Solar Siting and Land-use in Decarbonized Energy Systems: Final Technical Report

Wesley Cole and Anthony Lopez

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
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Technical Report
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NOTICE

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Final Technical Report (FTR)

Cover Page

a. Federal Agency	Department of Energy	
b. Award Number	DE-EE00038421	
c. Project Title	Solar Siting and Land-use in Decarbonized Energy Systems	
d. Recipient Organization	National Renewable Energy Laboratory	
e. Project Period	*Start:* Oct 1, 2021	*End:* Sept 30, 2024
f. Principal Investigator (PI)	Wesley Cole Energy Systems Engineer wesley.cole@nrel.gov	
g. Business Contact (BC)	Jeff Cook Program Lead Jeff.Cook@nrel.gov	
h. Certifying Official (if different from the PI or BC)	N/A	

Wesley Cole — **Signature of Certifying Official**

11/01/2024 — **Date**

1. **Acknowledgement:** This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the FY21-24 Lab Call Award Number 38421.

2.

3. **Project Summary:** The goals of this work were to improve the solar resource supply curves that are used in long-term planning models such as the Regional Energy Deployment System (ReEDS); provide alternate resource supply curves and generation profiles for various climate pathways, land-use projections, and regulatory regimes and interests; and improve understanding of how solar deployment based on various land uses or restrictions could impact the cost and ability to achieve deep decarbonization of the power sector. These goals were addressed primary through developing and collecting high-resolution spatial datasets of land uses and through detailed modeling using the Renewable Energy Potential (reV) and ReEDS models. The dataset creations and associated analysis led to two publications in *Nature Energy*, and the datasets have been made publicly available.

4. **Project Objectives and Outcomes:** The project pulled together a wide range of datasets to develop high-resolution datasets of solar resource availability. It also developed forward-looking solar resource datasets that incorporated land-use change and climate impacts. These high-resolution datasets are used as the basis for all NREL long-term planning studies, as well as by many other institutions that do long-term planning. Some of the key outputs of this work were not just the datasets and associated analysis, but the documentation of the methods applied to create those datasets. Because the datasets cover the contiguous U.S., there are many assumptions and nuanced details incorporated in the data creation, and the transparency provided by the publications enables broader usage across the stakeholder community. Throughout this project, methods, datasets, and approaches were coordinated with similar efforts performed for wind resource datasets.

   Besides the publications and datasets listed in section 5, this project also provided annual updates of the solar resource supply curves used in long-term planning

models. This work also met the 14 project milestones summarized in the table below.

Table 1.Project Milestones

Milestone	Delivery Date
Technical review committee established with at least five members	12/31/2021
Automated capability developed to report individual sites for solar buildout in the ReEDS model	3/31/2022
At least two IPCC pathways selected for downscaling	3/31/2022
Updated solar supply curves included in ReEDS version 2022 and corresponding non-technical outreach material complete	6/30/2022
Siting ordinance database compiled and categorized with full coverage of the conterminous United States	9/30/2022
Solar land-use analysis on existing ReEDS scenarios completed	9/30/2022
Downscaling of at least two IPCC pathways completed with less than 10% mean squared error (MSE) on unseen training data	12/31/2022
Land-use change projections for the conterminous United States completed	3/31/2023
Updated solar supply curves included in ReEDS version 2023 and corresponding non-technical outreach material complete	6/29/2023
Manuscript on climate impacts on solar resource completed	9/29/2023
Manuscript on land-use change completed	1/16/2024
Condition-specific supply curves completed	3/29/2024
Solar ordinance database update evaluation and long-term management strategy completed	6/27/2024
Manuscript on solar siting in decarbonization scenarios and accompanying outreach completed	9/30/2024

5. **Path Forward:** While this work has significantly advanced the state-of-the-art in understanding and representing solar resource potential, there is more to be done.

For example, while this work compiled a national-scale dataset of solar siting ordinances, those ordinances are constantly evolving, and automated methods to maintain an up-to-date dataset of siting ordinances would be valuable to many stakeholders. Additionally, new or improved datasets on federal land availability, the value of agricultural land, plant and animal species habitats and migration corridors, etc. are regularly becoming available. Regular updates to estimated solar resource availability are needed to ensure that stakeholders are using the best datasets when making decisions about the future of solar energy.

6. Inventions, Patents, Publications, and Other Results: This project resulted in several publications, datasets, and model updates. Those are summarized below.

Publications:

- "Impact of siting ordinances on land availability for wind and solar development," Anthony Lopez, Wesley Cole, Brian Sergi, Aaron Levine, Jesse Carey, Cailee Mangan, Trieu Mai, Travis Williams, Pavlo Pinchuk & Jianyu Gu, *Nature Energy*, 2023. https://doi.org/10.1038/s41560-023-01319-3. OSTI ID: 1996228.
- "Super-Resolution for Renewable Energy Resource Data with Climate Change Impacts using Generative Machine Learning," Grant Buster, Brandon Benton, Andrew Glaws, & Ryan King, *Nature Energy*, 2024. https://doi.org/10.1038/s41560-024-01507-9. OSTI ID: 2345176.
- "The interplay of future solar energy, land cover change, and their projected impacts on natural lands and croplands in the US," Jay Diffendorfer, Brian Sergi, Anthony Lopez, Travis Williams, Michael Gleason, Zach Ancona, & Wesley Cole, *Science of the Total Environment*, 2024. https://doi.org/10.1016/j.scitotenv.2024.173872. OSTI ID: 2382837.
- "Solar Photovoltaics and Land-Based Wind Technical Potential and Supply Curves for the Contiguous United States: 2023 Edition," Anthony Lopez, Pavlo Pinchuk, Michael Gleason, Wesley Cole, Trieu Mai, Travis Williams, Owen Roberts, Marie Rivers, Mike Bannister, Sophie-Min Thomson, Gabe Zuckerman, and Brian Sergi, NREL Technical Report, 2024. https://www.nrel.gov/docs/fy24osti/87843.pdf. OSTI ID: 2283517.

Datasets:

- "U.S. Solar Siting Regulation and Zoning Ordinances." https://data.openei.org/submissions/5734. OSTI ID: 1873867.
- "U.S. Wind and Solar PV Supply Curves with Future Land-use Change." https://data.openei.org/submissions/6160. OSTI ID: 2438326.
- "Super-Resolution for Renewable Energy Resource Data with Climate Change Impacts (Sup3rCC)." https://data.openei.org/submissions/5839. OSTI ID: 1970814.

In addition to the above releases, the ReEDS modeling capabilities and solar resource supply curves have been made available through the public ReEDS repository: https://github.com/NREL/ReEDS-2.0. The repository includes both the latest versions, as well as those used for specific studies. For example, the exact model version used for the paper "The interplay of future solar energy, land cover change, and their

projected impacts on natural lands and croplands in the US" is available at https://github.com/NREL/ReEDS-2.0/tree/LULC_supply_curves.

7. **Project Team:** The table below lists the key team members and their roles for this project.

Table 2. Key team members and their institutions and roles for this project.

Team Member	Institution	Role
Jesse Carey	NREL	Collect solar siting ordinances
Wesley Cole	NREL	Serve as project co-PI with Anthony Lopez, direct ReEDS modeling work, support writing and analysis throughout
Jay Diffendorfer	USGS	Develop land-use change datasets and lead land-use change analysis
Michael Gleason	NREL	Model developer and analyst for reV and associated supply curve development
Jianyu Gu	NREL	Develop methods for capturing parcel-level details in reV
Ryan King	NREL	Develop high-resolution climate datasets for solar resources
Aaron Levine	NREL	Compile and analyze siting ordinances for solar technologies
Anthony Lopez	NREL	Serve as co-PI with Wesley Cole, direct reV model development, oversee solar siting ordinances and associated analysis
Cailee Mangan	NREL	Collect solar siting ordinances
An Pham	NREL	Perform ReEDS model development and analyze land-use outputs from ReEDS
Paul Pinchuk	NREL	Model developer and analyst for reV and associated supply curve development
Marie Rivers	NREL	Analyst for reV and associated supply curve development
Brian Sergi	NREL	Perform ReEDS model development and analyze land-use outputs from ReEDS
Travis Williams	NREL	Analyst for reV and associated supply curve development