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Understanding Emerging Impacts and Requirements Related to Utility-Scale Solar Development

Environmental Science Division

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ANL/EVS-16/9

Understanding Emerging Impacts and Requirements Related to Utility-Scale Solar Development

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NOTATION

ac	acre
AIM	Assessment, Inventory, and Monitoring
BACI	Before-After/Control-Impact
BBCS	Bird and Bat Conservation Strategy
BLM	Bureau of Land Management
BMP	best management practices
CASSP	California Archaeology Site Steward Program
CM	compensatory mitigation
CSP	concentrating solar power
CUPV	centralized utility-scale photovoltaics
CWA	Clean Water Act
DOE	U.S. Department of Energy
DRECP	Desert Renewable Energy Conservation Plan
DUPV	distributed utility-scale photovoltaics
EIR	environmental impact report
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
GIS	geographic information system
ISEGS	Ivanpah Solar Electric Generating System
LTM	long-term monitoring
LTMS	long-term monitoring strategy
MBTA	Migratory Bird Treaty Act
NEPA	National Environmental Policy Act
NGO	non-governmental organization
NPS	National Park Service
PV	photovoltaic
RCRA	Resource Conservation and Recovery Act
REA	Rapid Ecoregional Assessment
ReEDS	Regional Electricity Deployment System

SEZ	solar energy zone
Solar PEIS	Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States
SRMS	Solar Regional Mitigation Strategy
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

Utility-scale solar energy plays an important role in the nation's strategy to address climate change threats through increased deployment of renewable energy technologies, and both the federal government and individual states have established specific goals for increased solar energy development. In order to achieve these goals, much attention is paid to making utility-scale solar energy cost-competitive with other conventional energy sources, while concurrently conducting solar development in an environmentally sound manner.

Important benefits of the use of solar power in comparison with power obtained from fossil fuels include decreased greenhouse gas emissions, decreased emissions of other pollutants that cause respiratory diseases, and decreased water usage. However, like other sources of power the production of solar energy also has an impact on the environment and society. In the past few years, as utility-scale solar development has expanded, there has been increasing focus on a few issues and challenges related to environmental and human impacts. These issues include difficulty in obtaining land required for solar facilities in appropriate locations, and landscape-scale ecological, cultural, and visual impacts. These impact issues, which are the focus of this report, have the potential to result in barriers to continued rapid solar development,

The utility-scale[1] solar energy industry in the United States has seen dramatic growth in the past decade. This growth is expected to continue; according to the U.S. Energy Information Administration (EIA 2016), the total capacity of utility-scale solar installations in the U.S. is projected to increase by 123% (12 GW) between the end of 2014 and the end of 2016. Land use requirements for utility-scale solar facilities range from about 8 to 10 acres/MW, depending on technology used (Ong et al. 2013). Using technology-specific projections, this report finds land use for utility-scale solar could be 450 mi^2 in 2020 and 2,800 mi^2 in 2030 within the contiguous United States, if U.S. Department of Energy (DOE) development scenarios are achieved (Section 2.2.1).

Any large-scale land use that involves activities such as clearing, grading, and fencing can lead to a range of adverse environmental impacts. Construction of utility-scale solar installations often includes these actions, although in some cases they are not needed or can be avoided (Macknick et al. 2013a). The growth of utility-scale solar has been accompanied by the development of best management practices designed to avoid or minimize the adverse impacts associated with land use for solar facilities (BLM and DOE 2010, 2012; BLM 2015a). Federal, state, and local agencies have also developed permitting requirements to avoid and minimize impacts. As experience with constructing and operating utility-scale solar facilities has increased, a few issues and impacts have emerged for which solutions are still being worked out. These issues include siting solar facilities in appropriate locations that minimize ecological effects,

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1 Utility-scale defined here as facilities with capacity >1 MW delivering electricity to the transmission grid.

landscape-scale[2] ecological impacts (including impacts on avian species), landscape-scale cultural impacts, and landscape-scale visual impacts (including glare impacts). These issues could present barriers to continued rapid solar development. Several stakeholder groups (including federal and state agencies, industry, non-governmental organizations, and academia) are working and collaborating to develop new methods to assess these emerging issues, and are developing approaches to address them through strategies such as compensatory mitigation, monitoring, and adaptive management (TNC and TWS 2014; Walston et al. 2015). Key impact issues and innovative approaches that are considered in this report include the following:

- *Land Requirements*. Despite concerns regarding high land requirements, the analysis of this report estimates that to meet DOE goals for 2020, total land requirements for ground-based solar are approximately 0.01% of the total surface area of the contiguous United States. The total land requirements to meet DOE goals for 2030 would be less than 0.1% of the total surface area of the contiguous U.S. Current evidence suggests that, on a life-cycle basis, ground-based solar is among the most land-use efficient (per kWh generated) of electricity generation technologies, considering both renewable and fossil sources (Fthenakis and Kim 2009). Rooftop or other building-integrated (distributed) solar is even more efficient in terms of land use since it is installed on structures with other primary purposes. Utilization of distributed solar is an important strategy to avoid or mitigate the potential impacts related to land use for solar facilities.

  There are also several other co-location strategies that could help to mitigate potential land use-related impacts of solar. These include co-location with agriculture, co-location with other energy systems, and re-use of certain types of previously used and/or degraded lands for solar installations. An analysis in this report of the potential suitability of siting solar projects on certain types of previously used lands (e.g., formerly contaminated sites and other disturbed lands as defined in the report) indicated that such lands might meet the total land requirements to meet DOE Sunshot program goals, although additional assessment is needed to confirm the suitability of specific sites for solar development and their economic and logistical feasibility.

- *Ecological - Impacts on Avian Species.* In the past few years, the potential for solar-related bird fatalities, both collision-related and solar flux-related, has been identified as an area of concern. However, more data are needed regarding the nature and magnitude of these impacts, the potential attraction of birds to solar arrays, and the need for and effectiveness of mitigation

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2 Landscape-scale (or regional) means focusing on a large, connected geographical region that may cross administrative boundaries but has similar environmental characteristics. Other potential impact issues such as water use in arid environments, air quality impacts and associated human health effects, and albedo (heat absorption) effects are not addressed in this report, primarily because there already are effective methods for avoiding or minimizing those impacts, or they are not currently the focus of efforts to develop innovative solutions.

measures. Recently established avian solar working groups, involving collaboration among state and federal agencies, industry, and other stakeholders, are working to address these issues and identify research needs.

- *Visual Issues*. Because of their large size, reflective surfaces, rectilinear geometry, and lighting at night, utility-scale solar projects may give rise to large visual impacts. A visual impact specific to utility-scale solar facilities is glare (sometimes intense) from solar arrays, power tower receivers, and other components. Recently, the DOE and the Bureau of Land Management (BLM) have both published guidance on visual impact mitigation methods for solar facilities. Considerable progress has also been made by the BLM in developing and applying an improved methodology to assess visual impacts at a landscape-scale, and applying compensatory mitigation.

- *Compensatory Mitigation (CM) for Environmental and Human Impacts.* CM is actions or projects undertaken to offset (or "compensate for") the adverse environmental and human impacts of other actions or projects (in this report, "human" impacts primarily considers visual and cultural impacts). Although offsetting impacts through CM can address stakeholder concerns and allow project development to proceed, CM costs can be a large source of uncertainty for developers. While often conducted at a project-specific level, CM strategies can also be developed programmatically using approaches now being implemented to address ecological, cultural, and visual resource impacts at a landscape scale. Such strategies also identify likely CM needs prior to development, allowing CM costs to be built into facility financial plans.

- *Long-Term Monitoring and Adaptive Management.* Stakeholders and land management agencies have identified the need for more robust scientific information about the potential long-term impacts of utility-scale solar development. Increased emphasis is being placed on the implementation of monitoring and adaptive management responses (that is, using monitoring to evaluate whether management actions are achieving desired outcomes and, if not, changing policies or operations to achieve desired outcomes). Resource management decisions would benefit from publicly available data consistently collected during the pre-construction (baseline) and post-construction periods. Because comprehensive long-term monitoring programs can be costly, agencies are working to control costs by developing programs that consider regional conditions and trends of key resources on the basis of clear monitoring objectives, priorities, and appropriate indicators.

- *Feasibility and Cost Considerations*. The issues related to environmental and human impacts discussed in this report have the potential to result in barriers to solar development. For utility-scale solar energy to be a key component in the nation's strategy to address climate change threats, it is important for the solar industry that these environmental and socio-cultural impact issues be thoroughly addressed. It is also important that new approaches to address

> these issues be developed jointly by regulators, industry, and other stakeholders, and fully evaluated in terms of technical feasibility, effectiveness, and cost.

Although some of the impact mitigation approaches discussed in this report are still being evaluated in terms of feasibility, effectiveness, and cost, they are providing some promising new methods for evaluating and resolving impacts. The potential for impacts varies by project and so, too, do the solutions. These innovative approaches, developed collaboratively, provide several options for resolving emerging concerns. In the case of siting solar facilities on certain previously used lands, it may be possible to avoid some of the impacts discussed in this report entirely. In the case of applying landscape-scale assessments, the goal is to gain a much better understanding, prior to development, of the nature and magnitude of impacts and to determine in a regional context which impacts require further mitigation, where and how to mitigate most effectively, and how to maximize investment of mitigation funds. Long-term monitoring and adaptive management programs, appropriately designed, will ensure continued evaluation and adjustment to maximize mitigation effectiveness.

1 INTRODUCTION

Stretching back over a decade, a number of federal mandates and policies have been issued promoting expedited development of domestic renewable energy resources. The importance of this development was underscored in 2013 with issuance of The President's Climate Action Plan (Executive Office of the President 2013), which set a priority on reducing carbon emissions to limit climate change and related public health impacts, in part through accelerated deployment of renewable energy technologies, including utility-scale[1] solar power. This priority is consistent with and supported by state-level Renewable Portfolio Standards that establish timelines for achieving specific levels of electricity generation from renewable sources within a given state. Accordingly, increased development of utility-scale solar energy is considered critical in the fight against climate change, although this development – like all forms of energy development – must be done in an environmentally sound manner.

In support of the many federal directives, the U.S. Department of Energy (DOE) launched the SunShot Initiative in 2011 to promote innovation and advances to make solar energy cost-competitive, without subsidies, with conventional energy sources by the end of the decade. One specific goal is to reduce the cost of utility-scale solar electricity to about $0.06 per kilowatt-hour. The DOE's 2012 *SunShot Vision Study* (DOE 2012a) estimated that meeting this and other cost reduction goals could allow rapid growth in solar power such that it would generate up to 14% of the nation's electricity demand by 2030 and 27% by 2050.

Increased solar development is important because, compared to non-renewable electricity generating technologies, such development can result in significant benefits in the form of greenhouse gas, air pollutant, and water-use reductions, as discussed by Wiser et al. (2016). However, these benefits of increased solar development need to be considered in the context of challenges associated with land use and disturbance, and environmental and human (e.g., visual and cultural) resource issues.

Large utility-scale solar projects in the U.S. are subject to extensive planning and review processes, which can successfully avoid or significantly reduce many potential adverse impacts.[2] Impact avoidance, minimization, and mitigation can be achieved through site selection, technology selection, project design, and implementation of proven best practices. Regulators

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1 For the purposes of this analysis, utility-scale solar development includes all projects that generate electricity for delivery via the electric transmission grid and for sale in the utility market. These projects differ from distributed solar energy systems, which typically are designed at smaller scales (<1 MW), only use PV technologies, avail themselves of land already developed (i.e., utilize rooftop space), and deliver power for local use.

2 The potential impacts of utility-scale solar development and appropriate mitigation measures are described and evaluated in numerous documents, including Hernandez et al. (2015), Hernandez et al. (2014), the *Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States* (the Solar Programmatic EIS; BLM [Bureau of Land Management] and DOE 2010, 2012), the Desert Renewable Energy Conservation Plan (DRECP) Phase I final environmental impact statement for public lands in California (BLM 2015a), and project-specific environmental review documents. Comparative analyses of the potential impacts of a number of energy technologies also are available (Fthenakis and Kim 2009, Brown and Whitney 2011, Macknick et al. 2012, Meldrum et al. 2013, Hertwich et al. 2015).

and industry already employ a broad set of measures to avoid, minimize, and mitigate potential adverse impacts of utility-scale solar. However, a few issues and impacts have emerged for which solutions are still being worked out. These include siting solar facilities in appropriate locations that minimize ecological effects; landscape-scale ecological impacts (including impacts on avian species), landscape-scale cultural impacts, and landscape-scale visual impacts (including glare impacts). Work is ongoing by several stakeholder groups (e.g., regulators, industry, non-governmental organizations [NGOs], academia) to address these issues. Feasibility and cost considerations need to be incorporated into the solutions, and developers need to have some measure of certainty about cost implications. Care should also be taken to ensure that new approaches are proven effective at successfully addressing the impact issues before they become mandatory.

This report describes and evaluates emerging environmental and human impact issues that could present barriers to increased deployment. The report also describes methods and approaches being developed to address these issues through compensatory mitigation (CM) strategies and long-term monitoring. Specifically, the focus is on continuing and emerging issues associated with land requirements, ecological impacts on avian species, and impacts on visual values. Potential ways to avoid or minimize impacts, for example through the utilization of certain previously-used lands, are discussed. This paper also describes a landscape-scale approach to evaluating and addressing ecological, cultural, and visual impacts in the context of CM. And finally, a long-term monitoring approach to identify environmental and human issues on a landscape scale is presented. Other potential impact issues such as water use in arid environments, air quality impacts and associated human health effects, and albedo (heat absorption) effects are not addressed in this report, primarily because there already are effective methods for avoiding or minimizing those impacts (even if further research is necessary), they are not currently the focus of efforts to develop innovative solutions, or they have not currently been identified as a significant concern at the individual project level.

2 LAND REQUIREMENTS

The cost goals of the DOE's SunShot Initiative were projected to result in approximately 53 gigawatts (GW) of solar electricity generation systems installed by 2020 and nearly 330 GW by 2030, representing 14% of electricity demand in 2030 (DOE 2012a).[3] Health benefits related to the substantially increased deployment of solar power are numerous and have been quantified (Wiser et al. 2016). There are also some environmental impacts that are, in large measure, contingent on the amount of land required to support the increased deployment. Rooftop (distributed) solar contributes a substantial portion of the solar deployment associated with meeting SunShot cost goals, and by definition does not require solar installation on the land surface, therefore avoiding land-based impacts. However, the majority of projected solar deployment would be installed on the ground. While solar facilities can be large compared to other industrial land uses, it should also be remembered that when considering life-cycle land use, solar electricity generation has been shown to be quite low in land occupation per unit of electricity generated in comparison with some other electricity generation sources (Fthenakis and Kim, 2009). This section quantifies the amount of land required to realize the SunShot solar development goals to help frame the consideration of various land-related impacts and mitigation opportunities, as discussed in subsequent sections.

Since the *SunShot Vision Study* (DOE 2012a) was published, knowledge of and methods for assessment of land use for solar technologies have advanced considerably. This section leverages these advances to improve upon the estimates of land requirements from the *SunShot Vision Study*. These advances include robust, empirical quantification of land being used by solar facilities currently installed, based on high-resolution satellite imagery. In addition, this study refines analyses for land requirements on a regional basis (i.e., electrical grid balancing areas,[4] then aggregated to states), which was not attempted in the *SunShot Vision Study*, in order to characterize land requirements and availability more precisely. This section provides more robust, empirically based estimates of regional land requirements based on re-analysis of the *SunShot Vision Study* capacity expansion modeling, accounting for national and state total land availability.

There are numerous strategies for avoiding or minimizing land disturbance and related impacts. As mentioned above, siting solar on rooftops of buildings avoids adding to land-based impacts by utilizing the existing structure's land footprint. Additional "co-location" strategies include co-location of solar with agriculture, co-location with other energy systems, and re-use of certain types of previously used lands[5] that have been degraded by their prior use. The latter is quantitatively addressed in this chapter; the others are not explored further except to point the

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3 The *SunShot Vision Study* considered the contiguous United States, and the focus of this report is the same.

4 A balancing (authority) area is defined as "The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority. The Balancing Authority maintains load resource balance within this area." (http://en.openei.org/wiki/Definition:Balancing_Authority_Area)

5 In this study, these include formerly contaminated sites and other disturbed lands, as defined in Section 2.1.

interested reader to existing literature on this topic (Hernandez et al. 2014; Ravi 2015; Macknick et al. 2013a).

2.1 METHODS

As in the *SunShot Vision Study*, the current effort considers four types of solar technologies. Each solar technology type, along with all other conventional and renewable electricity generation technologies, is deployed on the basis of an economic optimization within the Regional Electricity Deployment System (ReEDS) model developed by the National Renewable Energy Laboratory (Short et al. 2011). The first solar technology evaluated is small-scale (<1 MW) distributed photovoltaic (PV). These solar installations are considered to be located on rooftops, and thus do not require additional land resources for their deployment.[6] As discussed above, the use of rooftop solar has been framed as a significant mitigation strategy for avoiding land-related impacts of meeting the SunShot deployment objectives. In the *SunShot Vision Study*, rooftop solar was estimated to contribute 19 GW in 2020 and 121 GW in 2030, a substantial part of the totals of 53 and 330 GW, respectively, mentioned above.

The remaining 34 GW by 2020 and 209 GW by 2030 of projected solar capacity are represented by three technology categories, hereafter collectively called *ground-based solar*, which includes the following:

1. Centralized utility-scale PV (CUPV): single-axis tracking, ground-mounted PV systems greater than 20 MW in installed capacity represent this technology class;

2. Distributed utility-scale PV (DUPV): single-axis tracking, ground-mounted PV systems 1–20 MW in installed capacity represent this technology class; and

3. Concentrating solar power (CSP): centralized, power tower technology with thermal storage represent this technology class.[7]

Land use requirements for the above three categories were estimated utilizing recent, empirically-derived estimates of land used by existing solar facilities per unit of installed capacity (MW) (Ong et al. 2013). In terms of total project area, CUPV was found by Ong et al. (2013) (who called it UPV) to use, on average, 8.3 acres (ac) per installed MW, DUPV 8.7 ac/MW, and CSP 10 ac/MW. Hereafter, land use per unit capacity is referred to as a measure of land use intensity. Multiplying land use intensity by the estimated capacity in two benchmark years of 2020 and 2030 yields an estimate of the total land area required for ground-based solar in those years.

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6 Other than small areas for additional distribution assets required in some jurisdictions, which are not considered here.

7 A small amount (~2%) of CSP is estimated to be centralized parabolic trough systems without storage.

There are a few important distinctions and caveats. First, total project area (total area) is distinguished (consistent with the usage of Ong et al. [2013]) from the area directly impacted by project infrastructure (direct area). The fence line of the total project area is always larger than the area that is directly impacted by the solar arrays, roads and other infrastructure, yet the direct area makes up between 70% and 90+% of total area. For rhetorical simplicity and to err on the side of being more conservative, total area is the focus of this land requirements assessment, understanding that the direct area will be a smaller amount.

Second, one can consider attributing additional land area to solar development to account for the land used throughout the life cycle of solar technology manufacture and use, for instance, by facilities that manufacture components (like PV modules), utilization of the road network for transportation of the manufactured components, and land use by the offices of development and installation companies. The results of one study of life cycle land use for multiple electricity generation technologies are presented in Table 2-1 (Fthenakis and Kim 2009). It is worth noting that in that study, solar land use per unit of electricity generated is comparable on a life cycle basis to land use for other electricity generation technologies, and in some cases substantially lower. A more recent study estimated the land area required throughout the life cycle of solar technologies and concluded the additional area was less than 1% of the land used by PV or CSP electricity generation facilities (Murphy et al. 2015). For this reason, in this study, the life-cycle land requirements of the *SunShot Vision Study* scenario are not quantified, since these additional area requirements would not materially change the conclusions of the study. In addition, land required in other parts of the life cycle is not necessarily located in the same region as the generation facility. Therefore, interpretations of the regionalized results from such an analysis would be complex and impractical.

Third, it should be remembered that the land estimated to be required in a given year (here, 2020 or 2030) represents the cumulative capacity installed as of that year.

Fourth, as electrical conversion efficiency increases for solar technologies, less land will be required per unit of installed capacity. Embedded in the SunShot program cost reduction targets is the assumption that solar device efficiency improves over time. This cost reduction driver is one of many, and was not explicitly reported as an individual target, so it is not possible to quantify the effect of efficiency improvement on the land requirements in an internally consistent manner. Instead, it is noted here that efficiencies have improved dramatically over the years (see, for instance, NREL's historical chart[8]), that DOE is funding projects to continue improving efficiency,[9] and that increases in efficiency tend to decrease land requirements, assuming constant electricity generation targets.

Finally, the analysis of previously used lands available in the same regions modeled in the *SunShot Vision Study* for ground-based solar builds on prior land availability and suitability analysis performed by NREL (Macknick et al. 2013b). Achieving the market penetration goals of

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8 Available at http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.

9 See http://energy.gov/articles/energy-department-announces-102-million-tackle-solar-challenges-expand-access-clean.

TABLE 2-1 Life Cycle Land Use of Selected Electricity Generation Technologies[a]

Technology	ac/GWh
PV rooftop, average	***0.01***
Nuclear	0.02
Coal, surface (WY)	0.04
Coal, underground	0.06
Natural gas	0.07
PV (US Southwest)	***0.07***
Coal, surface (Eastern)	0.10
Wind (CA)	0.25
Hydroelectric, reservoir, CO	1.01
Biomass, willow gasification, NY	3.11

[a] Source: Fthenakis and Kim 2009, Figure 3. The following assumptions were stated: Based on 30-year timeframe (U.S. cases unless otherwise specified). The estimates for PV are based on multi-crystalline PV modules with 13% efficiency. The U.S. Southwest PV case refers to utility-scale ground-mount installation with an insolation of 2400 kWh/m^2/year, while the rooftop case is based on the U.S. average insolation of 1800 kWh/m^2/year. The estimate for wind is based on a capacity factor of 0.24 for California.

the SunShot Initiative could require utility-scale solar installations to be designed and deployed in ways that maximize land use efficiency and minimize negative biodiversity impacts. Potential previously used sites of certain types that could be used for solar development across the United States were identified using geographic information system (GIS) data, after filtering for key exclusion criteria related to land slope, minimum contiguous area requirements, and solar resource quality (Macknick et al. 2013b; Appendix A).

One category of previously used lands considered here includes lands that in the past have been contaminated by improper handling or disposal of toxic and hazardous materials and wastes, but have been remediated such that they could be suitable for some forms of re-use, including industrial development, as identified on federal and state lists. Such lands include Resource Conservation and Recovery Act (RCRA) and Superfund sites (EPA 2009) as well as landfills, abandoned mine lands, brownfields, and non-federally-owned RCRA and Superfund sites. A full list of the types of contaminated lands considered in this study is presented in Table A-1 in Appendix A.

A second category of previously used lands considered in this report includes other types of disturbed lands not considered contaminated. The United States Geological Survey (USGS) defines disturbed lands as land in an altered and often non-vegetated state due to prior disturbances (USGS 2012). Disturbed lands are different from environmentally contaminated lands and may include former industrial sites, various types of intensively used agricultural lands, public lands that have been severely impacted by activities such as livestock grazing or the use of off-road vehicles, and severely impacted mining or oil and gas development lands. Disturbed lands are not designated by the U.S. Environmental Protection Agency (EPA) as reaching the necessary threshold to be considered environmentally contaminated, yet they still might not be suitable for productive agricultural or other beneficial use. For the purposes of this study, disturbed lands include barren lands, invasive species-impacted lands, and other types of non-vegetated lands that include gravel pits or recently burned areas, as defined in prior studies (listed in Table A-1) utilizing USGS methods. (See Appendix A for further definition.)

The categories of previously used lands and the coarse suitability screening criteria utilized are useful for estimating land availability at an aggregated, regional level. Additional and more specific screening criteria and analyses would be required to actually site a facility in any given location, and decisions about the suitability of any given plot of land for solar development would require additional examination of site-specific characteristics and the costs, benefits and impacts of development.

2.2 ESTIMATES OF LAND REQUIREMENTS

2.2.1 Total State Area Compared to Ground-based Solar Land Requirement

Each state's deployment of ground-based solar varies in accordance with the economic optimization of the ReEDS model for 2020 and 2030. The product of estimated capacity multiplied by the land use intensity for each ground-based solar technology yields an estimate of the land requirement. Summed across the three ground-based solar technologies, the result can initially be compared with the total surface area of each state for a sense of scale of the estimated solar deployment. Despite concerns that ground-based solar technologies require large amounts of land because of low energy density, it was determined that total land requirements in 2020 for ground-based solar are approximately 0.01% of the total surface area of the contiguous United States, and less than 0.1% in 2030. These percentages equate to about 290,000 acres (450 mi^2) and 1.8 million acres (2,800 mi^2), respectively. Only one state (Rhode Island) is estimated to require greater than 1% of its land area to deploy all of the solar envisioned under the *SunShot Vision Study* (Table A-3 in Appendix A). Figure 2-1 displays the national results graphically. It is worth noting that this result is consistent with prior assessment globally (WWF 2013).

2.2.2 Area Available on Contaminated and Disturbed Lands Compared to Ground-based Solar Land Requirements

Although ground-based solar requires a small fraction of total surface area nationally and for each state, given increasing population and economic development along with protected land

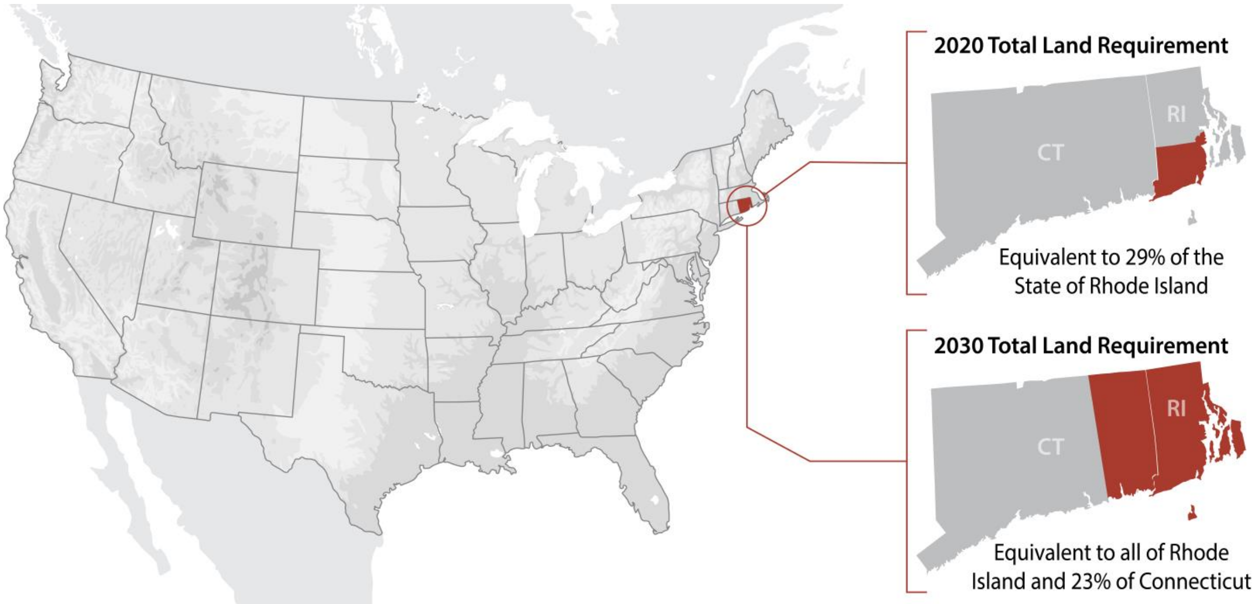

FIGURE 2-1 Estimates of Land Requirements of Ground-Based Solar in 2020 and 2030 based on *SunShot Vision Study* Capacity Projections

areas, it is imperative to ensure that the demand for land that is suitable for other productive uses is minimized. In that context, it is useful to compare the land requirements of ground-based solar to lands that are available in each state and do not have a current productive use, such as contaminated and disturbed lands. Analysis to estimate national and regional deployment potential of solar on available agricultural lands (agricultural co-location) and co-located with existing energy facilities (whether in hybrid energy systems or simply co-located) is suggested as a topic of future research.

Prior efforts have demonstrated that there is sufficient acreage of contaminated and disturbed lands available nationally to meet *SunShot Vision Study* ground-based solar development goals (Macknick et al. 2013b), summarized in Table 2-2. Many potentially contaminated or disturbed sites will not meet requirements of siting the technology or of the project developers, local communities or regulatory agencies having jurisdiction, but given the amount of such lands available, a portion if not all of the SunShot deployment goals could potentially be met on these lands. Furthermore, examining the available contaminated and disturbed lands on a technology and regional basis (balancing areas), it appears that, with the exception of Florida, nearly every region seeing solar development under the *SunShot Vision Study* scenario potentially has sufficient contaminated and/or disturbed land acreage that could be utilized for solar development to meet the SunShot expected deployment (see Figure 2-2. (For more detailed maps and a state-by-state calculation, see Figures A-1 through A-3 and Table A-4 in Appendix A.)

TABLE 2-2 Comparison of Capacity Available from Contaminated and Disturbed Lands Suitable for Solar Development and *SunShot Vision Study* Goals (Macknick et al. 2013b)

	Total PV (CUPV, DUPV) Capacity Potential (GW)	Total CSP Installed Capacity Potential (GW)
Disturbed lands	1,600	900
Contaminated lands	370	70
SunShot Goals (2030)	209	34

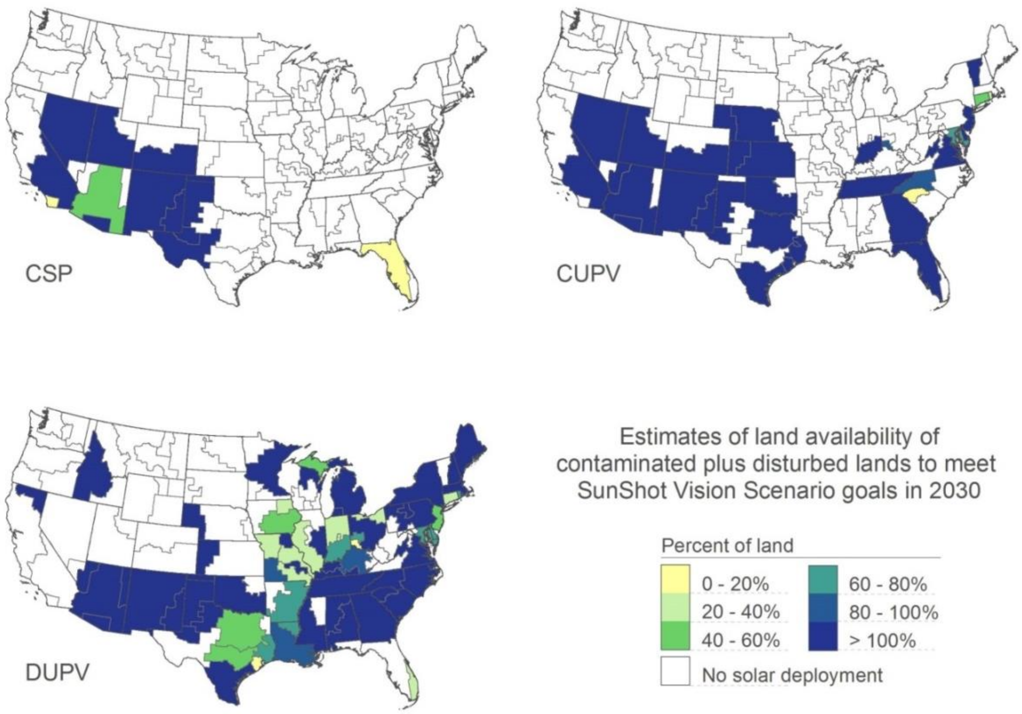

FIGURE 2-2 Estimates of Availability of Contaminated and Disturbed Lands to Meet *SunShot Vision Study* Scenario Goals for CSP (upper left), CUPV (upper right), and DUPV (lower left) in 2030

2.3 CONSIDERATIONS REGARDING USE OF FORMERLY CONTAMINATED AND DISTURBED LANDS

Utilization of contaminated and disturbed lands carries both benefits and challenges. This section briefly reviews some considerations regarding the deployment of solar technologies on these lands. Citations listed in this section can provide further information to the interested reader.

Many stakeholders have noted a preference for siting solar power development on non-productive, previously used lands. These lands often are located in rural areas or in marginal regions of urban areas, which may be in need of economic revitalization. Siting a financially attractive project in an area without productive land opportunities could improve temporary and permanent local economic conditions. The EPA, in conjunction with the DOE, has been actively exploring the feasibility of renewable energy development on contaminated lands through the *RE-Powering America's Land* Program (EPA 2012a). When carefully implemented, using disturbed or formerly contaminated lands for solar deployment (after cleanup, as needed) can minimize stress on intact, undeveloped lands, and could also improve soil stability and associated health impacts in some areas. These lands may also have some existing onsite infrastructure (e.g., roads, water service), potentially lower transaction costs, greater public support for development, and streamlined permitting and zoning processes, and they are often already located close to roads, rail, and transmission lines (EPA 2012a).

However, these lands also have inherent challenges associated with them related to potential legal liability, worker safety, remediation costs, land stability and economic viability in terms of risks and project finance. Soil disturbance during construction or decommissioning, and associated potential air emissions, could be an issue for contaminated lands, and further remediation needs should be evaluated (e.g., in terms of cost, timeliness, and safety considerations). In some instances, a human health risk screening assessment may be needed in order to assess potential risks and determine the need for additional remediation (Cheng et al. 2013). In addition, differences in surface and mineral rights ownership on mining sites could prove to be a challenge, should surface development of solar projects prevent a desired extraction of subsurface resources. While there have been successful examples of projects sited on formerly contaminated lands (EPA 2015a), further dialogue between government, industry, landowners, and the concerned public is needed to streamline utilization of these lands, address legal liability concerns, and reduce financial risks and associated costs and thus to make development of these lands more viable. Despite these challenges, feasibility studies confirm the potential benefits associated with utilizing previously used lands for renewable energy projects, and they could serve as an important land base for solar development in the future (Simon and Mosey 2013a; Simon and Mosey 2013b; Steen et al. 2013; Salasovich and Mosey 2011; Salasovich and Mosey 2012; VanGeet and Mosey 2010; Lisell and Mosey 2010a; Lisell and Mosey 2010b).

Other productive uses of these contaminated and disturbed lands may need to be considered. For example, many lands classified as contaminated or disturbed could potentially be suitable habitat for protected species, which may for some stakeholders represent a more productive use and thus preclude solar development. Moreover, disturbed lands potentially could be returned to a productive state over time. This study does not account for these gradual changes in land quality and instead assumes a static contaminated and disturbed land base. It is important to reiterate that the analysis conducted in this study does not provide a complete set of information that would be required for siting solar projects in specific locations (especially for contaminated or disturbed lands); rather it offers perspectives on the potential magnitude and general location of promising areas for solar development.

2.4 CONCLUSIONS

This study analyzed the land requirements of ground-based solar in 2020 and 2030 on the basis of the *SunShot Vision Study* projected capacities using the latest solar land use intensity research. The main finding is that even if solar deployment is increased by more than an order of magnitude (10 times) compared to deployment in 2015, the land requirement of ground-based solar is less than 0.1% of contiguous U.S. surface area and no state (except one) is estimated to require more than 1% of its land for solar deployment.

There are many strategies to avoid or mitigate potential conflicts over solar deployment and lands productively used for other purposes. Chief among these is the use of distributed (rooftop) solar, which the *SunShot Vision Study* estimated would make up a substantial fraction of total solar deployment (36% in 2020 and 37% in 2030). Additional strategies include sharing land occupation with other productive uses such as agriculture and other energy projects. There also exists a large and geographically distributed stock of lands that were previously contaminated or disturbed. After applying certain coarse suitability screening criteria, the calculated amount of contaminated or disturbed lands that potentially could support ground-based solar deployment was found to be significant. There are challenges to using these lands, but their abundance and potential benefits could provide a win-win scenario in certain circumstances, and other land types could provide a pathway to avoid conflicts with prime, productive lands. These estimates of land requirements form one foundation of understanding potential impacts on ecosystem habitats, cultural resources, and visual resources as well as mitigation and monitoring strategies that are discussed in the remainder of this report.

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3 ECOLOGICAL - IMPACTS ON AVIAN SPECIES

Despite its benefits, utility-scale solar development can have ecological consequences by directly or indirectly impacting plant and wildlife species and their habitats (Lovich and Ennen 2011; Hernandez et al. 2014). Siting decisions for solar projects have been greatly improved through the use of decision support systems and other tools to evaluate environmental criteria and identify areas of low ecological conflict across the landscape. However, in the past few years, new concerns have arisen related to the potentially increased risk of avian mortality associated with operation of utility-scale solar projects).

There are currently two known types of direct solar-related bird fatalities that could occur at solar projects (McCrary et al. 1986; Hernandez et al. 2014; Kagan et al. 2014):

1. Collision-related fatality—fatality resulting from the direct contact of the bird with a project structure(s). This type of fatality has been documented at solar projects of all technology types.

2. Solar-flux-related fatality—fatality resulting from the burning/singeing effects of exposure to concentrated sunlight. Passing through the area of solar flux may result in (a) direct fatality; (b) singeing of flight feathers that causes loss of flight ability, leading to grounding or collision with other objects; or (c) sufficient impairment of flight capability to reduce the ability to forage or avoid predators, resulting in starvation or predation of the individual (Kagan et al. 2014). Solar-flux-related fatality has been observed only at facilities employing power tower technologies.

Because most native bird species in the United States are protected by the Migratory Bird Treaty Act (MBTA) (50 CFR 10.13), it is unlawful to "take" migratory birds (or their nests or eggs). The U.S. Fish and Wildlife Service (USFWS) defines "take" to mean to "pursue, hunt, shoot, wound, kill, trap, capture, or collect" (50 CFR 10.12). The incidental take of birds at industrial facilities (such as solar energy facilities) is permitted through the MBTA (16 United States Code 1539(a)). The USFWS is currently considering a proposed rule to authorize the incidental take of migratory birds, which would evaluate several approaches to regulating incidental take, and establish appropriate standards to ensure that incidental take is appropriately mitigated (80 FR 30032).

Little is currently known about the nature and magnitude of solar impacts on bird populations, as there are relatively few science-based studies that address avian fatality issues at solar facilities (Walston et al. 2015). It has been hypothesized that solar-energy-related fatalities for some avian guilds may result from bird attraction to the project site (e.g., Kagan et al. 2014). Projects that include evaporative cooling ponds may provide artificial habitat to birds and their prey (e.g., insects). Such projects may attract more birds to the site and result in a greater risk of collision with project structures (Lovich and Ennen 2011; BLM and DOE 2010, 2012). Glare and polarized light emitted by solar projects may also attract insects, which, in turn, could attract foraging birds. For example, insects may perceive polarized light as water bodies and may be attracted to such sources (Horváth et al. 2009, 2010). Lastly, it has also been hypothesized that utility-scale PV facilities may attract migrating waterfowl and shorebirds that perceive the reflective surfaces of PV panels as bodies of water and collide with project structures as they attempt to land on the panels (Kagan et al. 2014). However, no empirical research has been conducted to evaluate the attraction of solar facilities for migrating birds. Furthermore, either systematic avian fatality monitoring is not conducted or the data are not widely available across all solar facilities. This type of information is necessary to understand the nature and magnitude of solar impacts on avian populations, as well as technology-specific contributing factors.

3.1 AVIAN MONITORING AND MITIGATION

Systematic monitoring of avian fatalities at solar facilities is necessary to understand the impact of solar development on bird populations and contextualize those impacts to other anthropogenic sources of avian mortality. One goal of these monitoring designs, which are often formally documented in Bird and Bat Conservation Strategies (BBCSs), is to quantify avian mortality risk using empirical data obtained through monitoring efforts. Quantifying mortality risk incorporates science-based approaches to address areas of uncertainty and sources of bias such as those factors related to the length of the monitoring period, survey effort, and monitoring frequency, size of the project, searcher efficiency, and the carcass persistence rate (Huso 2011). An additional adjustment to consider at solar facilities with large spatial footprints is the role of background mortality, which could be addressed through a Before-After/Control-Impact (BACI) experimental design, which requires that indicator data be collected both before development begins (to define baseline conditions) and after development occurs (Walston et al. 2015, 2016a). The factors that influence the calculation of avian mortality rates are summarized in Table 3-1.

Another goal of project-specific BBCSs is to describe in detail the types of measures that would be implemented to reduce or offset impacts on bird populations and to monitor the effectiveness of those measures. Such measures include siting projects to avoid sensitive bird habitats and nest locations, measures to reduce collision with solar energy structures and other infrastructure, and measures to reduce potential attraction of birds towards the solar facility (e.g., deterring birds from evaporation ponds). For example, recent efforts at power tower facilities have considered the positioning of “standby” heliostats and the associated risk of solar flux effects on migrating birds. Recent solar flux models have indicated that altering the aiming positions of standby heliostats could lower the flux levels around the power tower receiver and lower avian mortality risk (Walston et al. 2015, 2016a). If altering the direction of heliostats in standby mode is shown to reduce avian mortality risk at power tower facilities, then this approach might represent a cost-effective measure to be implemented at these facilities.

There is currently variability in avian monitoring activities conducted at solar energy facilities. Better coordination among regulatory agencies, industry, and stakeholders is important to develop a standardized framework for preparing avian monitoring protocols that would provide guidance on selecting appropriate monitoring designs and the types of information to be collected. Such a framework would improve consistency and comparability in monitoring results across solar energy projects. Federal agencies and solar industry groups have recognized the importance of multi-organization coordination to address avian-solar interactions and have

TABLE 3-1 Factors Influencing Avian Mortality Rate Calculation (Sources: Huso 2011, Walston et al. 2015, Korner-Nievergelt et al. 2015)

Factor	Description
Searcher efficiency	The percentage of fatalities found by individual searchers or teams of searchers. Mortality rate estimations are influenced by how well a searcher can detect the actual number of birds within the project. Searcher efficiency percentage is typically determined by conducting field trials, where a predetermined number of bird carcasses of various sizes are placed in the different areas throughout the project footprint and searchers record the number of birds detected. The adjustment for searcher efficiency is a common bias-correction tool employed in mortality estimation for many studies. Quality assurance through training can also contribute in part to correcting bias.
Spatial and temporal search effort	The percentage of the project footprint surveyed over space and time. Overall mortality estimates are typically calculated for 100% of the project footprint's area. Therefore, surveys of less than 100% of the project often require an adjustment to estimate mortality across the entire footprint. Similarly, overall mortality estimates are calculated for a standard unit of time (e.g., annually). Therefore, surveys of different temporal periods often require adjustment to standardize mortality estimates on an annual basis.
Predation and scavenging	Predators and scavengers may transport carcasses on and off the project footprint, and may therefore contribute to uncertainty in mortality estimation. Carcass removal trials are commonly used to quantify the amount of time (days) that a carcass usually persists in the field before it is removed by predators and scavengers. The adjustment for carcass removal is a common bias-correction tool employed in mortality estimation. Recent studies have highlighted the potential for predators to transport carcasses to the project footprint from offsite locations, where the bird may have died from causes unrelated to the project. Understanding the role of this form of background mortality in the estimation of solar-avian mortality has been identified as a need for future research.
Environmental parameters	Displacement of carcasses related to wind speed and direction away from the actual strike area (and outside a sample plot) must be taken into account to arrive at an estimate of the proportion of killed or injured animals in the search area that actually fall into the search area.
Species-specific parameters	Lighter-weight bird carcasses may be displaced further from the strike site than heavier ones. Smaller carcasses may disappear more quickly because they may be consumed/carried off by a greater number of predators.
Background mortality	An estimate of natural avian mortality occurring independently from human-caused fatality. Some avian fatality observations within project footprints may be attributable to background mortality. To better understand background mortality and adjust project-related mortality estimates, background mortality is examined by surveying for avian fatalities in offsite reference areas (i.e., control plots). Background mortality studies at utility-scale solar facilities have shown that a large portion of fatalities may be attributable to background and unrelated to the project. Mortality estimates at some solar facilities have been calculated with adjustments to account for background mortality.

recently initiated avian-solar working group discussions (through a multi-agency Collaborative Working Group established by state and federal agencies and an Avian Solar Working Group established by industry and NGO groups).

3.2 RECOMMENDATIONS

Findings in the avian-solar report prepared for DOE (Walston et al. 2015) identified several recommendations to improve understanding of avian fatality issues at utility-scale solar facilities. Recently established multi-stakeholder avian solar working groups, involving collaboration among state and federal agencies, industry, and other stakeholders, will work to address these recommendations as well as other research needs. These recommendations can be summarized as follows:

- Need for additional systematic fatality information with consistent monitoring and other baseline data to understand the nature and magnitude of avian mortality risk;

- Need to improve consistency and standardization in monitoring protocols contained in BBCSs;

- Need for collaboration among agencies, industry, and stakeholders to identify research studies that will lead to better understanding the causal factors of avian mortality and magnitude of impacts (e.g., population-level effects);

- Need to assess mitigation options in terms of technical feasibility, effectiveness, and cost; and

- Implementation of feasible, science-based mitigation measures.

4 VISUAL ISSUES

The construction, operation, and decommissioning of utility-scale solar facilities create visual contrasts with the existing landscape in which the projects are sited. Some of these contrasts are similar to those of other large electricity generation facilities (e.g., extensive night lighting and power blocks with large generators at CSP facilities are similar to those at conventional generation facilities), while others contrasts are unique to solar (e.g., identical rectilinear components aligned in symmetrical arrays over a large area, glare from solar fields and power towers). These contrasts can change the visual qualities and landscape character of the surrounding area or affect the views from visually sensitive areas (which may include scenic or historic resource areas, recreation areas, wilderness or lands with wilderness characteristics, residential areas, lands important to tribes, or other areas where landscape views are important to people). As multiple facilities are built, there is also potential for cumulative visual impacts. The potential for visual impacts is increasingly of concern to stakeholders who value landscape character and the potentially affected visually sensitive areas. The primary visual impacts associated with utility-scale solar facilities and associated transmission projects, as well as recent advances in visual impact characterization, impact assessment methodology, and mitigation methods are presented below.

4.1 UTILITY-SCALE SOLAR FACILITY VISUAL IMPACTS

As for any large-scale energy generation facility, solar facilities include various engineered structures, roads, and fences. All large-scale energy generation facilities must have electric transmission infrastructure, including a substation, towers, and conductors that transmit the electricity generated by the facility to the electrical grid. Depending on the energy technology, facilities may also include cooling ponds, cooling towers (with associated visible water vapor plumes), landform changes, and clearing of vegetation over large areas. All solar facilities have some lighting at night, although the amount and type of lighting differs by technology type. The visible forms, lines, colors, and textures of these elements may be sources of visual contrast if they do not blend in with the existing landscape.

All solar facilities include either collector arrays (PV panels) or reflector arrays (parabolic trough mirrors or power tower heliostats). Smaller facilities of less than 20 MW typically have solar fields with areas of less than 200 acres, while the fields for the highest capacity solar facilities can occupy several thousand acres. Additional components include transmission equipment, access roads, steam turbine generators (power tower and parabolic trough facilities only), cooling towers (power tower and parabolic trough facilities using wet or hybrid cooling only); and fencing.

The solar arrays are usually the dominating visual element of the facilities. The rectilinear forms, straight or regular curved lines of the collector/reflector array and other structures often contrast strongly with the organic, asymmetric forms and lines of the existing landscape, and cause scale contrasts because of their large extent (scale contrasts also are applicable for tall power towers). Similarly, the strong colors and distinctly artificial visual pattern or texture of the collector/reflector array and other structures and roads contrast with most natural-appearing landscapes. Additionally, some facilities require landform changes such as site grading that cause form and line contrasts. Glare and glinting from solar collectors/reflectors and from ancillary components such as fences are a serious concern (see further discussion below). Other sources of visual contrast include color contrast from aviation obstruction lighting (for power towers only) both during the day and at night; water vapor plumes (for facilities with wet or hybrid cooling only); ancillary structures, such as administration or maintenance buildings and communications towers; and activity of workers and vehicles, including dust plumes from vehicles (BLM and DOE 2010).

As is true for all large-scale energy generation facilities, the form, line, color, and texture contrasts from required transmission lines and substations may add substantially to the visual contrasts from the solar facility (Sullivan et al. 2014). Transmission tower types vary widely in design, size, and materials depending on the required voltage for the lines, but in general, would be taller than many other structures associated with the solar facility, and may contrast with the geometry of both the solar facility and the surrounding landscape. Substations, which include complex geometry, cleared gravel pads, fences, and lighting can sometimes create large visual contrasts.

Whether these visual contrasts result in adverse visual impacts depends largely on the size and location of the solar facility. Visual impacts may be a relatively minor concern for smaller facilities that are sited in already developed industrial or agricultural areas. However, for larger facilities sited in previously undeveloped natural areas (such as the desert Southwest), visual impacts may be a much larger concern that should be addressed during site planning. Design-based mitigation measures, such as lighting controls and the use of fences and vegetative screening, are used to lessen contrasts (BLM and DOE 2010; Sullivan 2011; Sullivan and Abplanalp 2013; Sullivan and Abplanalp 2015; Sullivan et al. 2012). A range of potential visual impact mitigation measures for renewable energy facilities, including solar and associated transmission, are presented in the BLM publication *Best Management Practices for Reducing Visual Impacts of Renewable Energy Facilities* (BLM 2013a).

Glare Impacts. Glare is excessively bright light, typically but not always reflected light of sufficient brightness to cause annoyance, physical discomfort, or in the worst cases, ocular damage. Glare is commonly observed from windshields, building roofs, and the surfaces of water bodies, and thus is not unique to solar facilities, However, solar facilities can create glare and glinting (brief flashes of bright light) of unusual intensity and unique appearance. Major solar facility glare sources include various components of the reflector/collector arrays, including power tower heliostats, parabolic trough heat transfer fluid tubes, PV panels, and the illuminated portions of power tower receivers. Other glare and glint sources include pipes, fences, panel supports, and buildings. Health and safety impacts of glare from solar facilities have been documented extensively by Ho and colleagues (Barrett 2013; Ho et al. 2009, 2011; Ho and Khalsa 2010; Ho 2011, 2012, 2013; Ho and Sims 2013) and others (Riley and Olson 2011). Ocular damage from glare viewed at very short distances is possible, depending on the type of facility and its configuration, but is primarily a concern for workers because public access to facilities is controlled.

Glare from both power towers and parabolic trough facilities (see Figures 4-1 and 4-2) can cause discomfort for viewers miles away from the facilities (Sullivan 2011; Sullivan et al. 2012), creating a potential hazard for drivers and pilots (BLM 2010). Glare from the Ivanpah Solar Electric Generating System (ISEGS) power tower facility observed at long distances from the facility has resulted in complaints from pilots about temporary blindness or distraction that interfered with navigation (Sullivan and Abplanalp 2015). In addition to health and safety concerns associated with solar facility glare, there can be effects on the aesthetic experiences of persons in the surrounding area, including recreation areas, historic sites and trails, scenic byways, communities and residential areas, and other visually sensitive areas. For example, glare from the ISEGS facility is visible from many locations within Mojave National Preserve (Sullivan and Abplanalp 2015).

Night Sky Impacts. Because they require lighting at night, all large-scale energy facilities, including utility-scale solar facilities, are sources of night sky impacts (see Figure 4-3). Solar facility lighting includes safety and security lighting and lighting used in the course of nighttime maintenance or repair activities. In addition, power tower receiver towers have aerial hazard navigation lighting that can be visible for long distances (Sullivan and Abplanalp 2013). These light sources can contribute to skyglow, the general brightening of dark skies at night; glare, direct visibility of excessively bright light; light trespass, the illumination of an area where lighting is not wanted or needed; and light clutter, the excessive grouping of light sources that can create distractions. DOE-funded research has shown that the use of best management practices (BMPs), such as the use of motion detector-activated lighting and properly shielded lighting fixtures, can significantly reduce night sky impacts from solar facilities (Sullivan and Abplanalp 2013).

FIGURE 4-1 Glare from Receiver Towers and a Single Heliostat, Viewed at Approximately 18 mi from the Ivanpah Solar Electric Generating System in San Bernardino County, California
Credit: Robert Sullivan, Argonne National Laboratory

FIGURE 4-2 Glare from Parabolic Trough Facility, Viewed at Approximately 2 mi from the Nevada Solar One Facility in Clark County, Nevada
Credit: Robert Sullivan, Argonne National Laboratory

FIGURE 4-3 Nevada Solar One Parabolic Trough Facility in Clark County, Nevada, at Night
Credit: Marc Sanchez, BLM

Technology-Specific Impact Considerations. Of the three major solar technology types, PV facilities clearly have the lowest visual impacts for a facility of a given size (see Figure 4-4). PV facilities generally have lower height structures than parabolic trough or power tower facilities, and are more easily screened from view by topography and vegetation. PV panels are black or dark blue, which often makes them harder to see, especially at longer distances, and also reduces (but does not eliminate) the likelihood and severity of glare. They require less lighting than parabolic trough and power tower facilities, reducing contrasts at night. Because they do not have steam turbine generators, they have fewer structures and generally fewer types of structures, which contributes to a generally simpler geometry that reduces contrast, as does the lack of water vapor plumes. Finally, PV facilities require far fewer workers to operate and maintain the facility than parabolic trough and power tower facilities, so there is less visible activity.

FIGURE 4-4 Silver State North Thin-film PV Facility in Clark County, Nevada
Credit: Robert Sullivan, Argonne National Laboratory

Parabolic trough arrays are taller than PV arrays, and include structures that usually exceed the array height (see Figure 4-5), so they have a higher profile than PV facilities, though still much lower in height than a power tower central receiver tower. (see Figure 4-1). Because parabolic trough facilities require steam turbine generators, they have more pipes, tanks, and other structures than PV facilities, and also require substantially more lighting at night (see Figure 4-3). Because they have many more highly reflective surfaces (mirrors rather than panels), they are more likely to cause glare than PV facilities. They also require more workers, creating more visible activity at the project site.

The central receiver towers of power tower facilities are hundreds of feet tall,[10] and because they reflect the light of thousands or tens of thousands of heliostats in the array, they are exceedingly bright, cause glare, and are easily visible at very long distances (Ho et al. 2014; Sullivan and Abplanalp 2015) (see Figure 4-1).The strong vertical line of the tower(s) contrasts strongly with the generally flat landscapes in which they are typically located. Because of their height, the central receivers have Federal Aviation Administration-required aerial hazard navigation lighting. This lighting includes slowly flashing red lights at night, and pulsating white strobe lights during the day and twilight. Both types of lighting may be visible for long distances. In general, power towers have the highest level of visual contrast of the three major solar technologies.

4.2 STAKEHOLDER CONCERNS

Visual impacts were recognized in the *Sunshot Vision Study* (DOE 2012a) as an obstacle to siting solar facilities and associated transmission infrastructure, and have been identified as a concern by the public and other stakeholders for numerous proposed projects. Certain large

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[10] In the United States, central receiver towers of constructed power tower facilities have ranged from approximately 180 ft to 640 ft (55 to 195 m). Taller central receiver towers (750 ft [229 m] or greater) have been proposed (Roth 2014).

FIGURE 4-5 Nevada Solar One Parabolic Trough Facility in Clark County, Nevada (Note glare from reflector array at right.)
Credit: Robert Sullivan, Argonne National Laboratory

capacity solar facilities have been identified as causing substantial visual impacts in natural settings, and substantial impacts on cultural resources through impacts on the visual settings of the cultural resources (BLM 2010; CEC 2010; DOE 2012b; Testa 2012; CEC 2013l; see discussion of CM for cultural impacts in Section 5.2.2). Stakeholder opposition resulting from perceived negative visual impacts has been a deciding factor leading to the cancellation of at least one utility-scale solar project in the United States to date (Trout 2015), and contributing to the cancellation of others, e.g., the Silurian Valley Solar project (BLM 2014c). Local governments, such as San Bernardino and Sonoma Counties in California, have passed ordinances restricting commercial solar facilities specifically to protect scenic resources, among other values (San Bernardino County Sentinel 2013; Sonoma County 2013). Concerns over potential negative visual impacts of large solar facilities are also routinely expressed by tribes, local governments, environmental groups, and the National Park Service (NPS) during the environmental impact assessment processes that are required for these types of facilities (Basin and Range Watch 2010; DOE 2012b; NPCA 2012; Colorado River Indian Tribes 2013; Kessler 2013; NPS 2013).

The NPS supports renewable energy and believes its development can be consistent with the protection of visual resources; however, appropriate evaluation and mitigation must be applied. On the basis of potential visual impacts on NPS units that were identified in the BLM and DOE’s Solar Programmatic Environmental Impact Statement (EIS) (BLM and DOE 2010, 2012), the NPS requested that the BLM conduct further analyses of visual impacts on two national parks (Death Valley and Joshua Tree) and a national historic trail (El Camino Real de Tierra Adentro) (Sullivan et al. 2013). The study found that some locations in each NPS unit could potentially be subjected to strong visual contrasts from solar development within BLM-designated solar energy zones (SEZs).

4.3 SOLAR VISUAL IMPACT-RELATED RESEARCH

Recent studies to better characterize the visual properties (including glare) of solar facilities have substantially improved understanding of visual impacts from the range of solar technologies, especially power towers (Ho et al. 2014; Sullivan 2011; Sullivan and Abplanalp 2013; Sullivan and Abplanalp 2015; Sullivan et al. 2012). The BLM has also funded research to characterize and assess visual impacts from electric transmission facilities (Sullivan et al. 2014). These studies have helped to better define the area of impact analysis for visual impact assessments by tying the impact analysis boundary to empirically derived data about the visibility of solar and transmission facilities.

DOE-funded research has resulted in development of new mitigation methods for solar facility visual impacts through collaborative efforts with the BLM and the solar industry (Sullivan and Abplanalp 2013). With industry input, the BLM has published new guidance on visual impact mitigation for renewable energy facilities, including solar and associated transmission (BLM 2013a). The NPS has published guidance on visual impact assessments for solar and other renewable facilities (Sullivan and Meyer 2014).

Considerable progress has also been made recently by the BLM in developing and applying an improved methodology to assess visual impacts at a landscape scale, and in applying regional CM (Sullivan et al. 2016; see also Section 5.2.2). This method includes a systematic approach to 1) assessing scenic values and identifying key observation points within visually sensitive areas; 2) characterizing visual contrasts from proposed development as seen from key observation points; and 3) characterizing the likely number and type of viewers within the visually sensitive areas; and then using this information to determine likely impacts on the visually sensitive areas and whether the impacts warrant regional CM. The methodology also includes an innovative approach for assessing the regional impacts of solar development by evaluating likely changes to inventoried scenic values at a landscape scale, the scarcity of high-value scenic resources within the region, the condition and trend of regional scenic resources, and the visual sensitivity of impacted areas.

The BLM is also developing long-term monitoring (LTM) protocols for solar energy development, including an innovative approach for visual resources LTM (see Section 6). The approach includes the new LTM protocols for visually sensitive areas, impacts on inventoried visual resource values (including scenic quality), and visual impacts on night skies.

4.4 FUTURE RESEARCH AND DEVELOPMENT NEEDS

While significant progress has been made in improving the state of knowledge with respect to solar facility visual impact assessment and mitigation, important research gaps remain. First, there is a great need for research into factors that affect public acceptance, and for improved understanding about people's response to seeing solar energy facilities. Little is known about how people respond to the visual presence of the various types of solar facilities in different landscape settings, including whether there are preferences or aversions to particular solar facility types, sizes, or setting, or whether particular types of viewers, e.g., residents vs. tourists, respond differently to solar facilities. Related research would examine the effects of proximity of solar facilities on property values based on potential scenic impacts, which have been cited in complaints about planned solar developments (Trout 2015). Results of these studies could affect the siting, design, and mitigation measures for solar facilities in visually sensitive settings, and would also inform stakeholder interactions during the solar facility siting and design process.

Further research and development of solar facility visual impact mitigation is also needed. DOE-funded research showed that facility engineers from the solar industry were willing to undertake a collaborative process for systematic consideration of visual impacts from solar facilities that led to reasonable and effective mitigation measures (Sullivan and Abplanalp 2013). The limited scope of the research did not include pilot testing and demonstration of proposed new mitigation, but such demonstrations could be included in future projects, ultimately resulting in reduced or avoided visual impacts.

Additional glare assessment and monitoring methods would also promote understanding of these impacts. While tools exist for predicting the occurrence of glare and its magnitude (Ho and Khalsa 2010; Ho and Sims 2013), field-based monitoring and measurement of glare is needed. Sophisticated visual simulations of glare from proposed solar facilities is sometimes used for impact assessment purposes, but field observations of the completed ISEGS power tower facility suggested that simulations produced for the ISEGS facility environmental impact assessment (BLM 2010) lacked spatial accuracy and realism, and did not accurately represent the glare produced by the operating facility (Sullivan and Abplanalp 2015). It is critical that glare effects be accurately characterized in impact assessments, and further efforts to ensure that predictions are in accordance with actual, observed glare effects are needed. Research is also needed to determine the responses of viewers to glare events at solar facilities, in order to determine if the glare events interfere with aesthetic or historic appreciation, recreation, or other visually sensitive views and activities.

5 COMPENSATORY MITIGATION FOR ENVIRONMENTAL AND HUMAN IMPACTS

Compensatory Mitigation (CM) is actions or projects undertaken to offset (or "compensate" for) the adverse impacts of other actions or projects. Steps to avoid or minimize impacts are preferred over CM by U.S. regulatory agencies, but where impacts cannot be adequately avoided or minimized, CM is often recommended or required. In the U.S., several federal laws require consideration of CM for environmental damage caused by land development such as for utility-scale solar projects; these include the Clean Water Act of 1972 (CWA; administered by the EPA and the U.S. Army Corps of Engineers [USACE]), the Endangered Species Act of 1973 (ESA; administered by the USFWS and the National Marine Fisheries Service), and the National Environmental Policy Act (NEPA) (administered by all federal agencies). In general, the CWA has the strongest CM requirements, especially for wetland losses, while the other laws require consideration of CM when other forms of mitigation will not reduce impacts to less than significant levels. CM is a soft-cost of development that will be unavoidable for certain solar facilities. Although offsetting impacts through CM can address stakeholder concerns and allow project development to proceed, CM costs can be a large source of uncertainty for developers.

The use of regional or landscape-scale[11] mitigation strategies to compensate for impacts is a focus of policy development for the federal agencies administering CWA, ESA, and NEPA, and at the state level (e.g., the California Desert Renewable Energy Conservation Plan, DRECP). A regional mitigation strategy considers long-term trends across a larger but connected region or watershed in identifying the impacts that need to be mitigated for and the most beneficial CM actions from a landscape perspective. Such strategies also identify likely CM needs prior to development, allowing CM costs to be built into facility financial plans.

This discussion of CM focuses on NEPA requirements and CM policies applicable to utility-scale solar development on public lands or receiving federal funding, because these policies are currently under development, and can affect project schedules and costs. The methods used to identify recommended regional CM requirements for solar facilities on public lands are reviewed, and examples of CM requirements and costs for utility-scale solar facilities on public and other lands are provided.

[11] The terms "regional" and "landscape-scale" are often used interchangeably, and definitions vary somewhat by program. For CM studies to support CWA requirements, regional is generally taken to mean watershed-level. Another definition of regional or landscape-scale follows: "*Landscapes are large, connected geographical regions that have similar environmental characteristics, such as the Sonoran Desert and the Colorado Plateau. These landscapes span administrative boundaries….*" (BLM 2014d).

5.1 NATIONAL ENVIRONMENTAL POLICY ACT AND COMPENSATORY MITIGATION POLICIES FOR PUBLIC LANDS

Mitigation of adverse impacts from development of all kinds is a standard requirement of permitting at the local, state, and federal levels. As specified under NEPA regulations applicable to actions of all federal agencies (40 CFR 1508.2), avoidance, minimization, rectification (e.g., through restoration), and reduction (e.g., through preservation and maintenance) of impacts are ways to mitigate for impacts through careful siting and onsite BMPs. Under NEPA, an additional method, CM, is defined as "compensating for the impact by replacing or providing substitute resources or environments."

To better implement the NEPA regulations, the BLM has issued several policies on CM (BLM 2005; 2008a; 2013b). All of the policies have required the application of onsite mitigation actions before the use of CM (earlier, BLM used the term "offsite mitigation" for CM). The 2008 interim policy clarified that "the BLM's policy is to mitigate impacts to an acceptable level onsite whenever possible through avoidance, minimization, remediation, or reduction of impacts over time" (this preference for onsite mitigation actions to be required prior to identification of CM requirements is termed "the mitigation hierarchy"). Cases in which CM would be warranted were described as those where onsite mitigation could not sufficiently maintain the mission and objectives for that location (as defined in regional land use planning documents). Examples of regional objectives include managing habitats to support the viability of sensitive species within the region, or maintaining soil productivity at a specified level across the region. In cases where resources are present offsite that could suitably compensate for onsite impacts remaining after other mitigation, CM at offsite locations could allow land use authorizations (such as for solar facilities) to go forward.

The 2013 interim regional mitigation policy and draft manual (BLM 2013b) require consideration of mitigation opportunities at the regional scale, and on both public lands and other lands (i.e., other federal, tribal, state, and private lands). The policy applies to all types of BLM land use authorizations, including oil and gas development and renewable energy applications (geothermal, wind, and solar projects). The emphasis on regional mitigation is intended to help identify mitigation locations and actions that will aid in meeting landscape-scale resource objectives, as well as to mitigate for the specific impacts that would likely occur because of an individual project. Specific to solar development, the BLM's solar energy program, established in 2012, committed to developing a regional mitigation strategy for each of the SEZs identified on public lands. An intent of developing these regional mitigation strategies was "to enhance the ability of state and Federal agencies to invest in larger scale conservation efforts that benefit sensitive resources through higher quality habitat, improved connectivity between habitat areas, and long-term conservation of landscapes" (BLM 2012a), as well as to increase permit efficiencies and financial predictability for developers. Finally, a recently-released Department of Interior manual on implementing mitigation at the landscape scale continues and reasserts the BLM policies (DOI 2015), calling for a land-scape-scale approach to reviewing project impacts and identifying CM actions that will provide the maximum benefit to the impacted resources.

Most recently, the importance of CM in achieving a "net benefit" goal for natural resource use at the national level was acknowledged in a Presidential Memorandum on the topic released in November of 2015 (White House 2015). This memo encourages agencies to use landscape- or watershed-scale planning to take the full impacts of their decisions into account and to pick the best locations for mitigation.

5.2 METHODS FOR CONDUCTING REGIONAL MITIGATION STRATEGIES

Regional mitigation strategies have been drafted or completed for eight of 19 SEZs (three in Arizona BLM 2016a]; three in Colorado [BLM 2016c]; and two in Nevada BLM [2014b, 2016b]), and are underway for one SEZ in New Mexico and three SEZs in Utah. These projects make good case studies on an evolving methodology that may eventually be referenced by permitting agencies for utility-scale solar projects on private as well as public lands. The basic elements of a solar regional mitigation strategy (SRMS) were described for the solar energy program (Appendix A in BLM and DOE 2012), and have been retained as elements for all of the SRMS projects, with some variations in methodology, terminology, and order implemented in order to respond to stakeholder comments and gain consistency with newly issued BLM policies. Each element in conducting an SRMS includes collaboration with or review by stakeholders.

5.2.1 Overview of Methodology

The elements of developing a SRMS are shown in Figure 5-1. For Elements 1 and 2, programmatic knowledge about potential impacts from solar development for leading PV and CSP technologies is supplemented with additional local data where available. These data are used to evaluate the potential residual impacts of solar development (i.e., those that would remain after the application of avoidance and minimization measures).

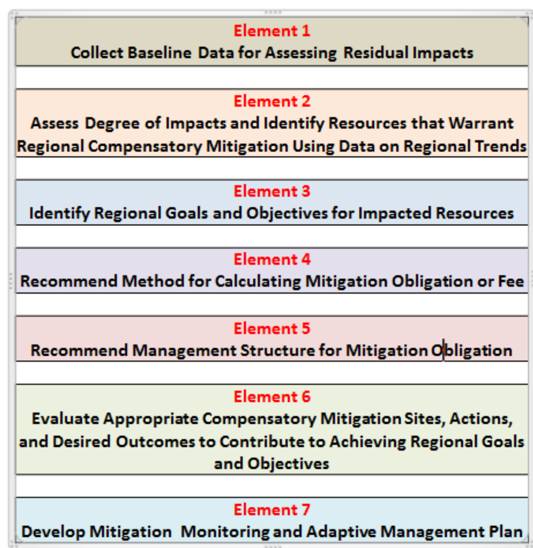

FIGURE 5-1 Elements of a Solar Regional Mitigation Strategy (as presented in BLM 2016a-c)

Element 4, recommending a preliminary CM fee, has been refined considerably since the SRMS pilot project for the Dry Lake SEZ in Nevada (BLM 2014b), based in part on comments provided by stakeholders in a July 2014 workshop (TNC and TWS 2014). The applicable baseline fee or fees are identified, and if appropriate, an adjustment factor is applied to account for the already-degraded status of some areas. The more recent draft SRMS projects also include contingency fees and fees to cover administration costs, and no longer include a “development incentive” adjustment that was included for the pilot project (BLM 2014a). The Dry Lake pilot project per-acre CM fee was about $3,200, including an ESA Section 7 fee for desert tortoise and costs for monitoring that were added as part of the implementation strategy (BLM 2015b). After release of the mitigation strategy for the Dry Lake SEZ, the BLM went on to auction parcels in the SEZ for $5.8 million in leasing fees that were separate from the mitigation fees (Ho 2015). Construction of a solar PV facility began in the SEZ in the summer of 2016.

Through the BLM's ongoing SRMS projects and associated stakeholder engagement, the importance of clearly articulating the difference between regional goals and objectives (identified under Element 3 of the process) and desired mitigation outcomes (identified under Element 6) has been identified. Stakeholders have emphasized that regional goals and objectives need to be identified early in the SRMS process in order to subsequently identify desired mitigation outcomes that are linked to those regional goals and objectives, as well as based on impacts occurring in the SEZ. The concerns are stated in a stakeholder report, *Building a Roadmap for Successful Regional Mitigation* (Cava and Dubois 2015). These issues point out the need to conduct the elements of a regional mitigation strategy iteratively. That is, although preliminary mitigation sites may be identified prior to full delineation of goals and objectives and quantitative desired mitigation outcomes (for example, "restore an equivalent amount of vegetation lost to SEZ development"), the preliminarily-identified mitigation sites and actions should be re-evaluated for meeting the desired outcomes before final sites and actions are identified. A scored candidate site matrix has been used as a tool to evaluate potential mitigation sites and actions against many criteria, including feasibility, effectiveness, additionality (defined as consisting of actions that would not otherwise be undertaken by the BLM), risk of mitigation failure, and durability.

5.2.2 Use of Regional Resource Data to Identify Impacts Warranting Compensatory Mitigation and Evaluate Potential Mitigation Actions and Locations

Once the residual impacts on various resources have been identified, the importance of those impacts in a regional context need to be evaluated in order to identify impacts warranting CM; not all residual impacts on resources from solar development warrant CM. One important source of regional information is any land use plans applicable to the region. For example, when development in SEZs would adversely impact the achievement of the regional resource goals and objectives identified in land use plans, this situation lends support to a determination that the impact warrants CM. Regional resource goals are also used for the evaluation of potential mitigation actions and locations (Figure 5-1, Element 6). The regional goals are needed to guide the selection of locations where development impacts can be mitigated AND the mitigation actions (e.g., preservation and/or restoration) can contribute to achieving the regional goals. One of the main aims of developing regional CM strategies instead of project-by-project CM plans is to identify CM actions and locations that aid in meeting regional goals and objectives.

Federal agencies and the Department of the Interior have recognized the value of a landscape or regional approach towards understanding impacts, and of developing regional mitigation strategies for solar energy development and other large-scale land management decisions (e.g., BLM 2013b; DOI 2015; EPA 2012b; USFWS 2012). This landscape-focused approach addresses several challenges of incorporating climate change, cumulative impacts, and other broad-scale environmental pressures/stressors (such as invasive species and wildfires) into mitigation decisions by shifting focus from project-by-project decisions to landscape-scale decisions. Several examples of the landscape approach to mitigation have been described

(Clement et al. 2014; BLM 2014a). These approaches can guide the consideration of resources at all levels of the mitigation hierarchy—from the siting of a solar project to avoid sensitive areas, to the development and implementation of minimization measures, and finally to decisions regarding offsite CM.

Methods being developed to utilize landscape approaches to determine impacts warranting CM for ecological, cultural, and visual resources are discussed below.

CM for Ecological Resources. To date, most regional resource data for identifying ecological impacts warranting mitigation has come from BLM Rapid Ecoregional Assessments (REAs). For example, for the Arizona SRMS (BLM 2016a), the ecological resources identified as unavoidably impacted included creosote bush-bursage desert scrub and Paloverde-mixed cacti desert scrub. The trend assessment, based on Sonoran Desert REA data on ecological intactness for these vegetation communities across the entire ecoregion (Strittholt et al. 2012), indicated that the vegetation communities are exhibiting a downward trend, and that they are further at risk from future human development and climate change. This regional trend assessment supported the determination that the impact on these vegetation communities from solar development in the SEZs warrants CM, because the impacted resource can be expected to diminish over time throughout the region.

REA intactness data can be used for preliminary identification of mitigation locations throughout a region that are good candidates for preservation (i.e., relatively intact areas) or restoration (i.e., relatively degraded areas). For example, landscape ecological intactness may be used to screen and evaluate areas protected for biodiversity for potential restoration/enhancement opportunities (Figure 5-2; Walston et al. 2016b). Protected area with relatively low ecological intactness at present may be identified for particular restoration actions (e.g., invasive species removal) to improve habitat quality. In addition, in conjunction with other landscape data and analytical tools, ecological intactness models may assist in the identification of core habitat areas (with relatively low habitat fragmentation) that represent acquisition and/or preservation opportunities as durable mitigation for solar development impacts. Similarly, other spatial models (e.g., for climate change) that predict future conditions across a landscape can help identify areas where acquisition or restoration efforts might be more cost-effective. These decision support tools can be used to identify actions that would most effectively compensate for the ecological impacts of solar energy development.

CM for Cultural Resources. One limitation is that REAs available to date do not fully address other resources of concern (e.g., cultural resources, visual resources, lands with wilderness character). A pilot Cultural Heritage Values and Risk Assessment with the purpose of providing regional characterization of cultural resources has been included as part of the San Luis Valley/Taos Plateau SRMS project in Colorado (Wescott et al. 2016). Cultural heritage values and risk assessments consider the interaction between groups of people and their environment by looking at both the temporal and spatial relationships between traditionally-defined archaeological sites and culturally-important places and the traditional uses of the environment in general. In essence, these studies recognize the interaction between humans and their environment over time and the importance of that relationship for societal well-being.

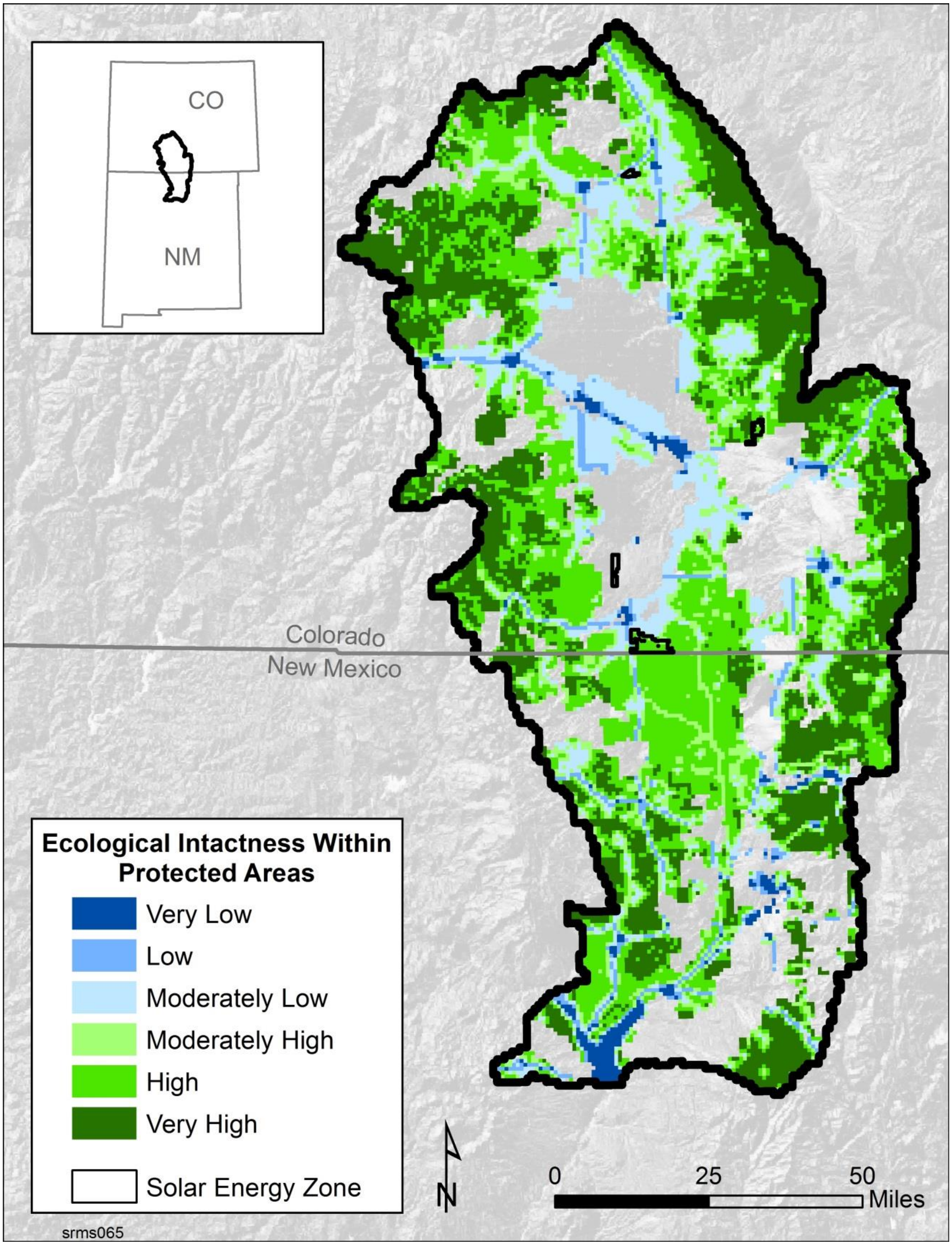

FIGURE 5-2 Ecological Intactness within Protected Areas Managed for Biodiversity [prepared for the Draft Colorado Solar Regional Mitigation Strategy, BLM 2016c].)

If avoidance of a cultural impact is not possible and everything has been done to reduce the effect through project design and implementation of best practices, CM for the residual impact may be required. A cultural heritage values and risk assessment provides a framework for recognizing at a regional scale where the high-value cultural resources are most likely to occur, where those areas of high cultural value may be subjected to risk, and where the best places might be for CM.

The San Luis Valley/Taos Plateau Cultural Heritage Values and Risk Assessment (Wescott et al. 2016) identifies, at a regional scale, areas of cultural value based not just on known archaeological site locations, but also on places of traditional importance to tribes and Hispano residents; traditional collection areas for certain plants, clays, and other resources; and a series of trails and historic structures that have played important roles in the development of the communities that live in the valley today. In addition to the identification of the cultural resources, change agents corresponding to those evaluated in REAs (i.e., human development, climate change, spread of invasive species, and wildfires) were evaluated regarding how they might influence the ability of the cultural resources to survive in their current state into the future. By looking at the projected risks associated with these agents, a spatial representation of where high-value cultural resources may be at greatest risk of destruction or where high-value cultural resources may be best protected becomes possible (Figure 5-3). From a siting perspective, the assessment can be used to avoid places of high cultural value from the start. From a mitigation perspective, if cultural resources are determined to warrant mitigation as a result of project development, the assessment can be used to negotiate the terms of the mitigation in ways that are valuable but have the least impact on a project. For example, requirements for extensive onsite mitigation that could delay the project schedule might be reduced and enhanced with off-site regional, compensation that offers comparable or added value to the cultural community. Another benefit of this work is that it helps to address the management and integration of data collected through the process of engaging with the tribes and other groups in the study area.

CM for Visual Resources. Considerable progress has also been made recently in developing and applying an improved methodology to assess visual impacts at a landscape scale, and in applying regional CM (Sullivan et al. 2016). This method includes a systematic approach to assessing scenic values and identifying key observation points within visually sensitive areas, characterizing visual contrasts from proposed development as seen from key observation points, and using this information to determine likely impacts on the visually sensitive areas and whether the impacts warrant regional CM. The methodology also includes an innovative approach for assessing the regional impacts of solar development by evaluating likely changes to inventoried scenic values at a landscape scale, the scarcity of high-value scenic resources within the region, the condition and trend of regional scenic resources, and the visual sensitivity of impacted areas.

For all these resources (ecological, cultural, and visual), the cost and feasibility of mitigation actions to compensate for loss is related to the types of resources affected, their status and trends in the region, and the scale of development. The landscape approach to mitigation planning provides a transparent process for federal land management agencies, industry, and stakeholders to better understand mitigation obligations and costs. This approach also should

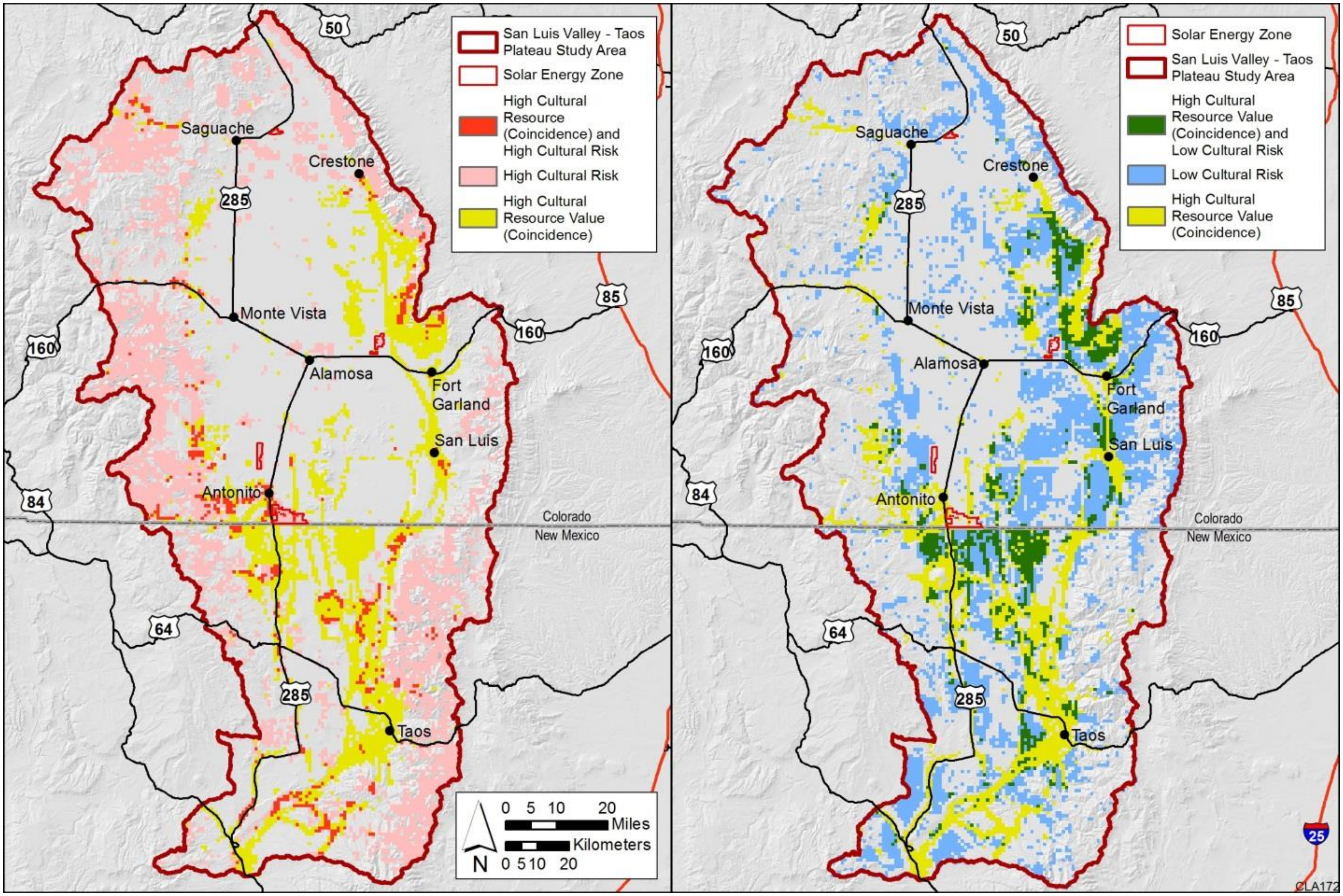

FIGURE 5-3 Areas of High Cultural Heritage Value and Risk Levels from Future Trends of Change Agents. Source: Wescott et al. 2016

result in effective use of mitigation funds by focusing on mitigation of impacts on resources at greatest risk within the region, in areas with a high probability of achieving successful mitigation.

5.2.3 Stakeholder Involvement

Many federal, state, and local agencies; tribal groups; NGOs; and local citizens have participated in the SRMS projects for the SEZs. Often these groups have conservation goals that can be contributed to through well-designed CM actions. Local citizens have represented local concerns such as grazing rights, water availability, air quality, environmental justice, and recreational uses. Solar developers and consultants have participated; in general, their comments have been favorable in terms of the potential for SRMSs to provide greater cost and acceptance certainty prior to bidding on parcels in SEZs. However, industry stakeholders have expressed a preference for maintaining flexibility in how mitigation goals are achieved, and for requiring follow-through on investments in data collection and analysis (BLM 2012b).

5.3 OTHER SOLAR COMPENSATORY MITIGATION REQUIREMENTS

The DRECP is a collaborative renewable energy planning effort between state, federal, and local agencies in California that is intended to help provide effective protection and conservation of desert ecosystems while allowing for renewable energy development. The planning effort is being conducted in two phases; the first phase addresses renewable energy development on public lands in southern California. The Phase I Final EIS, released in November 2015, is a multi-agency conservation planning effort for 10 million acres of public lands (BLM 2015a). The plan identifies renewable energy development focus areas as well as protected conservation areas, and required conservation and management actions for focus species and natural communities. CM requirements are specified on the basis of impacts on species habitat (see BLM 2015a, Chapter II.3 on Preferred Alternative). The plan also includes CM requirements for ground disturbance in National Conservation Lands and Areas of Critical Environmental Concern; bird and bat mortalities; recreation impacts on some categories of roads; impacts on vegetation important to Native American tribal interests (i.e., desert vegetation, desert fan palm oasis, and microphyll woodland communities); direct impacts on lands with wilderness characteristics; impacts on National Scenic and Historic Trails; and some visual impacts. The plan’s CM requirements are illustrative of a different approach that is being taken for utility-scale solar development in California.

The CM requirements for projects on private lands vary significantly in accordance with state and local laws as well as the potential for harm of protected species. Information on CM requirements for projects located on private lands is difficult to obtain, because these projects are generally permitted at the county level and environmental assessment documents are not readily available. An exception is some projects in California, for which environmental impact reports (EIRs) required under the California Environmental Quality Act are available. For example, the EIR for the Topaz Solar Farm project in San Luis Obispo County indicates requirements for CM for lost kit fox habitat and for replacement of converted agricultural land at a 1:1 compensation ratio (County of San Luis Obispo 2011). No cost estimates for the required CM were provided.

5.4 SUMMARY OF COMPENSATORY MITIGATION FOR SOLAR FACILITIES

Available data are currently insufficient to comprehensively compare CM requirements for utility-scale solar development either between states or for projects on public lands versus private lands. Preliminary observations include the following:

1. Projects are typically required to provide CM for loss of ESA-listed species habitat as determined through consultation with the USFWS, and for loss of wetlands or stream functions as determined through consultation with the EPA and USACE. Where possible, developers would likely avoid these resources in order to facilitate project reviews and approvals.

2, New projects located on public lands in SEZs will be required to compensate for residual impacts warranting mitigation as identified in regional mitigation strategies developed under BLM’s solar energy program. Strategies conducted to date have outlined CM costs for loss of habitat and ecosystem services on a per-acre basis.

3. Individual state laws may require CM that is not required elsewhere (for example, the California Land Conservation Act requires CM for converted farmland).

4. Additional data on CM requirements and costs for projects on private lands are needed to increase the predictability of such costs.

6 LONG-TERM MONITORING AND ADAPTIVE MANAGEMENT STRATEGIES

There is a need for robust scientific information regarding long-term impacts from solar energy facilities on ecological and human resources. In this context, increasing emphasis is being placed on the implementation of monitoring and on adaptive management responses to monitoring information that will identify adverse impacts at local and landscape scales and provide for appropriate modification of project design, operations, and/or mitigation actions.

Currently, project-specific monitoring data are often collected during construction and operations of solar energy facilities as a permitting requirement to inform management decisions and to ascertain site-specific impacts. However, the data collected often do not encompass areas or control sites outside of project boundaries ("footprint") or across varied landscapes. Further, such project-level data are not generally collected continuously over long-term temporal scales. The limited scope of existing data collection makes it difficult to understand cumulative, landscape-level impacts and to distinguish natural changes from changes related to solar energy development. The availability of solar monitoring data is also limited, making it difficult for researchers to analyze landscape-level resource trends. Resource management decisions would benefit from publicly available ecological, physical, visual, cultural, and socioeconomic data consistently collected during the pre-construction (baseline) and post-construction periods. Consequently, a comprehensive and standardized LTM strategy (LTMS) with a landscape-scale focus is recommended.

Mindful that comprehensive LTM programs are likely to be very costly, federal and state agencies are developing programs that consider regional conditions and trends of key resources based on clear monitoring objectives, priorities, and appropriate indicators. In addition, agencies are evaluating the applicability of new technologies (e.g., remote sensing) to more cost-efficiently track resources across large areas and identify significant changes in resource conditions. For example, as part of its solar energy program, the BLM has committed to establishing a LTMS for each SEZ that includes monitoring of physical, ecological, and socio-cultural resources (BLM and DOE 2012). The LTMS projects are planned to be: regional in scale (rather than project-by-project); inform status and trends of key resources and ecological processes; leverage existing data collection activities; provide timely information to inform adaptive management; and be consistent with the BLM Assessment, Inventory, and Monitoring (AIM) Strategy (Toevs et al. 2011). As the largest SEZ with the most development[12], the Riverside East SEZ in California was chosen as the pilot for implementing a solar development LTMS that began in December 2013 and was completed in May of 2016 (BLM 2016d). If the pilot LTMS is demonstrated as a useful and effective practice on public lands, a similar LTMS approach could be beneficial for utility-scale solar development on private lands.

Adaptive management is defined as an iterative process that uses monitoring to evaluate whether management actions are achieving specific, clearly defined outcomes and, if they are not, recommends changes in policies or operations to ensure that desired outcomes will be

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12 As of April 2015, there were two operational, two additional authorized, and three pending project applications located within or partially within the Riverside East SEZ.

achieved (BLM 2008b, Williams et al. 2009). An adaptive management regime would be enacted to help reduce uncertainty, improve the ability to predict outcomes over time, and make future management actions more effective as a result of learning.

An important use for LTMS data in aiding adaptive management is to detect changes in resource conditions in relation to a management threshold. Such thresholds may trigger the adoption of new or revised facility design features, mitigation measures, other project requirements, and/or related management actions, if LTMS data suggest that some are not effective. Management thresholds established in a LTMS may themselves be subject to adaptive alteration as new information becomes available. Although the goal of a LTMS is to detect changes in key resources within the region of solar energy development, the detection of change does not necessarily mean the change was due to solar development activities. In fact, a LTMS may have a limited capacity to determine cause and effect, especially for ecological resources controlled by a complex set of physical, biological, and human drivers, including climate change. However, if thresholds are exceeded, more intensive and applied research-oriented data collection can be initiated to determine whether there is a causal relationship between the observed resource change and solar energy development. If the change in the resource is found to be related to solar energy development, new or revised design features and/or management recommendations may be developed to return the resource to the desired state. In this way, LTMS data can be an important contribution to adaptive management decision-making.

This section discusses the benefits of a LTMS (Section 6.1), and provides details about the methods for developing an LTMS (Section 6.2).

6.1 BENEFITS OF LONG-TERM MONITORING STRATEGY FOR STAKEHOLDERS

Benefits of a LTMS to solar energy developers include coordination with federal, state, and local agencies to maximize partnerships and data sharing as well as a potential reduction in monitoring costs, owing to the ability to pool monitoring funds. For projects on public lands, the collection of project-level baseline data will largely be the responsibility of developers, although the BLM will take an active role in identifying and collecting priority baseline data for each SEZ and in developing consistent monitoring schema to reduce administrative and financial burdens to developers. This process will provide a replicable, consistent dataset across a large region (including multiple solar developments) that can be used to identify cumulative impacts, to adaptively manage siting and permitting.

Another benefit of a LTMS is the opportunity for public engagement, transparency, and data availability, thereby achieving greater acceptability for solar facilities. Public involvement should entail multiple meetings with stakeholders to get input on their concerns about impacts on resources related to solar energy development, as well as industry concerns about monitoring costs. Stakeholders would also benefit from the production of a publicly available annual report summarizing the condition and trend of areas under analysis.

Finally, there is considerable uncertainty with regard to the impacts of solar energy development. Recent reviews have stressed the lack of available monitoring data and consequent uncertainty about the ecological impacts of solar energy development projects (Turney and Fthenakis 2011; Lovich and Ennen 2011; Northrup and Wittemyer 2013; Hernandez et al. 2014). Therefore, another benefit of the LTMS for developers is greater certainty about resource impacts and more focused and potentially fewer monitoring and mitigation requirements.

6.2 DEVELOPING A LONG-TERM MONITORING STRATEGY

6.2.1 Management Questions, Management Goals, and Monitoring Objectives

Although terminology varies, the general process for developing a LTMS starts with identifying management questions, management goals, and monitoring objectives. To help explain these terms, Table 6-1 provides examples in the context of potential impacts of utility-scale solar development on vegetation. For the BLM LTM approach, management questions capture the issues relevant to landscape-level impact of solar energy development, and, where relevant, reflect existing land management plan requirements. The management questions provide the basis for developing management goals, which specify the broad desired outcome from management actions designed to minimize solar development impacts.

Monitoring objectives define the level of resource change detection needed to determine whether management goals are being achieved. Approaches to developing monitoring objectives to evaluate the success of mitigation sites are described by Cava and Dubois (2015). All monitoring objectives should be specific, measurable, achievable, relevant, and time sensitive, and derived from the ecosystem conceptual models and/or linked to specific management questions (Williams et al. 2009). For example, monitoring objectives need to indicate the desired amount of change (specific), level of confidence for the measured change (measurable), funding and capacity requirements (achievable), relationship to the management question (relevant), and time frame during which the measurement occurs to effectively inform management (time sensitive).

6.2.2 Monitoring Indicators and Sampling Strategy

Monitoring indicators refer to the actual resource endpoints that will be measured along with the measurement units (e.g., rate of change, abundance, number of species) (Table 6-1). Monitoring indicators for the LTMS should address physical, ecological, and socio-cultural resources using a rigorous sampling design. For example, the BLM AIM Strategy requires a statistically valid sampling design that defines the study area, relevant environmental strata within the study area, and the allocation of sampling points using a stratified random sampling design. The AIM Strategy identifies a specific set of core indicators relevant to the functioning of all ecosystems the BLM manages, as well as indicator collection methods to ensure consistency of resource information across the United States (MacKinnon et al. 2011; Taylor et al 2014). AIM terrestrial core indicators include bare ground, the proportion of soil surface in large gaps between plant canopies, and vegetation height (m) and composition (MacKinnon et al. 2011; Taylor et al. 2014).

TABLE 6-1 Example Management Question, Management Goals, Monitoring Objectives, and Monitoring Indicators Related to Potential Utility-Scale Solar Development Impacts on Vegetation

Management Question	Are solar facility operations affecting vegetation communities in offsite areas?
Management Goals	• Maintain vegetation communities, especially those that depend on groundwater • Maintain vegetation ecophysiological functions • Preserve rare vegetation communities • Preserve important vegetation habitats for wildlife consistent with recovery goals or to ensure the viability of healthy populations
Monitoring Objectives	• Detect statistically significant changes in total plant cover, intercanopy gaps, and woody plant height • Detect statistically significant changes in rare and high-priority vegetation communities • Detect new introductions of invasive plant species • Detect presence of viable species populations
Monitoring Indicators	• Extent of bare ground • Vegetation composition • Vegetation height • Non-native invasive species occurrence • Species richness

To the extent possible the LTMS should also adopt the BACI methodology. A BACI design requires that indicator data be collected both before development begins (to define baseline conditions) and after development occurs. The collection of baseline data that reflect the conditions of resources before construction and operation is necessary to detect long-term deviations from baseline conditions. The BACI approach also requires that resource indicator data be collected at both impact sites and multiple control sites (i.e., sites considered to be outside the area of potential effect but that otherwise have characteristics similar to impact sites). Control sites are necessary to distinguish changes caused by solar development from changes that result from natural, regional environmental variation.

6.2.3 Cost and Feasibility

There are many uncertainties related to the feasibility and the sustainability of a LTM program because landscape-level monitoring is in the early stages of implementation on public lands, and has not likely been conducted for projects on private lands. Given the variety of social, ecological, and physical resources that a LTMS could address, it is not possible to directly and comprehensively monitor all resources. The constraints of manpower and long-term funding for carrying out the monitoring strategy may vary over time. Therefore, a key consideration in the development of a LTMS is assessing the feasibility and cost of collecting data to fulfill the proposed monitoring objectives. Ways to increase feasibility and reduce cost include:

1. Incorporating existing data collection efforts into the monitoring plan to the extent possible and coordinating with other developers, government agencies and NGOs to ensure data collection efforts are not duplicated;

2. Using lower-cost remote sensing techniques, when appropriate;

3. Using volunteers to collect monitoring data;

4. Conducting targeted sampling; and

5. Prioritizing monitoring objectives.

Existing data sources include project-specific data collected under project permits and data collected by NGOs, universities and government agencies. Examples include historical data used to establish baseline monitoring conditions as well as data from ongoing monitoring activities. The goal is to avoid duplication of data collection to minimize cost.

With regard to remotely sensed data, there are several publicly available data sources that would allow the analysis of historical, current, and future conditions for plant communities and, in some cases, physical resources. These data sources include not only aerial and satellite imagery, but also image analysis products such as the Normalized Difference Vegetation Index, an index used to quantify plant density. However, the application of remote sensing image analysis to specific regions may require field validation of quantitative image analysis data (i.e., plant cover, stream morphology) and therefore could entail potentially large upfront costs.

Volunteers are important resources for monitoring physical, cultural and biological resources. Christmas bird counts are an example of volunteer data collection that has provided important bird species data for decades. For cultural resources, the California BLM uses site stewards trained through the California Archaeology Site Steward Program (CASSP) for LTM of cultural resources within the Riverside East SEZ. Individuals enrolled in CASSP pay for their own training, which is offered by the Society for California Archaeology. Site stewards either are assigned specific sites to monitor regularly on the basis of their location and interests, or can contact the local BLM office when they are planning recreation activities to be assigned sites to monitor near the locations they plan to visit. One drawback is that data provided by volunteers may not be collected using standard methods and can be biased toward certain regions, which may confound data interpretation.

Targeted sampling is another way to improve feasibility and reduce cost. Targeted sampling should be based on the anticipated spatial extent of offsite impacts on a resource. Such targeted sampling should focus on sampling only what is required to achieve the monitoring objective. For example, if there are concerns about dust or groundwater drawdown, sampling at multiple locations at a regional spatial scale may be necessary. However, if the monitoring objective is to determine whether site grading and clearing is causing offsite stream or soil erosion, monitoring efforts may only need to focus on the channels that drain the project site in the vicinity of the facility.

Finally, not all resources can or should be monitored. Confining monitoring activity to only the highest-priority objectives is one way to constrain the expenditure of financial and human resources and increase the feasibility of a LTMS. For example, in the BLM's pilot LTMS project for the Riverside East SEZ (BLM 2016d), the need to prioritize monitoring activities was critical because of the BLM's dependence on unpredictable appropriations from year to year and uncertainty regarding the level of future development in the SEZ. Prioritization can be based on stakeholder concern for a particular resource and the anticipated likelihood and magnitude of solar development impacts on a particular resource.

7 CONCLUSIONS

Utility-scale solar energy plays an important role in the nation's strategy to address climate change threats through increased deployment of renewable energy technologies, and both the federal government and individual states have established specific goals for increased solar energy development. In order to achieve these goals, much attention is paid to making utility-scale solar energy cost-competitive with other conventional energy sources, while concurrently conducting solar development in an environmentally sound manner.

In the past few years, as utility-scale solar development has expanded, there has been increasing focus on a few issues and challenges related to environmental and human impacts. These issues include difficulty in identifying and obtaining land required for solar facilities in appropriate locations; landscape-scale ecological impacts (including impacts on avian species), landscape-scale cultural impacts, and landscape-scale visual impacts (including glare impacts). These impact issues, which are the focus of this report, have the potential to result in barriers to continued rapid solar development, in the form of increased stakeholder opposition, protracted project reviews, delays in project approvals, project denials, project abandonment or significant redesign by the proponent, and increased costs.

In response to the emergence of these issues, several stakeholder groups, including federal and state agencies, industry, NGOs, and academia, are working and collaborating to fully assess the issues and identify new approaches for addressing them. These approaches, discussed in this report, consider ways to minimize potential impacts through better siting of solar projects, whether that be on previously used lands such as formerly contaminated sites or other disturbed lands, or through the use of tools such as ecological landscape assessments and cultural heritage values and risk assessments that assemble regional-scale models of the distribution of sensitive resources. These new approaches also focus on developing a better understanding of the magnitude and significance of emerging impact issues and on evaluating appropriate mitigation methods, in many cases in the context of regional conditions and trends of the impacted resource. New ways to address potential impact issues in a more programmatic fashion through the development of regional CM and LTM strategies are also being developed.

As important as it is to address these emerging impact issues, it is also important that each new approach be developed jointly by regulators, industry, and other stakeholders. Feasibility and cost considerations need to be incorporated into the solutions, and developers need to have some measure of certainty about cost implications. Care should also be taken to ensure that new approaches are proven effective at successfully addressing the impact issues before they become mandatory. While emerging issues can present barriers to increased solar development, innovative approaches to addressing those issues through additional data collection, refined mitigation measures, compensatory mitigation, and long-term monitoring can facilitate successful project completion.

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APPENDIX A:

SUPPLEMENTAL INFORMATION REGARDING LAND REQUIREMENTS

Federal contaminated lands considered in the analysis of this report are typically tracked and categorized by the EPA and include Superfund sites, Resource Conservation and Recovery Act (RCRA) sites, brownfields, and abandoned mine lands (EPA 2009) (Table A-1). Other formerly contaminated properties are tracked by state voluntary cleanup programs, which are agreements between EPA regional authorities and state environmental programs that promote coordination and define general roles regarding the cleanup of sites.

Disturbed lands considered in this report are further defined here. Barren lands are defined as lands of limited ability to support life, and invasive species-impacted lands contain non-indigenous plants or animal species that can harm the environment. GIS data for disturbed lands were retrieved from three primary sources: the California Gap Analysis Project for California (Lennartz et al. 2008), the Southwest Regional Gap Analysis Project for southwestern states (Lowry et al. 2005), and the National Land Cover Database for all other states (Homer et al. 2007). Each dataset had slightly different land cover categories and definitions. No single definition of disturbed lands has been accepted, and the amount of such land and its suitability for solar development should be further clarified by future research. For the present study, land cover types from all datasets related to barren lands, invasive species-impacted land, and other types of non-vegetated lands were aggregated into the disturbed land category.

The suitability of solar energy development on previously used lands was evaluated considering technology type (PV and CSP). In this suitability screening process, all solar technologies were assumed to require at least 10 ac of land for every megawatt (MW) installed (DOE 2012a). CSP projects, which are generally developed at the utility scale, were assumed to be at least 50 MW in capacity, and thus to require a minimum of 500 contiguous acres. For this analysis, DUPV projects were assumed to be 1–10 MW in capacity and thus to require between 10 and 100 contiguous acres of land.[13] CUPV projects were assumed to be at least 10 MW in capacity, and thus to require a minimum of 100 contiguous acres. All types of projects were assumed to require an average slope of land of less than 5% (Mehos et al. 2009). CSP projects had an additional, technology-based restriction, namely, requiring a solar resource of at least 6 $kWh/m^2/day$ (DOE 2012a).

[13] This capacity range differs from the main land requirements analysis. Here, it is only used as a screening aid, not for land use quantification purposes, which uses more refined and up-to-date estimates.

TABLE A-1 EPA Definitions for Contaminated Lands

Contaminated Land Type	Definition
Abandoned Mine Land (EPA 2012a)	Those lands, waters, and surrounding watersheds contaminated or scarred by extraction, beneficiation, or processing of ores and minerals. Abandoned mine lands include areas where mining or processing activity is temporarily inactive.
Brownfield Site (EPA 2012b)	The term "brownfield site" means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.
Resource Conservation and Recovery Act (RCRA) Site (EPA 2012c)	A site that is subject to cleanup under RCRA because of past or current treatment, storage or disposal of hazardous wastes and that has historical releases of contamination. "RCRA brownfields" are RCRA facilities where reuse or redevelopment is slow due to real or perceived concerns about actual or potential contamination, liability, and RCRA requirements.
Superfund Site (EPA 2012d)	1) The program operated under the legislative authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and Superfund Amendments and Reauthorization Act (SARA) that funds and carries out EPA solid waste emergency and long-term removal and remedial activities. These activities include establishing the National Priorities List, investigating sites for inclusion on the list, determining their priority, and conducting and/or supervising cleanup and other remedial actions. 2) A fund set up under CERCLA to help pay for cleanup of hazardous waste sites and to take legal action to force those responsible for the sites to clean them up. The Superfund consists of funds from taxes imposed upon the petroleum and chemical industries, from an environmental tax on corporations, and from general tax revenues (also known as Trust Fund and Hazardous Waste Superfund).

TABLE A-2 Disturbed Lands Categories from Multiple Sources

Source	Categories
National Land Cover Dataset (Homer et al. 2007)	Undifferentiated barren land Introduced upland vegetation - annual grassland Introduced upland vegetation - perennial grassland and forbland Introduced upland vegetation - shrub Disturbed, non-specific Disturbed/successional - grass/forb regeneration Disturbed/successional - shrub regeneration Quarries, mines, gravel pits and oil wells
Southwest Regional Gap Analysis Project (Lowry et al. 2005)	Barren lands, non-specific Invasive plants Disturbed, non-specific Recently burned Recently mined or quarried Disturbed, oil well
California Gap Analysis Project (Lennartz et al. 2008)	Mixed barren land Quarries and gravel pits Transitional bare areas

TABLE A-3 Total Land Area Required for All Ground-mounted Solar Technologies (CSP, CUPV, DUPV) Under SunShot Vision Study Deployment Projections

	State	2020 Ground-based Solar Land Requirement					2030 Ground-based Solar Land Requirement				
	Surface Area (ac)	Total Area (ac)	% CSP	% CUPV	% DUPV	% of State Area	Total Area (ac)	% CSP	% CUPV	% DUPV	% of State Area
Alabama	33,548,845	-				0.0%	15,034	0%	0%	100%	0.0%
Arizona	72,953,792	22,165	6%	33%	60%	0.0%	158,519	64%	15%	22%	0.2%
Arkansas	34,034,272	-				0.0%	11,849	0%	0%	100%	0.0%
California	104,764,634	58,752	17%	83%	0%	0.1%	174,227	58%	42%	0%	0.2%
Colorado	66,619,949	3,468	63%	37%	0%	0.0%	38,363	56%	44%	0%	0.1%
Connecticut	3,547,782	15,727	0%	37%	63%	0.4%	25,801	0%	60%	40%	0.7%
Delaware	1,592,781	4,001	0%	26%	74%	0.3%	9,147	0%	66%	34%	0.6%
Florida	42,084,928	15,811	49%	51%	0%	0.0%	255,374	7%	88%	5%	0.6%
Georgia	38,032,096	-				0.0%	90,959	0%	55%	45%	0.2%
Idaho	53,484,128	-				0.0%	2,772	0%	0%	100%	0.0%
Illinois	37,064,672	1,119	0%	0%	100%	0.0%	7,029	0%	0%	100%	0.0%
Indiana	23,308,512	4,041	0%	100%	0%	0.0%	44,756	0%	64%	36%	0.2%
Iowa	36,014,598	-				0.0%	7,088	0%	0%	100%	0.0%
Kansas	52,658,150	4,225	0%	83%	17%	0.0%	25,731	0%	97%	3%	0.0%
Kentucky	25,860,992	-				0.0%	18,793	0%	0%	100%	0.1%
Louisiana	33,522,003	-				0.0%	20,748	0%	0%	100%	0.1%
Maine	22,643,034	1,635	0%	0%	100%	0.0%	2,670	0%	0%	100%	0.0%
Maryland	7,939,795	33,000	0%	59%	41%	0.4%	49,867	0%	68%	32%	0.6%
Massachusetts	6,754,810	3,913	0%	0%	100%	0.1%	7,255	0%	0%	100%	0.1%
Michigan	61,896,646	-				0.0%	12,202	0%	0%	100%	0.0%
Minnesota	55,638,931	-				0.0%	6,422	0%	0%	100%	0.0%
Mississippi	30,996,339	-				0.0%	8,502	0%	0%	100%	0.0%
Missouri	44,612,474	10,191	0%	0%	100%	0.0%	30,787	0%	0%	100%	0.1%
Montana	94,105,414	-				0.0%	-				0.0%
Nebraska	49,502,598	-				0.0%	6,717	0%	88%	12%	0.0%
Nevada	70,765,965	2,872	13%	87%	0%	0.0%	21,299	23%	77%	0%	0.0%
New Hampshire	5,983,462	49	0%	0%	100%	0.0%	2,963	0%	0%	100%	0.0%
New Jersey	5,582,451	11,745	0%	0%	100%	0.2%	39,248	0%	32%	68%	0.7%

TABLE A-3 (Cont.)

State	State Surface Area (ac)	2020 Ground-based Solar Land Requirement Total Area (ac)	% CSP	% CUPV	% DUPV	% of State Area	2030 Ground-based Solar Land Requirement Total Area (ac)	% CSP	% CUPV	% DUPV	% of State Area
New Mexico	77,817,792	4,833	50%	0%	50%	0.0%	40,762	52%	20%	28%	0.1%
New York	34,915,187	-				0.0%	9,955	0%	0%	100%	0.0%
North Carolina	34,444,262	18,941	0%	40%	60%	0.1%	50,072	0%	45%	55%	0.1%
North Dakota	45,246,925	-				0.0%	-				0.0%
Ohio	28,688,371	5,464	0%	0%	100%	0.0%	23,689	0%	15%	85%	0.1%
Oklahoma	44,735,277	1,295	100%	0%	0%	0.0%	85,465	3%	75%	23%	0.2%
Oregon	62,962,266	-				0.0%	-				0.0%
Pennsylvania	29,474,784	1,104	0%	0%	100%	0.0%	13,931	0%	0%	100%	0.0%
Rhode Island	988,730	12,760	0%	70%	30%	1.3%	16,370	0%	75%	25%	1.7%
South Carolina	20,493,114	27,607	0%	100%	0%	0.1%	115,366	0%	77%	23%	0.6%
South Dakota	49,354,035	-				0.0%	-				0.0%
Tennessee	26,972,320	2,098	0%	100%	0%	0.0%	23,438	0%	29%	71%	0.1%
Texas	71,901,734	14,454	21%	58%	21%	0.0%	225,012	3%	48%	50%	0.1%
Utah	54,334,003	5,216	0%	100%	0%	0.0%	46,717	2%	98%	0%	0.1%
Vermont	6,154,470	11	0%	100%	0%	0.0%	1,407	0%	100%	0%	0.0%
Virginia	27,375,955	3,539	0%	100%	0%	0.0%	58,796	0%	43%	57%	0.2%
Washington	45,630,688	-				0.0%	-				0.0%
West Virginia	15,507,226	-				0.0%	-				0.0%
Wisconsin	41,917,683	-				0.0%	1,527	0%	0%	100%	0.0%
Wyoming	62,600,326	-				0.0%	-				0.0%
Contiguous U.S.	1,997,072,941	290,034	10%	57%	33%	0.01%	1,806,631	15%	51%	34%	0.09%

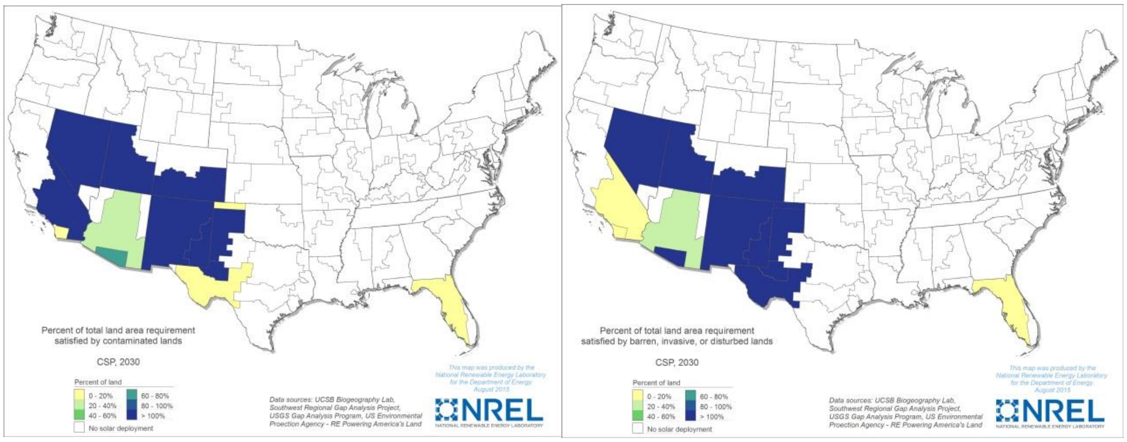

FIGURE A-1 Estimates of Land Availability of Contaminated (L) and Disturbed (R) Lands to Meet SunShot Vision Study Scenario Goals for CSP in 2030

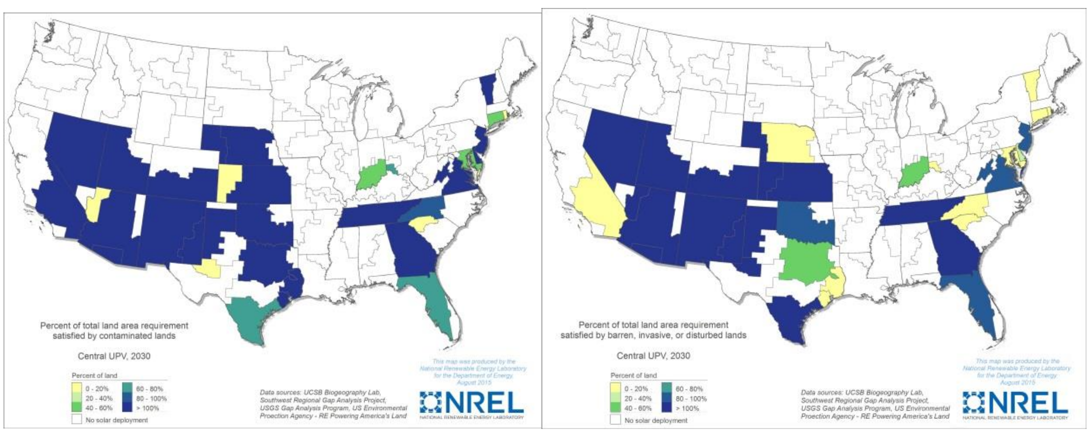

FIGURE A-2 Estimates of Land Availability of Contaminated (L) and Disturbed (R) Lands to Meet SunShot Vision Study Scenario Goals for CUPV in 2030

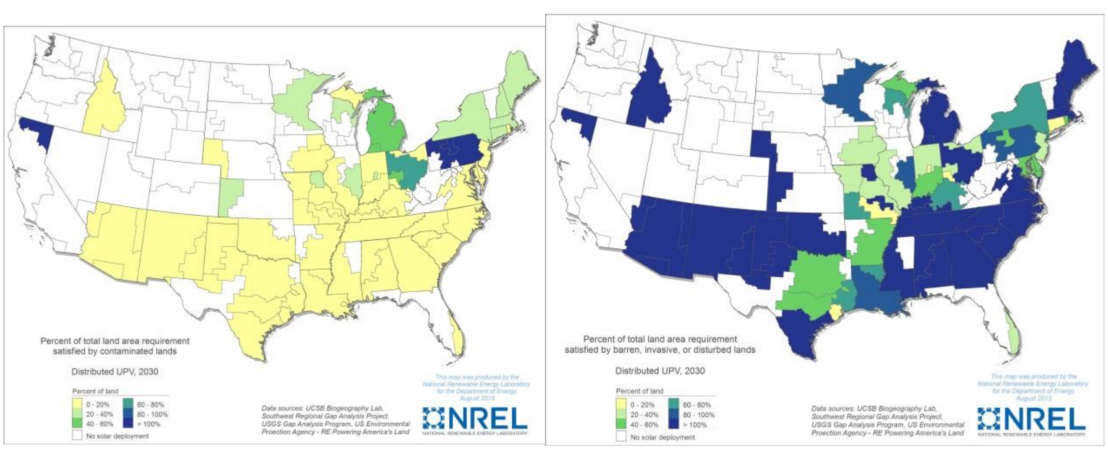

FIGURE A-3 Estimates of Land Availability of Contaminated (L) and Disturbed (R) Lands to Meet SunShot Vision Study Scenario Goals for DUPV in 2030

TABLE A-4 Estimates of Land Availability of Contaminated and Disturbed Lands to Meet SunShot Vision Study Scenario Goals in 2020 and 2030, by State

	CSP				CUPV				DUPV			
	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)
Alabama	-	-	-	-	-	-	29,392	18,698	-	15,034	1,279	97,523
Arizona	1,386	100,818	30,577	114,194	7,393	23,618	33,484	169,757	13,386	34,084	504	98,683
Arkansas	-	-	-	-	-	-	142,963	7,577	-	11,849	446	7,996
California	9,941	100,651	1,420,047	3,989	48,811	73,304	1,744,336	48,037	-	272	6,996	4,560
Colorado	2,173	21,301	162,349	43,160	1,294	17,061	224,604	184,468	-	-	614	191,216
Connecticut	-	-	-	-	5,752	15,518	6,663	122	9,975	10,283	2,709	1,397
Delaware	-	-	-	-	1,048	6,029	10,288	1,729	2,952	3,119	615	1,470
Florida	7,724	18,600	-	-	8,088	225,029	794,462	242,612	-	11,745	3,199	409,380
Georgia	-	-	-	-	-	50,404	522,434	90,130	-	40,555	1,847	597,801
Idaho	-	-	-	-	-	-	27,412	691,849	-	2,772	425	206,050
Illinois	-	-	-	-	-	-	63,301	1,578	1,119	7,029	2,943	6,108
Indiana	-	-	-	-	4,041	28,851	42,091	16,413	-	15,904	1,873	5,985
Iowa	-	-	-	-	-	-	7,388	218	-	7,088	911	4,123
Kansas	-	-	-	-	3,515	24,955	44,911	148,729	710	776	1,173	43,004
Kentucky	-	-	-	-	-	-	139,008	6,763	-	18,793	881	23,824
Louisiana	-	-	-	-	-	-	271,796	16,013	-	20,748	1,225	17,840
Maine	-	-	-	-	-	-	15,204	2,083	1,635	2,670	536	7,533
Maryland	-	-	-	-	19,348	33,947	17,844	6,300	13,651	15,920	1,042	9,949
Massachusetts	-	-	-	-	-	-	10,746	4,936	3,913	7,255	1,486	7,609
Michigan	-	-	-	-	-	-	30,782	26,446	-	12,202	3,992	27,267
Minnesota	-	-	-	-	-	-	59,901	36,280	-	6,422	1,613	7,836
Mississippi	-	-	-	-	-	-	14,023	10,650	-	8,502	798	33,270
Missouri	-	-	-	-	-	-	581,251	3,932	10,191	30,787	1,791	10,862
Montana	-	-	-	-	-	-	209,000	1,750,643	-	-	589	466,557
Nebraska	-	-	-	-	-	5,935	85,761	8,615	-	782	981	16,309
Nevada	368	4,794	66,141	377,825	2,504	16,505	66,944	541,115	-	-	213	116,661
New Hampshire	-	-	-	-	-	-	5,065	979	49	2,963	878	4,081

TABLE A-4 (Cont.)

	CSP				CUPV				DUPV			
	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)	Land Needed in 2020 (Acres)	Land Needed in 2030 (Acres)	Contaminated Lands Available (Acres)	Disturbed Lands Available (Acres)
New Jersey	-	-	-	-	-	12,587	60,022	12,457	11,745	26,661	3,930	9,127
New Mexico	2,415	21,175	3,264,173	111,364	-	8,199	3,266,280	133,180	2,418	11,388	526	18,892
New York	-	-	-	-	-	-	312,055	6,841	-	9,955	3,507	8,875
North Carolina	-	-	-	-	7,535	22,366	173,831	81,635	11,405	27,707	1,426	167,439
North Dakota	-	-	-	-	-	-	374,315	17,044	-	-	125	38,625
Ohio	-	-	-	-	-	3,583	47,827	6,112	5,464	20,106	3,631	10,650
Oklahoma	1,295	2,141	-	369,460	-	63,824	187,817	225,281	-	19,500	2,387	111,608
Oregon	-	-	-	-	-	-	15,524	277,432	-	-	1,194	110,231
Pennsylvania	-	-	-	-	-	-	258,486	4,177	1,104	13,931	36,360	12,427
Rhode Island	-	-	-	-	8,987	12,352	2,198	640	3,773	4,018	376	2,141
South Carolina	-	-	-	-	27,607	88,963	280,064	9,870	-	26,403	1,748	94,739
South Dakota	-	-	-	-	-	-	950	147,810	-	-	159	147,104
Tennessee	-	-	-	-	2,098	6,814	111,014	19,669	-	16,624	1,462	42,347
Texas	2,991	5,660	147,934	1,090,728	8,371	107,570	499,547	1,375,632	3,092	111,782	2,626	458,914
Utah	-	1,117	814,719	169,265	5,216	45,600	869,472	442,388	-	-	425	142,426
Vermont	-	-	-	-	11	1,407	1,931	-	-	-	275	517
Virginia	-	-	-	-	3,539	25,343	117,798	24,165	-	33,453	4,651	98,591
Washington	-	-	-	-	-	-	417,125	204,758	-	-	1,480	31,148
West Virginia	-	-	-	-	-	-	19,751	713	-	-	2,868	3,206
Wisconsin	-	-	-	-	-	-	77,770	118	-	1,527	2,901	3,359
Wyoming	-	-	-	-	-	-	12,385	238,249	-	-	100	161,364

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