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Matching renewable energy and conservation targets for a sustainable future

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Renewable energy facilitates emission reductions, but its deployment also presents challenges. Recently in *Joule*, Cole et al. examined barriers to establishing a 100% renewable energy power system in the United States, but land-use-change impacts of renewable energy deployment on biodiversity conservation were unexplored and warrant interdisciplinary investigation.

Climate change results from CO_2 emitted by the combustion of fossil fuels entering Earth's atmosphere.[1] Under the United Nations Paris Agreement, countries agreed to limit the global average temperature increase to well below 2°C relative to pre-industrial baselines; the Intergovernmental Panel on Climate Change later proposed a roadmap to allow an energy transition toward net-zero carbon emissions via significant reduction in fossil fuel production and increased renewable energy capacity.[2] The forthcoming United Nations Climate Change Conference (COP26) is expected to accelerate actions toward meeting the goals of the Paris Agreement. The potential for renewable energy to mitigate climate change, create jobs, evoke environmental justice, and meet the electricity demand of a growing human population now fuels sociopolitical activity pushing aggressive agendas for emission reductions and carbon neutrality. According to a recent Briefing Room fact sheet from the White House, the Biden-Harris Administration targets a 50%–52% reduction in emissions by 2030 through increased production of renewable energy.[3]

Although the need for renewable energy deployment is apparent,[3] pathways to achieving a transition to renewable energy remain unclear. Recently in *Joule*, Cole et al.[4] used state-of-the-art modeling to estimate the cost of achieving a 100% renewable energy system for the contiguous United States under a wide range of future conditions. The authors' goals were to inform electric-sector decision-maker assessments of the cost and value of pursuing higher penetration of renewable energy systems and to bolster understanding of the requirements to decarbonize the electricity sector. The authors highlighted the complex, cost-related challenges associated with a 100% renewable energy transition, including but not limited to nonlinear increases in cost, variable definitions of 100% renewable energy, the speed of transition, and capital cost contributions to system cost. However, as the authors acknowledge, the challenges of the transition to renewable energy span beyond economic costs alone. Specifically, insufficient consideration of land-use change in pathways for a transition to renewable energy could lead to knowledge gaps with socioecological implications that, in turn, could affect the sustainability of renewable energy buildout. Therefore, research that investigates and addresses the ecological challenges associated with a transition to renewable energy is warranted.[5]

The likely acceleration of the sixth mass species extinction and increasing biodiversity loss pose additional socioenvironmental challenges and necessitate global biodiversity conservation to maintain humanity's life-support system.[6] Species extinctions are permanent and affect the living systems upon which humans depend.[6] Human pressures on the biosphere, including habitat loss from anthropogenic land-use change, have steadily increased, leading to reductions in biodiversity and the ecosystem goods and services that wild species provide.[6–8] Powers and Jetz[7] evaluated potential loss in range-wide suitable habitat and extinction risk for ~19,400 vertebrate species on the basis of global decadal land-use scenarios to year 2070; the authors identified substantial declines of suitable habitat for species worldwide and 1,700 species at risk of imperilment from land-use change alone. In June 2021, G7 leaders committed to the G7 2030 Nature Compact[9] to halt and reverse biodiversity loss by conserving at least 30% of global land and 30% of global ocean by 2030 with the goal of facilitating both a net-zero and nature-positive world for people and the planet. In the 2021 report titled "Conserving and restoring America the beautiful,"[10] the Biden-Harris Administration also committed to conserving at least 30% of the lands and waters of the United States by the same 2030 benchmark.

Competition for finite land resources exists among land uses, including but certainly not limited to renewable energy production and conservation. Land-use competition could continue to intensify with the rapid growth of renewable energy development and human populations, the latter of which in turn results in further urban sprawl and necessitates increased agricultural production of food. Siting decisions around renewable energy could be influenced by factors other than conservation, including economics, the technical state of renewable energy technologies, and government-issued energy-supply mandates. Therefore, utility-scale renewable energy development often occurs near and in conservation lands and globally important biodiversity areas.[11,12] Rehbein et al.[11] identified ~3,000 renewable energy facilities affecting 886 protected areas, 749 key biodiversity areas, and 40 distinct wilderness areas worldwide; the next wave of renewable energy development could increase the number of affected protected areas and key biodiversity areas by ~30% and the number of wilderness areas by 60%.[11] In California, most utility-scale solar energy installations are sited in shrublands and scrublands with a high conservation value within 10 km of protected natural areas.[12]

Land-use change associated with renewable energy development could have profound effects on biodiversity, ecosystems, and ecosystem services.[8,13] Land used for conservation could be directly converted to renewable energy production, thereby diminishing or, in some cases, potentially eliminating its capacity to support biodiversity and ecosystems services in relation to its previously undeveloped state.[12,13] For example, solar energy development in the Mojave Desert negatively affected cacti and yucca, which in turn reduced plant-based ecosystem services.[8] In general, we know little about the interactions between renewable energy and ecosystems, be they negative, neutral, or positive. Research on the interactions between renewable energy and ecosystems is presently proceeding more slowly than the buildout of renewable energy. The lack of standardization and inconsistent methodologies among ecological studies at renewable energy facilities could further limit our ability to understand the effects of renewable energy development on ecosystems with currently available data.

Renewable energy production and biodiversity conservation might not necessarily be mutually exclusive. This very notion has created a novel, fertile research environment in which we can explore the possibilities of a sustainable transition to renewable energy. Most researchers agree that the critical first step to avoiding any negative effects of renewable energy development on biodiversity is science-informed, conservation-minded siting of renewable energy facilities.[13] For example, in a case study in California's Great Central Valley,[14] solar energy development in marginalized lands with low conservation value, including developed land-cover types, salt-affected agricultural land, and contaminated sites, offered extensive opportunities to spare land for conservation while meeting projected electricity needs. Hernandez et al.[15] developed the concept of techno-ecological synergy—a framework for engineering mutually beneficial relationships between technological and ecological systems—as it applies to solar energy technologies. Restoration of pollinator habitat at solar facilities is a potential techno-ecological synergy buzzing around social, academic, and industry circles alike. In the pollinator-friendly solar scenario, the same parcel of land could support solar energy production and pollinator habitat (i.e., native, low-growing flowering plants), and there are potential synergies between the two to the benefit of both the solar industry and biodiversity conservation. The techno-ecological synergies of restoring native vegetation at solar facilities could extend beyond pollinators to include increased solar energy production, carbon sequestration, erosion control, and reduced colonization by invasive species. The explication of techno-ecological synergies for renewable energy systems could lead to win-win scenarios for renewable energy and biodiversity conservation while reducing land-use competition between the two. Yet, techno-ecological synergies—or simply put, co-benefits—of conservation-minded renewable energy development have only just begun to be quantified.

Given the realities of current renewable energy deployment, research efforts that empirically test the effects of renewable energy development on biological conservation and identify means by which to mitigate its negative effects on biodiversity, ecosystems, and ecosystem services are warranted. Research can guide such mitigation by experimentally testing the efficacy of adaptive approaches to developing renewable energy to minimize impacts to biodiversity conservation and ecosystem services, including the following: (1) variable site-preparation practices, (2) novel conservation measures, (3) adaptive facility designs from the local to the landscape level, and (4) altered operations and maintenance procedures.[13] Further, more research is needed to identify potential techno-ecological synergies of all renewable energy sources in a variety of ecosystems. For example, potential techno-ecological synergies of wind energy remain largely unexplored in comparison with those presently discussed for solar energy.

The solution for producing knowledge that allows us to match renewable energy and biodiversity goals in the United States and around the world most likely lies in creative, interdisciplinary collaboration among researchers in combination with inclusive engagement of diverse stakeholders.[13,15] The collective ability of scientists to produce knowledge that informs a sustainable transition to renewable energy most likely hinges on coordinated and transdisciplinary research approaches that holistically address renewable energy deployment scenarios.[13,15] For example, renewable energy penetration pathways such as those simulated by Cole et al.[4] could integrate explicit biodiversity conservation considerations via input from energy ecologists to guide realistic yet sustainable renewable energy deployment in terms of both economic and biodiversity costs. Quantifying the effects of renewable energy development on cultural ecosystem services could provide a path for assessing the environmental justness of renewable energy deployment while connecting to biodiversity conservation as a maintainer of ecosystem services. Researchers and stakeholders across diverse fields can all cooperate, collaborate, and communicate through coordinated engagement to generate knowledge that facilitates a sustainable transition to renewable energy. For example, representatives and researchers in the renewable energy industry can together play a key role in the development of sustainable renewable energy via collaborative research, fundraising, and science applications.[13] Through such collaboration, we can more efficiently achieve techno-ecological synergies of renewable energy and better deploy renewable energy in more viable, environmentally responsible, and sustainable ways. Creativity, collaboration, and human ingenuity can help pave the path forward for matching renewable energy and biodiversity goals to sustain all natural resources for future generations.

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