Renewable and Sustainable Energy Reviews 29 (2014) 766–779

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Environmental impacts of utility-scale solar energy

R.R. Hernandez [a,b,*], S.B. Easter [b,c], M.L. Murphy-Mariscal [d], F.T. Maestre [e], M. Tavassoli [b], E.B. Allen [d,f], C.W. Barrows [d], J. Belnap [g], R. Ochoa-Hueso [h], S. Ravi [a], M.F. Allen [d,i,j]

[a] Department of Environmental Earth System Science, Stanford University, Stanford, CA, USA
[b] Department of Global Ecology, Carnegie Institution for Science, Stanford, CA, USA
[c] Ecofactor, Redwood City, CA, USA
[d] Center for Conservation Biology, University of California, Riverside, CA, USA
[e] Departamento de Biología y Geología, Universidad Rey Juan Carlos, Móstoles, Spain
[f] Department of Botany and Plant Science, University of California, Riverside, CA, USA
[g] U.S. Geological Survey, Southwest Biological Science Center, Moab, UT, USA
[h] Hawkesbury Institute for the Environment, University of Western Sydney, Penrith, 2751, New South Wales, Australia
[i] Department of Biology, University of California, Riverside, CA, USA
[j] Department of Plant Pathology, University of California, Riverside, CA, USA

ARTICLE INFO

Article history:
Received 22 February 2013
Received in revised form
29 July 2013
Accepted 11 August 2013
Available online 28 September 2013

Keywords:
Biodiversity
Conservation
Desert
Greenhouse gas emissions
Land use and land cover change
Photovoltaic
Renewable energy

ABSTRACT

Renewable energy is a promising alternative to fossil fuel-based energy, but its development can require a complex set of environmental tradeoffs. A recent increase in solar energy systems, especially large, centralized installations, underscores the urgency of understanding their environmental interactions. Synthesizing literature across numerous disciplines, we review direct and indirect environmental impacts – both beneficial and adverse – of utility-scale solar energy (USSE) development, including impacts on biodiversity, land-use and land-cover change, soils, water resources, and human health. Additionally, we review feedbacks between USSE infrastructure and land-atmosphere interactions and the potential for USSE systems to mitigate climate change. Several characteristics and development strategies of USSE systems have low environmental impacts relative to other energy systems, including other renewables. We show opportunities to increase USSE environmental co-benefits, the permitting and regulatory constraints and opportunities of USSE, and highlight future research directions to better understand the nexus between USSE and the environment. Increasing the environmental compatibility of USSE systems will maximize the efficacy of this key renewable energy source in mitigating climatic and global environmental change.

Contents

* Corresponding author. Department of Environmental Earth System Science, 51 Dudley Lane, Apt 125, 260 Panama Street, Stanford, CA 94305, USA. Tel.: +1 650 681 7457.
E-mail address: rebecca.hernandez@stanford.edu (R.R. Hernandez).

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.08.041

1. Introduction

Renewable energy is on the rise, largely to reduce dependency on limited reserves of fossil fuels and to mitigate impacts of climate change ([58, 110, 150]). The generation of electricity from sunlight directly (photovoltaic) and indirectly (concentrating solar power) over the last decade has been growing exponentially worldwide [150]. This is not surprising as the sun can provide more than 2500 terawatts (TW) of technically accessible energy over large areas of Earth′s surface [82,125] and solar energy technologies are no longer cost prohibitive [9]. In fact, solar power technology dwarfs the potential of other renewable energy technologies such as wind- and biomass-derived energy by several orders of magnitude [150]. Moreover, solar energy has several positive aspects – reduction of greenhouse gases, stabilization of degraded land, increased energy independence, job opportunities, acceleration of rural electrification, and improved quality of life in developing countries [17,126] – that make it attractive in diverse regions worldwide.

In general, solar energy technologies fall into two broad categories: photovoltaic (PV) and concentrating solar power (CSP). Photovoltaic cells convert sunlight into electric current, whereas CSP uses reflective surfaces to focus sunlight into a beam to heat a working fluid in a receiver. Such mirrored surfaces include heliostat power towers (flat mirrors), parabolic troughs (parabolic mirrors), and dish Stirling (bowl-shaped mirrors). The size and location of a solar energy installation determines whether

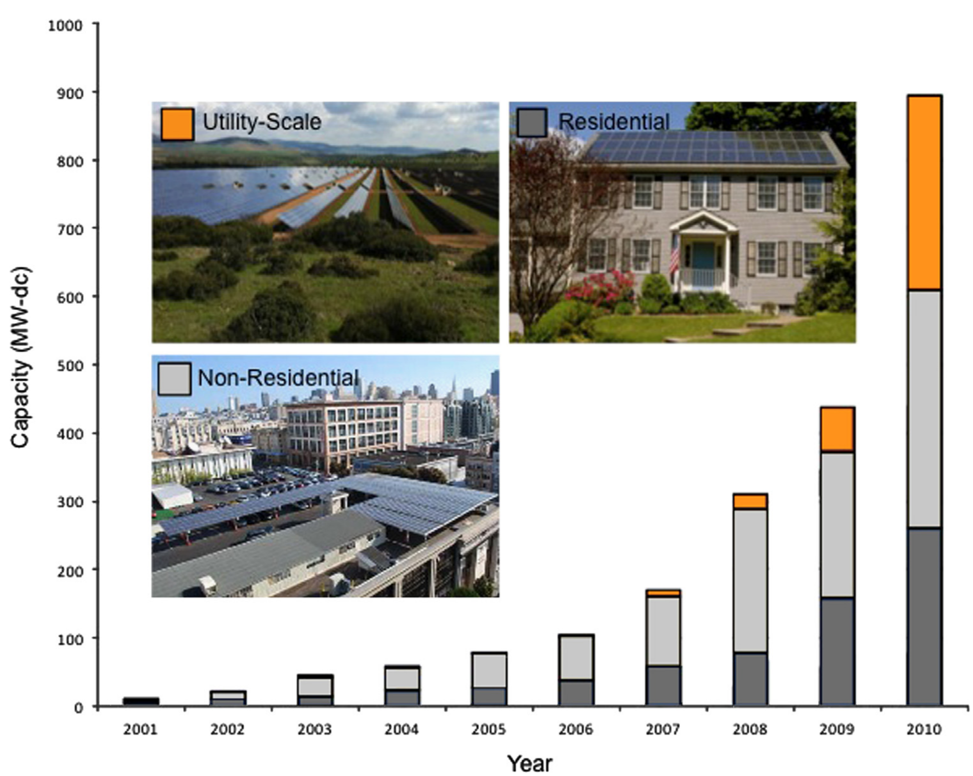

Fig. 1. Annual installed grid-connected photovoltaic (PV) capacity for utility-scale (> 20 MW) solar energy schemes and distributed solar energy schemes (i.e., non-residential and residential) in the United States. Total PV capacity was 900 MW in 2010; approximately double the capacity of 2009. Data reprinted from Sherwood [114]. Photo credits: RR Hernandez, Jeff Qvale, National Green Power.