# Developing conservoltaic systems to support biodiversity on solar farms

Habitat conversion is one of the leading threats to biodiversity globally (Fischer & Lindenmayer, ). Renewable energy initiatives such as large-scale solar, wind and hydroelectric power installations have recently boomed, requiring large areas of land for power generation. To offset decreasing land available for biodiversity and nature conservation, land sharing (i.e. using the same land for multiple purposes; Fischer et al., ) could maximise land value.

Agrivoltaic systems (agriculture + voltaic [solar energy]) are one of the suggested multifunction land uses for renewable energy. In these systems, solar energy and agricultural practices coexist to produce beneficial outcomes for both industries, emerging to better meet the needs for multiple commercial-scale financial returns (Adeh et al., ; Dinesh & Pearce, ; Dupraz et al., ). No such scheme, however, exists for combining solar energy and wildlife conservation in Australia.

Here, we introduce the concept of *conservoltaic systems* to identify and exploit opportunities to combine solar energy production and biodiversity conservation. Innovative design and management strategies on solar farms could contribute to nature conservation. Solar panels may provide suitable habitat and structural complexity for wildlife, including shelter from predators, perch or nesting structures and shading (Nordberg et al., ; Figure 1 and 2), which can be enhanced with appropriate management (e.g. targeted habitat restoration activities). Consequently, a few studies from Europe have identified opportunities to enhance pollinator biodiversity on large-scale solar parks (Blaydes et al., , ; Montag et al., ).

**FIGURE 1**

Spotted marsh frog (*Limnodynastes tasmaniensis*) found within a solar farm in Armidale, NSW, Australia. Photographer: Eric Nordberg, 2022.

**FIGURE 2**

Solar farm at the University of New England, Armidale, NSW, Australia. Photographer: Eric Nordberg, 2022.

Clearly defining the required characteristics of conservoltaic sites and the management required for wildlife to benefit from such opportunities is urgent, especially given the current and rapidly increasing extent of solar farms worldwide (Agha et al., ; Nordberg et al., ). Furthermore, building solar farms on sites degraded by previous land uses, such as arable cropland or livestock grazing, especially in areas with low productivity, provides an opportunity to minimise land conversion while simultaneously increasing land value by creating habitat for local wildlife.

We are, however, lacking research on appropriate locations, configurations and management schemes on solar farms to enhance biodiversity retention and recovery. We urgently require empirical data on wildlife use of solar farms and adjoining areas to successfully identify land sharing opportunities of hybrid landscape designs, or 'conservoltaic' systems. A collaborative approach across industry, land managers and research organisations is needed to facilitate land management schemes that promote energy production and conservation actions simultaneously (Moore-O'Leary et al., ).

| References | Aim of the study | Key results | Manageme recommer |
|---|---|---|---|
| Adeh et al. (2019) | 1. Identified environmental factors that influence solar panel efficiency<br>2. Applied results to global land types/conditions to identify greatest potential | 1. Solar panel efficacy was influenced by insolation, air temperature, wind speed, and relative humidity<br>2. Croplands showed the highest median solar potential at 28 W/m$^2$ | 1. Duel-u (agriv systen reduce compe land u<br>2. Solar produ could global demar 1% of were c to an a systen |

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| Agha et al. (2020) | Examined:<br>1. Recent trends in the literature on the impact of wind and solar energy development on wildlife in the USA<br>2. How site and design of development may maximise energy benefits while minimising negative effects on wildlife<br>3. The availability and benefits of before-after control-impact studies<br>4. Possible approaches to mitigate impacts of renewable energy development on wildlife | 1. Impacts of renewable energy development on wildlife are still lacking or are species-specific<br>2. Identifying renewable facility location/footprint is paramount to minimise negative impacts<br>3. Lack of well-designed BACI studies limit our capacity to identify threats and present solutions | 1. Mitiga be imp using suppo<br>2. Sugge applyi wildlife deterr detect systen<br>3. Partne with conse and fa manag evalua impac future develc |
| Blaydes et al. (2022) | 1. Identify how the shape, size, management, and landscape context impact ground-nesting bumble bee density, nest | 1. Bumble bee and nest density was driven by solar park management<br>2. Bumble bee and nest density was twice as high in parks managed for wildflower meadows compared to those with only wildflower margins | 1. Solar have t potent boost bumbl densit potent pollina servic adjace if desi manag optima |

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| | density, and nest productivity | 3. Size, shape, and landscape context had less of an effect, but large resource rich parks were most effective at increasing bumble bee responses | 2. Incorp biodiv solar p manag can cc to wid enviro landsc values |
| Blaydes et al. (2021) | 1. Review evidence that solar parks can enhance pollinator biodiversity | Present ten evidence-based management recommendations centred around five main themes:<br><br>1. Foraging resources<br>2. Nesting, breeding and reproductive resources<br>3. Site management<br>4. Landscape and connectivity<br>5. Climate | Produced t recommenc enhance bi<br><br>1. Provid divers key flc plant s<br>2. Plant c mainta rows a bound<br>3. Ensure long a foragi resour<br>4. Provid of nes breedi reproc resour<br>5. Graze, mow a intens late in seaso<br>6. Create mainta variati vegeta structi<br>7. Minim use of agrocl<br>8. Target manag |

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| Dinesh and Pearce (2016) | 1. Reviews theoretical and experimental work on agrivoltaics and analyses the potential crop yields and solar power output as a function of the incoming solar radiation<br>2. Conducted a sensitivity analysis of agrivoltaic systems using the potential economic value of agrivoltaic farms to determine viability and for guiding future dual use farms | 1. Solar energy and agricultural practices can co-exist and provide mutually beneficial outcomes, especially for shade-tolerant crops<br>2. Economic value of farms with both solar and shade-tolerant crops can greatly increase land value and provide co-benefits | 1. More types geogr areas investi<br>2. Many oppor for co- includ angle/ panels irrigati wateri panel and m retenti |
| | | | 1. Variou photo panel |

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| Dupraz et al. (2011) | 1. Proposes combining agriculture and solar energy production to maximise energy conversion for power and food | 1. Combining land uses drastically increases land equivalent ratios (LERs)<br>2. Solar energy production and crop production can be effectively combined | modifi could to incr crop p (panel semi-transp panels<br>2. More neede identif microc effect |
| Fischer et al. (2008) | 1. Compare and contrast 'land sharing' and 'land sparing' | 1. Outline a series of recommended policy guidelines for agricultural landscapes, including fine-grained/heterogenous farming, coarse-grained/homogenous areas, and frontier landscapes undergoing rapid land conversion | 1. Protec expan patche native veget<br>2. Maint corrid betwe existin resear refuge<br>3. Active a mix sparin wildlif farmin approp |
| Fischer and Lindenmayer | 1. To provide a holistic view of the ecology of modified landscapes by synthesising recent | 1. Developed a conceptual framework for understanding the effects of landscape modification on species and assemblages<br>2. Identified the threatening processes associated with landscape modification and their | 1. Maint restor buffer sensiti travel landsc heter<br>2. Maint specie |

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| (2007) | developments across a range of different research themes | effect on individual species and species interactions<br>3. Identified key knowledge gaps and created a list of tangible management recommendations for conservation management in modified landscapes | interac functic divers apply approp disturk regime |
| Montag et al. (2016) | 1. To compare biodiversity within and outside solar farms<br>2. Research focused on botany (grasses and broadleaf plants), invertebrates (butterflies and bumble bees), birds (notable species and ground-nesting species), and bats | 1. Solar farms showed greater botanical diversity in solar farms compared to control sites<br>2. Greater abundance of bumblebee and butterflies in solar farms compared to control sites<br>3. Greater abundance and diversity of birds on solar farms compared to control sites<br>4. Great bat activity on control plots but no difference in diversity | 1. Solar f lead tc increa divers abund broad- plants butter bumbl and bi<br>2. Sites v highes value v seede divers mix up compl constr limitec of herl provid margir habita wildlife emplo conse grazin mowir<br>3. Sites r for wil to a gr positiv respor |

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| Moore-O'Leary et al. (2017) | 1. Argue the connections between utility-scale solar energy development and environmental conservation should be closely examined | Discuss 5 critical concepts to improve sustainable solar energy development:<br><br>1. Solar energy exists within the land-energy- ecology nexus<br>2. There are 'winner' and 'loser' species in solar ecosystems<br>3. Cumulative and large-scale environmental impacts require careful consideration and planning<br>4. Solar ecological commonalities and idiosyncrasies<br>5. Long-term ecological consequences of large-scale solar sites are unknown | 1. Resea neede identif impac sites h wildlif to ider we ca these outcor<br>2. Requir coordi action many includ indust manag resear and pc maker<br>3. Scient resear limitec need r to info and manag action |
| Nordberg et al. (2021) | 1. Identify opportunities among renewable energy generation, agriculture, and conservation, through co-location and innovative | 1. Identified opportunities whereby solar farms can be designed to improve biodiversity, land condition, and conservation outcomes, while maintaining or increasing commercial returns | 1. Design manag solar f shoulc agricu ecolog expert maxim win str<br>2. Modifi to sola dimen could potent |

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| | design of photvoltaic solar energy farms on grazing and croplands | 2. Highlight the lack of information on supporting wildlife on solar farms | grazin minim need f veget manag under |

**Eric J. Nordberg:** Conceptualization (equal); writing – original draft (lead); writing – review and editing (equal). **Lin Schwarzkopf:** Conceptualization (equal); writing – original draft (supporting); writing – review and editing (equal).