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HOT TOPICS IN ECOLOGY

Developing conservoltaic systems to support biodiversity on solar farms

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Habitat conversion is one of the leading threats to biodiversity globally (Fischer & Lindenmayer, 2007). 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., 2008) 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., 2019; Dinesh & Pearce, 2016; Dupraz et al., 2011). 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., 2021; Figure 1 and 2), which can be enhanced with appropriate management (e.g.

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.

References	Aim of the study	Key results	Management/policy recommendations	Type of study	Ecosystems & location	Date reference added
Adeh et al. (2019)	1. Identified environmental factors that influence solar panel efficiency 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 2. Croplands showed the highest median solar potential at 28 W/m^2	1. Duel-use land (agrivoltaic systems) may reduce competition for land use 2. Solar production could offset global energy demand if even 1% of cropland were converted to an agrivoltaic system	Research Article	Temperate agrivoltaic system; Northwest USA	20-Dec-22
Agha et al. (2020)	Examined: 1. Recent trends in the literature on the impact of wind and solar energy development on wildlife in the USA 2. How site and design of development may maximise energy benefits while minimising negative effects on wildlife 3. The availability and benefits of before-after control-impact studies 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 2. Identifying renewable facility location/footprint is paramount to minimise negative impacts 3. Lack of well-designed BACI studies limit our capacity to identify threats and present solutions	1. Mitigation can be improved using decision support tools 2. Suggested applying novel wildlife deterrent and detection systems 3. Partnerships with conservation and facility managers to evaluate impacts for future development	Review	Arid landscapes; Western USA	09-Aug-22
Blaydes et al. (2022)	1. Identify how the shape, size, management, and landscape context impact ground-nesting bumble bee density, nest density, and nest productivity	1. Bumble bee and nest density was driven by solar park management 2. Bumble bee and nest density was twice as high in parks managed for wildflower meadows compared to those with only wildflower margins 3. Size, shape, and landscape context had less of an effect, but large resource rich parks were most effective at increasing bumble bee responses	1. Solar parks have the potential to boost local bumble bee density and potentially pollination services to adjacent crops if designed and managed optimally 2. Incorporating biodiversity into solar park management can contribute to wider environmental landscape values	Research Article	Temperate; Northwest Europe	10-Dec-22

References	Aim of the study	Key results	Management/policy recommendations	Type of study	Ecosystems & location	Date reference added
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: 1. Foraging resources 2. Nesting, breeding and reproductive resources 3. Site management 4. Landscape and connectivity 5. Climate	Produced ten recommendations to enhance biodiversity 1. Provide a diverse mix of key flowering plant species 2. Plant or maintain hedge rows at the site boundaries 3. Ensure season-long access to foraging resources 4. Provide a range of nesting, breeding, and reproductive resources 5. Graze, cut, or mow at low intensity and late in the season 6. Create or maintain variation in vegetation structure 7. Minimise the use of agrochemicals 8. Target management for pollinators on solar parks located in homogenous and intensive agricultural-dominated landscapes 9. Promote connectivity to semi-natural habitat 10. Generate a range of microclimates	Review	Temperate; Northwest Europe	10-Dec-22
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 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 2. Economic value of farms with both solar and shade-tolerant crops can greatly increase land value and provide co-benefits	1. More crop types and geographic areas should be investigated 2. Many opportunities for co-benefits, including angle/height of panels, irrigation for watering and panel cleaning, and moisture retention	Review	Agrivoltaic systems; Global	09-Aug-22
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) 2. Solar energy production and crop production can be effectively combined	1. Various photovoltaic panel modifications could be made to increase crop production (panel tilt, semi-transparent panels, etc.) 2. More data is needed to identify microclimate effects	Research Article	Agrivoltaic system; France	09-Aug-22

References	Aim of the study	Key results	Management/policy recommendations	Type of study	Ecosystems & location	Date reference added
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. Protect and expand large patches of native vegetation 2. Maintain travel corridors between existing research and refuge habitat 3. Actively plan for a mix of land sparing and wildlife-friendly farming where appropriate	Concepts and Questions	Agricultural and native vegetation; Global	09-Aug-22
Fischer and Lindenmayer (2007)	1. To provide a holistic view of the ecology of modified landscapes by synthesising recent developments across a range of different research themes	1. Developed a conceptual framework for understanding the effects of landscape modification on species and assemblages 2. Identified the threatening processes associated with landscape modification and their effect on individual species and species interactions 3. Identified key knowledge gaps and created a list of tangible management recommendations for conservation management in modified landscapes	1. Maintain or restore habitat buffers around sensitive areas, travel corridors, landscape heterogeneity 2. Maintain species interactions, functional diversity, and apply appropriate disturbance regimes	Review/Synthesis	Modified and natural landscapes; global	09-Aug-22
Montag et al. (2016)	1. To compare biodiversity within and outside solar farms 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 2. Greater abundance of bumblebee and butterflies in solar farms compared to control sites 3. Greater abundance and diversity of birds on solar farms compared to control sites 4. Great bat activity on control plots but no difference in diversity	1. Solar farms can lead to an increase in the diversity and abundance of broad-leaved plants, grasses, butterflies, bumblebees and birds 2. Sites with the highest wildlife value were seeded with a diverse seed mix upon completion of construction, limited the use of herbicides, provided good marginal habitat for wildlife and employed a conservation grazing or mowing regime 3. Sites managed for wildlife lead to a greater positive response by biodiversity	Report	Temperate; Northwest Europe	10-Dec-22

References	Aim of the study	Key results	Management/policy recommendations	Type of study	Ecosystems & location	Date reference added
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: 1. Solar energy exists within the land- energy- ecology nexus 2. There are 'winner' and 'loser' species in solar ecosystems 3. Cumulative and large-scale environmental impacts require careful consideration and planning 4. Solar ecological commonalities and idiosyncrasies 5. Long-term ecological consequences of large-scale solar sites are unknown	1. Research is needed to identify the impacts solar sites have on wildlife but also to identify how we can improve these outcomes 2. Require coordinated action across many groups, including industry, land managers, researchers, and policy makers 3. Scientific research is limited and we need more data to inform policy and management actions	Review/ Synthesis	Renewable landscapes; Global	10-Dec-22
Nordberg et al. (2021)	1. Identify opportunities among renewable energy generation, agriculture, and conservation, through co-location and innovative design of photvoltaic solar energy farms on grazing and croplands	1. Identified opportunities whereby solar farms can be designed to improve biodiversity, land condition, and conservation outcomes, while maintaining or increasing commercial returns 2. Highlight the lack of information on supporting wildlife on solar farms	1. Design and management of solar farms should consult agricultural and ecological experts to maximise win-win strategies 2. Modifications to solar panel dimensions could increase potential for grazing or minimise the need for vegetation management under panels	Review/ Synthesis	Agricultural and renewable landscapes; Global	09-Aug-22

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., 2021, 2022; Montag et al., 2016).

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., 2020; Nordberg et al., 2021). 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., 2017).

AUTHOR CONTRIBUTIONS

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).

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