Renewable and Sustainable Energy Reviews 70 (2017) 161–184

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

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

Alexandros Gasparatos[a,*], Christopher N.H. Doll[b], Miguel Esteban[c], Abubakari Ahmed[c], Tabitha A. Olang[c]

[a] Integrated Research System for Sustainability Science (IR3S), University of Tokyo, Tokyo, Japan
[b] Institute for the Advanced Study of Sustainability (UNU-IAS), United Nations University, Tokyo, Japan
[c] Graduate Programme on Sustainability Science – Global Leadership Initiative (GPSS-GLI), University of Tokyo, Kashiwa, Japan

ARTICLE INFO

Keywords:
Renewable energy
Biodiversity
Mitigation strategies
Ecosystem services
Green Economy

ABSTRACT

This 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 the backbone of Green Economy efforts, an emerging body of literature demonstrates that 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 impact mechanisms for 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 each of the five MA drivers of ecosystem change and biodiversity loss, the actual impact mechanisms depend significantly between the different pathways, specific technologies and the environmental contexts within which they operate. 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 renewable energy policies. We put these findings into perspective by illustrating the major knowledge/practices gaps and policy implications at the interface of renewable energy, biodiversity conservation and the 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).

* Correspondence to: Integrated Research System for Sustainability Science (IR3S), University of Tokyo Institutes for Advanced Study (UTIAS), University of Tokyo, Administration Bureau Building 2, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan.
E-mail address: gasparatos@ir3s.u-tokyo.ac.jp (A. Gasparatos).

http://dx.doi.org/10.1016/j.rser.2016.08.030
Received 11 December 2015; Received in revised form 29 May 2016; Accepted 14 August 2016
1364-0321/

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.

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 can 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 [19–21], hydropower [22], bioenergy [23–24] and ocean energy [25,26]; as well as by 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 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 pathway, and the main interventions that can mitigate negative biodiversity outcomes. The renewable energy pathways 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 rely 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 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)

[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 the role of biodiversity for the provision of ecosystem services, and as an extent its contribution to human wellbeing, is much more complicated [8–10].

[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].

(*footnote continued*)
[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 pathways (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 pathways contributes to ecosystem change and biodiversity loss.

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

[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. They are more akin to conventional PV in design but, as yet, have experienced relatively limited deployment.