS OF AGRISOLAR



Compatible with:
Horticulture, floriculture
and aquaculture

PV GREENHOUSES/ROOFTOPS

One increasingly common form of agrisolar internationally is the construction of large-scale greenhouses with solar-panelled roofs, allowing for continuous horticultural production while utilising roof space for electricity generation to satisfy the greenhouse's power needs.[14] Photovoltaic greenhouses are an efficient solution in terms of protection from the weather, climate, insects and, in the case of rooftops over aquaculture ponds, water evaporation and predators.



Compatible with:
Aquaculture

FLOATING PV SYSTEMS

Floating PV systems refer to the installation of solar farms over bodies of water. This type of system was first installed in 2007 in Japan as an alternative where appropriate terrain, high population density and land constraints made ground-mounted solar challenging.

In Thailand, some proponents are exploring the dual energy and food production of floating PV with fish or shrimp farming. While there is relatively little literature on the compatibility of aquaculture and floating PV, it may reduce water evaporation, slow algal growth and reduce embankment erosion.[15]

1.3 COMPATIBILITY OF SOLAR AND AGRICULTURAL PRODUCTION

While research into agrisolar is an emerging field, a number of international studies conducted in recent years have suggested strong synergies in the co-location of agriculture and solar energy production for crop productivity, water conservation and higher renewable energy production.[16]

BENEFITS FOR AGRICULTURE

While agrisolar is unlikely to be compatible with all crops, early international studies indicate that the shade of the PV panels can result in the same or higher production yields with more significant water savings, depending on the climate and agrisolar system.[17] This is particularly so in arid regions[18] (see Box 4).

In a livestock grazing context, solar panels and solar farm fences improve the sheep's welfare by providing protection from the elements and predators. While these results are generally anecdotal in Australia (see the case studies in Section 2), research conducted by Oregon State University in the USA has made similar observations.[19] Another benefit is that moisture from condensation or light rainfall events collects on the panels and drips down to water the pasture directly below, supporting concentrated pasture growth even during drought. Furthermore, preliminary results from a wool analysis of the sheep at the Parkes Solar Farm indicated that the wool quality was high, even during drought conditions.[20]

Planting native and flowering vegetation on a solar farm also has provided excellent habitat for bees and other pollinators in countries such as the USA. According to research by Oregon State University, there is an extended bloom period due to the climate created by the solar panels and the increase in soil moisture, meaning that bees have food for longer before winter and can produce more honey.[21] Not only is this prime habitat beneficial for bees and beekeepers, but nearby farms also benefit from the pollination services provided by the bees, leading to improved crop yields.[22]

"Agri-PV allows for solar to be combined with specific rural and agricultural activities, providing solutions to the needs of farmers and rural communities by driving investments and creating jobs in rural areas, supporting traditional and sustainable agricultural practices, or increasing the climate resilience of agricultural activities"[23]

SolarPower Europe, 2020

Bee hives at IMS Solar, a pollinator friendly PV array site in St. Joseph, Minnesota, USA.

BOX 2

Solar farm buzzes with opportunity for beekeepers

Location	Mount Majura, Australian Capital Territory
Property size	9.9 hectares
Solar farm size	2.3 MW (7340 PV panels)
Owner	Impact Investment Group Solar Income Fund
Asset manager	Impact Investment Group
Beekeeper	Canberra Bees
Number of beehives	10 hives

Beekeeping group, Canberra Bees, approached Impact Investment Group's Mount Majura Solar Farm in 2017 about the opportunity of placing several beehives on the solar farm. The attraction for the beekeeper was the proximity to native vegetation and flowering plants, proximity to the centre of Canberra and the security for the hives within the fenced solar farm.

Bees provide a vital service for biodiversity, acting as pollinators, whilst also producing several products including honey. After a site induction and provision of licences and insurance, the hives were placed on the solar farm in late 2017. On average, the bees produce 48 kg of honey each year, 1 kg of bees' wax, 250 grams of propolis and various quantities of pollen. Key considerations for the placement of beehives on solar farms include access to water, permission from the landowner, permission from the operations and maintenance contractor, and appropriate licences and insurance.

NREL researchers survey the test plot at the UMass Crop Animal Research and Education Center in South Deerfield, Massachusetts. / Dennis Schroeder - NREL

BENEFITS FOR SOLAR FARM PROPONENTS

One study conducted in Arizona, USA found that solar panels over vegetation were significantly cooler (on average, 8.9°C cooler) during daylight hours compared to panels above bare land.[24] This research indicates that the presence of vegetation beneath panels can have potential positive implications for PV energy yield in hot climates, as solar PV efficiency is diminished where ambient temperature increases.[25] Vegetation also acts as an effective dust suppressant, typically a significant inhibitor to solar module efficiency.[26]

Sheep grazing, too, delivers benefits for the operation of solar farms, as the vegetation is maintained in a cost-effective and safe manner by reducing the need for mowing or spraying. This maintenance reduces the risk of fire hazard, protecting the solar assets and neighbouring properties.

"It's a win-win for the community and the solar farm. It helps the Show Society stay afloat while reducing the maintenance costs for the solar farm"

Cr. Ken Keith, Show Society member and Mayor of Parkes

BOX 3

Agrisolar: what's in it for me?

Farmers

- ✓ Potential compatibility with crop production and livestock
- ✓ Improves water use efficiency of crops/vegetation as well as run-off water from panels
- ✓ Encouraging pollinator habitat which can, in turn, improve agricultural yields on surrounding farms

Solar farm proponents

- ✓ Improved solar PV efficiency due to cooler panels
- ✓ Reduced operations and maintenance costs by keeping vegetation under control
- ✓ Reduction of fire risk
- ✓ Strengthened relationships with neighbouring farmers

BOX 4

Why is plant performance improved under solar panels?

While Australian studies are currently underway (see Box 16), recent international studies suggest that the growth rate of certain crops is not reduced under solar panels[27] and indeed can even improve the performance of some crops.[28] The key possible reasons for these improved outcomes are outlined below.

1. REDUCED EXPOSURE TO SUN AND EXTREME WEATHER EVENTS

Although the panels create shade for the crops, plants only require a fraction of the incident sunlight to reach their maximum rate of photosynthesis and eventually a photosynthesis saturation point is reached.[29] Surplus sunlight does not boost photosynthesis after light saturation point, and too much sunlight hinders crop growth and can cause damage to the crop.[30]

The coverage provided by the panels also protects from extreme weather events, which are likely to become more frequent with climate change.[31]

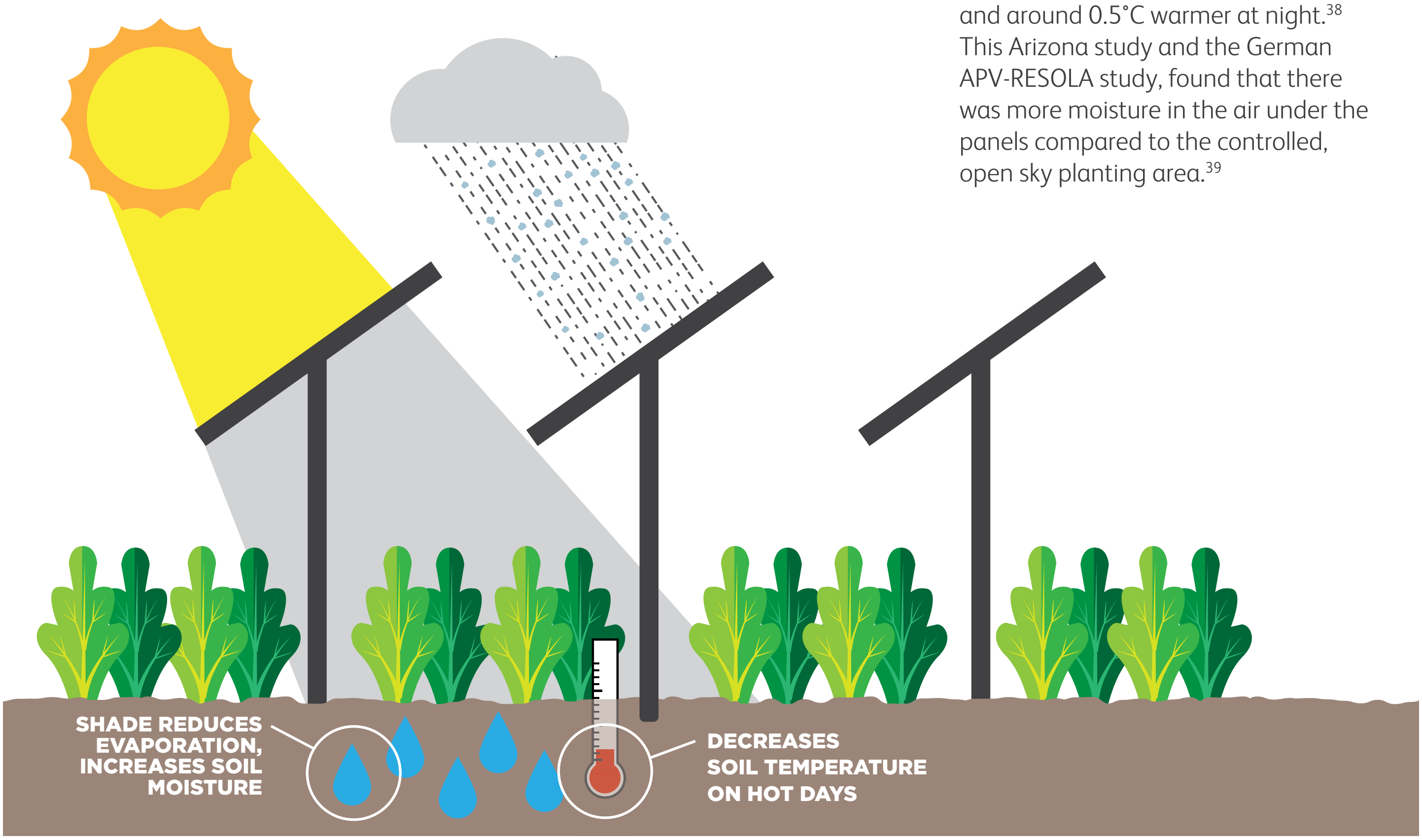
2. SOIL MOISTURE AND TEMPERATURE

The shade provided by solar panels reduces water evaporation and increases soil moisture, which is particularly beneficial in hot, dry environments.[32] Depending on the level of shade, water savings of 14-29 per cent have been observed.[33] By reducing moisture evaporation, the solar panels also alleviate soil erosion.[34] In Germany, Fraunhofer Institute for Solar Energy Systems' study known as APV-RESOLA found that soil temperature is also reduced on particularly hot days.[35]

3. AMBIENT TEMPERATURE

The lower the height of the structure supporting the panels, the more pronounced the microclimate, according to findings from APV-RESOLA.[36] Studies indicate that daily air temperature under the panels can differ depending on the location and the technology. One French study, led by an agricultural institute in Montpellier, reported similar temperatures in full sun (no PV panel coverage) to the temperatures under the panels, regardless of the season.[37] Other studies have reported cooler temperatures during the day and warmer temperatures at night. For example, one study in Arizona found temperatures under the panels were around 1.2°C lower during the day and around 0.5°C warmer at night.[38] This Arizona study and the German APV-RESOLA study, found that there was more moisture in the air under the panels compared to the controlled, open sky planting area.[39]

PROTECTION FROM SUN DAMAGE AND EXTREME WEATHER EVENTS



BOX 5

What varieties of crops can be grown beneath panels?

Although long-term data on crop growth below solar panels is not yet available, early studies, mainly from arid or rangeland climates, suggest that the efficacy and extent of the positive impacts caused by solar panels is dependent on the plant species, the agrisolar system and the climate.[40] In more humid climates, the compatibility of crops and solar PV is largely unknown at this time.

GROUND-MOUNTED PV

Plants with less root density and a high net photosynthetic rate are ideal for agrisolar systems.[41] Studies undertaken in the USA have found that the following crops could be successfully grown under and around ground-mounted solar panels.

CROP	LOCATION	PERFORMANCE UNDER SOLAR PV	STUDY
Tomatoes	Arizona, California (USA)	Improved – yield doubled	Barron-Gafford et al. (2019) Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands
Jalapenos	Arizona (USA)	Slight reduction in production but water use efficiency improved by 150 per cent	Barron-Gafford et al. (2019) Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands
Kale and chard	California (USA)	Same production rate at 55 per cent or more sun exposure	Hudelson, T (2020) Conference Crop Production in Partial Shade of Solar Photovoltaic Panels
Broccoli	California (USA)	Improved production rate at 85 per cent sun exposure	Hudelson, T (2020) Conference Crop Production in Partial Shade of Solar Photovoltaic Panels

ELEVATED PV PANELS

While studies indicate that all types of crops are generally able to be incorporated into an agrisolar system, the yield of crops differs depending on the shade. German-based Fraunhofer Institute for Solar Energy Systems suggests that shade-tolerant crops such as leafy vegetables, grass/clover, stone fruits, berries and soft fruits and other crops, such as asparagus and hops, are particularly well-suited to agrisolar applications.

In Japan, a wide range of crops are grown underneath the elevated PV structures as part of a 'solar sharing scheme', with farmers growing cereals, vegetables, mushrooms, fruit trees, tea and coffee, and ornamental flowers.[42]

Although Fraunhofer Institute for Solar Energy Systems' Heggelbach farm trial in Germany found that potatoes, wheat and other types of grain suffered a yield reduction of up to 20 per cent on a typical year, there were significant positive effects on the yield in a hot, dry year. (It is important to note that the average solar irradiation levels and average temperatures in Australia are significantly higher than in Germany, and as such, outcomes could vary in Australian conditions.)

While it has been shown that large-scale crops such as wheat and corn can be grown underneath elevated solar panels, studies suggest that crop rotation systems are not economically viable.[43]

Instead, they recommend incorporating elevated solar panels with permanent cultures such as berries, fruits, grapes, almonds or hops. This is because the agrisolar system can replace structures or protection systems already in place, such as shade sails or foil tunnels, and these types of crops also attract a relatively high produce price. Agrisolar can be particularly beneficial for vineyards whose grape quality is beginning to suffer due to the effects of climate change, such as increased solar radiation and temperature changes.

SECTION 2: SOLAR GRAZING

Lambs at the University of Queensland's Gatton Solar Farm. / Andrew Wilson, UQ

2.1 INTRODUCTION

Sheep grazing on solar farms ('solar grazing') has been employed in England for at least a decade, and since then, has been introduced across many countries across Europe and the Americas. Indeed, in the USA, the interest in solar grazing has become so significant that the American Solar Grazing Association was formed in 2016 to connect solar farm proponents and farming businesses.

In Australia, the earliest-known trial of grazing on a large-scale solar farm was at the Royalla Solar Farm in 2015. By 2020, there were at least 13 large-scale solar farms grazing sheep in Australia. This guide shares the learnings and case studies of solar grazing at six of those farms.

Other animals such as cattle and goats have been proposed for solar grazing. However, they have usually been deemed inappropriate for large-scale solar farms due to their size (cattle) or behaviour (goats).

"The use of the land underneath the panels is absolutely compatible with sheep grazing"

Tom Warren, Grazier, Dubbo Solar Farm

Pasture growth under solar arrays in extreme drought conditions at the University of Queensland's Warwick Solar Farm. / Sarah Haskmann, UQ

2.2 BENEFITS OF SOLAR GRAZING

The integration of solar energy and grazing within a single site provides the opportunity for renewable energy operators and landholders/farmers to work in partnership to maximise the productive use of rural land and reduce operating costs for all parties.

FOR PROPONENTS, OWNERS AND OPERATORS OF SOLAR FARMS, SHEEP GRAZING:

- keeps the pasture down, reducing fire risk
- contributes to a stronger vegetation management regime
- reduces operation and maintenance costs through the avoidance of regular mowing services, a reduction in herbicide application and reduced risk of potential damage caused by mechanical equipment
- provides additional monitoring when farmer onsite
- reduces health and safety risks for solar farm personnel due to reduced need for operation of mowers and machinery
- strengthens relationships, communication and interaction with local landholders and farming communities.

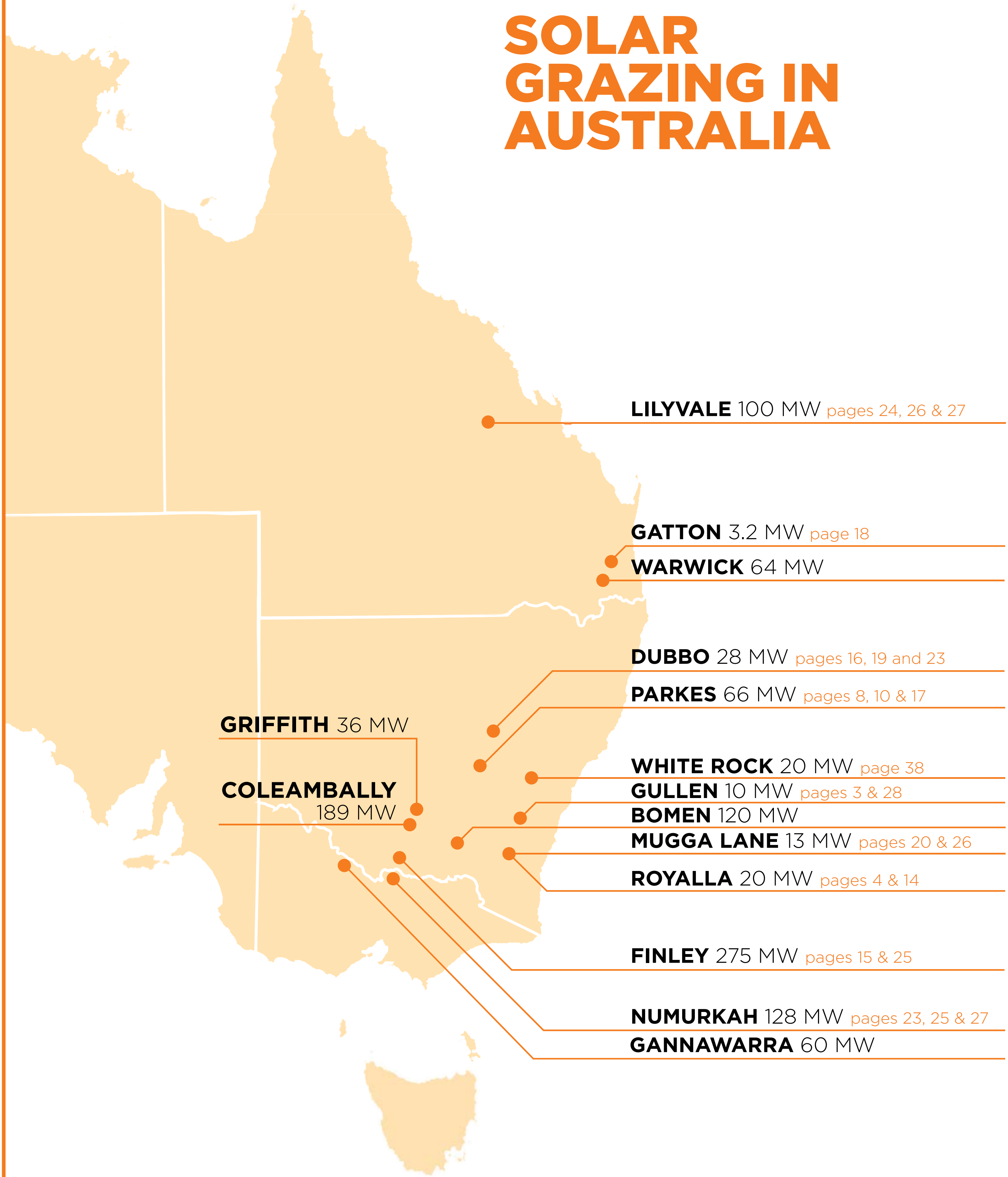
FOR LANDHOLDERS/FARMERS, SHEEP GRAZING ON SOLAR FARMS CAN CONTRIBUTE TO:

- access to free agistment (the taking in and feeding of livestock)
- increased health and wellbeing of sheep due to protection from the elements
- less water consumption by sheep[44]
- safety from predators for livestock due to secure fencing
- access to greener pasture, particularly during dry conditions or drought, leading to reduced operating costs
- high wool quality, according to a preliminary analysis
- supporting the transition to clean energy and a healthier environment.

"The free agistment is very important, especially during a tough year"

Damien Sexton, grazier at Finley Solar Farm

SOLAR GRAZING IN AUSTRALIA



Mayor of Parkes and grazier, Councillor Ken Keith, was very pleased with the quality of wool from the Parkes Solar Farm sheep. / Cr Ken Keith

BOX 6

Solar grazing trial for cattle in NSW

While livestock other than sheep may not be compatible with ground-mounted PV, with modifications to the design of a solar farm, co-location with larger or more agile animals may be possible. Wynergy, an Australian design company specialising in agrisolar, intends to trial solar panels with a 2.4 m clearance distance to the ground to accommodate dairy cows at an agricultural school in New South Wales to be constructed in early 2021. Overseas, a 2.8 MW cattle grazing project is currently under development in Massachusetts, USA.

BOX 7

Solar farm sheep produce excellent results

The Parkes Pastoral, Agricultural and Horticultural Association (the Show Society) is well known for putting on its annual Show and Elvis Festival. It also conducts sheep trials as part of a four-year national study to measure the performance of different wether sheep bloodlines in the same conditions.

When the opportunity arose to trial the merino wethers at the Parkes Solar Farm in 2019, the Show Society jumped at the chance. Usually, the trial sheep are kept on a member's farm, but the drought in the area had been so bad that it wasn't possible, and the solar farm was in a good location close to town.

Members of the Show Society each introduced 12 of their sheep to the solar farm in mid 2019, with a total of 132 sheep on the solar farm. When the sheep were shorn in August 2020, the Show Society was pleased with the quality of the wool and the sheep's health.

The results showed that the sheep were a healthy weight, particularly considering the drought conditions. The average greasy wool weight, staple strength and yield – all indicators of wool quality – were all above average for the region.

Show Society member and Mayor of Parkes, Councillor Ken Keith, attributed the excellent results to the access to green pasture from the run-off of condensation and light rainfall events from the solar panels, which sustained the sheep during drought conditions and led to a reduction of dust in the sheep's wool.

UNIVERSITY OF QUEENSLAND'S GATTON SOLAR FARM

The University of Queensland's (UQ) Gatton Solar Farm has grazed sheep in partnership with its Veterinary School since 2016. It has worked so well that UQ designed its new solar farm at the rural community of Warwick, Queensland with sheep grazing in mind.

Location	Gatton, Queensland
Property size	10 hectares
Solar farm size	3.2 MW
Owner	University of Queensland
Operations and maintenance	University of Queensland and UGL
Asset manager	University of Queensland
Sheep type	Dorper and merino
Number of sheep	Approximately 10 per hectare, varying with season and vegetation growth

SITE DESIGN CONSIDERATIONS

UQ introduced sheep on all paddocks of its Gatton Solar Farm with three different types of solar arrays: fixed-tilt arrays (stationary panels), single-axis trackers and dual-axis trackers (panels that move, generally 'tracking' the sun from east to west).

There was initial hesitation around grazing in the fixed-tilt array paddocks due to the modules being much lower to the ground (with some only 30 cm from the bottom of the panel to the ground), too low for livestock to fit underneath and potentially hazardous to the animals. However in 2019, following consultation with the Veterinary School and several inspections for hazards to livestock and property, grazing commenced in the paddocks with fixed-tilt arrays. Necessary modifications included securing the cables to the module support structures more firmly to prevent the sheep from getting tangled, as well as installing more water troughs.

SHEEP WELLBEING AND SAFETY

UQ has found the arrangement has been beneficial to the sheep's health, with the panels providing protection from the elements (sun, wind, rain etc.), and supporting improved vegetation growth, increasing feed for the animals.

However, the greatest advantage by far has been the security provided by the solar farm perimeter fence. This secure perimeter prevents death and injury caused by wild dog attacks to the livestock, a prevalent issue in Queensland. In fact, stock levels were increased in the fixed-tilt array paddocks over Christmas 2019 due to the safety provided by the fences and is now considered the best paddock on site.

COST SAVINGS

Aside from the wellbeing of the sheep, grazing has saved UQ a considerable amount of money, as the requirement to mow has been completely eradicated. Prior to the introduction of the sheep at Gatton, mowing was contractually required once a quarter, which was costly and led to a significant amount of infrastructure damage, including broken panels. Even with the purchase of yard equipment, installation of water access and partition fencing, the costs saved from mowing are approximately $100,000 per year. There have been a few damaged panels in the fixed-tilt array paddocks where a sheep may have pushed its way through the small gap between panel and ground, but any damage caused by the sheep has been minimal compared to the damage caused from mowing.

DUBBO SOLAR FARM

Farmer Tom Warren's story is a great case for 'doing your research'. When considering Neoen's offer to lease part of his property, Tom looked up the company's solar farms overseas and saw that some of them were grazing sheep. "Right from the word go, it's something I insisted on", explained Tom. Five years on and Tom's idea has been a success. The use of the land underneath is "absolutely compatible", according to Tom, who reports there has been no loss to his grazing productivity.

Location	Dubbo, NSW
Solar farm size	28 MW
Owner	Neoen
Operations and maintenance	Bouygues Construction
Asset manager	Neoen
Sheep type	Merino
Number of sheep	Approximately 150

ARRANGEMENT BETWEEN PARTIES

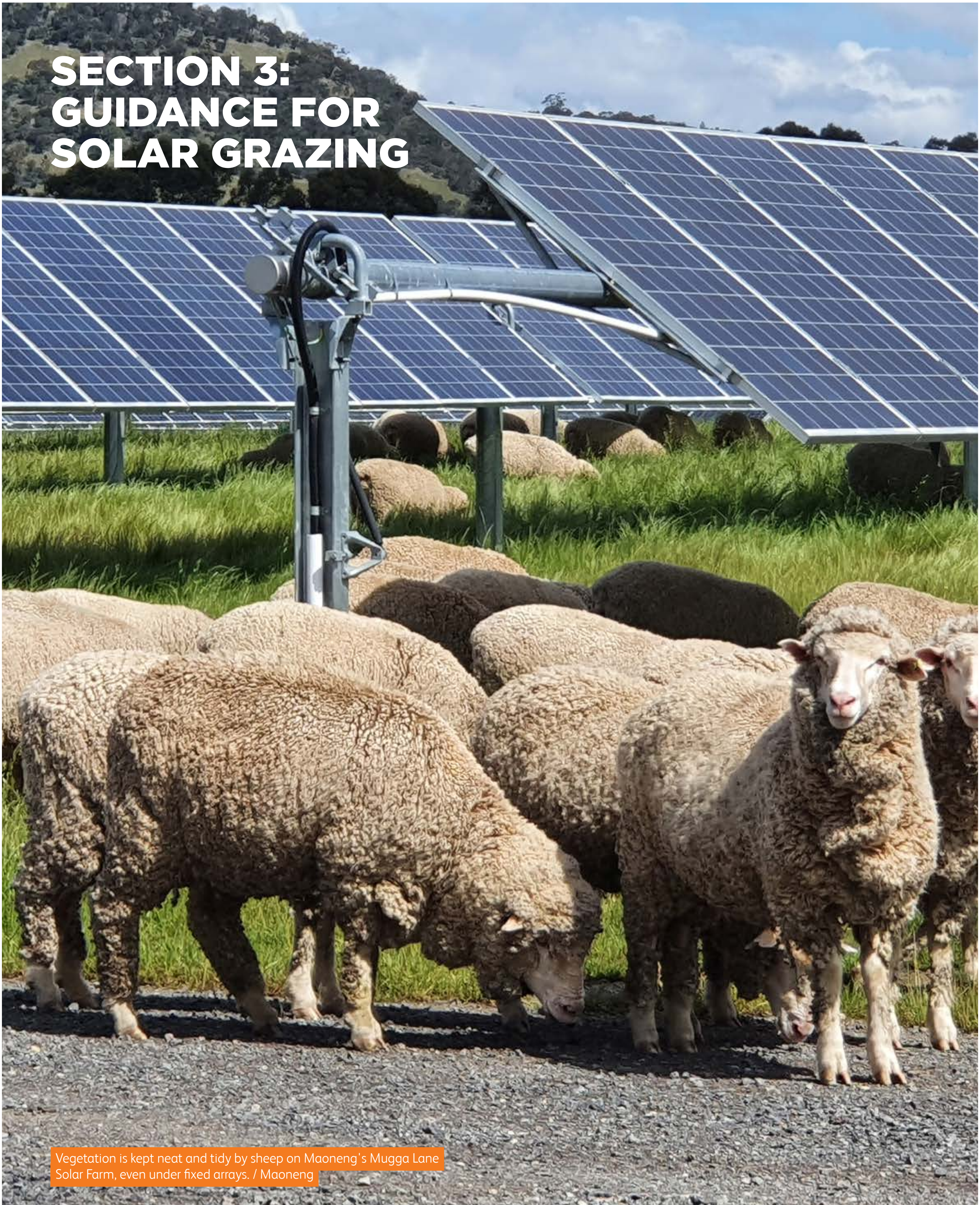
The parties entered into a contract covering any compensation between them for the agistment of the sheep on the solar farm (none), the allocation of responsibilities for the health and safety of the sheep (farmer) and the treatment of liabilities (shared), with Neoen being responsible for asset damage and Tom being responsible for livestock health. The agreement also covers right of access, with Tom able to enter the site whenever required, subject to notification of the site manager. Tom determines how many sheep are within the solar farm perimeter and can move them to the adjoining paddocks through a rear gate.

COST SAVINGS

For the operations and maintenance team, the frequency of mowing has been reduced. Tom, on the other hand, has been able to maintain his grazing business, while earning income from leasing his property. The grazing arrangement has even presented opportunities for Tom to save money. For example, during the recent drought, the solar farm retained green pasture due to the condensation from the panels running off between the rows. While other farms in the district needed to resort to additional feed for sheep for over 18 months, Tom needed to source additional feed for just three months.

Dubbo Solar Farm grazier Tom Warren, with Neoen team member. / Neoen

SECTION 3: GUIDANCE FOR SOLAR GRAZING



Vegetation is kept neat and tidy by sheep on Maoneng's Mugga Lane Solar Farm, even under fixed arrays. / Maoneng

3.1 CONSIDERATIONS FOR PROPONENTS

The early experience of solar grazing across different parts of Australia has generated valuable learnings. This section outlines key considerations for project proponents and graziers exploring running sheep on a solar farm.

While it is possible to graze sheep on a solar farm without early-stage planning and design to accommodate this co-use, any required changes to the solar farm are covered by the proponent. Therefore, by planning for the facilitation of sheep grazing from the outset, the project will save time and money, and provide an improved experience for both proponent and grazier.

"I recommend that developers think about sheep grazing early on, try to integrate it into operation strategy and development... it will optimise operations and maintenance costs"

Bouygues Construction Operations & Maintenance Manager, Dubbo Solar Farm

SITE SUITABILITY

GRAZING IN THE AREA

The Australian experience indicates that sheep grazing should be considered only for those projects situated in regions where sheep grazing practices are already present. Where this is not the case, the initiative can be costly, provide sub-optimal outcomes for the sheep's wellbeing and, ultimately, be unsustainable. Consulting the local farming community is recommended to understand the viability of sheep grazing.

ACCESS TO WATER

Access to water is essential for hosting sheep on a solar farm. It is ideal to have multiple water sources so that cell grazing can be easily implemented. More water sources also means that the sheep do not create dust walking long distances to drink. If a water source is not already present on the land, such as a dam or agricultural bore, consider whether water on neighbouring properties can be diverted through pipes to water troughs or ponds on the property. Registrations and approvals may be required depending on the jurisdiction.

APPROVALS AND PERMISSION

Planning assessment authorities are typically keen to encourage agricultural co-use and will welcome the integration of sheep grazing within a project's application.

For grazing on solar farms to date, approvals haven't typically been required. However, proponents may consider including internal fencing, crossing gates, water tanks/dams and potential alternative site entrances to facilitate sheep grazing within development applications.

If leasing the land, proponents should also consider whether consent from the landholder to graze sheep is required as part of the lease, particularly if the grazier is not the landholder.

DESIGN CONSIDERATIONS

SITE LAYOUT AND FENCES

One of the advantages of grazing sheep on a solar farm is that a standard perimeter fence offers protection from predators and livestock theft. Perimeter fences in the southern states are generally sufficiently secure and do not require modifications. On Queensland solar farms, however, dog-proof perimeter fences are advised, due to the prevalence of wild dogs. These fences are similar to standard perimeter fences but have half a metre of mesh buried into the ground to prevent dogs from digging beneath the fence.

Another factor to consider in the site layout is the vegetation buffer that is sometimes required for visual screening of the solar farm. As any vegetation buffer will need to be protected from the sheep, it is advisable to plan for the buffer to be planted outside of the perimeter fence so that an additional internal fence is not required to protect the plantings which will be timely and costly.

Internal fencing is also a key consideration when planning site layout. Grazing efficiency is increased where 'cell grazing' techniques are employed, whereby the land is sub-divided into separate areas using internal fences to enable greater control of the livestock and ensure that certain areas are not over-grazed. The fencing also allows the farmer to isolate the sheep if herbicide needs to be applied in certain areas. Cell grazing around the perimeter of the solar farm is also excellent for fire prevention.

Internal fences are less sophisticated and are, therefore, significantly cheaper. An internal fence can be three to five metal cables, square mesh lock or a mobile electrical fence running around the area at around 1.5 m high supported by stakes. A gate, such as a swing gate, also needs to be installed to allow the sheep to be moved and vehicles to pass through. It is necessary to have a minimum of 4 m between adjacent solar panel edges and a fence to allow for car or tractor access, or 2.5 m if using a utility terrain vehicle. While internal fences can be installed post-construction, one major difficulty with installing fences after construction is that it is necessary to avoid crossing underground cabling which can be challenging and time-consuming. Considering internal fencing during the design phase will reduce safety risks and increase the efficiency of the site establishment.

SITE PREPARATION

The National Renewable Energy Lab in the USA recommends minimising grading (where the land is levelled) where possible as mass grading can strip fertile soils,[45] and may lead to erosion.

Establishing a healthy ground cover prior to the introduction of sheep is important for ensuring they have appropriate feed and that erosion is minimised. It is also an efficient way to avoid weed infestation, as grazing does not usually eliminate the need for weed management on a solar farm. (Sheep will not eat certain types of weeds, and some species of weeds can make sheep ill). Therefore, the following steps are suggested to minimise and manage weeds:

- Consult with the grazing partner to identify appropriate ground cover for sheep, and timing for seeding. Proponents may also consider seeking advice from an agronomist.
- If there is existing agricultural pasture, consider whether it can be retained.
- Detect and eradicate patches of weeds before construction.
- Check and clean construction equipment prior to arrival on-site to prevent the introduction and spread of weeds in accordance with the Construction Environmental Management Plan.
- If revegetating, use seeds of recommended perennial or annual grasses over the property. Some solar farms use a mix of barley and clover. Other solar farms have planted species of native grasses.

Another factor to consider when determining the type of ground cover to plant is whether to encourage/host pollinator insects, such as bees, which are beneficial to nearby crops.

WATER POINTS

Strategically planning a water source prior to construction can be beneficial as it avoids the challenge of working around underground cables if later needing to install pipes, ponds or tanks. It also provides the necessary flexibility to support cell-grazing.

Where supply to water points can be controlled, it can also be possible to achieve cell-grazing without fences by simply turning the water supply on in an area where grazing is desired, and turning it off in the areas where it isn't.

Although installing water is considered an additional cost, it is generally the case that any additional costs to enable grazing are outweighed by the savings from mowing. Furthermore, water sources can be helpful when complying with fire regulations or when watering vegetation perimeters.

BOX 8

Water pipe agreement at Numurkah Solar Farm

The Numurkah Solar Farm agreed with the surrounding neighbours to establish a water pipeline to the solar farm. The pipeline ensures a ready supply of water for the firefighting tanks on-site, as well as the livestock watering troughs. All neighbours now use the pipeline for sweetening bore water for irrigation. The agreement has led to more open communication with neighbours which has been beneficial to the solar farm.

SITE EQUIPMENT

Type of array

The most important aspect of compatible solar design is the ability for the grass to grow beneath the panels and the sheep to move around and beneath them. Single-axis or dual-axis solar arrays, which track the movement of the sun, are considered to be "extremely compatible" with grazing, according to farmer Tom Warren at the Dubbo Solar Farm. This is because the gradual movement of the panels throughout the day allows exposure to sunlight for the ground cover beneath the panels at some stage each day, enabling pasture growth.

Ideally, the height of the solar panels should allow the sheep to move freely and maintain eye contact with other sheep so that they do not lose their flock; however, this is not essential. Older solar farms have also demonstrated that sheep can be successfully grazed in paddocks with fixed-axis arrays on a 20-degree tilt, where the height of its panels sits as low as 30 cm above ground level.

Motor guards

Some solar farms with shaft-tracking systems have installed motor guards to prevent the sheep's wool from being caught in the moving parts and universal joints of the motors which drive the solar array trackers. Motor guards also prevent sheep from hitting the equipment, including pressing the emergency stop buttons.

Position of cabling

Cables should be tightly secured to the rear of modules to minimise the risk of interference with module cabling, the risk of the sheep's horns getting tangled or, at the extreme, the chance of strangulation. Site engineers may also consider running the cabling along the middle of the panel to avoid any risks presented by cable slippage when the panel tracks the sun. This can be achieved by using stainless steel clips.

Safety measures such as installing conduits – standard practice in contemporary solar farms to guard against mechanical risks (e.g. mowers) – can also minimise the (already low) risks of sheep chewing the cables as they transition from the solar modules to underground. There have been no observed incidents of sheep chewing cables to date on Australian solar farms.

3.2 CONSIDERATIONS FOR GRAZIERS

Graziers, Kylie and Angus Gross, unloading their sheep onto Warwick Solar Farm. / Sarah Haskmann, UQ

The research carried out for this guide indicates that the experience of farmers involved in grazing sheep within solar farms in Australia has been overwhelmingly positive. This is largely due to the improved health, wellbeing and safety of the sheep. This section details the key learnings for farmers who may already be involved with a solar farm, or local graziers interested in grazing on a solar farm.

SHEEP TYPE

Merino sheep, particularly wethers and merino-cross, are currently the most common breeds of sheep involved in solar grazing at Australian solar farms. As a breed, the merino has a reputation for keeping its head down and not jumping on equipment. Dorpers have also been successfully grazed on Australian solar farms, despite a reputation for being livelier (see Box 9) and are often chosen for solar grazing in the USA.

BOX 9

Dorpers successful on Lilyvale Solar Farm

Grazier Peter Cheal breeds dorper sheep on his farm, and as such, this was the species introduced to Lilyvale Solar Farm when he entered into an agistment arrangement with proponent FRV. Despite dorpers being considered a livelier breed than merinos and tending to rub against objects to help shed their wool, the breed is working well on the solar farm, with no notable damage to the solar modules or other equipment caused by the sheep.

GRAZING TRIAL

It is recommended that the introduction of sheep is subject to a short trial (typically one month) in a small, controlled area within the site to assess any potential issues associated with co-use.

The trial is a good opportunity to identify and assess the following key considerations:

- suitability of the sheep temperament for the solar farm environment
- interaction of the sheep with the equipment
- existence of any hazards to the sheep or equipment that should be addressed
- rate of grazing by the sheep[45]
- communication between grazier and the site team.

Some proponents have also engaged consultants to analyse and report on the suitability of grazing on site.

SITE ACCESS FOR GRAZIERS

The terms for site access by the grazier to the solar farm should be documented within the agreement. Typically, graziers require site access around the clock to ensure they can attend to the needs of the livestock. However, as with any site personnel, this access is subject to operational health and safety requirements and notifying members of the operations and maintenance team.

STOCKING RATE

Getting the balance right with stock numbers can be difficult. Overstocking can lead to an increase in dirt and dust on the panels and the sheep's wool, but there needs to be a sufficient number of sheep to manage the vegetation growth. Many graziers supplement their sheep numbers during periods of rain and remove them later in the year. Graziers need to have the flexibility to increase and reduce stock numbers accordingly.

LAMBING ON THE SOLAR FARM

One of the most significant risks during lambing season is predators, and as such, the security fencing which surrounds solar farms can significantly reduce the chances of livestock fatalities. Some farmers have also reported that the panels provide additional protection for the lambs from wedge-tailed eagles.

However, some graziers prefer to remove ewes for the lambing season due to the need for closer supervision and the restricted visibility within the solar farm. For graziers contemplating lambing on the solar farm, it, therefore, remains advisable to trial and monitor the flock's wellbeing during the lambing season.

FREQUENCY OF SHEARING

In the case of merino sheep, some farmers have found that sheep require shearing more frequently depending on the type of panel system installed – every nine months (or fewer in some instances), rather than every 12 months – to prevent their wool from being caught in the equipment, particularly the drive shafts of motors. Graziers reported that this did not materially diminish the value of the wool.

BOX 10

Phased trial on Numurkah Solar Farm

Before the broadscale introduction of sheep at Numurkah Solar Farm, an on-farm trial was conducted using dummy solar panels to help assess the potential hazards to the sheep, the quantity and pace at which the grass was grazed, and what breed of sheep would work well.

After a successful four-week trial, the sheep were introduced to an isolated part of the solar farm for another four weeks, before they were more widely introduced across the solar farm

BOX 11

Frequent shearing on Finley Solar Farm

Grazier on the Finley Solar Farm, Damien Sexton, shears the sheep on the solar farm every 12 weeks to prevent their wool from being caught in the motor drive shaft and resulting fatalities. This wool is then sold off as "short wool".

This higher-frequency shearing regime means that Damien has had to bear additional costs (approximately $20 extra per head per year). Still, in return, Damien gains advantages such as the improved safety of the sheep and the agistment on neighbouring paddocks.

He is also looking to rotate the flocks so that those with longer wool can be hosted on his own property, while newly-shorn sheep are agisted within the solar farm.


Sheep enjoy the shade at the University of Queensland's Gatton Solar Farm. / Sarah Haskmann, UQ

MUSTERING

Mustering of the sheep on a solar farm is easiest in the middle of the day when tracker panels are horizontal to the ground, and visibility through the rows is maximised. It is still possible to use four-wheel or two-wheel motorbikes, a vehicle and a well-trained dog when mustering.

However, some solar farm operators prefer not to employ vehicular mustering due to the risk of damaging the equipment and the safety risk to the rider. In these cases, mustering is done mostly on foot and using dogs, sometimes driving a vehicle outside the border of the modules.

SHEEP HEALTH/BEHAVIOUR

Sheep on solar farms tend to be safer due to enhanced protection from predators from secure perimeter fencing. They also enjoy greater protection from the elements under the panels and will tend to seek out the shelter of the panels for shade and rain protection. These factors have meant that graziers have found the sheep to be more relaxed than flocks agisted in other conditions.

The panels also concentrate any rainfall or condensation into long rows beneath the panels, which have improved pasture growth even during dry or drought conditions.

While sheep on solar farms have not generally been found to be prone to an elevated risk of injury, there have been rare instances of sheep fatalities involving sheep being caught in the equipment. Any risk of injury or fatality can be reduced if the design and grazing recommendations within this guide are followed.

BOX 12

Oregon State University study confirms improvement in sheep health

Preliminary findings from an Oregon State University study[46] has indicated that agrisolar systems "can be used to improve lamb production and welfare…". The study found that less water was consumed, there was an ability to maintain a higher stocking rate in summer, and there were increased herbage yields.

"The sheep are happier here"

Peter Cheal, grazier at Lilyvale Solar Farm

"The sheep at Mugga Lane appear to seek shelter offered by the panels over summer months"

Asset Manager, Maoneng

3.3 THE GRAZIER/PROPONENT PARTNERSHIP

The relationship between the proponent/asset manager and the farmer is vital to the success of agrisolar. Generally, if they already have an established grazing practice, landowners or neighbouring farmers will be the natural choice as a partner to the solar farm. However, this is not always the case, and there are other important criteria to consider when selecting a grazier, and proximity may not be essential (see box 14).

CONSIDERATIONS FOR PROPONENTS

An ideal grazier partner should:

- have an established and large grazing enterprise, so that sheep numbers can fluctuate on the solar farm without putting financial stress on the farmer
- be able to move sheep easily and efficiently between the solar farm and their other paddocks, for example when vegetation growth fluctuates or if civil work is required
- have access to the necessary equipment for animal husbandry including equipment for shearing and treating the sheep
- be willing to work within the site's occupational health and safety requirements and hold appropriate insurance
- be willing to work in partnership with the site's operations and maintenance team.

If a potential grazier is not suggested or recommended by the local community or workforce during construction, it may be useful to advertise through extended community networks such as local Facebook pages, or by seeking expressions of interest. If the grazier is not the landholder, the lease between the landholder and the owner may need to be amended to allow for grazing.

CONSIDERATIONS FOR GRAZIERS

Farmers may approach developers with a proposal to graze. If considering forming a partnership with a solar farm or if approached by a developer, it is important to consider the following qualities that make an ideal solar farm partner:

- allowing the farmer to access the land when needed
- being conscious of, and prioritising, sheep safety and wellbeing
- a commitment to keeping the site secure for livestock, by keeping gates closed
- maintaining open communication, particularly where there are issues with the sheep when the farmer is not on site
- accommodating needs to utilise equipment within the solar farm to muster sheep (within safe limits)
- being willing to assist with mustering or moving sheep to a different area or property
- being responsive to farmer suggestions regarding vegetation management.

BOX 13

Farmer/proponent relationship on Numurkah Solar Farm

When it became evident that the vegetation had to be managed to align with local fire-prevention requirements, it was the former landowner Eddy Rovers' idea to bring his sheep onto the solar farm. Eddy's situation makes him a strong grazing partner: he has access to the necessary equipment to care for the sheep, lives close to the solar farm and contributes his expertise on animal welfare and husbandry. He is also able to provide advice about vegetation management and where or when to move the sheep.

A strong partnership has formed between Eddy and the solar farm's operations and maintenance team, with benefits flowing to both parties. "They say it's free agistment, I say it's free lawn-mowing!" says Eddy.

BOX 14

The grazier who lives just down the road (100 km away)

At Lilyvale Solar Farm in Queensland, Gransolar engaged Peter Cheal – a farmer running a large grazing enterprise in Emerald. Peter first saw the opportunity to run sheep on the solar farm when it was advertised on Facebook. Although Peter "lives down the road" – 100 km away – his successful grazing business and enthusiasm made him the prime candidate.
Peter has been inducted on workplace health and safety procedures and, due to the distance from his property, visits every few weeks to check on the sheep and the electric fence he has also installed. The site staff keep an eye on the sheep otherwise and maintain regular communication with Peter.

"I would absolutely recommend this sort of opportunity to other farmers where it arises"

Peter Cheal, grazier at Lilyvale Solar Farm

BOTH PARTIES STRIKING AN AGREEMENT

Most grazing partnerships enter into a formal agreement which details the arrangements between the solar farm proponent (often the operations and management company but sometimes the owner) and the grazier, outlining matters such as roles and responsibilities, costs and liabilities, health and safety obligations, site access, and communications. This usually occurs after a successful trial on site (see page 25). The following is a checklist of some of the key features of sheep grazing agreements. It is recommended that the grazier seeks legal advice before entering into an agreement.

COMPENSATION FOR AGISTMENT (HOSTING OF THE SHEEP)

There is typically no agistment fee, or compensation exchanged for sheep grazing on solar farms in Australia, with both parties recognising the in-kind benefits provided through the partnership.

MANAGEMENT OF SHEEP

The agreement/contract will often stipulate the minimum and the maximum number of sheep to be kept at the solar farm to ensure continuous vegetation management, while allowing flexibility for adverse conditions or events, such as drought.

Other grazier responsibilities that have been formalised in contracts between the parties include:

- that the animals be kept in good health
- that shearing occurs frequently
- conditions around mustering (e.g. no mechanical equipment to be used)
- that any fatalities are managed by the farmer.

It is also recommended that the agreement specify who is responsible for maintaining watering points and internal fencing etc.

Grazier Ken Ikin and BJCE's Leo Pearce inspect pasture on the Gullen Solar Farm before reintroducing sheep. / BJCE Australia

OPERATIONAL HEALTH AND SAFETY/ACCESS TO SITE

Any grazier partnering with a solar farm will need to be provided with a site induction and any other necessary occupational health and safety training to enable them to access the site as needed to tend to livestock. This training and any re-training requirements should be included as part of the agreement. The agreement between parties should specify conditions around access to site, such as signing in and out and after-hours access.

The operations and maintenance team should also clarify protocols such as communication and contacts in an emergency (e.g. a bushfire or workplace safety incident) as well as management of emergency access. Any of these plans and protocols should be reviewed and audited periodically to ensure they remain appropriate.

ALLOCATING RISKS AND LIABILITIES

Two of the key risks and liabilities of grazing sheep that must be covered in the agreement are:

- injury caused to the sheep by the equipment
- damage to the equipment caused by the sheep.

Approaches differ in the allocation of these risks and liabilities. In some cases, operators cover damage to the equipment while the farmers are responsible for any injury or fatalities of the sheep. In other circumstances, the farmers were liable for both risks and needed to ensure that they had appropriate insurance cover. The agreement should reflect the fair allocation of risk and reward of the respective parties. It is recommended that the grazier take out liability insurance to protect themselves from any risk. Some operators have been known to ask for a bond from the farmer for any damage caused to the equipment by the farmer's vehicles or sheep.

A number of other considerations and topics for agreements between the grazier and the proponent are outlined in Section 1 of the National Wind Farm Commissioner's 2019 Annual Report (see nwfc.gov.au).

SECTION 4: OTHER EMERGING FORMS OF AGRISOLAR

While solar sheep grazing is currently the most viable and common form of agrisolar for utility-scale solar farms both in Australia and around the world, there is a wide array of research and innovation underway exploring different approaches for integrating solar energy and agricultural production.

This section of the guide provides an overview of other forms of agrisolar in use or being explored in other markets, which can inform the expansion of agrisolar applications in the Australian context.

Akuo's 'Aquanergie' project on Réunion island. / Akuo

Vegetables grow under PV arrays at a test plot at the UMass Crop Animal Research and Education Center in South Deerfield, Massachusetts. / Dennis Schroeder - NREL

HORTICULTURE

According to the National Renewable Energy Laboratory (NREL) in the USA, agricultural crops can thrive underneath the partial shade conditions of solar installations, with panels creating the following conditions for plants grown under or around the panels:

- reducing the amount of direct sunlight reaching the crops and reducing sunburn on crops
- creating cooler conditions during the day and warmer conditions at night
- reducing heat stress as well as reducing risks of frost damage
- extending growing seasons in multiple regions
- increasing soil moisture levels, which can lead to a reduction in irrigation needs.[47]

USA

At the University of California – Davis, one study looked at the different levels of shade provided by ground-mounted tracker panels and how various types of leafy green vegetables fared under the different levels of light or photosynthetically active radiation (PAR).

The results from this study found that kale, chard and tomatoes produced the same amount of harvestable biomass in situations where the PAR was 55 per cent or more, indicating that moderate shade can be easily tolerated. Broccoli, capsicum and spinach were not as shade-tolerant, requiring at least 85 per cent or greater full sun irradiance. However, the broccoli produced better results in 85 per cent PAR than full sunlight. The study recommended careful attention when developing agrisolar systems, including the PV configurations and the crops that grow among them and ensuring that the crops are suited to the local environment.[48]

BIODIVERSITY AND BEES

The solar industry has been exploring the opportunities for solar farms to support biodiversity outcomes by reinstating native vegetation. Native vegetation is beneficial to the developer as it requires less ongoing maintenance than traditional gravel or grass (e.g. mowing) and is also prime habitat for pollinator insects.

In Europe, the USA and now Australia, interest has grown in recent years in utilising solar farms to provide protected habitat for wildlife, including beekeeping, by planting and cultivating native wildflowers. Hives can be located inside or outside of the project fence. Indeed, pollinator-friendly PV is more established in the USA than any other form of agrisolar, with an estimated 1 GW of solar farms with pollinator habitat across the nation.[49]

One example is Enel Green Power, which has partnered with the National Renewable Energy Lab in the USA to engage in low-impact solar development. In this process, the topsoil is retained, the PV panels are installed and then native plants, including flowers such as wild lupine and prairie grasses, are planted to create a habitat for bees, butterflies and moths. Research from the USA has shown that there tend to be more flowers and bees in the rows between the panels than outside.[50]

Recent research indicates that biodiversity gains on solar farms can be significant.[51] These pollinator insects benefit the surrounding farms and pollinator-dependent crops (e.g. soybean) as they transport pollen from one flower to another. For instance, in the USA, it is estimated that approximately 350,000 hectares of agricultural land near existing and planned large-scale solar facilities may benefit from increased pollination services if pollinator habitat was established on the solar farms.[52]

Sheep grazing can be implemented on the same land as beekeeping and native flora as it has a lower impact than mowing. Preliminary findings suggest that the movement of the sheep also stimulates vegetation growth by carrying and spreading seeds from plants around the landscape.[53] It should be noted, however, that this process can also increase the need for weed control.

Sheep grazing can be implemented on the same land as beekeeping and native flora as it has a lower impact than mowing. The movement of the sheep also stimulates vegetation growth by carrying and spreading seeds from plants around the landscape.

A bee keeper inspects hives outside IMS Solar, a pollinator friendly PV array site in Minnesota, USA. Early in growth, the IMS Solar site uses a diverse mix of pollinator-friendly native flowers and grasses. / NREL

4.2 SOLAR GREENHOUSES AND ROOFTOPS

Solar greenhouses, in which solar panels are integrated into the rooftops of horticultural greenhouses, have grown in popularity in some developed and developing markets.

The power generated from the solar panels can be used to satisfy the greenhouse's operational needs, including lighting, pumps for heating, cooling and irrigation, and monitoring systems. This technology can potentially take greenhouses off-grid. Furthermore, studies conducted by the University of California (UC) Santa Cruz have shown that crops grown inside these greenhouses were as healthy and grew at the same rate as conventional greenhouses.[54]

The solar panel configurations can completely or partially cover the rooftop, allowing for varying levels of solar radiation to suit crop needs. In one breakthrough advance, Murdoch University in Perth, is constructing the world's first clear solar glass greenhouse using ClearVue solar glazing technology, due for completion in 2021. Under a collaborative research agreement, the university and ClearVue will work together to design, test and conduct suitable plant science trials to evaluate the effectiveness of the glazing for use in plant growth.[55]

HORTICULTURE AND FLORICULTURE

New Caledonia

French renewable energy developer, Akuo, has utilised solar greenhouses as part of its 'Agrinergie' project in New Caledonia. Flowers and vegetables are grown inside cyclone-proof greenhouses all year-round, while solar panels cover half of the rooftops. The photovoltaic greenhouses are an efficient solution in terms of protection from weather, climate and insects.[56]

Australia

One Australian fresh produce grower, Sundrop Farms in South Australia, has taken this model a step further, and in 2016 established a solar-thermal plant next to its 20 hectare greenhouse facility. The solar-thermal site purifies seawater for irrigation and provides power to the greenhouses for tomato cultivation. See Box 15 for a closer look at this ground-breaking agrisolar facility.

Akuo's 'Agrinergie' solar greenhouses in New Caledonia. / Akuo

Sundrop's hydroponic greenhouses grow 17 kilotons of tomatoes annually. / Sundrop

BOX 15

Solar-thermal plant powers Sundrop Farms, South Australia

Traditional agriculture methods struggle in arid environments such as South Australia's Port Augusta. However, Sundrop's world-first system at its Port Augusta farm has demonstrated the transformative power of high-quality solar resources for productive agriculture in even inhospitable farming locations.

Completed in 2016, the farm hosts 20 hectares of hydroponic greenhouses growing tomatoes and using thermal solar energy for electricity, heating, cooling and most importantly, to irrigate its tomato crops.

The thermal power is generated by a 115 m solar tower located next to the greenhouses, with 23,000 mirrors faced towards it for maximum sunlight exposure. At its peak, the solar tower produces 39 MW of thermal energy for use by the farm.

To irrigate the crops, seawater is piped 5 km from the Spencer Gulf into a desalination plant where it is turned into freshwater for the tomato plants, the process wholly powered by thermal solar power.

The tomatoes are grown all year round and are sold at a leading supermarket chain in Australia, with the farm producing 17 kilotons of tomatoes annually, accounting for 15 per cent of Australia's tomato production. The greenhouses allow for protection against the abnormal weather events that affect other crops, meaning a steady and consistent supply for the supermarket.

The success of the Port Augusta farm has led to Sundrop developing pilot plants in other arid environments in Portugal and Tennessee, USA.[57]

Sundrop's tomato yields are 15-30 times higher per hectare than conventional field production. / Sundorp

AQUACULTURE

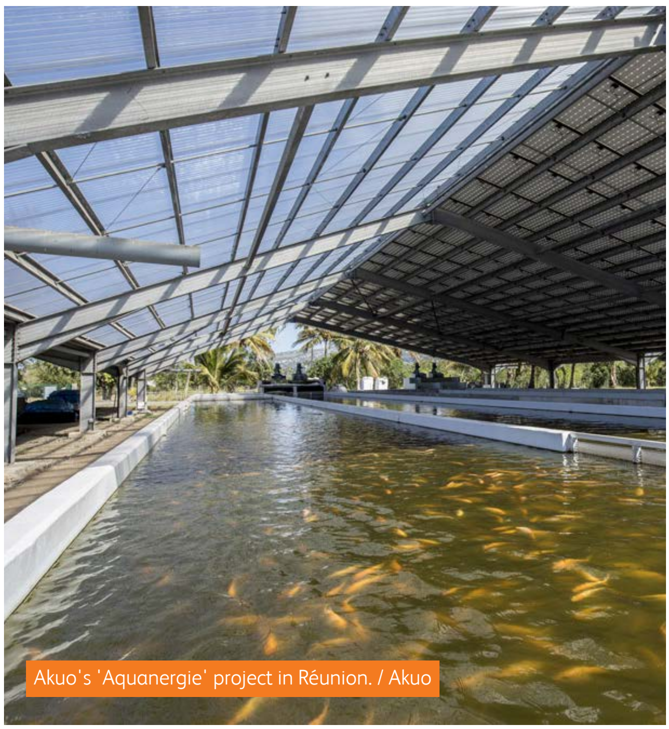
Some niche applications are also emerging for the integration of solar and aquaculture. In Thailand, PV plants have been built over on-land shrimp farms and fish farms, acting as shade houses, or are being integrated into existing greenhouses. Pilot projects have shown that by providing shade, the solar panels offer protection from predators, reduce water evaporation and regulate water temperature, enhancing aquaculture growth.

Réunion

As well as horticulture, the French company Akuo has developed a solar roof project over fish farming ponds in Réunion. The 'Aquanergie' project involves 12 shade houses with PV roofs over fishponds, producing 9 MW of electricity.[58]

Vietnam

In Vietnam, German research institutes Fraunhofer ISE and GIZ have carried out a pre-feasibility study for combining shrimp farming with photovoltaics, with research indicating that water consumption is cut by 75 per cent compared to that of a conventional shrimp farm. The German organisations have now entered into an agreement with private shrimp farms to develop project 'SHRIMPS' (Solar-aquaculture Habitats as Resource-efficient and Integrated Multilayer Production Systems) to test technical and commercial feasibility.[59]



Akuo's 'Aquanergie' project in Réunion. / Akuo

4.3 ELEVATED PV SYSTEMS

While research has shown that elevated PV systems have a higher capital cost premium than ground-mounted due to extra costs of the modified structures,[60] these systems (typically 2.5-5.0 m above the ground) that can accommodate taller crops (e.g. grains, corn or fruit trees) may be economically viable in some circumstances.

These elevated PV systems, which have been trialled and deployed in some markets, tend to allow for more sun to filter through to the plants below, and are typically tall enough for people, as well as planting and harvesting machinery to pass underneath.

There are multiple designs of elevated PV structures, including 'stilt-mounted' designs, raised panels with reinforced structures and vertical panels with bifacial panels. The amount of shading provided by the panels – that is, how close the rows of panels are situated to one another, or if the panels allow light to pass through – must be carefully determined depending on the type of crop to be grown. In other cases, such as the system that has developed in Japan where the farmer is paid for the electricity generated, the type of crop may be determined by the amount of shading.

HORTICULTURE

Research has shown elevated PV systems to be effective for fruit trees and plants that are shade-tolerant such as leafy greens and parsley. Even crops that are shade-intolerant can be successfully grown, with recent studies in Japan showing crop yields of corn are improved under elevated panels.[61]

The Netherlands

In the Netherlands, companies BayWa r.e. and its Dutch subsidiary GroenLeven, have adapted the elevated PV model to grow various types of berries along the arches supporting the panels at the Piet Albers Fruit Farm in the Dutch municipality of Zevenaar. By implementing this form of agrisolar, the farmer has replaced his foil tunnels which protected the berries with a 2.67 MW solar plant.

Rather than spacing apart the rows to allow light penetration to the crops below, these companies have developed semi-transparent solar modules in a single-row system, allowing sufficient sunlight for the plants while at the same time protecting the crops from direct sunlight, rain, hail and frost. This type of agrisolar also allows for fruits such as apples, pears, cherries and plums to be grown below the panels (see the example in France on page 36).

The results from the trial showed that not only is it feasible to grow berries under a solar array, but crop productivity was also improved. The study also resulted in a reduction in labour, waste, variable costs and the application of pesticide due to better air ventilation.

Illustration of elevated PV over an orchard. / © Fraunhofer ISE

Fraunhofer ISE's elevated PV site near Lake Constance. / © Fraunhofer ISE

Japan

The concept of panels elevated above agricultural land on stilts was first developed by Akira Nagashima in Japan in 2003. He named this concept 'solar sharing', referring to the sharing of solar energy between agriculture and power generation.

There are now 2000 solar sharing farms across Japan, with agrisolar responsible for 0.08 per cent of national solar generation in 2019. The solar sharing concept has seen the revitalisation of abandoned farms, with 31 per cent of solar sharing farms being constructed on former deserted farmland.[62]

Over 120 different types of crops have been grown underneath the elevated PV structures in Japan, including cereals, vegetables, mushrooms, fruit trees, tea, coffee and ornamental flowers. The type of crop chosen depends on the amount of shading provided by the panels.

One example is the construction of PV panels elevated on stilts 3 m above rice paddies in Japan, with some farmers in the Chiba Prefecture earning nine times what they earn from the crops below from the sale of solar energy.[63]

USA

A study conducted at the University of Arizona analysed the growth of vegetables below ground-mounted panels that were higher than most ground-mounted PV, sitting at 3.3 m above ground at their lowest point. The study looked at the growth of cherry tomatoes, jalapeños and chiltepin peppers (a type of capsicum native to the Americas), with different irrigation regimes.

Results from the study showed that in the agrisolar system:

- for cherry tomatoes, water-use efficiency was 65 per cent greater and total production doubled
- for jalapeños, water efficiency was 150 per cent greater
- the total chiltepin fruit production was three times greater.[64]

The panels in an agrisolar system were ~8.9°C cooler in daylight hours,[65] leading to an increase in system performance. The study estimated a 3 per cent increase in generation by the panels from May-July (late spring to summer) and 1 per cent increase in generation annually.[66]

France

Sun'Agri's La Pugère site in France is trialling the effect of PV panels over apples and pears. The tracker panel solar system was built in 2019 over a 10-year old orchard of golden delicious apples. There is spacing of 4 m between rows, and the panels are 5 m high to allow machinery to pass through. The light interception of plants is 40 per cent and the orientation of the tracker panels adjusted according to the apple orchard's needs. The design is also compatible with the installation of anti-hail nets.[67]

Germany and India

A trial has been underway since 2016 near Lake Constance in Germany, testing the effect of PV modules mounted on 5 m high structures on the growth of potatoes, wheat, clover and celery planted beneath the arrays.

The project, directed by German-based Fraunhofer ISE, found that the yield for celery, potato and wheat was greater under the modules than it was for the reference yield (area not beneath solar modules) in a hot year, but lower in an average year.[68] The results indicate the potential for agrisolar in arid regions. This was confirmed in another Fraunhofer pilot study in Maharashtra, India, showing that shading and lower evaporation from the modules result in up to 40 per cent higher yields for tomatoes and cotton crops.[69]

Another elevated PV structure innovation occurring in Germany is a vertical, bifacial panels structure created by company Next2Sun. The two sides of the modules face east and west, and the rows are spaced at least 8 m apart. The areas in between the rows can be used for various types of pasture utilisation, such as hay, cattle or sheep grazing, and chickens.[70]

BOX 16

Solar energy generation in orchards, Agriculture Victoria

In 2021, a horticultural solar energy project commenced at Agriculture Victoria's SmartFarm Tatura site as part of the Victorian Agriculture Energy Investment Plan.

Researchers will investigate the potential for integrating solar panels within a pear orchard to improve fruit quality by protecting the trees and fruit from extreme heat events and sunburn. Different solar panel configurations (see photo) will be installed above the tree canopy.

Apart from energy production, the panels' impact on tree growth, fruit yield, fruit colour and water-use efficiency will also be measured. The project will continue over three growing seasons. Energy use in Australian orchards accounts for a large proportion of production costs.

This project aims to combine renewable energy generation with management tools that provide strategic shade to trees and allow orchardists to adapt to climate change.

Fraunhofer ISE's elevated PV site near Lake Constance. / © Fraunhofer ISE

Solar panels being constructed above a pear orchard as part of Agriculture Victoria's project at the SmartFarm in Tatura, Victoria. / Agriculture Victoria

VITICULTURE

Across the world, viticulture has been impacted by increasing temperatures, leading to earlier harvests, water stress, unpredictable grape quality and higher sugar content in the grapes. It is estimated that suitable viticultural land in Europe will have decreased by 68 per cent by 2050.[71]

In Australia, a 2007 report by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) identified the wine industry as particularly vulnerable to climate change due to its dependence on unique terroirs which are closely related to climate.[72] Australian grape growers are acutely aware of the challenges caused by climate change, with some installing canopies over the grapevines for hot summers to prevent sunburn and heat exposure, as well as applying straw mulch to cool the soil.[73]

A French study run by company Sun'Agri and supported by the French Environment and Energy Management Agency found that placing elevated PV systems over vines resulted in:

- reduced water demand by 12-34 per cent
- similar or improved crop yields
- reduced alcohol content of the wine
- improved aromatic properties of the wine.[74]

One example where such an agrisolar system has been installed is at the Nidolères Wine Estate in Tressere in the south of France. The estate, a family-owned vineyard for eight generations, constructed a 2 MW solar farm over three varieties of vine: Grenache blanc, Chardonnay and Marselan. The panels are 4.5 m from the ground, and the rows are distanced 2.25 m from each other. The first harvest is expected in 2021, and preliminary results have shown a 20 per cent reduction in water consumption on the farm, a decrease in growth arrest and a reduction of leaf burn events during the heatwaves of the 2019 summer.[75]

BOX 17

Agrisolar proposal for South Australian winegrower

Renewable energy development company Energy Estate has been working with Paxton Wines in McLaren Vale, a significant wine-growing region in South Australia, to collaboratively explore the opportunities for an agrisolar system on its estates. The system aims to integrate existing agricultural practices and machinery to generate clean energy, potentially reducing grid-connected electricity consumption on the estate, and providing a range of agricultural benefits. The project is in the early design stages and will be formalised throughout 2021.

The partnership has already identified a number of potential agricultural benefits of agrivoltaics installation on the estate, including the prevention of extreme weather effects such as sunburn, hail and storm damage, a cooler microclimate during heatwaves, and water savings.

Challenges identified include fitting the infrastructure around the existing growing, harvesting and maintenance equipment requirements, as well as how to strike the right balance between solar and viticultural solar exposure throughout the day and year to maximise agricultural yield and profitability.

The project aims to be an Australian-first, with inspiration drawn from international experience, promising academic research and Energy Estate's infrastructure development experience.

Sun'Agri's elevated PV panels at Nidolères Estate are 4.5 metres above the ground and sit over one of the vineyards. / (c) Sun'Agri

SECTION 5: RESOURCES

Grazing on Goldwind's White Rock Solar Farm. / Andrew Homewood of Green Bean Design

INTERNATIONAL AGRISOLAR GUIDES

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GUIDELINES FOR PREPARING SOLAR FARMS FOR AGRISOLAR

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- Bees and pollinators – *Fresh Energy, (2021) Best Practices and Training.* https://fresh-energy.org/beeslovesolar/best-practices-and-training/.

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COST COMPARISON OF AGRISOLAR SYSTEMS

- National Renewable Energy Laboratory, (2020) *Capital Costs for Dual-Use Photovoltaic Installations: 202 Benchmark for Ground-Mounted PV Systems with Pollinator-Friendly Vegetation, Grazing and Crops.* https://www.nrel.gov/docs/fy21osti/77811.pdf.
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BIODIVERSITY AND BEE RESEARCH

- Walston, L et al, (2018) *Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States,* Environmental Science & Technology 2018 52 (13), 7566-7576. https://pubs.acs.org/doi/pdf/10.1021/acs.est.8b00020.

GUIDANCE FOR LANDHOLDERS AND PROPONENTS FOR SOLAR FARM DEVELOPMENT AND OPERATION

- NSW Farmers, (2019) *Renewable Energy Landholder* Guide. http://nswfarmers.org.au/NSWFA/Content/IndustryPolicy/Resource/Renewable_Energy_Landholder_Guide.
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APPENDICES

Sheep enjoy the shade of the dual-axis tracker array on the University of Queensland's Gatton Solar Farm. / Sarah Haskmann, UQ

APPENDIX 1:

CLEAN ENERGY COUNCIL BEST PRACTICE CHARTER FOR RENEWABLE ENERGY DEVELOPMENTS

Visit cleanenergycouncil.org.au/charter for a list of signatories to the Best Practice Charter.

CLEAN ENERGY COUNCIL

BEST PRACTICE CHARTER FOR RENEWABLE ENERGY DEVELOPMENTS

We commit to honouring the Clean Energy Council's Best Practice Charter in our renewable energy developments and associated transmission infrastructure:

1. We will engage respectfully with the local community, including Traditional Owners of the land, to seek their views and input before finalising the design of the project and submitting a development application.
2. We will provide timely information, and be accessible and responsive in addressing the local community's feedback and concerns throughout the lifetime of the development.
3. We will be sensitive to areas of high biodiversity, cultural and landscape value in the design and operation of projects.
4. We will minimise the impacts on highly productive agricultural land where feasible, and explore opportunities to integrate continued agricultural production into the project.
5. We will consult the community on the potential visual, noise, traffic and other impacts of the development, and on the mitigation options where relevant.
6. We will support the local economy by providing local employment and procurement opportunities wherever possible.
7. We will offer communities the opportunity to share in the benefits of the development, and consult them on the options available, including the relevant governance arrangements.
8. We commit to using the development to support educational and tourism opportunities where appropriate.
9. We will demonstrate responsible land stewardship over the life of the development and welcome opportunities to enhance the ecological and cultural value of the land.
10. At the end of the project's design or permitted life we will engage with the community on plans for the responsible decommissioning, or refurbishment/repowering of the site.

APPENDIX 2:

COMMON QUESTIONS ABOUT SOLAR FARMS

1. WHY CAN'T SOLAR FARMS AVOID FARM LAND ALTOGETHER AND BE LOCATED IN REMOTE LOCATIONS AWAY FROM COMMUNITIES AND FARMING ACTIVITIES?

The most important consideration for solar farm siting (like other types of power stations) is proximity to strong parts of the electricity transmission network, and the population centres they are designed to serve.

It is significantly more challenging to develop a solar farm in remote, outback locations due to the very high costs associated with transmission line extensions and the energy losses that occur when electricity is transported over longer distances to consumers.

Other key features that solar farm proponents seek in a suitable site are flat or gently sloping land where impacts on native vegetation and cultural heritage can be minimised. This is most often land which has been previously cleared for farming purposes.

Many companies working within the Australian utility-scale solar sector have committed to minimising the impacts on highly productive agricultural land (see the Clean Energy Council's Best Practice Charter for Renewable Energy Developments in Appendix 1) and prioritising the use of less-productive land wherever possible.

As this guide indicates, there are opportunities for agricultural and solar production to be integrated, bringing benefits and advantages for farming communities and renewable energy proponents.

2. DO SOLAR FARMS CAUSE A 'HEAT ISLAND EFFECT'?

Only a small number of studies have been carried out worldwide concerning a possible heat island effect associated with solar farms.

While the findings across these studies vary depending on the site context, the following broad themes have emerged to date:

- temperatures in the centre of a solar farm are slightly higher than ambient temperature, returning to ambient temperature several metres above a solar farm
- temperatures are slightly warmer directly adjacent to a solar farm, returning to ambient temperatures with distance from the solar arrays
- air temperatures at ground level underneath panels may be slightly cooler during summer months
- air temperatures directly above solar arrays may be slightly warmer at night and during warmer months.[75]

In some Australian jurisdictions, a 30 m buffer between arrays and neighbouring properties has been determined an adequate distance for heat dissipation. Vegetation can also be used to assist with cooling and to create a heat buffer.[76] Given the relatively small changes in temperatures around a solar farm, the Clean Energy Council considers that such buffer areas are only needed where there is temperature-sensitive food production (e.g. stone fruits) on adjoining land.

3. DO SOLAR FARMS INCREASE FIRE RISK IN OUR COMMUNITY?

The planning consent conditions for solar farms require consultation with local fire authorities, the thorough assessment of bushfire risk and compliance with strict standards. This typically includes maintaining buffer areas of cleared land within the perimeter of the solar farm, as well as the provision of water tanks on site.

Asset managers are required to have an emergency management plan in place, and once operational, solar farms are monitored around the clock providing an early warning system.

4. DO SOLAR FARMS CAUSE GLINT AND GLARE?

Photovoltaic solar panels are designed to absorb light rather than reflect it, and as such, they have relatively low levels of reflectivity. They are constructed of dark, light-absorbing materials, and many panels are also covered with an anti-reflective coating. As an example, this low reflectivity enables solar farms to be constructed in close proximity to airports.

Glare can be found in both the natural environment (bodies of water, snow) and the built environment. The glare associated with some natural landscapes is far more significant than a dark, light-absorbing solar farm.

While the metal frames around the individual panels and the mounting frames may have glint impacts, this is limited to a minimal surface area. In addition, some panels now have a dual glass frameless design and hence have zero glint.

5. WHEN THE SOLAR FARM COMES TO THE END OF ITS LIFE, WILL THE LAND BE RETURNED TO THE WAY IT WAS BEFORE?

Modern solar farms have a relatively light footprint on the land compared with other forms of development. (For example, in contemporary solar farms, steel piles that support the solar arrays are driven directly into the soil, without the need for concrete foundations.) This light footprint makes it relatively straight forward to return solar farms to their former land uses at the end of their permitted operating life.

Any commercial agreement between a landholder and proponent typically does and should include decommissioning plans, detailing the responsibilities of the solar farm owner to remove the solar arrays and other infrastructure at the end of a project’s permitted operating life and returning the property to its original condition to the extent that is possible.

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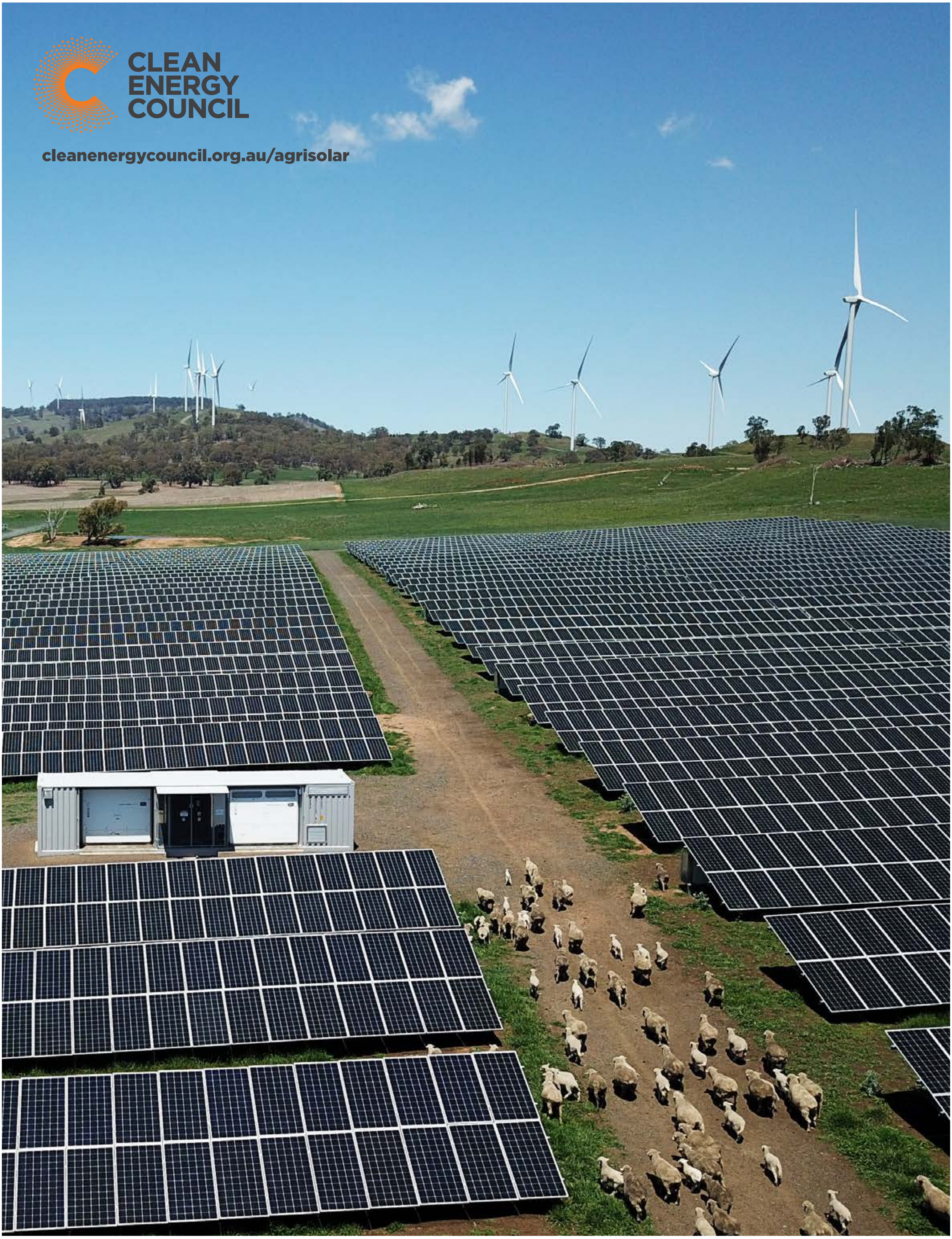
Back cover photo: heep grazing at Goldwind's White Rock Solar Farm in New England, co-located with 175 MW White Rock Wind Farm Stage 1. / Andrew Homewood, Green Bean Design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