Evidence review of the impact of solar farms on birds, bats and general ecology (NEER012)

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Evidence review of the impact of solar farms on birds, bats and general ecology

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Executive Summary

i. The UK energy landscape is partially orienting towards renewable electricity generation. Recently, this has begun to include solar PV (photovoltaic) technologies.

ii. Solar PV technologies exist at a distributed scale (e.g. roof mounted solar panels) and at utility scale (i.e. solar farms) in the UK.

iii. Utility scale solar PV developments are likely to have a greater ecological impact than distributed scale developments due to their larger size and the requirement for new infrastructure. As such, this review will focus on utility scale solar PV developments.

iv. Natural England has identified birds and bats as the taxa most urgently requiring an evidence base for potential impacts relating to solar PV developments. The focus of this review will be on these taxa, however general ecological impacts will also be considered.

v. Around 420 scientific documents with potential relevance to this review were identified using tailored search strings and subsequently screened for evidence relating to the ecological impacts of solar farms. The majority of these documents were of no relevance, and were returned by the literature search due to irresolvable linguistic and conceptual ambiguities. These documents were not considered further.

vi. Grey literature from 37 non-governmental and governmental organisations was examined for evidence of the potential ecological impacts of solar farms.

vii. Twelve rejected planning applications for solar PV developments with generating capacity of > 1 MW in the north west of England were examined to determine whether these rejections were made on an ecological basis.

viii. No peer reviewed experimental scientific evidence exists relating solely to the ecological impacts of solar PV developments.

ix. Some scientific and grey literature data, based upon carcass searches around solar PV developments suggests that bird collision risk from solar panels is very low. There is likely to be more of a collision risk to birds presented by infrastructure associated with solar PV developments, such as overhead power lines.

x. Evidence from both the grey literature and the peer-reviewed scientific literature suggests that protected areas should be avoided when considering site selection of solar PV developments, with some sources suggesting that locations close to

protected areas should be avoided also. This recommendation is not quantified in any of the reviewed literature.

xi. Indirect evidence of bird presence is often presented in the engineering literature, where designs for solar panel cleaning devices often cite bird droppings as a contaminant.

xii. Solar panels have the capacity to reflect polarised light, which can attract polarotactic insects, which has the potential to impact their reproductive biology. The polarising effect of solar panels may also induce drinking behaviour in some bird taxa, where the birds mistake the panels for water.

xiii. Birds and bats should be assessed by taxon or guild, with different behavioural traits and habitat requirements taken into consideration. The potential for solar developments to attract or repel birds or bats should be considered, alongside the potential for negative interactions to occur between these taxa and solar farms.

xiv. Future research should focus on examining the potential of solar PV developments to support biodiversity. The grey literature often refers to mitigation/enhancement practices such as wildflower meadow planting, hedgerow laying and tree planting with some grey literature studies attempting to quantify diversity on solar PV sites. These studies should be formalised and replicated within a scientific framework.

xv. Governmental and non-governmental organisations that provide advice and guidance that may have ecological implications have a duty to contribute to evidence towards their guidance, especially where evidence is lacking. In the case of solar farms, there is almost no evidence and research into their ecological impacts is urgently needed.

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1. Introduction

1.1. Background

As part of the effort to combat climate change, the UK has a commitment under European directive 2009/28/EC to increase the proportion of energy consumption provided by renewable sources to 15% by the year 2020 (EC, 2009). Considering that this figure stood at 1.3% in 2005- the third lowest amongst EU member states at that time (EC, 2009), the UK energy landscape has undertaken significant changes in recent years, resulting in 4.1% of the national energy consumption coming from renewable sources in 2012 (DECC, 2013a).

Multiple technologies are used to generate renewable energy in the UK including solar PV (Photovoltaic), onshore and offshore wind, hydro, wave/tidal and bioenergy (DECC, 2015). Wind power has been the dominant source of renewable energy in the UK since 2008[1] with different technologies having varying contributions to energy generation over time since 2003 (DECC, 2014a). Solar PV has undergone a rapid increase in popularity in the UK (and globally) in recent years due to reduced hardware costs, improved efficiency of hardware, and the introduction of FiTs (Feed in Tariffs) that allow operators of renewable energy developments to sell surplus electricity to the grid (Balta-Ozkan et al., 2015).

The potential ecological impacts of solar PV installations are poorly understood and there is a lack of coherent guidance in the UK for local planning authorities, statutory bodies, charities, non-governmental organisations, commercial enterprises and ecological consultancies to make informed decisions or provide advice on the potential ecological effects of new and existing solar PV developments.

This review aims to gather and synthesise evidence from the scientific and grey literature in order to provide a comprehensive and cohesive report on current thinking towards the potential ecological impacts of solar PV developments. Special emphasis will be given to the taxa Aves (birds) and Chiroptera (bats). Gaps in the literature will be identified and suggestions will be made for future research needs. In addition, planning applications and decisions for solar PV developments in the North West of England will be reviewed in an attempt to identify reasons for the refusal of planning permission by local authorities,

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1 Prior to 2008 there was no separation in the statistics for electricity generation between wind and wave using the data available within DECC (2014).

reflecting perceived negative impacts of solar PV and to determine whether any of these reasons are ecologically based.

1.2. Solar farms

Solar PV developments can be broadly categorised into one of two scales- distributed or utility scale (Hernandez, Easter, et al., 2014). Distributed scale solar PV systems are represented by relatively small developments that are integrated into the infrastructure of a building (e.g. on the rooftop) that are usually < 1 MW (megawatt) in capacity and may act autonomously from the grid. Utility scale developments are larger (> 1 MW), more centralised developments (analogous to a power station) generating electricity on a commercial scale (Hernandez, Easter, et al., 2014). This review will focus on utility scale developments as these are believed to potentially have greater ecological impact due to their large size, and because unlike their distributed counterparts, there is a requirement for new infrastructure and land, rather than relying largely on existing development for physical support and the distribution of electricity (Dale et al., 2011).

In terms of functionality and infrastructure, there are parallels between PV solar farms and onshore wind farms. For example, both require a large area of land in order to maximise the energy yield from their respective resources sun and wind, both generate large amounts of electricity and both require the infrastructure necessary to transport electricity to the place of consumption. As such, there are likely to be some similarities in the risks posed to birds and bats by solar farms and wind farms. There are four broad types of impacts wind farms can have on birds: mortality due to collision, disturbance displacement, barrier effects and habitat loss (Drewitt and Langston, 2006). However, wind turbines have the critical characteristics of large fast moving parts and structures extending attitudinally. These characteristics do not exist in solar farms, which would intuitively suggest that the potential collision risk for flying animals is lower for solar farms than it is for wind farms. The potential risk of disturbance displacement, barrier effects and habitat loss are on the other hand could occur in utility scale solar PV development, simply because of the land area they require and the necessary surface area required to harvest sunlight. These four impacts will form the backbone of this literature review.

1.3. Aims and Objectives

This review was commissioned by Natural England in order to provide a synthesis of the available evidence on the ecological implications of solar farms, with special emphasis to birds and bats. The objectives of the report are listed below.

1) To interrogate the scientific literature for evidence of any ecological impact (positive or negative) that solar farms may have on birds.
2) To interrogate the scientific literature for evidence of any ecological impact (positive or negative) that solar farms may have on bats.
3) To interrogate the scientific literature for evidence of any ecological impact (positive or negative) solar farms may have outside of objective 1 and objective 2.
4) To summarise any guidance, opinion or involvement that Governmental Organisations or NGOs may have with regards the ecological impact of solar farms.
5) To investigate ecological information presented by solar panel and solar farm manufacturers and supplier and summarise this information.
6) To investigate planning decisions made with regards to solar farms in the north west of England, and determine whether any projects were declined planning permission on an ecological basis.
7) To investigate any other grey literature available on the ecological impacts of solar farms and summarise ecological arguments or evidence presented by this literature.

2. Methods

2.1. Scientific literature search

Scopus is a database operated by Elsevier and contains citation and abstract information for peer reviewed literature including scientific journals, books and conference proceedings. Three distinct search strings were constructed to extract literature from Scopus relating to solar farms and birds, bats and ecology. Combinations of the phrases ‘solar farm’, ‘solar panels’ and ‘photovoltaic’ were used alongside ‘birds’, ‘bats’ and ‘ecology*’ (asterisk indicates a wildcard, and represents all phrases prefixed with the characters prior to the asterisk). For the full search strings, see Appendix 1 for birds, Appendix 2 for bats and Appendix 3 for general ecology. These search strings were applied to the Scopus search engine on 8th November 2015, and the results were extracted as a bibliography for input into Mendeley reference management software. In addition to these search strings, searches were conducted where the terms ‘birds’ and ‘bats’ were replaced with ‘aves’ and ‘chiropter*’ respectively, however no further relevant results were yielded.

To determine relevant literature, the abstract of each result for birds and bats was examined and if deemed relevant, was followed by an examination of the full text (where available). Due to the large number of results for general ecology, only the titles of the search results were vetted for relevance, with subsequent referral to the abstract or full text where relevance seemed likely.

Although the academic search engine Google Scholar is not as powerful as Scopus in the implementation of refined and structured literature searches, it has a tendency to return results that are not included in Scopus. This could be because some of the search results are not necessarily peer reviewed, but still present scientific findings that may be relevant, especially when peer reviewed literature on a subject is scarce. Google Scholar was utilized by adopting a variety of search strings to obtain scientific literature that may not be included in the Scopus database.

Some additional relevant literature was indirectly obtained (i.e. through reference by literature included in the search results).

2.2. Grey literature search

The acquisition of grey literature for use in comprehensive scientific literature reviews can be problematic due to inherent inconsistencies in definition (Gelfand and Lin, 2013) and exclusion from most scientific literature databases (Banks, 2006). Nevertheless, the importance of grey literature has been recognised for both building ecological and conservation evidence (Haddaway and Bayliss, 2015) and for evidence based guidance on public policy and practice (Lawrence et al., 2015).

For the purposes of this review, the scope of the term ‘grey literature’ will pertain to any document that is outside of the traditional scientific body of literature as defined by the results of a comprehensive literature search in the Scopus search engine and/or is not a peer reviewed document, but holds information that could potentially provide evidence relating to the ecological impact of solar farms. As such, any peer reviewed literature found in addition to the Scopus search results will be included in the scientific literature review and not in the grey literature review.

Google Scholar returns a mixture of grey literature and scientific literature (Haddaway and Bayliss, 2015) making it a powerful tool for finding and acquiring documents that would not be included in Scopus. However this lack of specificity along with inefficiencies in search terms makes Google Scholar unsuitable as a sole resource for the extraction of scientific literature (Giustini and Boulos, 2013). Google Scholar was utilised informally, using a multitude of search terms with the subsequent extraction of potentially useful documents, some of which were added to the body of scientific literature as previously described, and some of which fell under the category of grey literature. A full list of relevant citations obtained through Google Scholar can be found in appendix 4.

A list of ecological and conservation NGOs in the UK was extracted from the CIEEM (Chartered Institute of Ecology and Environmental Management) website[2] in order to determine which may hold relevant information on potential effects of solar panels. The names of other specialist bodies relating to ecology and conservation was also extracted from Haddaway et al. (2014)- a systematic literature review on UK peatland management. Potentially relevant organisations were compiled from both lists along with any other organisations thought to be relevant to form a resource for potential repositories of grey literature to be used in this review. Google searches and visits to each organisations website were undertaken to determine whether the organisation has a stance on the ecological effects of solar panels and to come to a conclusion as to what the organisation's position on this topic might be. In addition to NGOs, Governmental bodies in the UK were investigated in this way. A complete list of these organisations is shown in Table 1.

Planning applications for solar farms and the subsequent planning decisions were examined for the north west of England in order to gather more grey literature and to determine whether any planning rejections were made on an ecological basis. These planning applications were found using the DECC (Department for Energy and Climate Change)

2 http://www.cieem.net/non-governmental-organisations-ngo- [last accessed 14/04/2016]

renewable energy planning database monthly extract for July 2015[3]. Planning reference numbers relating to projects with rejected planning permission for solar PV developments in the North West of England were cross referenced to the UK planning portal[4] (a repository for links to all local authorities holding planning applications in the UK and associated documents) and documents relating to ecology or planning decisions were subsequently extracted.

Table 1. Non-governmental and governmental agencies investigated for evidence or guidance on the ecological impact of solar farms.

Organisation name	
BCT (Bat Conservation Trust)	IUCN (International Union For Conservation Of Nature)
BASC (British Association for Shooting and Conservation)	JNCC (Joint Nature Conservation Committee)
BES (British Ecological Society)	Macaulay Land Use Research Institute
Birdlife International	National Trust
BSBI (Botanical Society of the British Isles)	NE (Natural England)
BTO (British Trust for Ornithology)	NFU (National Farmers Union of England and Wales)
CCCR (Centre For Climate Change Research)	NIEA (Northern Ireland Environment Agency)
CCW (Countryside Council Wales)	NRW (Natural Resources Wales)
CEH (Centre for Ecology and Hydrology)	Plantlife International
CIEEM (Chartered Institute for Ecology and Environmental Management)	Plantlife UK

3 https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract [last accessed 15/04/2016]. This database is updated regularly, with no access to previous versions. As such, the link does not refer to the July 2015 extract.

4 https://1app.planningportal.co.uk/YourLpa/FindYourLpa [last accessed 15/04/2016]

Organisation name	
DECC (Department Of Energy And Climate Change)	Ramsar
EPA (Environmental Protection Agency)	RSPB (Royal Society for the Protection of Birds)
EPAI (Environment Protection Agency Ireland)	SEPA (Scottish Environment Protection Agency)
European Commission Joint Research Centre	SNH (Scottish Natural Heritage)
European Environment Agency	SRUC (Scotland’s Rural College)
Friends of the Earth	UNEP (United Nations Environment Programme)
FWAG (Farming and Wildlife Advisory Group)	Wildlife Trusts
Greenpeace	WWT (Wildfowl and Wetlands Trust)
IPCC (Intergovernmental Panel on Climate Change)	

3. Results

3.1. The Scientific Literature

A total of 417 items of literature were recognised through Scopus, with 58 relating to birds, 20 relating to bats and 339 relating to general ecology. Many of the results were not relevant to this review and were included in the search results due to linguistic or conceptual ambiguities. Examples of linguistic ambiguities include the abbreviation of 'battery' to 'bat' (e.g. Kaldellis et al., 2010; Ray et al., 2013; Sadeghi and Ameri, 2014), the use of acronyms such as BIRD (bispectral infrared detection) (Stoll et al., 2009) and the use of names such as Lady Bird Johnson Middle School (Kure, 2010). Conceptual ambiguities include the use of solar powered bird tracking devices (e.g. Bouten et al., 2013; Hansen et al., 2014; Thaxter et al., 2014); the use of nature inspired algorithms by technical disciplines involved in solar panel research such as 'Bird-Mating algorithm' (Gao et al., 2014) and 'bat clustering method' (Munshi and Mohamed, 2014); the inspiration from nature or analogy to nature of technical achievements such as a solar powered flapping wing aeroplane (Colozza, 2007), a Mars rover with 'the feet of a bird' (Ramesh et al., 2009) and the description of a technical data pattern as 'bird beak' (Kattakayam et al., 1996). Citations and notes on the relevance of each search result can be found in appendix 1 for birds and appendix 2 for bats. Due to the large amount of literature returned for general ecology, notes of relevance are not included in this review, however the citations for these documents can be found in appendix 3.

The use of Google Scholar yielded 39 additional pieces of literature. Some of these were ecologically oriented, whereas some were oriented towards solar panel usage and policy in the UK. The results from Google Scholar can be found in appendix 4.

3.1.1. Potential effects of solar panels on birds

To date there are no experimental studies in the peer reviewed scientific literature that attempt to quantify the impact of PV solar farms on birds purely from an ecological perspective. DeVault et al. (2014) conducted a study that examined habitat use by birds at PV solar installations versus adjacent habitats in order to assess whether PV installations at airports increase the risk of aircraft bird strike. The attraction of birds to solar PV installations was recognised as a concern by a focus group held to determine the potential hazards of large scale PV development at airports (Wybo, 2013). The main attractant for birds recognised by Wybo (2013) was the potential for solar arrays to be used as nesting grounds; however, this claim was not supported with evidence. DeVault et al (2014) examined whether birds were more likely to use habitat at PV installations than nearby airfield grassland. This study was oriented towards the risk of bird airstrike presented by solar PV installations, so it is difficult to draw ecological conclusions from the results as a BHI (Bird Hazard Index) was the primary variable measured, rather than more robust ecological measurements. Nevertheless, DeVault et al (2014) found that higher bird densities were recorded at the PV sites than at the grassland sites, with similar species richness represented at both. The vegetation at each site is described showing considerable qualitative variation between the airfield sites and the PV sites. Generally, the grassland airfield sites had taller vegetation than the PV sites. The former were mowed at least once per year, with no management regime referred to for the latter. DeVault et al (2014) stated that PV arrays generally appear to be negative for wildlife at the local scale because airfield grasslands are managed to be unattractive to birds, and the small differences between these sites and the PV sites suggest that PV arrays are also unattractive. The study also states that birds were rarely observed foraging on or near PV arrays. Since no details on habitat management are provided for the PV sites, it is difficult to draw conclusions from this study regarding the general capacity of PV arrays to support avian biodiversity. In terms of collision risk, DeVault et al (2014) observed no obvious evidence for bird casualty caused by solar panels, despite conducting 515 bird surveys at solar PV sites.

Walston et al. (2016) compiled data on avian mortalities at USSE (Utility Scale Solar Energy) facilities in South West California, including both Concentrated Solar Power (CSP) and PV developments. The authors found that mortality rate (proportional to the generating capacity of the facility) associated directly with solar facilities was between 7 and 21 times higher at CSP sites than at PV sites, however it is worth noting that only three sites were assessed. As CSP and PV are pooled in the results of this study, it is difficult to extrapolate the likely mortality associated solely with solar PV developments, but this study shows that traumatic mortality can occur as a direct result of solar PV facilities, albeit at a much lower incidence than at CSP facilities.

Pearce-Higgins and Green (2014) studied the impacts of climate change on birds, including conservation responses (to climate change). They refer to the potential of CSP to have a detrimental effect on birds, whereas any negative impact of solar PV on birds is likely to be relatively low. The latter is presented with the caveat that there is little evidence available, and that further research is urgently required. A study into the effect of CSP on birds at a facility in the Mojave desert, California presented in a non-peer reviewed study by McCrary et al. (1984), found that there is the potential for bird mortality through collision and incineration at CSP facilities. The risks from CSP and PV solar are not comparable as the mechanism of exploiting solar energy is fundamentally different. As CSP is not currently implemented in the UK, it will not be considered further in this review. Further reference is made in Pearce-Higgins and Green (2014) suggesting that solar is potentially the least ecologically detrimental renewable energy source, however there is the possibility of bird mortality through collision with associated overhead powerlines.

There is some evidence in the scientific literature that it is perceived as inappropriate to build solar developments in areas protected for their bird assemblage. For example, Sánchez-Lozano et al. (2014) exclude SPAs from a GIS (Geographic Information System) suitability model designed to inform on solar development placement in Spain. Although this approach is not substantiated with evidence, it reflects an approach advocated by some practitioners, policy makers and advisors outside of the academic scientific community in the UK. This will be discussed further in the grey literature results section of this review.

There are several general statements made regarding the potential effect of solar panels on birds in the scientific literature that are not supported with evidence. Terzioglu et al. (2015) suggest that solar developments are comparably less ecologically damaging and more environmentally friendly than electricity generation from wind. Ghazi and Ip (2014) refers to birds being attracted to the warmth of solar panels in summer months for which a citation is provided, however the original paper could not be found for this review. Toral and Figuerola (2010) state that the installation of solar farms on land used for rice cultivation would be detrimental to some water bird species. This claim is based on the study’s findings that land used to cultivate rice in south west Spain is used as habitat by some migratory water bird species, rather than any specific impact of solar farms. It is also suggested that the construction of solar farms will result in the loss of wetlands in southern Europe; however, no citation providing evidence of a negative impact of solar farms is presented.

The engineering literature frequently refers to bird droppings as a contaminant on solar panels, often with a proposal for a mechanism to remove guano (Ramaprabha, 2009; Al-Dhaheri et al., 2010; Dorobantu et al., 2011; Lamont and El Chaar, 2011; Vasiljev et al., 2013; Xie et al., 2013; Ghazi and Ip, 2014; Maghami et al., 2014; Mondal and Bansal, 2015a, 2015b), or makes reference to bird shadow as an obstacle to optimisation of energy generation potential (Ramaprabha, 2009; Liu and Liu, 2011; Pareek and Dahiya, 2014;

Uprety and Lee, 2014; Liu et al., 2015). Interestingly, Pareek and Dahiya (2014) exclude bird shadow from a predictive model for the shading of solar panels because it is ‘difficult to predict’. This could be interpreted as suggesting that bird use of solar farms is not temporally consistent, not geographically consistent or not consistent between PV developments. If the latter is true, then there must be a driver of bird use at solar farms other than the solar arrays themselves. The recognition of a potential conflict between solar electricity generation and birds is historical, Maag Jr. (1977) makes reference to “unwelcome migratory birds” as an environmental variable that may affect PV performance- perhaps reflecting a shift in attitude towards the conservation of biodiversity too.

Brinkworth and Sandberg (2006) discuss devices designed to prevent birds, insects and rain from entering cooling ducts associated with PV arrays. As this is oriented around the operation of the cooling ducts, rather than for the protection of birds, no ecological inference can be made other than, birds are expected to occupy habitat near cooling duct entrances at solar PV developments. Although providing little ecological information, these engineering articles provide indirect evidence for the presence of birds at solar farms, birds using airspace above the panels, and possibly birds using the arrays to perch. The hypothesis that birds may perch on PV arrays is also presented by DeVault et al. (2014) alongside the suggestion that there is potential for birds to use shade provided by the arrays at solar developments. Lamont and El Chaar (2011) refer to birds using solar arrays (predominantly on offshore rigs) as nesting sites. Photographs of bird nests atop solar arrays and bird droppings on solar panels are provided as evidence to support this but as this paper is primarily concerned with deterring birds from breeding near these structures, little ecological inference can be made.

Photovoltaic panels have been shown to reflect polarised light that is attractive to polarotactic aquatic insects, which confuse solar panels with water and attempt to lay eggs on the surface, resulting in mortality and reproductive failure (Horváth et al., 2010; Blahó et al., 2012). Insectivorous predators including birds such as White Wagtail (*Motacilla alba*), Yellow Wagtail (*Motacilla flava*), Magpie (*Pica pica*), House Sparrow (*Passer domesticus*) and Great Tit (*Parus major*) have been recorded feeding on polarotactic insects attracted to sources of polarised light such as vertical glass windows, horizontal black plastic sheets and dry asphalt roads (Kriska et al., 1998; Bernáth et al., 2008; Horváth et al., 2009). Bernáth et al. (2001) describe birds such as Black Kite (*Milvus migrans*), Great White Egret (*Ardea alba*) and Swallow (*Hirundo rustica*) attempting to drink from plastic sheets, hypothesising that this behaviour may be due to an attraction to surfaces reflecting polarised light. The study also describes the mortality of birds at a waste oil lake in Hungary, again attributing this to the direct attraction to polarised light or to insects attracted to polarised light. As solar PV panels are solid, if this hypothesis is correct, there is unlikely to be a significant hazards to perched birds attempting to drink, however Swallows and related birds could be presented with a collision risk as hirundines are known to drink ‘on the wing’ (Bryant et al., 1984).

In summary, little scientific evidence exists that demonstrates a direct impact of solar PV on birds. It is likely that different avian species are likely to be affected differently by solar developments, dependant on the habitat within and around a solar PV development, the spatial requirements of a given species (e.g. flocking species such as pink-footed goose *Anser brachyrhynchus* that require large areas to host the flock) and the foraging behaviour of a given species. Until further scientific evidence is accrued to support any positive or negative impacts of solar farms on birds, we recommend that developments should be considered on a site by site basis with consideration given to 1) the habitat available prior to the development, 2) the habitat that will co-occur with the development and 3) the potential for attraction to polarotactic insect species (i.e. is the development close to a water body).

3.1.2. Potential effects of solar panels on bats

Based on this review, there is currently no experimental observational or theoretical scientific literature on the effect solar panels may have on bats. This is in contrast to wind power where a number of papers have been published (e.g. Arnett et al., 2008; Baerwald et al., 2008; Horn et al., 2008; Hayes, 2013; Rydell et al., 2016). Cryan and Barclay (2009) show that the causes of bat fatality at wind turbine sites can be separated into two categories, proximate and ultimate. Proximate causes represent direct fatalities such as barotrauma and collision with rotating blades or turbine masts. Ultimate causes encompass the reasons why bats may be near turbines, which may lead to a proximate fatality. As most of the threats and consequences associated with wind turbines for bats such as barotrauma (Arnett et al., 2016) and collision with blades (Alvarez and Lidicker Jr, 2015) are not presented by solar panels, it is difficult to draw comparisons. However, the concept of proximate and ultimate causes of fatality is a useful tool, as it allows hypothetical questions to be asked about the interaction between solar panels and bats in a way that is similar to the approach taken within the framework of wind turbines presented by Cryan and Barclay (2009). ‘Ultimate’ would be the hypothetical reasons that have the potential to lead to bats being near solar panels, and ‘proximate’ would be the consequences of bats being near solar panels.

A third category of remote causes has been included in this review. These are similar to the aforementioned ultimate causes; however, the emphasis is on factors that may repulse bats from a solar farm site in contrast to attraction. Once hypotheses are drawn from these three causal mechanisms, a framework for the design of experimental testing can be established (Table 2). It is worth noting that the information in Table 2 represents generalised risks, however research into the risk of solar panels to individual bat species is needed.

Table 2. Hypothetical modes of collision mortality for bats at PV solar farms, modified from the approach presented by Cryan and Barclay (2009) for wind turbines and bat collision mortality. Proximate causes represent the potential direct mechanism of death, remote causes represent direct reasons mechanism by which bats are excluded from solar farms and ultimate causes represent the mechanisms by which bats occupy the airspace of solar farms or are repulsed from solar farms resulting in a proximate or remote death. Generalised experimental approaches for proving hypotheses are presented. These risks, hypotheses and experimental approaches are not species specific.

Mode of action	**Hypothesis**	**Experimental approach**
Proximate causes	Bats fatally collide with solar panels	Find evidence of traumatic bat fatality close to solar panels.
	Bats fatally collide with solar farm infrastructure	Find evidence of traumatic bat fatality close to solar farm infrastructure.
Remote causes	Bats cannot use the habitat within solar farms and there is no alternative suitable habitat near the solar farm.	Determine whether bats used the site prior to conversion to a solar farm. Determine habitats within bat relocation distance of solar farms.
	Solar farms provide a barrier to movement to bats.	Determine whether bats prefer to commute around solar farms over commuting through solar farms. Determine the energy requirement of bats; calculate energy expenditure of bats commuting around a solar farm as opposed to commuting directly through.
Ultimate causes: Random	Bat fatalities at solar farms are proportional to the population and demography	Determine whether the number of fatalities is proportional to the population of active bats engaging in a particular

Mode of action	Hypothesis	Experimental approach
	of the bats present.	behaviour at all times of year outside of torpor, regardless of environmental conditions. Determine whether age, sex, and morphological/ pathological (excluding traumatic injury) measurements of fatally injured bats at solar farms differ from live bats at solar farms.
Ultimate causes: Coincidental	Susceptibility increased during migration due to aggregation in space and time.	Determine whether a given bat species is gregarious during migratory period. Determine whether aggregation of bats occur at solar farms during migratory periods.
	Susceptibility increased during migration because migratory bats are less likely to echolocate.	Determine whether migratory bats produce less frequent echolocation calls than non-migratory bats. Determine whether migratory bats fly at altitudes corresponding to the altitude of solar panels.
	Susceptibility is lower for migratory bats than for non-migratory bats because migratory bats fly higher.	Determine whether migratory bats fly at higher altitudes than non-migratory bats. Determine whether solar panels are raised to elevations within the altitudinal range of migratory bat flight.
	Susceptibility increases with increased feeding activity.	Determine whether there are more recorded collision mortalities at solar farms during periods of higher feeding activity.
	Susceptibility increased during breeding season due	Determine whether there are more recorded collision mortalities during

Mode of action	Hypothesis	Experimental approach
	to higher mating activity.	periods of breeding activity.
	Susceptibility increased immediately after breeding season due to inexperience of flying by juveniles.	Determine whether there is a disproportionate ratio of juvenile collision fatalities to total number of juveniles compared to adults.
Ultimate causes: Attraction	Bats are generally attracted to solar panels or farms	Determine whether bats flight movement near solar panels is biased towards the solar panels. Determine whether abundances of bats at solar farms are greater than the number of bats at control sites. Determine whether abundances of bats at solar farms are greater than the number of bats present prior to the solar farm.
	Bats are attracted to noise at solar farms.	Noise from solar farm needs to be quantified. Do playback experiments of recorded solar farm noise attract bats? If noise from solar farms can be adjusted, determine the effect of adjustment on bats.
	Bats are attracted to lights associated with solar farms.	Comparison of bat activity with lights off at solar farms versus lights on.
	Flying insects are attracted to solar farms, resulting in bat attraction to insects at solar farms.	Determine flying insect abundance at solar farms versus control sites. Quantify bat feeding buzzes as a function of distance from solar panels.
	Bats are attracted to modified landscape features	Categorise and quantify modified features at solar farms. Use knowledge of bat ecology and behaviour to determine

Mode of action	Hypothesis	Experimental approach
	associated with solar farms	whether it is likely that these features are attractive. Determine whether bat activity is spatially correlated with modified landscape features. Determine whether spatial patterns of bat collision mortality are correlated with the location of modified landscape features.
	Bats are attracted to solar panels as potential roosts.	Assess whether solar panels and associated infrastructure offer roosting potential. If there is roosting potential, undertake emergence/ re-entry surveys to determine whether bats are roosting at solar farms.
	Bats are attracted to solar panels as mating or gathering sites	Determine whether territorial or mating behaviour is correlated with solar panel locations. Determine whether social behaviour is correlated with solar panel locations.
	Bats are displaced by solar farms.	Determine whether bat abundances at solar farms are lower than at control sites. Determine whether bat abundances at solar farms are lower than those at the same site prior to the solar farm.
Ultimate causes: Repulsion	Solar farm create a barrier to movement	Compare bat movement through solar farms to bat movement around solar farms.

The lack of scientific literature on the effect of solar PV arrays or panels on bats makes it difficult to draw conclusions. Naïve juvenile bats have been shown to demonstrate drinking behaviour over smooth plates (Greif and Siemers, 2010), however this study makes no reference to solar panels and does not quantify collision risk or any potential ecological impact presented by this behaviour. Greif and Siemers (2010) state that the results of their experiment demonstrate that bats use echolocation to detect and recognise water bodies and smooth surfaces. If this is the case, and bats do indeed mistake solar panels for waterbodies, there may be a collision risk presented to bats through attempts to drink from solar PV panels. However, the fact that bats use echolocation to recognise smooth surfaces, with no collisions reported in Grief and Siemers (2010) suggests that some bat species may be adept at avoiding collision with flat surfaces. The study species used in Grief and Siemers (2010) were Schreiber's bat (*Miniopterus schreibersii*), Daubenton’s bat (*Myotis daubentonii*), Greater Mouse-eared bat (*Myotis myotis*) and Greater Horseshoe bat (*Rhinolophus ferrumequinum*).

Horváth et al. (2009) present an image of a bat trapped in a waste oil lake in Budapest and suggest that this may be because the bat was killed by predating on polarotactic insects attracted to the surface of the oil. Polarotactic insects are indeed known to be attracted to solar panels (Horváth et al., 2010; Blahó et al., 2012), which in turn would suggest that insectivorous bats have the potential to be attracted to solar PV arrays. Further research is needed to determine whether this presents a collision risk. Excluding collision risk, the attraction of bat to solar farms as foraging ground may have a positive impact providing suitable roosting and breeding habitat is within the vicinity of the solar farm, however, further research is needed to determine this. In addition, insectivorous bats have the potential to disrupt the population cycles of agricultural pest insect species providing an ecosystem service (Boyles et al., 2011) and a potential benefit if insectivorous bats are attracted to solar farms.

In order to determine the impacts of solar PV developments on bats, experimental or observational research is urgently required and should be conducted on a species or guild basis in the UK due to behavioural differences and variation in ecological requirements. The hypotheses and experimental approaches presented in table 2 provide a rudimentary foundation for further research.

3.1.3. Potential effects of solar panels on general ecology

Several publications take into account the ecological and environmental impacts of the manufacturing, deployment and disposal/recycling of PV solar panels, often with a LCA (Life Cycle Assessment) approach (e.g. (Coleman et al., 1980; Moskowitz et al., 1994; Doi et al., 2003; Góralczyk, 2003; Fernández-Infantes et al., 2006; Müller et al., 2006; Kim et al., 2012; Kreiger et al., 2013)). As this review is concerned with the ecological impact of in-situ large scale PV developments, any ex-situ risks or impacts of PV developments will not be considered.

Although the potential environmental benefits of solar PV developments are recognised in terms of reduced GHG (greenhouse gas) emissions and a reduction in the reliance on fossil fuels for electricity generation (Tyagi et al., 2013), there is little reference in the scientific literature to ecological benefits at a local or landscape level. Akikur et al. (2013) state that the deployment of solar PV has “thus far been ecologically friendly”; however, this is not support with evidence or reference. This article also states that solar PV facilities emit no sound pollution during operation- a quality that reduces the potential for local ecological impact- however the reference provided does not make reference to sound pollution (Joshi et al., 2009), rendering this an unsubstantiated claim.

In terms of the potential for negative ecological impacts of solar-PV developments, no peer-reviewed experimental publications were found during the literature search that provide evidence of negative impact, and very few discuss implications (Fthenakis et al., 2011; Lovich and Ennen, 2011). Several articles discuss the potential environmental impact of large-scale solar PV developments, incorporating the possible effects on biodiversity and ecology (Lovich and Ennen, 2011; Turney and Fthenakis, 2011; Hernandez, Easter, et al., 2014; Hernandez, Hoffacker, et al., 2014; van der Winden et al., 2014; Hernandez et al., 2015). Unfortunately, the discussions within the literature often to refer to CSP and PV systems alongside one another, making it difficult to disentangle potential ecological impacts relating solely to solar PV developments. Hernandez et al. (2014) suggest that land-use efficiency can be maximised for large scale solar developments by building arrays on brownfield sites to create ‘brightfield sites’ or on bodies of water (‘floatovoltaics’) or by maintaining agricultural practices at solar developments. Although these suggestions are not necessarily made from an ecological perspective, rather from the perspective of economic streamlining, the suggestion that arrays can co-exist with secondary practices leads to the possibility of opportunities for biodiversity enhancement and ecological benefits.

Hernandez et al. (2015) attempted to quantify land-use change and land cover characteristics of existing utility scale solar developments in California, United States. The article concludes that poor siting of large scale solar developments can result in ecologically adverse land-use change, including outside of protected areas where the removal or conversion of habitat providing contiguity and corridors between protected areas may lead to habitat fragmentation. This is agreed upon in Hernandez, Easter, et al., (2014), who refer to the potential for changes in soil dynamics leading to invasive species propagation and water stress caused by the necessity to clean solar PV systems. The potential land change impacts of solar farms on biodiversity is discussed in Fthenakis et al (2011), who state that the land may be scraped to bare earth during a facility's construction, requiring a long time period to return to habitat of ecological value. This article also refers to shadows cast by solar PV panels that have the potential to alter microclimatic conditions within a solar development. Dale et al. (2011) highlight that further research is needed to determine the ecological impacts of renewable energy developments (including solar developments) at spatially appropriate scales (i.e. landscape and local).

The potential impact of large-scale solar PV developments on aquatic ecosystems is explored in Grippo et al., (2014). This paper highlights that an understanding of the hydrological effects that the construction of a utility scale solar development will have is vital for maintaining the health of surrounding aquatic environments. Alterations in water flow may have the potential to change nutrient flows and the leaching of contaminants such as dust suppressants used on solar panels may have adverse effects on aquatic ecosystems and soil stability.

Ecologically considerate placement of solar farms is likely to be critical to the reduction of any ecological impact a solar development might have. Several studies have attempted to determine optimal siting for solar developments (Haurant et al., 2011; De Marco et al., 2014; Calvert and Mabee, 2015) which often incorporate an ecological element, however also take into account other factors such as economic impact and visual impact, highlighting a complex decision process in the siting of solar developments. De Marco et al. (2014) frame the potential for conflict between solar PV developments and biodiversity around the provision of ecosystem services. De Marco et al. (2014) conclude that ecologically sympathetic siting of solar PV developments is critical not only for minimising the impact on habitat connectivity and on protected areas, but also on the connectivity of ecosystem service providing units. More research is needed to empirically and quantitatively understand the effects that solar PV developments may have on biodiversity. Lovich and Ennen (2011) call for more research using a BACI (Before and After, Control and Impact) approach and for work to be undertaken to better understand the potential cumulative impact of solar facilities on biodiversity.

3.1.4. The Grey Literature

Non-Governmental and Governmental Organisations with relevance to the UK – the impact on birds and bats

The organisations listed in Table 1 were investigated for information and advice pertaining to solar PV developments and their ecological effects. Some organisations such as Birdlife International and DECC provide relatively detailed information, whereas others provide no readily available information. The findings of these investigations are presented below for birds, bats, and general ecology. Organisations that do not provide relevant information are not included in the body of this review, however a table summarising the information presented by each organisation can be found in Appendix 5.

Birdlife International produced a document containing information on the potential ecological impacts of solar development, with special emphasis on birds (Birdlife International, n.d.). This document relates to a specific project ('Migratory Soaring Bird Project') in the Rift Valley/ Red Sea Flywall region of Egypt[5]. Some of the information relates to technologies not in use in the UK (e.g. CSP), however there is reference to ecology and large-scale solar farms. The document states that governments should incorporate solar energy as a part of their renewable energy plans, but emphasises that the potential ecological impacts of large scale solar developments are poorly understood. Birdlife International suggests five potential negative impacts that solar PV arrays may have on birds. These are habitat loss/fragmentation, collision risk, disturbance, barrier effect, and change of habitat function. It is advised that an SEA (Strategic Environmental Assessment) should be undertaken alongside sensitivity mapping at the pre-planning stage in order to avoid development on areas that are particularly ecologically sensitive or are protected for their ecological significance.

More general, project non-specific information on the ecological impacts of solar PV have been published by Birdlife including a document outlining the organisation's position on climate change, which includes the potential impacts of solar technologies (Birdlife International, 2015). This document states that PV developments that do not rely on existing

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5 http://migratorysoaringbirds.undp.birdlife.org/en/sectors/energy/solar-energy-toc [last accessed 15/04/2016]

built infrastructure have the potential to negatively impact birds through habitat loss, fragmentation of habitat and disturbance or displacement of species during construction, operation, and maintenance activity. In summary, Birdlife recognises the importance of solar PV in a renewable energy landscape and supports the use of the technology, providing that developments are on existing built infrastructure or in areas of low biodiversity value. The organisation advises appropriate design and management including in-situ biodiversity enhancing practices and recommends seeking advice from ornithologists when undertaking EIA in relation to solar developments. Birdlife (2015) repeatedly states that there is a need for further research into the potential impacts of solar developments on birds.

Birdlife Europe (2011) is a document that provides detailed information on the potential ecological effects of various forms of renewable energy technologies, with emphasis on Europe. Within this document, solar PV requiring new infrastructure is classified as a ‘medium risk’ technology, as determined through “ecological reasoning and conservation experience.” Scientific evidence is presented for other renewable technologies, however not for solar PV, reflecting a lack of scientific literature available. The document highlights the potential for solar PV developments to result in habitat modification and fragmentation with potential significant negative impacts on biodiversity in areas of high ecological value. Birdlife Europe (2011) states that solar PV arrays on farmland may present particularly high risks for open habitat bird species such as Lapwing (*Vanellus vanellus)* and Skylark (*Alauda arvensis*) with the potential for disturbance resulting in reduced opportunities for foraging, breeding, and roosting. The potential for cumulative impacts of multiple solar PV developments in a concentrated locality is highlighted, which could negatively affect bird species at the population level. Mitigation options are provided, however it is emphasised that these should be tailored on a case by case basis for solar PV developments. These include avoiding areas legally protected for their wildlife, undertaking the construction and maintenance of solar PV developments in a time-sensitive manner (e.g. avoiding the breeding bird season), and planting hedgerows between sections to minimise collision risk to waterfowl (Birdlife is openly aware however that there is no scientific evidence of collision risk presented by solar PV arrays). Birdlife Europe (2011) advocates the use of land within the vicinity of solar PV arrays for biodiversity enhancement including the conversion of improved and intensely farmed grassland to wildflower meadow, the use of hedgerows for screening, enhancing associated infrastructure for wildlife (e.g. incorporating bird boxes) and the use of grazing in preference to mowing for managing grassland. Birdlife Europe (2011) is echoed by CIEEM, where it is used to provide a summary and synthesis on the ecological impacts of renewables, including solar developments (Scrase and Gove, 2012).

The RSPB contributed to Birdlife Europe (2011), however they have produced their own policy briefing that outlines the society's position on solar PV developments (RSPB, 2014). This document states that the RSPB advocate solar technologies, however recommends avoiding deployment in locations close to protected areas, or close to water features (highlighting a potential negative impact upon aquatic invertebrates as a risk, both independently and as a food resource for birds). In contrast to this advice, RSPB are also supportive of floating solar arrays with the caveat that the ecological quality of the water body must not be negatively affected. Within this document, it is highlighted that there is always a risk of bird collision with man-made objects and there is a lack of evidence pertaining specifically to solar farms. RSPB (2014) also refers to security fencing as a potential barrier to movement for mammals and amphibians. It is stated that loss of habitat through the development of solar PV arrays may be an issue for rare arable forbs, however the RSPB states that the capacity for vegetation to grow under raised solar panels could provide opportunities for biodiversity enhancement including roosting potential, hibernation refuges, mutualistic use of land for agri-environment schemes and managed realignment of land behind sea walls. The RSPB calls for the monitoring of solar PV developments to determine ecological risk. The RSPB is currently working alongside a solar energy developer (ANESCO) to determine how solar developments can benefit biodiversity; however, there are no results from this partnership readily available.[6]

A brochure for the BTO's farmland bird appeal highlights the need for research into strategies for minimising negative impacts and maximising positive impacts of solar farms on birds (BTO, n.d.). This document suggests that bird surveys should be undertaken (taxa non-specific) at solar farms to determine how birds might be affected. The brochure is not dated; however, a current live link is available through the BTO website[7].

SNH published a document providing information on the potential environmental effects of small scale renewables (i.e. developments of <50kW), which in the case of solar PV appears to refer to roof mounted units. It is advised by SNH that these solar developments may cause problems if they obstruct a known bat roost, or bird's nest (SNH, 2016b). SNH produced a document on small scale renewables and their potential effect on the environment. This refers to developments of <50kW, and in the case of solar PV appears to

6 http://anesco.co.uk/anesco-and-rspb-shine-light-on-solar-farm-biodiversity-2/ [last accessed 21/04/2016]

7 http://www.bto.org/support-us/appeals/farmland-bird-appeal [last accessed 15/04/2016]

refer to roof mounted units. It is advised that these solar developments may cause problems if they obstruct a known bat roost, or bird's nest (SNH, 2016b). SNH (2016a) goes on to say that SNH recommend that protected species surveys should be conducted prior to works starting (otter is given as an example species). This document states that there may be a collision risk for ground nesting birds under solar arrays, that solar panels may deter birds from feeding and that displacement and collision risks may be presented by infrastructure however, these risks are not referenced.

The BCT provides no readily available information on the ecological impacts of utility scale solar PV developments. However, the BCT is attempting to collect data on incidents involving bat and solar PV installations with reference to the construction industry. This insinuates an interest in distribution scale solar developments, but not necessarily utility scale developments.[8] A short statement on the BCT website emphasises that although BCT welcome microgeneration renewable technologies, the installation of rooftop solar panel may disturb bats.[9]

In a document published by Natural England (Natural England, 2011), a scientific paper relating to the potential impact of solar panels on bats is referenced that did not appear in the literature search (Greif and Siemers, 2010). This citation is misleading as the scientific paper in question demonstrates that naïve juvenile bats spontaneously demonstrate drinking behaviour in response to smooth plates- not solar panels. No mention of solar panels is made in Greif and Siemers (2010).

The potential for birds to collide with powerlines, the potential loss of bat habitat, and the attraction of bats to light on site are identified in DOE (2015). Mitigation advice given is general and includes avoiding the loss of bat habitat, using sensor activated security lights, and avoiding placement of powerlines that obstruct bird movement. A document produced by BRE providing biodiversity guidance for solar developments is cited (BRE, 2014b).

Non-Governmental and Governmental Organisations with relevance to the UK: the impact of solar farms on general ecology

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8 http://www.bats.org.uk/news.php/283/we_need_your_help [last accessed 15/04/2016]

9 http://www.bats.org.uk/pages/microgeneration_issues.html [last accessed 15/04/2016]

In the DECC's 'UK solar PV Strategy' part 1, it is stated that there is increasing evidence that solar farms can provide benefits to biodiversity (DECC, 2013b), citing several grey literature documents to support this (GREA, 2010; Natural England, 2011; Parker and McQueen, 2013). This document also quotes the NPPF (National Planning Policy Framework) stating that if a solar proposal involves greenfield land then it should allow for continued agricultural use and/or encourages biodiversity around arrays (DCLG, 2013). In a separate document produced by DECC, 'UK solar PV Strategy Part 2' (DECC, 2014b) it is stated that the DECC is committed to working with industry to promote and develop best guidance practices for solar developments including with regards to biodiversity enhancement. Paragraph 73 of DECC (2014b) states that DECC and Defra will collaborate with industry to better under positive and negative ecological impacts of solar farms, although the document does not specify how this will be achieved. It is recognised by DECC that solar farms have the potential to benefit biodiversity, but also have the potential to be damaging to biodiversity and ecosystems. Although no specific effects are referred to in this document, several items of grey literature are referenced (BRE, 2013, 2014b; STA, 2013).

Natural England published a document stating that there is the potential for solar panels to have negative ecological impacts in areas of high wildlife value, or close to protected or designated conservation sites (Natural England, 2011). Mitigation measures such as habitat creation and the careful use of lighting are advised, and it is recognised that biodiversity impacts will differ from site to site and in different regions. Biodiversity enhancement practices are also advised including the creation of hedgerows and ponds, the planting of wild bird seed mixtures and the planting of nectar rich margins. The opportunities for biodiversity enhancement at solar PV arrays on agricultural land are presented in a positive light in comments made in a 2012 issue of the bulletin of the IEEM (Institute for Ecology and Environmental management, now CIEEM) (Box, 2012). Friends of the Earth provide uncited advice suggesting that solar farms should avoid "the best agricultural land and areas important to wildlife", with preference to brownfield and contaminated land (FOE, 2014). The document also states that solar farms can provide an opportunity to create habitat.

There is little information on the specific impacts of solar farms on plant taxa. An assessment by NRW of the distribution and potential threats to *Sphagnum spp.* States that "solar arrays can cause local loss of Sphagnum habitats" (NRW, 2013). This statement is unsupported with evidence. Although this document was provided through the JNCC website, it explicitly states that all the information within relates to Wales only and is provided by NRW. Two documents available through the BSBI (Kitchener,2015; Kitchener, 2016) describes a botanical survey site as not particularly affected by construction works (it is insinuated that the construction relates to the solar farm and that the effect in question is ecological) when noting the occurrence of mossy stonecrop (*Crassula tillaea*).[10] An evidence review of the conservation impacts of energy production was written on behalf of JNCC by IEEP (Institute for European Environmental Policy) in 2008 (Tucker et al., 2008) which cites Abbasi and Abbasi (2000) to support a claim that large scale solar developments may cause soil erosion and compaction. It is likely that this has the potential to negatively impact plant communities, however Tucker et al (2008) concludes that although large land areas may be required by utility scale PV developments, there is likely to be "relatively low or no impact" on UK biodiversity.

The NFU produced a briefing on solar PV and agriculture in 2013 (NFU, 2013) and an updated version in 2015 (NFU, 2015). These documents discuss the fact that multi-purpose land use is encouraged by most solar developers. This may include the continuation of farming practices such as sheep grazing or chicken rearing, but can also include practices encouraged by Environmental Stewardship (ES) schemes such as the creation of habitat for pollinating insects, winter foraging habitat for birds and nest boxes. The document also states that it can be advantageous to fence off solar developments from other agricultural land either to avoid losing out on Single Payment Scheme remuneration, or to "provide fenced wildlife refuges." The NFU has worked with industry to provide best practice guides for solar developments, including for biodiversity enhancement. The two main industrial bodies are the Solar Trade Association (STA) and the National Solar Centre (the date for the STA guidance document was taken from NFU (2015)) (STA, 2013; BRE, 2014a).

A document produced by JNCC in 2015 attempts to investigate the ecological concerns of a selection of UK businesses and the biodiversity enhancement measures implemented by these businesses (McNab et al., 2015). Although the businesses were anonymised, it is consistently stated throughout this document that within some businesses representative of the energy sector there is concern at the lack of research and available evidence on biodiversity enhancement and environmental gain around solar farms. One business surveyed (an electricity supply company with an approximate turnover of £28 million, 130 employees and operations throughout the UK) states that biodiversity enhancements such as wildflower meadow and wetland creation and hedgerow and tree planting are incorporated into the operational design of their solar PV projects. On top of this, the

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10 http://bsbi.org.uk/KentRPR2016Ce.pdf [last accessed 15/04/2016]

business undertakes ecological monitoring of these sites and reports the biodiversity status of the solar PV sites internally.

A document produced by IUCN providing advice on solar developments (in the pacific region) states that operating PV systems are silent (IUCN, n.d.). If this is true then this may reflect a reduced risk of attraction or repulsion for some taxa, however no experimental evidence has been found supporting this claim during the course of this review. Under the IUCN red list entry for Kit Fox *Vulpes macrotis*, reference to large scale solar farms in western North America are cited as a potential cause for decline in this species[11]. The entry states that further information on the effects of solar farms is needed, and that research is being undertaken in Mexico on the effects of solar development on the San Joaquin Kit Fox, however no reference is given. This research would be useful, as it may provide insight into the potential impacts of solar PV on small to medium sized mammals.

The NIEA (under the name of its parent body, the Department of the Environment) published a document that provides standing guidance on the considerations to take into account when seeking planning for solar development, including impacts on biodiversity (DOE, 2015). It is stated within this document that solar arrays are not considered to impact significantly on wildlife. Impacts on habitats include the potential drainage of wetlands along cabling routes, and direct loss of habitat within the footprint of a solar development and associated infrastructure. The potential for indirect impacts on habitat outside of a solar development footprint is highlighted, although this is not expanded on or referenced. General potential impacts of groundwork projects are highlighted including the potential for a negative impact on ground nesting birds during the construction phase of a development and a potential negative impact on badgers. Mitigation advice given is general and includes providing mammal gates in security fencing and using sensor activated security. A document produced by BRE providing biodiversity guidance for solar developments is cited (BRE, 2014b).

There is no readily apparent centralised opinion on solar PV developments presented by the wildlife trusts. There are concerns about the ecological impact of specific solar PV developments from some wildlife trusts, whereas other wildlife trusts appear to be more supportive of solar PV developments. For example, Wiltshire wildlife trust strongly opposed a

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11 http://www.iucnredlist.org/details/41587/0 [last accessed 19/04/2016]

development on Rampisham Down[12,13] and Shropshire wildlife trust opposed a temporary access road to a solar farm at Granville Country Park[14]. In contrast, at Cleworth Hall Farm in Tyldsley a solar farm is being planned in conjunction with a solar developer (Solstice) to be built on Lancashire wildlife trust land. The trust and Solstice are working together to maximise the potential for the site to deliver biodiversity benefits alongside the development[15]. Despite opposition to the development at Rampisham down, Wiltshire wildlife trust supports WWCE (Wiltshire Wildlife Community Energy), an organisation that helps to develop renewable projects including solar PV developments[16]. WWCE promotes the use of solar as means of generating electricity, providing that site placement is appropriate and that biodiversity management plans are in place including management of meadows in the array footprint using grazing and placing beehives underneath arrays[17]. A presentation slideshow from WWCE claims that warm air above the solar panels will attract insects in turn attracting birds, that voles and mice use habitat underneath the panels and that skylarks will nest between the panels, however these statements are uncited (Bennett, 2014). The presentation also refers to a 2014 study that showed three times the number of bumblebees at a solar development compared to a control plot, however this study is uncited.

SRUC provide a solar PV consultancy service, however no information on the ecological impacts of these developments is readily available[18], despite producing a guide on behalf of the Scottish government providing advice on farm scale renewables, including solar (SRUC,

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12 http://www.wildlifetrusts.org/news/2015/01/16/solar-farm-shock-decision-will-destroy-legally-protected-wildlife-site [Last accessed 22/04/2016]

13 http://www.wildlifetrusts.org/RampishamDown [last accessed 22/04/2016]

14 http://www.shropshirewildlifetrust.org.uk/news/2015/09/30/nature-reserve-under-threat [last accessed 22/04/2016]

15 http://www.lancswt.org.uk/news/2015/09/08/solar-farm-boost-wildlife [last accessed 22/04/2016]

16 http://wwce.org/about/ [last accessed 22/04/2016]

17 http://wwce.org/wp-content/uploads/2015/10/Impact-of-solar-farms-on-ecology-and-biodiversity.pdf [last accessed 22/04/2016]

18 http://www.sruc.ac.uk/info/120137/renewables/1049/solar_and_photovolotaics [last accessed 21/04/2016]

n.d.). In searching for information provided by SRUC, several news stories were found citing a ‘solar meadow’ built at Edinburgh College[19,20,21]. The solar meadow is discussed on Edinburgh College’s engineering webpage[22], however there is no information on the ecology of the site other than that the solar meadow will allow the study of the interaction between biodiversity and solar PV. There is no indication as to why the development is named a ‘meadow’- all photographs of the development on this website, and in news reports show bare earth under the solar panels. If used appropriately, this facility has the potential to allow research into the ecological impacts of solar PV developments.

3.1.5. Non peer reviewed scientific research

During the course of assessing the grey literature available for this review, several non-peer reviewed studies assessing the ecological impact of solar PV developments were discovered.

Parker and McQueen (2013) conducted a survey of four solar farms alongside control plots for each. The experimental design seems reasonable and some basic statistical analysis is provided, adding credibility to the results of this study. Botanical surveys, bumblebee surveys and butterfly surveys were conducted at all four sites. Bumblebee and butterfly diversity was consistently higher at all four solar farm sites when compared to the control sites. Differences in abundance of bumblebees and butterflies varied between sites, however statistically significantly higher number of bumblebees were found at three of the

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19 http://www.heraldscotland.com/business/13209486.Solar_power_comes_of_age_in_Scotland_as_investment_boom_could_see_building_of_first_industrial_solar_array/ [last accessed 21/04/2016]

20 http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-22282888 [last accessed 21/04/2016]

21 http://www.scotsman.com/news/education/edinburgh-college-powered-by-new-solar-meadow-1-2908688 [last accessed 21/04/2016]

22 http://www.edinburghcollege.ac.uk/Welcome/Centres/Engineering/Our-Facilities [last accessed 21/04/2016]

solar farms when compared to the control sites, and at two of the solar farms for butterflies. Botanical diversity was consistently higher at solar farms when compared to control sites. Two of the solar sites had been seeded with wildflower mix, suggesting that with good habitat management, solar PV developments can be beneficial for biodiversity.

Feltwell (2013a) and Feltwell (2014a) are articles published in the Newsletter of the Kent Field Club. Feltwell (2013a) used a casual walkover method to survey for bird mortality at a 12.5ha solar farm in Kent. A total of 25 visits were made between September 2011 and September 2012, with a total of 3.5 km walked between the solar PV arrays on each visit. No bird mortalities observed were obviously attributable to collision with the arrays, however one mute swan appeared to have been killed by overhead powerlines, and a further 16 mortalities of four species (Little Egret (*Egretta garzetta*), Carrion Crow (*Corvus corone*), Pheasant (*Phasianus colchicus*), and Woodpigeon (*Columba palumbus*)) were attributed to predation. A total of 62 species of bird were recorded over and amongst the solar arrays during the walkovers, suggesting that some solar farms are capable of supporting a healthy assemblage of bird species. Casual vantage point surveys were also conducted, where the author describes regularly seeing Wheatear *Oenanthe oenanthe* and swallow *Hirundo rustica* perching on the solar arrays. The habitat is described as improved farmland, suggesting that the site is not managed to be beneficial for biodiversity. Feltwell, (2014a) describes an informal invertebrate survey that appears to be have been undertaken during the aforementioned bird survey (Feltwell, 2013a). Over 60 species of insect were recorded, with “buffer areas” on site described as reservoirs for invertebrate diversity. Butterfly species appeared to be benefitting from the grass species on site, with some using the infrastructure of the solar farm as substrate to pupate. Diptera and Coleoptera were the only orders of insect observed on the solar panels themselves.

Kadaba (2014) is a Master’s degree project that describes the ecology of the desert kit fox (*Vulpes macrotis arsipus*) in the Chuckwalla Valley, California. Although heavy reference is made to the potential threats of high land cover of solar developments, no citations are provided. Some of the threats referred to are however intuitively plausible. They included habitat fragmentation and loss, displacement and mortality on new roads. No attempt is made to quantify the threats directly related to solar facilities, and it is not clear whether the author is referring to CSP or PV developments.

3.1.6. Solar energy hardware manufacturers, suppliers and advisory groups

BRE has produced several documents providing information and advice on ways to maximise biodiversity potential at solar farm sites. The most often cited is BRE (2014b). This document provides options for habitat enhancement on site once a development has been completed, and advice for minimal impact during the construction phase. The advice is general in its approach and involves recommendations that one might expect to see in ecological consultancy reports. BRE (2013) and BRE (2014a) provide similar information, although the latter is more oriented towards agricultural good practice, incorporating elements of biodiversity enhancement.

The Solar Trade Association has produced '10 commitments' associated with solar farms, three of which pertain to the conservation and enhancement of biodiversity. These are general in nature and not prescriptive[23].

3.1.7. Planning decisions on solar PV developments in the North West of England

Using the July 2015 renewable development planning database provided by the UK government, 49 applications for planning permission for solar PV developments were identified in the North West of England. Records for applications in the North West of England within this database begin on 29th May 1991, however the first record for a PV development does not appear until 14th March 2011 reflecting the recent surge in solar energy developments in the region. Of the 49 planning applications for solar PV developments, 32 applications had been processed at the time of acquiring these data. Twelve of these applications had been refused planning permission, two applications were withdrawn, and the remaining 18 were granted planning permission (figure 1). All of these applications relate to developments with a generating capacity of greater than 1 MW.

23 http://www.solar-trade.org.uk/solar-farms/ [last access 26/04/2016]

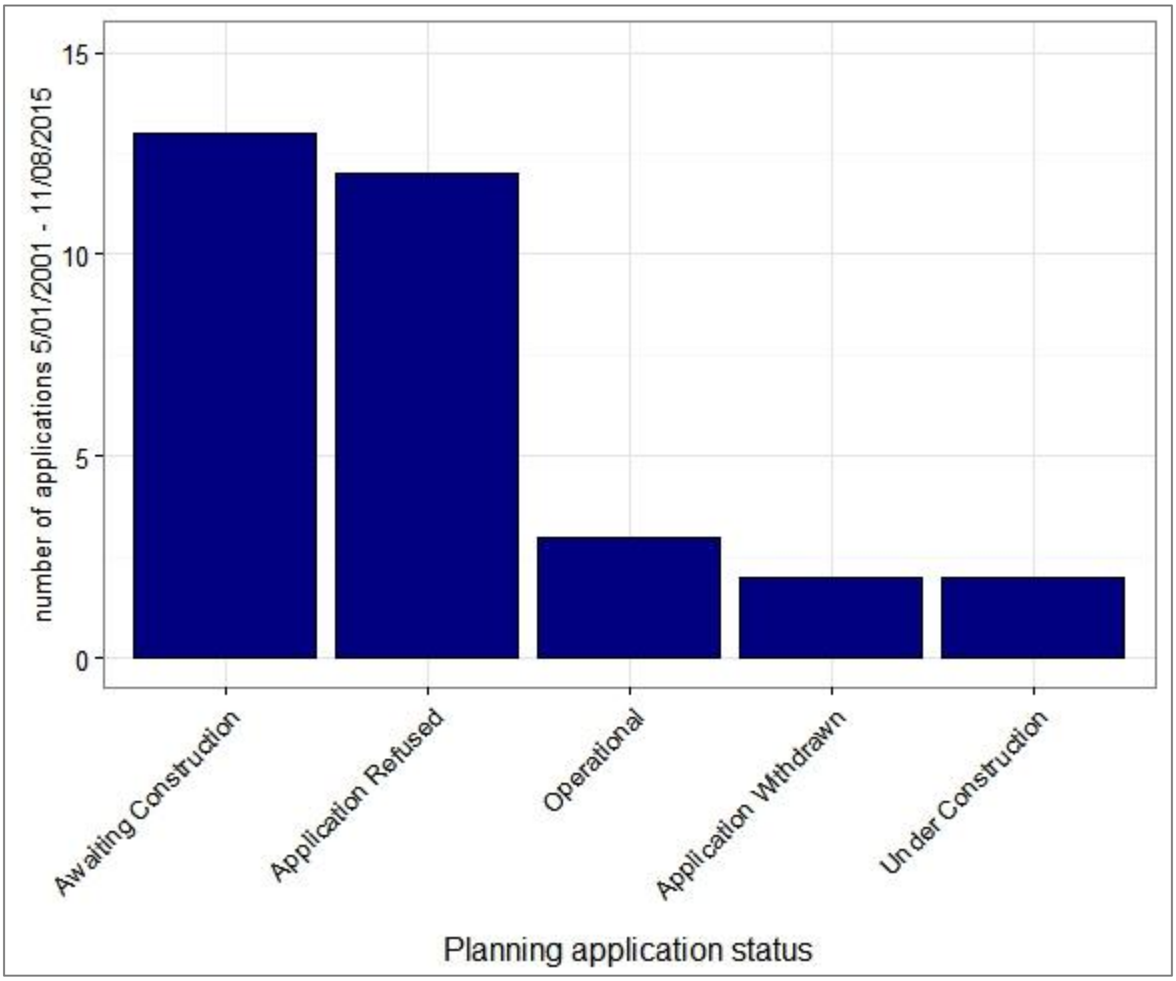

Figure 1. The application status of all planning applications for solar PV developments in the North West of England where a planning decision has been reached. A large proportion of these applications are rejected.

Of the applications that were refused, several were refused on ecological grounds. These decisions are summarised in table 4. This is despite the fact that some of those refused applications such as a solar farm in Aughton, Lancashire (planning reference: Ref: 2014/0601/FUL) provide details of biodiversity mitigation including hedgerow laying and wildflower meadow planting. Many of the refused applications included detailed ecological appraisals or impact assessments of the proposed developments and were not refused on ecological grounds (table 4).

Table 4. Planning applications in the North West of England for all solar PV developments that have been refused planning permission. Where ecological reasons for refusal are presented by the relevant planning authority, they are summarised.

Planning application	Ecological reason for refusal of planning permission
16MW solar farm: Lathom, Lancashire Ref: 2014/0791/FUL	• Development will result in disruption of the green belt and encroachment into the countryside. • Insufficient evidence provided to demonstrate that no adverse effect to protected species and habitat will occur. • Insufficient evidence that agricultural land of lower quality is available as an alternative.
Solar farm: Aughton, Lancashire Ref: 2014/0601/FUL	• Development will result in disruption of the green belt and encroachment into the countryside.
14.63 MW solar farm: Wigton, Cumbria Ref: 2/2014/0636	• None. Refusal was made on grounds of landscape character, including backing on this from Natural England.
Solar park: Workington, Cumbria Ref: 2/2014/0899	• None. Refusal was made on grounds of negative impacts on amenity value.
8.28 MW solar park: Nantwich, Cheshire Ref: 14/4296N	• None. Refusal was made on the grounds of landscape character, and on the grounds that it would result in the loss of some of the “best and most versatile agricultural land,” referring primarily to the land’s economic value.
13.28 MW solar park: Marbury, Cheshire Ref: 14/4380N	• None. Refusal was made on grounds of landscape character.
Up to 4.99 MW solar farm: Heapey, Chorley Ref: 14/01132/FULMAJ	• Development will result in disruption of the green belt. • In addition, landscape character and amenity impact are cited.
Up to 8 MW solar farm: Heapey, Chorley	• Development will result in disruption of the green belt.

Ref: 13/00811/FULMAJ	• Insufficient information presented on the potential ecological impacts of the development, with special emphasis on Great Crested Newts (*Triturus cristatus*) , habitat connectivity and habitat loss.
Solar Park: Hightown, Sefton Ref: DC/2014/01439	• Development will result in disruption of the green belt. • Other reasons for refusal include loss of best and most versatile agricultural land and impact on assets with heritage value.
15 MW solar farm: Bilsborrow, Lancashire Ref: 14/00558/LMAJ	• None. Reasons cited include landscape character and loss of access to Public Rights of Way.
Solar farm and gas power plant: Widnes Cheshire Ref: 2014/24931	• Development will result in disruption of the green belt. • Reference to environmental concerns associated with works analogous to a landfill operation planned at the site.
16MW solar farm: Wrea, Preston Ref: 14/0696	• The application does not provide sufficient evidence that there will be no impact on the ecology of nearby SPAs (Special Protection Areas) and SSSIs (Sites of Special Scientific Interest). • The planning authority expresses concerns that the development may adversely impact ground nesting birds such as Lapwing (*Vanellus vanellus*) and Skylark (*Alauda arvensis*). • The application does not provide sufficient evidence that there will be no impact on protected species such as Great Crested Newt or Common Toad (*Bufo bufo*). • Concerns are raised by the planning authority about the general potential impact the development may have on biodiversity, and the lack of evidence for potential mitigation that is provided.

	• Other reasons cited include loss of landscape character and impact on public rights of way. Interestingly, the planning authority expresses concerns for the plan to erect 2.4m hedges, that will restrict views- however also expresses concerns about the potential loss of hedgerows that the development may cause.

4. Conclusions

A combination of climate change policy, improvements in solar PV technology and reduced costs of solar PV hardware have led to the UK adopting solar powered electricity generation as part of the national energy landscape. Due to the spatial requirements of utility scale solar PV developments, the physical landscape of UK habitats will be affected by the implementation of these technologies necessitating an understanding of the potential effects that solar PV may have on biodiversity. Understanding requires evidence which is traditionally gathered through robust scientific investigation and peer reviewed publication. No experimental studies specifically designed to investigate the in-situ ecological impacts of solar PV developments were found in the peer reviewed literature. Considering that cumulative installed global PV capacity is projected to reach between 450 GW and 880 GW by 2030, up from 67 GW in 2011 (Gan and Li, 2015), this lack of ecological evidence is heavily under representative of the interest and investment in solar PV deployment.

Incidental and informal evidence suggests that the collision risk presented by solar panels to birds is low but not impossible. It is likely that the infrastructure associated with transporting electricity (e.g. powerlines) presents more of a collision risk for birds than the solar arrays themselves. With regards collision risk to bats, there is no evidence.

When considering site selection for utility scale solar developments it is generally agreed that protected areas should be avoided. This is reflected in the scientific literature where modelling approaches include many factors such as economic considerations and visual impact but also often avoid protected areas such as SPAs. This is echoed by organisations such as Natural England and the RSPB that recommend that solar PV developments should not be built on or near protected areas. As sensitive species and habitats are not necessarily restricted to the geographical boundaries of protected areas, it is imperative that research is undertaken into the potential interactions between solar PV arrays and biodiversity- especially sensitive habitats and species. Quantifying the effect of solar PV developments as a function of distance to protected areas is equally as important as it would allow statutory bodies and ecological organisations to provide more detailed guidance on the placement of these developments where the conservation integrity of a protected area is potentially at risk. Research into the impacts that solar PV developments may have on biodiversity should be undertaken using a multiscale approach, allowing potential impacts to be understood both within the immediate vicinity of solar farms and within the wider landscape, taking into account ecologically functionally connected land and a wide selection of habitats.

The lack of evidence available relating to the ecological impact of solar farms is concerning. It has led to authoritative organisations making speculative arguments and publishing information that on occasion appears to conflict. For conservation organisations to provide sound advice that is coherent and consistent, evidence is needed. The move towards renewable energy sources by many governments is progressive and admirable, however more needs to be done to understand the interaction between these new technologies and the ecology that they are ultimately designed to protect.

5. Recommendations

Advice given by non-governmental and governmental organisations has been referred to throughout this document. These organisations invariably state that appropriate siting, appropriate timing of construction and maintenance, biodiversity mitigation and biodiversity enhancing practices should be taken into consideration when considering a utility scale solar PV development. Although these general pieces of advice are sensible, no hard evidence has been found during the course of this literature review that allows any more specific recommendation to be given. In the literature, concerns have been raised that solar PV developments have the potential to negatively impact a broad range of taxa including birds, bats, mammals, insects and plants. In light of this, it is highly recommended that research is undertaken into the ecological impacts of solar PV arrays across a broad range of taxa at multiple geographical scales.

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7. References

Abbasi, S. . and Abbasi, N. (2000) 'The likely adverse environmental impacts of renewable energy sources.' *Applied Energy*, 65(1) pp. 121–144.

Akikur, R. K. ., Saidur, R. . b, Ping, H. W. . and Ullah, K. R. . (2013) 'Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review.' *Renewable and Sustainable Energy Reviews*, 27 pp. 738–752.

Al-Dhaheri, S. M., Lamont, L. A., El-Chaar, L. and Al-Ameri, O. A. (2010) 'Automated design for boosting offshore photovoltaic (PV) performance.' *In 2010 IEEE PES Transmission and Distribution Conference and Exposition: Smart Solutions for a Changing World*. Electrical Engineering Department, Petroleum Institute, P.O. Box: 2533, Abu Dhabi, United Arab Emirates.

Alvarez, S. T. and Lidicker Jr, W. Z. (2015) 'Managing coexistence for bats and wind turbines.' *THERYA*, 6(3) pp. 505–513.

Armstrong, A., Waldron, S., Whitaker, J. and Ostle, N. J. (2014) 'Wind farm and solar park effects on plant-soil carbon cycling: uncertain impacts of changes in ground-level microclimate.' *Global change biology*, 20(6) pp. 1699–706.

Arnett, E. B., Baerwald, E. F., Mathews, F., Rodrigues, L., Rodríguez-Durán, A., Rydell, J., Villegas-Patraca, R. and Voigt, C. C. (2016) 'Bats in the Anthropocene: Conservation of Bats in a Changing World.' *In* Voigt, C. C. and Kingston, T. (eds). Cham: Springer International Publishing, pp. 295–323.

Arnett, E. B., Brown, W. K., Erickson, W. P., Fiedler, J. K., Hamilton, B. L., Henry, T. H., Jain, A., Johnson, G. D., Kerns, J., Koford, R. R., Nicholson, C. P., O'Connell, T. J., Piorkowski, M. D. and Tankersley, R. D. (2008) 'Patterns of Bat Fatalities at Wind Energy Facilities in North America.' *Journal of Wildlife Management*, 72(1) pp. 61–78.

Baerwald, E. F., D'Amours, G. H., Klug, B. J. and Barclay, R. M. R. (2008) 'Barotrauma is a significant cause of bat fatalities at wind turbines.' *Current biology : CB*, 18(16) pp. R695–6.

Balta-Ozkan, N., Yildirim, J. and Connor, P. M. (2015) 'Regional distribution of photovoltaic deployment in the UK and its determinants: a spatial econometric approach.' *Energy Economics*. Elsevier, 51 pp. 417–429.

Banks, M. A. (2006) ‘Towards a continuum of scholarship: The eventual collapse of the distinction between grey and non-grey literature.’ *Publishing Research Quarterly*, 22(1) pp. 4–11.

Bennett, L. (2014) ‘Impact of solar farms on ecology and biodiversity as explained to members.’ Wilthshire Wildlife Comunity Energy.

Bernáth, B., Kriska, G., Suhai, B. and Horváth, G. (2008) ‘Wagtails (Aves: Motacillidae) as insect indicators on plastic sheets attracting polarotactic aquatic insects.’ *Acta Zoologica Academiae Scientiarum Hungaricae*. Hungarian Natural History Museum, Budapest, 54(1) pp. 145–155.

Bernáth, B., Szedenics, G., Molnár, G., Kriska, G. and Horváth, G. (2001) ‘Visual ecological impact of a peculiar waste oil lake on the avifauna: dual choice field experiments with water-seeking birdsusing huge shiny black and white plastic sheets.’ *Arch Nature Conserv Landsc Res*, 40 pp. 1–28.

Birdlife Europe (2011) ‘Meeting Europe’s Renewable Energy Targets in Harmony with Nature.’ Sandy, UK: RSPB (eds. Scrase I. and Gove B).

Birdlife International (2015) ‘BirdLife International’s Position on Climate Change.’ Cambridge, UK.

Birdlife International (n.d.) ‘Migratory Soaring Birds Project Solar Energy Guidance V.1: Governments.’

Blahó, M., Egri, Á., Barta, A., Antoni, G., Kriska, G. and Horváth, G. (2012) ‘How can horseflies be captured by solar panels? A new concept of tabanid traps using light polarization and electricity produced by photovoltaics.’ *Veterinary parasitology*, 189(2-4) pp. 353–65.

Bouten, W., Baaij, E. W., Shamoun-Baranes, J. and Camphuysen, K. C. J. (2013) ‘A flexible GPS tracking system for studying bird behaviour at multiple scales.’ *Journal of Ornithology*. Computational Geo-Ecology, Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, P.O. Box 94248, 1090 GE Amsterdam, Netherlands, 154(2) pp. 571–580.

Box, J. (2012) ‘From your President.’ In Practice: Bulletin of the Institute of Ecology and Environmental Management, 78 p. 2.

Boyles, J. G., Cryan, P. M., McCracken, G. F. and Kunz, T. H. (2011) ‘Economic importance of bats in agriculture.’ *Science*, 332(6025) pp. 41–42.

BRE (2013) National Planning Guidance - Biodiversity. St Austell.

BRE (2014a) ‘Agricultural Good Practice Guidance for Solar Farms.’ Ed. Scurlock, J.

BRE (2014b) BRE National Solar Centre Biodiversity Guidance for Solar Developments. Parker, G. . and Greene, L. (eds).

Brinkworth, B. J. and Sandberg, M. (2006) ‘Design procedure for cooling ducts to minimise efficiency loss due to temperature rise in PV arrays.’ *Solar Energy*. Cotswold, 11 Wellesley Close, Waterlooville, Hants, United Kingdom, 80(1) pp. 89–103.

Bryant, D. M., Hails, C. J. and Tatner, P. (1984) ‘Reproductive Energetics of Two Tropical Bird Species.’ *The Auk*. American Ornithologists’ Union, 101(1) pp. 25–37.

BTO (n.d.) ‘Farmland Bird Appeal. Skylarks are calling out for your help!’ Thetford, UK: British Trust for Ornithology.

Calvert, K. . and Mabee, W. . (2015) ‘More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada.’ *Applied Geography*, 56 pp. 209–221.

Coleman, M. G., Grenon, L. A. and Hild, N. R. (1980) ‘Environmental control: an evaluation of the economic and ecological requirements for the silicon photovoltaic industry.’ *In Conference Record of the IEEE Photovoltaic Specialists Conference*, pp. 1042–1048.

Colozza, A. (2007) ‘Fly like a bird.’ *IEEE Spectrum*. Analex Corp., Fairfax, VA, United States, 44(5) pp. 38–43.

Cryan, P. M. and Barclay, R. M. R. (2009) ‘Causes of bat fatalities at wind turbines: hypotheses and predictions.’ *Journal of Mammalogy*. The Oxford University Press, 90(6) pp. 1330–1340.

Dale, V. H., Efroymson, R. A. and Kline, K. L. (2011) ‘The land use–climate change–energy nexus.’ *Landscape Ecology*. Springer Netherlands, 26(6) pp. 755–773.

DCLG (2013) Planning practice guidance for renewable and low carbon energy. London, UK.

DECC (2013a) UK Renewable Energy Roadmap Update 2013. London, UK.

DECC (2013b) UK Solar PV Strategy Part 1: Roadmap to a Brighter Future.

DECC (2014a) Regional Statistics 2003-2013: Generation. London, UK.

DECC (2014b) UK Solar PV Strategy Part 2: Delivering a Brighter Future. London, UK.

DECC (2015) Energy Trends section 6: renewables. London, UK.

DeVault, T. L., Seamans, T. W., Schmidt, J. A., Belant, J. L., Blackwell, B. F., Mooers, N., Tyson, L. A. and Van Pelt, L. (2014) 'Bird use of solar photovoltaic installations at US airports: implications for aviation safety.' *Landscape and Urban Planning*. Elsevier, 122 pp. 122–128.

DOE (2015) 'Energy generation – Solar farms. Advice for planning officers and applicants seeking planning permission for solar farms which may impact on natural heritage.' Department of the Environment (Northern Ireland).

Doi, T. ., Tsuda, I. ., Sakuta, K. . and Matsui, G. . (2003) 'Development of a recyclable PV-module: Trial manufacturing and evaluation.' *In Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion*, pp. 1952–1955.

Dorobantu, L., Popescu, M. O. and Popescu, C. L. (2011) 'Yield loss of photovoltaic panels caused by depositions.' *In 2011 7th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2011*. Politehnica University of Bucharest, Splaiul Independentei 313, Romania.

Drewitt, A. L. and Langston, R. H. W. (2006) 'Assessing the impacts of wind farms on birds.' *Ibis*, 148, March, pp. 29–42.

EC (2009) '28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30.' *Brussels: European Commission*.

EEA (2015) 'Renewable energy in Europe- approximated recent growth and knock-on effects.' Luxembourg: Publications Office of the European Union.

Feltwell, J. (2013a) 'Are photovoltaic solar arrays an influencing factor in avian mortality?' *The Newsletter of the Kent Field Club*, 77 pp. 18–27.

Feltwell, J. (2013b) 'No Biodiversity on solar farms – building tomorrow's solar farms.' *Solar Business Focus UK*, 10 pp. 6–7.

Feltwell, J. (2013c) *Résumé of solar farms in England and Wales, Briefing given at National Trust roundtable*. www/solar-trade/org.uk. [Online] http://www.solar-trade.org.uk/solarFarms.cfm.

Feltwell, J. (2013d) *Solar Farms and Biodiversity*. Solar Power Portal. [Online] [Accessed on 18th April 2016] http://www.solarpowerportal.co.uk/guest_blog/solar_farms_and_biodiversity_2356.

Feltwell, J. (2013e) ‘Solar farms for bumblebees.’ *Buzzword, The Bumblebee Conservation Trust’s Members Newsletter.*, (23) pp. 13–14.

Feltwell, J. (2014a) ‘Observations on the effects of photovoltaic solar panels on invertebrates at Ebbsfleet Farm, Sandwich, Kent.’ *The Newsletter of the Kent Field Club*, 79 pp. 4–17.

Feltwell, J. (2014b) ‘Solar farms: gain or grain?’ *Solar Business Focus UK*, 11 pp. 40–41.

Fernández-Infantes, A. ., Contreras, J. . and Bernal-Agustín, J. L. . (2006) ‘Design of grid connected PV systems considering electrical, economical and environmental aspects: A practical case.’ *Renewable Energy*, 31(13) pp. 2042–2062.

FOE (2014) ‘20 things you need to know about solar power.’ London, UK: The Printworks.

Fthenakis, V., Blunden, J., Green, T., Krueger, L. and Turney, D. (2011) ‘Large photovoltaic power plants: Wildlife impacts and benefits.’ *In Photovoltaic Specialists Conference (PVSC), 2011 37th IEEE*. IEEE, pp. 2011–2016.

Gao, X., Yao, C., Gao, X. and Yu, Y. (2014) ‘Identification of solar cell model parameters by combining analytical method with Nelder-Mead simplex method.’ *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering*. Key Laboratory of New Materials and Facilities for Rural Renewable Energy, Ministry of Agriculture, Henan Agricultural University, Zhengzhou 450002, China: Chinese Society of Agricultural Engineering, 30(6) pp. 97–106.

Gelfand, J. and Lin, A. (Tony) (2013) ‘Grey literature: format agnostic yet gaining recognition in library collections.’ *Library Management*. Emerald, 34(6/7) pp. 538–550.

Ghazi, S. and Ip, K. (2014) ‘The effect of weather conditions on the efficiency of PV panels in the southeast of UK.’ *Renewable Energy*. Environmental Engineering Department of Islamic Azad University-Parand Branch, Parand, Iran: Elsevier BV, 69 pp. 50–59.

Giustini, D. and Boulos, M. N. K. (2013) ‘Google Scholar is not enough to be used alone for systematic reviews.’ *Online Journal of Public Health Informatics*.

Góralczyk, M. (2003) ‘Life-cycle assessment in the renewable energy sector.’ *Applied Energy*, 75(3-4) pp. 205–211.

GREA (2010) ‘Solar parks – Opportunities for Biodiversity. A report on biodiversity in and around ground-mounted photovoltaic plants.’ *Renews Special*, (45).

Greif, S. and Siemers, B. M. (2010) ‘Innate recognition of water bodies in echolocating bats.’ *Nature Communications*. Nature Publishing Group, 1, November, p. 107.

Grippo, M. ., Hayse, J. W. . and O'Connor, B. L. . (2014) 'Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs.' *Environmental Management*, 55(1) pp. 244–256.

Haddaway, N. R. and Bayliss, H. R. (2015) 'Shades of grey: Two forms of grey literature important for reviews in conservation.' *Biological Conservation*, 191, November, pp. 827–829.

Haddaway, N. R., Burden, A., Evans, C. D., Healey, J. R., Jones, D. L., Dalrymple, S. E. and Pullin, A. S. (2014) 'Evaluating effects of land management on greenhouse gas fluxes and carbon balances in boreo-temperate lowland peatland systems.' *Environmental Evidence*, 3(1) pp. 1–30.

Hansen, C. P., Rumble, M. A. and Gamo, R. S. (2014) 'Auxiliary VHF transmitter to aid recovery of solar argos/GPS PTTs.' *USDA Forest Service - Research Note RMRS-RN*. USDA Forest Service, 72 pp. 1–13.

Haurant, P. ., Oberti, P. . and Muselli, M. . (2011) 'Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: A real case study using the ELECTRE outranking framework.' *Energy Policy*, 39(2) pp. 676–688.

Hayes, M. A. (2013) 'Bats Killed in Large Numbers at United States Wind Energy Facilities.' *BioScience*. Oxford University Press, 63(12) pp. 975–979.

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R. and Ravi, S. (2014) 'Environmental impacts of utility-scale solar energy.' *Renewable and Sustainable Energy Reviews*. Elsevier, 29 pp. 766–779.

Hernandez, R. R., Hoffacker, M. K. and Field, C. B. (2014) 'Land-use efficiency of big solar.' *Environmental science & technology*. American Chemical Society, 48(2) pp. 1315–23.

Hernandez, R. R., Hoffacker, M. K., Murphy-Mariscal, M. L., Wu, G. C. and Allen, M. F. (2015) 'Solar energy development impacts on land cover change and protected areas.' *Proceedings of the National Academy of Sciences*, 112(44) pp. 13579–13584.

Horn, J. W., Arnett, E. B. and Kunz, T. H. (2008) 'Behavioral Responses of Bats to Operating Wind Turbines.' *Journal of Wildlife Management*, 72(1) pp. 123–132.

Horváth, G., Blahó, M., Egri, Á., Kriska, G., Seres, I. and Robertson, B. (2010) 'Reducing the maladaptive attractiveness of solar panels to polarotactic insects.' *Conservation Biology*, 24(6) pp. 1644–1653.

Horváth, G., Kriska, G., Malik, P. and Robertson, B. (2009) ‘Polarized light pollution: a new kind of ecological photopollution.’ *Frontiers in Ecology and the Environment*. Ecological Society of America, 7(6) pp. 317–325.

IPCC (2002) ‘Climate change and biodiversity- IPCC technical paper V.’

IUCN (n.d.) ‘Small scale solar photovoltaic Pacific energy projects: Impacts on nature and people.’ Suva, Fiji Islands: International Union for Conservation of Nature.

JNCC (2006) JNCC response to DTI Energy Review- Appendices.

Joshi, A. S., Dincer, I. and Reddy, B. V. (2009) ‘Performance analysis of photovoltaic systems: A review.’ *Renewable and Sustainable Energy Reviews*, 13(8) pp. 1884–1897.

Kadaba, D. (2014) Ecology of the desert kit fox (Vulpes macrotis arsipus) in Chuckwalla Valley, California. Duke University.

Kaldellis, J. K. ., Zafirakis, D. . and Kondili, E. . (2010) ‘Energy pay-back period analysis of stand-alone photovoltaic systems.’ *Renewable Energy*, 35(7) pp. 1444–1454.

Kattakayam, T. A., Khan, S. and Srinivasan, K. (1996) ‘Diurnal and environmental characterization of solar photovoltaic panels using a PC-AT add on plug in card.’ *Solar Energy Materials and Solar Cells*. Department of Mechanical Engineering, Indian Institute of Science, Bangalore 560012, India, 44(1) pp. 25–36.

Kim, H. C., Fthenakis, V., Choi, J.-K. and Turney, D. E. (2012) ‘Life Cycle Greenhouse Gas Emissions of Thin-film Photovoltaic Electricity Generation: Systematic Review and Harmonization.’ *Journal of Industrial Ecology*, 16(SUPPL.1) pp. S110–S121.

Kitchener, G. (2015) ‘Kent Bontany 2014.’ Botanical Society of Britain and Ireland.

Kitchener, G. (2016) ‘Kent Rare Plant Register Draft species accounts C (second part Ce-Cy).’ Kent Bontanical Recording Group.

Kreiger, M. A. ., Shonnard, D. R. . and Pearce, J. M. . c (2013) ‘Life cycle analysis of silane recycling in amorphous silicon-based solar photovoltaic manufacturing.’ *Resources, Conservation and Recycling*, 70 pp. 44–49.

Kriska, G., Horváth, G. and Andrikovics, S. (1998) ‘Why do mayflies lay their eggs en masse on dry asphalt roads? Water-imitating polarized light reflected from asphalt attracts Ephemeroptera.’ *The Journal of experimental biology*, 201(Pt 15) pp. 2273–86.

Kure, S. (2010) ‘Give and take: A Texas school will make as much energy as it uses.’ *EC and M: Electrical Construction and Maintenance*, 109(10).

Lamont, L. A. and El Chaar, L. (2011) ‘Enhancement of a stand-alone photovoltaic system’s performance: Reduction of soft and hard shading.’ *Renewable Energy*. Petroleum Institute, Electrical Engineering Department, P.O. Box 2533, Abu Dhabi, United Arab Emirates, 36(4) pp. 1306–1310.

Lawrence, A., Thomas, J., Houghton, J. and Weldon, P. (2015) ‘Collecting the Evidence: Improving Access to Grey Literature and Data for Public Policy and Practice.’ *Australian Academic & Research Libraries*. Routledge, October.

Liu, C. and Liu, L. (2011) ‘Particle SWARM optimization MPPT method for PV materials in partial shading.’ *2011 International conference on Intelligent Materials and Mechanical Engineering, MEE2011*. Institute of Computer Science and Technology, Taiyuan University of Science and Technology, Taiyuan 030024, Shanxi Province, China pp. 72–75.

Liu, L.-Q., Liu, C.-X., Wang, J.-S., Yang, K., Zhang, W.-Y. and Gao, H.-M. (2015) ‘Optimal azimuth and elevation angles prediction control method and structure for the dual-axis sun tracking system.’ *JVC/Journal of Vibration and Control*. College of Electronic and Information Engineering, Taiyuan University of Science and Technology, 66 Waliu Road, Wanbolin District, Taiyuan, China: SAGE Publications Inc., 21(2) pp. 402–407.

Lovich, J. E. and Ennen, J. R. (2011) ‘Wildlife conservation and solar energy development in the desert southwest, United States.’ *BioScience*. Oxford University Press, 61(12) pp. 982–992.

Maag Jr., C. R. (1977) ‘OUTDOOR WEATHERING PERFORMANCE OF SOLAR ELECTRIC GENERATORS.’ *J Energy*, 1(6) pp. 376–381.

Maghami, M. R., Hizam, H., Gomes, C. and Ismail, A. G. (2014) ‘Characterization of dust materials on the surface of solar panel.’ *Life Science Journal*. Department of Electrical and Electronic Engineering, Universiti Putra Malaysia, 43400 Serdang, Malaysia: Zhengzhou University, 11(SPEC. ISSUE 4) pp. 387–390.

De Marco, A., Petrosillo, I., Semeraro, T., Pasimeni, M. R., Aretano, R. and Zurlini, G. (2014) ‘The contribution of Utility-Scale Solar Energy to the global climate regulation and its effects on local ecosystem services.’ *Global Ecology and Conservation*. Elsevier, 2 pp. 324–337.

McCrary, M. D., McKernan, R. L., Flanagan, P. A. and Wagner, W. D. (1984) *Wildlife interactions at Solar One. Final report*. Los Angeles County Natural History Museum Foundation, CA (USA). Section of Ornithology.

McNab, D., Davies, J., Eves, C., Rowcroft, P. and Dunscombe, R. (2015) *Realising nature’s value in UK business JNCC Report, No. 558,*. Peterborough, UK.

Mondal, A. K. and Bansal, K. (2015a) ‘A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels.’ *Advanced Robotics*. Electronics and Instrumentation Department, University of Petroleum and Energy Studies, Dehradun, India: Robotics Society of Japan, 29(8) pp. 515–524.

Mondal, A. K. and Bansal, K. (2015b) ‘Structural analysis of solar panel cleaning robotic arm.’ *Current Science*. Electronics and Instrumentation Department, University of Petroleum and Energy Studies, Dehradun, India: Indian Academy of Sciences, 108(6) pp. 1047–1052.

Moskowitz, P. D., Steinberger, H. and Thumm, W. (1994) ‘Health and environmental hazards of CdTe photovoltaic module production, use and decommissioning.’ *In Conference Record of the IEEE Photovoltaic Specialists Conference*, pp. 115–118.

Müller, A. ., Wambach, K. . and Alsema, E. . (2006) ‘Life cycle analysis of solar module recycling process.’ *In Materials Research Society Symposium Proceedings*, pp. 89–94.

Munshi, A. A. A. and Mohamed, Y. A.-R. I. (2014) ‘Photovoltaic power pattern grouping based on bat bio-inspired clustering.’ *In 2014 IEEE 40th Photovoltaic Specialist Conference, PVSC 2014*, pp. 1461–1466.

Natural England (2011) ‘Natural England Technical Information Note TIN101. Solar parks: maximising environmental benefits.’ Natural England.

NFU (2013) ‘Solar photovoltaic electricity in agriculture – on your roofs and in your fields.’ National Farmer’s Union.

NFU (2015) ‘Solar photovoltaic electricity in agriculture – on your roofs and in your fields.’ National Farmer’s Union.

NRW (2013) European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) Supporting documentation for the Third Report by the United Kingdom under Article 17 on the implementation of the Directive from January 2007 to D.

Pareek, S. and Dahiya, R. (2014) ‘Output power comparison of TCT and SP topologies for easy-to-predict partial shadow on a 4×4 PV field.’ *International Symposium on Engineering and Technology, ISET 2014*. National Institute of Technology, Kurukshetra, India: Trans Tech Publications Ltd pp. 71–76.

Parker, G. and McQueen, C. (2013) Can Solar Farms Deliver Significant Benefits for Biodiversity? Preliminary Study July-August 2013.

Pearce-Higgins, J. W. and Green, R. E. (2014) *Birds and climate change: impacts and conservation responses*. Cambridge, UK: Cambridge University Press.

Ramaprabha, R. (2009) 'MATLAB based modelling to study the influence of shading on series connected SPVA.' *In 2009 2nd International Conference on Emerging Trends in Engineering and Technology, ICETET 2009*, pp. 30–34.

Ramesh, S., Sairam, M., Manoj Kumar, S., Sreekanth and Harikrishnan, R. (2009) 'The Martian man - A heuristic approach on robots to mars.' *In 2009 IEEE International Conference on Robotics and Biomimetics, ROBIO 2009*. Department of Information Technology, Meenakshi Sundararajan Engineering College, India, pp. 1099–1104.

Ramsar (2012) 'Resolution XI.10 Wetlands and energy issues.' *In Wetlands: home and destination*. Bucharest.

Ray, S. ., Chakraborty, A. K. . and Debnath, D. . (2013) 'Development of a cost-optimized hybrid off-grid power system for a model site in north-eastern India involving photovoltaic arrays, diesel generators and battery storage.' *International Journal of ChemTech Research*, 5(2) pp. 771–779.

RSPB (2014) 'Solar Energy, RSPB Policy Briefing.'

Rydell, J., Bogdanowicz, W., Boonman, A., Pettersson, S., Suchecka, E. and Pomorski, J. J. (2016) 'Bats may eat diurnal flies that rest on wind turbines.' *Mammalian Biology - Zeitschrift für Säugetierkunde*, 81(3) pp. 331–339.

Sadeghi, S. and Ameri, M. (2014) 'Multiobjective optimization of PV-bat-SOFC hybrid system: Effect of different fuels used in solid oxide fuel cell.' *Journal of Energy Engineering*, 140(2).

Sánchez-Lozano, J. M., Henggeler Antunes, C., García-Cascales, M. S. and Dias, L. C. (2014) 'GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain.' *Renewable Energy*. Centro Universitario de la Defensa de San Javier, Univ. Centre of Defence at the Spanish Air Force Academy, MDE-UPCT, C/ Coronel López Peña s/n, 30720 Santiago de la Ribera, Murcia, Spain, 66 pp. 478–494.

Scrase, I. and Gove, B. (2012) 'Meeting Europe's Renewable Energy Targets in Harmony with Nature.' *In Practice: Bulletin of the Institute of Ecology and Environmental Management*, 78 pp. 7–11.

SNH (2016a) 'Large scale solar photovoltaic installations: considering landscape, visual and ecological impacts.'

SNH (2016b) ‘Micro renewables and the natural heritage, Revised guidance.’

SRUC (n.d.) ‘Farm Scale Renewable Energy Guide.’ The Scottish Government’s Veterinary and Advisory Services Programme.

STA (2013) ‘Solar Farms: 10 Commitments.’ Solar Trade Association.

Stoll, E., Letschnik, J., Walter, U., Artigas, J., Kremer, P., Preusche, C. and Hirzinger, G. (2009) ‘On-orbit servicing.’ *IEEE Robotics and Automation Magazine*. Technische Universität München (TUM), Germany, 16(4) pp. 29–33.

Terzioglu, H., Kazan, F. A. and Arslan, M. (2015) ‘A new approach to the installation of solar panels.’ *In* Y., C., Y., D., and S., L. (eds) *2015 2nd International Conference on Information Science and Control Engineering, ICISCE 2015*. Electricity and Energy Department, Selçuk University, Vocational School of Technical Sciences, Selçuklu/Konya, Turkey: Institute of Electrical and Electronics Engineers Inc., pp. 573–577.

Thaxter, C. B., Ross-Smith, V. H., Clark, J. A., Clark, N. A., Conway, G. J., Marsh, M., Leat, E. H. K. and Burton, N. H. K. (2014) ‘A trial of three harness attachment methods and their suitability for long-term use on Lesser Black-backed Gulls and Great Skuas.’ *Ringing and Migration*. British Trust for Ornithology, The Nunnery, Thetford, Norfolk, United Kingdom: British Trust for Ornithology, 29(2) pp. 65–76.

Toral, G. M. and Figuerola, J. (2010) ‘Unraveling the importance of rice fields for waterbird populations in Europe.’ *Biodiversity and Conservation*. Department of Wetland Ecology, Doñana Biological Station, Avda. Américo Vespucio s/n 41092, P.O. Box 1056, 41080 Seville, Spain, 19(12) pp. 3459–3469.

Tucker, G., Bassi, S., Anderson, J., Chiavari, J., Casper, K. and Fergusson, M. (2008) *Provision of Evidence of the Conservation Impacts of Energy Production*. London.

Turney, D. and Fthenakis, V. (2011) ‘Environmental impacts from the installation and operation of large-scale solar power plants.’ *Renewable and Sustainable Energy Reviews*. Elsevier, 15(6) pp. 3261–3270.

Tyagi, V. V., Rahim, N. A. A., Rahim, N. A. and Selvaraj, J. A. /L. (2013) ‘Progress in solar PV technology: Research and achievement.’ *Renewable and Sustainable Energy Reviews*, 20, April, pp. 443–461.

Uprety, S. and Lee, H. (2014) ‘23.6 A 43V 400mW-to-21W global-search-based photovoltaic energy harvester with 350μs transient time, 99.9% MPPT efficiency, and 94% power efficiency.’ *In 2014 61st IEEE International Solid-State Circuits Conference, ISSCC 2014*. University of Texas, Dallas, Richardson, TX, United States, pp. 404–405.

Vasiljev, P., Borodinas, S., Bareikis, R. and Struckas, A. (2013) ‘Ultrasonic system for solar panel cleaning.’ *Sensors and Actuators, A: Physical*. Department of Physics, Lithuanian University of Educational Sciences, Laboratory of Ultrasonic Mechanisms, Vilnius, Lithuania, 200 pp. 74–78.

Walston, L. J., Rollins, K. E., LaGory, K. E., Smith, K. P. and Meyers, S. A. (2016) ‘A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States.’ *Renewable Energy*, 92, July, pp. 405–414.

van der Winden, J., van Vliet, F., Patterson, A. and Lane, B. (2014) ‘Renewable energy technologies and migratory species: guidelines for sustainable deployment.’ *In Convention on migratory species. 18th meeting of the scientific council*. Bonn, Germany.

Wybo, J.-L. (2013) ‘Large-scale photovoltaic systems in airports areas: safety concerns.’ *Renewable and Sustainable Energy Reviews*, 21, May, pp. 402–410.

Xie, L., Sun, Y., Li, X. and Hong, R. (2013) ‘The performance analysis of gird-connected PV system with some typical shading effects.’ *Zhongshan Daxue Xuebao/Acta Scientiarum Natralium Universitatis Sunyatseni*. Institute for Solar Energy Systems, Sun Yat-sen University, Guangzhou 510275, China, 52(6) pp. 129–132.

Appendices

Appendix 1: Scopus search results for birds and solar panels.

Search string

((TITLE-ABS-KEY("photovoltaic") AND TITLE-ABS-KEY("birds")) OR (TITLE-ABS-KEY("solar panels") AND TITLE-ABS-KEY("birds")) OR (TITLE-ABS-KEY("solar farm") AND TITLE-ABS-KEY("birds")))

Results

1. Terzioglu, H., Kazan, F. A. & Arslan, M. A new approach to the installation of solar panels. In *2015 2nd Int. Conf. Inf. Sci. Control Eng. ICISCE 2015* (Y., C., Y., D. & S., L.) 573–577 (Institute of Electrical and Electronics Engineers Inc., 2015). Doi:10.1109/ICISCE.2015.133

Relevant paper?	Y
Reason for inclusion in search results	• Mention of birds and renewables, including solar power.
If relevant, key points	• Very little. Uncited statement saying that wind energy can be damaging to birds, however insinuates that solar power is less damaging to nature and is more environmentally friendly than wind.

2. Mondal, A. K. & Bansal, K. Structural analysis of solar panel cleaning robotic arm. *Curr. Sci.* **108,** 1047–1052 (2015).

Relevant paper?	Y
Reason for inclusion in search results	• Paper about robotic cleaning arms. Bird droppings used as an example of dirt to be cleaned.
If relevant, key points	• Bird dropping presence infers presence of birds either above or on the solar panels.

3. Askarzadeh, A. & Dos Santos Coelho, L. Determination of photovoltaic modules parameters at different operating conditions using a novel bird mating optimizer approach. *Energy Convers. Manag.* **89,** 608–614 (2015).

Relevant paper?	N
Reason for inclusion in search results	• Uses a “bird mating optimizer” algorithm (mathematical model)
If relevant, key points	• Not relevant, but interesting to include as an example of off topic search results.

4. Herrero, R., Askins, S., Antón, I. & Sala, G. Evaluation of misalignments within a concentrator photovoltaic module by the module optical 55ypriote: A case of study concerning temperature effects on the module performance. *Jpn. J. Appl. Phys.* **54,** (2015).

Relevant paper?	N
Reason for inclusion in search results	• Unknown
If relevant, key points	• Not relevant

5. Mondal, A. K. & Bansal, K. A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels. *Adv. Robot.* **29,** 515–524 (2015).

Relevant paper?	Y
Reason for inclusion in search results	• Paper about robotic cleaning arms. Bird droppings used as an example of dirt to be cleaned.
If relevant, key points	• No access to full article • Bird dropping presence infers presence of birds either above or on the solar panels.

6. Liu, L.-Q. *et al.* Optimal azimuth and elevation angles prediction control method and structure for the dual-axis sun tracking system. *JVC/Journal Vib. Control* **21,** 402–407 (2015).

Relevant paper?	Y
Reason for inclusion in search results	• Paper about sun tracking, includes bird shadow as an obstacle to optimisation
If relevant, key points	• Bird shadow insinuates bird presence

- Access to full article not available

7. Uprety, S. & Lee, H. 23.6 A 43V 400mW-to-21W global-search-based photovoltaic energy harvester with 350µs transient time, 99.9% MPPT efficiency, and 94% power efficiency. In *2014 61st IEEE Int. Solid-State Circuits Conf. ISSCC 2014* **57,** 404–405 (2014).

Relevant paper?	Y
Reason for inclusion in search results	• Paper about Partial Shading Conditions (PSCs) and solar panels, includes bird shadow as an obstacle to optimisation
If relevant, key points	• Bird shadow insinuates bird presence

8. DeVault, T. L. *et al.* Bird use of solar photovoltaic installations at US airports: Implications for aviation safety. *Landsc. Urban Plan.* **122,** 122–128 (2014).

Relevant paper?	Y
Reason for inclusion in search results	• An experimental study on the effect of solar panels on birds
If relevant, key points	• The study is from the US and relates to airfields • The hypothesis is reversed- i.e. are birds attracted to solar panels and therefore do they pose a risk to aircraft safety (due to birdstrike) • “Photovoltaic arrays could potentially serve as attractants to birds hazardous to aviation because they provide shade and perches for birds” unsubstantiated • “Dark glass panels such as those used to construct PV arrays also reflect polarized light, which can attract insects (Horváth, Kriska, Malik, & Robertson, 2009), and subsequently, insectivorous birds. Relevant for bats too. • “in some situations reflected polarized light may cause structures such as glass panels to be mistaken by some birds species for open water, resulting in mortalities from collisions with these structures or

being stranded on surfaces from which they cannot take off (Horváth et al., 2009)."

- "solar development is generally considered detrimental to wildlife (Lovich & Ennen, 2011)"

9. Tapakis, R. & Charalambides, A. G. Enhanced values of global irradiance due to the presence of clouds in Eastern Mediterranean. *Renew. Energy* **62,** 459–467 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Heavy reference to an author called 'Bird'.
If relevant, key points	• Not relevant

10. Sánchez-Lozano, J. M., Henggeler Antunes, C., García-Cascales, M. S. & Dias, L. C. GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain. *Renew. Energy* **66,** 478–494 (2014).

Relevant paper?	Y/N
Reason for inclusion in search results	• Suitability modelling paper for allocation of solar panel locations in Spain. • SPA locations used as part of the model (to exclude areas that can't be built on).
If relevant, key points	• SPA locations used to exclude non suitable areas

11. Maghami, M. R., Hizam, H., Gomes, C. & Ismail, A. G. Characterization of dust materials on the surface of solar panel. *Life Sci. J.* **11,** 387–390 (2014).

Relevant paper?	Y/N
Reason for inclusion in search results	• Evidence of bird droppings in dirt on solar panels
If relevant, key points	• Bird droppings

12. Ghazi, S. & Ip, K. The effect of weather conditions on the efficiency of PV panels in the southeast of UK. *Renew. Energy* **69,** 50–59 (2014).

Relevant paper?	Y
Reason for inclusion in search results	• Heavy reference to bird droppings as a contaminant on solar panels. • Reference to solar panels being attractive to birds

due to heat.

If relevant, key points	• “the challenging problem is how to clean the bird droppings from the arrays when rain is infrequent during the summer months *while the bird are attracted to the warmth of the panels*”. Bad link to reference for this statement. No evidence presented.

13. Hansen, C. P., Rumble, M. A. & Gamo, R. S. Auxiliary VHF transmitter to aid recovery of solar argos/GPS PTTs. *USDA For. Serv. – Res. Note RMRS-RN* **72,** 1–13 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Paper about solar powered bird trackers
If relevant, key points	

14. Thaxter, C. B. *et al.* A trial of three harness attachment methods and their suitability for long-term use on Lesser Black-backed Gulls and Great Skuas. *Ringing Migr.* **29,** 65–76 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Paper about solar powered bird trackers
If relevant, key points	

15. Singh, A. & Dhawan, S. Airborne internet providing tethered balloon system. In *65th Int. Astronaut. Congr. 2014 Our World Needs Space, IAC 2014* **6,** 4204–4210 (International Astronautical Federation, IAF, 2014).

Relevant paper?	N
Reason for inclusion in search results	• Unknown. Paper about solar panels on balloons. No reference to birds
If relevant, key points	

16. Pareek, S. & Dahiya, R. Output power comparison of TCT and SP topologies for easy-to-predict partial shadow on a 4×4 PV field. *Int. Symp. Eng. Technol. ISET 2014* **612,** 71–76 (2014).

Relevant paper?	Y/N
Reason for inclusion in search results	• Paper about shading of solar panels, including birds.
If relevant, key points	• Full paper not available • Does not take into account bird shadow as they are deemed “difficult to predict”. • Mention of bird shadow insinuates presence of birds at solar arrays.

17. Gao, X., Yao, C., Gao, X. & Yu, Y. Identification of solar cell model parameters by combining analytical method with Nelder-Mead simplex method. *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.* **30,** 97–106 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Bird-Mating algorithm for design of solar panel arrays (not to do with ecology).
If relevant, key points	Not relevant.

18. ICMECE. 2013 3rd International Conference on Machinery Electronics and Control Engineering, ICMECE 2013. *2013 3rd Int. Conf. Mach. Electron. Control Eng. ICMECE 2013* **441,** (2014).

Relevant paper?	N
Reason for inclusion in search results	• Includes a presentation on mp3 bird scarers with a photosensitive module. No full text available, only title. Paper sourced via title, still no full text available to download.
If relevant, key points	Not relevant.

19. Gowri, N. V & Babu, G. S. A novel bidirectional DC-DC converter drive. In *2013 IEEE Int. Conf. Smart Struct. Syst. ICSSS 2013* 19–23 (2013). Doi:10.1109/ICSSS.2013.6622993

Relevant paper?	N
Reason for inclusion in search results	• Analogy to bird feathers. Not relevant.
If relevant, key points	Not relevant.

20. Xie, L., Sun, Y., Li, X. & Hong, R. The performance analysis of gird-connected PV system with some typical shading effects. *Zhongshan Daxue Xuebao/Acta Sci. Natralium Univ. Sunyatseni* **52,** 129–132 (2013).

Relevant paper?	Y/N
Reason for inclusion in search results	• Mention of bird droppings on solar panel as shading. • Poorly translated and full text unavailable.
If relevant, key points	Insinuates presence of birds at solar panel sites.

21. Weber, A. Volkswagen rethinks what it means to be green. *Assembly* **56,** (2013).

Relevant paper?	N
Reason for inclusion in search results	• Magazine article about Volkswagen site with solar panels. • Mention of birds on site, but not necessarily where the solar panels are.
If relevant, key points	Not relevant.

22. Vasiljev, P., Borodinas, S., Bareikis, R. & Struckas, A. Ultrasonic system for solar panel cleaning. *Sensors Actuators, A Phys.* **200,** 74–78 (2013).

Relevant paper?	Y/N
Reason for inclusion in search results	• Mentions bird droppings as contaminant. No reference.
If relevant, key points	• Quantifies potential energy losses. Not referenced.

23. Bouten, W., Baaij, E. W., Shamoun-Baranes, J. & Camphuysen, K. C. J. A flexible GPS tracking system for studying bird behaviour at multiple scales. *J. Ornithol.* **154,** 571–580 (2013).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered GPS tracker for birds.
If relevant, key points	Not relevant.

24. Chen, G.-J. Research and development of solar energy automatic bird expeller device. *2012 Int. Conf. Intell. Syst. Appl. Mater. GSAM 2012* **466-467,** 1181–1185 (2012).

Relevant paper?	N
Reason for inclusion in search results	• Mention of birds and solar panels, paper does not make sense.
If relevant, key points	Not relevant.

25. Maroufmashat, A., Seyyedyn, F., Roshandel, R. & Bouroshaki, M. Hydrogen generation optimization in a hybrid photovoltaic-electrolyzer using intelligent techniques. In *ASME 2012 10th Int. Conf. Fuel Cell Sci. Eng. Technol. FUELCELL 2012 Collocated with ASME 2012 6th Int. Conf. Energy Sustain.* 19–24 (American Society of Mechanical Engineers (ASME), 2012). Doi:10.1115/FuelCell2012-91512

Relevant paper?	N
Reason for inclusion in search results	• Power generation paper using "PSO". • "PSO is a novel method in optimization inspired from observation of bird flocking and fish schooling."
If relevant, key points	Not relevant.

26. Dorobantu, L., Popescu, M. O. & Popescu, C. L. Yield loss of photovoltaic panels caused by depositions. In *2011 7th Int. Symp. Adv. Top. Electr. Eng. ATEE 2011* (2011).

Relevant paper?	Y/N
Reason for inclusion in search results	• Mentions bird droppings as contaminant. No reference.
If relevant, key points	• Indicates presence of birds at or over solar farms. Not referenced.

27. Liu, C. & Liu, L. Particle SWARM optimization MPPT method for PV materials in partial shading. *2011 Int. Conf. Intell. Mater. Mech. Eng. MEE2011* **321,** 72–75 (2011).

Relevant paper?	Y/N
Reason for inclusion in search results	• Mentions birds as a cause of shadow over PV installation. • Full text not readily available
If relevant, key points	• Shadow indicates bird presence.

28. Lamont, L. A. & El Chaar, L. Enhancement of a stand-alone photovoltaic system's performance: Reduction of soft and hard shading. *Renew. Energy* **36,** 1306–1310 (2011).

Relevant paper?	Y
Reason for inclusion in search results	• Heavy mention of bird droppings and nests adversely affecting the operation of PV units. • Some emphasis on offshore rigs. • Discussion of methods for deterring birds.
If relevant, key points	• Pictures of bird droppings and bird nests on solar panels. Discusses different ways in which to repel birds. Including lights, buzzers, wipers, fishing wire, sirens and mention of chemical deterance (labelled as inhumane in paper).

29. Qu, F. & Li, C. Design of transmission line solar ultrasonic birds repeller. In *2011 IEEE Power Eng. Autom. Conf. PEAM 2011* **1,** 217–220 (IEEE Computer Society, 2011).

Relevant paper?	N
Reason for inclusion in search results	• Splar powered bird repeller. • Very badly translated and difficult to read.
If relevant, key points	

30. Hall, S. G., Smith, D. D. & Thompson, B. Autonomous aquatic vehicle fleet development: Sensors, communications and software. In *Am. Soc. Agric. Biol. Eng. Annu. Int. Meet. 2011* **3,** 1950–1960 (American Society of Agricultural and Biological Engineers, 2011).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered units that can be used for deterring predatory birds from aquaculture ponds.
If relevant, key points	

31. Kure, S. Give and take: A Texas school will make as much energy as it uses. *EC M Electr. Constr. Maint.* **109,** (2010).

Relevant paper?	N
Reason for inclusion in search results	• "Lady Bird Johnson Middle School" • Solar panels at this school
If relevant, key points	

32. Toral, G. M. & Figuerola, J. Unraveling the importance of rice fields for waterbird populations in Europe. *Biodivers. Conserv.* **19,** 3459–3469 (2010).

Relevant paper?	Y
Reason for inclusion in search results	Compares conversion of agricultural land to rice fields and to solar farms.
If relevant, key points	• Proposes that solar farms are more detrimental environmentally than rice fields. • “current solar energy projects in the Don˜ana area will transform about 1,000 ha of rice fields: this transformation of rice fields into solar farms may represent an important and silent secondary loss of wetlands in southern Europe” • No references to back this up, other than areas of solar farms.

33. Al-Dhaheri, S. M., Lamont, L. A., El-Chaar, L. & Al-Ameri, O. A. Automated design for boosting offshore photovoltaic (PV) performance. In *2010 IEEE PES Transm. Distrib. Conf. Expo. Smart Solut. A Chang. World* (2010). Doi:10.1109/TDC.2010.5484258

Relevant paper?	Y
Reason for inclusion in search results	• Very similar paper to 28. Bird nests, dropppings and shadow.
If relevant, key points	• Addresses the same issues and same solutions.

34. Conti, J. P. In search of the zero-emission continent. *Eng. Technol.* **4,** 46–49 (2009).

Relevant paper?	N
Reason for inclusion in search results	• Addresses installation of solar panels in Antarctica. • Full text not available.
If relevant, key points	

35. Ramesh, S., Sairam, M., Manoj Kumar, S., Sreekanth & Harikrishnan, R. The Martian man – A heuristic approach on robots to mars. In *2009 IEEE Int. Conf. Robot. Biomimetics, ROBIO 2009* 1099–1104 (2009). Doi:10.1109/ROBIO.2009.5420990

Relevant paper?	N
Reason for inclusion in	• Proposed design for a mars rover with “the feet of

search results	a bird, leg of a dinosaur and the body of a rat”.
If relevant, key points	

36. Stoll, E. *et al.* On-orbit servicing. *IEEE Robot. Autom. Mag.* **16,** 29–33 (2009).

Relevant paper?	N
Reason for inclusion in search results	• “bispectral infrared detection (BIRD)”
If relevant, key points	

37. Grivas, C. *et al.* An audio-visual nest monitoring system for the study and manipulation of siblicide in bearded vultures Gypaetus barbatus on the island of Crete (Greece). *J. Ethol.* **27,** 105–116 (2009).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered unit for nest monitoring Bearded vultures.
If relevant, key points	

38. Chung, O. Greening the gables. *Taiwan Rev.* **57,** 10–15 (2007).

Relevant paper?	N
Reason for inclusion in search results	• Mention of solar panels and mention of bird shelters, not in relation to one another.
If relevant, key points	

39. Colozza, A. Fly like a bird. *IEEE Spectr.* **44,** 38–43 (2007).

Relevant paper?	N
Reason for inclusion in search results	• Bird in title. • Flapping wing plane, with solar panels.
If relevant, key points	

40. Brinkworth, B. J. & Sandberg, M. Design procedure for cooling ducts to minimise efficiency loss due to temperature rise in PV arrays. *Sol. Energy* **80,** 89–103 (2006).

Relevant paper?	Y/N
Reason for inclusion in search results	• Paper about cooling ducts, mentions devices across duct inlet and outlets to exclude birds, insects and rain.
If relevant, key points	• Insinuates measures taken to prevent birds entering cooling ducts. Reasons unknown, likely for operation of duct rather than protection of birds.

41. Cruz, O. B. & Olavarrieta, L. D. A bird's eye view of materials and manufacturing processes for photovoltaic cells. In *15th Int. Conf. Electron. Commun. Comput. CONIELECOMP 2005* **2005,** 251–257 (2005).

Relevant paper?	N
Reason for inclusion in search results	• Bird in title. • Paper about PV cell fabrication.
If relevant, key points	

42. Nemerow, N. L. in *Environ. Solut.* 212–221 (Elsevier Inc., 2005). Doi:10.1016/B978-012088441-4/50011-3

Relevant paper?	Unknown
Reason for inclusion in search results	• This is a book, no access available
If relevant, key points	

43. Begonja, K. Rebuilding the gateway to Coney Island. *Railw. Gaz. Int.* **161,** 415 (2005).

Relevant paper?	Y/N
Reason for inclusion in search results	• Solar panels installed as a semi-transparent canopy • "Bird protection system in place". Protection of the canopy. No mention as to what this system involves.

If relevant, key points	• "A distinctive feature of the station is the 110m long triple-vaulted canopy. This incorporates 2730 photovoltaic semi-transparent glass panels" • "A bird protection system is installed on the shed trusses to train birds to avoid the glass canopy and keep them away from the public areas"

44. Childress, B. *et al.* Satellite tracking Lesser Flamingo movements in the Rift Valley, East Africa: Pilot study report. *Ostrich* **75,** 57–65 (2004).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered battery transmitters for satellite tracking Lesser flamingo.
If relevant, key points	

45. Photovoltaics Bulletin. RSPB, solarcentury join forces. *Photovoltaics Bull.* 4 (2003).

Relevant paper?	Y/N
Reason for inclusion in search results	• "Going solar" package: collaboration between RSPB, Solarcentury, RSPB Energy and Co-op bank. •
If relevant, key points	• Appears that RSPB have been on board with solar since 2003. Unclear as to how RSPB were involved. • "The RSPB is to install PV systems at six of its nature reserves — it manages 176 of these nationwide, covering 120 000 hectares" • From :http://www.energylinx.co.uk/rspb_energy.html "At the time when it was available, customers switching both their gas and electricity to RSPB Energy, enabled SSE to contribute £30 to the RSPB in the first year. Customers were not

	impacted by the closure of RSPB Energy at the end of March 2011 as they simply continued to be supplied by SSE on one of their standard price packages.”

46. Shapiro, F. R. Utilities in the sky?: Comparison of space-based and terrestrial solar power systems. *Refocus* **3,** 54–57 (2002).

Relevant paper?	Y/N
Reason for inclusion in search results	• Short mention of the environmental concerns of space based versus terrestrial solar generation
If relevant, key points	• Terrestrial and space based both block large areas of land. • Space based exposes large areas of land (mention of birds, plants and animals) to microwave radiation. • Concludes that terrestrial system have less of an impacts as they can be spread out over a large area, allow some sunlight to pass between generation units, and be positioned to avoid environmentally sensitive areas.

47. IECEC. 35th Intersociety Energy Conversion Engineering Conference and Exhibit 2000. In *35th Intersoc. Energy Convers. Eng. Conf. Exhib. 2000* (2000).

Relevant paper?	N
Reason for inclusion in search results	• Not a paper, but a collection of 849 papers from a research conference. • Search of titles within the proceedings yielded no hits for “bird” and all hits for “solar” did not yield any relevant titles.
If relevant, key points	

48. Kattakayam, T. A., Khan, S. & Srinivasan, K. Diurnal and environmental characterization of solar photovoltaic panels using a PC-AT add on plug in card. *Sol. Energy Mater. Sol. Cells* **44,** 25–36 (1996).

Relevant paper?	N
Reason for inclusion in search results	• Technical paper on solar panel performance. • Refers to 'bird beak' as a means of describing a data pattern.
If relevant, key points	

49. Anon. Electronic sound system rids platforms of seagulls. *Oil Gas J.* **94,** 64 (1996).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered gull repeller for offshore oil/gas platforms.
If relevant, key points	

50. Long, F. M. & Weeks, R. W. WILDLIFE BIOTELEMETRY. *IEEE Eng Med Biol Soc Annu Conf, 1st, Fron Eng Heal. Care* 256–259 (1979).

Relevant paper?	N
Reason for inclusion in search results	• Discussion of wildlife biotelemetry including reference to a Solar powered biotelemetry unit.
If relevant, key points	

51. Maag Jr., C. R. OUTDOOR WEATHERING PERFORMANCE OF SOLAR ELECTRIC GENERATORS. *J Energy* **1,** 376–381 (1977).

Relevant paper?	Y/N
Reason for inclusion in search results	• Old paper looking at the effect of weathering and exposure on PV cells. • No access to full paper, reference in abstract as "unwelcome migratory birds" as an environmental variable that may affect PV performance.
If relevant, key points	• Early paper indicating potential for conflict between birds and solar panels.

52. Klaassen, R. . b c, Schlaich, A. E. . b, Bouten, W. ., Both, C. . d & Koks, B. J. . First results of year-round tracking of Hen Harriers Circus cyaneus breeding in the agricultural landscape of East. *Limosa* **87,** 135–148 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered GPS trackers for Hen Harriers.
If relevant, key points	

53. Herden, C., Geiger, S. & Milašauskaitė, E. Regional impacts of renewable energy expansion on nature and landscape outcomes of an r&d project [Regionale Auswirkungen des Ausbaus der erneuerbaren Energien auf Natur und Landschaft Teilergebnisse eines F + E-Vorhabens]. *Natur und Landschaft* **87,** 531–537 (2012).

Relevant paper?	Y
Reason for inclusion in search results	• Bought article as appears relevant- waiting for delivery • Article in German • Appear to look at effect of renewables on ecology. • Needs translating.
If relevant, key points	• Significant negative impacts of ground-based photovoltaic arrays on species have not been found.

54. Lundberg, K. 25 years ago. *IEEE Control Syst. Mag.* **30,** 11+21 (2010).

Relevant paper?	N
Reason for inclusion in search results	• Paper about control systems in spacecraft. • Refers to launching " a bird"- which is not literal.
If relevant, key points	

55. b c, R. & Mathur, B. L. . MATLAB based modelling to study the influence of shading on series connected SPVA. In *2009 2nd Int. Conf. Emerg. Trends Eng. Technol. ICETET 2009* 30–34 (2009). Doi:10.1109/ICETET.2009.142

Relevant paper?	Y/N
Reason for inclusion in search results	• Paper looking at shading of solar panels.
If relevant, key points	• Refers to birds and "bird litter" as causes of shading in abstract. No reference to birds in the main text.

56. Jessel, B. . & Kuler, B. . Evaluation of standalone photovoltaic power plants [Naturschutzfachliche beurteilung von freiland-photovoltaikanlagen]. *Naturschutz und Landschaftsplan.* **38,** 225–232 (2006).

Relevant paper?	Y
Reason for inclusion in search results	• Discussion of the impact of solar panels on ecology, including birds.
If relevant, key points	• In German. Needs translating.

57. Hadjisterkotis, E. . b. The survival of captive bred chukar Alectoris chukar 70ypriotes, released for restocking in Cyprus [Überlebenschancen von in Gefangenschaft aufgezogenen und zur Bestandsaufstockung ausgewilderten Chukarhühnern (Alectoris chukar 70ypriotes)]. *Z. Jagdwiss.* **45,** 238–249 (1999).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered radio transmitters for birds.
If relevant, key points	

58. Von Hadjisterkotis, E. . b c. The survival of captive bred chukar alectoris chukar 70ypriotes, released for restocking in Cyprus [Überlebenschancen von in gefangenschaft aufgezogenen und zur bestandsaufstockung ausgewilderten chukarhühnern (Alectoris chukar 70ypriotes)]. *Eur. J. Wildl. Res.* **45,** 238–249 (1999).

Relevant paper?	N
Reason for inclusion in search results	• Solar powered radio transmitters for birds.
If relevant, key points	

Appendix 2: Scopus search results for bats and solar panels.

Search string

((TITLE-ABS-KEY(photovoltaic) AND TITLE-ABS-KEY(bats)) OR (TITLE-ABS-KEY(solar panels) AND TITLE-ABS-KEY(bats)) OR (TITLE-ABS-KEY(solar farm) AND TITLE-ABS-KEY(bats)))

Results

1. Herden, C., Geiger, S. & Milašauskaitė, E. Regional impacts of renewable energy expansion on nature and landscape outcomes of an r&d project [Regionale Auswirkungen des Ausbaus der erneuerbaren Energien auf Natur und Landschaft Teilergebnisse eines F + E-Vorhabens]. *Natur und Landschaft* **87,** 531–537 (2012).

Relevant paper?	Y
Reason for inclusion in search results	• Bought article as appears relevant- waiting for delivery • Article in German • Appear to look at effect of renewables on ecology. • Needs translating. • Does not appear to be hugely relevant. More emphasis on wind and biogas.
If relevant, key points	• Significant negative impacts of ground-based photovoltaic arrays on species have not been found.

2. Oshaba, A. S. ., Ali, E. S. . & Abd Elazim, S. M. . MPPT control design of PV system supplied SRM using BAT search algorithm. *Sustain. Energy, Grids Networks* **2,** 51–60 (2015).

Relevant paper?	N
Reason for inclusion in search results	• Technical paper about PV units. • BAT search algorithm
If relevant, key points	

3. PSC. 2015 Clemson University Power Systems Conference, PSC 2015. In *2015 Clemson Univ. Power Syst. Conf. PSC 2015* (2015).

Relevant paper?	N
Reason for inclusion in search results	• "Bat and flower pollination algorithm" for power flow optimisation.
If relevant, key points	

4. Sadeghi, S. & Ameri, M. Multiobjective optimization of PV-bat-SOFC hybrid system: Effect of different fuels used in solid oxide fuel cell. *J. Energy Eng.* **140,** (2014).

Relevant paper?	N
Reason for inclusion in search results	• Looks at solar panels and batteries- abbreviates battery to BAT.
If relevant, key points	

5. Baniasad Askari, I. ., Baniasad Askari, L. ., Kaykhah, M. M. . & Baniasad Askari, H. . Optimisation and techno-economic feasibility analysis of hybrid (photovoltaic/wind/fuel cell) energy systems in Kerman, Iran; considering the effects of electrical load and energy storage technology. *Int. J. Sustain. Energy* **33,** 635–649 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Technical paper looking a hybrid power generation systems. Includes "bat"- probably an abbreviation of battery.
If relevant, key points	

6. Tabassum, -A., Premalatha, M., Abbasi, T. & Abbasi, S. A. Wind energy: Increasing deployment, rising environmental concerns. *Renew. Sustain. Energy Rev.* **31,** 270–288 (2014).

Relevant paper?	Y/N
Reason for inclusion in search results	• Opening line of abstract: "Of all the renewable energy sources (RESs)—except direct solar heat and light—wind energy is believed to have the least adverse environmental impacts". Not really sure what this means- not expanded upon in text.
If relevant, key points	• "With competition for uninhabited spaces increasing due to the needs of other space-consuming renewable–based power generation

systems such as solar thermal/solar photovoltaic and small hydropower, it will become increasingly difficult to find sites for wind farms that would not jeopardize the few remaining areas of wilderness"

- Highlights the potential cumulative impact of renewable developments

7. Munshi, A. A. A. & Mohamed, Y. A.-R. I. Photovoltaic power pattern grouping based on bat bio-inspired clustering. In *2014 IEEE 40th Photovolt. Spec. Conf. PVSC 2014* 1461–1466 (2014). Doi:10.1109/PVSC.2014.6925191

Relevant paper?	N
Reason for inclusion in search results	• Technical paper using a bio-inspired "Bat clustering method" for analysing power distribution in solar arrays.
If relevant, key points	

8. Ramawan, M. K., Othman, Z., Sulaiman, S. I., Musirin, I. & Othman, N. A hybrid bat algorithm artificial neural network for grid-connected photovoltaic system output prediction. in *Proc. 2014 IEEE 8th Int. Power Eng. Optim. Conf. PEOCO 2014* 619–623 (2014). doi:10.1109/PEOCO.2014.6814502

Relevant paper?	N
Reason for inclusion in search results	• Bat Algorithm-Artificial Neural Network analysis to predict output power of PV systems.
If relevant, key points	

9. Bahmani-Firouzi, B. & Azizipanah-Abarghooee, R. Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm. *Int. J. Electr. Power Energy Syst.* **56,** 42–54 (2014).

Relevant paper?	N
Reason for inclusion in search results	• Optimization of power distribution in PV systems using bat algorithm**.**
If relevant, key points	

10. Thounthong, P. . *et al.* Differential flatness control approach for fuel cell/solar cell power plant with Li-ion battery storage device for grid-independent applications. in *2014 Int.*

Symp. Power Electron. Electr. Drives, Autom. Motion, SPEEDAM 2014 261–266 (2014). doi:10.1109/SPEEDAM.2014.6872100

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	

11. Benaouadj, M. . *et al.* Flatness control of batteries/supercapacitors hybrid sources for electric traction. in *Int. Conf. Power Eng. Energy Electr. Drives* 141–146 (2013). doi:10.1109/PowerEng.2013.6635595

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to BAT.
If relevant, key points	

12. Ray, S. ., Chakraborty, A. K. . & Debnath, D. . Development of a cost-optimized hybrid off-grid power system for a model site in north-eastern India involving photovoltaic arrays, diesel generators and battery storage. *Int. J. ChemTech Res.* **5,** 771–779 (2013).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to BAT.
If relevant, key points	

13. Askari, I. B. . b & Ameri, M. . b. Techno-economic feasibility analysis of stand-alone renewable energy systems (PV/bat, wind/bat and hybrid PV/wind/bat) in Kerman, Iran. *Energy Sources, Part B Econ. Plan. Policy* **7,** 45–60 (2012).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	

14. Baniasad Askari, I. . b & Ameri, M. . b. The effect of fuel price on the economic analysis of hybrid (photovoltaic/diesel/battery) systems in Iran. *Energy Sources, Part B Econ. Plan. Policy* **6,** 357–377 (2011).

Relevant paper?	Y/N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	• Some reference to the benefits of renewables over fossil fuels at to reduce pollution.

15. Kaldellis, J. K. ., Zafirakis, D. . & Kondili, E. . Energy pay-back period analysis of stand-alone photovoltaic systems. *Renew. Energy* **35,** 1444–1454 (2010).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	

16. Malek, M. F. . *et al.* Monitoring of a 1 kWp solar photovoltaic system. in *AIP Conf. Proc.* **1136,** 621–626 (2009).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	

17. Kaldellis, J. K. ., Zafirakis, D. . & Kondili, E. . Optimum autonomous stand-alone photovoltaic system design on the basis of energy pay-back analysis. *Energy* **34,** 1187–1198 (2009).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.
If relevant, key points	

18. Baniasad Askari, I. B. . b & Ameri, M. . b. Optimal sizing of photovoltaic-battery power systems in a remote region in Kerman, Iran. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **223,** 563–570 (2009).

Relevant paper?	N
Reason for inclusion in search results	• Combination of PV and batteries abbreviated to bat.

If relevant, key points

19. Flinn, S. C. Greening on a shoestring. *Altern. J.* **33,** 18–19 (2007).

Relevant paper?	N
Reason for inclusion in search results	Mention of solar panels and “fiberglass bats for the insulation”.
If relevant, key points	

20. Salas, V., Olias, E., Rascon, M., Vazquez, M. & Quinones, C. Hybrid powering system for stand-alone remote telecom applications. in *INTELEC, Int. Telecommun. Energy Conf.* 311–316 (2000).

Relevant paper?	N
Reason for inclusion in search results	Combination of PV and batteries abbreviated to BAT.
If relevant, key points	

21. Salas, V., Olias, E., Quiñones, C., Vázquez, M. & Rascón, M. Application of hybrid power systems of low power to the remote radio equipment telecommunication. in *IEEE Int. Symp. Ind. Electron.* **1,** 174–178 (2000).

Relevant paper?	N
Reason for inclusion in search results	Combination of PV and batteries abbreviated to BAT.
If relevant, key points	

Appendix 3: Scopus search results for general ecology and solar panels.

Search string

((TITLE-ABS-KEY("photovoltaic") AND TITLE-ABS-KEY(ecolog*)) OR (TITLE-ABS-KEY("solar panels") AND TITLE-ABS-KEY(ecolog*)) OR (TITLE-ABS-KEY("solar farm") AND TITLE-ABS-KEY(ecolog*)))

Results

1. Weinberg, S. A relative irradiance meter for submarine ecological measurements. *Netherlands J. Sea Res.* **8,** 354–360 (1974).

2. Moses, H. Impacts of Satellite Power System technology. *Energy* **4,** 799–809 (1979).

3. Coleman, M. G., Grenon, L. A. & Hild, Environmental control: an evaluation of the economic and ecological requirements for the silicon photovoltaic industry. in *Conf. Rec. IEEE Photovolt. Spec. Conf.* 1042–1048 (1980).

4. Moses, H. IMPACTS OF SATELLITE POWER SYSTEM TECHNOLOGY. *Solid State Ionics* 799–809 (1980).

5. PLEA. PASSIVE AND LOW ENERGY ECOTECHNIQUES, PROCEEDINGS OF THE THIRD INTERNATIONAL PLEA CONFERENCE. in (1985).

6. Kuenstle, K., Reiter, K. & Riedle, K. Possibilities and limitations for the supply of renewable energy [Moeglichkeiten und Grenzen der regenerativen Energien]. *VGB-Kraftwerkstechnik* **70,** 106–114 (1990).

7. Wolfe, P. & Murray, A. Solar photovoltic systems for rural communications. in *IEE Conf. Publ.* 137–140 (1990).

8. El-Bakry, M. A. & El-Hagry, M. T. Multiprocessor structure for managing multi-nature energy sources. in *IECON Proc. (Industrial Electron. Conf.* **3,** 1851–1854 (1991).

9. Schley, W. RWE Energie traps the sun [RWE Energie zapft die Sonne an]. *StromThemen* **8,** 4–5 (1991).

10. Schwerdhelm, R. The application of solar energy for the aeration of lakes and [Der Einsatz von Solarenergie zur Hypolimnionbeluftung]. *GWF WASSER ABWASSER* **133,** 348–353 (1992).

11. Knaupp, W. & Schafer, I. Solar powered airship - challenge and chance. in *Conf. Rec. IEEE Photovolt. Spec. Conf.* 1314–1319 (1993).

12. Lozar, C. C. D. Advanced technology proposals for infrastructure rebuilding for sustainable development. in *Proc. Infrastruct. Plan. Manag.* 217–221 (1993).

13. McEvoy, A. J. Outlook for photovoltaic electricity. *Endeavour* **17,** 17–20 (1993).

14. Nishinoiri, K., Warabisako, M. & Ishimaru, N. Development of photovoltaic power generation technology. *Hitachi Rev.* **42,** 235–242 (1993).

15. Moskowitz, P. D., Steinberger, H. & Thumm, W. Health and environmental hazards of CdTe photovoltaic module production, use and decommissioning. in *Conf. Rec. IEEE Photovolt. Spec. Conf.* **1,** 115–118 (1994).

16. Nijs, J. Photovoltaic cells and modules: Technical and economic outlook towards the year 2000. *Int. J. Sol. Energy* **15,** 91–122 (1994).

17. Rudischer, R. & Ulbrich, G. Transportable stand-alone solar immission measuring station with optimised photovoltaic energy supply. in *Conf. Rec. IEEE Photovolt. Spec. Conf.* **1,** 1161–1164 (1994).

18. Haas, R. The value of photovoltaic electricity for society. *Sol. Energy* **54,** 25–31 (1995).

19. Chendo, M. A. C. Photovoltaic development and diffusion in Nigeria: Its potential for human development Index. *Renew. Energy* **10,** 149–152 (1997).

20. Hanžič, A. . b c & Voršič, J. . d e f g. Economical authorization of building a photovoltaic system [Ekonomska upravičenost postavitve fotonapetostnega sistema]. *Elektroteh. Vestnik/Electrotechnical Rev.* **64,** 189–193 (1997).

21. Murthy, M. R. L. N. Solar cell materials, technologies, applications and their impact on developing countries. *Int. J. Mater. Prod. Technol.* **12,** 172–209 (1997).

22. Sørensen, B. Long-term scenarios for the integration of photovoltaics into the global energy system. *Sol. Energy Mater. Sol. Cells* **47,** 203–211 (1997).

23. Badescu, V. Model for a solar-assisted climatization system. *Energy* **23,** 753–766 (1998).

24. Kobayashi, H., Kresling, B. & Vincent, J. F. V. The geometry of unfolding tree leaves. *Proc. R. Soc. B Biol. Sci.* **265,** 147–154 (1998).

25. Quinones, C., Vazquez, M., del Prado, A., de la Cruz, E. & Garrido, A. Technical and economical comparison of photovoltaic solar system and AC mains powering for advanced Optical Network Units at remote sites. in *INTELEC, Int. Telecommun. Energy Conf.* 790–796 (1998).

26. Turner, C. D. Teaching sustainable design using engineering economics. in *ASEE Annu. Conf. Proc.* 8pp (1998).

27. Yang, J. C. Advances in amorphous silicon alloy technology - The achievement of high-efficiency multijunction solar cells and modules. *Prog. Photovoltaics Res. Appl.* **6,** 181–186 (1998).

28. NA. Air conditioning-/refrigeration engineering. Refrigerant supply of the new Munich fair runs according to plan [Klima-/kältetechnik. Kälteversorgung der neuen messe München läuft planmäßig]. *HLH Heizung Luftung/Klima Haustechnik* **50,** 70 (1999).

29. Dunn, S. Micropower: Electrifying the digital economy. *Greener Manag. Int.* 43–56 (2000).

30. Muntasser, M. A. & Mozgovoy, A. G. Practical solar photovoltaic application in the international energy foundation. *Appl. Sol. Energy (English Transl. Geliotekhnika)* **36,** 12–18 (2000).

31. Ou, S. . *et al.* Prospect of building integrated photovoltaic system in China. *Taiyangneng Xuebao/Acta Energiae Solaris Sin.* **21,** 434–438 (2000).

32. Salas, V., Olias, E., Rascon, M., Vazquez, M. & Quinones, C. Hybrid powering system for stand-alone remote telecom applications. in *INTELEC, Int. Telecommun. Energy Conf.* 311–316 (2000).

33. Applebaum, J. . e *et al.* Aeration of fishponds by photovoltaic power. *Prog. Photovoltaics Res. Appl.* **9,** 295–301 (2001).

34. Sangpetch, T. . b, Galloway, S. J. ., Burt, G. M. . & McDonald, J. R. . Risk and distributed generation in a competitive energy market. in *Proc. Univ. Power Eng. Conf.* **36,** 945–949 (2001).

35. Badescu, V. First and second law analysis of a solar assisted heat pump based heating system. *Energy Convers. Manag.* **43,** 2539–2552 (2002).

36. Bakos, G. C. . & Soursos, M. . Technical feasibility and economic viability of a grid-connected PV installation for low cost electricity production. *Energy Build.* **34,** 753–758 (2002).

37. Çelebi, G. Using principles of photovoltaic panels on vertical building envelope [Bina düşey kabuğunda fotovoltaik panellerin kullanim ilkeleri]. *J. Fac. Eng. Archit. Gazi Univ.* **17,** 17–33 (2002).

38. Jack, D. A. ., Nakamura, T. ., Sadler, P. . & Cuello, J. L. . c. Evaluation of two fiber optic-based solar collection and distribution systems for advanced space life support. *Trans. Am. Soc. Agric. Eng.* **45,** 1547–1558 (2002).

39. Kucera, S. ., Kučera, M. . & Boroška, J. . Distribution of power output in the hybrid passenger automobile. *Mech. Mech. Eng.* **6,** 33–40 (2002).

40. NA. Germany urges integration, Japan proves flexible. *Photovoltaics Bull.* 4 (2002).

41. Pearce, J. . & Lau, A. . Net energy analysis for sustainable energy production from silicon based solar cells. in *Int. Sol. Energy Conf.* 181–186 (2002). doi:10.1115/SED2002-1051

42. Popov, V. P. *et al.* Properties of silicon oversaturated with implanted hydrogen. *Thin Solid Films* **403-404,** 500–504 (2002).

43. Brogren, M. . & Green, A. . Hammarby Sjöstad-an interdisciplinary case study of the integration of photovoltaics in a new ecologically sustainable residential area in Stockholm. *Sol. Energy Mater. Sol. Cells* **75,** 761–765 (2003).

44. Buchholz, B. M. & Boese, C. The impact of dispersed power generation in distribution systems. in *CIGRE/IEEE PES Int. Symp. Qual. Secur. Electr. Power Deliv. Syst. CIGRE/PES 2003* 198–203 (2003). doi:10.1109/QSEPDS.2003.159820

45. Chiriac, F., Dumitrescu, R., Ilie, A., Gavriliuc, R. & Pirvu, C. Hybrid ammonia water absorption system of small and medium capacity. in *Am. Soc. Mech. Eng. Adv. Energy Syst. Div. AES* **43,** 97–101 (2003).

46. Doi, T. ., Tsuda, I. ., Sakuta, K. . & Matsui, G. . Development of a recyclable PV-module: Trial manufacturing and evaluation. in *Proc. 3rd World Conf. Photovolt. Energy Convers.* **B,** 1952–1955 (2003).

47. Góralczyk, M. Life-cycle assessment in the renewable energy sector. *Appl. Energy* **75,** 205–211 (2003).

48. Melero, A. *et al.* Application of thermoelectricity and photovoltaic energy to air conditioning. in *Int. Conf. Thermoelectr. ICT, Proc.* **2003-Janua,** 627–630 (2003).

49. Salameh, Z. M. & Davis, A. J. Case Study of A Residential-Scale Hybrid Renewable Energy Power System in an Urban Setting. in *2003 IEEE Power Eng. Soc. Gen. Meet. Conf. Proc.* **4,** 2320–2322 (2003).

50. Sanchez, K. *et al.* Solar Cell Analysis with Light Emission and OBIC Techniques. *Microelectron. Reliab.* **43,** 1755–1760 (2003).

51. Ashraf, I., Chandra, A. & Sodha, M. S. Techno-economic and environmental analysis for grid interactive solar photovoltaic power system of Lakshadweep islands. *Int. J. Energy Res.* **28,** 1033–1042 (2004).

52. Brabec, C. J. Organic photovoltaics: Technology and market. *Sol. Energy Mater. Sol. Cells* **83,** 273–292 (2004).

53. Keong, C. Y. . b. Sustainable Energy Strategy for the New Millennium - The Bakun's Dam Strategy Versus Photovoltaic Technology. *Energy Sources* **26,** 205–213 (2004).

54. NA. How innovation supports sustainability. *Chem. Week* **166,** 16 (2004).

55. Stecky, N. Renewable energy for high-performance buildings in New Jersey: Discussion of PV, wind power, and biogas and New Jersey's incentive programs. in *2004 Winter Meet. - Tech. Symp. Pap. Am. Soc. Heating, Refrig. Air-Conditioning Eng.* 587–594 (2004).

56. Agbossou, K. . b, Doumbia, M. L. . b & Anouar, A. . Optimal hydrogen production in a stand-alone renewable energy system. in *Conf. Rec. - IAS Annu. Meet. (IEEE Ind. Appl. Soc.* **4,** 2932–2936 (2005).

57. Belov, E. P. . et al. New chlorine-free solar-grade silicon technology. in Proc. Sol. World Congr. 2005 Bringing Water to World, Incl. Proc. 34th ASES Annu. Conf. Proc. 30th Natl. Passiv. Sol. Conf. **2,** 1064–1069 (2005).

58. Dewulf, J. & Van Langenhove, H. Integrating industrial ecology principles into a set of environmental sustainability indicators for technology assessment. *Resour. Conserv. Recycl.* **43,** 419–432 (2005).

59. Lapithis, P. A. Importance of passive solar design for Cyprus. in Proc. Sol. World Congr. 2005 Bringing Water to World, Incl. Proc. 34th ASES Annu. Conf. Proc. 30th Natl. Passiv. Sol. Conf. **1,** 13–18 (2005).

60. Larbi, N. An overview of hybrid Solid Oxide Fuel Cells (SOFCS) power systems. in *Proc. 1st Eur. Fuel Cell Technol. Appl. Conf. 2005 - B. Abstr.* **2005,** 256 (2005).

61. Naveh, Z. Toward a transdisciplinary landscape science. Issues Perspect. Landsc. Ecol. (2005). doi:10.1017/CBO9780511614415.034

62. Peharz, G. & Dimroth, F. Energy payback time of the high-concentration PV system FLATCON®. *Prog. Photovoltaics Res. Appl.* **13,** 627–634 (2005).

63. Ribeiro, H. P. & Da Motta, A. L. T. S. Solar energy systems and environmental comfort techniques for an allotment in rio das ostras district - RJ, Brazil. in *Proc. Sol. World Congr. 2005 Bringing Water to World, Incl. Proc. 34th ASES Annu. Conf. Proc. 30th Natl. Passiv. Sol. Conf.* **1,** 625–630 (2005).

64. Riffel, S. iRoof/iWall - Electricity, heating and cooling through intelligent precast elements the concept [iRoof/iWall - Strom, Wärme und Kühlung mit intelligenten Fertigteilen aus Beton - das Konzept]. *Betonw. und Fert. Precast. Plant Technol.* **71,** 50–51 (2005).

65. Shrestha, J. N. Performance of solar powered water pumping systems in Nepal: An analysis. in Proc. Sol. World Congr. 2005 Bringing Water to World, Incl. Proc. 34th ASES Annu. Conf. Proc. 30th Natl. Passiv. Sol. Conf. **4,** 2951–2955 (2005).

66. Strebkov, D. S. & Irodionov, A. E. PV research and technological development in Russia. in Proc. Sol. World Congr. 2005 Bringing Water to World, Incl. Proc. 34th ASES Annu. Conf. Proc. 30th Natl. Passiv. Sol. Conf. **2,** 1120–1125 (2005).

67. ASME. Proceedings of the ASME International Solar Energy Conference - Solar Engineering 2006. in *Int. Sol. Energy Conf.* **2006,** (2006).

68. Dimroth, F. High-efficiency solar cells from III-V compound semiconductors. in *Phys. Status Solidi C Conf.* **3,** 373–379 (2006).

69. Fernández-Infantes, A. ., Contreras, J. . & Bernal-Agustín, J. L. . Design of grid connected PV systems considering electrical, economical and environmental aspects: A practical case. *Renew. Energy* **31,** 2042–2062 (2006).

70. Hirschberg, S. *et al.* Sustainability of current electricity supply technologies: A comparative evaluation. in *Proc. 8th Int. Conf. Probabilistic Saf. Assess. Manag. PSAM 2006* (2006).

71. Jessel, B. . & Kuler, B. . Evaluation of standalone photovoltaic power plants [Naturschutzfachliche beurteilung von freiland-photovoltaikanlagen]. *Naturschutz und Landschaftsplan.* **38,** 225–232 (2006).

72. Lafferty, J. C. Extreme protection. *Ind. Fabr. Prod. Rev.* **91,** 40–44 (2006).

73. Makhkamdjanov, B. M. Cars with hybrid drive and elektrocarsa way to decision of the ecological problems in Uzbekistan. *Renew. Energy* **31,** 611–616 (2006).

74. Müller, A. ., Wambach, K. . & Alsema, E. . Life cycle analysis of solar module recycling process. in *Mater. Res. Soc. Symp. Proc.* **895,** 89–94 (2006).

75. NA. The Polliniferoused Container: An opportunity for the maritime industry. *HSB Int.* **55,** 30–31 (2006).

76. Pehnt, M. Dynamic life cycle assessment (LCA) of renewable energy technologies. *Renew. Energy* **31,** 55–71 (2006).

77. Randall, J. F. Designing Indoor Solar Products: Photovoltaic Technologies for AES. Des. Indoor Sol. Prod. Photovolt. Technol. AES (2006). doi:10.1002/0470017155

78. Biagioni, E. S. Practical experience with an experimental wireless sensor network for environmental observations. Multi-Hop Ad Hoc Networks from Theory to Real. (2007).

79. Grzela, G. Energy - Spread generation. in *AIP Conf. Proc.* **958,** 213–214 (2007).

80. Liberati, A. & Luu, S. Trim direction. *Text. View2 Mag.* 132–139 (2007).

81. McHugh, K. E. & Gabriel, P. F. HDD utility tunnel to peddocks Island - Fort andrews. in *Pipelines 2007 Adv. Exp. with Trenchless Pipeline Proj. - Proc. ASCE Int. Conf. Pipeline Eng. Constr.* 48 (2007). doi:10.1061/40934(252)48

82. Szargut, J. & Stanek, W. Thermo-ecological optimization of a solar collector. *Energy* **32,** 584–590 (2007).

83. Vlk, R. Modification of control system of solar panels. in *Proc. 8th Int. Sci. Conf. Electr. Power Eng. 2007, EPE 2007* 415–419 (2007).

84. Wedde, H. F. ., Lahnhoff, S. ., Handschin, E. . & Krause, O. . Decentralized electric power grid architecture and management for reliable and cost-effective supply (DEZENT) [Dezentrale Vernetzte Energiebewirtschaftung (DEZENT) im Netz der Zukunft]. *Wirtschaftsinformatik* **49,** 361–369 (2007).

85. Balas, V. E., Balas, M. M. & Putin-Racovita, M. V. Passive greenhouses and ecological reconstruction. in *12th Int. Conf. Intell. Eng. Syst. - Proceedings, INES 2008* 77–82 (2008). doi:10.1109/INES.2008.4481273

86. Denholm, P. . & Margolis, R. M. . Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. *Energy Policy* **36,** 3531–3543 (2008).

87. Klenk, I. & Kunz, M. European bioethanol from grain and sugarbeet from an economic and ecological viewpoint (2nd Part) [Europäisches Bioethanol aus Getreide und Zuckerrüben - Eine Ökologische und Ökonomische Analyse (2. Teil)]. *Zuckerindustrie* **133,** 710–718 (2008).

88. Mikhailova, M. P. . *et al.* Photovoltaic detector based on type II p-InAs/AlSb/InAsSb/AlSb/p-GaSb heterostructures with a single quantum well for mid-infrared spectral range. in *Proc. SPIE - Int. Soc. Opt. Eng.* **7138,** (2008).

89. Nishida, Y. ., Sumiyoshi, S. . & Omori, H. . Integrated power converter for photovoltaic and fuel cell systems in home. in *2008 13th Int. Power Electron. Motion Control Conf. EPE-PEMC 2008* 2530–2537 (2008). doi:10.1109/EPEPEMC.2008.4635644

90. Pearce, J. M. Industrial symbiosis of very large-scale photovoltaic manufacturing. *Renew. Energy* **33,** 1101–1108 (2008).

91. Siracusa, G., La Rosa, A. D., Palma, P. & La Mola, E. New frontiers for sustainability: Emergy evaluation of an eco-village. *Environ. Dev. Sustain.* **10,** 845–855 (2008).

92. Teal, R. Placing the fourfold: Topology as environmental design. *Footprint* 65–78 (2008).

93. Tovar-Pescador, J. Modelling the statistical properties of solar radiation and proposal of a technique based on boltzmann statistics. Model. Sol. Radiat. Earth’s Surf. Recent Adv. (2008). doi:10.1007/978-3-540-77455-6_3

94. Wakeham, D. L., Donne, S. W., Belcher, W. J. & Dastoor, P. C. Electrochemical and morphological characterization of electrodeposited poly(2,2′:5′,2″-terthiophene) for photovoltaic applications. *Synth. Met.* **158,** 661–669 (2008).

95. Amon, A. Lightening solar: The emphemeralization of energy production. in *38th ASES Natl. Sol. Conf. 2009, Sol. 2009* **3,** 1686–1709 (2009).

96. Amon, A. The skinny on photovoltaics using fabric and where to find it. *Fabr. Archit.* **21,** 26–30 (2009).

97. Bălaş, M. M. . *et al.* On a promising sustainable energy system and its control - The passive greenhouse. in *Proc. - 2009 3rd Int. Work. Soft Comput. Appl. SOFA 2009* 235–240 (2009). doi:10.1109/SOFA.2009.5254844

98. Barranco-Jiménez, M. A. ., Arias-Hernández, L. A. . & Angulo-Brown, F. . Study on the intermittence of certain energy sources based on a nonendoreversible power plant

model. in *ECOS 2009 - 22nd Int. Conf. Effic. Cost, Optim. Simul. Environ. Impact Energy Syst.* 79–88 (2009).

99. Bica, S., Rosiu, L. & Radoslav, R. What characteristics define ecological building materials. in *Proc. 7th IASME / WSEAS Int. Conf. Heat Transf. Therm. Eng. Environ. HTE '09* 159–164 (2009).

100. Glasnovic, Z. . & Margeta, J. . Optimal sizing of photovoltaic-hydro power plant. *Prog. Photovoltaics Res. Appl.* **17,** 542–553 (2009).

101. Ioanel, I. ., Pădurean, I. ., Silaghi, D. ., Stepan, D. . & Silaghi, F. . Economical and ecological analysis of a solar thermal system working in west Romania. *Metal. Int.* **14,** 36–40 (2009).

102. Jacobson, M. Z. Review of solutions to global warming, air pollution, and energy security. *Energy Environ. Sci.* **2,** 148–173 (2009).

103. Krstic-Furundzic, A. . & Kosoric, V. . Improvement of energy performances of existing buildings in suburban settlements. in *PLEA 2009 - Archit. Energy Occupant's Perspect. Proc. 26th Int. Conf. Passiv. Low Energy Archit.* (2009).

104. Madadnia, J. & Park, M. H. Design of compact BIPV façades for the buildings at the University of Technology Sydney (UTS). in *Proc. ASME Summer Heat Transf. Conf. 2009, HT2009* **3,** 801–808 (2009).

105. Nosrat, A. H., Jeswiet, J. & Pearce, J. M. Cleaner production via industrial symbiosis in glass and large-scale solar photovoltaic manufacturing. in *TIC-STH'09 2009 IEEE Toronto Int. Conf. - Sci. Technol. Humanit.* 967–970 (2009). doi:10.1109/TIC-STH.2009.5444358

106. Nouni, M. R. ., Mullick, S. C. . & Kandpal, T. C. . Providing electricity access to remote areas in India: Niche areas for decentralized electricity supply. *Renew. Energy* **34,** 430–434 (2009).

107. Pearce, J. M. ., Santini, A. L. . & DeSilva, J. M. . Solar photovoltaic energy for mitigation of climate change: A catalytic application of catholic social thought. *Worldviews Environ. Cult. Relig.* **13,** 92–118 (2009).

108. Rud, V. Y. ., Rud, Y. V. ., Gremenok, V. F. . & Zalesski, V. B. . Cd-free Cu(In, Ga)Se2/In2S3 thin-film heterostructures. *Phys. Status Solidi Curr. Top. Solid State Phys.* **6,** 1269–1272 (2009).

109. Stark, M., Hausmann, M. & Krost, G. Expert system for component selection of self-sufficient and regenerative electricity supply systems with hydrogen storage. in *2009 15th Int. Conf. Intell. Syst. Appl. to Power Syst. ISAP '09* (2009). doi:10.1109/ISAP.2009.5352848

110. Veitch, D. C. G. & Mahkamov, K. Assessment of economical and ecological benefits from deployment of a domestic combined heat and power unit based on its experimental performance. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **223,** 783–798 (2009).

111. Wagner, S. Polar power. *Engineer* **294,** 40–41 (2009).

112. Amor, M. B. ., Lesage, P. . b, Pineau, P.-O. . & Samson, R. . Can distributed generation offer substantial benefits in a Northeastern American context? A case study of small-scale renewable technologies using a life cycle methodology. *Renew. Sustain. Energy Rev.* **14,** 2885–2895 (2010).

113. Axelevitch, A. & Golan, G. Efficiency analysis for multi-junction PV hetero-structures. Photovoltaics Dev. Appl. Impact (2010).

114. Bastiani, M. ., Venerucci, V. ., Nori, M. . & Giovannini, F. . ECO-industrial planning model: 'Apea Carpinello' forlì. in *Proc. CESB 2010 Prague - Cent. Eur. Towar. Sustain. Build. 'From Theory to Pract.* 1–4 (2010).

115. Bellingeri, M. ., Longhi, S. . & Scotognella, F. . Transmission of light in crystals with different homogeneity: Using shannon index in photonic media. *J. Eur. Opt. Soc.* **5,** (2010).

116. Boney, C. . b *et al.* Growth and characterization of INGAN for photovoltaic devices. in *Conf. Rec. IEEE Photovolt. Spec. Conf.* 3316–3321 (2010). doi:10.1109/PVSC.2010.5617082

117. Choi, J.-K. . & Fthenakis, V. . Economic Feasibility of Recycling Photovoltaic Modules: Survey and Model. *J. Ind. Ecol.* **14,** 947–964 (2010).

118. Cinquepalmi, F., Cumo, F., Gugliermetti, F. & Sforzini, V. Advanced technologies for sustainable building in the protected areas: Two case studies in Italy. *WIT Trans. Ecol. Environ.* **128,** 551–560 (2010).

119. Filippidou, F., Botsaris, P. N., Angelakoglou, K. & Gaidajis, G. A comparative analysis of a cdte and a poly-Si photovoltaic module installed in North Eastern Greece1. *Appl. Sol. Energy (English Transl. Geliotekhnika)* **46,** 182–191 (2010).

120. Fu, Q. & Tong, N. A new PSO algorithm based on adaptive grouping for photovoltaic MPP prediction. in *Proc. - 2010 2nd Int. Work. Intell. Syst. Appl. ISA 2010* (2010). doi:10.1109/IWISA.2010.5473243

121. Gorgolewski, M. If i had a hammer. *Altern. J.* **36,** 33–34 (2010).

122. Horváth, G. . *et al.* Reducing the maladaptive attractiveness of solar panels to polarotactic insects. *Conserv. Biol.* **24,** 1644–1653 (2010).

123. Klocke, B. . & Lenz, J. . The innovation off ensive of the German gas sector [Die Innovationsoffensive des deutschen Gasfaches]. *GWF, Gas - Erdgas* **151,** 542–547 (2010).

124. Kraines, S. B. ., Ishida, T. . & Wallace, D. R. . Integrated environmental assessment of supply-side and demand-side measures for carbon dioxide mitigation in Tokyo, Japan. *J. Ind. Ecol.* **14,** 808–825 (2010).

125. Kumar, A. A. A study on renewable energy resources in India. in *ICEEA 2010 - 2010 Int. Conf. Environ. Eng. Appl. Proc.* 49–53 (2010). doi:10.1109/ICEEA.2010.5596088

126. Nosonovsky, M. Towards ‘Green tribology’: Self-organization at the sliding interface for biomimetic surfaces. in *ASME 2010 10th Bienn. Conf. Eng. Syst. Des. Anal. ESDA2010* **1,** 621–625 (2010).

127. Polyakov, Y. S. ., Musaev, I. . & Polyakov, S. V. . Closed bioregenerative life support systems: Applicability to hot deserts. *Adv. Sp. Res.* **46,** 775–786 (2010).

128. Taieb, A. H., Msahli, S. & Sakli, F. Design concept for an ecological relaxing textile product using solar energy. *Int. J. Sustain. Eng.* **3,** 133–142 (2010).

129. Toral, G. M. & Figuerola, J. Unraveling the importance of rice fields for waterbird populations in Europe. *Biodivers. Conserv.* **19,** 3459–3469 (2010).

130. Vorobiev, P. . & Vorobiev, Y. . Automatic Sun tracking solar electric systems for applications on transport. in *Progr. Abstr. B. - 2010 7th Int. Conf. Electr. Eng. Comput. Sci. Autom. Control. CCE 2010* 66–70 (2010). doi:10.1109/ICEEE.2010.5608582

131. Wu, D. & Mohapatra, P. QuRiNet: A wide-area wireless mesh testbed for research and experimental evaluations. in *2010 2nd Int. Conf. Commun. Syst. NETworks, COMSNETS 2010* (2010). doi:10.1109/COMSNETS.2010.5431993

132. Zhao, L., Prousch, S., Hübner, M. & Moser, A. Simulation methods for assessing electric vehicle impact on distribution grids. in *2010 IEEE PES Transm. Distrib. Conf. Expo. Smart Solut. a Chang. World* (2010). doi:10.1109/TDC.2010.5484386

133. Biedorf, R. European semiconductor technology, microsystem technology, photovoltaics and FOLAE [Europäische Halbleitertechnik, Mikrosystemtechnik, Photovoltaik und FOLAE]. *Galvanotechnik* **102,** 2768–2775 (2011).

134. Bristow, D. ., Richman, R. ., Kirsh, A. ., Kennedy, C. A. . & Pressnail, K. D. . Hour-by-hour analysis for increased accuracy of greenhouse gas emissions for a low-energy condominium design. *J. Ind. Ecol.* **15,** 381–393 (2011).

135. Chel, A. . & Kaushik, G. . Renewable energy for sustainable agriculture. *Agron. Sustain. Dev.* **31,** 91–118 (2011).

136. Chobanov, V. What is profitable dispersed generation? in Proc. 24th Int. Conf. Effic. Cost, Optim. Simul. Environ. Impact Energy Syst. ECOS 2011 1785–1793 (2011).

137. Economou, A. Photovoltaic systems in school units of Greece and their consequences. *Renew. Sustain. Energy Rev.* **15,** 881–885 (2011).

138. Grigore, L. . *et al.* A class of autonomous robots prepared for unfriendly sunny environment. *Lect. Notes Electr. Eng.* **132 LNEE,** 73–80 (2011).

139. Haurant, P. ., Oberti, P. . & Muselli, M. . Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: A real case study using the ELECTRE outranking framework. *Energy Policy* **39,** 676–688 (2011).

140. Kubík, J. AB solar development activities in the construction Of photovoltaic power plants. in *Creat. Glob. Compet. Econ. A 360-Degree Approach - Proc. 17th Int. Bus. Inf. Manag. Assoc. Conf. IBIMA 2011* **4,** 325–332 (2011).

141. Lemmer, H. Photovoltaic system in rainwater detention basins: New sources of revenue for the Weiterstadt Public Utility Company [PV-anlage im regenrückhaltebecken: Neue einnahmequellen für die stadtwerke weiterstadt]. *Wasser und Abfall* **13,** 20–23 (2011).

142. Metzger, M., Szabo, A. & Bamberger, J. Control as a key technology for the grid integration of renewables. in *IFAC Proc. Vol.* **18,** 14772–14777 (2011).

143. Oancea, C. D. . & Florescu, A. . Virtual instrument to evaluate parameters of photovoltaic panels. *Int. Rev. Comput. Softw.* **6,** 661–666 (2011).

144. Palm, J. & Tengvard, M. Motives for and barriers to household adoption of small-scale production of electricity: Examples from Sweden. *Sustain. Sci. Pract. Policy* **7,** 6–15 (2011).

145. Pauly, T. Getting prepared for tomorrow: The European market development network and its priorities. in *7th Eur. Stainl. Steel Conf. Sci. Mark. Proc.* (2011).

146. Ping, X. . b, Jiang, Z. . & Li, C. . Status and future perspectives of energy consumption and its ecological impacts in the Qinghai-Tibet region. *Renew. Sustain. Energy Rev.* **15,** 514–523 (2011).

147. Pohl, J. Building Science: Concepts and Application. Build. Sci. Concepts Appl. (2011). doi:10.1002/9781444392333

148. Smrčka, L. Economic harm of promoting photovoltaics. *Int. J. Math. Model. Methods Appl. Sci.* **5,** 813–821 (2011).

149. Smyth, H. Managing the Professional Practice: In the Built Environment. Manag. Prof. Pract. Built Environ. (2011). doi:10.1002/9781444392364

150. Węcel, D. & Ogulewicz, W. Study on the possibility of use of photovoltaic cells for the supply of electrolysers. *Arch. Thermodyn.* **32,** 33–53 (2011).

151. Xu, S. ., Ye, T. . & Ma, X. . Perspective on building skins integrated with photovoltaics. in *2011 Int. Conf. Consum. Electron. Commun. Networks, CECNet 2011 - Proc.* 2409–2412 (2011). doi:10.1109/CECNET.2011.5769169

152. Yu, Y., Liu, J., Wang, H. & Liu, M. Assess the potential of solar irrigation systems for sustaining pasture lands in arid regions - A case study in Northwestern China. *Appl. Energy* **88,** 3176–3182 (2011).

153. Yum, J.-H., Baranoff, E., Wenger, S., Nazeeruddin, M. K. & Grätzel, M. Panchromatic engineering for dye-sensitized solar cells. *Energy Environ. Sci.* **4,** 842–857 (2011).

154. Abbes, D. ., Martinez, A. . & Champenois, G. . Eco-design optimisation of an autonomous hybrid wind-photovoltaic system with battery storage. *IET Renew. Power Gener.* **6,** 358–371 (2012).

155. Chuchmała, A. ., Iwan, A. . & Palewicz, M. . Polymeric photovoltaic cells - Present status and development perspectives [Polimerowe ogniwa fotowoltaiczne - Status obecny i perspektywa rozwoju]. *Rynek Energii* **98,** 145–150 (2012).

156. De Schepper, E. ., Van Passel, S. ., Manca, J. . & Thewys, T. . Combining photovoltaics and sound barriers - A feasibility study. *Renew. Energy* **46,** 297–303 (2012).

157. ECOS. Proceedings of the 25th International Conference on Efficiency, Cost, Optimization and Simulation of Energy Conversion Systems and Processes, ECOS 2012. in *Proc. 25th Int. Conf. Effic. Cost, Optim. Simul. Energy Convers. Syst. Process. ECOS 2012* **7,** (2012).

158. Faludi, J. . & Lepech, M. . Ecological payback time of an energy-efficient modular building. *J. Green Build.* **7,** 100–119 (2012).

159. Gaines, S. Sustainable development as a guide to the energy technology revolution. *Prog. Ind. Ecol.* **7,** 285–306 (2012).

160. Guevara-Stone, L. Women's empowerment through renewable energy: A case study in Nicaragua. in *World Renew. Energy Forum, WREF 2012, Incl. World Renew. Energy Congr. XII Color. Renew. Energy Soc. Annu. Conf.* **3,** 1846–1849 (2012).

161. Hsu, D. D. *et al.* Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation: Systematic Review and Harmonization. *J. Ind. Ecol.* **16,** S122–S135 (2012).

162. Jordanov, G. . *et al.* Numerical study of the wind energy potential in Bulgaria - Some preliminary results. in *AIP Conf. Proc.* **1487,** 71–78 (2012).

163. Kim, H. C., Fthenakis, V., Choi, J.-K. & Turney, D. E. Life Cycle Greenhouse Gas Emissions of Thin-film Photovoltaic Electricity Generation: Systematic Review and Harmonization. *J. Ind. Ecol.* **16,** S110–S121 (2012).

164. Kralovcova, V. & Martinek, Z. Evaluation of photovoltaic power plant. in *Proc. 13th Int. Sci. Conf. Electr. Power Eng. 2012, EPE 2012* **1,** 535–538 (2012).

165. Lau, A. & Sulewski, T. L. Design of a Zero Energy Home as a first year design project. in *ASEE Annu. Conf. Expo. Conf. Proc.* (2012).

166. McPartland, S. Landscape alteration due to renewable energy development: Agenda setting in the social sciences. *Int. J. Interdiscip. Soc. Sci.* **6,** 63–69 (2012).

167. Merkisz, J. *et al.* The impact of application of photovoltaic cells for bus ecological properties [Wpływ zastosowania ogniw fotowoltaicznych na ekologicznoś ć autobusu miejskiego]. *J. Konbin* **22,** 159–170 (2012).

168. Mišák, S., Stuchlý, J. & Vramba, J. Accumulation of electric energy in batteries for use in the distribution system [Akumulace energie v bateriích pro aplikaci v distribuč ní soustavě]. in *Proc. 13th Int. Sci. Conf. Electr. Power Eng. 2012, EPE 2012* **2,** 703–706 (2012).

169. Pastrana, A. Ceramic photovoltaic panel for ventilated façade [Placa cerámica fotovoltaica para fachadas ventiladas]. *Bol. la Soc. Esp. Ceram. y Vidr.* **51,** LIV–LVIII (2012).

170. Sadeghi, S. & Ameri, M. Comparison the combination of different power generators with photovoltaic panels and batteries. *Commun. Comput. Inf. Sci.* **339 CCIS,** 376–387 (2012).

171. Shepovalova, O. ., Strebkov, D. . & Dunichkin, I. . Energetically independent buildings of the resort-improving and educational-recreational complex in ecological

settlement GENOM. in *World Renew. Energy Forum, WREF 2012, Incl. World Renew. Energy Congr. XII Color. Renew. Energy Soc. Annu. Conf.* **5,** 3767–3772 (2012).

172. Tošer, P. ., Abraham, P. ., Bača, P. . & Tauš, P. . Analysis of V-A characteristics of the hybrid photovoltaic system. *Acta Montan. Slovaca* **17,** 247–250 (2012).

173. Von Unwerth, T., Al-Saleh, F. & Al-Kharabsheh, A. Beyond oil: Economic and ecologic options with hydrogen-based energy use and storage. *Environ. Pract.* **14,** 79–84 (2012).

174. Vramba, J. & Stuchlý, J. The negative feedback effects of solar power plant to the distribution system [Negativní zpětné vlivy fotovoltaické elektrárny na distribuční soustavu]. in *Proc. 13th Int. Sci. Conf. Electr. Power Eng. 2012, EPE 2012* **2,** 707–712 (2012).

175. Žák, P., Hrdina, D. & Kudláček, I. Comparison of technical and environmental performance of photovoltaic panels [Porovnání technických a ekologických parametrů fotovoltaických panelů]. in *Proc. 13th Int. Sci. Conf. Electr. Power Eng. 2012, EPE 2012* **1,** 523–527 (2012).

176. Zhang, H. . b, Davigny, A. . b, Colas, F. . c, Poste, Y. . & Robyns, B. . b. Fuzzy logic based energy management strategy for commercial buildings integrating photovoltaic and storage systems. *Energy Build.* **54,** 196–206 (2012).

177. Zhao, Z.-Q. & Tao, L. The study of solar photovoltaic building integration design methods. *Appl. Mech. Mater.* **178-181,** 169–172 (2012).

178. Akikur, R. K. ., Saidur, R. . b, Ping, H. W. . & Ullah, K. R. . Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review. *Renew. Sustain. Energy Rev.* **27,** 738–752 (2013).

179. Ali, M. A. & Rahim, A. H. M. A. A bess supervisory controller for microgrid performance enhancement. in *Proc. IASTED Int. Conf. Model. Simul.* 169–176 (2013). doi:10.2316/P.2013.802-022

180. Balato, M. & Vitelli, M. A hybrid MPPT technique based on the fast estimate of the Maximum Power voltages in PV applications. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521576

181. Balato, M. & Vitelli, M. A new strategy for the identification of the optimal operating points in PV applications with Distributed MPPT. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521518

182. Basiuk, V. A. ., Henao-Holguín, L. V. ., Álvarez-Zauco, E. ., Bassiouk, M. . & Basiuk, E. V. . Gas-phase noncovalent functionalization of carbon nanotubes with a Ni(II) tetraaza[14]annulene complex. *Appl. Surf. Sci.* **270,** 634–647 (2013).

183. Bouharchouche, A. ., Berkouk, E. M. . & Ghennam, T. . Control and energy management of a grid connected hybrid energy system PV-wind with battery energy storage for residential applications. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521525

184. Bouten, W., Baaij, E. W., Shamoun-Baranes, J. & Camphuysen, K. C. J. A flexible GPS tracking system for studying bird behaviour at multiple scales. *J. Ornithol.* **154,** 571–580 (2013).

185. Brendle, B. . *et al.* Model-predictive energy management for the integration of plug-in-hybrid electric vehicles into building energy systems. *SAE Tech. Pap.* **2,** (2013).

186. Carli, G. . & Williamson, S. S. . Technical considerations on power conversion for electric and plug-in hybrid electric vehicle battery charging in photovoltaic installations. *IEEE Trans. Power Electron.* **28,** 5784–5792 (2013).

187. CEABM. 2013 International Conference on Civil, Architecture and Building Materials, 3rd CEABM 2013. *Appl. Mech. Mater.* **357-360,** (2013).

188. Chang, Y., Gao, L., Gao, F. & Li, F. Benefit assessment of solar photovoltaic industry in China. *Adv. Mater. Res.* **608-609,** 11–16 (2013).

189. Claudy, M. C. ., Peterson, M. . & O'Driscoll, A. . Understanding the Attitude-Behavior Gap for Renewable Energy Systems Using Behavioral Reasoning Theory. *J. Macromarketing* **33,** 273–287 (2013).

190. Danaci, H. M. Photovoltaic panels and aesthetics aspects in architecture. *Ecol. Environ. Conserv.* **19,** 1211–1215 (2013).

191. Di Dio, V., Cipriani, G., La Cascia, D. & Miceli, R. Design, sizing and set up of a specific low cost electronic load for PV modules characterization. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521573

192. EVER. 2013 8th International Conference and Exhibition on Ecological Vehicles and Renewable Energies, EVER 2013. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013).

193. Gao, X. . *et al.* Feasibility evaluation of solar photovoltaic pumping irrigation system based on analysis of dynamic variation of groundwater table. *Appl. Energy* **105,** 182–193 (2013).

194. GBMCE. 2nd International Conference on Green Building, Materials and Civil Engineering, GBMCE 2013. *Appl. Mech. Mater.* **368-370,** (2013).

195. Grewal, P. S. & Grewal, P. S. Can cities become self-reliant in energy? A technological scenario analysis for Cleveland, Ohio. *Cities* **31,** 404–411 (2013).

196. Gustin, F., Bienaime, D., Pera, M.-C. & Berthon, A. Energy flow management strategy in an hybrid DC multisource system. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521634

197. Huang, W.-C. . & Jhong, C.-H. . Study on sustainable development of the green energy in Taiwan. in *Proc. Int. Offshore Polar Eng. Conf.* 42–49 (2013).

198. Iannuzzi, D. ., Piegari, L. . & Tricoli, P. . A novel PV-modular multilevel converter for building integrated photovoltaics. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521620

199. ICEEEE. 2013 International Conference on Energy Engineering and Environmental Engineering, ICEEEE 2013. *Appl. Mech. Mater.* **316-317,** (2013).

200. ICFMM. 2013 3rd International Conference on Frontiers of Manufacturing Science and Measuring Technology, ICFMM 2013. *Appl. Mech. Mater.* **401-403,** (2013).

201. ICMMA. 2013 International Conference on Materials, Mechatronics and Automation, ICMMA 2013. *Adv. Mater. Res.* **740,** (2013).

202. Kazem, H. A., Alkurwi, A. A., Alabdul Salam, M. M. & Alwaeli, A. H. A. Levelized electricity cost for photovoltaic system in Sohar-Oman. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521534

203. Kervalishvili, P. Novel Fuels and Materials for Nuclear Energy Generation Technologies. *NATO Sci. Peace Secur. Ser. C Environ. Secur.* **128,** 67–86 (2013).

204. Keyrouz, F., Hamad, M. & Georges, S. A novel unified maximum power point tracker for controlling a hybrid wind-solar and fuel-cell system. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521526

205. Khemiri, N. ., Khedher, A. . & Mimouni, M. F. . A backstepping control strategy applied to the connected hybrid renewable energy system operated in MPPT. in *2013 8th Int.*

Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013 (2013). doi:10.1109/EVER.2013.6521532

206. Kim, H. C. . & Fthenakis, V. . b. Life cycle energy and climate change implications of nanotechnologies: A Critical Review. *J. Ind. Ecol.* **17,** 528–541 (2013).

207. Korzeniewska, E. . & Drzymała, A. . Photovoltaic power plants - technical and economic aspects [Elektrownie fotowoltaiczne- aspekty techniczne i ekonomiczne]. *Prz. Elektrotechniczny* **89,** 324–327 (2013).

208. Kreiger, M. A. ., Shonnard, D. R. . & Pearce, J. M. . c. Life cycle analysis of silane recycling in amorphous silicon-based solar photovoltaic manufacturing. *Resour. Conserv. Recycl.* **70,** 44–49 (2013).

209. Kreiger, M. . & Pearce, J. M. . b. Environmental impacts of distributed manufacturing from 3-D printing of polymer components and products. in *Mater. Res. Soc. Symp. Proc.* **1492,** 85–90 (2013).

210. Kumar, R. ., Gupta, R. A. . & Bansal, A. K. . Economic analysis and power management of a stand-alone wind/photovoltaic hybrid energy system using biogeography based optimization algorithm. *Swarm Evol. Comput.* **8,** 33–43 (2013).

211. Laselle, D. W., Liechty, R., Alzamzam, H., Foster, R. & Dzabic, J. Stirling dish generator using a focal point internal to the dish. in *IEEE Green Technol. Conf.* 211–214 (2013). doi:10.1109/GreenTech.2013.39

212. Malanina, D. O., Tyukov, A. P., Shcherbakov, M. V & Kamaev, V. A. Solar energy system design and feasibility study support system. *World Appl. Sci. J.* **24,** 117–125 (2013).

213. Merei, G. . b c, Berger, C. . & Sauer, D. U. . b c. Optimization of an off-grid hybrid PV-Wind-Diesel system with different battery technologies using genetic algorithm. *Sol. Energy* **97,** 460–473 (2013).

214. Metatla, A., Talbi, N. & Benzahioul, S. On the modelling of photovoltaic generators: A comparative study. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521568

215. MREE. 2013 International Conference on Materials for Renewable Energy and Environment, MREE 2013. *Adv. Mater. Res.* **773,** (2013).

216. Muntwyler, U. Has Europe a need for solar plants in Africa? in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521529

217. Nekrasov, M. ., Chumkiew, S. . & Shinn, P. . Poster - Instrumenting Thailand's coastline: Mobile devices for environmental and disaster monitoring. in *MobiSys 2013 - Proc. 11th Annu. Int. Conf. Mob. Syst. Appl. Serv.* 535–536 (2013). doi:10.1145/2462456.2465720

218. Okou, A. F. ., Akhrif, O. . & Taheri, H. . Adaptive control scheme based maximum power point tracking controller for PV generators. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521601

219. Ostrowska, A., Sobczyk, W. & Pawul, M. Evaluation of Economic and Ecological Effects of Solar Energy on the Example of a Single-family House [Ocena efektów ekonomicznych i ekologicznych wykorzystania energii słonecznej na przykładzie domu jednorodzinnego]. *Rocz. Ochr. Sr.* **15,** 2697–2710 (2013).

220. Papoutsidakis, M. G., Piromalis, D. & Tseles, D. Implementation of a mobile and stretchable energy production system using P/V cells. in *2013 World Congr. Sustain. Technol. WCST 2013* 84–89 (2013). doi:10.1109/WCST.2013.6750411

221. Priščakova, Z. & Rabova, I. An accessibility solution of cloud computing by solar energy. *Acta Univ. Agric. Silvic. Mendelianae Brun.* **61,** 2649–2654 (2013).

222. Santana-Rodŕiguez, G. . *et al.* Evaluation of a grid-connected photovoltaic system and in-situ characterization of photovoltaic modules under the environmental conditions of Mexico city. *Rev. Mex. Fis.* **59,** 88–94 (2013).

223. Schuepbach, E. & Muntwyler, U. Short courses in photovoltaic for worldwide professionals. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521530

224. SGEM. 13th International Multidisciplinary Scientific Geoconference and EXPO, SGEM 2013. in *Int. Multidiscip. Sci. GeoConference Surv. Geol. Min. Ecol. Manag. SGEM* (2013).

225. Taheri, H. ., Akhrif, O. . & Okou, A. F. . Nonlinear frequency and voltage regulation in a PV-battery-diesel microgrid. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521599

226. Takahashi, Y. & Uda, K. Project based learning using natural energy powered small electric vehicle for sustainable technology education. in *Int. Conf. Control. Autom. Syst.* 788–793 (2013). doi:10.1109/ICCAS.2013.6704020

227. Tarek, B. ., Said, D. . & Benbouzid, M. E. H. . Maximum Power Point Tracking Control for Photovoltaic System Using Adaptive Neuro-Fuzzy 'ANFIS'. in *2013 8th Int. Conf. Exhib. Ecol. Veh. Renew. Energies, EVER 2013* (2013). doi:10.1109/EVER.2013.6521559

228. Unami, K. ., Yangyuoru, M. ., Badiul Alam, A. H. M. . & Kranjac-Berisavljevic, G. . Stochastic control of a micro-dam irrigation scheme for dry season farming. *Stoch. Environ. Res. Risk Assess.* **27,** 77–89 (2013).

229. Urban, R. A. & Bakshi, B. R. Techno-ecological synergy as a path toward sustainability of a north American residential system. *Environ. Sci. Technol.* **47,** 1985–1993 (2013).

230. Vorobiev, P. . & Vorobiev, Y. . About the possibilities of using the renewable energy power sources on railway transport. *J. Adv. Transp.* **47,** 681–691 (2013).

231. Walter, K. & Bosch, S. Intercontinental cross-linking of power supply-calculating an optimal power line corridor from North Africa to central Europe. *Energy. Sustain. Soc.* **3,** (2013).

232. Wardach, M., Kubarski, K., Paplicki, P. & Cierzniewski, P. Proposition of application of autonomous power supply system for single-family house [Propozycja zastosowania autonomicznego układu zasilania domu jednorodzinnego]. *Prz. Elektrotechniczny* **89,** 48–50 (2013).

233. Weber, B. ., Chávez, G. . & Durán, M. D. . Electric mobility as part of city transportation systems. in ASME 2013 7th Int. Conf. Energy Sustain. Collocated with ASME 2013 Heat Transf. Summer Conf. ASME 2013 11th Int. Conf. Fuel Cell Sci. Eng. Technol. ES 2013 (2013). doi:10.1115/ES2013-18347

234. Werulkar, A. ., Shankar, D. . & Kulkarni, P. S. . A soft switching boost converter with simulation of maximum power point tracking for solar home lighting system. *Int. J. ChemTech Res.* **5,** 935–946 (2013).

235. Xie, R.-J. . & Hintzen, H. T. . Optical properties of (oxy)nitride materials: A review. *J. Am. Ceram. Soc.* **96,** 665–687 (2013).

236. Yang, Q. . b c e *et al.* Environmental sustainability of wind power: An emergy analysis of a Chinese wind farm. *Renew. Sustain. Energy Rev.* **25,** 229–239 (2013).

237. Yin, B. Q. ., Wang, Y. P. . b, Zhu, L. . & Cui, Y. . Photosynthesis of plant and photovoltaic integrated application of buildings. *Appl. Mech. Mater.* **357-360,** 467–473 (2013).

238. Absi Halabi, M. ., Al-Qattan, A. . & Al-Otaibi, A. . Application of solar energy in the oil industry - Current status and future prospects. *Renew. Sustain. Energy Rev.* **43,** 296–314 (2014).

239. Ammous, M. & Chaabene, M. Design of a PV/T based desalination plant: Concept and assessment. in *IREC 2014 - 5th Int. Renew. Energy Congr.* (2014). doi:10.1109/IREC.2014.6827025

240. Ančić, I., Šestan, A., Vladimir, N. & Klisarić, V. Influence of new power sources on the attained EEDI. in *RINA, R. Inst. Nav. Archit. - Influ. EEDI Sh. Des. 2014* 129–134 (2014).

241. Balas, M. M. Seven passive greenhouse synergies. *Acta Polytech. Hungarica* **11,** 199–210 (2014).

242. Balato, M., Manganiello, P. & Vitelli, M. Fast dynamical reconfiguration algorithm of PV arrays. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6843998

243. Balato, M. & Vitelli, M. An algorithm for the estimation of the Maximum Power Voltages in microconverters based PV applications. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844109

244. Barbini, N. ., Lughi, V. ., Mellit, A. ., Pavan, A. M. . & Tessarolo, A. . On the impact of photovoltaic module characterization on the prediction of PV plant productivity. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844014

245. Basterrech, S., Prokop, L., Buriańek, T. & Mišák, S. Optimal design of neural tree for solar power prediction. in *Proc. 2014 15th Int. Sci. Conf. Electr. Power Eng. EPE 2014* 273–278 (2014). doi:10.1109/EPE.2014.6839522

246. Blaabjerg, F., Ma, K. & Yang, Y. Power electronics - The key technology for renewable energy systems. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844159

247. Boscaino, V., Cipriani, G., Di Dio, V., Miceli, R. & Capponi, G. A simple and accurate model of photovoltaic modules for power system design. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844088

248. Boscaino, V., Ferraro, V., Miceli, R. & Capponi, G. Design and control of a novel multi-source renewable energy system. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844091

249. Bouzguenda, M., Al Omair, A., Al Naeem, A., Al-Muthaffar, M. & Wazir, O. B. Design of an off-grid 2 kW solar PV system. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844001

250. Brandt, T. . b, DeForest, N. ., Stadler, M. . & Neumann, D. . Power systems 2.0: Designing an energy information system for microgrid operation. in *35th Int. Conf. Inf. Syst. "Building a Better World Through Inf. Syst. ICIS 2014* (2014).

251. CEABM. 4th International Conference on Civil Engineering, Architecture and Building Materials, CEABM 2014. *Appl. Mech. Mater.* **587-589,** (2014).

252. Chang, Y.-H., Wu, B.-Y. & Lai, C.-F. The effect of a green energy landscape fountain on water quality improvement. *Ecol. Eng.* **73,** 201–208 (2014).

253. Chen, H. & Yang, X. Progress of analytical chemistry. *Chem. Bull. / Huaxue Tongbao* **77,** 623–630 (2014).

254. Chen, P.-Y. . b *et al.* Environmentally responsible fabrication of efficient perovskite solar cells from recycled car batteries. *Energy Environ. Sci.* **7,** 3659–3665 (2014).

255. Cipriani, G., Di Dio, V., La Manna, D., Miceli, R. & Ricco Galluzzo, G. Technical and economical comparison between different topologies of PV plant under mismatch effect. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844089

256. Cipriani, G., La Cascia, D., Di Dio, V. & Miceli, R. Photovoltaic plant array reconfiguration: Design of a new device. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844090

257. Claudia Roldán, M. ., Martínez, M. . & Peña, R. . Scenarios for a hierarchical assessment of the global sustainability of electric power plants in México. *Renew. Sustain. Energy Rev.* **33,** 154–160 (2014).

258. Colak, I. ., Garip, I. . & Issi, F. . An application of maintaining constant grounding resistance of renewable energy sources by using a dspic. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844063

259. De Castro, C. ., Carpintero, O. ., Frechoso, F. ., Mediavilla, M. . & de Miguel, L. J. . A top-down approach to assess physical and ecological limits of biofuels. *Energy* **64,** 506–512 (2014).

260. Dekate, A. ., Ghorpade, N. ., Rana, A. ., Karandikar, P. B. . & Kamal, A. . Autocap-supercapacitor based intelligent self start unit for 2 wheelers. in *Proceeding IEEE Int. Conf. Green Comput. Commun. Electr. Eng. ICGCCEE 2014* (2014). doi:10.1109/ICGCCEE.2014.6922422

261. Ding, Y. . b, Zhang, Y. ., Zheng, Q.-S. . b & Tyree, M. T. . d. Pressure-volume curves: Revisiting the impact of negative turgor during cell collapse by literature review and simulations of cell micromechanics. *New Phytol.* **203,** 378–387 (2014).

262. Drid, S. ., Chrifi-Alaoui, L. ., Bussy, P. . & Ouriagli, M. . Robust control of the Photovoltaic system with improved maximum power point tracking. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844120

263. EESD. 3rd International Conference on Energy, Environment and Sustainable Development, EESD 2013. *Adv. Mater. Res.* **869-870,** (2014).

264. EVER. 2014 9th International Conference on Ecological Vehicles and Renewable Energies, EVER 2014. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014).

265. Feller, J.-F. Different Strategies for Ecoplastics Development. Environ. Impact Polym. (2014). doi:10.1002/9781118827116.ch10

266. Fischhendler, I., Boymel, D. & Boykoff, M. T. How Competing Securitized Discourses over Land Appropriation Are Constructed: The Promotion of Solar Energy in the Israeli Desert. *Environ. Commun.* (2014). doi:10.1080/17524032.2014.979214

267. Grippo, M. ., Hayse, J. W. . & O'Connor, B. L. . Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. *Environ. Manage.* **55,** 244–256 (2014).

268. Haddad, S., Metatla, A. & Benzahioul, S. Optimal sizing of PV system and energy management in Buildings. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844071

269. Hoier, A. ., Erhorn, H. ., Hoppe, M. . c, Asböck, B. . c & Daubenmerkl, J. . c. New construction of an energy-surplus day care center for children to experience energy-efficiency. in *Energy Procedia* **48,** 1474–1481 (2014).

270. Hornborg, A. Why solar panels don't grow on trees: Technological utopianism and the uneasy relation between marxism and ecological economics. Green Utop. Perspect. Polit. Micro-Practices (2014). doi:10.4324/9780203067215

271. ICAMMS. 2012 International Conference on Advanced Material and Manufacturing Science, ICAMMS 2012. *Adv. Mater. Res.* **875-877,** (2014).

272. ICCET. 3rd International Conference on Civil Engineering and Transportation, ICCET 2013. *Appl. Mech. Mater.* **507,** (2014).

273. ICMSE. 3rd International Conference on Materials Science and Engineering, ICMSE 2014. *Adv. Mater. Res.* **852,** (2014).

274. ICMSE. 2014 4th International Conference on Mechanical Science and Engineering, ICMSE 2014. *Appl. Mech. Mater.* **472,** (2014).

275. ICSEEE. 2013 2nd International Conference on Sustainable Energy and Environmental Engineering, ICSEEE 2013. *Appl. Mech. Mater.* **525,** (2014).

276. Jones, P. ., Hillier, D. . & Comfort, D. . Solar farm development in the United Kingdom. *Prop. Manag.* **32,** 176–184 (2014).

277. Kahn, J. R. . b, Freitas, C. E. . c & Petrere, M. . e. False shades of green: The case of Brazilian Amazonian hydropower. *Energies* **7,** 6063–6082 (2014).

278. Kraler, A. ., Krismer, V. . & Glatzl, H. . Ökonflex: An IT-tool for configuring wooden house constructions. in *WCTE 2014 - World Conf. Timber Eng. Proc.* (2014).

279. Le Goff Latimier, R., Kovaltchouk, T., Ben Ahmed, H. & Multon, B. Preliminary sizing of a collaborative system: Photovoltaic power plant and electric vehicle fleet. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844110

280. Lluri, L. Utilization of solar energy for an ecological tourism in the region of Durrës in Albania. *Mediterr. J. Soc. Sci.* **5,** 303–309 (2014).

281. Lotveit, M. ., Suul, J. A. . b c, Tedeschi, E. . b c & Molinas, M. . c. A study of biomass in a hybrid stand-alone Micro-Grid for the rural village of Wawashang, Nicaragua. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844057

282. Manaullah & Ansari, M. S. Solar photo voltaic power generation in union territory of Lakshadweep Island: Projected level dissemination using technology diffusion models. in *Proc. Int. Conf. Innov. Appl. Comput. Intell. Power, Energy Control. with Their Impact Humanit. CIPECH 2014* 395–399 (2014). doi:10.1109/CIPECH.2014.7019036

283. Marwede, M. . & Reller, A. . Estimation of life cycle material costs of cadmium telluride- and copper indium gallium diselenide-photovoltaic absorber materials based on life cycle material flows. *J. Ind. Ecol.* **18,** 254–267 (2014).

284. Mizukoshi, A., Ushijima, J., Tsuji, F., Saito, T. & Fukumura, Y. Smart park in Okinawa prefectural peace memorial park. in *2013 World Electr. Veh. Symp. Exhib. EVS 2014* (2014). doi:10.1109/EVS.2013.6914739

285. Mulvaney, D. Are green jobs just jobs? Cadmium narratives in the life cycle of Photovoltaics. *Geoforum* **54,** 178–186 (2014).

286. NA. Each floor erected in three and a half hours [Nur dreieinhalb Stunden Bauzeit je Geschoss]. *Betonw. und Fert. Plant Precast Technol.* **80,** 26–27 (2014).

287. Natsheh, A. Chaotic behaviour in parallel-connected DC-DC buck-boost converters. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844126

288. Nowotny, J. . *et al.* Sustainable practices: Solar hydrogen fuel and education program on sustainable energy systems. *Int. J. Hydrogen Energy* **39,** 4151–4157 (2014).

289. Oravcová, E. Construction in the trend of sustainability_ wooden houses with integrated photovoltaic systems. *Adv. Mater. Res.* **899,** 209–212 (2014).

290. Ozcan, G. E. ., Cicek, O. ., Enez, K. . & Yildiz, M. . Article; biodiversity and ecosystems a new approach to determine the capture conditions of bark beetles in pheromone-baited traps. *Biotechnol. Biotechnol. Equip.* **28,** 1057–1064 (2014).

291. Piotrowski, A. & Nieszporek, T. The solar tracker - a control system and a frame construction. *Appl. Mech. Mater.* **613,** 340–349 (2014).

292. Reddy, K. G. . *et al.* On global energy scenario, dye-sensitized solar cells and the promise of nanotechnology. *Phys. Chem. Chem. Phys.* **16,** 6838–6858 (2014).

293. Ruiz, A., Morillón, D. & Muñoz, F. Renewable energy devices in ecological park. in *Energy Procedia* **57,** 957–964 (2014).

294. Sadeghi, S. . b & Ameri, M. . b. Exergy analysis of photovoltaic panels-coupled solid oxide fuel cell and gas turbine-electrolyzer hybrid system. *J. Energy Resour. Technol. Trans. ASME* **136,** (2014).

295. Sadeghi, S. . b & Ameri, M. . b. Comparison of different power generators in PV-battery-power generator hybrid system. *J. Mech. Sci. Technol.* **28,** 387–398 (2014).

296. Sadeghi, S. & Ameri, M. Multiobjective optimization of PV-bat-SOFC hybrid system: Effect of different fuels used in solid oxide fuel cell. *J. Energy Eng.* **140,** (2014).

297. Samuels, A. Solar farms: Ground mounted solar photovoltaic developments. *J. Plan. Environ. Law* 1207–1210 (2014).

298. Selmi, T. ., Abdul-Niby, M. ., Devis, L. . & Davis, A. . P&O MPPT implementation using MATLAB/Simulink. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844065

299. SEMEE. 2013 International Conference on Solar Energy Materials and Energy Engineering, SEMEE 2013. *Adv. Mater. Res.* **827,** (2014).

300. Shou, Q. Y. ., Pei, X. M. . & Zhang, J. Y. . Research on application of building photovoltaic system in Shanghai - Taking Chenjia town as an example. *Appl. Mech. Mater.* **587-589,** 220–223 (2014).

301. Talaat, Y. . c, Hegazy, O. . c c, Amin, A. . & Lataire, P. . Control and analysis of multiphase Interleaved DC/DC Boost Converter for photovoltaic systems. in *2014 9th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2014* (2014). doi:10.1109/EVER.2014.6844009

302. Taylor, A. *et al.* Development of an autonomous boat for sustainable aquatic plant biomass collection. in *Am. Soc. Agric. Biol. Eng. Annu. Int. Meet. 2014, ASABE 2014* **4,** 2747–2751 (2014).

303. Thaxter, C. B. *et al.* A trial of three harness attachment methods and their suitability for long-term use on Lesser Black-backed Gulls and Great Skuas. *Ringing Migr.* **29,** 65–76 (2014).

304. Triki, A. ., Karray, M. ., Poilâne, C. ., Picart, P. . & Gargouri, M. . Effect of ecological treatment on adhesion of woven flax fibers in epoxy matrix. in *2014 North African Work. Dielectr. Mater. Photovolt. Syst. NAWDMPV 2014* (2014). doi:10.1109/NAWDMPV.2014.6997596

305. Wu, Z. . *et al.* Evaluation on aeration performance of movable solar aerator. *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.* **30,** 246–252 (2014).

306. Xue, Y. B. . b & Lan, Y. R. . Application of building energy-saving technology - Student accommodation in Shandong Jianzhu University. *Adv. Mater. Res.* **889-890,** 1343–1346 (2014).

307. Baitie, H. E.-K. & Selmi, T. Review of smart grid systems' requirements. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7113004

308. Balato, M., Costanzo, L. & Vitelli, M. Optimization of both the energetic efficiency and the duration of life of PV arrays by means of the dynamical reconfiguration of PV modules connections. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112922

309. Besiou, M. . & Van Wassenhove, L. N. . Closed-Loop Supply Chains for Photovoltaic Panels: A Case-Based Approach. *J. Ind. Ecol.* (2015). doi:10.1111/jiec.12297

310. Boromisa, A.-M., Tišma, S. & Ležaić, A. R. *Green jobs for sustainable development*. *Green Jobs Sustain. Dev.* **41,** (2015).

311. Calvert, K. . & Mabee, W. . More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada. *Appl. Geogr.* **56,** 209–221 (2015).

312. Chang, Y.-H., Wu, B.-Y. & Lai, C.-F. A study of the ecological benefits of the green energy landscape fountain. *Ecol. Eng.* **75,** 128–136 (2015).

313. Ciupercă, R. *et al.* Organic plant and animal waste management system [Sistem ecologic de gestionare a deşeurilor vegetale şi animale]. *INMATEH - Agric. Eng.* **46,** 69–76 (2015).

314. Colomboc, E. ., Roccob, M. V. ., Toroa, C. . & Sciubbad, E. . An exergy-based approach to the joint economic and environmental impact assessment of possible photovoltaic scenarios: A case study at a regional level in Italy. in *27th Int. Conf. Effic. Cost, Optim. Simul. Environ. Impact Energy Syst. ECOS 2014* **2014-Janua,** 1–23 (2015).

315. Cubi, E. ., Zibin, N. F. ., Thompson, S. J. . & Bergerson, J. . Sustainability of rooftop technologies in cold climates: Comparative life cycle assessment of white roofs, green roofs, and photovoltaic panels. *J. Ind. Ecol.* (2015). doi:10.1111/jiec.12269

316. Czerniak, J. ., Ewald, D. ., Macko, M. ., Śmigielski, G. . & Tyszczuk, K. . Approach to the monitoring of energy consumption in eco-grinder based on ABC optimization. *Commun. Comput. Inf. Sci.* **521,** 516–529 (2015).

317. Elmahni, L. ., Bouhouch, L. ., Alaoui, R. . & Moudden, A. . Modeling and control of a hybrid microgrid by multi-agent system. *Int. Rev. Electr. Eng.* **10,** 145–153 (2015).

318. Etier, I. ., Ababneh, M. . & Al Tarabsheh, A. . Design and simulation of a PV-grid connected system. *Int. J. Comput. Sci. Eng.* **10,** 423–429 (2015).

319. Goe, M. ., Gaustad, G. . & Tomaszewski, B. . System tradeoffs in siting a solar photovoltaic material recovery infrastructure. *J. Environ. Manage.* **160,** 154–166 (2015).

320. Guaita-Pradas, I. ., Ullah, S. . & Soucase, B. M. . Sustainable development with renewable energy in India and Pakistan. *Int. J. Renew. Energy Res.* **5,** 575–580 (2015).

321. Haddad, S. ., Touafek, K. . & Khelifa, A. . Investigation of the electrical and thermal performance of a PV/T hybrid system. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112928

322. Hmidet, A. ., Rebei, N. . & Hasnaoui, O. . Experimental studies and performance evaluation of MPPT control strategies for solar-powered water pumps. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112975

323. Hosoda, T. Case study on installation status of ecological equipment, ventilation, and natural lighting of classroom planning for eco-schools in Tottori. *AIJ J. Technol. Des.* **21,** 243–248 (2015).

324. Izadpanahi, P. ., Elkadi, H. . & Tucker, R. . Greenhouse affect: the relationship between the sustainable design of schools and children's environmental attitudes. *Environ. Educ. Res.* (2015). doi:10.1080/13504622.2015.1072137

325. Kapoor, R. . & Furr, N. R. . Complementarities and competition: Unpacking the drivers of entrants' technology choices in the solar photovoltaic industry. *Strateg. Manag. J.* **36,** 416–436 (2015).

326. Lahouar, F. E., Hamouda, M. & Slama, J. B. H. Design and control of a grid-tied three-phase three-level diode clamped single-stage photovoltaic converter. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112930

327. Lamnatou, C. & Chemisana, D. Evaluation of photovoltaic-green and other roofing systems by means of ReCiPe and multiple life cycle-based environmental indicators. *Build. Environ.* **93,** 376–384 (2015).

328. Longo, M. ., Zaninelli, D. ., Viola, F. ., Romano, P. . & Miceli, R. . Eletric vehicles impact using renewable energy. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7113007

329. Mendoza, J. M. F. . *et al.* Development of urban solar infrastructure to support low-carbon mobility. *Energy Policy* **85,** 102–114 (2015).

330. Overholm, H. Collectively created opportunities in emerging ecosystems: The case of solar service ventures. *Technovation* **39-40,** 14–25 (2015).

331. Prina, M. G. . *et al.* Economic and environmental impact of photovoltaic and wind energy high penetration towards the achievement of the Italian 20-20-20 targets. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112993

332. Quéval, L. ., Vido, L. ., Coty, A. . & Multon, B. . Photovoltaic motors review, comparison and switched reluctance motor prototype. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7113028

333. Schaffer, A. J. & Brun, S. Beyond the sun - Socioeconomic drivers of the adoption of small-scale photovoltaic installations in Germany. *Energy Res. Soc. Sci.* **10,** 220–227 (2015).

334. Schuepbach, E. *et al.* Swiss energy strategy 2050: Research on photovoltaic electricity production. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7112992

335. Stanek, W., Gazda, W. & Kostowski, W. Thermo-ecological assessment of CCHP (combined cold-heat-and-power) plant supported with renewable energy. *Energy* (2015). doi:10.1016/j.energy.2015.02.005

336. Stapf, A., Gondek, C., Lippold, M. & Kroke, E. HF-(NH4)2S2O8-HCl mixtures for HNO3- and NOx-free etching of diamond wire- and SiC-slurry-sawn silicon wafers: Reactivity studies, surface chemistry, and unexpected pyramidal surface morpho. *ACS Appl. Mater. Interfaces* **7,** 8733–8742 (2015).

337. Tushar, W. ., Huang, S. ., Yuen, C. ., Zhang, J. A. . & Smith, D. B. . d. Synthetic generation of solar States for smart grid: A multiple segment Markov chain approach. in *IEEE PES Innov. Smart Grid Technol. Conf. Eur.* **2015-Janua,** (2015).

338. Viola, F. . *et al.* Performance of the glass block in photovoltaic generation. in *2015 10th Int. Conf. Ecol. Veh. Renew. Energies, EVER 2015* (2015). doi:10.1109/EVER.2015.7113008

339. Wolf, P. Solar energy utilization in overall energy budget of the Johann Gregor Mendel antarctic station during austral summer season. *Czech Polar Reports* **5,** 1–11 (2015).

340. Zeng, C., Ramos-Ruiz, A., Field, J. A. & Sierra-Alvarez, R. Cadmium telluride (CdTe) and cadmium selenide (CdSe) leaching behavior and surface chemistry in response to pH and O2. *J. Environ. Manage.* **154,** 78–85 (2015).

341. Zhang, X., Ying, W., Wu, W., Li, J. & Hua, J. Synthesis and photovoltaic performance of (octyloxyphenyl)pyrido-[3,4-b]pyrazine-based sensitizers for dye-sensitized solar cells. Acta Chim. Sin. 73, 272–280 (2015).

342. Ali Oglu, E. N. Solarvilla - innovative concept of habitat using solar photovoltaic technology in energy self-sufficient housing for remote settlements throughout saudi arabia. in Energy Dev. New Forms, Renewables, Conserv. Proc. ENERGEX ’84, Glob. Energy Forum 679–702 (1987).

Appendix 4: Google Scholar relevant search results

1. Balta-Ozkan, N., Yildirim, J. & Connor, P. M. Regional distribution of photovoltaic deployment in the UK and its determinants: a spatial econometric approach. *Energy Econ.* **51,** 417–429 (2015).

2. Bhola, R. & Heiser, J. Analysis of soil temperatures in the Long Island Solar Farm (LISF) and its impact on the local fauna and flora. in *A Compil. Internsh. Reports* 26–28 (Brookhaven National Laboratory, 2013).

3. Burnett, D., Barbour, E. & Harrison, G. P. The UK solar energy resource and the impact of climate change. *Renew. Energy* **71,** 333–343 (2014).

4. Cherrington, R., Goodship, V., Longfield, A. & Kirwan, K. The feed-in tariff in the UK: a case study focus on domestic photovoltaic systems. *Renew. Energy* **50,** 421–426 (2013).

5. Dale, V. H., Efroymson, R. A. & Kline, K. L. The land use–climate change–energy nexus. *Landsc. Ecol.* **26,** 755–773 (2011).

6. De Marco, A. *et al.* The contribution of Utility-Scale Solar Energy to the global climate regulation and its effects on local ecosystem services. *Glob. Ecol. Conserv.* **2,** 324–337 (2014).

7. DECC. Energy Trends section 6: renewables. (2015).

8. DECC. UK Renewable Energy Roadmap Update 2013. (2013).

9. DECC. Regional Statistics 2003-2013: Generation. (2014).

10. DeVault, T. L. *et al.* Bird use of solar photovoltaic installations at US airports: implications for aviation safety. *Landsc. Urban Plan.* **122,** 122–128 (2014).

11. EC. 28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30. *Brussels Eur. Comm.* (2009).

12. Fthenakis, V., Blunden, J., Green, T., Krueger, L. & Turney, D. Large photovoltaic power plants: Wildlife impacts and benefits. in *Photovolt. Spec. Conf. (PVSC), 2011 37th IEEE* 2011–2016 (IEEE, 2011).

13. Gasparatos, A. & Willis, K. J. *Biodiversity in the Green Economy*. (Routledge, 2015).

14. Grippo, M., Hayse, J. W. & O'Connor, B. L. Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. *Environ. Manage.* **55,** 244–256 (2015).

15. Hamada, Y. & Grippo, M. A. Remote-sensing application for facilitating land resource assessment and monitoring for utility-scale solar energy development. *J. Appl. Remote Sens.* **9,** 97694 (2015).

16. Hernandez, R. R. *et al.* Environmental impacts of utility-scale solar energy. *Renew. Sustain. Energy Rev.* **29,** 766–779 (2014).

17. Horváth, G. *et al.* Reducing the Maladaptive Attractiveness of Solar Panels to Polarotactic Insects. *Conserv. Biol.* **24,** 1644–1653 (2010).

18. Jones, P., Comfort, D. & Hillier, D. Spotlight on solar farms. *J. Public Aff.* **15,** 14–21 (2015).

19. Jones, P., Hillier, D. & Comfort, D. Solar farm development in the United Kingdom. *Prop. Manag.* **32,** 176–184 (2014).

20. Kadaba, D. Ecology of the desert kit fox (Vulpes macrotis arsipus) in Chuckwalla Valley, California. (2014).

21. Kagan, R. A., Viner, T. C., Trail, P. W. & Espinoza, E. O. Avian mortality at solar energy facilities in Southern California: A preliminary analysis. Natl. Fish Wildl. Forensics Lab. (2014).

22. Kalogirou, S. A. Environmental benefits of domestic solar energy systems. *Energy Convers. Manag.* **45,** 3075–3092 (2004).

23. Lovich, J. E. & Ennen, J. R. Wildlife conservation and solar energy development in the desert southwest, United States. *Bioscience* **61,** 982–992 (2011).

24. Masden, E. A., McCluskie, A., Owen, E. & Langston, R. H. W. Renewable energy developments in an uncertain world: The case of offshore wind and birds in the UK. *Mar. Policy* **51,** 169–172 (2015).

25. McCrary, M. D., McKernan, R. L., Flanagan, P. A. & Wagner, W. D. *Wildlife interactions at Solar One. Final report*. (Los Angeles County Natural History Museum Foundation, CA (USA). Section of Ornithology, 1984).

26. Morris, A. W. & Owley, J. Mitigating the Impacts of the Renewable Energy Gold Rush. *Minnesota J. Law, Sci. Technol. Forthcom.* 2008–2014 (2013).

27. Parker, G. & McQueen, C. Can Solar Farms Deliver Significant Benefits for Biodiversity? Preliminary Study July-August 2013. (2013).

28. Robateau, N. L. Understory Vegetation Analysis in the Proposed Long Island Solar Farm of Pine Barrens Forest, NY. (Brookhaven National Laboratory, 2010).

29. Smith, A., Kern, F., Raven, R. & Verhees, B. Spaces for sustainable innovation: Solar photovoltaic electricity in the UK. *Technol. Forecast. Soc. Change* **81,** 115–130 (2014).

30. South Coast Wildlands, Energy Commision, CDFG, S. L. O. C. Carrizo Energy Solar Farm (07-AFC-8) Responses to Comments on the Input Data for Modeling the Wildlife Corridor to Determine Effects and to Consider Mitigation for Species That Would be Impacted by Three Proposed Solar Projects Background. (2009).

31. Strugnell, L. Eleven solar PV Facilities and Supporting Electrical Infrastructure near Dealesville in the Free State Province, Avifaunal specialist study. (2015).

32. Todd, S. W. Proposed Olyven Kolk solar power plant, northern cape: botanical and faunal specialist assessment. (2011).

33. TOURISM, S. New rural spaces. Towards renewable energies, multifunctional farming, and sustainable tourism. (Institute of Geonics, Academy of Sciences of the Czech Republic, 2013).

34. Trapani, K. & Redón Santafé, M. A review of floating photovoltaic installations: 2007–2013. *Prog. Photovoltaics Res. Appl.* **23,** 524–532 (2015).

35. Tsoutsos, T., Frantzeskaki, N. & Gekas, V. Environmental impacts from the solar energy technologies. *Energy Policy* **33,** 289–296 (2005).

36. Turney, D. & Fthenakis, V. Environmental impacts from the installation and operation of large-scale solar power plants. *Renew. Sustain. Energy Rev.* **15,** 3261–3270 (2011).

37. van der Winden, J., van Vliet, F., Patterson, A. & Lane, B. Renewable energy technologies and migratory species: guidelines for sustainable deployment. in *Conv. Migr. species. 18th Meet. Sci. Counc.* (2014).

38. Walston, L. J., White, E. M., Meyers, S. A., Turchi, C. & Sinclair, K. *Bibliography of Literature for Avian Issues in Solar and Wind Energy and Other Activities*. (2015). doi:10.2172/1176922

39. Ware, H. E., McClure, C. J. W., Carlisle, J. D. & Barber, J. R. A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. *Proc. Natl. Acad. Sci.* **112,** 12105–9 (2015).

Appendix 5. Availability and summaries of information on the ecological impacts of solar developments presented by non-governmental and governmental organisations with relevance to the UK.

The information summarised in the table below was obtained through google searches and visits to the organisation's website. Definitions of acronyms can be found in table 1.

Organisation	Information disseminated through the organisation
BCT	• No information readily available on utility scale solar PV developments. • BCT is making an attempt to collect data on incidents involving bat and solar PV installations with reference to the construction industry. This insinuates an interest in distribution scale solar developments, but not necessarily utility scale developments.[24] • A short statement emphasises that although BCT welcome microgeneration renewable technologies, the installation of rooftop solar panel may disturb bats.[25]
BASC	• No information readily available on the ecological effect of PV developments.
BES	• No information readily available on the ecological effect of utility scale PV systems. • A blog post discusses the installation of a small PV system in Sundarbans, India[26]. This states that the installation has helped to reduce the community's reliance on unsustainable fishing methods. However, the post does not state how this is

24 http://www.bats.org.uk/news.php/283/we_need_your_help [last accessed 15/04/2016]

25 http://www.bats.org.uk/pages/microgeneration_issues.html [last accessed 15/04/2016]

26 http://www.britishecologicalsociety.org/blog/2012/02/16/navigating-the-perfect-storm-the-international-challenge-of-food-water-and-energy-security/ [last accessed 15/04/2016]

Organisation	Information disseminated through the organisation
	achieved and there is no reference to fishing in a linked WWF article.[27]
Birdlife International	• Birdlife International have produced a document containing information on the potential ecological impacts of solar development, with special emphasis on birds (Birdlife International, n.d.). This document relates to a specific project ('Migratory Soaring Bird Project') in the Rift Valley/ Red Sea Flywall region of Egypt[28]. Some of the information relates to technologies not in use in the UK (e.g. CSP), however there is reference to ecology and large-scale solar farms which has relevance. This document will be summarised in the text of this review. • A 'case studies' section on the Migratory Soaring Bird Project website remains empty[9], which is perhaps indicative of the lack of evidence for the ecological impact of solar farms. • Birdlife have published a document outlining the organisation's position on climate change which includes the potential impacts of solar technologies (Birdlife International, 2015). • A document published by Birdlife explores the effect of renewables on nature in Europe and contains a dedicated section to Solar PV installations. This document provides a summary of policy recommendations given by birdlife partners across Europe. (Birdlife Europe, 2011).
BSBI	• In Kitchener (2015) and Kitchener (2016), accounts of the occurrence of mossy stonecrop (*Crassula tillaea*) at a survey site near a new solar farm describes the survey site as not particularly affected by construction works (it is insinuated that the

27 http://www.wwfindia.org/news_facts/?5720/Micro-solar-power-station-in-Sundarbans [last accessed 15/04/2016]

28 http://migratorysoaringbirds.undp.birdlife.org/en/sectors/energy/solar-energy-toc [last accessed 15/04/2016]

Organisation	Information disseminated through the organisation
	construction relates to the solar farm and that the effect in question is ecological).[29]
BTO	• A brochure for the BTO's farmland bird appeal highlights the need for research into strategies for minimising negative impacts and maximising positive impacts of solar farms on birds (BTO, n.d.). This document suggests the survey (taxa non-specific) of solar farms to determine how birds might be affected. The brochure is not dated, however a current live link is available through the BTO website[30].
CCCR	• No information readily available on the ecological effect of PV developments.
CCW	• See NRW (Natural Resources Wales)
CEH	• Link to Armstrong et al. (2014), a paper on the microclimatic effects of solar farms. This is primary literature and was incorporated into the scientific literature review.
CIEEM	• Comment from the (now) CIEEM President's introduction in a 2012 issue of the bulletin of the (then) IEEM (Institute for Ecology and Environmental management) to a conference presentation on the potential for biodiversity gain on agricultural land being developed for solar parks (Box, 2012). • CIEEM provide a summary and synthesis on the ecological impacts of renewables, including solar developments (Scrase and Gove, 2012) which was originally presented by Birdlife Europe (Birdlife Europe, 2011). • There is an indirect association via google to a website for a consultancy 'wildlife matters'[31] founded by a CIEEM member, Dr John Feltwell. Links to several grey literature documents

29 http://bsbi.org.uk/KentRPR2016Ce.pdf [last accessed 15/04/2016]

30 http://www.bto.org/support-us/appeals/farmland-bird-appeal [last accessed 15/04/2016]

31 http://www.wildlifematters.com [last accessed 18/04/2016]

Organisation	Information disseminated through the organisation
	pertaining to ecology and solar farms, all written by Dr John Feltwell, some of which are not freely available (Feltwell, 2013a, 2013b, 2013c, 2013d, 2013e, 2014a, 2014b).
DECC	• In the DECC's 'UK solar PV Strategy' part 1, it is stated that there is increasing evidence that solar farms can provide benefits to biodiversity (DECC, 2013b), citing several grey literature documents to support this (GREA, 2010; Natural England, 2011; Parker and McQueen, 2013). This document also quotes the NPPF (National Planning Policy Framework) stating that if a solar proposal involves greenfield land then it should allow for continued agricultural use and/or encourages biodiversity around arrays (DCLG, 2013). • In a separate document produced by DECC, 'UK solar PV Strategy Part 2' (DECC, 2014b) it is stated that the DECC is committed to working with industry to promote and develop best guidance practices for solar developments including with regards to biodiversity enhancement. Paragraph 73 of DECC (2014b) states that DECC and Defra will collaborate with industry to better under positive and negative ecological impacts of solar farms, although the document does not specify how this will be achieved. It is recognised by DECC that solar farms have the potential to benefit biodiversity, but also have the potential to be damaging to biodiversity and ecosystems. Although no specific effects are referred to in this document, several items of grey literature are referenced (BRE, 2013, 2014b; STA, 2013)
EPA	• No information readily available on the ecological effect of PV developments.
EPAI	• No information readily available on the ecological effect of PV developments.
European Commission Joint Research	• No information readily available on the ecological effect of PV developments.

Organisation	Information disseminated through the organisation
Centre	
European Environment Agency	• No information readily available on the ecological effect of utility scale PV systems. • In a technical report, a short passage states that it is generally accepted that the ecological footprint of solar PV is lower than that of fossil fuel electricity generation (EEA, 2015). This is of limited relevance to this review, especially considering the statement is made in the context of life-cycle emissions and probably refers to ecology in a more general context than that in the immediate vicinity of a solar development.
Friends of the Earth	• Uncited advice in a document produced by Friends of the Earth (FOE, 2014) suggests that solar farms should avoid “the best agricultural land and areas important to wildlife”, with preference to brownfield and contaminated land. The document also states that solar farms can provide an opportunity to create habitat, however this is without reference.
FWAG	• No information readily available on the ecological effect of PV developments.
Greenpeace	• No information readily available on the ecological effect of PV developments.
IPCC	• The IPCC produced a document on climate change and biodiversity, which includes the potential environmental and ecological effects of renewable technologies (IPCC, 2002). Only a short paragraph is included for solar projects, and nothing is included specifically for PV developments. This document cites water use and land use as the primary concerns for solar developments and focusses on desert environments, possibly excluding temperate regions because of the age of the document and available technologies.
IUCN	• A document produced by IUCN providing advice on solar developments (in the pacific region) states that operating PV systems are silent (IUCN, n.d.). If this is true then this may reflect

Organisation	Information disseminated through the organisation
	a reduced risk of attraction or repulsion for some taxa, however no experimental evidence has been found supporting this claim during the course of this review. • Under the IUCN red list entry for Kit Fox *Vulpes macrotis*, reference to large scale solar farms in western North America are cited as a potential cause for decline in this species[32]. The entry states that further information on the effects of solar farms is needed, and that research is being undertaken in Mexico on the effects of solar development on the San Joaquin Kit Fox, however no reference is given.
JNCC	• An evidence review of the conservation impacts of energy production was written on behalf of JNCC by IEEP (Institute for European Environmental Policy) in 2008 (Tucker et al., 2008). This document focusses predominantly on energy technologies other than solar PV. Where reference is to the potential ecological and environmental impacts of solar PV it often relates to the negative impact of mining of raw materials for use in production of solar panels (outside of the UK) or the manufacturing process (potentially within the UK). The document concludes that although large land areas may be required by utility scale PV developments, there is “relatively low or no impact” on UK biodiversity. The documents cites Abbasi and Abbasi (2000) to support a claim that large scale solar developments may cause soil erosion and compaction. • A short statement in JNCC (2006) refers to the opinion that large scale solar developments should be assessed prior to development in a manner similar to terrestrial windfarms. That is, to conduct EIA (Environmental Impact assessment) and SEA (Strategic Environmental Assessment) to assess the potential for impacts such as bird strike and land alteration and/or habitat fragmentation in areas of sensitive or rare habitat. No evidence or

32 http://www.iucnredlist.org/details/41587/0 [last accessed 19/04/2016]

Organisation	Information disseminated through the organisation
	references are provided with regards the potential for these risks with regards to solar PV developments. • An assessment of the distribution and potential threats to *Sphagnum spp.* States that "solar arrays can cause local loss of Sphagnum habitats" (NRW, 2013). This statement is unsupported with evidence. Although this document was found on the JNCC website, it explicitly states that all the information within relates to Wales only and is provided by NRW. • A document produced by JNCC in 2015 attempts to investigate the ecological concerns of a selection of UK businesses and the biodiversity enhancement measures implemented by these businesses (McNab et al., 2015). Although the businesses were anonymised, it is consistently stated throughout this document that within some businesses representative of the energy sector there is concern at the lack of research and available evidence on biodiversity enhancement and environmental gain around solar farms. One particular business (an electricity supply company with an approximate turnover of £28 million, 130 employees, and operations throughout the UK) states that biodiversity enhancements such as wildflower meadow and wetland creation and hedgerow and tree planting are incorporated into the operational design of their solar PV projects. On top of this, the business undertakes ecological monitoring of these sites and reports the biodiversity status of the solar PV sites internally.
Macaulay Land Use Research Institute	• No information readily available on the ecological effect of PV developments.
National Trust	• No information readily available on the ecological effect of PV developments.
Natural England	• Natural England have produced a document that highlights the impact that solar panels may have in areas of high wildlife value, or close to protected or designated conservation sites (Natural England, 2011). Mitigation measures are advised, and it is

Organisation	Information disseminated through the organisation
	recognised that biodiversity impacts will differ from site to site and in different regions. • In the above Natural England document, a scientific paper is referenced that did not appear in the literature search (Greif and Siemers, 2010). This citation is misleading as the scientific paper in question demonstrates that naïve juvenile bats spontaneously demonstrate drinking behaviour in response to smooth plates- not solar panels. No mention of solar panels is made in Greif and Siemers (2010).
NFU	• The NFU produced a briefing on solar PV and agriculture in 2013 (NFU, 2013) and an updated version in 2015 (NFU, 2015). These documents discuss the fact that multi-purpose land use is encouraged by most solar developers. This may include the continuation of farming practices such as sheep grazing or chicken rearing, but can also include practices encouraged by Environmental Stewardship (ES) schemes such as the creation of habitat for pollinating insects, winter foraging habitat for birds and nest boxes. The document also states that it can be advantageous to fence off solar developments from other agricultural land to either avoid losing out on Single Payment Scheme remuneration, or to "provide fenced wildlife refuges". • The NFU has worked with industry to provide best practice guides for solar developments, including for biodiversity enhancement. The two main industrial bodies are the Solar Trade Association (STA) and the National Solar Centre (the date for the STA guidance document was taken from NFU (2015)) (STA, 2013; BRE, 2014a).
NIEA	• The NIEA (under the name of its parent body, the Department of the Environment) published a document that provides standing guidance on the considerations to take into account when seeking planning for solar development, including impacts on biodiversity (DOE, 2015). It is stated within this document that solar arrays are not considered to impact significantly on wildlife. Impacts on

Organisation	Information disseminated through the organisation
	habitats include the potential drainage of wetlands along cabling routes, and direct loss of habitat within the footprint of a solar development and associated infrastructure. The potential for indirect impacts on habitat outside of a solar development footprint is highlighted, although this is not expanded on or referenced. General potential impacts of groundwork projects are highlighted including the potential for a negative impact on ground nesting birds during the construction phase of a development and a potential negative impact on badgers. The potential for birds to collide with powerlines is identified. The potential loss of bat habitat and the attraction of bats to light on site are also stated. Mitigation advice given is general and includes avoiding the loss of bat habitat, providing mammal gates in security fencing, using sensor activated security lights and avoiding placement of powerlines that obstruct bird movement. A document produced by BRE providing biodiversity guidance for solar developments is cited (BRE, 2014b).
NRW	• No information readily available on the ecological effect of PV developments.
Plantlife International	• No information readily available on the ecological effect of PV developments.
Plantlife UK	• No information readily available on the ecological effect of PV developments.
RSPB	• The RSPB have produced a policy briefing that outlines the society’s position on solar PV developments (RSPB, 2014). This document highlights that the RSPB advocate solar technologies, however recommend avoiding deployment in locations close to protected areas, or close to water features (highlighting a potential negative impact upon aquatic invertebrates as a risk, both independently and as a food resource for birds). In contrast to this advice, RSPB are also supportive of floating solar arrays with the caveat that the ecological quality of the water body must not be negatively affected. Within this document, it is highlighted that

Organisation	Information disseminated through the organisation
	there is always a risk of bird collision with man-made objects and there is a lack of evidence pertaining specifically to solar farms. The document also refers to security fencing as a potential barrier to movement for mammals and amphibians. It is stated that the loss of habitat may be an issue for rare arable forbs, however the RSPB states that the capacity for vegetation to grow under raised solar panels could provide opportunities for biodiversity enhancement including roosting potential, hibernation refuges, mutualistic use of land for agri-environment schemes and managed realignment of land behind sea walls. The RSPB calls for the monitoring of solar PV developments to determine ecological risk. • The RSPB is working alongside a solar energy developer (ANESCO) to determine how solar developments can benefit biodiversity, however there are no results from this partnership readily available.[33]
Ramsar	• Resolution XI.10 of the Ramsar convention makes reference to solar energy in the context of wetland conservation, however no specific impacts are addressed (Ramsar, 2012). • It would appear that solar PV is endorsed by the Ramsar convention in situations where it is presented as an alternative to fossil fuels such as on the Aladabra Atoll in the Seychelles, where risk of diesel leakage and high associated transport costs of fossil fuels resulted in a €500,000 solar project being implemented on a Ramsar and world heritage site[34].
SEPA	• There is a short statement on the SEPA website indicating that

33 http://anesco.co.uk/anesco-and-rspb-shine-light-on-solar-farm-biodiversity-2/ [last accessed 21/04/2016]

34 http://www.ramsar.org/news/aldabra-atoll-ramsar-site-runs-with-sustainable-solar-energy [last accessed 21/04/2016]

Organisation	Information disseminated through the organisation
	SEPA do not have a large agenda with regards to solar energy[35]. They state that their only concern might be when it has the potential affect the water environment, however this is not expanded upon.
SNH	• SNH produced a document on small scale renewables and their potential effect on the environment. This refers to developments of <50kW, and in the case of solar PV appears to refer to roof mounted units. It is advised that these solar developments may cause problems if they obstruct a known bat roost, or bird's nest (SNH, 2016b). • A separate document has been produced by SNH for large scale solar developments (SNH, 2016a). This document highlights that SNH will only consult on a project if the proposed development is in a protected area or on land supporting protected species. SNH recommend that protected species surveys should be conducted prior to works starting (otter is given as an example species). This document states that there may be a collision risk for ground nesting birds under solar arrays, that solar panels may deter birds from feeding and that displacement and collision risks may be presented by infrastructure. These risks are not referenced.
SRUC	• SRUC provide a solar PV consultancy service, however no information on the ecological impacts of these developments is readily available[36], despite producing a guide on behalf of the Scottish government providing advice on farm scale renewables, including solar (SRUC, n.d.). • In searching for information provided by SRUC, several news

35 http://www.sepa.org.uk/environment/energy/renewable/#solar [last accessed 21/04/2016]

36 http://www.sruc.ac.uk/info/120137/renewables/1049/solar_and_photovolotaics [last accessed 21/04/2016]

Organisation	Information disseminated through the organisation
	stories were found citing a 'solar meadow' built at Edinburgh College[37,38,39]. The solar meadow is discussed on Edinburgh College's engineering webpage[40], however there is no information on the ecology of the site other than that the solar meadow will allow the study of the interaction between biodiversity and solar PV. There is no indication as to why the development is named a 'meadow'- all photographs of the development on this website, and in news reports show bare earth under the solar panels.
UNEP	• No information readily available on the ecological effect of PV developments.
Wildlife Trusts	• There is no readily apparent centralised opinion on solar PV developments presented by the wildlife trusts. • There are concerns for some solar projects- Wiltshire wildlife trust strongly opposed a development on Rampisham Down[41,42] and

37 http://www.heraldscotland.com/business/13209486.Solar_power_comes_of_age_in_Scotland_as_investment_boom_could_see_building_of_first_industrial_solar_array/ [last accessed 21/04/2016]

38 http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-22282888 [last accessed 21/04/2016]

39 http://www.scotsman.com/news/education/edinburgh-college-powered-by-new-solar-meadow-1-2908688 [last accessed 21/04/2016]

40 http://www.edinburghcollege.ac.uk/Welcome/Centres/Engineering/Our-Facilities [last accessed 21/04/2016]

41 http://www.wildlifetrusts.org/news/2015/01/16/solar-farm-shock-decision-will-destroy-legally-protected-wildlife-site [Last accessed 22/04/2016]

42 http://www.wildlifetrusts.org/RampishamDown [last accessed 22/04/2016]

Organisation	Information disseminated through the organisation
	Shropshire wildlife trust opposed a temporary access road to a solar farm at Granville Country Park[43]. • Other solar developments are supported by the wildlife trusts, such as Cleworth Hall Farm in Tyldsley where a solar farm is being planned in conjunction with a solar developer (Solstice) to be built on Lancashire wildlife trust land. The trust and Solstice are working together to maximise the potential for the site to deliver biodiversity benefits alongside the development[44]. • Despite opposition to the development at Rampisham down, Wiltshire wildlife trust supports WWCE (Wiltshire Wildlife Community Energy), an organisation that helps to develop renewable projects including solar PV developments[45], and promotes the use of solar as means of generating electricity, providing that site placement is appropriate and that biodiversity management plans are in place including management of meadows in the array footprint using grazing and placing beehives underneath arrays[46]. A presentation slideshow from WWCE is available that claims warm air above the solar panels will attract insects in turn attracting birds, that voles and mice use habitat underneath the panels and that skylarks will nest between the panels, however these statements are uncited (Bennett, 2014). The presentation also refers to a 2014 study that showed three times the number of bumblebees at a solar development compared to a control plot, however this study is uncited.

43 http://www.shropshirewildlifetrust.org.uk/news/2015/09/30/nature-reserve-under-threat [last accessed 22/04/2016]

44 http://www.lancswt.org.uk/news/2015/09/08/solar-farm-boost-wildlife [last accessed 22/04/2016]

45 http://wwce.org/about/ [last accessed 22/04/2016]

46 http://wwce.org/wp-content/uploads/2015/10/Impact-of-solar-farms-on-ecology-and-biodiversity.pdf [last accessed 22/04/2016]

Organisation	Information disseminated through the organisation
WWT	• No information readily available on the ecological effect of PV developments.

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