Renewable energy and biodiversity: Implications for transitioning to a Green Economy

Abstract

This extensive literature review identifies the impacts of different renewable energy pathways on ecosystems and biodiversity, and the implications of these impacts for transitioning to a Green Economy. While the higher penetration of renewable energy is currently a backbone of Green Economy efforts, an emerging body of literature demonstrates how the renewable energy sector can affect ecosystems and biodiversity. The current review synthesizes the existing knowledge at the interface of renewable energy and biodiversity accross the five drivers of ecosystem change and biodiversity loss of the Millennium Ecosystem Assessment (MA) framework (i.e. habitat loss/change, pollution, overexploitation, climate change and introduction of invasive species). It identifies the main impacts and key mechanisms for a number of different renewable energy pathways, including solar, wind, hydro, ocean, geothermal and bioenergy. Our review demonstrates that while all reviewed renewable energy pathways are associated (directly or indirectly) with all of the five MA drivers of ecosystem change and biodiversity loss, the actual mechanisms of impact depend significantly between the different pathways (and the environmental contexts within which they operate). We put these findings into perspective by illustrating major knowledge/practices gaps and policy implications at the interface of renewable energy, biodiversity conservation and the Green Economy.

Keywords: renewable energy; biodiversity; mitigation strategies; ecosystem services; Green Economy

1. Introduction

The concept of the Green Economy has gradually gained prominence amongst academics and policy-makers [1][2]. The Green Economy was one of the two themes of the 2012 United Nations Conference on Sustainable Development (UNCSD-2012) held in Rio de Janeiro, commonly known as Rio+20. The United Nations Environment Programme (UNEP) has been at the forefront of the Green Economy discourse in the run-up to Rio+20, which culminated in the publication of its landmark Green Economy report [2] and guidance on how to formulate green economic policies, measure progress and model the future effects of a transition to a Green Economy [3].

In this discourse the Green Economy is defined as an economic system that results in "*improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities… In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services*" [2] (page 15). Conserving biodiversity[1] and maintaining ecosystem services[2] are key pillars of the efforts to transition to a Green Economy [11].

Investing in natural capital and increasing energy/resource efficiency are the two key strategies to develop "green" economic sectors, as a means of transitioning towards a Green Economy [2]. The former is a major strategy for economic sectors that depend on biological resources, such as agriculture, forestry and fisheries. The latter is key to reducing resource intensity and environmental impact to economic sectors that depend on the transformation of natural capital such as manufacturing, transport and construction.

---

[1] Biodiversity is "*the variability among living organisms from all sources including … terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems*" [4]. In the present review we adopt the definition of biodiversity proposed by the Convention on Biological Diversity (CBD) as it is in common usage, has policy status and is inclusive [5].

[2] Ecosystem services are the benefits that humans derive directly and indirectly from ecosystems, which contribute manifold to human wellbeing [6]. In the early ecosystem services discourse, biodiversity was not conceptualized as an ecosystem service, but as the basis of ecosystem services [7]. However biodiversity's role in the provision of ecosystem services, and as an extent its contribution to human wellbeing, is much more complicated [8][9][10].

According to UNEP [2], the large-scale penetration of renewable energy is a key intervention for greening the economy considering its[3]:

- climate change mitigation potential
- fossil energy-saving potential
- ability to generate "green jobs"

While renewable energy currently accounts for a relatively small proportion of global final energy consumption (~19.1%[4] in 2013), it has the potential to provide for all human energy needs [14]. In 2014, 164 countries had already adopted some type of renewable energy policy (up from 48 in 2004) [13], with some of the targets being quite bold. For example the EU aims to meet 20% of its total energy needs through renewable energy by 2020 [12].

However, there are some interesting and under-appreciated interplays between renewable energy generation and biodiversity conservation. For example, some renewable energy pathways can have major negative impacts on biodiversity by disrupting ecosystem processes [15], and thus potentially take a toll on the provision of ecosystem services [16]. This has been confirmed by a number of synthesis studies for individual renewable technologies, e.g. wind [17][18], solar [19][20][21], hydropower [22], bioenergy [23][24] and ocean energy [25][26]; as well as comparative studies between renewable and conventional energy technologies [27][28]

This implies that while a large-scale adoption of renewable energy could reduce GHG emissions and enhance resource efficiency (two key pillars of a Green Economy), it could also clash with biodiversity conservation and the maintenance of ecosystem services (a third pillar of the Green Economy, as explained above). Yet, with the exception of some land-intensive renewable energy pathways such as bioenergy, the potential negative impacts of renewable energy on biodiversity and ecosystems have been underappreciated within the current Green Economy discourse [2].

The aim of this review is to systematize the evidence about the mechanisms through which different renewable energy technologies can drive ecosystem change and contribute to biodiversity loss, as well as identify emerging green-economic trade-offs. The review is

[3] This triptych of policy objectives often features in policy frameworks that aim to catalyse the penetration of renewable energy, e.g. the EU Renewable Energy Directive [12].
[4] Of which 10.1% came from modern renewables and 9% from traditional biomass [13].

structured alongside the five direct drivers of ecosystem change and biodiversity loss identified in the Millennium Ecosystem Assessment (MA)[5]; namely habitat loss/change, overexploitation, introduction of invasive species, pollution and climate change. Several knowledge synthesis exercises, including follow-ups to the MA from the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), have discussed how the direct drivers of ecosystem change emerge in different parts of the world, and are linked to a multitude of human interventions [6][29][30]. A deeper exposition of the links between these direct drivers and biodiversity loss can be found elsewhere [6][7][31][32].

The present study initially identifies through an extensive literature review the main mechanisms of ecosystem change and biodiversity loss for each renewable energy technology, and the main interventions that can mitigate negative biodiversity outcomes. The renewable energy technologies covered include solar (Section 2), wind (Section 3), hydro (Section 4), bioenergy (Section 5), ocean (Section 6) and geothermal energy (Section 7)[6]. We focus on renewable energy technologies that have moved beyond the laboratory phase[7], as it allows us identify the impact mechanisms based on empirical studies, rather than solely relying on hypotheses or simulations. Section 8.1 summarizes the current evidence across the different MA drivers of ecosystem change and biodiversity loss. Section 8.2 identifies key knowledge/practice gaps and offers suggestions on how to better capture biodiversity trade-offs during the planning of large-scale renewable energy projects. Finally, Section 8.3 discusses some of the key policy implications at the interface or renewable energy, biodiversity conservation and the Green Economy.

2 Solar energy

2.1 Background

Solar energy harnesses the power of the sun to generate electricity either directly through photovoltaic (PV) cells, or indirectly by means of concentrated solar power (CSP). CSP

[5] These drivers of ecosystem change and biodiversity loss share significant similarities with those of subsequent initiatives such as TEEB [29] and IPBES [30].

[6] There is a large body of relevant literature for some renewable energy sources (e.g. hydro, bioenergy) and a lack for others (e.g. ocean, geothermal). For this reason our review, rather than being exhaustive, it attempts to identify the key mechanisms through which each of these renewable energy technologies contribute to ecosystem change and biodiversity loss.

[7] For example, we do not consider some advanced renewable energy technologies such as 3rd generation biofuels (algal biofuels) that have not been deployed beyond laboratory conditions [13], even though they might have some impact on ecosystems and biodiversity.

technologies use arrays of mirrors that track the sun and continuously reflect its rays to a point (heliostats) to heat a working liquid, which is then used to generate electricity in a conventional turbine[8]. Emerging solar energy technologies also use concentrated sunlight on higher quality PVs[9]. CSP generally requires large areas to be effective, while solar PV panels may be distributed and mounted on any surface exposed to the sun, making them ideal for integration into the urban environment or man-made structures.

Large-scale solar energy generation is usually referred to as Utility Scale Solar Energy (USSE) and has a typical lifespan of 25-40 years. Solar energy generation has increased rapidly in the past decades. By 2014 177 GW of solar PV and 4.4 GW of solar CSP have been installed globally [13].

The ecological impacts of solar energy are often assumed to be negligible [15]. However USSE can affect ecosystems in multiple ways throughout its lifecycle (i.e. construction–operation–decommission) [33] although currently, many of these effects are hypothesized with little peer-reviewed evidence available [27].

2.2 Drivers of ecosystem change and biodiversity loss

Most of the well-documented effects of solar energy on ecosystems and biodiversity manifest through the loss and change of habitats. This is because the development of solar energy infrastructure can take up significant amounts of land modifying and fragmenting habitats in the process.

Regarding habitat loss, solar power infrastructure, and especially USSE, increasingly occupies substantial tracts of land but its design, footprint and land-use efficiency can vary considerably [21]. Supporting infrastructure such as access roads and electrical equipment, combined with the spacing requirement of the panels, can result in the actual space requirement of solar power developments being around 2.5 times the area of the panels themselves [20].

---

8 CSP can have a 'tower power' configuration where mirrors focus solar energy to a central tower, or a trough system of parabolic mirrors that reflect heat onto the focal point of the array.

9 CPV (Concentrator photovoltaic) systems use lenses and sun-trackers to concentrate sunlight onto PV cells and are more akin to conventional PV in design but as yet, have experienced relatively limited deployment.

Regarding habitat change, the disruption to the landscape caused by USSE infrastructure and land preparation activities (e.g. vegetation clearing, removal of upper soil layers) can fragment habitats, become a barrier to the movement of species, affect hiding places, preying strategies and the availability of food [20][21][27][10]. Studies have also documented the direct mortality of birds from heliostat collisions and burning from solar rays directed to the central receiving point [35]. Mortality rates and mechanisms (e.g. mortality due to collision with the structures vs. mortality from solar fluxes) vary significantly between solar PV, CSP-tower and CSP-trough configurations [36]. The polarized light that is often found at such facilities can confuse insects into laying their eggs on the panel, affecting their chances of reproduction [37][38]. Also, the bright glare from CSP plants can attract insects, which in turn attracts birds. In turn, these can be killed by the solar flux or be subjected to higher-level predators, making the installation an ecological trap [36]. CSP also uses large amounts of water, having a dramatic effect in water-scarce environments such as the extended drying periods of ephemeral water bodies that host endemic and migratory species [39][40].

It should be noted that contrary to USSE that require significant tracts of undeveloped land, the diffusion of solar PVs on rooftops and building facades may reduce some of the habitat loss/change effects of solar energy. This is because the solar panels are mounted on existing structures (largely in urban settings) so they do not convert or fragment habitats. Interestingly if these solar PV installations are combined with green roofs then they can potentially provide habitat for certain plant/insect species and provide a number of ecosystem services in urban areas [502][503].

Solar energy installations have also been associated with pollution effects. For example, in order to keep panel access to the sun, the cleared land is often maintained in an appropriate state using dust suppressants and herbicides (in addition to other toxins used in USSE operation) [33]. The use of dust suppressants can both increase runoff and alter key chemical properties of adjoining waterways when washed out [39].

Finally, USSE can potentially affect local microclimates. For example, soil temperature changes have been reported around a CSP plant in China (0.5-4°C lower in spring and summer and higher by the same range in winter), compared to control sites with no collectors [41]. This insulation effect was attributed not only to physical shading but also to

[10] USSE infrastructure has sometimes been found to provide nesting sites [21]. However, this nesting potential can become a threat if it attracts species to hazardous areas such as airports [34].

alteration of the air-flows around the structure [41]. However, available peer-review literature regarding such micro-climatic effects is still extremely scarce.

2.3 Mitigation measures

In order to reduce the impact of the deployment of solar energy on ecosystems and biodiversity, common mitigation measures include:
(a) locating solar energy installations in areas with little biodiversity
(b) developing biodiversity-friendly operational procedures for solar energy installations

Regarding (a), a general rule of thumb is to develop USSE infrastructure in desert areas that combine high levels of solar insolation with relatively low levels of cloud cover and biodiversity[11] [19][20]. Simulation modeling suggests that there is sufficient compatible land in the desert of Californian to meet the State's solar energy targets [45] [12]. Other suggestions include using degraded areas of low conservation value or even the urban environment [46]. For example, it has been estimated that 200,000 ha of shallow slope, low-conservation value land would be sufficient to achieve all of California's renewable electricity targets [40].

Regarding (b), many government agencies and other organisations provide guidelines on how to effectively plan future solar energy installations, e.g. [47]. Such guidelines have proliferated in the US, but the actual specific biodiversity guidance varies considerably across States. For instance, in North Carolina guidelines indicate that certain protected tree species may be at risk if they are removed to minimise shading of the panels [48]. Guidelines in other States go further and actively detail how biodiversity can be managed on solar energy farms through guidance on how to develop biodiversity action plans. For example, in Arizona the importance of surface water to wildlife is noted and it is pointed out that solar installations should be developed outside of key breeding periods [49]. In the UK, where solar power installations are commonly located in grassland or pasture land,

[11] However some desert ecosystems host highly specialized and rare species that are known to be particularly vulnerable to human activity [42][43][44].

[12] Such simulation models are based on the premise that solar energy development should preferentially occur on highly degraded lands, so as to conserve land of higher ecological value. Some of these studies have employed a hierarchical multi-criteria framework that evaluates both the onsite degradation, as well as the off-site degradation expected to occur from linking the solar energy facility to the grid [45]. In a particular study for the deserts of California, 19 layers were used in the raster model and included degradation functions related to regeneration from farming and the impact of the prevailing fire regime [45].

recommendations include promoting nesting areas, sowing pollen and nectar strips, using sheep for grazing around panels and returning the land to its original use during the decommissioning of the project [47]. Mitigation measures for the aquatic environment include avoiding high-conservation value and sensitive areas, creating buffer zones to limit erosion and runoff around surface waters, and reducing herbicide use [39]. Much of the advice concerns detailed site monitoring including monitoring related to water withdrawals [47].

3 Wind power

3.1 Background

Wind power is generated from turbines powered by large rotating blades. Since their widespread introduction in the 1980s, their size (radius of blade) and above-ground height has increased markedly. The largest current blades are >100m in diameter, rotating ~100-120m above the ground and generating ~5MW of power [17].

Wind power has constituted one of the fastest growing energy generation technologies over the last two decades [51]. In 2014, installed wind energy capacity amounted to 370 GW, with China, the US and Germany being the world leaders [13].

While wind energy generation can have a number of ecological impacts on avian and aquatic species [17][18], the affected species, mechanisms and magnitude of these ecological impacts depend to a large extent on whether it is generated onshore (Section 3.2) or offshore (Section 7.2).

3.2 Drivers of ecosystem change and biodiversity loss

Any wind energy installation will result in a small loss of habitat area, either through direct occupation of the land occupied by the towers, or indirectly through species that, in turn, avoid the areas surrounding wind power facilities. However, habitat change due to the operation of the wind turbines could have more significant effects as it could hinder the normal movement and feeding activity of different bird and bat species.

Regarding habitat loss, it has been reported that different bird and bat species might avoid areas that contain wind generators [17][18] (for aquatic species refer to Section 7.2). However, several studies have found minimal effects of wind farms on the occurrence/sightings of several species, including wintering birds in farmlands [52], or birds in cropland and secondary forests in southern Mexico [53]. Environmental Impact Assessments (EIAs) and post-construction monitoring studies have found no discernable effects on the populations of black grouse [54].

Regarding habitat change, unsurprisingly, the main threat to biodiversity arises from the collision of birds (especially raptors) and bats with the wind generators, as well as from the downdraught generated by the spinning blades and barotrauma [51][13]. In general, bird species that are rare/endangered, or have long lifespans and are slow to reproduce, face the greatest risk from the deployment of wind turbines [56][57][58]. Larger and less agile birds (e.g. geese and swans) also face greater risks [59], as do those that tend to fly in lower light conditions (dawn or dusk), as they are less likely to detect and evade the wind turbines [60][61]. While some birds can sense and adapt to wind turbines, such landscape disruptions could still affect certain activities such as distant feeding and roosting [60].

Greater collision risks exist around heavily used flyways (including migratory routes) or in areas that are regularly used for feeding and/or roosting [17]. Similarly to birds, high collision risks do not only extend to native bat species, but also to non-native species during their migration. For example, the origin of bat species killed at German wind farms was found to be as far afield as Scandinavia, Estonia and Russia [62]. It should also be noted that relative collision risk can vary for a particular species during different times of the year. For example, the little bustard tends to fly at lower altitudes during the breeding season, but at higher altitudes, closer to power lines, during winter and post-breeding [63].

An estimated 234,000 birds are killed annually from wind turbines in the United States alone [64] but bats suffer disproportionately more than birds [65][66], with the impact estimated to be to the order of tens of bat fatalities/turbine/year [500][51] (see section 8.2 for further discussion). While the collision risks due to the architecture of wind turbines are relatively

[13] Bats suffer barotrauma due to changes in air pressure, which results in severe internal organ damage [51].

well documented, the actual effects of collisions on bat and bird populations are less well understood [57].

Interestingly, although wind power generation facilities can pose a risk to bird and bat species, they can have the opposite effect for some land animals such as tortoises, as decreases in road traffic, enhanced resource availability, and decreased predator populations may influence annual survivorship [67].

3.3 Mitigation measures

In order to reduce the impact of wind energy generation on ecosystems and biodiversity, common mitigation measures include:
(a) locating wind power installations in areas of little biodiversity
(b) developing biodiversity-friendly operational procedures for wind energy generation
(c) adopting innovative policies

Regarding (a), and in contrast to solar power (Section 2), the most suitable places to locate wind power turbines may also be the ones that could cause the most damage to avian biodiversity [17]. For example, whilst most proposed sites for onshore wind farms in the UK are located in upland areas (conveniently away from populated areas), these remote windy areas are also areas of high conservation importance for avifauna [66]. Identifying areas of low biodiversity to locate wind energy facilities would be important to mitigate their potential negative biodiversity outcomes, but sensitivity mapping studies would require frequent updating to reflect changing patterns in species distribution and their adaptation to the presence of wind farms [51][68].

Regarding (b), depending on turbine type, bird and bat species are at risk at altitudes between 20-180m above the ground. Proposed mitigation measures include the minimization of the overall development footprint (e.g. by installing transmission cables underground) and the risk of collision (e.g. by making blades more visible or grouping them in configurations aligned with the main flight pathways) [17]. Interestingly, modeling studies have suggested that increasing rotor speed does not significantly affect collision risk with the blades, as it is the areas closer to the hub of the turbine where collisions are more likely to occur [55]. This also suggests that increasing blade size to increase wind power generation per unit of land may only have a marginal effect on the collision risk for birds, compared to the existence of the structures themselves. On the other hand, studies have suggested that reducing rotor speed could reduce mortality for bats [501].

Other mitigation actions include halting power generation during critical migration periods [69] or times of high activity, e.g. just after sunset, during high insect activity or episodic/ad-hoc moments when threatened species are detected or predicted [27]. Modelling exercises also suggest that aggregating turbines in wind farms can lower the collision risk to raptor populations [57]. At the European level, an inter-sessional working group at the Agreement on the Conservation of Populations of European Bats (EUROBATS) investigates the effect of wind turbines on bats and develops guidelines for monitoring and impact assessment [70][14].

Regarding (c), biodiversity offsetting[15] has been identified as a potential mechanism to mitigate the negative impact of wind power on biodiversity loss. Offset schemes have been suggested for bats [51] and birds in the case of offshore installations [75]. Forest management, creation of riparian environments and other landscape features could be beneficial for the foraging, roosting and mobility of bats [51][76][77]. Other innovative policy mechanisms to curb the negative biodiversity outcomes of wind energy generation include using subsidies to promote the avoidance and mitigation strategies discussed above [78].

4 Hydropower

4.1 Background

Hydropower is obtained through the use of fresh flowing water to run turbines and generate electricity. Different hydropower technologies can be used, depending on specific geographical constraints and human demand patterns. These include:

- conventional hydropower from dams;
- run-of-river hydropower;
- pumped-storage hydropower.

[14] For more information refer to: http://www.eurobats.org/node/874

[15] Biodiversity offsetting entails compensating for biodiversity loss in one site, by generating ecological gains elsewhere [71]. Biodiversity gains can be converted into ‘credits’ that can be traded [72]. While biodiversity offsetting has been identified as a promising market-based conservation mechanism in the Green Economy discourse [2], it has been criticized for failing to deliver the expected conservation benefits, e.g. [73][74].

When considering the amount of electricity generated, a usual distinction is usually made between small hydro (<10 MW)[16] and large hydro (>10 MW). In 2012, hydropower constituted by far the largest source of renewable energy, ~16.2% of global electricity production [13]. Apart from being a renewable and dependable source of low carbon electricity, hydropower can have numerous other co-benefits such as water supply regulation, flood/drought control and agricultural irrigation [79].

Due to its longer deployment history, hydropower is the renewable energy source for which we have the most solid information regarding its influence on biodiversity. Early hydropower developments gave little consideration to aquatic species (e.g. migratory fish) and often had a significant impact on aquatic habitats, especially through the alteration of water flows upstream and downstream of dams [80][81][82][83][84][85].

4.2 Drivers of ecosystem change and biodiversity loss

Several studies have confirmed that overall, hydropower projects can be a major driver of habitat loss/change and fragmentation [86][87][88] affecting a number of species [89][90][91][92]. Regarding habitat loss, hydropower plants and dams can flood extensive upstream areas, thus fragmenting habitats (e.g. through island creation) and affecting ecosystems and the species they harbor [87], [93][94]. In some cases they can even disaffect natural reserves [95]. However, in some cases hydroelectric developments can create habitats for iconic species such as the giant otter in Brazil, due to the creation of dozens of artificial islets [96].

Regarding habitat change, the most important mechanisms perhaps relate to the modification of upstream and downstream water flow regimes [85], and the obstacles that hydropower infrastructure poses to diadromous fish during their migration to upstream spawning areas [107][108]. Studies have associated water flow regime changes with negative effects on individual species [97] or species communities/assemblages, such as fish [98], insects [99][100], invertebrates [101][102] and plants [103]. However, the actual biodiversity impacts due to water flow regime changes can be different upstream and downstream of hydropower plants, as has been observed for some macro-invertebrate

[16] This can be further subdivided into mini- (10-1000 KW) and micro-hydro (5-100 KW).

communities [104] and fish assemblages [105]. To complicate matters even more, intra-species diversity can be affected if unique genetic lineages are located upstream and downstream of a hydroelectric plant [106].

A decline in water quality (upstream, downstream and within the reservoir) due to changes in sediment loading and nutrient cycles can have negative environmental effects such as eutrophication [109], eventually affecting biodiversity [99], [110][111]. However, there have been cases of hydropower plants (mainly small-scale) that had negligible effects on water quality [112], or whose initial negative effects were stabilized over time, eventually reaching the pre-plant water quality levels [113].

While hydropower is considered a low carbon electricity pathway [14], hydropower plants can in fact emit large amount of GHGs, mainly carbon dioxide and methane from reservoirs [114][115][116][117][118][119]. These emissions can be comparable (or even higher) to those of conventional power plants [120]. Even though the latest studies suggest lower overall emissions than initially expected [121], there are hydropower plants whose carbon neutrality is contested [93][122].

The above suggests that hydropower expansion can be a potent threat to biological diversity in parts of the world that host unique and highly biodiverse ecosystems such as Amazonia [87][88][93][123], the Himalayas [124][125], China [126][127], the Mekong River delta [128] and tropical Africa [92]. In fact, there have been several cases of iconic species being negatively affected by hydropower developments, such as the panda [89], the Himalayan mahseer in the Ganges River [90], and primates in Tibet [91] and tropical Africa [92].

Future hydropower expansion could potentially have more severe global biodiversity outcomes considering that there is (a) a higher annual hydropower growth in biodiversity hotspot countries [129], and (b) a higher probability of threat to biodiversity in areas where a large fraction of available surface water is withdrawn for hydropower [130].

4.3 Mitigation measures

In order to reduce the impact of hydropower generation on ecosystems and biodiversity, common mitigation measures include:

(a) selecting hydropower technologies that have lower impacts on ecosystems and biodiversity;

(b) using biodiversity-friendly elements in hydropower installations;

(c) adopting innovative policies.

Regarding (a), it is sometimes assumed that several smaller hydropower facilities would have a lower aggregate impact than a few larger ones considering the large-scale land conversion associated with large hydro [131]. While small hydro can indeed have a lower impact on biodiversity due to its lower space requirement, some comparative studies suggest that it can be worse if other biodiversity-related metrics are taken into account [132][133]. Specific hydropower plant technologies such run-of-river (that store lower quantities of water) or the use of bypass water with no dam, can have lower impacts on water flow regime and water quality [80], but still not zero ecological impact [134][135]. The above suggests that establishing optimum operational characteristics for hydropower development can be quite difficult, especially considering variable local contexts and the need to balance multiple impacts on ecosystems and human wellbeing [136][137].

Regarding (b), technological measures, both upstream (fish ladders) and downstream (fish-friendly turbines, bypass flows), could mitigate impacts on biodiversity [80][138]. However in some contexts the actual effectiveness of such measures has been scrutinized [108][139][140].

Regarding (c), regulatory measures and market-based conservation schemes could improve the environmental performance of hydropower generation. For example, it has been suggested that issuing hydropower generation licenses for a limited term after which the operators can renew them only if they manage to comply with current environmental laws, could ensure that hydropower installations comply with the latest environmental legislation [141]. Biodiversity offsetting (Section 3.2) could also potentially mitigate some of the negative biodiversity outcomes of hydropower [71], but it is still an unproven mechanism that should be a last resort and complemented with other policies, especially in countries with poor governance and recent histories of civil conflict [92].

5. Bioenergy

5.1 Background

Bioenergy refers to the use of plant- and animal-based matter to generate renewable energy. Bioenergy sources can be as diverse as wood and residues from the forestry/arboricultural sector, crops/residues/livestock waste from the agricultural sector, waste from the manufacturing sector and food/domestic/municipal waste from the residential sector [142].

In 2014, total primary energy demand from bioenergy was ~16,250 TWh (58.5 EJ), with bioenergy's share in the total global primary energy consumption being ~10% [13]. Of these, traditional bioenergy (often associated with poor households) such as woodfuel, charcoal and dung accounted for 54%-60% and was used mainly for cooking and heating [13]. Modern uses of bioenergy that are usually associated with the Green Economy include bio-heating (for the residential and industrial sectors), bio-power and biofuels for transport [2]. Section 5.2 focuses on the ecosystem and biodiversity impacts of these modern forms of bioenergy.

The major technologies to derive modern bioenergy are broadly classified into thermochemical conversion (including combustion, gasification, pyrolysis) and biochemical conversion (including digestion and fermentation) [13][142]. Generally speaking, thermochemical conversion technologies produce bio-heat and bio-power, whilst biochemical conversion technologies produce liquid biofuel principally for transport and also for cooking and lighting (e.g. bioethanol, biodiesel)[17] [18].

Popular feedstocks for bio-heat and bio-power include poplar, willow, eucalyptus, and other types of woodfuel [14]. Primary agricultural residues such as wheat straw (EU, North Anerica), sugarcane bagasse (Brazil), maize straw (India, North America) and forest residues

[17] Sometimes the product of biochemical biomass conversion can be used to provide electricity, e.g. electricity generation through the combustion of biogas produced from the digestion of organic waste.

[18] Bioethanol and biodiesel can be blended with conventional transport fuel in different proportions. “E5” denotes a mix of 5% bioethanol and 95% gasoline, while “B5” a mix of 5% biodiesel and 95% conventional diesel.

(wood pellets, wood chips) have gradually become more important for bio-heat and bio-power generation [13].

Depending on the feedstock and conversion technology used, liquid biofuels for transport can be distinguished as first-, second- or third-generation. First-generation biofuels (mainly derived from oil, sugar and starch crops) have been developed around the world using a variety of different crops. These include maize ethanol in the US; sugarcane ethanol and soybean biodiesel in Brazil; rapeseed biodiesel in the EU; oilseed biodiesel and molasses ethanol in India; and, jatropha-based fuels and sugarcane ethanol in Sub-Sahara Africa [143]. Second-generation biofuels derived from the biochemical conversion of lignocellulosic material are gaining attention in the US and Europe and are slowly moving beyond the pilot scale [13]. Third-generation biofuels from algae are still at an experimental stage [13].

Considering the wide variety of bioenergy production pathways discussed above, Section 5.2.1 focuses on the impacts of biomass energy derived from lignocellulosic biomass that is combusted to directly produce heat and electricity, while Section 5.2.2 focuses on biomass convertion to liquid biofuels. In both cases the cultivation, processing and harvesting of feedstock can have some major implications for ecosystems and biodiversity. Whether these impacts are negative or positive depends on a large number of factors [23][144][145] as discussed below.

5.2 Drivers of ecosystem change and biodiversity loss

5.2.1 Biomass energy

Habitat loss and change is one of the most important drivers of ecosystem change and biodiversity loss due to feedstock cultivation [23]. Direct and indirect land use change effects from biomass energy expansion have resulted in habitat and biodiversity loss [144][146], especially when large-scale land conversion using mono-cultural feedstock production is adopted, e.g. [147]. Habitat change is highly context specific but mostly associated with a number of mechanisms such as tree canopy closure; rapid changing size and shape of plants;

alteration of important landscape features such as riparian forests; and soil loss [144][148][149][150][151][152][153][154]. However, some biomass energy landscapes can provide habitat and other supporting ecosystem services to a number of species than intensified agricultural landscapes [155][156][157][158]

Several life-cycle assessments (LCAs) have demonstrated that most biomass energy production pathways emit GHGs and atmospheric/water pollutants that can have negative effects on ecosystems and biodiversity such as eutrophication, acidification and toxicity. Atmospheric emissions from biomass energy chains can also contribute to tropospheric ozone formation, which has a negative effect on plants [174][177]. Such emissions have been confirmed for key biomass energy species such as eucalyptus [159][160][161][162][163], poplar [164][165][166][167] and willow [168][169][170][171][172], as well as short rotation coppice [173][174] and wood pellets [175][176].

However, the type and level of emissions (and thus the extent of the environmental impact) varies considerably between different biomass energy options. For example, different LCAs have demonstrated the global warming potentials of different biomass energy options to be highly variable [14]. Important factors that affect these emissions include the feedstock, yields, conversion technologies and pollution control mechanisms [159][165][175][176] [177][178][179]. Also, the stage of the life-cycle can be a major determinant of the type/magnitude of emissions and environmental impact, e.g. silvicultural operations are mostly associated with eutrophication due to phosphorus fertilizer use, while harvesting and transport operations are mostly linked to atmospheric emissions [165][178][179].

It should be noted that direct and indirect land use can have important climatic effects, both due to GHG emissions [180][181][182] and the alteration of local micro-climates following changes in albedo and evapotranspiration [183][184][185][186], see also Section 5.2.2.

Finally, some biomass energy feedstocks (Eucalyptus species in particular) are potentially invasive [187][188]. Even though field studies across multiple continents suggest Eucalyptus disperses more slowly than predicted by risk assessments [189], still there is evidence to suggest that it has replaced native woody species in different ecosystems [190][191][192][193][194].

5.2.2 Biofuels

Feedstock for liquid biofuel production is seen as an emerging threat to biodiversity [195][196]. Habitat loss and change during feedstock cultivation (essentially an agricultural activity) is perhaps the most important mechanism of biofuel-related ecosystem change and biodiversity loss. However, the magnitude of biodiversity loss due to land use change depends on the type of land that was converted, the feedstock and the vulnerability of the affected species [197][494]. The direct conversion of natural ecosystems (e.g. grassland, forest) is more likely to result in higher levels of biodiversity loss when compared to the conversion of cultivated or idle land [196][198][494], as discussed further below. Indirect land use change can affect areas much further away from where feedstock production is concentrated [199], but its quantification is particularly challenging and often controversial [200][201][202]

There are several examples around the world that demonstrate the negative biodiversity outcomes of habitat loss and change due to biofuel feedstock expansion. For example, sugarcane production (for ethanol) has contributed to the destruction of riparian forests in the State of Sao Paulo (Brazil), and has been linked to biodiversity loss[19] [203][204][205]. Oil palm cultivation in Southeast Asia has mainly replaced primary/secondary tropical forests rather than agricultural land [208], potentially taking a significant toll on biodiversity [198][209][210] as oil palm plantation are less hospitable to a wide range of species [211][212][213][214][215]. Sugarcane (for ethanol) and jatropha (for biodiesel) expansion in Sub-Sahara Africa can also be detrimental to local ecosystems [216][217]. EU biofuel blending mandates could result in cropland expansion throughout the world (primarily within the EU but also in Brazil and Sub-Saharan Africa) [218], with potentially severe negative impacts on biodiversity [219]. In the US, soybean (for biodiesel) and maize/sugarcane (for ethanol) will consistently have larger effect on future land use change than other renewable energy pathways, with most new feedstock production areas expected to be directly claimed from temperate forests and grasslands [220].

[19] Future sugarcane expansion in the Brazilian Southeast can pose an even more significant threat to biodiversity (both directly and indirectly) in highly biodiverse biomes such as the Cerrado and the Amazon [146][206][207].

On the other hand, 2nd generation biofuel feedstock landscapes (e.g. miscanthus, switchgrass) can provide habitat to a number of species [221][222]. Often such landscapes are more accommodating to biodiversity than 1st generation feedstock landscapes (e.g. maize, soy, rapeseed) [223][224][225][226][227][228][229][230][231][494]. This could result in enhanced provision of ecosystem services such as pollination [232] or biocontrol [233]. However, when forests or fallow agricultural land is converted, some biodiversity loss is to be expected [231][234]. It should be noted that in the US the future expansion areas of 2nd generation feedstocks will be outside the Midwest Cornbelt, meaning that more species and habitats might be affected, resulting in potentially negative effects on biodiversity [235][236].

Several comparative LCAs have confirmed that different biofuel options can have widely differing GHG emissions depending on feedstock, agricultural production practices and production area choices [237][238][239][240][241][242][243][244][245][246][247][248]. While several early biofuel LCAs have disregarded the effect of land use change on GHG emissions, subsequent studies have shown that they can substantially alter carbon balances, if factored in [249]. Several studies have calculated high carbon debts that might take several decades to be repaid [250]. As a rule of thumb, biofuel pathways that entail the conversion of natural habitats and especially forests, in addition to having the highest direct effects on biodiversity (see above), also tend to have the highest carbon debts and payback periods [251][252] (see Table 1). Indirect land use change can result in even higher carbon debts [207][253] but these are difficult to quantify [200][201][202]. It should be noted that biofuels, apart from affecting the global climate, can also affect local micro-climates due to changes in surface albedo and evapotranspiration [183][234][254][255][256][257][258][259].

Biofuels have been linked to the emission of atmospheric and aquatic pollutants [273]. However, the type and magnitude of emissions can vary significantly between different biofuel pathways and stages of the life cycle e.g. [241][247][248][274][275][276]. For some pollutants (and in some geographical contexts) biofuels can have higher emissions than conventional fossil fuels, and contribute to reduce ambient air quality [273][274]. This is the case for particulate matter emissions from Brazilian sugarcane ethanol, as life-cycle emissions are dominated by the agricultural phase (agricultural burning in particular) [277], with most of the negative effects observed during the harvesting season when burning is used for harvesting [203][278][279]. Similar air quality deterioration has been reported in areas adjacent to oil palm plantations in Southeast Asia [174][280]. Studies in Europe have also modeled tropospheric ozone increases (and their subsequent negative effects on plants) due to the expansion of biofuel production [281].

It should be mentioned that emission savings for atmospheric pollutants and GHGs can materialize through the use of agricultural waste (e.g. wheat/maize/rice straw, sugarcane bagasse) for electricity/power co-generation and 2nd generation biofuel production [241], [282][283][284][285], or the development of integrated configurations, including biorefineries [286][287][288][289]

Fertilizers, agrochemicals and industrial effluents from biofuel production are major sources of water pollution in Brazil [203][290] and Southeast Asia [291][292]. Several studies have modeled water quality decline in the US due to biofuel expansion [293][294][295][296]. Increased nitrogen loading should be expected along the Mississippi river (contributing to increasing levels of hypoxia in the Gulf of Mexico) if the US maize ethanol production meets the 2022 targets without changes in prevailing cultivation practices [297]. Similarly, eutrophication effects associated with biofuel expansion have been predicted for parts of Europe [298][299]. Biofuel-related ecotoxicity effects due to pesticide use can be highly variable between regions and feedstocks, thus posing different risks to ecosystems and biodiversity [300][301].

Finally, certain feedstocks, especially perennial grasses such as miscanthus and switchgrass, might be invasive [302][303][304][305][306]. There is some evidence to suggest that riparian habitats are particularly susceptible [226][307][308][309][310], while there are fears that non-sterile strands of miscanthus will be difficult (or even impossible) to be contained [311]. Jatropha is the main 1st generation feedstock linked to invasive behavior and has been banned from cultivation in parts of Australia and South Africa (pre-emptively) [312]. However, recent studies suggest that the fears of jatropha's invasiveness might have been overstated, at least in Sub-Sahara Africa [313][314][315].

5.3 Mitigation measures

In order to reduce the impact of bioenergy on ecosystems and biodiversity, common mitigation measures include:

(a) adopting environmentally-friendly bioenergy production practices;
(b) locating bioenergy production in marginal, degraded and/or underutilized lands;
(c) designing multi-functional bioenergy landscapes.

Regarding (a), proposed measures include limiting the expansion of monoculture plantations, adopting wildlife-friendly production practices, installing pollution control mechanisms, and undertaking continuous landscape monitoring [24][204][316][317]. Other measures include a careful feedstock selection, as different feedstocks can have radically different environmental trade-offs [318]. For example, US studies have demonstrated that 2nd generation feedstocks grown in unfertilized land could provide benefits to biodiversity when compared to monocultural annual crops such as corn and soy that make extensive use of agrochemicals [319][320]. Other studies have found that adopting biodiversity-friendly practices, such as preserving understory vegetation, conserving tree patches within plantations, conserving riparian habitats and/or using buffer zones, can have positive biodiversity outcomes [152][156][204][316][321]. The above suggests that there is a need for more systematic land-use planning to achieve bioenergy production targets, while avoiding negative biodiversity trade-offs [322][323]. Increasingly such planning approaches must consider feedstock invasiveness, e.g. by developing buffer zones at plot edges to spot invasive behavior early and prevent spread [324].

Regarding (b), it is often advocated that bioenergy feedstock should be grown in marginal, degraded or underutilized lands that harbor little biodiversity [195][325][326][327][328]. Apart from having positive biodiversity outcomes, growing feedstock in such land could on some occasions have ecological restoration effects [327][329]. For example, in wetlands, willow production can purify wastewater from sewage [330]. Similarly, the bioremediation potential of some crops such as miscanthus or jatropha means that they could potentially be grown on contaminated land, restoring some ecosystem services [331][332][333].

Regarding (c), it has often been proposed to design multifunctional bioenergy landscapes that employ a variety of biodiversity-friendly elements such as mixed-cropping for food/feed/bioenergy, crop rotation, habitat corridors, and conservation area remnants with native vegetation [158][232][334][335][336][337][338]. Such landscape approaches could not only preserve biodiversity, but also the services it provides such as pollination, that could in turn contribute to higher bioenergy yields [232][339]. However, such landscape approaches should consider a number of planning principles if they are to be successful [340].

The mitigation options discussed above can be promoted through different types of policies, ranging from regulatory instruments to market-based mechanisms such as certification [24][146][273][341][342].

6 Ocean energy

6.1 Background

Ocean Energy encapsulates a wide range of engineering technologies to obtain energy from the ocean, including through:

- trapping the incoming tide and slowly releasing it to produce electricity, in a way similar to how conventional dams operate (tidal barrages) (Section 4.1);
- capturing the energy of ocean currents and tides through devices installed under the surface of the water to produce hydrokinetic energy;
- using the energy of the surface wind waves to produce electricity through various devices installed on the sea surface (wave energy);
- using the temperature differential between cold water from the deep ocean and warm surface water (ocean thermal energy, OTEC);
- using osmotic energy, which relates to the pressure differential between salt and fresh water;
- obtaining power from offshore wind generators, similar to those discussed in Section 3.

Of these, only tidal barrages can be considered a relatively “mature” technology [343][20]. However in several countries it is not clear whether tidal barrages are economically viable, considering the massive infrastructure investments they require and their potential environmental impact [345]. For example, large-scale tidal barrages are being re-appraised in the UK, through opposition from the Environment Agency and other groups appears to

[20] La Rance in France (1966) is the earliest such example and is still operational today. This was followed by projects in Canada, China and Russia [343][482]. At present the only country that seriously undertakes efforts to construct tidal barrages is South Korea, which has recently completed a 254MW tidal barrage at Sihwa-ho Lake, and planned another one almost three times the size at Ganghwa [483][484].

make it unlikely that any new project will ever reach construction phase [346]. Smaller schemes such as the Swansea Bay Tidal Lagoon might have more chances of being built [344].

The other ocean technologies mentioned above are typically referred to as modern ocean energy. These technologies were expected to develop significantly in the past years [347][348], but (with the exception of offshore wind power) rather limited developments have actually taken place[21][13]. Interestingly, despite this lack of modern ocean energy development, the perceived environmental impacts are key obstacles to the proliferation of ocean energy projects [26][349][350][351]. Such impacts include effects on coastal ecosystems at (or near) the seabed, which are known to be important habitats for many species [25][26]. The limited deployment of modern ocean energy means that there is little empirical evidence to quantify the actual effects on ecosystem change and biodiversity, with many of these effects being essentially speculative [25][26][352]. Furthermore, there is no evidence that ocean energy installations will have the same impact on biodiversity as existing (pre-commercial) isolated units, which highlights the need for further study in this area [353].

6.2 Drivers of ecosystem change and biodiversity loss

Habitat change/loss is a key driver of ecosystem change and biodiversity loss associated with ocean energy. Habitat loss essentially manifests due to fact that any type of modern ocean energy unit or offshore wind pole will result in the direct loss of a small habitat area, as the section of the sea and the bottom occupied by such units will be unavailable for biodiversity. Tidal barrages can also result in habitat loss through the permanent inundation of the upstream portion of estuaries [345]. Habitat change is usually associated with the operation of ocean energy devices that can hinder the normal movement and feeding activity of bird and aquatic species, or even change the characteristics of the marine environment adjacent to the installations, including hydrodynamic processes [354][355].

---

[21] While the first tidal arrays might come online in 2016 [485], there have been many setbacks in several ocean energy companies and projects. For example, Pelamis Wave Power faced financial difficulties and was put into administration in 2014, while Aquamarine Power cut back to a skeleton staff [486]. Other big firms have either abandoned ocean energy projects or collapsed altogether [487].

When it comes to habitat loss, scour pits for the monopole foundations of offshore wind generators and ocean energy devices installed/anchored in the seabed might result in a local change in fish species composition, though the long-term effects are not yet fully understood [356]. Marine mammals often avoid areas of underwater construction (especially piling), only slowly returning after construction is finished [357][358]. However, there is great concern that some seabird species might be displaced from the immediate vicinity of offshore wind farms and within a 2-4km buffer zone, resulting in a loss of feeding grounds [361]. Nevertheless, and despite some differences amongst species, for the most part seabirds seem to be relatively unhindered by the presence of offshore wind farms [356], with effects on overall bird population being negligible [357][361][362]. Finally, a study of 3 pre-commercial tidal units showed that 1-3 years of monitoring after installation was finished could not find any negative impacts on local biodiversity for any of the projects [353].

It is worth noting that there is some evidence that offshore wind farm foundation scour protection has resulted in the increase of benthic species [361][363][364][365] and fish, possibly due to shelter effects [361][366][367][368]. Similar effects have been identified for other wave [369][370]) and tidal energy [371] developments. Nevertheless, such direct impacts on seabed habitats, whether positive or negative, are likely to be limited to within 100-200 meters of the array, with bedforms under the monopoles being undisturbed.

Habitat change from ocean energy installations can be a more substantial driver of ecosystem change and biodiversity loss. For example, tidal barrages could entrap species, and for example a whale was already entrapped at the Annapolis plant in Canada [343]. Offshore wind farms can pose collision risks to birds, similar to onshore wind farms (Section 2.2), but mortality assessments are more difficult compared to conventional wind farms [18][372]. Some studies have identified that while some bird species avoided offshore wind farms, others were attracted (particularly nocturnal migrant species attracted to illuminated obstacles), increasing the risk of collision [373][374][22]. However, the proximity of offshore wind farms to the coast can also affect migratory bird species that use the coastline for navigation. The rotors of wave energy devises can pose collision risks to aquatic species [26][350][375][376] or affect the routes, navigation and feeding patterns of some migratory species [377], although strong evidence is lacking due to the small number of operational

[22] It should be mentioned that seabird-wind farm interactions, and risks posed to bird populations, may vary over longer time-scales [488].

units (see above). Similarly, tidal turbines could interfere with some species such as diving birds or fish [359][360]. The only direct measurements of animals and tidal arrays (around the six-machine Verdant RITE project) showed that fish tended to perceive each machine as an independent object and that at least some species interacted closely with them [378]. Furthermore, no changes have been reported in the distribution and numbers of bird species and benthic species such as lobsters [379][380][381].

The alteration of hydrodynamic (i.e. wave/current patterns) and sedimentations processes can be another driver of habitat change from tidal and ocean energy devices [26][354][382][383][385]. Both types of technologies could alter depositional processes, change current and wave fields and result in the alteration of substrates that form the habitat for benthic organisms [26][378][23]. However, benthic organisms that live in areas with high tidal or wave energy resources are likely to be relatively resistant to the low levels of disturbance caused by modern ocean energy devices [359]. OTEC plants can also induce habitat change on coastal ecosystems in tropical countries[24] as they could upwell nutrient-rich water when extracting cold water from deeper regions of the ocean [384]. OTEC plants can have effects on a number of marine species [490], including excess mortality of tropical fish due to temperature shocks from upwelled cold water[387].

There have been concerns about the pollution effects of ocean energy installations, including chemical, noise and electromagnetic pollution [26]. For example, similar to conventional hydroelectric dams (Section 4), tidal barrages can change sediment loading, salinity and water turbidity or influence the exchange between flushing of oxygenated water [378]. This can lead to instances of mass mortality of fish and other benthic species [371]. Furthermore, the installation and decommissioning of ocean energy devices could result in a temporary degradation of habitat and water quality through increased turbidity in the water column due to disturbances to the seabed [388]. Furthermore, noise generation during the construction and operation of some ocean energy projects, or the rotary movement of tidal/offshore wind turbines, could have an effect on some (not all) aquatic species [355][356][389][390][496]. Increased vessel movements and noise during these phases could also have an impact on various marine animals, fish stocks and bird populations

[23] They can also potentially affect coastal erosion [26], though these effects appear to be rather small [386].

[24] OTEC plants must be located in areas where the warm surface seawater differs ~20°C from the cold deep water that is no more than about 1,000 meters below the surface. This typically happens between latitudes 20° North and South of the Equator [489]. .

[388][495], though these phases are relatively limited in time. Finally, electromagnetic fields [385][388] could affect sensitive species [26], though these effects are likely to be limited to the vicinity of grid connection cables [359][388]. However, it is difficult to establish such causal effects on fish and other organisms [357][383]. Finally, there has been some speculation about the toxicity of lubricants and paints used in ocean energy facilities on marine life [26][360][375].

6.3 Mitigation measures

In order to mitigate the impact of ocean energy deployment on biodiversity and ecosystems suggested measures include:

(a) selecting carefully the operational parameters of ocean energy devices
(b) locating ocean energy facilities in areas that can minimize habitat loss and disturbance to the sea bottom
(c) adopting biodiversity-friendly elements in the design of tidal barrages
(d) minimizing disturbances during the construction phase
(e) designating areas around ocean energy installations as no-go zones for fishing and other maritime activities

Regarding (a), the first commercial Seagen device was located in Strangford Narrows, Northern Ireland, hosted a nearby seal colony and occasionally basking sharks. With a speed of rotation of 12rpm, and a maximum rotor blade tip velocity of around 12m/s, it had no influence on animals that can hunt down fish in fast moving turbulent water and are as likely to collide with the tidal turbine rotor blades as with rocks [359][378][381][391]. Other studies at this site using Acoustic Doppler Current Profiling showed no evidence of any significant change to current flow velocities due to the installation of the turbine [381]. While fish do not entirely avoid the area occupied by the turbine, there appears to be no evidence of dead or dying fish recorded after passing through turbines [378]. Reports from other sites such as the ORPC's TGU demonstration deployment in Cobscook Bay (USA), Verdant turbine in New York (USA), the GFE turbine in Minnesota (USA) and OpenHydro in EMEC (Scotland) report similar findings [378]. Regarding noise reduction during the operation of ocean energy devises, mitigation strategies include acoustic shielding or damping on devices, tuning devices to operate at different frequencies, or operating at different rotational speeds [376]. In any case, given the small size of proposed developments and the negligible impacts observed up to now, fine-tuning the operational characteristics of actual installation of (slightly larger) farms and arrays appears warranted at present. Such efforts will require the establishment of a baseline, which can be a long and resource demanding process [394].

Regarding (b), over recent years there is a trend in Europe to want to situate offshore wind farms further out and in deeper water, which will require anchoring (i.e. floating) rather than fixed structures [392]. Such new developments in offshore wind energy could reduce habitat loss from the wind turbine foundations [393], and minimize their effects on benthic environments during the construction phase (see below).

Regarding (c), to minimize habitat loss/change effects from tidal barrages it has been suggested that these structures should adopt biodiversity-friendly elements. These could include (i) intertidal areas/lagoons that can provide feeding grounds during the high water period landward of the barrage, (ii) use a dual cycle generation regime, (iii) use fish-passes similar to hydropower projects and (iv) substitute the barrage by a tidal fence [25].

Regarding (d), some of the most important ecological impacts of ocean energy facilities can manifest themselves during the construction phase, not the least due to the high vessel traffic, noise and disturbance of the sea bottom (Section 6.2). In particular the noise generated during construction, such as pile-driving, could affect marine mammals [496]. The installation of underwater structures (e.g. wind farm foundations) can also affect migratory fish routes [35][395]. Minimising the extent of such disturbances during construction can reduce possible negative impacts on ecosystems.

Regarding (e) the installation of ocean energy units will require that the areas around them remain out of bound for fishing and other sea traffic [348]. The delimitation of some sea areas around ocean energy installation could act as de facto marine reserves that could allow the preservation of fishing stocks and other marine life [396][498], which could be beneficial for biodiversity.

7 Geothermal energy

7.1 Background

Geothermal energy is defined as the heat derived from the earth's crust. This can include high temperature hydrothermal resources, deep aquifer systems with low and medium temperatures, and hot rock resources. Only ~6.5% of the overall global geothermal energy potential has been tapped, with the total installed capacity being in the order of 12.8 GW [13].

Geothermal power plants consist of various components such as production/reinjection boreholes, connecting/delivery pipelines, silencers, separators, turbines/generators and cooling towers. Each of these components has some environmental impacts, whether temporary (e.g. during construction) or lasting (e.g. silencer noise)[397].

Geothermal resources are often located in pristine areas of high endemic biodiversity [397], and often intersect with protected areas [398]. Evidence about the biodiversity impacts of geothermal energy is scarce in the academic literature, although the process is perhaps not totally benign [397][399]. For this reason, it has been suggested to consider potential ecological effects when planning geothermal facilities and to adopt a triple-bottom line sustainability approach [400][401].

7.2 Mechanisms of ecosystem change and biodiversity loss

Geothermal energy generation has been associated with habitat change and loss, often in highly biodiverse and/or fragile ecosystems. For example, in Kenya, the Olkaria geothermal power project is situated in the Hell's Gate National Park, causing some level of habitat loss from the geothermal facilities and ancillary infrastructure [403]. Similar concerns have been raised for other parts of Kenya [404][405] and Costa Rica [406]. Activities such as site clearing, road construction, well drilling and seismic surveys [397], may cause habitat disturbance that could affect the breeding, foraging and migration patterns of certain species [402]. Habitat change effects linked to geothermal energy development could also manifest through the increase of activities such as tourism (e.g. in New Zealand [407]).

A typical geothermal plant using hot water and steam to generate electricity emits GHGs (CO_2), air pollutants (NH_3, H_2S) and other gases (H_2, O_2, N_2) and elements (Rn, He, As, Hg, B) whose levels vary between geothermal areas [408][409][410]. While GHG emissions are negligible compared to conventional electricity generation [14][411], the emission of toxic pollutants such as H_2S and boric acid can have a more substantial effect on surrounding vegetation [412][413][414][415]. Geothermal activity can also be responsible for elevated arsenic concentrations in water and soil, that can be absorbed by plants and fish, e.g. arsenic discharge due to geothermal development around Waikito River in New Zealand exacerbated the already high arsenic levels in the water [416]. Noise and heat pollution from geothermal facilities can also possibly have some ecological impact [409][417][418].

7.3 Mitigation measures

In order to reduce the impact of geothermal energy deployment on ecosystems and biodiversity, common mitigation measures include:

(a) adopting geothermal technologies that have low ecological impacts;

(b) promoting eco-tourism around appropriate geothermal energy facilities

Regarding (a), some geothermal energy generation technologies prevent the emission of aquatic and ambient air pollutants. For instance, binary plants that are closed-loop systems do not emit gases, while dry steam and flashed steam plants emit water vapor that contains non-condensable gases, as geothermal fluids have been re-injected into the geothermal reservoir [419]. Redirecting emissions during well testing could prevent brine spray and associated defoliation in forest locations [420]. Minimizing openings and directional drilling could allow compact work areas, reducing the overall land requirement of geothermal facilities [421].

Regarding (b), natural areas could be conserved around some geothermal facilities as parts of eco-tourism sites. Eco-tourism has been identified as a potential conservation strategy around geothermal facilities, such as the Bacon-Manito Geothermal Production Field (BGPF) in Sorsogon (Philippines) [422], Rotorua (New Zealand) [423], and the Icelandic Central Highlands [424].

8. Discussion

8.1 Synthesis of drivers

Sections 2-7 demonstrate that there are indeed important interplays between biodiversity and the renewable energy sector. Each of the different renewable energy pathways reviewed can be linked to at least one of the five MA drivers of ecosystem change and biodiversity loss (Table 2). However, despite the growing body of literature that confirms such causal links, strong evidence is lacking for some renewable energy pathways such as ocean energy and geothermal.

[Table 2]

The actual mechanisms of ecosystem change and biodiversity loss can be much more diverse, depending greatly on the renewable technology, its operational characteristics[25] and the environmental context within which the renewable technology operates (Table 3).

[Table 3]

It is worth noting that none of the renewable energy pathways reviewed is directly linked to overexploitation (Table 2). However, indirect overexploitation effects can emerge due to land use change associated with the deployment of renewables, especially in contexts where populations rely significantly on ecosystem services for their livelihoods. In such cases overexploitation effects can manifest by displacing natural resource harvesting (e.g. forest products, pasture) from the areas taken up by the renewable energy infrastructure, to ever diminishing habitats. Such points have been made for the potential future expansion of biofuels in Sub-Sahara Africa [425], hydropower in the Indian Himalayas [94] and ocean energy in Europe [426]. However, further studies are needed to understand better the true magnitude of such indirect overexploitation effects.

Finally, an interesting link between renewable energy and habitat loss/change is through the development of supporting infrastructure such as roads. Several studies have linked the construction, operation and ancillary developments alongside roads to the direct loss of

[25] For bioenergy this includes the type of feedstock and mode of feedstock production (Section 5).

habitat and the fragmentation of the wider landscape [427][428][429][430][431], as well as the proliferation of invasive species [432][433]. Such effects can be significant drivers of ecosystem change and potentially be highly detrimental to some species and habitats, e.g. [434][435][436][437][438][439][440].

8.2 Knowledge/practice gaps and recommendations

Habitat change/loss is the most prevalent driver of ecosystem change and biodiversity loss due to renewable energy expansion. In fact, all renewable energy pathways reviewed in this paper seem to have some habitat change/loss effect (Table 2) that can, however, vary across locations and species (Table 3). It is no wonder that a key mitigation strategy for most renewable energy pathways is the careful selection of the site where the renewable energy infrastructure will be located (Section 2.3, 3.3, 5.3, 6.3, 7.3).

Advanced technologies such as geographic information systems (GIS) and other geospatial analysis tools can be very useful for understanding the spatial constraints (and hence suitable locations) for developing renewable energy infrastructure without compromising critical biodiversity. For example, remote sensing has been used in the assessment and monitoring of USSE installations [50]. Advanced geospatial analysis has been applied for mapping bird sensitivities to on- and off-shore wind farms [68][441][442][443]. Some NGOs have produced resources to reduce negative biodiversity outcomes, including vulnerable species, sensitivity maps, and guidelines to minimize the impact of such projects [444][445][446]. Furthermore understanding the proximate causes of bird migratory activity such as weather conditions in departure points, can be combined with surveillance and detection mechanisms as a means of reducing the negative effects of wind power farms to migratory bird species [18]. Ecological modelling could also assist during the planning and operation of renewable energy facilities, e.g. to identify the occurrence and abundance of threatened plant species in the vicinity of hydropower plants [447]. Other tools can map the expected wave energy potential and inform the selection of appropriate sites for ocean energy installations that provide maximal returns yet avoid spatial competition with other ocean uses [448]. However, such techniques can be data-intensive, which can pose a big challenge as access to appropriate biodiversity data can be challenging even when monitoring schemes are in place [449].

Furthermore, while it is relatively easy for some renewable energy pathways (e.g. solar, wind, hydro, ocean, geothermal) to identify the actual location of renewable energy facilities and thus the potential biodiversity trade-offs, for others such as bioenergy (and biofuels in particular) this is not the case. For example, while it is relatively straightforward to estimate the amount of land that must be converted to meet bioenergy mandates, it is very difficult to identify in advance the exact location where this land conversion will take place. This is due to a number of factors including the multifunctional nature[26] of bioenergy feedstocks, the complexity of bioenergy chains and the lack of updated datasets with sufficient spatial resolution and/or global coverage [450]. In such contexts, attempts have been made to integrate models from ecology and energy planning to offer some insights into the potential biodiversity conflicts of bioenergy expansion [197][216][451][452].

When it comes to pollutant emissions from renewable energy projects (mainly bioenergy, Table 2), the biodiversity impacts of these emissions are either considered separately in impact assessments or are not incorporated effectively into Life Cycle Assessments (LCAs). A major issue here is that the type and magnitude of these emissions differs between the different stages of the life cycle (Section 5.2). Even for pollutants for which overall life-cycle emissions savings are achieved, the actual pollutant emissions (and emission savings) manifest at different areas, i.e. emissions savings at combustion sites (usually cities) and emissions at feedstock production and biofuel refining sites (usually rural or peri-urban areas) [275][277][453]. This means that the spatial distribution of these emissions, and thus their associated impact on ecosystems and biodiversity, can vary accordingly. Including a spatial element in LCAs can help identify those areas most likely to experience negative biodiversity outcomes due to these emissions. In any case integrating advanced technological options that can control pollution and increase efficiency in biofuel processing plants can reduce emissions harmful to ecosystems and biodiversity [504][505].

Setting up effective metrics for communicating biodiversity impacts from the renewable energy sector has also garnered some attention and controversy. For example, scholars have examined fatality estimates (avian mortality for wind farms) and compared them to fossil and nuclear energy sources [454], concluding that fatalities per MWh would be a better

[26] A similar point has been made for large hydropower, where the reservoirs can be used for irrigation and other human uses. This multifunctionality complicates the allocation of the burden of actual energy generation on freshwater biodiversity [80].

indicator[27]. The ensuing spat over basic ecological understanding, data and interpretation, "birds and not bats" [455] vs. "megawatts are not megawatt-hours" [456], highlights the different perspectives and assumptions employed by biodiversity and energy specialists. This highlights the need to be actively aware of different disciplinary approaches at the interface of renewable energy and biodiversity conservation, in order to make sensible planning decisions.

A large amount of evidence about the interrelationship between renewable energy and biodiversity focuses on potential risks (Section 2-7, Table 3). A common criticism about the lack of direct information on impacts at the species-level is beginning to be addressed through an emerging body of literature, especially in the southwestern US context; e.g. for the San Joaquin kit fox [457], desert tortoise [458] and the Mohave ground squirrel [459].

Finally, it is worth noting that despite the negative biodiversity impacts discussed throughout this chapter, some renewable energy pathways can have some lower overall biodiversity impacts compared to other energy forms, or even positive effects (Table 4). A study examining a range of 12 impacts of solar energy on wildlife and habitats found that only one to be more detrimental to biodiversity than conventional electricity pathways [20][28]. Similarly, despite the potentially large negative effects of some bioenergy pathways on ecosystems and biodiversity (Section 5), it has been argued that the total negative biodiversity outcomes of future bioenergy expansion might be lower to those of fossil fuel exploration and extraction [461].

[Table 4]

8.3 Policy implications

When exploring policy implications at the interface of renewable energy and biodiversity it is important to keep in mind that different countries have pursued renewable energy (and often different types of renewable energy) for different reasons. The most common drivers of renewable energy adoption have been energy security, economic development (through

[27] Similar comparative studies have been conducted for large/small hydro and wind energy, also reaching interesting results [132].

[28] In fact, three quarters of the other impacts were found to be beneficial to biodiversity, including lower pollutant/GHG emissions, even when factoring in that solar installations would have necessitated the removal of forests [20].

the often termed "green jobs") and climate change mitigation [13], e.g. see the EU Renewable Energy Directive (2009/28/EC) [12]. The influence of these drivers differs among countries, and is obvious for some renewable energy pathways such as biofuels. For example, most countries promoted biofuels to meet energy security and economic development objectives, rather than to promote environmental sustainability [273][462][491][29].

This suggests that it is not always the case that the environment is a consideration when adopting renewable energy policies. It also seems that in those cases that the environment was a strong driver for adopting renewable energy policies, such concerns were equated to climate change mitigation, treating climate as synonymous with the entire range of environmental issues. In this respect local negative biodiversity outcomes might have been overshadowed by the deep optimism that renewable energy could overall pose a lower risk to ecosystems than the alternative of using fossil fuels [463][481].

Whatever the case, the fact remains that trade-offs do exist between renewable energy and biodiversity as discussed throughout this review. In the authors' opinion these trade-offs need to be considered in policies that promote the expansion of renewable energy if economic growth is to be achieved in a socially inclusive manner within environmental limits (i.e. the professed targets of the Green Economy, Section 1). This reflects that biodiversity conservation is (and should be) as much a legitimate goal of the Green Economy as curbing GHG emissions (Section 1), and that green economic policies that promote renewable energy should take into account potential biodiversity trade-offs.

Considering (a) the different drivers of renewable energy adoption (see above), (b) the very diverse (and often highly contextual) biodiversity outcomes of renewable energy (Section 2-7) and (c) the numerous policy instruments at the interface of renewable energy and biodiversity [80][492], it is not straightforward to make concrete policy recommendations within the confines of this review.

Yet, four factors that need to be considered during the development of green economic policies at the interface of renewable energy and biodiversity conservation are:

[29] Furthermore, in several countries biofuel mandates were put in place to regulate demand, and were not necessarily complemented with policies to improve the environmental performance of biofuels [14][462].

- the scale mismatches between the policy objectives of renewable energy and biodiversity conservation;
- the growing importance of the private sector;
- the appropriate definition(s) of degraded lands;
- the clashes with market-based biodiversity conservation instruments.

There is a clear mismatch between the scale that the negative biodiversity outcomes of renewable energy manifest (local/landscape, Table 3), and its intended benefits such as climate change mitigation, energy security and green growth (mainly national, regional and global), e.g. [463]. This scale mismatch can result in implementation conflicts between site/local-specific conservation goals and national energy policy/climate change mitigation priorities [481]. Mechanisms for addressing such scale mismatches do exist in some regions (e.g. EU) considering the current attempts to mainstream biodiversity across different policy domains [11][492]. However in several other countries (particularly developing) such capacity is simply lacking [464]. Different initiatives such as energy efficiency indicators, certification schemes and market-based conservation instruments, are currently being developed for various renewable energy technologies. However, most still await adoption and implementation, as renewable energy production and biodiversity conservation are largely not approached in an integrated way [273]. Yet, there are numerous international biodiversity agreements (e.g. CBD, Ramsar Convention on Wetlands) with agreed international biodiversity targets (e.g. CBD Aichi Targets) that require implementation at the national-level. Although often separately considered, these instruments can offer a space to align national-level energy and biodiversity policies with renewable energy development. Identifying potential synergies between multi-lateral environmental agreements such as the UNFCCC and the CBD [493] could be a first step towards appropriately overcoming such scale mismatches.

Within the current Green Economy discourse private enterprises are a key player for catalyzing green economic transitions, including the renewable energy sector [2]. In fact, the private sector is seen as a key investor, a provider of the intellectual property necessary for technological innovation, and even a supplier of raw material (e.g. bioenergy feedstock) for energy generation [2]. Regarding the latter, bioenergy feedstock production can affect ecosystems and biodiversity in multiple ways, especially if it entails large land clearing and monocultures (Section 5.2). In this respect a major policy challenge falls within the purview of managing biodiversity conservation in lands privately owned by individuals or companies [465]. Some scholars argue that with the appropriate incentives and policies in place (e.g. zoning), biodiversity conservation in privately-owned bioenergy lands could improve [466][467][468]. However, the lack of clear land tenure and land acquisition laws for bioenergy production has been a major policy challenge for the conservation of biodiversity, especially in developing countries [469][470]. This suggest there is a fine line between attracting green investments for renewable energy from the private sector, whilst at the same, regulating and incentivizing the private sector to conserve biodiversity in privately-owned lands used for renewable energy purposes.

Relevant to the above discussion, is the issue of expanding renewable energy in degraded lands [45][327], (Section 2.2 and 5.2). In the US for example, abandoned cropland of approximately 683,000 Km^2 could allow for the production of 14,000 GW of solar, wind and bioenergy [474]. However, there are wide differences between definitions and policies to determine what constitutes a degraded land [471][472][473]. In the context of renewable energy the terms ‘degraded’ and ‘marginal’ land have been used synonymously and interchangeably with unused, idle, abandoned, undeveloped, fallow and low biomass land [473]. What is more important though is that marginal lands suitable for renewable energy generation can still have high biodiversity value or provide multiple ecosystem services [216]. The loss of access to such ecosystem services provided by degraded lands used for bioenergy generation can have important ramifications for human livelihoods [473][475].

Finally, the renewable energy sector can have interesting interplays with market-based conservation instruments that have gained popularity within the current Green Economy discourse such as Payment for Ecosystem Services (PES) schemes, biodiversity offsetting and product certification [2][144]. For example, studies have identified the negative effect of hydropower on PES schemes [476], or the multiple challenges that such schemes face [477]. Other studies have suggested the positive synergies between hydropower and forest conservation PES schemes that reward local communities’ long-term cooperation in conserving and protecting restored forest ecosystems [478]. Apart from PES schemes, certification standards for bioenergy and feedstock production have proliferated in the past decade [146]. While these standards often promote environmentally-sensitive production practices, their actual biodiversity outcomes are yet to be ascertained. This is not least due to the indicators chosen, which aim to achieve compliance with existing legislation rather than ensure environmental sustainability [479]. Finally, biodiversity offsetting has also been promoted as a potential way to minimize the negative ecological impacts of hydropower and wind energy, with mixed results [71][92]. These examples suggest that whilst there are some interesting synergies between renewable energy and market-based biodiversity conservation, their interplay can be quite complicated.

9. Conclusions

Renewable energy technologies are often implicitly considered as environmentally benign because of their crucial role in combating climate change. In truth there are no renewable energy technologies at present that have zero environmental impact, especially if they are to be deployed at the large-scale needed to enable a transition towards a Green Economy [2].

Our review demonstrates that current renewable energy pathways are associated (directly or indirectly) with all of the five MA drivers of ecosystem change and biodiversity loss (Table 2). The actual mechanisms vary significantly between the different renewable energy pathways and the environmental contexts within which they operate. While the current evidence is stronger for some pathways (e.g. bioenergy, hydropower) than others (e.g. solar, wind, ocean, geothermal), the fact remains that the large-scale deployment of renewable energy can have some biodiversity tradeoffs.

Given the important role of the renewable energy sector in the development of a Green Economy, this could be translated to green-economic tradeoffs with economic sectors that directly depend on biological resources such as agriculture, forestry and fisheries [11]. Similarly, broader human wellbeing trade-offs that go beyond simple economic losses may emerge due to the loss of biodiversity-derived regulating and cultural ecosystem services that play a multi-faceted role within a Green Economy [11]. Such examples include, among several others, the decline of cultural ecosystem services (e.g. recreation) following the large-scale deployment of renewables [480][481].

Considering that the biodiversity impacts of renewable energy vary between technologies, locations and species; adopting the avoid-minimize-restore-compensate mitigation hierarchy [2] on a case-by-case basis would seem to be appropriate. The model of displacement, diffusion and intensification (of activities) that has been used to understand policy impacts on fish stocks [460] could also be useful to classify renewable energy impacts and mitigation actions.

It is also important to recognize the chain of information flow about the biodiversity impacts of renewable energy. Usually raw site evidence coming from the biological sciences is often further aggregated and interpreted by ecologists, and then passed on to planners to regulate and implement; with energy policy coming in as a top-down, governmental process. It is therefore entirely likely that renewable energy goals are conceived without fully considering their practical implementation, let alone their impacts on biodiversity.

While biodiversity assessments would be useful tools to identify and minimize biodiversity conflicts from renewable energy expansion, these assessments should not exclusively focus on the negative impacts as this runs the risk of ignoring any potential benefits that may accrue from sensible planning. In fact, our review has highlighted some potential direct benefits of renewable energy technologies on biodiversity (Table 4). In any case, to bridge the gap from site suitability analysis to broader biodiversity planning it will be necessary to adopt wider disciplinary perspectives.

We must note that with this review we do not question the fundamental logic of renewable energy expansion as it has been shown to have high environmental and socio-economic benefits. However, we want to make the point that some negative impacts on biodiversity do exist, and need to be considered when developing energy policies. This is particularly important given that non-linear effects in the scaling process can manifest themselves during the development of renewable energy projects. This means that caution must be taken when assessing the risk of new renewable energy technologies as seemingly low impacts can become considerable when deployed at a scale commensurate to achieve a transition towards a Green Economy.

To sum up, determining the hidden “green-economic” trade-offs of renewable energy expansion is crucial for understanding better both the role of biodiversity within a Green Economy, as well as the economic costs and benefits that its conservation may yield [11]. While some knowledge exists about the nature of these trade-offs, developing a stronger evidence base and appropriate assessment/planning tools will be necessary to guide the transition towards a Green Economy while avoiding negative biodiversity outcomes.

Acknowledgements

AG acknowledges support from the Japan Science and Technology Council (JST) for the Belmont Forum project FICESSA. AA and TAO acknowledge the support of Monbukagakusho scholarships offered by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and through the Graduate Program in Sustainability Science - Global Leadership Initiative (GPSS-GLI), at the University of Tokyo. André Neto-Bradley provided valuable input in Section 6.

References

[1] Pearce D, Markandya A, Barbier EB. Blueprint for a Green Economy. London:Earthscan;1989.

[2] UNEP. Towards a green economy: pathways to sustainable development and poverty eradication, Nairobi: United Nations Environmental Programme (UNEP);2011.

[3] UNEP. A Guidance Manual for Green Economy Policy Assessment. Nairobi: United Nations Environmental Programme (UNEP);2014.

[4] CBD.Text of the Convention on Biological Diversity, Montreal: Convention on Biological Diversity (CBD);1992.

[5] Mace GM, Norris K, Fitter AH. Biodiversity and ecosystem services: A multilayered relationship. Trends Ecol Evol 2012;27:19-25.

[6] MA. Millennium Ecosystem Assessment: Current State and Trends Assessment. Washington DC: Island Press;2005.

[7] MA. Millennium Ecosystem Assessment: Biodiversity Synthesis. Washington DC: Island Press;2005.

[8] Naeem S, Bunker DE, Hector A, Loreau M, Perrings C (eds). Biodiversity, Ecosystem Functioning, and Human Wellbeing: an Ecological and Economic Perspective. Oxford: Oxford University Press;2009.

[9] Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, et al. Biodiversity loss and its impact on humanity. Nature 2012;486:59–67. doi:10.1038/nature11148.

[10] Harrison, P.A., Berry, P.M., Simpson, G., Haslett, J.R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamănă, N., Geertsema, W., Lommelen, E., Meiresonne, L., Turkelboom, F. Linkages between biodiversity attributes and ecosystem services: A systematic review. Ecosystem Services 2014;9:191-203.

[11] Gasparatos A, Willis KJ (eds,). Biodiversity in the green economy. London: Routledge;2015.

[12] EC. Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources. Official Journal of the European Union, L140 2009;16-62.

[13] REN21.Renewables 2015: Global Status Report. Paris: REN21 Secretariat;2015.

[14] Edenhofer O, Pichs R, Madruga Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C (eds.). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge: Cambridge University Press;2011.

[15] Katzner T, Johnson JA, Evans DM, Garner TWJ, Gompper ME, Altwegg R, Branch TA, Gordon IJ, Pettorelli N. Challenges and opportunities for animal conservation from renewable energy development. Animal Conservation 2013;16:367-9

[16] Hastik R, Basso S, Geitner C, Haida C, Poljanec A, Portaccio A, et al. Renewable energies and ecosystem service impacts. Renew Sustain Energy Rev 2015;48:608–23 doi:10.1016/j.rser.2015.04.004.

[17] Tabassum A, Premalatha M, Abbasi T, Abbasi SA. Wind energy: Increasing deployment, rising environmental concerns. Renew Sustain Energy Rev 2014;31:270–88. doi:10.1016/j.rser.2013.11.019.

[18] Schuster E, Bulling L, Köppel J. Consolidating the State of Knowledge: A Synoptical Review of Wind Energy's Wildlife Effects. Environ Manage 2015:300–31. doi:10.1007/s00267-015-0501-5.

[19] Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from the solar energy technologies. Energy Policy 2005;33:289–96. doi:10.1016/S0301-4215(03)00241-6.

[20] Turney D, Fthenakis V. Environmental impacts from the installation and operation of large-scale solar power plants. Renew Sustain Energy Rev 2011;15:3261–70. doi:10.1016/j.rser.2011.04.023.

[21] Hernandez RR, Easter SB, Murphy-Mariscal ML, Maestre FT, Tavassoli M, Allen EB, et al. Environmental impacts of utility-scale solar energy. Renew Sustain Energy Rev 2014;29:766–79. doi:10.1016/j.rser.2013.08.041.

[22] Carew-Reid J, Kempinski J, Clausen A. Biodiversity and Development of the Hydropower Sector: Lessons from the Vietnamese Experience - Volume I: Review of the Effects of Hydropower Development on Biodiversity in Vietnam. Hanoi:International Centre for Environmental Management (ICEM);2010.

[23] Dauber J, Jones MB, Stout JC. The impact of biomass crop cultivation on temperate biodiversity. GCB Bioenergy 2010;2:289–309. doi:10.1111/j.1757-1707.2010.01058.x.

[24] Verdade LM, Piña CI, Rosalino LM. Biofuels and biodiversity: Challenges and opportunities. Environ Dev 2015. doi:10.1016/j.envdev.2015.05.003.

[25] Frid C, Andonegi E, Depestele J, Judd A, Rihan D, Rogers SI, et al. The environmental interactions of tidal and wave energy generation devices. Environ Impact Assess Rev 2012;32:133–9. doi:10.1016/j.eiar.2011.06.002.

[26] Bonar PAJ, Bryden IG, Borthwick AGL. Social and ecological impacts of marine energy development. Renew Sustain Energy Rev 2015;47:486–95. doi:10.1016/j.rser.2015.03.068.

[27] Northrup JM, Wittemyer G. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecol Lett 2012;16:1–14. doi:10.1111/ele.12009.

[28] Brook BW, Bradshaw CJA. Key role for nuclear energy in global biodiversity conservation. Conservation Biology 2015;29:702-12.

[29] TEEB. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. London: Earthscan;2010.

[30] Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, et al. The IPBES Conceptual Framework: connecting nature and people. Curr Opin Environ Sustain 2015;14:1–16. doi:10.1016/j.cosust.2014.11.002.

[31] SCBD. Global Biodiversity Outlook 3, Montreal: Secretariat of the Convention on Biological Diversity;2010.

[32] SCBD. Global Biodiversity Outlook 4, Montreal: Secretariat of the Convention on Biological Diversity;2014.

[33] Lovich JE, Ennen JR. Wildlife conservation and solar energy development in the desert Southwest, United States. BioScience 2011;61:982-992.

[34] DeVault TL, Seamans TW, Schmidt J a., Belant JL, Blackwell BF, Mooers N, et al. Bird use of solar photovoltaic installations at US airports: Implications for aviation safety. Landsc Urban Plan 2014;122:122–8. doi:10.1016/j.landurbplan.2013.11.017.

[35] McCrary, MD, McKernan, RL, Schreiber, RL, Wagner, WD, Sciarrotta, TC. Avian mortality at a solar energy power plant. J Field Ornith 1986:57;135-41.

[36] Kagan R, Viner TC, Trail PW, Espinoza EO. Avian mortality at solar energy facilities in southern California: A preliminary analysis. Ashland:National Fish and Wildlife Forensics Laboratory;2014.

[37] Horváth G, Kriska G, Malik P, Robertson B. Polarized light pollution: A new kind of ecological photopollution. Front Ecol Environ 2009;7:317–25. doi:10.1890/080129.

[38] Horváth G, Blahó M, Egri Á, Kriska G, Seres I, Robertson B. Reducing the maladaptive attractiveness of solar panels to polarotactic insects. Conserv Biol 2010;24:1644–53. doi:10.1111/j.1523-1739.2010.01518.x.

[39] Grippo M, Hayse JW, O'Connor BL. Solar energy development and aquatic ecosystems in the southwestern United States: potential impacts, mitigation, and research needs. Environ Manage 2015;55:244–56. doi:10.1007/s00267-014-0384-x.

[40] Cameron DR, Cohen BS, Morrison SA. An Approach to Enhance the Conservation-Compatibility of Solar Energy Development. PLoS One 2012;7:1–12. doi:10.1371/journal.pone.0038437.

[41] Wu Z, Hou A, Chang C, Huang X, Shi D, Wang Z. Environmental impacts of large-scale CSP plants in northwestern China. Environ Sci Process Impacts 2014;16:2432–41. doi:10.1039/c4em00235k.

[42] Durant SM, Pettorelli N, Bashir S, Woodroffe R, Wacher T, De Ornellas P, et al. Forgotten biodiversity in desert ecosystems. Science 2012;336:1379–80. doi:10.1126/science.336.6087.1379.

[43] Brito JC, Godinho R, Martínez-Freiría F, Pleguezuelos JM, Rebelo H, Santos X, et al. Unravelling biodiversity, evolution and threats to conservation in the Sahara-Sahel. Biol Rev Camb Philos Soc 2014;89:215–31. doi:10.1111/brv.12049.

[44] Villarreal ML, Norman LM, Boykin KG, Wallace CSA. Biodiversity losses and conservation trade-offs: assessing future urban growth scenarios for a North American trade corridor. Int J Biodivers Sci Ecosyst Serv Manag 2013;9:90–103. doi:10.1080/21513732.2013.770800.

[45] Stoms DM, Dashiell SL, Davis FW. Siting solar energy development to minimize biological impacts. Renew Energy 2013;57:289–98. doi:10.1016/j.renene.2013.01.055.

[46] Hernandez RR, Hoffacker MK, Field CB. Efficient use of land to meet sustainable energy needs. Nat Clim Chang 2015;5:353–8. doi:10.1038/nclimate2556.

[47] BRE. Biodiversity Guidance for Solar Developments. St Blazey:BRE National Solar Centre;2014.

[48] Loveday, A. Planning and Zoning for Solar in North Carolina. School of Government. The University of North Carolina at Chapel Hill, 2014.

[49] Arizona Game and Fish Department. Guidelines for Solar Development in Arizona. Phoenix: Arizona Game and Fish Department;2009.

[50] Hamada Y, Grippo MA. Remote-sensing application for facilitating land resource assessment and monitoring for utility-scale solar energy development. J Appl Remote Sens 2015;9:097694. doi:10.1117/1.JRS.9.097694.

[51] Peste F, Paula A, da Silva LP, Bernardino J, Pereira P, Mascarenhas M, et al. How to mitigate impacts of wind farms on bats? A review of potential conservation measures in the European context. Environ Impact Assess Rev 2015;51:10–22. doi:10.1016/j.eiar.2014.11.001.

[52] Devereux CL, Denny MJH, Whittingham MJ. Minimal effects of wind turbines on the distribution of wintering farmland birds. J Appl Ecol 2008:45;1689-94.

[53] Villegas-Patraca R, MacGregor-Fors I, Ortiz-Martínez T, Pérez-Sánchez CE, Herrera-Alsina L, Muñoz-Robles C. Bird-Community Shifts in Relation to Wind Farms: A Case Study Comparing a Wind Farm, Croplands, and Secondary Forests in Southern Mexico. Condor 2012;114:711–9. doi:10.1525/cond.2012.110130.

[54] Zwart MC, Robson P, Rankin S, Whittingham MJ, McGowan PJK. Using environmental impact assessment and post-construction monitoring data to inform wind energy developments. Ecosphere 2015;6. doi:10.1890/ES14-00331.1.

[55] Kikuchi R. Adverse impacts of wind power generation on collision behaviour of birds and anti-predator behaviour of squirrels. J Nat Conserv 2008;16:44–55. doi:10.1016/j.jnc.2007.11.001.

[56] Carrete M, Sánchez-Zapata JA, Benítez JR, Lobón M, Donázar JA. Large scale risk-assessment of wind-farms on population viability of a globally endangered long-lived raptor. Biol Conserv 2009;142:2954–61. doi:10.1016/j.biocon.2009.07.027.

[57] Schaub M. Spatial distribution of wind turbines is crucial for the survival of red kite populations. Biol Conserv 2012;155:111–8. doi:10.1016/j.biocon.2012.06.021.

[58] Furness RW, Wade HM, Masden EA. Assessing vulnerability of marine bird populations to offshore wind farms. J Environ Manage 2013;119:56–66. doi:10.1016/j.jenvman.2013.01.025.

[59] Brown MJ, Linton E, Rees EC. Causes of mortality among wild swans in Britain. Wildfowl 1992;43:70–9.

[60] Drewitt AL, Langston RHW. Assessing the impacts of wind farms on birds. Ibis 2006;148:29–42. doi:10.1111/j.1474-919X.2006.00516.x.

[61] Saidur R, Rahim N, Islam MR, Solangi KH. Environmental impact of wind energy. Renew Sustain Energy Rev 2011;15:2423–30. doi:10.1016/j.rser.2011.02.024.

[62] Voigt CC, Popa-Lisseanu AG, Niermann I, Kramer-Schadt S. The catchment area of wind farms for European bats: A plea for international regulations. Biol Conserv 2012;153:80–6. doi:10.1016/j.biocon.2012.04.027.

[63] Silva JP, Palmeirim JM, Alcazar R, Correia R, Delgado A, Moreira F. A spatially explicit approach to assess the collision risk between birds and overhead power lines: A case study with the little bustard. Biol Conserv 2014;170:256-63.

[64] Loss SR, Will T, Marra PP. Estimates of bird collision mortality at wind facilities in the contiguous United States. Biol Conserv 2013;168:201–9. doi:10.1016/j.biocon.2013.10.007.

[65] Bastian O.The role of biodiversity in supporting ecosystem services in Natura 2000 sites. Ecol Indic 2013;24:12-22.

[66] Pearce-Higgins JW, Stephen L, Douse A, Langston RHW. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. J Appl Ecol 2012;49:386-94.

[67] Agha M, Lovich JE, Ennen JR, Augustine B, Arundel TR, Murphy MO, et al. Turbines and Terrestrial Vertebrates: Variation in Tortoise Survivorship Between a Wind Energy Facility and an Adjacent Undisturbed Wildland Area in the Desert Southwest (USA). Environ Manage 2015;56:332–41. doi:10.1007/s00267-015-0498-9.

[68] Bright J, Langston R, Bullman R, Evans R, Gardner S, Pearce-Higgins J. Map of bird sensitivities to wind farms in Scotland: A tool to aid planning and conservation. Biol Conserv 2008;141:2342–56. doi:10.1016/j.biocon.2008.06.029.

[69] Liechti F, Guélat J, Komenda-Zehnder S. Modelling the spatial concentrations of bird migration to assess conflicts with wind turbines. Biol Conserv 2013;162:24–32. doi:10.1016/j.biocon.2013.03.018.

[70] Rodrigues L, Bach L, Dubourg-Savage MJ, Karapandza B, Kovac D, Kervyn T, Dekker J, Kepel A, Bach P, Collins J, Harbusch C, Park K, Micevski D, Minderman J. Guidelines for Consideration of Bats in Wind Farm Projects: Revision 2014. Bonn:UNEP/EUROBATS Secretariat;2014.

[71] BBOP. Compensatory Conservation Case Studies. Washington, D.C.:Business and Biodiversity Offsets Programme(BBOP);2009.

[72] Pawliczek J, Sullivan S. Conservation and concealment in SpeciesBanking.com, USA: an analysis of neoliberal performance in the species offsetting industry. Environ Conserv 2011;38:435–44. doi:10.1017/S0376892911000518.

[73] Bull JW, Suttle KB, Gordon A, Singh NJ, Milner-Gulland EJ. Biodiversity offsets in theory and practice. Oryx 2013;47:369–80. doi:10.1017/S003060531200172X.

[74] Gardner TA, Von Hase A, Brownlie S, Ekstrom JMM, Pilgrim JD, Savy CE, et al. Biodiversity Offsets and the Challenge of Achieving No Net Loss. Conserv Biol 2013;27:1254–64. doi:10.1111/cobi.12118.

[75] Vaissière A-C, Levrel H, Pioch S, Carlier A. Biodiversity offsets for offshore wind farm projects: The current situation in Europe. Mar Policy 2014;48:172–83. doi:10.1016/j.marpol.2014.03.023.

[76] Millon L, Julien J-F, Julliard R, Kerbiriou C. Bat activity in intensively farmed landscapes with wind turbines and offset measures. Ecol Eng 2015;75:250–7. doi:10.1016/j.ecoleng.2014.11.050.

[77] Vindigni MA, Morris AD, Miller DA, Kalcounis-Rueppell MC. Use of modified water sources by bats in a managed pine landscape. For Ecol Manage 2009;258:2056-61.

[78] Kiesecker JM, Evans JS, Fargione J, Doherty K, Foresman KR, Kunz TH, et al. Win-win for wind and wildlife: a vision to facilitate sustainable development. PLoS One 2011;6:e17566. doi:10.1371/journal.pone.0017566.

[79] IEA. Technology Roadmap: Hydropower, Paris: International Energy Agency (IEA);2012.

[80] King CW. Principles for Protecting Freshwater Resources and Biodiversity during a Low-Carbon Energy Transition. Austin: Energy Institute;2013.

[81] Bunn SE, Arthington AH. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ Manage 2002;30:492–507.

[82] Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, et al. The Natural Flow Regime A paradigm for river conservation and restoration. Bioscience 1997;47:769-84

[83] Poff NL, Olden JD, Merritt DM, Pepin DM. Homogenization of regional river dynamics by dams and global biodiversity implications. Proc Natl Acad Sci U S A 2007;104:5732–7. doi:10.1073/pnas.0609812104.

[84] Poff NL, Zimmerman JKH. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshw Biol 2010;55:194–205. doi:10.1111/j.1365-2427.2009.02272.x.

[85] Renöfält BM, Jansson R, Nilsson C. Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. Freshw Biol 2010;55:49–67. doi:10.1111/j.1365-2427.2009.02241.x.

[86] Anderson EP, Pringle CM, Freeman MC. Quantifying the extent of river fragmentation by hydropower dams in the Sarapiquí River Basin, Costa Rica. Aquat Conserv Mar Freshw Ecosyst 2008;18:408–17. doi:10.1002/aqc.882.

[87] Benchimol M, Peres CA. Predicting local extinctions of Amazonian vertebrates in forest islands created by a mega dam. Biol Conserv 2015;187:61–72. doi:10.1016/j.biocon.2015.04.005.

[88] Finer M, Jenkins CN. Proliferation of hydroelectric dams in the Andean Amazon and implications for Andes-Amazon connectivity. PLoS One 2012;7:e35126. doi:10.1371/journal.pone.0035126.

[89] Zhang W, Hu Y, Chen B, Tang Z, Xu C, Qi D, Hu J. Evaluation of habitat fragmentation of giant panda (Ailuropoda melanoleuca) on the north slopes of Daxiangling Mountains, Sichuan province, China. Anim Biol 2007;57:485-500.

[90] Nautiyal P, Nautiyal R, Semwal VP, Mishra AS, Verma J, Uniyal DP, et al. Ecosystem health indicators in the Ganga Basin (Uttarakhand, India): Biodiversity, spatial patterns in structure and distribution of benthic diatoms, macro-invertebrates and ichthyofauna. Aquat Ecosyst Health Manag 2013;16:362-373

[91] Li C, Zhao C, Fan P-F. White-cheeked macaque (Macaca leucogenys): A new macaque species from Medog, southeastern Tibet. Am J Primatol 2015;77:753–66. doi:10.1002/ajp.22394.

[92] Kormos R, Kormos CF, Humle T, Lanjouw A, Rainer H, Victurine R, et al. Great apes and biodiversity offset projects in Africa: the case for national offset strategies. PLoS One 2014;9:e111671. doi:10.1371/journal.pone.0111671.

[93] Fearnside PM. Impacts of Brazil's Madeira River Dams: Unlearned lessons for hydroelectric development in Amazonia. Environ Sci Policy 2014;38:164–72. doi:10.1016/j.envsci.2013.11.004.

[94] Panwar S, Agrawal DK, Negi GCS, Kanwal KS, Sharma V, Lodhi MS, et al. Impact assessment of a hydroelectric project on the flora in the Western Himalayan region based on vegetation analysis and socio-economic studies. J Environ Plan Manag 2010:53;907-23.

[95] Ferreira J, Aragão LEOC, Barlow J, Gardner TA. Brazil's environmental leadership at risk : Mining and dams threaten protected areas. Science 2014;346:706–7.

[96] Palmeirim AF, Peres CA, Rosas FCW. Giant otter population responses to habitat expansion and degradation induced by a mega hydroelectric dam. Biol Conserv 2014;174:30–8. doi:10.1016/j.biocon.2014.03.015.

[97] Almodóvar A, Nicola GG. Effects of a small hydropower station upon brown troutSalmo trutta L. in the River Hoz Seca (Tagus basin, Spain) one year after regulation. Regul Rivers Res Manag 1999;15:477–84. doi:10.1002/(SICI)1099-1646(199909/10)15:5<477::AID-RRR560>3.0.CO;2-B.

[98] Anderson EP, Freeman MC, Pringle CM. Ecological consequences of hydropower development in Central America: impacts of small dams and water diversion on neotropical stream fish assemblages. River Res Appl 2006;22:397–411. doi:10.1002/rra.899.

[99] Vaikasas S, Palaima K, Pliūraitė V. Influence of hydropower dams on the state of macroinvertebrates assemblages in the Virvyte river, Lithuania. J Environ Eng Landsc Manag 2013:21;305-15.

[100] Zilihona IJE, Niemelä J, Nummelin M. Effects of a hydropower plant on Coleopteran diversity and abundance in the Udzungwa Mountains, Tanzania. Biodivers Conserv 2004;13:1453–64. doi:10.1023/B:BIOC.0000021325.90554.0b.

[101] Ambelu, A., Lock, K., Goethals, P.L.M. Hydrological and anthropogenic influence in the gilgel gibe i reservoir (Ethiopia) on macroinvertebrate assemblages. Lake Reserv Manage 2013:29;143-150.

[102] Lessard J, Hicks DM, Snelder TH, Arscott DB, Larned ST, Booker D, et al. Dam design can impede adaptive management of environmental flows: a case study from the Opuha Dam, New Zealand. Environ Manage 2013;51:459–73. doi:10.1007/s00267-012-9971-x.

[103] Sun, R.; Deng, W.;Yuan, J.; Li X. Influence of hydropower exploitation on characteristics of Riparian Plant communities in mountain rivers. Res Environ Sci 2015;28:915–22.

[104] Jesus T, Formigo N, Santos P, Tavares GR. Impact evaluation of the Vila Viçosa small hydroelectric power plant (Portugal) on the water quality and on the dynamics of the benthic macroinvertebrate communities of the Ardena river. Limnetica 2004;23:241–56.

[105] Sá-Oliveira JC, Hawes JE, Isaac-Nahum VJ, Peres C. Upstream and downstream responses of fish assemblages to an Eastern Amazonian hydroelectric dam. Freshw Biol 2015:60;2037-50. doi:10.1111/fwb.12628.

[106] Simões PI, Stow A, Hödl W, Amézquita A, Farias IP, Lima AP. The value of including intraspecific measures of biodiversity in environmental impact surveys is highlighted by the Amazonian brilliant-thighed frog (Allobates femoralis). Trop Conser Sci 2014; 7: 811-28.

[107] Marmulla G. Dams, fish and fisheries: Opportunities, challenges and conflict resolution, Rome: Food and Agriculture Organisation (FAO);2001.

[108] Brown JJ, Limburg KE, Waldman JR, Stephenson K, Glenn EP, Juanes F, et al. Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies. Conserv Lett 2013;6:280–6. doi:10.1111/conl.12000.

[109] Gunkel G, Lange U, Walde D, Rosa JWC.The environmental and operational impacts of Curuá-Una, a reservoir in the Amazon region of Pará, Brazil. Lakes Reserv Res Manag 2003;8:201-16.

[110] Siergieiev D, Widerlund A, Lundberg A, Almqvist L, Collomp M, Ingri J, et al. Impact of Hydropower Regulation on River Water Composition in Northern Sweden. Aquat Geochemistry 2013;20:59–80. doi:10.1007/s10498-013-9215-6.

[111] Fanny C, Virginie A, Jean-François F, Jonathan B, Marie-Claude R, Simon D. Benthic indicators of sediment quality associated with run-of-river reservoirs. Hydrobiologia 2012;703:149–64. doi:10.1007/s10750-012-1355-y.

[112] Pimenta AM, Albertoni EF, Palma-Silva C. Characterization of water quality in a small hydropower plant reservoir in southern Brazil. Lakes Reserv Res Manag 2012;17:243–51. doi:10.1111/lre.12007.

[113] Valero E. Characterization of the Water Quality Status on a Stretch of River Lerez around a Small Hydroelectric Power Station. Water 2012;4:815–34. doi:10.3390/w4040815.

[114] Pacheco FS, Soares MCS, Assireu AT, Curtarelli MP, Abril G, Stech JL, Alvalá PC, Ometto JP. The effects of river inflow and retention time on the spatial heterogeneity of chlorophyll and water-air CO2 fluxes in a tropical hydropower reservoir. Biogeosciences 2015;12:147-62.

[115] St. Louis VL, Kelly CA, Duchemin É, Rudd JWM, Rosenberg DM. Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate. Bioscience 2000;50:766. doi:10.1641/0006-3568(2000)050[0766:RSASOG]2.0.CO;2.

[116] Giles J. Methane quashes green credentials of hydropower. Nature 2006;444:524–525.

[117] Delsontro T, McGinnis DF, Sobek S, Ostrovsky I, Wehrli B. Extreme methane emissions from a Swiss hydropower reservoir: contribution from bubbling sediments. Environ Sci Technol 2010;44:2419–25. doi:10.1021/es9031369.

[118] Tremblay A, Lambert M, Gagnon L. Do Hydroelectric Reservoirs Emit Greenhouse Gases? Environ Manage 2004;33. doi:10.1007/s00267-003-9158-6.

[119] dos Santos MA, Rosa LP. Greenhouse gas emissions from hydropower reservoirs: A synthesis of knowledge. Int J Hydropower and Dams 2011;18:71-74.

[120] dos Santos MA, Rosa LP, Sikar B, Sikar E, dos Santos EO. Gross greenhouse gas fluxes from hydro-power reservoir compared to thermo-power plants. Energy Policy 2006;34:481–8.

[121] Barros N, Cole JJ, Tranvik LJ, Prairie YT, Bastviken D, Huszar VLM, et al. Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. Nat Geosci 2011;4:593–6. doi:10.1038/ngeo1211.

[122] Almeida, R.M., Barros, N., Cole, J.J., Tranvik, L., Roland, F. Emissions from Amazonian dams. Nat Clim Chang 2013;3:1005.

[123] Benchimol M, Peres CA. Widespread Forest Vertebrate Extinctions Induced by a Mega Hydroelectric Dam in Lowland Amazonia. PLoS One 2015;10:e0129818. doi:10.1371/journal.pone.0129818.

[124] Pandit MK, Grumbine RE. Potential effects of ongoing and proposed hydropower development on terrestrial biological diversity in the Indian Himalaya. Conserv Biol 2012;26:1061–71. doi:10.1111/j.1523-1739.2012.01918.x.

[125] Grumbine, R.E., Pandit, M.K. Threats from India's Himalaya dams. Science 2013;339:36-7

[126] Dudgeon D. River rehabilitation for conservation of fish biodiversity in monsoonal Asia. Ecol Soc, 2005;10: 15.

[127] Tullos DD, Foster-Moore E, Magee D, Tilt B, Wolf AT, Schmitt E, et al. Biophysical, Socioeconomic, and Geopolitical Vulnerabilities to Hydropower Development on the Nu River, China. Ecol Soc 2013;18:16. doi:10.5751/ES-05465-180316.

[128] Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I., Levin, S.A. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin Proc Natl Acad Sci USA 2012;109:5609-14.

[129] Guo Z, Zhang L, Li Y. Increased dependence of humans on ecosystem services and biodiversity. PLoS One 2010;5:e13113. doi:10.1371/journal.pone.0013113.

[130] McDonald, R.I., Olden, J.D., Opperman, J.J., Miller, W.M., Fargione, J., Revenga, C., Higgins, J.V., Powell, J. Energy, Water and Fish: Biodiversity Impacts of Energy-Sector Water Demand in the United States Depend on Efficiency and Policy Measures. PLoS ONE 2012;7:e50219,

[131] Koutsoyiannis D. Scale of water resources development and sustainability: small is beautiful, large is great. Hydrol Sci J 2011;56:553–75. doi:10.1080/02626667.2011.579076.

[132] Bakken TH, Aase AG, Hagen D, Sundt H, Barton DN, Lujala P. Demonstrating a new framework for the comparison of environmental impacts from small- and large-scale hydropower and wind power projects. J Environ Manage 2014;140:93–101. doi:10.1016/j.jenvman.2014.01.050.

[133] Kibler, K.M., Tullos, D.D. Cumulative biophysical impact of small and large hydropower development in Nu River, China. Water Resour Res:49;3104-18.

[134] SNIFFER. Impact of run of river hydro schemes up on fish populations. Edinburg: Scotland & Northern Ireland Forum for Environmental Research (SNIFFER);2011.

[135] Jager HI, Bevelhimer MS. How run-of-river operation affects hydropower generation and value. Environ Manage 2007;40:1004–15. doi:10.1007/s00267-007-9008-z.

[136] Lazzaro G, Botter G. Run-of-river power plants in Alpine regions: Whither optimal capacity? Water Resour Res 2015;51:5658–76 doi:10.1002/2014WR016642.

[137] Person E, Bieri M, Peter A, Schleiss AJ. Mitigation measures for fish habitat improvement in Alpine rivers affected by hydropower operations. Ecohydrology 2014;7:580–99. doi:10.1002/eco.1380.

[138] Pander J, Mueller M, Geist J. Ecological functions of fish bypass channels in streams: migration corridor and habitat for rheophilic species. River Res Appl 2013;29:441–50. doi:10.1002/rra.1612.

[139] Mallen-Cooper M, Brand DA. Non-salmonids in a salmonid fishway: what do 50 years of data tell us about past and future fish passage? Fish Manag Ecol 2007;14:319–32. doi:10.1111/j.1365-2400.2007.00557.x.

[140] Oldani NO, Baigún CRM, Nestler JM, Goodwin RA. Is fish passage technology saving fish resources in the lower La Plata River basin? Neotrop Ichthyol 2007;5:89–102. doi:10.1590/S1679-62252007000200002.

[141] Rudberg P. Mitigating the adverse effects of hydropower projects: A comparative review of river restoration and hydropower regulation in Sweden and the United States. Georgetown Inter Environ Law Rev 2015;27:251-74

[142] Roberts JJ, Cassula AM, Osvaldo Prado P, Dias RA, Balestieri JAP. Assessment of dry residual biomass potential for use as alternative energy source in the party of General Pueyrredón, Argentina. Renew Sustain Energy Rev 2015;41:568–83. doi:10.1016/j.rser.2014.08.066.

[143] Gasparatos A, Lee L, Maltitz GP von, Mathai M V., Oliveira JAP de, Johnson FX, et al. Catalysing biofuel sustainability - international and national policy interventions. Environ Policy Law 2013;43:216–21.

[144] Pedroli B, Elbersen B, Frederiksen P, Grandin U, Heikkilä R, Krogh PH, et al. Is energy cropping in Europe compatible with biodiversity? - Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. Biomass Bioenergy 2013;55:73–86. doi:10.1016/j.biombioe.2012.09.054.

[145] Gasparatos A, Stromberg P, Takeuchi K. Biofuels, ecosystem services and human wellbeing: Putting biofuels in the ecosystem services narrative. Agric Ecosyst Environ 2011;142:111–28. doi:10.1016/j.agee.2011.04.020.

[146] Kline KL, Martinelli FS, Mayer AL, Medeiros R, Oliveira COF, Sparovek G, et al. Bioenergy and Biodiversity: Key Lessons from the Pan American Region. Environ Manage 2015;56:1377-96 doi:10.1007/s00267-015-0559-0.

[147] Sweaney, N., Driscoll, D.A., Lindenmayer, D.B., Porch, N. Plantations, not farmlands, cause biotic homogenisation of ground-active beetles in South-Eastern Australia. Biol Conserv 2015;186:1-11.

[148] Christensen M, Rayamajhi S, Meilby H. Balancing fuelwood and biodiversity concerns in rural Nepal. Ecol Modell 2009;220:522–32. doi:10.1016/j.ecolmodel.2008.10.014.

[149] Eggers J, Troeltzsch K, Falcucci A, Maiorano L, Verburg PH, Framstad E, et al. Is biofuel policy harming biodiversity in Europe? GCB Bioenergy 2009;1:18–34. doi:DOI 10.1111/j.1757-1707.2009.01002.x.

[150] Lassauce A, Lieutier F, Bouget C. Woodfuel harvesting and biodiversity conservation in temperate forests: Effects of logging residue characteristics on saproxylic beetle assemblages. Biol Conserv 2012;147:204–12. doi:10.1016/j.biocon.2012.01.001.

[151] Specht MJ, Pinto SRR, Albuqueque UP, Tabarelli M, Melo FPL. Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. Glob Ecol Conserv 2015;3:200–9. doi:10.1016/j.gecco.2014.12.002.

[152] Millan CH, Develey PF, Verdade LM. Stand-level management practices increase occupancy by birds in exotic Eucalyptus plantations. For Ecol Manage 2015;336:174–82. doi:10.1016/j.foreco.2014.10.005.

[153] Calviño-Cancela M. Effectiveness of eucalypt plantations as a surrogate habitat for birds. For Ecol Manage 2013;310:692–9. doi:10.1016/j.foreco.2013.09.014.

[154] Ulrich W, Buszko J, Czarnecki A. The contribution of poplar plantations to regional diversity of ground beetles (Coleoptera: Carabidae) in agricultural landscapes. Ann Zool Fenn 2004;41:501–12.

[155] Dotta G, Verdade LM. Medium to large-sized mammals in agricultural landscapes of south-eastern Brazil. Mammalia 2011;75:345–52. doi:10.1515/MAMM.2011.049.

[156] Timo T, Lyra-Jorge M, Gheler-Costa C, Verdade L. Effect of the plantation age on the use of Eucalyptus stands by medium to large-sized wild mammals in south-eastern Brazil. iForest - Biogeosciences For 2015;8:108–13. doi:10.3832/ifor1237-008.

[157] Kumar MA, Mudappa D, Raman TRS. Asian Elephant Elephas maximus Habitat Use and Ranging in Fragmented Rainforest and Plantations in the Anamalai Hills, India. Trop Conserv Sci 2010;3:143–58.

[158] Fry DA, Slater F. The effect on plant communities and associated taxa of planting short rotation willow coppice in Wales. Asp Appl Biol 2008;90:287–93.

[159] Dias AC. Life cycle assessment of fuel chip production from eucalypt forest residues. Int J Life Cycle Assess 2014;19:705–17. doi:10.1007/s11367-013-0671-4.

[160] González-García S, Berg S, Moreira MT, Feijoo G. Evaluation of forest operations in Spanish eucalypt plantations under a life cycle assessment perspective. Scand J For Res 2009;24:160–72. doi:10.1080/02827580902773462.

[161] Morales M, Aroca G, Rubilar R, Acuña E, Mola-Yudego B, González-García S. Cradle-to-gate life cycle assessment of Eucalyptus globulus short rotation plantations in Chile. J Clean Prod 2015;99:239–49. doi:10.1016/j.jclepro.2015.02.085.

[162] Gabrielle B, Nguyen The N, Maupu P, Vial E. Life cycle assessment of eucalyptus short rotation coppices for bioenergy production in southern France. GCB Bioenergy 2013;5:30–42. doi:10.1111/gcbb.12008.

[163] Dias AC, Arroja L. Environmental impacts of eucalypt and maritime pine wood production in Portugal. J Clean Prod 2012;37:368–76. doi:10.1016/j.jclepro.2012.07.056.

[164] San Miguel G, Corona B, Ruiz D, Landholm D, Laina R, Tolosana E, et al. Environmental, energy and economic analysis of a biomass supply chain based on a poplar short rotation coppice in Spain. J Clean Prod 2015;94:93–101. doi:10.1016/j.jclepro.2015.01.070.

[165] González-García S, Bacenetti J, Murphy RJ, Fiala M. Present and future environmental impact of poplar cultivation in the Po Valley (Italy) under different crop management systems. J Clean Prod 2012;26:56–66. doi:10.1016/j.jclepro.2011.12.020.

[166] Roedl A. Production and energetic utilization of wood from short rotation coppice-a life cycle assessment. Int J Life Cycle Assess 2010;15:567–78. doi:10.1007/s11367-010-0195-0.

[167] Gasol CM, Gabarrell X, Anton A, Rigola M, Carrasco J, Ciria P, et al. LCA of poplar bioenergy system compared with Brassica carinata energy crop and natural gas in regional scenario. Biomass and Bioenergy 2009;33:119–29. doi:10.1016/j.biombioe.2008.04.020.

[168] Heller MC, Keoleian GA, Volk TA. Life cycle assessment of a willow bioenergy cropping system. Biomass Bioenergy 2003;25:147–65. doi:10.1016/S0961-9534(02)00190-3.

[169] Volk T, Verwijst T, Tharakan PJ, Abrahamson LP, White EH. Growing fuel: a sustainability assessment of willow biomass crops. Front Ecol Environ 2004;2:411–8.

[170] González-García S, Mola-Yudego B, Murphy RJ. Life cycle assessment of potential energy uses for short rotation willow biomass in Sweden. Int J Life Cycle Assess 2013;18:783–95. doi:10.1007/s11367-012-0536-2.

[171] Buonocore E, Franzese PP, Ulgiati S. Assessing the environmental performance and sustainability of bioenergy production in Sweden: A life cycle assessment perspective. Energy 2012;37:69–78. doi:10.1016/j.energy.2011.07.032.

[172] Kimming M, Sundberg C, Nordberg Å, Baky A, Bernesson S, Norén O, et al. Biomass from agriculture in small-scale combined heat and power plants: A comparative life cycle assessment. Biomass Bioenergy 2011;35:1572–81. doi:10.1016/j.biombioe.2010.12.027.

[173] Rugani B, Golkowska K, Vázquez-Rowe I, Koster D, Benetto E, Verdonckt P. Simulation of environmental impact scores within the life cycle of mixed wood chips from alternative short rotation coppice systems in Flanders (Belgium). Appl Energy 2015;156:449–64. doi:10.1016/j.apenergy.2015.07.032.

[174] Ashworth K, Folberth G, Hewitt CN, Wild O. Impacts of near-future cultivation of biofuel feedstocks on atmospheric composition and local air quality. Atm Chem Phys 2012;12:919-39.

[175] Hansson J, Martinsson F, Gustavsson M. Greenhouse gas performance of heat and electricity from wood pellet value chains - based on pellets for the Swedish market. Biofuels, Bioprod Biorefining 2015;9:378–96. doi:10.1002/bbb.1538.

[176] Röder M, Whittaker C, Thornley P. How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues. Biomass Bioenergy 2015;79:50–63. doi:10.1016/j.biombioe.2015.03.030.

[177] Ashworth K, Wild O, Eller ASD, Hewitt CN. Impact of Biofuel Poplar Cultivation on Ground-Level Ozone and Premature Human Mortality Depends on Cultivar Selection and Planting Location. Environ Sci Technol 2015;49:8566–75. doi:10.1021/acs.est.5b00266.

[178] González-García S, Moreira MT, Dias AC, Mola-Yudego B. Cradle-to-gate Life Cycle Assessment of forest operations in Europe: Environmental and energy profiles. J Clean Prod 2014;66:188–98. doi:10.1016/j.jclepro.2013.11.067.

[179] Muench S, Guenther E. A systematic review of bioenergy life cycle assessments. Appl Energy 2013;112:257–73. doi:10.1016/j.apenergy.2013.06.001.

[180] Zona D, Janssens IA, Aubinet M, Gioli B, Vicca S, Fichot R, et al. Fluxes of the greenhouse gases (CO_2, CH_4 and N_2O) above a short-rotation poplar plantation after conversion from agricultural land. Agric For Meteorol 2013;169:100–10. doi:10.1016/j.agrformet.2012.10.008.

[181] Don A, Osborne B, Hastings A, Skiba U, Carter MS, Drewer J, et al. Land-use change to bioenergy production in Europe: implications for the greenhouse gas balance and soil carbon. GCB Bioenergy 2012;4:372–91. doi:10.1111/j.1757-1707.2011.01116.x.

[182] Nikièma P, Rothstein DE, Miller RO. Initial greenhouse gas emissions and nitrogen leaching losses associated with converting pastureland to short-rotation woody bioenergy crops in northern Michigan, USA. Biomass Bioenergy 2012;39:413–26. doi:10.1016/j.biombioe.2012.01.037.

[183] Tölle MH, Gutjahr O, Busch G, Thiele JC. Increasing bioenergy production on arable land: Does the regional and local climate respond? Germany as a case study. J Geophys Res Atmos 2014;119:2711–24. doi:10.1002/2013JD020877.

[184] Murphy LN, Riley WJ, Collins WD. Local and Remote Climate Impacts from Expansion of Woody Biomass for Bioenergy Feedstock in the Southeastern United States. J Clim 2012;25:7643–59. doi:10.1175/JCLI-D-11-00535.1.

[185] Bright RM, Strømman AH, Peters GP. Radiative forcing impacts of boreal forest biofuels: a scenario study for Norway in light of albedo. Environ Sci Technol 2011;45:7570–80. doi:10.1021/es201746b.

[186] Bright RM, Cherubini F, Strømman AH. Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment. Environ Impact Assess Rev 2012;37:2–11. doi:10.1016/j.eiar.2012.01.002.

[187] Gordon DR, Tancig KJ, Onderdonk DA, Gantz CA. Assessing the invasive potential of biofuel species proposed for Florida and the United States using the Australian Weed Risk Assessment. Biomass Bioenergy 2011;35:74–9. doi:10.1016/j.biombioe.2010.08.029.

[188] Barney JN, DiTomaso JM. Global climate niche estimates for bioenergy crops and invasive species of agronomic origin: potential problems and opportunities. PLoS One 2011;6:e17222. doi:10.1371/journal.pone.0017222.

[189] Vance ED, Loehle C, Wigley TB, Weatherford P. Scientific basis for sustainable management of Eucalyptus and populus as short-rotation woody crops in the U.S. Forests 2014;5:901-18.

[190] Sax DF. Equal diversity in disparate species assemblages: A comparison of native and exotic woodlands in California. Glob Ecol Biogeogr 2002;11:49–57. doi:10.1046/j.1466-822X.2001.00262.x.

[191] Dukes JS, Mooney HA. Disruption of ecosystem processes in western North America by invasive species. Rev Chil Hist Nat 2004;77:411–37. doi:10.4067/S0716-078X2004000300003.

[192] Barbour RC, Potts BM, Vaillancourt RE. Gene flow between introduced and native Eucalyptus species: Early-age selection limits invasive capacity of exotic E. ovata × nitens F1 hybrids. For Ecol Manage 2006;228:206–14. doi:10.1016/j.foreco.2006.03.004.

[193] Branco S, Videira N, Branco M, Paiva MR. A review of invasive alien species impacts on eucalypt stands and citrus orchards ecosystem services: Towards an integrated management approach. J Environ Manage 2015;149:17–26. doi:10.1016/j.jenvman.2014.09.026.

[194] Calviño-Cancela M, Rubido-Bará M. Invasive potential of Eucalyptus globulus: Seed dispersal, seedling recruitment and survival in habitats surrounding plantations. For Ecol Manage 2013;305:129–37. doi:10.1016/j.foreco.2013.05.037.

[195] Fargione JE, Plevin RJ, Hill JD. The Ecological Impact of Biofuels. Annu Rev Ecol Evol Syst 2010;41:351–77. doi:10.1146/annurev-ecolsys-102209-144720.

[196] Immerzeel DJ, Verweij PA, van der Hilst F, Faaij APC. Biodiversity impacts of bioenergy crop production: a state-of-the-art review. GCB Bioenergy 2014;6:183–209. doi:10.1111/gcbb.12067.

[197] Chaudhary A, Verones F, de Baan L, Hellweg S. Quantifying Land Use Impacts on Biodiversity: Combining Species-Area Models and Vulnerability Indicators. Environ Sci Technol 2015;49:9987–95. doi:10.1021/acs.est.5b02507.

[198] Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Brühl CA, Donald PF, et al. How will oil palm expansion affect biodiversity? Trends Ecol Evol 2008;23:538–45. doi:10.1016/j.tree.2008.06.012.

[199] Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, et al. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319:1238–40. doi:10.1126/science.1151861.

[200] Khanna M, Crago CL, Black M. Can biofuels be a solution to climate change? The implications of land use change-related emissions for policy. Interface Focus 2011;1:233–47. doi:10.1098/rsfs.2010.0016.

[201] Sanchez ST, Woods J, Akhurst M, Brander M, O'Hare M, Dawson TP, et al. Accounting for indirect land-use change in the life cycle assessment of biofuel supply chains. J R Soc Interface 2012;9:1105–19. doi:10.1098/rsif.2011.0769.

[202] Finkbeiner M. Indirect land use change – Help beyond the hype? Biomass Bioenergy 2014;62:218–21. doi:10.1016/j.biombioe.2014.01.024.

[203] Martinelli LA, Filoso S. Expansion of sugarcane ethanol production in Brazil: environmental and social challenges. Ecol Appl 2008;18:885–98.

[204] Filoso S, Do Carmo JB, Mardegan SF, Lins SRM, Gomes TF, Martinelli LA. Reassessing the environmental impacts of sugarcane ethanol production in Brazil to help meet sustainability goals Renew Sustain Energy Rev 2015;52:1847-56.

[205] Smeets E, Junginger M, Faaij A, Walter A, Dolzan P, Turkenburg W. The sustainability of Brazilian ethanol: An assessment of the possibilities of certified production. Biomass Bioenergy 2008;32:781–813. doi:10.1016/j.biombioe.2008.01.005.

[206] Sparovek G, Berndes G, Egeskog A, de Freitas FLM, Gustafsson S, Hansson J. Sugarcane ethanol production in Brazil: An expansion model sensitive to socioeconomic and environmental concerns. Biofuels, Bioprod Biorefining 2007;1:270-82.

[207] Lapola DM, Schaldach R, Alcamo J, Bondeau A, Koch J, Koelking C, et al. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proc Natl Acad Sci USA 2010;107:3388–93. doi:10.1073/pnas.0907318107.

[208] Koh LP, Wilcove DS. Is oil palm agriculture really destroying tropical biodiversity? Conserv Lett 2008;1:60–4. doi:10.1111/j.1755-263X.2008.00011.x.

[209] Koh LP, Miettinen J, Liew SC, Ghazoul J. Remotely sensed evidence of tropical peatland conversion to oil palm. Proc Natl Acad Sci USA 2011;108:5127–32. doi:10.1073/pnas.1018776108.

[210] Lee JSH, Abood S, Ghazoul J, Barus B, Obidzinski K, Koh LP. Environmental Impacts of Large-Scale Oil Palm Enterprises Exceed that of Smallholdings in Indonesia. Conserv Lett 2014;7:25–33. doi:10.1111/conl.12039.

[211] Teuscher M, Vorlaufer M, Wollni M, Brose U, Mulyani Y, Clough Y. Trade-offs between bird diversity and abundance, yields and revenue in smallholder oil palm plantations in Sumatra, Indonesia. Biol Conserv 2015;186:306–18. doi:10.1016/j.biocon.2015.03.022.

[212] Danielsen F, Beukema H, Burgess ND, Parish F, Brühl CA, Donald PF, et al. Biofuel plantations on forested lands: double jeopardy for biodiversity and climate. Conserv Biol 2009;23:348–58. doi:10.1111/j.1523-1739.2008.01096.x.

[213] Peh KS-H, Jong J de, Sodhi NS, Lim SL-H, Yap CA-M. Lowland rainforest avifauna and human disturbance: persistence of primary forest birds in selectively logged forests and mixed-rural habitats of southern Peninsular Malaysia. Biol Conserv 2005;123:489–505. doi:10.1016/j.biocon.2005.01.010.

[214] Hamer KC, Hill JK, Benedick S, Mustaffa N, Sherratt TN, Maryati M, et al. Ecology of butterflies in natural and selectively logged forests of northern Borneo: the importance of habitat heterogeneity. J Appl Ecol 2003;40:150–62. doi:10.1046/j.1365-2664.2003.00783.x.

[215] Dumbrell AJ, Hill JK. Impacts of selective logging on canopy and ground assemblages of tropical forest butterflies: Implications for sampling. Biol Conserv 2005;125:123–31. doi:10.1016/j.biocon.2005.02.016.

[216] Blanchard R, O'Farrell PJ, Richardson DM. Anticipating potential biodiversity conflicts for future biofuel crops in South Africa: incorporating spatial filters with species distribution models. GCB Bioenergy 2015;7:273–87. doi:10.1111/gcbb.12129.

[217] van Eijck J, Romijn H, Smeets E, Bailis R, Rooijakkers M, Hooijkaas N, et al. Comparative analysis of key socio-economic and environmental impacts of smallholder and plantation based jatropha biofuel production systems in Tanzania. Biomass Bioenergy 2014;61:25–45. doi:10.1016/j.biombioe.2013.10.005.

[218] Britz W, Hertel TW. Impacts of EU biofuels directives on global markets and EU environmental quality: An integrated PE, global CGE analysis. Agric Ecosyst Environ 2011;142:102–9. doi:10.1016/j.agee.2009.11.003.

[219] Hellmann F, Verburg PH. Impact assessment of the European biofuel directive on land use and biodiversity. J Environ Manage 2010;91:1389–96. doi:10.1016/j.jenvman.2010.02.022.

[220] McDonald RI, Fargione J, Kiesecker J, Miller WM, Powell J. Energy sprawl or energy efficiency: Climate policy impacts on natural habitat for the United States of America. PLoS ONE 2009;4:e6802,

[221] Semere T, Slater F. Ground flora, small mammal and bird species diversity in miscanthus (Miscanthus×giganteus) and reed canary-grass (Phalaris arundinacea) fields. Biomass Bioenergy 2007;31:20–9. doi:10.1016/j.biombioe.2006.07.001.

[222] Semere T, Slater FM. Invertebrate populations in miscanthus (Miscanthus×giganteus) and reed canary-grass (Phalaris arundinacea) fields. Biomass Bioenergy 2007:31:30-9. doi: 10.1016/j.biombioe.2006.07.002

[223] Werling BP, Dickson TL, Isaacs R, Gaines H, Gratton C, Gross KL, et al. Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci USA 2014;111:1652–7. doi:10.1073/pnas.1309492111.

[224] Robertson BA, Doran PJ, Loomis ER, Robertson JR, Schemske DW. Avian use of perennial biomass feedstocks as post-breeding and migratory stopover habitat. PLoS One 2011a;6:e16941. doi:10.1371/journal.pone.0016941.

[225] Robertson BA, Doran PJ, Loomis LR, Robertson JR, Schemske DW. Perennial biomass feedstocks enhance avian diversity. GCB Bioenergy 2011;3:235–46. doi:10.1111/j.1757-1707.2010.01080.x.

[226] Robertson BA, Porter C, Landis DA, Schemske DW. Agroenergy Crops Influence the Diversity, Biomass, and Guild Structure of Terrestrial Arthropod Communities. BioEnergy Res 2011;5:179–88. doi:10.1007/s12155-011-9161-3.

[227] Robertson BA, Landis DA, Sillett TS, Loomis ER, Rice RA. Perennial Agroenergy Feedstocks as En Route Habitat for Spring Migratory Birds. Bioenergy Res 2013;6:311–20. doi:10.1007/s12155-012-9258-3.

[228] Fargione J. Is bioenergy for the birds? An evaluation of alternative future bioenergy landscapes. Proc Natl Acad Sci USA. 2010;107:18745–6. doi:10.1073/pnas.1014045107.

[229] Meehan TD, Hurlbert AH, Gratton C. Bird communities in future bioenergy landscapes of the Upper Midwest. Proc Natl Acad Sci USA 2010;107:18533–8. doi:10.1073/pnas.1008475107.

[230] Bellamy PE, Croxton PJ, Heard MS, Hinsley SA, Hulmes L, Hulmes S, et al. The impact of growing miscanthus for biomass on farmland bird populations. Biomass Bioenergy 2009;33:191–9. doi:10.1016/j.biombioe.2008.07.001.

[231] Rowe RL, Street NR, Taylor G. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. Renew Sustain Energy Rev 2009;13:271–90. doi:10.1016/j.rser.2007.07.008.

[232] Bennett AB, Isaacs R. Landscape composition influences pollinators and pollination services in perennial biofuel plantings. Agric Ecosyst Environ 2014;193:1–8. doi:10.1016/j.agee.2014.04.016.

[233] Werling BP, Meehan TD, Gratton C, Landis DA. Influence of habitat and landscape perenniality on insect natural enemies in three candidate biofuel crops. Biol Control 2011;59:304–12. doi:10.1016/j.biocontrol.2011.06.014.

[234] Jørgensen S V, Cherubini F, Michelsen O. Biogenic CO_2 fluxes, changes in surface albedo and biodiversity impacts from establishment of a miscanthus plantation. J Environ Manage 2014;146:346–54. doi:10.1016/j.jenvman.2014.06.033.

[235] Evans SG, Kelley LC, Potts MD. The potential impact of second-generation biofuel landscapes on at-risk species in the US. GCB Bioenergy 2015;7:337-48.

[236] Wright CK, Wimberly MC. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc Natl Acad Sci USA 2013;110:4134–9. doi:10.1073/pnas.1215404110.

[237] Zah R, Böni H, Gauch M, Hischier R, Lehmann M, Wäger P. Life cycle assessment of energy products: environmental assessment of biofuels. Lausanne: EPFL;2007.

[238] von Blottnitz H, Curran MA. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J Clean Prod 2007;15:607–19. doi:10.1016/j.jclepro.2006.03.002.

[239] Menichetti E, Otto M. Energy balance and Greenhouse Gas Emissions of bio- fuels from a product life-cycle perspective: In R.W. Howarth, and S. Bringezu (eds,) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Paris: Scientific Committee on Problems of the Environment (SCOPE);2009. pp. 81-109.

[240] Davis SC, Parton WJ, Grosso SJ Del, Keough C, Marx E, Adler PR, et al. Impact of second-generation biofuel agriculture on greenhouse-gas emissions in the corn-growing regions of the US. Front Ecol Environ 2012;10:69–74. doi:10.1890/110003.

[241] Borrion AL, McManus MC, Hammond GP. Environmental life cycle assessment of bioethanol production from wheat straw. Biomass Bioenergy 2012;47:9–19. doi:10.1016/j.biombioe.2012.10.017.

[242] Acquaye AA, Sherwen T, Genovese A, Kuylenstierna J, Lenny Koh S, McQueen-Mason S. Biofuels and their potential to aid the UK towards achieving emissions reduction policy targets. Renew Sustain Energy Rev 2012;16:5414–22. doi:10.1016/j.rser.2012.04.046.

[243] Wiloso EI, Heijungs R, de Snoo GR. LCA of second generation bioethanol: A review and some issues to be resolved for good LCA practice. Renew Sustain Energy Rev 2012;16:5295–308. doi:10.1016/j.rser.2012.04.035.

[244] Menten F, Chèze B, Patouillard L, Bouvart F. A review of LCA greenhouse gas emissions results for advanced biofuels: The use of meta-regression analysis. Renew Sustain Energy Rev 2013;26:108–34. doi:10.1016/j.rser.2013.04.021.

[245] Manik Y, Halog A. A meta-analytic review of life cycle assessment and flow analyses studies of palm oil biodiesel. Integr Environ Assess Manag 2013;9:134–41. doi:10.1002/ieam.1362.

[246] Tsiropoulos I, Faaij APC, Seabra JEA, Lundquist L, Schenker U, Briois J-F, et al. Life cycle assessment of sugarcane ethanol production in India in comparison to Brazil. Int J Life Cycle Assess 2014;19:1049–67. doi:10.1007/s11367-014-0714-5.

[247] Shonnard DR, Klemetsrud B, Sacramento-Rivero J, Navarro-Pineda F, Hilbert J, Handler R, et al. A Review of Environmental Life Cycle Assessments of Liquid Transportation Biofuels in the Pan American Region. Environ Manage 2015;56:1356-76 doi:10.1007/s00267-015-0543-8.

[248] Sieverding HL, Bailey LM, Hengen TJ, Clay DE, Stone JJ. Meta-Analysis of Soybean-based Biodiesel. J Environ Qual 2015;44:1038. doi:10.2134/jeq2014.07.0320.

[249] Bailis RE, Baka JE. Greenhouse gas emissions and land use change from Jatropha curcas-based jet fuel in Brazil. Environ Sci Technol 2010;44:8684–91. doi:10.1021/es1019178.

[250] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319:1235–8. doi:10.1126/science.1152747.

[251] Gibbs HK, Johnston M, Foley JA, Holloway T, Monfreda C, Ramankutty N, et al. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. Environ Res Lett 2008;3:034001. doi:10.1088/1748-9326/3/3/034001.

[252] Elshout PMF, van Zelm R, Balkovic J, Obersteiner M, Schmid E, Skalsky R, et al. Greenhouse-gas payback times for crop-based biofuels. Nat Clim Chang 2015;5:604–10. doi:10.1038/nclimate2642.

[253] Achten WMJ, Verchot LV. Implications of biodiesel-induced land-use changes for CO_2 emissions: Case studies in Tropical America, Africa and Southeast Asia. Ecol Soc 2011;16:14.

[254] Loarie SR, Lobell DB, Asner GP, Mu Q, Field CB. Direct impacts on local climate of sugar-cane expansion in Brazil. Nat Clim Chang 2011;1:105–9. doi:10.1038/nclimate1067.

[255] Ramdani F, Moffiet T, Hino M. Local surface temperature change due to expansion of oil palm plantation in Indonesia. Clim Change 2014;123:189–200. doi:10.1007/s10584-013-1045-4.

[256] Caiazzo F, Malina R, Staples MD, Wolfe PJ, Yim SHL, Barrett SRH. Quantifying the climate impacts of albedo changes due to biofuel production: a comparison with biogeochemical effects. Environ Res Lett 2014;9:024015. doi:10.1088/1748-9326/9/2/024015.

[257] Macedo MN, Coe MT, DeFries R, Uriarte M, Brando PM, Neill C, et al. Land-use-driven stream warming in southeastern Amazonia. Philos Trans R Soc Lond B Biol Sci 2013;368:20120153. doi:10.1098/rstb.2012.0153.

[258] Georgescu M, Lobell DB, Field CB. Potential impact of U.S. biofuels on regional climate. Geophys Res Lett 2009;36:L21806. doi:10.1029/2009GL040477.

[259] Georgescu M, Lobell DB, Field CB, Mahalov A. Simulated hydroclimatic impacts of projected Brazilian sugarcane expansion. Geophys Res Lett 2013;40:972–7. doi:10.1002/grl.50206.

[260] RFA. The Gallagher review of the indirect effects of biofuels production, St Leonards-on-Sea: Renewable Fuels Agency (RFA);2008.

[261] Achten WMJ, Vandenbempt P, Almeida J, Mathijs E, Muys B. Life cycle assessment of a palm oil system with simultaneous production of biodiesel and cooking oil in Cameroon. Environ Sci Technol 2010;44:4809–15. doi:10.1021/es100067p.

[262] de Souza SP, Pacca S, de Ávila MT, Borges JLB. Greenhouse gas emissions and energy balance of palm oil biofuel. Renew Energy 2010;35:2552–61. doi:10.1016/j.renene.2010.03.028.

[263] Vang Rasmussen L, Rasmussen K, Bech Bruun T. Impacts of Jatropha-based biodiesel production on above and below-ground carbon stocks: A case study from Mozambique. Energy Policy 2012;51:728–36. doi:10.1016/j.enpol.2012.09.029.

[264] Romijn HA. Land clearing and greenhouse gas emissions from Jatropha biofuels on African Miombo Woodlands. Energy Policy 2011;39:5751–62. doi:10.1016/j.enpol.2010.07.041.

[265] von Maltitz GP, Sugrue A, Gush MB, Everson C, Borman GD, Blanchard R. Environmental and socioeconomic considerations for jatropha growing in southern Africa. In: Gasparatos A and Stromberg P, editors. Socioeconomic and environmental impacts of biofuels: Evidence from developing nations. Cambridge: Cambridge University Press;2012.p.278–305.

[266] Skutsch M, de los Rios E, Solis S, Riegelhaupt E, Hinojosa D, Gerfert S, et al. Jatropha in Mexico: Environmental and Social Impacts of an Incipient Biofuel Program. Ecol Soc 2011;16:11 doi:10.5751/ES-04448-160411.

[267] Bailis R, Mccarthy H. Carbon impacts of direct land use change in semiarid woodlands converted to biofuel plantations in India and Brazil. GCB Bioenergy 2011;3:449-460.

[268] Thurlow J, Branca G, Felix E, Maltsoglou I, Rincón LE. Producing Biofuels in Low-Income Countries: An Integrated Environmental and Economic Assessment for Tanzania. Environ Resour Econ 2015: In Press doi:10.1007/s10640-014-9863-z.

[269] Vang Rasmussen L, Rasmussen K, Birch-Thomsen T, Kristensen SBP, Traoré O. The effect of cassava-based bioethanol production on above-ground carbon stocks: A case study from Southern Mali. Energy Policy 2012;41:575–83. doi:10.1016/j.enpol.2011.11.019.

[270] Kim H, Kim S, Dale BE. Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables. Environ Sci Technol 2009;43:961–7. doi:10.1021/es802681k.

[271] Yang Y, Suh S. Marginal yield, technological advances, and emissions timing in corn ethanol's carbon payback time. Int J Life Cycle Assess 2014;20:226–32. doi:10.1007/s11367-014-0827-x.

[272] Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL, Robertson GP. Sustainable bioenergy production from marginal lands in the US Midwest. Nature 2013;493:514-517.

[273] Souza GM, Joly CA (eds). Bioenergy and Sustainability: Bridging the gaps. Paris: Scientific Committee on Problems of the Environment (SCOPE);2015

[274] Hess P, Johnston M, Brown-Steiner B, Holloway T, d. Andrade JB, Artaxo P. Air quality issues associated with biofuel production and use: In R.W. Howarth, and S. Bringezu (eds.) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Paris: Scientific Committee on Problems of the Environment (SCOPE); 2009. pp. 169-94

[275] Millet DB, Apel E, Henze DK, Hill J, Marshall JD, Singh HB, et al. Natural and anthropogenic ethanol sources inNorth America and potential atmospheric impacts of ethanol fuel use. Environ Sci Technol 2012;46:8484–92. doi:10.1021/es300162u.

[276] Sunde K, Brekke A, Solberg B. Environmental impacts and costs of woody Biomass-to-Liquid (BTL) production and use: A review. For Policy Econ 2011;13:591–602. doi:10.1016/j.forpol.2011.05.008.

[277] Tsao C-C, Campbell JE, Mena-Carrasco M, Spak SN, Carmichael GR, Chen Y. Increased estimates of air-pollution emissions from Brazilian sugar-cane ethanol. Nat Clim Chang 2011;2:53–7. doi:10.1038/nclimate1325.

[278] Cançado JED, Saldiva PHN, Pereira LAA, Lara LBLS, Artaxo P, Martinelli LA, et al. The impact of sugar cane-burning emissions on the respiratory system of children and the elderly. Environ Health Perspect 2006;114:725–9.

[279] Lara L, Artaxo P, Martinelli L, Camargo P, Victoria R, Ferraz E. Properties of aerosols from sugar-cane burning emissions in Southeastern Brazil. Atmos Environ 2005;39:4627–37. doi:10.1016/j.atmosenv.2005.04.026.

[280] Obidzinski K, Andriani R, Komarudin H, Andrianto A. Environmental and social impacts of oil palm plantations and their implications for biofuel production in Indonesia, Ecol Soc 2012;17:25.

[281] Ashworth K, Wild O, Hewitt CN. Impacts of biofuel cultivation on mortality and crop yields. Nat Clim Chang 2013;3:492–6. doi:10.1038/nclimate1788.

[282] Monteleone M, Cammerino ARB, Garofalo P, Delivand MK. Straw-to-soil or straw-to-energy? An optimal trade off in a long term sustainability perspective. Appl Energy 2015;154:891–9. doi:10.1016/j.apenergy.2015.04.108.

[283] Whittaker C, Borrion AL, Newnes L, McManus M. The renewable energy directive and cereal residues. Appl Energy 2014;122:207–15. doi:10.1016/j.apenergy.2014.01.091.

[284] Silalertruksa T, Gheewala SH. A comparative LCA of rice straw utilization for fuels and fertilizer in Thailand. Bioresour Technol 2013;150:412–9. doi:10.1016/j.biortech.2013.09.015.

[285] Martinez-Hernandez E, Ibrahim MH, Leach M, Sinclair P, Campbell GM, Sadhukhan J. Environmental sustainability analysis of UK whole-wheat bioethanol and CHP systems. Biomass Bioenergy 2013;50:52–64. doi:10.1016/j.biombioe.2013.01.001.

[286] Gnansounou E, Vaskan P, Pachón ER. Comparative techno-economic assessment and LCA of selected integrated sugarcane-based biorefineries. Bioresour Technol 2015;196:364–75. doi:10.1016/j.biortech.2015.07.072.

[287] Canter CE, Dunn JB, Han J, Wang Z, Wang M. Policy Implications of Allocation Methods in the Life Cycle Analysis of Integrated Corn and Corn Stover Ethanol Production. BioEnergy Res. In press doi:10.1007/s12155-015-9664-4.

[288] Boldrin A, Astrup T. GHG sustainability compliance of rapeseed-based biofuels produced in a Danish multi-output biorefinery system. Biomass Bioenergy 2015;75:83–93. doi:10.1016/j.biombioe.2015.01.023.

[289] Souza SP, Seabra JEA. Environmental benefits of the integrated production of ethanol and biodiesel. Appl Energy 2013;102:5–12. doi:10.1016/j.apenergy.2012.09.016.

[290] Gunkel G, Kosmol J, Sobral M, Rohn H, Montenegro S, Aureliano J. Sugar Cane Industry as a Source of Water Pollution: Case Study on the Situation in Ipojuca River, Pernambuco, Brazil. Water Air Soil Pollut 2006;180:261–9. doi:10.1007/s11270-006-9268-x.

[291] Muyibi SA, Ambali AR, Eissa GS. Development-induced water pollution in Malaysia: policy implications from an econometric analysis. Water Policy 2008;10:193-206. doi:10.2166/wp.2008.039.

[292] Wu TA, Mohammad AW, Jahim JM, Anuar N. Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. J Environ Manage 2010;91:1467-1490.

[293] Love B, Nejadhashemi AP. Environmental Impact Analysis of Biofuel Crops Expansion in the Saginaw River Watershed. J Biobased Mater Bioenergy 2011;5:30–54. doi:10.1166/jbmb.2011.1119.

[294] Love BJ, Einheuser MD, Nejadhashemi AP. Effects on aquatic and human health due to large scale bioenergy crop expansion. Sci Total Environ 2011;409:3215–29. doi:10.1016/j.scitotenv.2011.05.007.

[295] Wu M, Demissie Y, Yan E. Simulated impact of future biofuel production on water quality and water cycle dynamics in the Upper Mississippi river basin. Biomass Bioenergy 2012;41:44–56. doi:10.1016/j.biombioe.2012.01.030.

[296] Jager HI, Baskaran LM, Schweizer PE, Turhollow AF, Brandt CC, Srinivasan R. Forecasting changes in water quality in rivers associated with growing biofuels in the Arkansas-White-Red river drainage, USA. GCB Bioenergy 2015;7:774–84. doi:10.1111/gcbb.12169.

[297] Donner SD, Kucharik CJ. Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. Proc Natl Acad Sci USA 2008;105:4513–8. doi:10.1073/pnas.0708300105.

[298] Van Wijnen J, Ivens WPMF, Kroeze C, Löhr AJ. Coastal eutrophication in Europe caused by production of energy crops. Sci Total Environ 2015;511:101–11. doi:10.1016/j.scitotenv.2014.12.032.

[299] Strokal MP, Kroeze C, Kopilevych VA, Voytenko LV. Reducing future nutrient inputs to the Black Sea. Sci Total Environ 2014;466-467:253–64. doi:10.1016/j.scitotenv.2013.07.004.

[300] Nordborg M, Cederberg C, Berndes G. Modeling Potential Freshwater Ecotoxicity Impacts Due to Pesticide Use in Biofuel Feedstock Production: The Cases of Maize, Rapeseed, Salix, Soybean, Sugar Cane, and Wheat. Environ Sci Technol 2014;48:11379–88. doi:10.1021/es502497p.

[301] Bunzel K, Schäfer RB, Thrän D, Kattwinkel M. Pesticide runoff from energy crops: A threat to aquatic invertebrates? Sci Total Environ 2015;537:187–96. doi:10.1016/j.scitotenv.2015.08.011.

[302] Raghu S, Anderson RC, Daehler CC, Davis AS, Wiedenmann RN, Simberloff D, et al. Ecology. Adding biofuels to the invasive species fire? Science 2006;313:1742. doi:10.1126/science.1129313.

[303] Pyke CR, Thomas R, Porter RD, Hellmann JJ, Dukes JS, Lodge DM, et al. Current practices and future opportunities for policy on climate change and invasive species. Conserv Biol 2008;22:585–92. doi:10.1111/j.1523-1739.2008.00956.x.

[304] Buddenhagen CE, Chimera C, Clifford P. Assessing Biofuel Crop Invasiveness: A Case Study. PLoS One 2009;4. doi:10.1371/journal.pone.0005261.

[305] Genovesi P. European biofuel policies may increase biological invasions: the risk of inertia. Curr Opin Environ Sustain 2011;3:66–70. doi:10.1016/j.cosust.2010.12.001.

[306] Smith AL, Klenk N, Wood S, Hewitt N, Henriques I, Yan N, et al. Second generation biofuels and bioinvasions: An evaluation of invasive risks and policy responses in the United States and Canada. Renew Sustain Energy Rev 2013;27:30–42. doi:10.1016/j.rser.2013.06.013.

[307] Hager HA, Rupert R, Quinn LD, Newman JA. Escaped Miscanthus sacchariflorus reduces the richness and diversity of vegetation and the soil seed bank. Biol Invasions 2015;17:1833–47. doi:10.1007/s10530-014-0839-2.

[308] Barney JN, Mann JJ, Kyser GB, DiTomaso JM. Assessing habitat susceptibility and resistance to invasion by the bioenergy crops switchgrass and Miscanthus × giganteus in California. Biomass Bioenergy 2012;40:143–54. doi:10.1016/j.biombioe.2012.02.013.

[309] Robertson BA, Porter C, Landis DA, Schemske DW. Agroenergy Crops Influence the Diversity, Biomass, and Guild Structure of Terrestrial Arthropod Communities. BioEnergy Res 2011;5:179–88. doi:10.1007/s12155-011-9161-3.

[310] Robertson BA, Rice RA, Sillett TS, Ribic CA, Babcock BA, Landis DA, et al. Are agrofuels a conservation threat or opportunity for grassland birds in the United States? Condor 2012;114:679–88. doi:10.1525/cond.2012.110136.

[311] Matlaga DP, Davis AS. Minimizing invasive potential of Miscanthus × giganteus grown for bioenergy: identifying demographic thresholds for population growth and spread. J Appl Ecol 2013;50:479–87. doi:10.1111/1365-2664.12057.

[312] von Maltitz G, Gasparatos A, Fabricius C. The Rise, Fall and Potential Resilience Benefits of Jatropha in Southern Africa. Sustainability 2014;6:3615–43. doi:10.3390/su6063615.

[313] Negussie A, Achten WMJ, Aerts R, Norgrove L, Sinkala T, Hermy M, et al. Invasiveness risk of the tropical biofuel crop Jatropha curcas L. into adjacent land use systems: from the rumors to the experimental facts. GCB Bioenergy 2013;5:419–30. doi:10.1111/gcbb.12011.

[314] Negussie A, Achten WMJ, Norgrove L, Hermy M, Muys B. Invasiveness risk of biofuel crops using Jatropha curcas L. as a model species. Biofuels Bioprod Biorefining 2013;7:485–98. doi:10.1002/bbb.1416.

[315] Negussie A, Nacro S, Achten WMJ, Norgrove L, Kenis M, Hadgu KM, et al. Insufficient Evidence of Jatropha curcas L. Invasiveness: Experimental Observations in Burkina Faso, West Africa. BioEnergy Res 2014;8:570–80. doi:10.1007/s12155-014-9544-3.

[316] Joly CA, Huntley BJ, Verdade LM, Dale VH, Mace G, Muok B, Ravindranath NH. Biofuel impacts on biodiversity and ecosystem services. In Souza GM and Joly CA (eds), Bioenergy and Sustainability: Bridging the gaps. Paris: Scientific Committee on Problems of the Environment (SCOPE);2015. pp. 554-80.

[317] Davis SC, Boddey RM, Alves BJR, Cowie AL, George BH, Ogle SM, et al. Management swing potential for bioenergy crops. GCB Bioenergy 2013;5:623–38. doi:10.1111/gcbb.12042.

[318] Dale VH, Kline KL, Wright LL, Perlack RD, Downing M, Graham RL. Interactions among bioenergy feedstock choices, landscape dynamics, and land use. Ecol Appl 2011;21:1039–54. doi:10.1890/09-0501.1.

[319] Myers MC, Mason JT, Hoksch BJ, Cambardella CA, Pfrimmer JD. Birds and butterflies respond to soil-induced habitat heterogeneity in experimental plantings of tallgrass prairie species managed as agroenergy crops in Iowa, USA. J Appl Ecol 2015;52:1176–87. doi:10.1111/1365-2664.12503.

[320] Chauvat M, Perez G, Hedde M, Lamy I. Establishment of bioenergy crops on metal contaminated soils stimulates belowground fauna. Biomass Bioenergy 2014;62:207–11. doi:10.1016/j.biombioe.2014.01.042.

[321] Zhao J, Wan S, Fu S, Wang X, Wang M, Liang C, et al. Effects of understory removal and nitrogen fertilization on soil microbial communities in Eucalyptus plantations. For Ecol Manage 2013;310:80–6. doi:10.1016/j.foreco.2013.08.013.

[322] Behrman KD, Juenger TE, Kiniry JR, Keitt TH. Spatial land use trade-offs for maintenance of biodiversity, biofuel, and agriculture. Landsc Ecol 2015. doi:10.1007/s10980-015-0225-1.

[323] Strassburg BBN, Latawiec AE, Barioni LG, Nobre C a., da Silva VP, Valentim JF, et al. When enough should be enough: Improving the use of current agricultural lands could meet production

demands and spare natural habitats in Brazil. Glob Environ Chang 2014;28:84–97. doi:10.1016/j.gloenvcha.2014.06.001.

[324] West NM, Matlaga DP, Davis AS. Managing Spread from Rhizome Fragments is Key to Reducing Invasiveness in Miscanthus × giganteus. Invasive Plant Sci Manag 2014;7:517–25. doi:10.1614/IPSM-D-14-00018.1.

[325] Hennenberg KJ, Dragisic C, Haye S, Hewson J, Semroc B, Savy C, et al. The power of bioenergy-related standards to protect biodiversity. Conserv Biol 2010;24:412–23. doi:10.1111/j.1523-1739.2009.01380.x.

[326] Koh LP, Ghazoul J. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. Proc Natl Acad Sci USA 2010;107:11140–4. doi:10.1073/pnas.1012681107.

[327] Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL, Robertson GP. Sustainable bioenergy production from marginal lands in the US Midwest. Nature 2013;493:514–7. doi:10.1038/nature11811.

[328] Harvolk S, Kornatz P, Otte A, Simmering D. Using existing landscape data to assess the ecological potential of miscanthus cultivation in a marginal landscape. GCB Bioenergy 2014;6:227–41. doi:10.1111/gcbb.12078.

[329] Dillen SY, Djomo SN, Al Afas N, Vanbeveren S, Ceulemans R. Biomass yield and energy balance of a short-rotation poplar coppice with multiple clones on degraded land during 16 years. Biomass Bioenergy 2013;56:157–65. doi:10.1016/j.biombioe.2013.04.019.

[330] Gregersen P, Brix H. Zero-discharge of nutrients and water in a willow dominated constructed wetland. Water Sci Technol 2001;44:407–12.

[331] Nsanganwimana F, Pourrut B, Mench M, Douay F. Suitability of Miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services. A review. J Environ Manage 2014;143:123–34. doi:10.1016/j.jenvman.2014.04.027.

[333] Marrugo-Negrete J, Durango-Hernández J, Pinedo-Hernández J, Olivero-Verbel J, Díez S. Phytoremediation of mercury-contaminated soils by Jatropha curcas. Chemosphere 2015;127:58–63. doi:10.1016/j.chemosphere.2014.12.073.

[334] Berndes G, Börjesson P, Ostwald M, Palm M. Multifunctional biomass production systems: An overview with presentation of specific applications in India and Sweden. Biofuels Bioprod Biorefining 2008;2:16–25. doi:10.1002/bbb.52.

[335] Koh LP, Levang P, Ghazoul J. Designer landscapes for sustainable biofuels. Trends Ecol Evol 2009;24:431–8. doi:10.1016/j.tree.2009.03.012.

[336] Porter J, Costanza R, Sandhu H, Sigsgaard L, Wratten S. The Value of Producing Food, Energy, and Ecosystem Services within an Agro-Ecosystem. AMBIO 2009;38:186–93. doi:10.1579/0044-7447-38.4.186.

[337] Verdade, L. M., Lyra-Jorge, M. C., Piña CI (Eds.). Applied Ecology and Human Dimensions in Biological Conservation. Berlin: Springer; 2014. doi:10.1007/978-3-642-54751-5.

[338] Jarchow ME, Liebman M, Dhungel S, Dietzel R, Sundberg D, Anex RP, et al. Trade-offs among agronomic, energetic, and environmental performance characteristics of corn and prairie bioenergy cropping systems. GCB Bioenergy 2015;7:57–71. doi:10.1111/gcbb.12096.

[339] Diekötter T, Peter F, Jauker B, Wolters V, Jauker F. Mass-flowering crops increase richness of cavity-nesting bees and wasps in modern agro-ecosystems. GCB Bioenergy 2013:219–26. doi:10.1111/gcbb.12080.

[340] Sayer J, Sunderland T, Ghazoul J, Pfund J-L, Sheil D, Meijaard E, et al. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc Natl Acad Sci USA 2013;110:8349–56. doi:10.1073/pnas.1210595110.

[341] Di Lucia L. External governance and the EU policy for sustainable biofuels, the case of Mozambique. Energy Policy 2010;38:7395–403. doi:10.1016/j.enpol.2010.08.015.

[342] Lovett JC, Hards S, Clancy J, Snell C. Multiple objectives in biofuels sustainability policy. Energy Environ Sci 2011;4:261–8. doi:10.1039/C0EE00041H.

[343] Esteban M, Leary D, Zhang Q, Utama A, Ishihara K. the Greening of the Offshore Energy Sector in the North Sea. Int J Labour Res 2011;2:245–68.

[344] CEBR. The Economic Case for a Tidal Lagoon Industry in the UK: A scenario-based assessment of the macroeconomic impacts of tidal lagoons for power generation on the UK economy. London: Cebr;2014.

[345] Kidd IM, Fischer A, Chai S, Davis JA. A scenario-based approach to evaluating potential environmental impacts following a tidal barrage installation. Ocean Coast Manag 2015;116:9–19. doi:10.1016/j.ocecoaman.2015.06.016.

[346] Owen E. Environment Agency boss opposes Severn Barrage. New Civ Eng J 2008;1:5.

[347] Esteban M, Leary D. Current developments and future prospects of offshore wind and ocean energy. Appl Energy 2012;90:128–36. doi:10.1016/j.apenergy.2011.06.011.

[348] Leary D, Esteban M. Recent Developments in Offshore Renewable Energy in the Asia-Pacific Region. Ocean Dev Int Law 2011;42:94–119. doi:10.1080/00908320.2010.521039.

[349] Isaacman L, Lee K. Current State of Knowledge on the Environmental Impacts of Tidal and Wave Energy Technology in Canada. Dartmouth: Bedford Institute of Oceanography;2009.

[350] Inger R, Attrill MJ, Bearhop S, Broderick AC, James Grecian W, Hodgson DJ, et al. Marine renewable energy: Potential benefits to biodiversity? An urgent call for research. J Appl Ecol 2009;46:1145–53. doi:10.1111/j.1365-2664.2009.01697.x.

[351] HCECCC. The Future of Marine Renewables in the UK, Volume 1. London:House of Commons Energy and Climate Change Committee (HCECCC);2012.

[352] Magagna D, Uihlein A. JRC Ocean Energy Status Report, Ispra: Joint Research Centre of the Euroipean Commission (JRC);2014.

[353] Wolf J, Walkington IA, Holt J, Burrows R. Environmental impacts of tidal power schemes. P I Civil Eng – Marit Eng 2009:162;165-77

[354] Shields MA, Woolf DK, Grist EPM, Kerr SA, Jackson AC, Harris RE, et al. Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean Coast Manag 2011;54:2–9. doi:10.1016/j.ocecoaman.2010.10.036.

[355] Boehlert GW, Gill AB. Environmental and Ecological Effects of Ocean Renewable Energy Development: A Current Synthesis. Oceanography 2010;23:68-81.

[356] OSPAR Commision. Assessment of the environmental impact of offshore wind-farms. London:OSPCAR Commission;2008.

[357] DEA. Offshore Wind Farms and the Environment: Danish Experience from Horns Rev and Hysted. Copenhagen:Danish Energy Authority (DEA);2006.

[358] OEERA. Fundy Tidal Energy Strategic Environmental Assessment: Final Report. Halifax:Offshore Energy Environmental Research Association;2008.

[359] Nautricity. Environmental Appraisal for the Argyll Tidal Demonstrator Project. Glasgow:Nautricity;2013.

[360] Esteban M, Webersik C, Leary D, Thompson-Pomeroy D. Innovation in Responding to Climate Change : Nanotechnology, Ocean Energy and Forestry. Yokohama:United Nations University Institute of Advanced Studies;2008.

[361] Lindeboom HJ, Kouwenhoven HJ, Bergman MJN, Bouma S, Brasseur S, Daan R, et al. Short-term ecological effects of an offshore wind farm in the Dutch coastal zona; a compilation. Environ Res Lett 2011;6:035101. doi:10.1088/1748-9326/6/3/035101.

[362] Plonczkier P, Simms IC. Radar monitoring of migrating pink-footed geese: behavioural responses to offshore wind farm development. J Appl Ecol 2012;49:1187–94. doi:10.1111/j.1365-2664.2012.02181.x.

[363] Coates DA., Deschutter Y, Vincx M, Vanaverbeke J. Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea. Mar Environ Res 2014;95:1–12. doi:10.1016/j.marenvres.2013.12.008.

[364] De Backer A, Van Hoey G, Coates D, Vanaverbeke J, Hostens K. Similar diversity-disturbance responses to different physical impacts: Three cases of small-scale biodiversity increase in the Belgian part of the North Sea. Mar Pollut Bull 2014;84:251–62. doi:10.1016/j.marpolbul.2014.05.006.

[365] Krone R, Gutow L, Joschko TJ, Schröder A. Epifauna dynamics at an offshore foundation: Implications of future wind power farming in the North Sea. Mar Environ Res 2013;85:1–12. doi:10.1016/j.marenvres.2012.12.004.

[366] Reubens JT, De Rijcke M, Degraer S, Vincx M. Diel variation in feeding and movement patterns of juvenile Atlantic cod at offshore wind farms. J Sea Res 2014;85:214–21. doi:10.1016/j.seares.2013.05.005.

[367] Reubens JT, Pasotti F, Degraer S, Vincx M. Residency, site fidelity and habitat use of Atlantic cod (Gadus morhua) at an offshore wind farm using acoustic telemetry. Mar Environ Res 2013;90:128–35. doi:10.1016/j.marenvres.2013.07.001.

[368] Stenberg, C., Støttrup, J.G., Van Deurs, M., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T.M., Leonhard SB. Long-term effects of an offshore wind farm in the North Sea on fish communities. Mar Ecol Prog Ser 2015;528:257–65.

[369] Witt MJ, Sheehan E V., Bearhop S, Broderick AC, Conley DC, Cotterell SP, et al. Assessing wave energy effects on biodiversity: the Wave Hub experience. Philos Trans R Soc A Math Phys Eng Sci 2012;370:502–29. doi:10.1098/rsta.2011.0265.

[370] Zanuttigh B, Angelelli E, Bellotti G, Romano A, Krontira Y, Troianos D, et al. Boosting blue growth in a mild sea: analysis of the synergies produced by a multi-purpose offshore installation in the Northern Adriatic, Italy. Sustainability 2015;7:6804–53. doi:10.3390/su7066804.

[371] Broadhurst M, Orme CDL. Spatial and temporal benthic species assemblage responses with a deployed marine tidal energy device: A small scaled study. Mar Environ Res 2014;99:76–84. doi:10.1016/j.marenvres.2014.03.012.

[372] Fijn RC, Krijgsveld KL, Poot MJM, Dirksen S. Bird movements at rotor heights measured continuously with vertical radar at a Dutch offshore wind farm. Int J Avian Sci 2015;157:558–66. doi:10.1111/ibi.12259.

[373] Aumüller R, Boos K, Freienstein S, Hill K, Hill R. Description of a bird strike event and its causes at a research platform in the German bight, North Sea [Beschreibung eines vogelschlagereignisses und seiner ursachen an einer forschungsplattform in der deutschen bucht]. Vogelwarte 2011;49:9-16.

[374] Vanermen N, Onkelinx T, Courtens W, Van de walle M, Verstraete H, Stienen EWM. Seabird avoidance and attraction at an offshore wind farm in the Belgian part of the North Sea. Hydrobiologia 2014;756:51–61. doi:10.1007/s10750-014-2088-x.

[375] Grecian WJ, Inger R, Attrill MJ, Bearhop S, Godley BJ, Witt MJ, et al. Potential impacts of wave-powered marine renewable energy installations on marine birds. Ibis 2010;152:683–97. doi:10.1111/j.1474-919X.2010.01048.x.

[376] Cada G, Ahlgrimm J, Bahleda M, Bigford T, Stavrakas SD, Hall D, et al. Potential Impacts of Hydrokinetic and Wave Energy Conversion Technologies on Aquatic Environments. Fisheries 2007;32:174–81. doi:10.1577/1548-8446

[377] Loring PH, Paton PWC, Osenkowski JE, Gilliland SG, Savard J-PL, Mcwilliams SR. Habitat use and selection of black scoters in southern New England and siting of offshore wind energy facilities. J Wildl Manage 2014;78:645–56. doi:10.1002/jwmg.696.

[378] Copping A, Hanna L, Whiting J, Geerlofs S, Grear M, Blake K, Coffey A, Massaua M, Brown-Saracino J, Bettey H. Environmental Effects of Marine Energy Development around the World: Annex IV Final Report. Washington DC:Pacific Northwest National Laboratory;2013.

[379] ORPC. Cobscook Bay tidal energy project: 2012 environmental monitoring report. Portland: Ocean Renewable Power Company;2013

[380] FORCE. Environmental Effects Monitoring Report: 2011-2013. Halifax:Fundy Ocean Research Center for Energy (FORCE);2013.

[381] Royal Haskoning. SeaGen Environmental Monitoring Programme: Final Report. Edinburg: Royal Haskoning;2011.

[382] Kadiri M, Ahmadian R, Bockelmann-Evans B, Rauen W, Falconer R. A review of the potential water quality impacts of tidal renewable energy systems. Renew Sustain Energy Rev 2012;16:329–41. doi:10.1016/j.rser.2011.07.160.

[383] Langhamer O, Haikonen K, Sundberg J. Wave power: Sustainable energy or environmentally costly? A review with special emphasis on linear wave energy converters. Renew Sustain Energy Rev 2010;14:1329–35. doi:10.1016/j.rser.2009.11.016.

[384] Liu CCK, Sou IM, Lin H. Artificial upwelling and near-field mixing of deep-ocean water effluent. J Mar Env Eng 2003;7:1-14.

[385] U.S. Department of Energy. Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies. Washington DC: U.S. Department of Energy;2009.

[386] Mendes L, Palha A, Fortes CJ, Brito e Melo A, Sarmento A. Analysis of the Impact of a Pilot Zone for Wave Energy Conversion Offshore Portugal. 18th Int. Offshore Polar Eng. Conf., Vancouver: 2008.

[387] Lamadrid-Rose Y, Boehlert GW. Effects of cold shock on egg, larval, and juvenile stages of tropical fishes: Potential impacts of ocean thermal energy conversion. Mar Environ Res 1988;25:175–93. doi:10.1016/0141-1136(88)90002-5.

[388] OERA. Marine Renewable Energy: Background Report to Support a Strategic Environmental Assessment (SEA) for the Cape Breton Coastal Region, inclusive of the Bras D'Or Lakes. Halifax:Offshore Energy Research Association;2012.

[389] Thomsen F, Luedemann K, Piper W, Judd A, Kafemann R. Potential effects of offshore wind farm noise on fish. Bioacoustics 2008;17:221–3. doi:10.1080/09524622.2008.9753825.

[390] Tougaard J. Underwater Noise from a Wave Energy Converter Is Unlikely to Affect Marine Mammals. PLoS One 2015;10:e0132391. doi:10.1371/journal.pone.0132391.

[391] Fraenkel P. Marine Current Turbines: Moving from Experimental Test Rigs to a Commercial Technology. 26th Int. Conf. Offshore Mech. Arct. Eng. San Diego; 2007. pp. 579-588 doi:10.1115/OMAE2007-29642

[392] EWEA. The European offshore wind industry: key trends and statistics 2014. European Wind Energy Association, Brussels, 2015.

[393] Zountouridou EI, Kiokes GC, Chakalis S, Georgilakis PS, Hatziargyriou ND. Offshore floating wind parks in the deep waters of Mediterranean Sea. Renew Sustain Energy Rev 2015;51:433–48. doi:10.1016/j.rser.2015.06.027.

[394] Hogan TW, Linebaugh C, Harmer A, Steinbeck J. A Field Program for Developing a Baseline Characterization of Ichthyoplankton Near a Potential OTEC Facility. Mar Technol Soc J 2013;47:137–41. doi:10.4031/MTSJ.47.4.9.

[395] OSPAR. Review of the Current State of Knowledge on the Environmental Impacts of the Location, Operation and Removal/Disposal of Offshore Wind-Farms. London:OSPAR Commission; 2006.

[396] Ashley MC, Mangi SC, Rodwell LD. The potential of offshore windfarms to act as marine protected areas – A systematic review of current evidence. Mar Policy 2014;45:301–9. doi:10.1016/j.marpol.2013.09.002.

[397] Bayer P, Rybach L, Blum P, Brauchler R. Review on life cycle environmental effects of geothermal power generation. Renew Sustain Energy Rev 2013;26:446–63. doi:10.1016/j.rser.2013.05.039.

[398] Moya P, Rodríguez EM, Mainieri A. Legal barriers to the utilization of geothermal energy in protected areas of Costa Rica. Trans Geoth Res Coun 2006;30:1059-65.

[399] Pasqualetti MJ. Geothermal energy and the environment: The global experience. Energy 1980;5:111–65.

[400] Shortall R, Davidsdottir B, Axelsson G. A sustainability assessment framework for geothermal energy projects: Development in Iceland, New Zealand and Kenya. Renew Sustain Energy Rev 2015;50:372–407. doi:10.1016/j.rser.2015.04.175.

[401] Shortall R, Davidsdottir B, Axelsson G. Development of a sustainability assessment framework for geothermal energy projects. Energy Sustain Dev 2015;27:28–45. doi:10.1016/j.esd.2015.02.004.

[402] Lee H. Protection policy for Hawaii’s native wildlife during geothermal energy development, Environ Manage 1986;10:611-21.

[403] Mwangi MW. Environmental and Socio-Economic Issues of Geothermal Development in Kenya. GRC Bulletin 2010;2:24-35.

[404] Chepkochei L, Njoroge F. Analysis of land use/cover changes in the Menengai landscape, geothermal prospect using landsat TM. Trans. Geotherm. Resour. Counc 2012;36:621-24.

[405] Manyara D, Mading P. Environmental and social considerations in geothermal development: Case study Menengai, Kenya: Moving towards green and clean economy. Trans. Geotherm. Resour. Counc 2012;36:1227–31.

[406] Guido-Sequeira H, Geothermal Development in Protected Areas: Case History from Costa Rica. Pro World Geoth Cong 2015. Melbourne; 2015.

[407] Burns BR, Ward J, Downs TM. Trampling impacts on thermotolerant vegetation of geothermal areas in New Zealand. Environ Manage 2013;52:1463–73. doi:10.1007/s00267-013-0187-5.

[408] Duffield WA, Sass JH. Geothermal Energy: Clean Power from the Earth's Heat. Reston: U.S. Geological Survey;2003.

[409] Barbier E. Nature and technology of geothermal energy: A review. Renew Sustain Energy Rev 1997;1:1–69. doi:10.1016/S1364-0321(97)00001-4.

[410] Bravi M, Basosi R. Environmental impact of electricity from selected geothermal power plants in Italy. J Clean Prod 2014;66:301–8. doi:10.1016/j.jclepro.2013.11.015.

[411] Amponsah NY, Troldborg M, Kington B, Aalders I, Hough RL. Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations Renew Sustain Energy Rev 2014;39:461-75.

[412] Loppi S, Nascimbene J. Monitoring H2S air pollution caused by the industrial exploitation of geothermal energy: The pitfall of using lichens as bioindicators. Environ Pollut 2010;158:2635–9. doi:10.1016/j.envpol.2010.05.002.

[413] Bussotti F, Tognelli R, Montagni G, Borghini F, Bruschi P, Tani C. Response of Quercus pubescens leaves exposed to geothermal pollutant input in southern Tuscany (Italy). Environ Pollut 2003;121:349–61.

[414] Loppi S, Paoli L, Gaggi C. Diversity of Epiphytic Lichens and Hg Contents of Xanthoria parietina Thalli as Monitors of Geothermal Air Pollution in the Mt. Amiata Area (Central Italy). J Atmos Chem 2006;53:93–105. doi:10.1007/s10874-006-6648-y.

[415] Manzo C, Salvini R, Guastaldi E, Nicolardi V, Protano G. Reflectance spectral analyses for the assessment of environmental pollution in the geothermal site of Mt. Amiata (Italy). Atmos Environ 2013;79:650–65. doi:10.1016/j.atmosenv.2013.06.038.

[416] Robinson BH, Brooks RR, Outred HA, Kirkman JH. Mercury and arsenic in trout from the Taupo Volcanic Zone and Waikato River, North Island, New Zealand. Chem Spec Bioavailab 1995;7:27-32.

[417] INL.The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. Idaho Falls: Idaho National Laboratory;2006.

[418] Brielmann H, Lueders T, Schreglmann K, Ferraro F, Avramov M, Hammerl V, et al. Oberflächennahe Geothermie und ihre potenziellen Auswirkungen auf Grundwasserökosysteme. Grundwasser 2011;16:77–91. doi:10.1007/s00767-011-0166-9.

[419] Kagel A. The State of Geothermal Technology Part II: Surface Technology. Wahington DC: Geothermal Energy Association;2008.

[420] Tuyor JB, de Jesus AC, Medrano RS, Garcia JRD, Salinio SM, Santos LS. Impact of geothermal well testing on exposed vegetation in the Northern Negros Geothermal Project, Philippines. Geothermics 2005;34:252–65. doi:10.1016/j.geothermics.2004.09.004.

[421] Arnorsson S. Environmental impact of geothermal energy utilization: In R. Ciere, and P. Stille (eds) Energy, waste and the environment: a geochemical perspective. London: Geological Society;2004.

[422] Roy PH. Ecotourism Potential of the Bacman Geothermal Production Field in Sorsogon City, Philippines. Proc World Geoth Cong. Bali;2010.

[423] Eijgelaar E. How eco is nature-based tourism? An analysis of German tourism to New Zealand's natural heritage and the impacts of nature-based activities. Eberswalde:Eberswalde University of Applied Sciences (MA Thesis); 2006. .

[424] Gunnarsson B, Gunnarsson M V., Watson AE, Alessa L, Sproull J. Iceland's Central Highlands: nature conservation, ecotourism, and energy resource utilization. In Watson AE, Alessa L, Sproull J, Wilderness circumpolar north Search. Anchorage: USDA Forest Services;2002, p. 54–63.

[425] Gasparatos A, Lee LY, von Maltitz G, Mathai MV, Puppim de Oliveira JA, and Willis KJ. Biofuels in Africa: Impacts on ecosystem services, biodiversity and human wellbeing. Yokohama: United Nations University; 2012.

[426] Campbell MS, Stehfest KM, Votier SC, Hall-Spencer JM. Mapping fisheries for marine spatial planning: Gear-specific vessel monitoring system (VMS), marine conservation and offshore renewable energy. Mar Policy 2014;45:293–300. doi:10.1016/j.marpol.2013.09.015.

[427] Laurance WF, Clements GR, Sloan S, O'Connell CS, Mueller ND, Goosem M, et al. A global strategy for road building. Nature 2014;513:229–32. doi:10.1038/nature13717.

[428] Laurance WF, Goosem M, Laurance SGW. Impacts of roads and linear clearings on tropical forests. Trends Ecol Evol 2009;24:659–69. doi:10.1016/j.tree.2009.06.009.

[429] Barber CP, Cochrane MA, Souza CM, Laurance WF. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. Biol Conserv 2014;177:203–9. doi:10.1016/j.biocon.2014.07.004.

[430] Fearnside PM, de Alencastro Graça PML. BR-319: Brazil's Manaus-Porto Velho highway and the potential impact of linking the arc of deforestation to central amazonia. Environ Manage 2006;38:705–16. doi:10.1007/s00267-005-0295-y.

[431] Marcantonio M, Rocchini D, Geri F, Bacaro G, Amici V. Biodiversity, roads, & landscape fragmentation: Two Mediterranean cases. Appl Geogr 2013;42:63–72. doi:10.1016/j.apgeog.2013.05.001.

[432] Forys EA, Allen CR, Wojcik DP. Influence of the proximity and amount of human development and roads on the occurrence of the red imported fire ant in the lower Florida Keys. Biol Conserv 2002;108:27–33. doi:10.1016/S0006-3207(02)00086-1.

[433] Gelbard JL, Belnap J. Roads as Conduits for Exotic Plant Invasions in a Semiarid Landscape. Conserv Biol 2003;17:420–32. doi:10.1046/j.1523-1739.2003.01408.x.

[434] Coffin AW. From roadkill to road ecology: A review of the ecological effects of roads. J Transp Geogr 2007;15:396–406. doi:10.1016/j.jtrangeo.2006.11.006.

[435] Davenport J, Davenport JL. (Eds). The ecology of transportation: Managing mobility for the environment, Dordrecht: Springer; 2006.

[436] Benítez-López A, Alkemade R, Verweij PA. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biol Conserv 2010;143:1307–16. doi:10.1016/j.biocon.2010.02.009.

[437] Fahrig L. Rytwinski, T. Effects of roads on animal abundance: An empirical review and synthesis, Ecol Soc 2009;14:21.

[438] Grilo C, Bissonette JA, Santos-Reis M. Spatial–temporal patterns in Mediterranean carnivore road casualties: Consequences for mitigation. Biol Conserv 2009;142:301–13. doi:10.1016/j.biocon.2008.10.026.

[439] Johnson W. Landscape effects on black-tailed prairie dog colonies. Biol Conserv 2004;115:487–97. doi:10.1016/S0006-3207(03)00165-4.

[440] Lee MA, Power SA. Direct and indirect effects of roads and road vehicles on the plant community composition of calcareous grasslands. Environ Pollut 2013;176:106–13. doi:10.1016/j.envpol.2013.01.018.

[441] Winiarski KJ, Miller DL, Paton PWC, McWilliams SR. A spatial conservation prioritization approach for protecting marine birds given proposed offshore wind energy development. Biol Conserv 2014;169:79–88. doi:10.1016/j.biocon.2013.11.004.

[442] Brabant R, Vanermen N, Stienen EWM, Degraer S. Towards a cumulative collision risk assessment of local and migrating birds in North Sea offshore wind farms. Hydrobiologia 2015;756:63–74. doi:10.1007/s10750-015-2224-2.

[443] Bradbury G, Trinder M, Furness B, Banks AN, Caldow RWG, Hume D. Mapping Seabird Sensitivity to Offshore Wind Farms. PLoS One 2014;9:1–17. doi:10.1371/journal.pone.0106366.

[444] BSA. Minimum Requirements for Avifaunal Impact Assessment for Wind Energy Facilities, Randburg: Birdlife South Africa; 2013.

[445] BSA. Guidelines to minimise the impact on birds of Solar Facilities and Associated Infrastructure in South Africa, Randburg: Birdlife South Africa; 2013.

[446] BSA. Best Practice Guidelines for Avian Monitoring and Impact Mitigation, Randburg: Birdlife South Africa; 2013.

[447] Guarino E de SG, Barbosa AM, Waechter JL. Occurrence and abundance models of threatened plant species: Applications to mitigate the impact of hydroelectric power dams. Ecol Modell 2012;230:22–33. doi:10.1016/j.ecolmodel.2012.01.007.

[448] Kim C-K, Toft JE, Papenfus M, Verutes G, Guerry AD, Ruckelshaus MH, et al. Catching the right wave: evaluating wave energy resources and potential compatibility with existing marine and coastal uses. PLoS One 2012;7:e47598. doi:10.1371/journal.pone.0047598.

[449] Rydell J, Bach L, Dubourg-Savage M-J, Green M, Rodrigues L, Hedenström A. Bat Mortality at Wind Turbines in Northwestern Europe. Acta Chiropterologica 2010;12:261–74. doi:10.3161/150811010X537846.

[450] Gao Y, Skutsch M, Drigo R, Pacheco P, Masera O. Assessing deforestation from biofuels: Methodological challenges. Appl Geogr 2011;31:508–18. doi:10.1016/j.apgeog.2010.10.007.

[451] Davis SC, House JI, Diaz-Chavez RA, Molnar A, Valin H, DeLucia EH. How can land-use modelling tools inform bioenergy policies? Interface Focus 2011;1:212–23. doi:10.1098/rsfs.2010.0023.

[452] Rivas Casado M, Mead A, Burgess PJ, Howard DC, Butler SJ. Predicting the impacts of bioenergy production on farmland birds. Sci Total Environ 2014;476-477:7–19. doi:10.1016/j.scitotenv.2013.12.080.

[453] Tessum CW, Marshall JD, Hill JD. A spatially and temporally explicit life cycle inventory of air pollutants from gasoline and ethanol in the United States. Environ Sci Technol 2012;46:11408–17. doi:10.1021/es3010514.

[454] Sovacool BK. Contextualizing avian mortality: A preliminary appraisal of bird and bat fatalities from wind, fossil-fuel, and nuclear electricity. Energy Policy 2009;37:2241–8. doi:10.1016/j.enpol.2009.02.011.

[455] Willis CKR, Barclay RMR, Boyles JG, Mark Brigham R, Brack V, Waldien DL, et al. Bats are not birds and other problems with Sovacool's (2009) analysis of animal fatalities due to electricity generation. Energy Policy 2010;38:2067–9. doi:10.1016/j.enpol.2009.08.034.

[456] Sovacool BK. Megawatts are not megawatt-hours and other responses to Willis et al. Energy Policy 2010;38:2070–3. doi:10.1016/j.enpol.2009.08.052.

[457] Wilbert TR, Woollett DA, Whitelaw A, Dart J, Hoyt JR, Galen S, et al. Non-invasive baseline genetic monitoring of the endangered San Joaquin kit fox on a photovoltaic solar facility. Endanger Species Res 2015;27:31–41. doi:10.3354/esr00649.

[458] Ennen JR, Lovich JE, Meyer KP, Bjurlin C, Arundel TR. Nesting Ecology of a Population of Gopherus agassizii at a Utility-Scale Wind Energy Facility in Southern California. Copeia 2012;2:222–8. doi:10.1643/CE-11-102.

[459] Inman R, Esque T, Nussear K, Leitner P, Matocq M, Weisberg P, et al. Is there room for all of us? Renewable energy and Xerospermophilus mohavensis. Endanger Species Res 2013;20:1–18. doi:10.3354/esr00487.

[460] Blasiak R, Doll C, Yagi N, Kurokura H. Displacement, diffusion and intensification (DDI) in marine fisheries: A typology for analyzing coalitional stability under dynamic conditions. Environ Sci Policy 2015;54:134–41.

[461] Dale VH, Parish ES, Kline KL. Risks to global biodiversity from fossil-fuel production exceed those from biofuel production. Biofuels, Bioprod Biorefining 2015;9:177–89. doi:10.1002/bbb.1528.

[462] Gasparatos A, von Maltitz GP, Johnson FX, Lee L, Mathai M, Puppim de Oliveira JA, et al. Biofuels in sub-Sahara Africa: Drivers, impacts and priority policy areas. Renew Sustain Energy Rev 2015;45:879–901. doi:10.1016/j.rser.2015.02.006.

[463] Allison TD, Root TL, Frumhoff PC. Thinking globally and siting locally: renewable energy and biodiversity in a rapidly warming world. Clim Change 2014;126:1–6. doi:10.1007/s10584-014-1127-y.

[464] Prip C, Gross, T, Johnston S, Vierros, M. Biodiversity Planning: an assessment of national biodiversity strategies and action plans. Yokohama: United Nations University Institute of Advanced Studies, Yokohama;2010.

[465] Petrokofsky G, Kanowski P, Brown ND, McDermott C. Biodiversity and the forestry sector. In: Gasparatos A and Willis KJ, editors. Biodiversity in the Green Economy. London, Routledge;2015.pp. 32-60.

[466] Bonilla-Moheno M, Redo DJ, Aide TM, Clark ML, Grau HR. Vegetation change and land tenure in Mexico: A country-wide analysis. Land Use Policy 2013;30:355–64. doi:10.1016/j.landusepol.2012.04.002.

[467] Puppim de Oliveira JA. Property rights, land conflicts and deforestation in the Eastern Amazon. For Policy Econ 2008;10:303–15. doi:10.1016/j.forpol.2007.11.008.

[468] Truax B, Gagnon D, Lambert F, Fortier J. Multiple-use zoning model for private forest owners in agricultural landscapes: A case study. Forests 2015:6;3614-64.

[469] Phalan B, Onial M, Balmford A, Green RE. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 2011;333:1289–91. doi:10.1126/science.1208742.

[470] Duvail S, Médard C, Hamerlynck O, Nyingi DW. Land and water grabbing in an East African coastal wetland: The case of the Tana delta. Water Alternatives 2012:5;322-343.

[471] Kuchler M, Linnér BO. Challenging the food vs. fuel dilemma: Genealogical analysis of the biofuel discourse pursued by international organizations. Food Policy 2012;37:581–8. doi:10.1016/j.foodpol.2012.06.005.

[472] Kang S, Post WM, Nichols JA, Wang D, West TO, Bandaru V, Izaurralde RC. Marginal Lands: Concept, Assessment and Management. J Agr Sci 2013:5;129-39.

[473] Shortall OK. "Marginal land" for energy crops: Exploring definitions and embedded assumptions. Energy Policy 2013;62:19–27. doi:10.1016/j.enpol.2013.07.048.

[474] Milbrandt AR, Heimiller DM, Perry AD, Field CB. Renewable energy potential on marginal lands in the United States. Renew Sustain Energy Rev 2014;29:473–81. doi:10.1016/j.rser.2013.08.079.

[475] Baka J, Bailis R. Wasteland energy-scapes: A comparative energy flow analysis of India's biofuel and biomass economies. Ecol Econ 2014;108:8–17. doi:10.1016/j.ecolecon.2014.09.022.

[476] Fu B, Wang YK, Xu P, Yan K, Li M. Value of ecosystem hydropower service and its impact on the payment for ecosystem services. Sci Total Environ 2014;472:338–46. doi:10.1016/j.scitotenv.2013.11.015.

[477] Bennett DE, Gosnell H, Lurie S, Duncan S. Utility engagement with payments for watershed services in the United States. Ecosyst Serv 2014;8:56–64. doi:10.1016/j.ecoser.2014.02.001.

[478] Guo Z, Li Y, Xiao X, Zhang L, Gan Y. Hydroelectricity production and forest conservation in watersheds. Ecol Appl 2007;17:1557–62.

[479] Meyer MA, Priess JA. Indicators of bioenergy-related certification schemes – An analysis of the quality and comprehensiveness for assessing local/regional environmental impacts. Biomass Bioenergy 2014;65:151–69. doi:10.1016/j.biombioe.2014.03.041.

[480] Davis J, Kidd IM. Identifying Major Stressors: The Essential Precursor to Restoring Cultural Ecosystem Services in a Degraded Estuary. Estuar Coast 2012;35:1007–17. doi:10.1007/s12237-012-9498-7.

[481] Jackson ALR. Renewable energy vs. biodiversity: Policy conflicts and the future of nature conservation. Glob Environ Chang 2011;21:1195–208. doi:10.1016/j.gloenvcha.2011.07.001.

[482] IRENA. Tidal Energy: Technology Brief. Masdar City:International Renewable Energy Agency (IRENA);2014.

[483] Ernst and Young GM. Rising tide: Global trends in the emerging ocean energy market. London:Ernst and Young;2013

[484] Noh C-H, Kim I, Jang W-H, Kim C-H. Recent trends in renewable energy resources for power generation in the republic of Korea. Resources 2105:4;751-64.

[485] Frankfurt School-UNEP Centre/BNEF. Global trends in renewable energy investment 2015. Frankfurt: Frankfurt School-UNEP Centre;2015.

[486] Aquamarine. Aquamarine power announces plans to downsize business. Edinburg: Aquamarine;2014 Available at http://www.aquamarinepower.com/news/aquamarine-power-announces-plans-to-downsize-business.aspx (Accessed 11 Decement 2015).

[487] Magagna D, Uihlein A. Ocean energy development in Europe: Current status and future perspective. Int J Mar Energy 2015:1184–104

[488] Thaxter CB, Ross-Smith VH, Bouten W, Clark NA, Conway GJ, Rehfisch MM, et al. Seabird–wind farm interactions during the breeding season vary within and between years: A case study of lesser black-backed gull Larus fuscus in the UK. Biol Conserv 2015;186:347–58. doi:10.1016/j.biocon.2015.03.027.

[489] Vega LA. Ocean Thermal Energy Conversion. In Meyer RA, Encyclopedia of Sustainability Science and Technology. Berlin: Springer;2012. pp. 7296-328.

[490]. CRRC. Ocean Thermal Energy Conversion: Assessing Potential Physical, Chemical and Biological Impacts and Risks. Durham: Coastal Response Research Center;2010.

[491] Zhou A, Thomson E. The development of biofuels in Asia. Appl Energy 2009;86:S11-S20.

[492] Bowyer C, Tucker G, Nesbit M, Baldock D, Illes A, Paquel C. Delivering Synergies between Renewable Energy and Nature Conservation: Messages for Policy Making up to 2030 and Beyond. London: Institute for European Environmental Policy (IEEP);2015.

[493] SCBD. Interlinkages between biological diversity and climate change: Advice on the integration of biodiversity considerations into the implementation of the United Nation Framework Convention

on Climate Change and its Kyoto protocol. Secretariat of the Convention on Biological Diversity (SCBD):Montreal;2003.

[494] Fletcher RJ, Robertson, BA, Evans J, Doran PJ, Alavalapati JRR, Schemske DW. Biodiversity conservation in the era of biofuels: risks and opportunities. Front Ecol Environ 2011:9;161–168. http://dx.doi.org/10.1890/090091

[495] Thompson D, Hall AJ, Lonergan M, McConnell B, Northridge. Current status of knowledge of effects of offshore renewable energy generation devices on marine mammals and research requirements. Edinburgh: Scottish Government;2013.

[496] Bailey H, Senior B, Simmons D, Rusin J, Picken G, Thompson PM. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Mar Pollut Bull 2010:60;888-97. doi: 10.1016/j.marpolbul.2010.01.003

[497] Tougaard J, Henriksen OD, Miller LA. Underwater noise from three types of offshore wind turbines: estimation of impact zones for harbor porpoises and harbor seals. J Acoust Soc Am 2009:125;3766-73. doi: 10.1121/1.3117444.

[498] Bailey H, Brookes KL, Thompson PM. Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystem 2014;10:8 doi: 10.1186/2046-9063-10-8

[499] Miyake S, Smith C, Peterson A, McAlpine C, Renouf M, Waters D. Environmental implications of using 'underutilised agricultural land' for future bioenergy crop production. Agric System 2015:139;180-95.

[500] Hayes MA. Bats killed in large numbers at United States wind energy facilities. BioScience 2013:63;975-9.

[501] Arnett EB, Huso MMP, Schirmacher MR, Hayes JP. Altering turbine speed reduces bat mortality at wind-energy facilities. Front Ecol Environ 2011:9;209-14.

[502] Vijayaraghavan K. Green roofs: A critical review on the role of components, benefits, limitations and trends Renew Sustain Energy Rev 2016:57;740-52

[503] Nash C, Clough J, Gedge D, Lindsay R, Newport D, Ciupala MA, Connon S. Initial insights on the biodiversity potential of biosolar roofs: a London Olympic Park green roof case study. Isr J Ecol Evol. 2015: DOI: 10.1080/15659801.2015.1045791

[504] Worldwatch Institute. Biofuels for Transport: Global Potential and Implications for Sustainable Energy and Agriculture. London: Earthscan;2007.

[505] Jones, DL. Potential Air Emission Impacts of Cellulosic Ethanol Production at Seven Demonstration Refineries in the United States. J the Air Waste Manage Assoc 2010:60:9;1118-43.

Tables

Table 1: Carbon debt payback period for different biofuel options

Biofuel type	Region	Original land use	Payback period (yrs)	Source
Palm oil biodiesel	S.E. Asia	Tropical rainforest	86	[250]
	S.E. Asia	Peat land rainforest	423	[250]
	Malaysia	Lowland tropical rainforest	76	[253]
	Indonesia	Mix of lowland tropical primary/secondary rainforest and agricultural land	58	[253]
	Indonesia	Mix of tropical peatland forest, swamp and agricultural land.	199	[253]
	Indonesia	Mainly lowland tropical primary rainforest with tropical peatland forest, swamp, agricultural land	84	[253]
	S.E. Asia	Tropical rainforest	75-93	[212]
	S.E. Asia	Peat land rainforest	692	[212]
	S.E. Asia	Grassland	10	[212]
	Malaysia	Grassland	0-11	[260]
	Malaysia	Forest	18-38	[260]
	Cameroon	Forest	45-53	[261]
	Brazil	Forest	39	[262]
Soybean biodiesel	Brazil	Tropical rainforest	319	[250]
	Brazil	Cerrado grassland	37	[250]
	Brazil	Cerrado woodland and pasture	41	[253]
	Brazil	Degraded pasture	7	[253]
	Brazil	Mainly permanent cropland with Amazonian rainforest	16	[253]
	US	Grassland	14-96	[260]
	US	Forest	179-481	[260]
Jatropha-based fuels	Ghana	Mix of open and closed woodland, permanent cropland and fallow land	71-129	[253]
	Zambia	Mix of mature miombo woodland, permanent cropland and allow land	20-NA	[253]
	Mozambique	Mature miombo woodland	187-966	[263]
	Africa	Miombo woodland	33	[264]
	South Africa	Converted savannas	17–36	[265]

	Zambia	Miombo woodland	32-81	[265]
	Mexico	Secondary woodland	60-101	[253]
	Mexico	Mix of secondary forest, fallow land and permanent cropland	72-183	[253]
	Mexico	Mainly agricultural land and pasture with secondary forest	7-30	[253]
	Mexico	Mix of secondary forest and low intensity pasture land	2-14	[266]
	Brazil	Caatinga woodland	10-20	[267]
Sugarcane ethanol	Brazil	Cerrado woodland	17	[250]
	Brazil	Grassland	3-10	[260]
	Brazil	Forest	15-39	[260]
	Tanzania	Forest	15-27	[268]
	Tanzania	Grassland	2-3	[268]
Cassava ethanol	Mali	Fallow land	37-81	[269]
Wheat ethanol	UK	Grassland	20-34	[260]
	UK	Forest	80-140	[260]
Maize ethanol	US	Grassland	93	[250]
	US	Abandoned cropland	48	[250]
	US	Grassland	2-25	[270]
	US	Forest	16-52	[270]
	US	Low-fertility CRP land	19-43	[271]
	US	Low-fertility CRP land	65-88	[271]
	US	Grassland	40-123	[272]
Prairie biomass ethanol	US	Abandoned cropland	1	[250]
	US	Marginal cropland	No carbon debt	[250]
	US	Grassland	No carbon debt	[272]

Table 2: MA drivers of biodiversity loss for different renewable energy pathways.

	Habitat Loss/Change	Pollution	Invasive-Alien Species	Over-exploitation	Climate Change
Wind (Section 2.2)	✓	?*	X	X	X
Solar (Section 3.2)	✓	?	X	X	?
Hydro (Section 4.2)	✓	✓*	?	?	?
Biomass energy (Section 5.2.1)	✓	✓	✓	?	✓
Biofuels (Section 5.2.2)	✓	✓	?	?	✓
Ocean energy (Section 6.2)	✓	?*	X	X	X
Geothermal (Section 7.2)	✓	✓*	X	X	X

✓ Strong evidence for the existence of a causal link
X Lack or minimal evidence for the existence of a causal link
? Theoretically possible causal link, but inconclusive or contextual evidence
* Includes non-chemical pollution such as sound, heat and light pollution

Table 3: Mechanisms of the negative effects of renewable energy pathways on ecosystems and biodiversity

Pathway	Mechanism	Scale of effect	Selected sources
Solar energy **(Section 2.2)**	Loss and/or fragmentation of habitats from solar power installations and ancillary developments	Local/landscape	[20][21][33]
	Bird collision/trauma with solar power installations	Local	[36]
	Intense solar fluxes can cause burns to birds	Local	[35][36]
	Pollution of water bodies from toxic chemicals used for treating the panels and the land prior to solr power infrastructure development	Local/landscape	[39]
	Prolonged drying of ephemeral water bodies due to increasing water use (especially in water-scarce environment such as deserts)	Local/landscape	[39][40]
	Attraction and disorientation of insects and birds caused by bright and/or polarized light	Local	[36][37]
	Potential to act as an ecological trap through cumulative attractor mechanisms	Local/landscape	[36]
	Cause changes to local micro-climate	Local	[41]
Wind energy **(Section 3.2)**	Bird and bat collision with wind turbines	Local	[17][18][56][57][58][59][63][64]
	Barotrauma to bats	Local	[51]
	Disrupt the migratory routes of some bird and bat species	Local/landscape Regional	[18][62]
	Alter feeding and roosting patterns of some bird species	Local/landscape	[60]
Hydropower **(Section 4.2)**	Flooding of upstream areas sinks ecosystems, fragments habitats and disaffects nature reserves	Local/landscape Regional	[87][93][94][95]
	Alteration of water flows upstream and downstream of hydropower installations	Local/landscape Regional	[98][99][100][101][102][103][104][105][106]
	Disrupt the migration routes of some diadromous fish species	Local/landscape Regional	[107][108]
	Deteriorate water quality due to changes in sediment loading, turbidity and eutrophication	Local/landscape Regional	[99][109][110][111]
	Emissions of GHGs from reservoir that contribute to anthropogenic climate change	Global	[114][115][116][117][118][119][120][121]
Bioenergy	Loss and fragmentation of habitats due to conversion into agricultural landscapes dominated by a single crop (usually associated with large-scale monoculture modes of feedstock production)	Local/landscape	[144][146][147][195][196][198][203][204][205][209][210][216][217][218][219][220]
	Simplification and homogenization of habitats due to modification of landscape elements and ecosystem processes, e.g. soil loss and access to light (usually associated with large-scale monoculture	Local/landscape	[195][196][198][203][204][210][216]

(Section 5.2)	modes of feedstock production)		
	Pollution of soil and water from fertiliser/pesticide use, causing toxicity and eutrophication (usually associated with large-scale monoculture modes of feedstock production)	Local/landscape, Regional	[203][290][291][292][293][294][295][296][297][298][299][300][301]
	Emission of ambient air pollutants that contribute to acidification and tropospheric ozone formation	Local/landscape Regional	[159][160][161][162][163][164][165][166][167][168][169][170][171][172][173][174][175][176][177][180][181][182][237][238][239][240][241][242][243][244][245][246][247][248][241][247][248][274][275][276][273][274][203][278][279][174][280][281] Table 1
	Emission of GHGs during the entire life-cycle of bioenergy generation (including from direct and indirect land use change) that contribute to anthropogenic climate change	Global	
	Effects to local micro-climates due to changes in albedo and evapotranspiration	Local/landscape, Regional	[183][234][254][255][256][257][258][259]
	Invasive behavior of some feedstock species (e.g. eucalyptus, miscanthus) that compete with native vegetation	Local/landscape, Regional	[302][303][304][305][306][312]
Ocean energy **(Section 6.2)**	Fish/benthic species composition changes due to habitat loss from scour pits at the foundations for offshore wind generators and ocean energy devices installed/anchored in the seabed	Local	[356]
	Permanent inundation of upstream portions of estuaries from tidal barrages.	Local/landscape	[345]
	Alteration of hydrodynamic and sedimentation processes	Local/seascape	[354] [26][382][383]
	Avoidance of underwater areas close to ocean energy installations by some species (especially during construction)	Local/seascape	[355][357][358]
	Species entrapment at tidal barrages	Local/landscape	[343]
	Collision risks of birds (with offshore wind generators) and aquatic species (with wave energy devises)	Local	[18][372] [26][350][375][376]
	Interference with navigation and feeding patterns of local and migratory species	Local/seascape	[359][360][377]
	Excess mortality of tropical fish due to temperature shocks from upwelled cold water at OTEC projects	Local	[387]
	Disturbances to the seabed can increase turbidity at water column	Local	[388]
	Changes in salinity, water turbidity and exchange between flushing of oxygenated water from tidal barrages	Local	[371][378]
	Noise pollution during the construction and operation can affect some aquatic species (particularly	Local	[356][389][390]

	aquatic mammals)		
	Electromagnetic fields from underwater cables can affect sensitive species	Local	[26] [385][388]
	Pollution from toxic lubricants and paints	Local	[26][360][375]
Geothermal (Section 7.2)	Loss of habitats during conversion intro geothermal facilities	Local/landscape	[403][404][405][406]
	Effect at the breeding, foraging and migration patterns of certain species from disturbances during site clearing, road construction, well drilling and seismic surveys	Local/landscape	[402]
	Emission of toxic pollutants such as H_2S, arsenic and boric acid which can defoliate plants or be uptaken by biota	Local/landscape	[412][413][414][415][416]
	Noise and heat pollution from geothermal facilities	Local/landscape	[409][417][418]

Table 4: Biodiversity benefits of renewable energy pathways

Renewable pathway	Biodiversity benefit	Selected sources
Solar energy	Solar energy installations can provide cover/habitat and feeding areas (e.g. grazing) for certain animals. This includes both USSE and photovoltaic panels mounted on rooftops and building facades.	[21][47]
Wind energy	Wind power installation might provide favourable grounds for some terrestrial species due to reduced traffic, greater availability of food and lack of predators	[66]
Hydropower	Hydroelectric facilities can create new habitats for some iconic species	[96]
Bioenergy	Some bioenergy landscapes can provide habitat, food and other supporting ecosystem services compared to other agricultural practices (especially intensified monocultures)	[155][156][157][158] [221][222] [232][233]
Bioenergy	2nd generation biofuel feedstock landscapes (e.g. miscanthus, switchgrass) can provide habitat to a number of species	[221][222][223][224] [225][226][227][228] [229][230][231][494]
Ocean/Offshore wind energy	Ocean/Offshore wind energy facilities can make marine areas inaccessible to fishing and maritime activities, protecting fish stocks and acting as de facto reserves for marine species	[396][498]
Ocean/Offshore wind energy	Benthic and fish species increases have been observed around offshore wind farms and wave/tidal infrastructure possibly due to shelter effects.	[361][363][364][365] [361][366][367][368] [369][370] [371]