LAND OF OPPORTUNITY: **Potential for Renewable Energy on Federal Lands**

Trieu Mai, Anthony Lopez, Melinda Marquis, Michael Gleason, Anne Hamilton, Whitney Trainor-Guitton, Jonathan Ho, Shashwat Sharma

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National Renewable Energy Laboratory

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List of Acronyms

AC	alternating current
ATB	Annual Technology Baseline
BECCS	bioenergy with CCS
BLM	Bureau of Land Management
CCS	carbon capture and sequestration
CEQ	Council on Environmental Quality
COD	commercial operation date
CONUS	contiguous United States
CSP	concentrating solar power
dGen	Distributed Generation
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EGS	enhanced geothermal systems
EIA	U.S. Energy Information Administration
FWS	U.S. Fish and Wildlife Service
GW	gigawatt
HVDC	high-voltage direct current
km	kilometer
LCOE	levelized cost of energy
m	meter
MIRTA	military installations, ranges, and training areas
MMT	million metric tons
MW	megawatt
MW_{DC}	megawatts direct current
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
PEIS	programmatic environmental impact statement
POI	point of interconnection
PV	photovoltaic
RE	renewable energy
ReEDS	Regional Energy Deployment Systems
reV	Renewable Energy Potential
TWh	terawatt-hour
UPV	utility photovoltaic
USDA	United States Department of Agriculture
USFS	United States Forest Service
VRE	variable renewable energy

Executive Summary

Renewable energy (RE) in the United States has historically been deployed primarily on private lands, with only 3% of currently operating utility photovoltaic (UPV), land-based wind, and geothermal generating capacity located on federal lands. This contrasts with fossil fuel production, where about 12% of all oil produced in the contiguous United States occurs on federal lands and 11% for natural gas (Prest 2024; Smith 2022). The growing interest in RE development, generally across the country and specifically on federal lands, raises questions about the potential for RE on federal lands. This study seeks to answer two primary research questions on this topic:

1. What is the renewable energy technical potential on federal lands in the contiguous United States?

2. How much renewable energy capacity is projected to be developed on federal lands under decarbonization scenarios for the United States?

To provide quantitative estimates for these questions, the study applied a combination of high-resolution geospatial analysis and power sector modeling conducted by the National Renewable Energy (NREL) author team. The assumptions used were developed through a multi-agency collaboration with experts in land and resource management from multiple partner federal agencies and land administrators: the Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (FWS), the U.S. Forest Service (USFS), the U.S. Department of Defense (DOD), and the U.S. Department of Energy (DOE). These assumptions include considerations for RE development on federal lands, such as competing uses of the land, constraints and exclusions to RE development, and other factors. The collaboration included data sharing, quantitative and qualitative feedback on assumptions and methods, and a review of the results—although the analysis outcomes are the responsibility of the author team.

We incorporated the partner federal agencies' perspectives on federal land management and considered RE siting more broadly—including social, environmental, technical, and other considerations—within a geospatial model to estimate the technical potential for three major land-based RE technologies: UPV, wind, and geothermal. Technical potential is the maximum amount of a resource that is available after siting and other development constraints are applied, and it can be measured in terms of land area, nameplate capacity, or electric generation. In our reference siting access case, we estimate 44 million acres of federal land across the contiguous United States (i.e., the lower 48 states and the District of Columbia; excludes Alaska, Hawaii, and U.S. territories) is potentially suitable for UPV development, which corresponds to a capacity technical potential of 5,750 gigawatts (GW) (Figure ES-1). Federal land area available for wind development (43 million acres) is similar to UPV but wind's generating capacity technical potential is lower (875 GW). The technical potential is estimated for two geothermal technologies, hydrothermal and enhanced geothermal systems (EGS), both of which have a smaller amount of federal land available for development (12 and 27 million acres, respectively). However, in terms of capacity, the technical potential for EGS (975 GW) is approximately equal to wind's technical potential and there is an estimated 130 GW of hydrothermal potential.

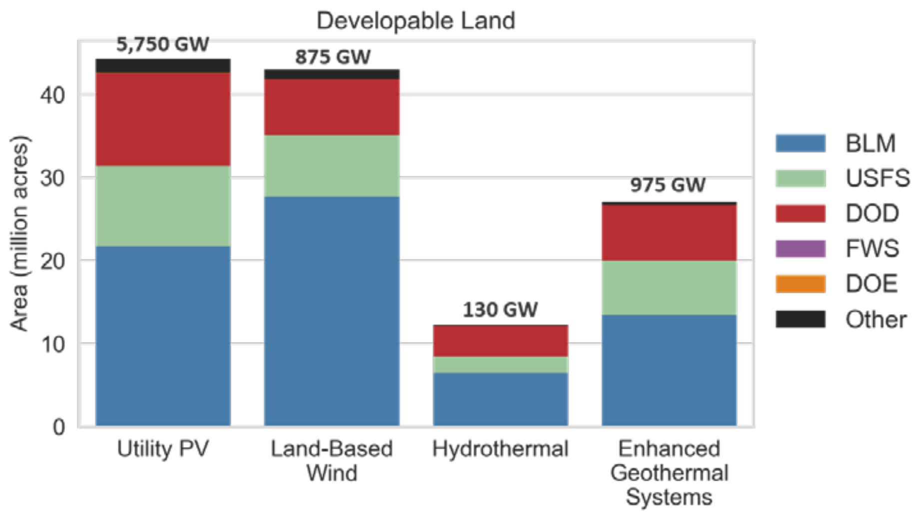

Figure ES-1. Technical Potential by Land Administrator under Reference Access

The developable land areas and capacities cannot be summed between technologies because of overlaps.

The distribution of technical potential among lands administered by federal agencies is determined by the amount of land administered, the suitability of the land for RE development, and the RE resource and technology. The BLM possesses the greatest RE technical potential with more than half of all developable technical potential on federal lands and the agency's mission is to sustain healthy, diverse, and productive public lands. Although the USFS administers a similar total land area within the contiguous United States (CONUS) as BLM (~170 million acres each), there are greater constraints to RE development on USFS land and thus much lower technical potential compared to BLM. USFS and DOD possess a similar amount of technical potential (Figure ES-1). All other federal land administrators have relatively modest amounts of RE technical potential.

In addition to estimating the total land area and corresponding generation capacity available for development, the geospatial analysis also considered the resource quality and costs, including transmission-related costs to interconnect new RE power plants. Including all such costs in the reference siting case, the analysis found a potential of approximately 1,300 GW of UPV and 60 GW of land-based wind with a levelized cost of energy (LCOE) less than $45/megawatt-hour (MWh) on federal lands, indicating sizeable opportunities for low-cost RE generation on federal lands.

We also developed cases with more-limited land available for UPV and wind (for federal and non-federal lands). A limited siting access case—that includes more stringent exclusions through greater setbacks to infrastructure, restrictions due to conservations, and other factors on both federal and non-federal lands—results in much lower RE technical potential for all federal land administrators and technologies, with wind technical potential more severely impacted than UPV (96% reduction for wind compared to 70% reduction for UPV, relative to the reference case). In a case with additional constraints applied to non-federal lands only (Limited Private), the overall (federal and non-federal) technical potential declines but the share of that technical potential on federal lands is higher than in the other cases.

The technical potential is the maximum amount that *could* be developed, but only a small fraction *would* be developed or needed in the future. To estimate future RE deployment, we used an electricity system planning model and examined seven scenarios (Figure ES-2) that all achieve 100% carbon-free electricity by 2035 and used electrification assumptions that are consistent with U.S. economy-wide net-zero greenhouse gas emissions by 2050. The scenarios capture a wide range of technology cost and performance assumptions, RE siting constraints, transmission assumptions, and other factors.

Default Settings	• Moderate tech costs • Reference tech siting • No CCS, new nuclear, and EGS • Constrained transmission
Many Options	• Lower solar and wind costs • CCS, new nuclear, and EGS allowed after 2030 • Lower transmission costs and more inter-regional coordination
Limited Options	• Limited VRE siting • Higher Distributed PV adoption
Federal Lands Favorable	• Reference VRE siting on public lands • Limited VRE on private lands
Solar & Storage Favorable	• Lower solar and battery costs • Higher wind and geothermal cost • Limited wind siting
Wind & Transmission Favorable	• Lower wind costs • Lower transmission costs and more inter-regional coordination • Higher solar and geothermal costs, limited solar siting
Geothermal Favorable	• Lower geothermal costs • EGS allowed • Higher VRE costs, limited VRE siting
CCS & Nuclear Favorable	• CCS and new nuclear allowed after 2030 • Limited VRE siting

Figure ES-2. Power sector modeling scenarios

In all scenarios, significant growth in UPV, land-based wind, and geothermal capacity is deployed throughout the country to meet these decarbonization targets. Figure ES-3 shows ranges of 600–1800 GW of UPV, 700–1200 GW of land-based wind, and 5–156 GW of geothermal installed on federal and non-federal lands by 2035 among the scenarios. These wide ranges reveal the existence of diverse pathways for decarbonization, but also the consistently large reliance on UPV and wind across all pathways. By 2050, each scenario includes at least ~1,000 GW each of UPV and land-based wind and at least 5 GW of geothermal on federal and non-federal lands. Deployment of geothermal capacity is strongly tied to availability and future cost reductions for EGS.

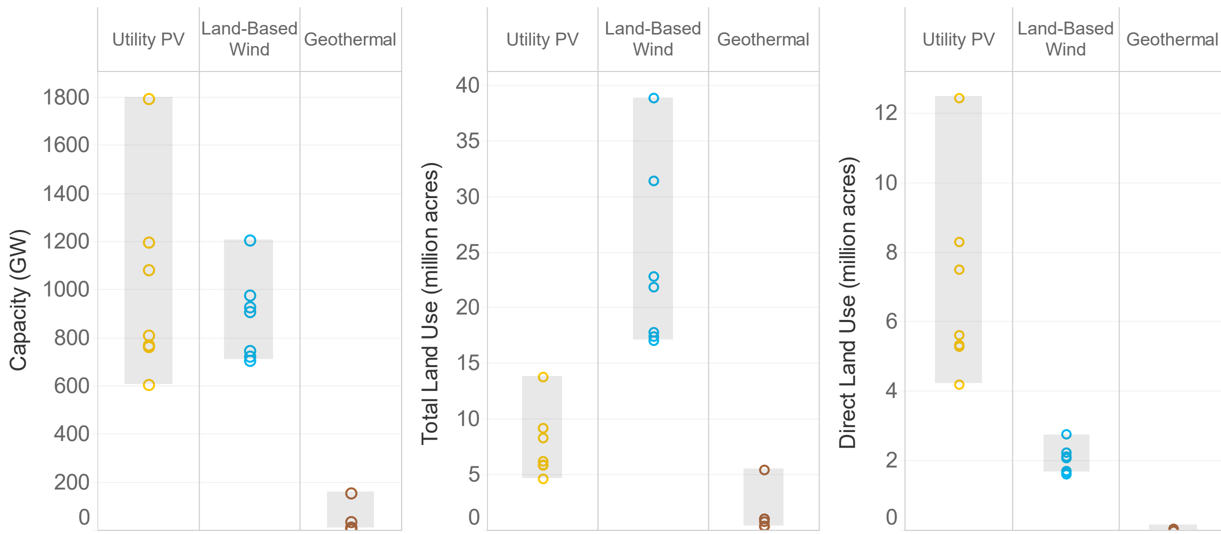

Figure ES-3. National installed capacity and land use on all (federal and non-federal) lands by 2035

Each dot represents one of the seven power sector scenarios, and the gray bars show the full range across all seven. The horizontal lines show the median value.

Figure ES-3 also shows the corresponding total and direct land use estimated for the three RE technologies of focus by 2035 across the scenarios. Total land use includes the area within the plant boundaries, and direct land use includes only disturbed land. Wind technologies have the greatest total land area requirements because of the spacing between turbines. UPV requires greater direct land use compared to wind and geothermal. The total amount of land required for these three technologies in 2035 is less than 4% of CONUS land area, and the direct land use required is less than 0.75%.

The power sector modeling estimates RE deployment and land use in the CONUS overall but does not have the resolution to characterize land ownership of the installed capacity. To estimate how much of the total deployed RE capacity would be projected on federal lands, we downscaled the power sector modeling results. This downscaling process introduces uncertainties, which are captured by analyzing a range of land use preferences including prioritizing federal lands vs. non-federal lands. Figure ES-4 shows the results from downscaling all seven power sector scenarios. In the two lowest deployment scenarios (CCS & Nuclear Favorable, Geothermal Favorable), 26–49 GW of combined UPV, wind, and geothermal capacity are deployed on federal lands by 2035. Estimated federal land development increases to 51–84 GW in the central three scenarios (Limited Options, Many Options, Wind & Transmission Favorable), followed by 81–128 GW in the Solar & Storage Favorable scenario. This range represents 2%–5% of total UPV, wind, and geothermal deployed across the CONUS (on both federal and non-federal lands), which is consistent with historical deployment experience. In the Federal Lands

Favorable scenario, where siting pressures are greater on non-federal lands compared to federal lands, 11–12.5% of total RE capacity (231–270 GW) is installed on federal lands.

The mix of RE technologies deployed on federal lands is similar to the technology mix nationally with an approximately even split between UPV and land-based wind and less deployment of geothermal in most scenarios. There is significant variation among scenarios revealing the underlying uncertainties. As with technical potential, projected deployment is greatest on BLM land, followed by an approximately even share between USFS and DOD, and with much less deployment on all other federal lands. In many scenarios, the majority of the RE deployed on BLM land is from UPV, whereas deployment on USFS is predominantly wind. Geothermal deployment is most significant on DOD land, but UPV and wind deployment are also estimated on DOD land under many scenarios.

Figure ES-4 also shows the total and direct federal land areas corresponding to the deployment results by 2035. As with capacity, there is a wide range across scenarios, but in most cases less than 2 million acres of total area would be developed for renewable energy—of which less than 815,000 acres would be disturbed. Total and direct land use are estimated to be approximately 4.8 million acres and 1.23 million acres, respectively, in the highest federal land development scenario. For context, during fiscal year 2023, 20.5 million acres of federal lands were under lease for oil and gas development, of which about 12.3 million acres were actively used for production. The projected capacity and land development shown in Figure ES-4 represent projected deployment by 2035, which implies project authorizations would need to occur prior to that year for power plants to start operating in 2035. Modeled results are also available for other years through 2050.

The analysis was designed to broadly inform energy, land, and resource planning for federal land administrators. However, although the modeling conducted has high spatial resolution, it cannot capture all complex siting factors for every location. Instead, the analysis applied a harmonized approach across the entire CONUS to provide a screening-level analysis of RE technical potential on federal lands as well as deployment projections under decarbonizations scenarios. None of the scenarios is intended to be a forecast. The large technical potential estimates and the increasing deployment projections from the collection of scenarios show the opportunities for RE development on federal lands. Capturing these opportunities—while minimizing conflicts with other land uses, federal department or agency missions, and public interest, and simultaneously maximizing the economic, grid, and social value of the projects—would require collaborative planning among federal land administrators, grid planners, project developers, the public, and other stakeholders.

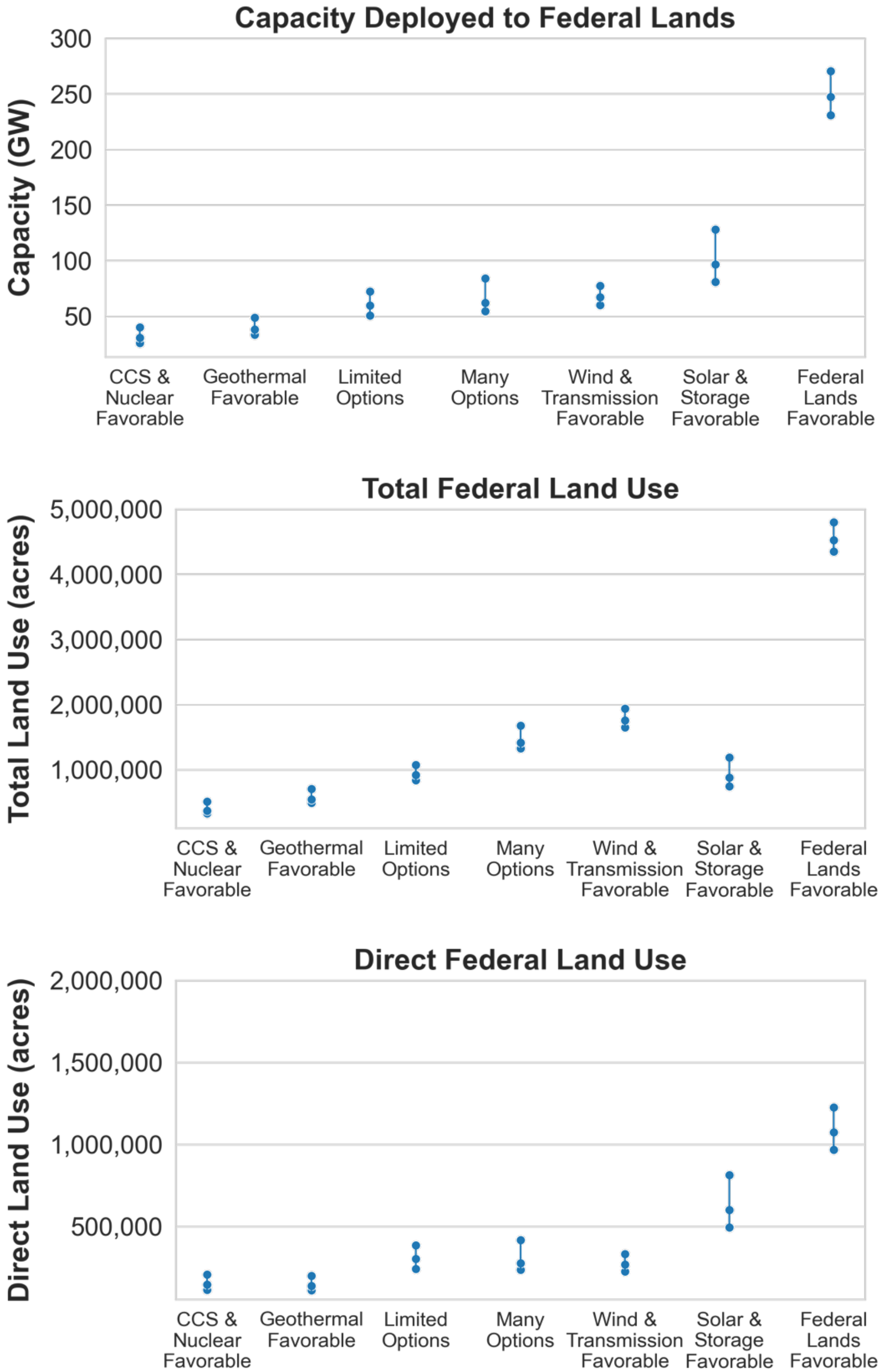

Figure ES-4. Combined UPV, wind, and geothermal deployment on all federal lands in 2035, including installed capacity (top), total land use (middle), and direct land use (bottom)

The markers reflect results across the three downscaling preference cases.

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1 Introduction

1.1 Background

Federal land administrators manage about 410 million acres of land in the contiguous United States (CONUS), which is equivalent to 21% of the total land area (Figure 1).[1] There are multiple uses of federal lands, including forestry and agriculture, military and defense, recreation, conservation of land, ecosystems, cultural heritage, and energy-related activities. Energy-related uses of federal lands include rights of way for energy infrastructure, such as oil and gas pipelines and electricity transmission, and energy production, such as fossil fuel extraction. During fiscal year 2023, 20.5 million acres of federal lands were under lease for oil and gas development, of which 12.3 million acres were actively used for production (Bureau of Land Management 2024d).[2] These acres are used to produce 12% of total oil produced in the contiguous United States and 11% of total natural gas produced (Prest 2024; Smith 2022).[3]

To a lesser extent, federal lands are also used for renewable energy (RE). Figure 2 shows utility-scale photovoltaic (UPV), land-based wind, and geothermal capacity installed in the CONUS on all lands (black lines) and on federal lands (colored lines) from 1990 through the present.[4] For the three technologies combined, deployment on federal lands totals 8.9 gigawatts (GW) representing 3.7% of their total installed capacity.[5] Nearly all the 8.9 GW of projects are on land administered by the Bureau of Land Management (BLM) or U.S. Department of Defense (DOD). Installed geothermal capacity has the largest share on federal lands at 72% (2.6 GW of 3.7 GW). Only 2.6% of all existing utility-scale land-based variable renewable energy (VRE) capacity, which includes UPV and wind, is installed on federal lands.

[1] The BLM administers about 700 million acres of federal subsurface mineral estate throughout the nation (Congressional Research Service 2017).
[2] These lease areas are for the CONUS. An additional 3 million acres of federal lands are leased for oil and gas production in Alaska with about 100,000 producing acres.
[3] Including federal offshore water production increases the U.S. (including Alaska and Hawaii) federal share to 25% and 12% for oil and natural gas, respectively. Note that oil and gas production can fluctuate year to year.
[4] Data for land-based wind and UPV include facilities that became operational as recently as March 2024 and September 2023, respectively.
[5] The 8.9 GW of operating RE capacity on federal lands is comprised of 4.85 GW of UPV, 2.62 GW of geothermal, and 1.46 GW of wind.

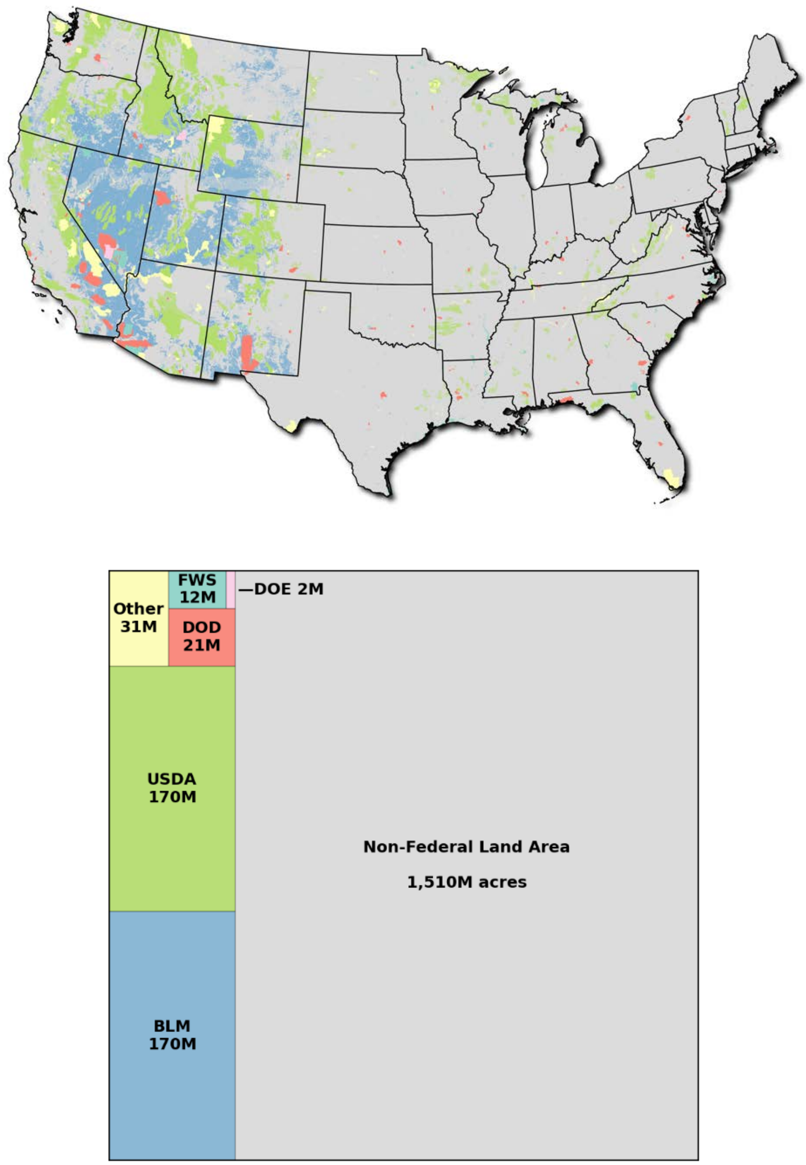

Figure 1. Land area by federal land administrator and non-federal lands. Areas in the bottom square are scaled equivalent with the top map

Sources: Bureau of Land Management (2024a); U.S. Forest Service (2024c); Office of the Assistant Secretary of Defense for Energy, Installations, and Environment (2022); U.S. Fish and Wildlife Service (2024); U.S. Geological Survey (2014).The U.S. Department of Agriculture (USDA) is predominantly (>99%) composed of U.S. Forest Service administered lands. Other federal land is composed predominantly of National Park Service land administered lands, and includes land administered by other agencies and departments other than BLM, USDA, DOD, FWS, and DOE.

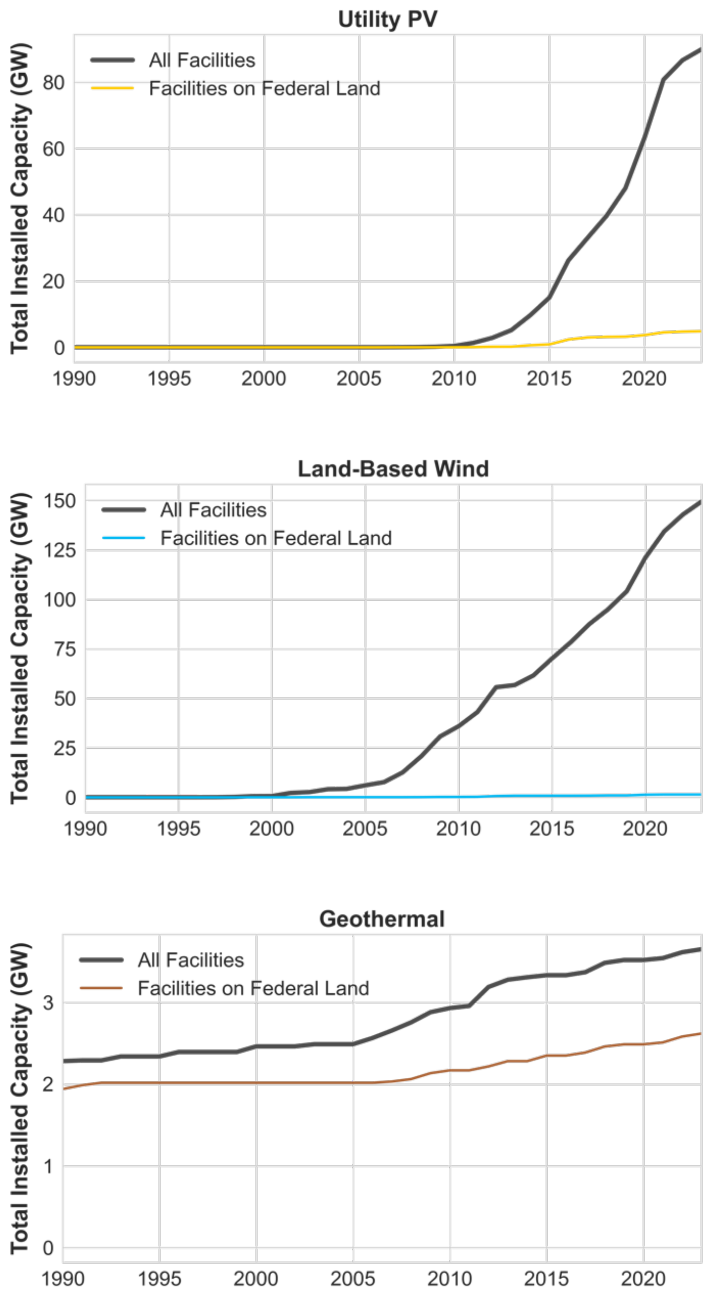

Figure 2. Installed utility PV (top), wind (middle), and geothermal (bottom) capacity on all lands and federal lands in the CONUS.

Different scales are used. Data for existing wind and PV facilities are from the U.S. Wind Turbine Database v7.1 (Hoen et al. 2024) and U.S. Photovoltaic Database v2.0 (Fujita et al. 2024), respectively. Existing geothermal facilities are from a National Renewable Energy (NREL)-curated dataset sources from EIA. Results only include installed projects; decommissioned facilities and projects that have been permitted but are still pending or under construction are excluded. Facilities with unknown capacity and/or unknown installation year are also excluded. For projects that are only partially on federal lands, the estimated proportion of capacity allocated to federal lands is proportional to the amount of the project (i.e., percent of turbines or percent of land) within federal land boundaries.

Although only a limited number of RE facilities have been installed on federal lands, numerous facilities have been permitted and are under various phases of construction, and there exists increasing interest and proposals for RE development on such lands. The Energy Act of 2020 set forth a production goal to issue permits for a minimum of 25 GW of wind, solar, and geothermal energy projects on federal lands by 2025 ("43 USC" n.d.). Recently, BLM announced achievement of the milestone with the approval of 30 GW of capacity, from 215 UPV, wind, geothermal, and gen-tie[6] projects ("Programs: Renewable Energy | Bureau of Land Management," n.d.). BLM also recently released a "proposed roadmap" for solar development on lands the agency administers through an updated solar programmatic environmental impact statement (PEIS) and proposed resource management plan amendments, known as the updated "Western Solar Plan" (BLM Releases 2024). The BLM has previously issued PEISs for leasing and development of solar in partnership with DOE (2012), geothermal in partnership with the U.S. Forest Service (2008), and wind (2005). Additionally, in 2024 the BLM adopted categorical exclusion for National Environmental Policy Act compliance from the Department of the Navy and U.S. Forest Service to expedite geothermal energy permitting (BLM 2024).

Furthermore, Executive Order 14057 (Federal Register 2021) establishes a goal for the federal government to procure 100% of its electricity from carbon pollution-free sources on a net annual basis by 2030, which could include RE development on federal lands to meet this goal. DOD is the nation's largest consumer of energy—using approximately 1% of total energy used in the United States and 77% of the energy used by the federal government—and is working to meet Executive Order 14057 through a mix of on-site clean energy development and procurement of clean energy. DOD recently announced new solar and geothermal projects on multiple military installations (DoD to Advance n.d.; DoD Announces n.d.). In 2023, the U.S. Department of Energy (DOE) launched "Cleanup to Clean Energy," an initiative to repurpose portions of DOE-owned lands used for the nation's nuclear weapons program. The aim of the initiative is to develop renewable and nuclear plants on these lands (Department of Energy, Office of Management, Sustainability Performance Office 2023). The DOE Office of Environmental Management, Office of Nuclear Energy, and National Nuclear Security Administration have identified approximately 35,000 acres of land with potential for development of clean energy.

These recent federal efforts are occurring within a broader environment where total demand for clean electricity is increasing as demonstrated by the 1,480 GW of zero-carbon generation capacity seeking transmission access in the interconnection queues in 2023 (Rand et al. 2024). These demands are driven in part by the decline in generation costs of wind and solar as well as state clean energy policies. As of 2024, 29 state renewable portfolio standards and 16 clean energy standards have been enacted (Barbose 2024). Achieving national goals, such as the 100% clean electricity by 2035 and long-term strategy of net-zero greenhouse gas emissions economy-wide by 2050 (The White House 2021), would further increase the demand for new clean electricity (Denholm et al. 2022).

Although new RE development is expected, how much and where it will be installed is uncertain and will be driven by land use prioritization and local siting factors. RE projects rely on the local

[6] BLM defines gen-tie projects as: "transmission lines that cross public lands to connect renewable energy projects that have been developed on private lands to the grid."

resource (e.g., wind speed, solar insolation, subsurface fluids and temperature) and often have larger plant footprints than many other electricity sources—especially if land used for fuel extraction is omitted. Therefore, siting can have greater influence on the magnitude and location of RE development. As with other energy related development, wind and solar technologies also have social, environmental, and wildlife impacts that complicate siting. Siting ordinances can be used to establish and codify common siting practices (Klass 2024). However, the recent growth of siting ordinances, many with increasingly stringent restrictions, indicates added pressure on new RE development (Lopez et al. 2023). Notwithstanding, co-uses of land that combines energy production with other uses, such as agriculture or recreation, offers additional development opportunities (Klass 2024).

Siting factors can influence the success, location, and layout of RE facilities in all areas; however additional considerations apply to projects on federal land due to public interest in these lands and the mission priorities of federal agencies and departments. This study aims to consider these unique siting considerations of federal land administrators to estimate the potential for renewable energy development on federal land across the CONUS.

1.2 Study Objectives and Scope

The objective of the study is to estimate the deployment potential for renewable energy on U.S. federal lands. Specifically, the study is designed to answer two primary questions:

1. What is the renewable energy technical potential on federal lands in the contiguous United States?

2. How much renewable energy capacity is projected to be developed on federal lands under decarbonization scenarios for the United States?

To answer these questions, we used an analytical approach that links geospatial and power sector models as described in Section 2. Renewable energy technologies within the scope of the analysis include UPV, land-based wind, and geothermal and, unless otherwise noted, "RE" refers to these three technologies only;[7] other renewable and non-renewable technologies are also modeled but we do not distinguish federal vs. non-federal land use for them. The geographic scope of the analysis is the contiguous United States; RE deployment potential in Alaska, Hawaii, or the U.S. territories is not evaluated.[8] Future deployment estimates are through 2050.

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[7] UPV represents large-scale ground-mounted PV power plants with characteristic sizes ≥10 megawatts (MW). The modeling used in our analysis also included distributed PV and concentrating solar power but, unless otherwise noted, "solar" refers to UPV only. Similarly, unless otherwise noted "wind" refers to utility-scale land-based wind—but offshore wind was also included in our power sector modeling. Geothermal technologies include hydrothermal and enhanced geothermal systems (EGS).

[8] Federal lands make up 64% and 20% of total land area for Alaska and Hawaii, respectively (https://forestry.alaska.gov/Assets/pdfs/posters/07who_owns_alaska_poster.pdf; https://archive.revenuedata.doi.gov/explore/HI/). The electrical grid in the CONUS is not connected to the grids in these states, which have unique land use, technology, and economic considerations given the separate distinct energy systems and remote locations. Future work using additional data and models would be needed to evaluate these states' RE technical potential and deployment potential.

Importantly, the study also required input from a broad range of experts from five federal land administrators: Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (FWS), U.S. Forest Service (USFS), U.S. Department of Defense (DOD), and U.S. Department of Energy (DOE). BLM and FWS are within the U.S. Department of the Interior (DOI), and the USFS is within the U.S. Department of Agriculture (USDA). To this end, the study is structured as an inter-agency collaboration including staff from the five partner federal land administrators, the NREL author team, core study members from DOE, and the White House Council on Environmental Quality (CEQ) (Figure 3). Appendix A lists the participants of the study.

Figure 3. Multi-agency collaboration structure of the study

The participation of the partner federal agencies is needed for this study given their expertise on suitability for RE development on lands administered by these agencies, as well as their role in reviewing projects on lands managed by other agencies,[9] and their expertise on other resource or land use considerations that might preclude or foster RE development. The partner federal land agencies and administrators[10] reviewed siting assumptions that are used in the geospatial tools to estimate technical potential (see Section 2). This review included general assumptions for RE development on all (including federal and non-federal) lands as well as specific federal land use considerations. The collaboration included data creation and sharing, quantitative input, and qualitative discussions. Note that although the federal agencies and land administrators provided

[9] FWS plays a critical role in Endangered Species Act reviews of proposed projects on all federal lands. FWS also manages a small share of federal lands.
[10] We use federal "agency" and "land administrator" interchangeably to refer to the partner organizations participating in this study (see Figure 3).

invaluable comments throughout the study, the ultimate decisions about assumptions were made by the NREL study team.

The multi-agency collaboration enabled the study to have a harmonized and consistent approach for evaluating RE potential and deployment for all federal lands in the CONUS. Prior analyses—for example, C. P. Barrows, Stoll, and Mooney (2017); C. Barrows et al. (2016); Frew et al. (2016); and Dahle et al. (2008)—and resource management plans have addressed similar topics for specific regions and federal land administrators, but, to our knowledge, previous assessments do not cover the broad geographic, administrator, and technology scope of our study. Given this broad scope, the study applied a screening-level assessment of RE development. Table 1 clarifies scope limitations of the study.

Table 1. Study Scope

What this study *does*	**What this study *doesn't do***
Estimate the technical potential for UPV, land-based wind, and geothermal on federal lands using a consistent set of siting assumptions	Determine siting suitability for any specific locations, e.g., to assess project or land lease applications
Develop future scenarios for the U.S. energy system using high resolution modeling and current available data	Provide market forecasts for the U.S. RE industries
Estimate land use requirements associated with the modeled scenarios	Analyze the tradeoffs between RE development, conservations, and other competing uses of federal lands
Consider transmission expansion and infrastructure needs self-consistently within the modeling framework	Analyze the siting and land use impacts of future transmission infrastructure development
Provide insights into future RE deployment to inform federal land planning	Replace federal land administrator planning processes or current energy permitting or approval processes

2 Methods and Assumptions

Our methodology included three primary analytical steps (Figure 4). The first uses Renewable Energy Potential (reV), a geospatial model that estimates the RE technical potential across the CONUS, including on federal and private lands. This technical potential, along with RE cost and performance estimates, is an input to the Regional Energy Deployment System (ReEDS) power sector capacity expansion model. ReEDS models the investment and dispatch of generation, storage, and transmission of all major technologies through 2050. Associating the future capacity deployed in ReEDS with federal lands requires spatial downscaling, which is the third step of the process. These steps are detailed in this section.

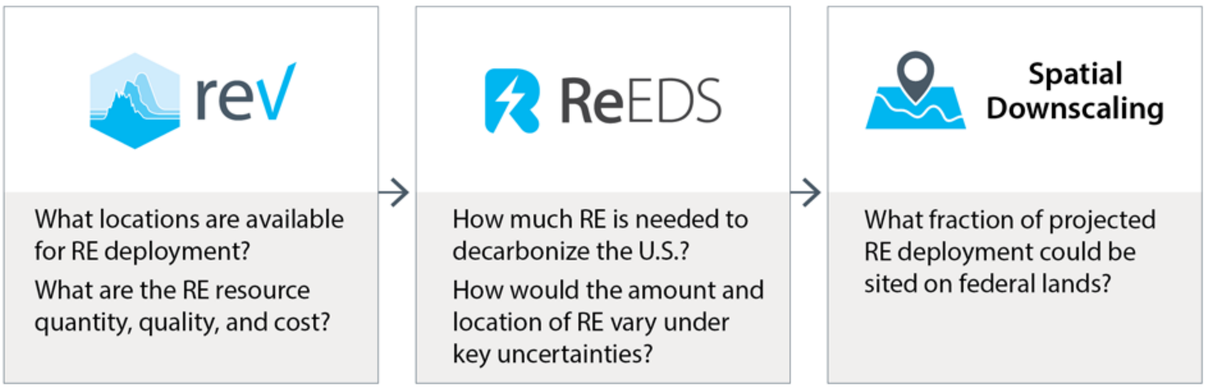

Figure 4. Study analysis approach

2.1 Renewable Energy Potential Modeling

Resource potential is often assessed in terms of geographic (or resource), technical, economic, and market potential. Each measure represents a succession of complexities and assumptions that ultimately result in a characterization of the developable quantity, quality, and cost of RE resource that can be sorted to represent a supply curve (Lopez et al. 2021). We first estimate technical potential, which is defined as the maximum amount of a resource that is available after siting and other development constraints are applied and system performance is estimated given the resource quality. Technical potential can be expressed by the total land area, generation capacity, and annual generation potential. Note the amount developed in a model scenario or in the real world is, often significantly, less than the technical potential.

reV is an open-source geospatial model[11] that estimates RE technical potential, or the land available for renewable energy development, the generation capacity associated with that land area, hourly and annual electricity generation that could be produced, and grid interconnection costs associated with each location. These estimates were produced for each of approximately 60,000 sites (11.5 kilometers [km] by 11.5 km for each site) in the CONUS. Separate reV models for the three technologies—UPV, land-based wind, and geothermal—were used for this analysis, but they all operate on a common framework. reV combines resource data, technology assumptions, power plant performance modeling, siting layers, and transmission costs to develop

[11] https://nrel.github.io/reV/

technical potential and cost estimates. Lopez et al. (2025) documents the major assumptions used in reV for our analysis.

Renewable energy technical potential is sensitive to the land exclusions applied in reV. These exclusions can include regulatory, technical, social, and ecological constraints to new RE development. Exclusions and other siting assumptions are based on a wide range of sources and are modeled with up to 90-meter (m) resolution as documented in Lopez et al. (2025). Here, we report the siting and land use exclusions assumed in our analysis, focusing on those applicable for federal lands.

Given the complexities and uncertainties with RE siting, we developed three siting cases to estimate the technical potential for UPV and land-based wind:[12]

- **Reference Access** is intended to represent deployment potential using best management practices, and/or typical current practices for siting RE projects.
- **Limited Access** provides an estimate of a floor on technical potential by employing stringent exclusions for RE siting on both federal and non-federal lands.
- **Limited Private** represents a case where siting RE is particularly challenging on privately-owned and state-administered lands, but current best management practices guide siting decisions on federal lands.

Known exclusions and regulatory restrictions for RE development were incorporated in all three cases. For each siting case, general exclusions were applied to all locations—including federal and non-federal lands—and specific ones applied only to federal lands. There is a broad spectrum of general exclusions, each of which help to narrow down developable lands based on local physical, social, environmental, or regulatory siting barriers. For example, there are siting incompatibilities from extreme terrain, mountainous landforms, or water bodies (for land-based technologies). Infrastructure of the built environment, including roads and buildings are physical obstacles that would prevent utility-scale energy development. Further, there are less obvious infrastructural barriers that include weather and military radar setbacks, intercontinental ballistic missiles, airport runways and associated aeronautical restrictions, and more. In addition to the built environment, there are natural environmental siting barriers. These primarily encompass those lands set aside for conservation. This includes not only the roughly 30 million acres of National Parks, Wilderness Areas, and National Monuments managed by the National Park Service, but also lesser-known areas including National Forest Inventoried Roadless Areas, Areas of Critical Environmental Concerns, Threatened and Endangered Species Critical Habitat, as well as private land conservation easements that account for almost 38 million acres of conserved land (National Conservation Easement Database 2017). Finally, there are ordinances or regulations passed by local communities that guide the placement of energy facilities within their communities by establishing setback requirements from residences, enact sound limits, apply height restrictions, set shadow flicker thresholds, and more.

[12] Reference Access cases are modeled for all three technologies (UPV, land-based wind, and geothermal). Limited Access and Limited Private are modeled only for UPV and wind.

Appendix B documents the full list of general exclusions used for this analysis and Lopez et al., (2025) provides additional detail.

The general exclusions summarized above apply to the Reference and Limited Access cases, but Limited Access applies additional constraints to wind and solar. For example, we applied more stringent setback requirements from residences and infrastructure to capture local community opposition. We applied line-of-sight exclusions to military radar stations to capture increasing wind energy saturation of radars. To represent growing calls for conservation of sagebrush ecosystem habitat we limited development in the core and growth opportunity areas. Appendix B compares the assumptions used for both Limited and Reference Access cases. In general, the Limited Access case represents a more pessimistic view on siting of renewables, capturing the siting constraints that are not necessarily binding from a regulatory perspective, but could lead to project failure due to stakeholder opposition. Together, the Reference and Limited Access cases represent a range of uncertainties for siting VRE in the future.

To supplement and refine the general exclusions (Appendix B) that are applied throughout the CONUS, we also modeled specific exclusions to federal lands to account for the unique land and resource considerations for each partner land administrator. Federal land datasets procured specifically for this analysis are presented in Tables 2, 3, and 4. Although many datasets were procured directly from the guiding federal land administrator, we created several based on the guidance of and review from the partner administrator. Details of these datasets can be found in Appendix B. In addition, some guidance—for example from FWS regarding endangered species—applied to lands administered by their sister agencies. There are technology agnostic siting assumptions and technology-specific assumptions; each is applied to either the Reference or Limited Access case. As with the general exclusions, more stringent assumptions are used under the Limited Access case. For example, we applied the more stringent Alternative for sage grouse, excluded lands adjacent to military operations, and excluded development within protected viewsheds of wild and scenic rivers and historic trails under the Limited Access case (see Tables 2, 3, and 4 for other assumptions). The Limited Private case applies the Limited Access exclusions to non-federal lands but retains the Reference Access assumptions for federal lands.

Table 2. Federal land siting assumptions that apply to both land-based wind and utility PV

"X" denotes where a layer is applied as an exclusion.

Dataset	Reference Access	Limited Access	Source
BLM RMPA/DEIS Sage Grouse Priority Habitat Management Area Avoidance Areas - Alternative 5 (on BLM Lands)	X (Alternative 5)	X (Alternative 3)	Bureau of Land Management (2024c)
368 Designated (2009) Transmission Corridors	X	X	Bureau of Land Management (2022c)
DOD Clear Zones and Accident Potential Zones	X	X	Readiness and Environmental Protection Integration Program (2020)
DOD Readiness and Environmental Protection Integration (REPI) Opportunity Areas		X	Readiness and Environmental Protection Integration Program (2020)
DOD Lands (all)		X	Office of the Assistant Secretary of Defense for Energy, Installations, and Environment (2022)
Old Growth Forests on USFS and BLM Lands	X	X	See Appendix B
USFS Lands Categorized as GAP Status 3 and 4 (Excluding National Forests)	X	X	United States Geological Survey (2024)
USFS Active Grazing Allotments		X	U.S. Forest Service (2024a)
USFS Recreation Opportunity Spectrum Excluded Categories	X	X	See Appendix B
RIBITS Mitigation Banks and In-Lieu Fee Program Lands	X	X	U.S. Army Corp of Engineers (2024)
Endangered Species Act Threatened and Endangered Species Critical Habitat (USGS subset) on Federal Lands except BLM	X (all Federal Lands except BLM)	X (all Federal Lands)	Lopez et al., (forthcoming)

Table 3. Utility PV federal land siting assumptions

"X" denotes where a layer is applied as an exclusion.

Dataset	Reference Access	Limited Access	Source
BLM Solar PEIS Proposed Plan Exclusion Areas [a]	X	X	Bureau of Land Management (2024b)
Desert Renewable Energy Conservation Plan (DRECP) Lands Closed to Solar on BLM Lands	X	X	Bureau of Land Management (2016a)
BLM No Surface Occupancy (NSO) Areas	X	X	Laura Fox, Argonne National Laboratory, personal communication, April 9, 2024
Clean Up to Clean Energy – Clean Energy Exclusion Areas (Solar)	X	X	DOE (2024b); DOE (2023); DOE (2023a; 2024d; 2024a; 2024c; 2023b); Department of Energy, Office of Management, Sustainability Performance Office (2023; Bureau of Land Management (2024a)
FWS Lands except for Wetland Waterfowl Protection Area (WPA) Easements	X	X	U.S. Fish and Wildlife Service (2024)

[a] Data were received from Argonne National Laboratory and BLM on June 20, 2024.

Table 4. Land-based wind federal land siting assumptions

"X" denotes where a layer is applied as an exclusion.

Dataset	Reference Access	Limited Access	Source
West-Wide Wind Mapping Project Composite Exclusion Areas		X	Bureau of Land Management (2016b)
West-Wide Wind Mapping Project Composite High Level of Siting Consideration Areas		X	Bureau of Land Management (2016b)
West-Wide Wind Mapping Project Composite Medium Level of Siting Consideration Areas		X	Bureau of Land Management (2016b)
Desert Renewable Energy Conservation Plan (DRECP) Lands Closed to Wind on BLM Lands	X	X	Bureau of Land Management (2016a)
BLM Resource Management Plan (RMP) Wind Exclusions	X	X	Bureau of Land Management (2016b)
BLM Wind Exclusions based on Solar PEIS Pre-final Proposed Plan Resource Based Exclusions	X	X	See Appendix B
BLM No Surface Occupancy (NSO) Areas		X	Laura Fox, Argonne National Laboratory, personal communication, April 9, 2024
DOE Clean Up to Clean Energy – Clean Energy Exclusion Areas (Wind)	X	X	DOE (2024b); DOE (2023); DOE (2023a; 2024d; 2024a; 2024c; 2023b); Department of Energy, Office of Management, Sustainability Performance Office (2023); Bureau of Land Management (2024a)
Wild and Scenic Rivers 10-mile Buffer for Viewshed Protection		X	U.S. Forest Service (2024b)
Scenic and Historic Trails 10-mile Buffer for Viewshed Protection		X	National Park Service (2018; Bureau of Land Management (2022a)
FWS Lands except for Wetland and Grassland WPA easements)	X	X	U.S. Fish and Wildlife Service (2024)

Siting assumptions for geothermal—on federal and non-federal lands—were based primarily on those applied for solar and are documented in Lopez et al. (2025). Like Lopez et al. (2025), this study used only the Reference Access geothermal case. The assumptions for geothermal that differ from those applied to UPV (under Reference Access) include the following:

- No property line setbacks were applied for geothermal projects.
- Solar moratoriums were not applied to geothermal development (there were no explicit geothermal bans).
- Exclusions based on terrain slope used a 25% value for geothermal, which is the same as for wind but differs from the 5% used for UPV.
- No contiguous area filter was applied for geothermal given separation between geothermal power plants and wellfields.
- Habitats of Greater Prairie Chicken, Dixie Valley toad, and Tiehms buckwheat habitat (<2 km^2 for CONUS) are excluded for development.

2.2 Power Sector Modeling

ReEDS is an open-source power sector capacity expansion model[13] that finds the lowest-cost portfolio of generation, storage, and transmission to meet demand, policy, and reliability requirements through 2050. Investment options considered in ReEDS include fossil fuel-based generation technologies (e.g., coal- and natural gas-fired generation with and without carbon capture and sequestration [CCS]), nuclear (including small modular reactors), wind (land-based and offshore), solar (PV and concentrating solar power), geothermal (hydrothermal and EGS), hydropower, storage (batteries and pumped-storage), hydrogen-based combustion turbines, biomass-based generation (including bioenergy with CCS [BECCS]), and transmission expansion. Technology cost and performance assumptions are from the Annual Technology Baseline (ATB) 2024 (NREL 2024). The ReEDS model version is based on the version used for the 2024 Standard Scenarios report (Gagnon et al. 2024a).[14]

ReEDS projects generation and capacity for each of 134 model zones (Figure 5, left). For each zone, UPV, land-based wind, and geothermal deployment options are represented using multiple resource classes (representing differences in performance for sites in the zone) and cost bins (representing differences in transmission interconnection costs) based on aggregation of the high-resolution site-level data from reV. The regional, class, and bin information is used for downscaling (Section 2.3). Existing and new transmission is also modeled between the 134 model zones, but ReEDS also treats interregional transmission, transmission between the

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[13] https://github.com/NREL/ReEDS-2.0

[14] There were two main updates made to the 2024 Standard Scenarios version from the older model version used here: 1) State offshore wind mandates in the 2024 Standard Scenarios include a *minimum* requirement of 53 GW of offshore wind deployment based on policies from October 2024, whereas our version represents state policies as of June 2023 (49 GW); 2) ReEDS represents existing and under-construction facilities using U.S. Energy Information Administration data (EIA 2024). In the model version used here, this process unintentionally omitted 25 GW of hybrid PV-battery capacity from the EIA data. However, this omission is unlikely to significantly alter the total amount of PV or battery capacity in the scenarios given the large deployment in the scenarios.

planning subregions (Figure 5, right)—differently than intraregional transmission as explained next.

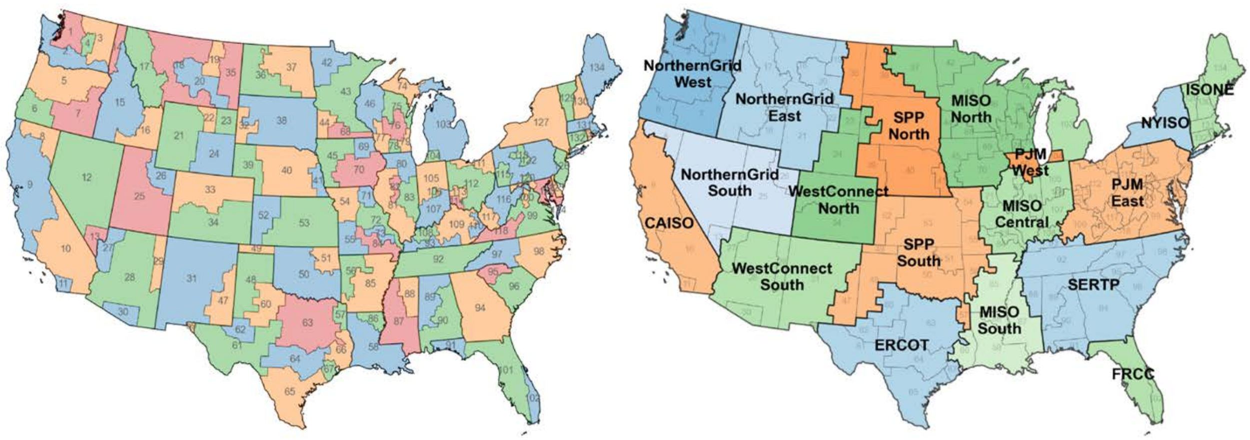

Figure 5. ReEDS model zones (left) and transmission planning subregions (right)

CAISO = California Independent System Operator; SPP = Southwest Power Pool; MISO = Midcontinent Independent System Operator; ERCOT = Electric Reliability Council of Texas; ISONE = ISO New England; NYISO = New York Independent System Operator; SERTP = Southeastern Regional Transmission Planning; FRCC = Florida Reliability Coordinating Council

Seven scenarios of the U.S. power sector were modeled. All scenarios were designed to achieve 100% carbon-free electricity by 2035 (100% by 2035) and assume electrification-driven demand growth that is consistent with achieving a net zero energy system by 2050. The 100% by 2035 target is represented as a constraint on net CO_2 emissions from the power sector (Figure 6, left) which enforces CO_2 emissions to be less than 480 million metric tons (MMT) by 2030 (80% reduction from 2005 levels), and 0 MMT by 2035 and for all subsequent years.[15] Existing policies as of June 2024, including the Inflation Reduction Act tax credits, Clean Air Act Section 111 regulations, and state renewable portfolio and clean energy standards, are also included in all scenarios (Gagnon et al. 2024a).

Demand growth assumptions are from the "Central" case of the 2022 Annual Decarbonization Pathway (Haley 2022) and result in a compound annual growth rate of 2.7%/year in U.S. load from 2021 to 2050 (Figure 6, right). Hourly demand is also assumed to change in these scenarios with winter peak demands growing faster than other seasons because of buildings electrification, particularly in cold weather regions. The demand trajectory shown by Figure 6 (right) includes direct end use demand only; transmission, distribution, and storage losses would require greater

[15] The CO_2 constraint is modeled on a "net" basis, meaning gross emissions from fossil-based generation can be offset by negative emissions technologies. BECCS is the only negative emissions technology included in this analysis and it is allowed to offset emissions only from fossil fuel-fired plants with CCS, according to our definition of 100% by 2035. Enforcing the constraint in this way requires all fossil fuel capacity without CCS to be retired by 2035. The CO_2 constraint limits emissions from direct combustion as well as upstream emissions from methane leakage. Methane leakage assumptions are from DOE (2024e).

generation than the demand shown, and electrolytic hydrogen production would increase electricity demand beyond the values shown.[16]

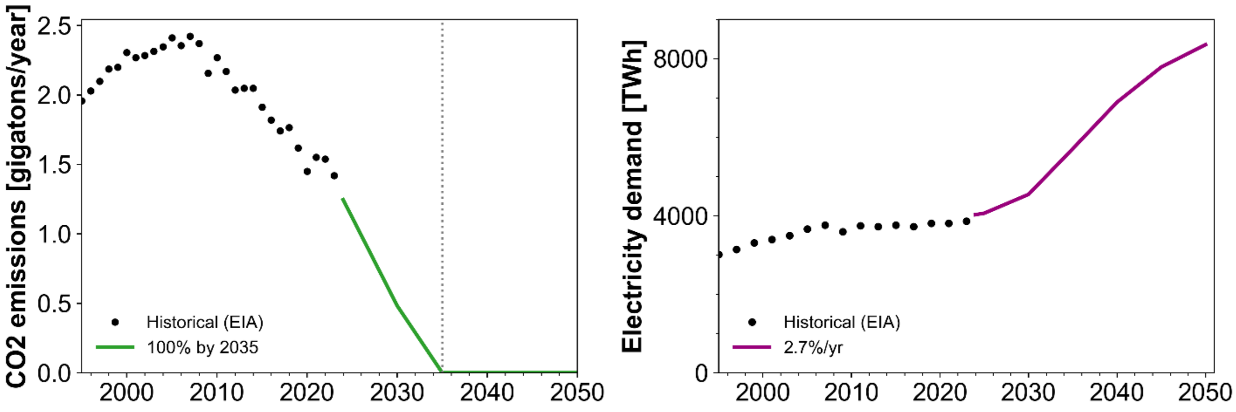

Figure 6. The 100% by 2035 CO_2 constraint (left) and annual demand growth (right) assumed in all scenarios

Black dots show historical emissions and demand (EIA 2024); TWh = terawatt-hours.

Achieving 100% by 2035 requires a significant change to the power system and previous studies (Denholm et al. 2022; U.S. Department of Energy 2024e) examined cost implications, deployment challenges, and technology pathways for reaching this level of decarbonization. We do not seek to replicate these prior studies but instead model scenarios that result in diverse portfolios for use in evaluating deployment on federal lands. Specifically, the scenarios are designed to capture a wide range of UPV, land-based wind, and geothermal deployment outcomes within the context of achieving 100% by 2035 using the latest available data. To capture this range, we vary technology, siting, and other major assumptions across the seven scenarios (Figure 7). Unless otherwise specified, the scenarios use the default settings,[17] which includes ATB 2024 Moderate costs for all technologies and Reference Access siting for RE technologies and excludes CCS, new nuclear, and EGS capacity. A constrained representation of transmission was also modeled by default.[18]

Figure 7 summarizes the assumptions for the seven scenarios:

- **Many Options** uses more optimistic assumptions for technology available and costs than the default settings. Specifically, fossil fuel- and biopower-based CCS, new nuclear, and EGS technologies are assumed to be commercially available for deployment after 2030. ATB 2024 Moderate costs are used for CCS and new nuclear technologies. This scenario also includes lower UPV, land-based wind, EGS geothermal and hydrothermal geothermal costs, based on the ATB 2024 Advanced case. Consistent with the default

[16] Hydrogen production and consumption are modeled endogenously in ReEDS with the same methods and assumptions as in DOE (2024e).
[17] Other assumptions are consistent with those from the 2024 Standard Scenarios Mid-case (Gagnon et al. 2024a).
[18] This includes restrictions to new transmission capacity between the 11 planning regions, an aggregation of the 18 transmission planning subregions (Figure 5, right). It also assumes double the transmission costs from the standard assumptions used in ReEDS (Gagnon et al. 2024a; DOE 2024e). A hurdle rate of $10/MWh is also applied for all electricity trades between the 18 planning subregions.

settings, all other generation and storage costs use the ATB 2024 Moderate assumptions. Many Options also includes more optimistic assumptions for transmission, including allowing interregional transmission expansion, lower hurdle rates between planning regions, and lower transmission costs.[19]

- **Limited Options** represents a future with stringent constraints to UPV and wind siting by using the Limited Access siting cases for both technologies. It also includes higher UPV, land-based wind and geothermal costs, based on the ATB 2024 Conservative case. In addition, it includes greater adoption of distributed rooftop PV, which does not face land use issues.[20] Consistent with the default settings, Limited Options does not allow for the deployment of CCS, new nuclear, or EGS and assumes constrained transmission.

- **Federal Lands Favorable** uses the Limited Private siting cases for UPV and wind, which assume stringent constraints to siting on non-federal lands and reference siting conditions on federal lands. All else being equal, this scenario leads to more favorable conditions for developing on federal lands.

- **Solar & Storage Favorable** assumes lower cost assumptions for UPV and batteries from the ATB 2024 Advanced case. Conversely, higher projected costs (from the ATB 2024 Conservative case) are used for land-based wind and geothermal. Wind siting is also assumed to be more constrained; the Limited Access siting case is used for land-based wind.

- **Wind & Transmission Favorable** assumes lower costs for land-based wind (ATB 2024 Advanced) and fewer constraints on transmission relative to the default settings. Transmission assumptions are the same as those from the Many Options scenario. In addition, higher costs are assumed for UPV and geothermal (ATB 2024 Conservative) and Limited Access is used for UPV siting.

- **Geothermal Favorable** expands the geothermal technologies available and assumes lower costs for new geothermal projects. EGS can be deployed starting after 2030 in this scenario and the ATB 2024 Advanced projections are used for both EGS and hydrothermal technologies. In addition, UPV and land-based wind costs are projected to improve at slower rates (ATB 2024 Conservative) and siting of both these technologies is also assumed to be more constrained (Limited Access).

- **CCS & Nuclear Favorable** assumes CCS is commercially available after 2030 and new nuclear capacity can be deployed starting at that same time. CCS options include new

[19] Interregional hurdle rates start at $10/MWh but decline to $0/MWh by 2050. New transmission costs are half those assumed in the default settings; that is, in this scenario they are the same as the standard assumptions used in Gagnon et al. (2024a) and for the core cases from DOE (2024e).

[20] Rooftop PV trajectories are from the 2023 Standard Scenarios report (Gagnon et al. 2024b) based on modeling from the Distributed Generation (dGen) model (Sigrin et al. 2016). Limited Options uses the 95% by 2035 dGen scenario, which results in 96 GW of rooftop PV by 2035 and 149 GW by 2050. The default settings (used in the other six power sector scenarios) use the Mid-Case dGen scenario, which includes 74 GW by 2035 and 108 GW by 2050.

fossil fuel (natural gas combined cycle and coal-fired) power plants with CCS, upgrades to existing fossil power plants to include CCS, and biopower with CCS. New nuclear capacity includes large and small nuclear. In addition, the Limited Access siting cases are used for UPV and wind in this scenario. ATB 2024 Moderate costs are used for all technologies.

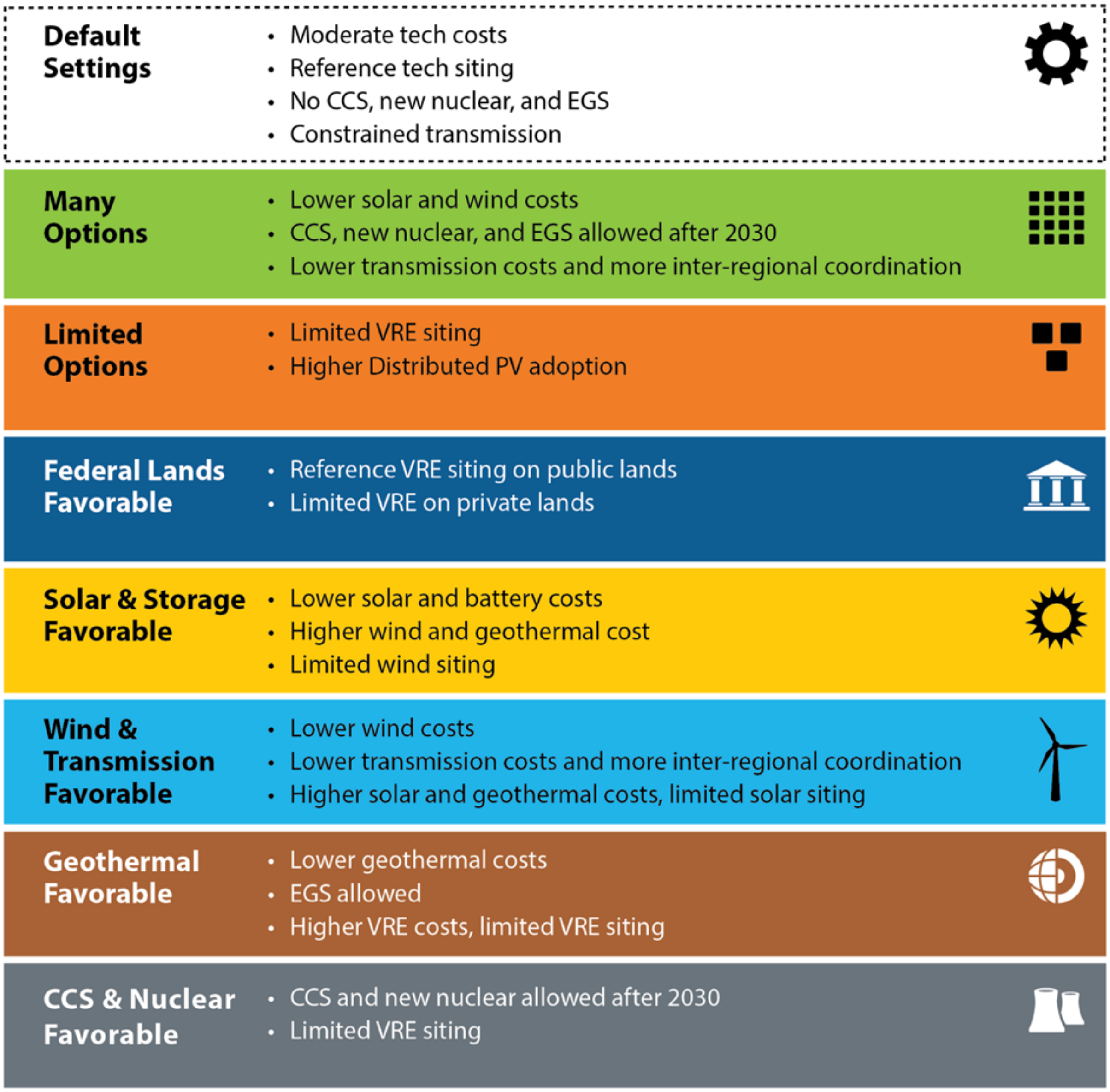

Figure 7. Power sector modeling scenario framework

2.3 Downscaling Methods

As described in Section 2.2, the spatial resolution for the ReEDS deployment estimates is represented by the 134 model zones (Figure 5, left). This resolution is not sufficient to determine the land use, land type, and land ownership of the projected deployment capacity. In other words, ReEDS model outputs by themselves are insufficient to determine how much federal land might be used for renewable energy. Downscaling is a modeling process used to allocate the regional deployment of RE to individual project sites. In doing so, the land ownership and other land use characteristics can be analyzed.

Our downscaling approach relies on the connections between reV and ReEDS. Because the individual project sites in reV (at 11.5 km resolution) are aggregated and used as inputs in ReEDS, downscaling disaggregates the ReEDS zonal deployment estimates back to the reV input data resolution. The disaggregation step conforms with the resource classes and cost bins used in ReEDS to characterize the resource potential within each model zone (Section 2.2). The projected capacity outputs from ReEDS are tracked for each zone-class-bin combination and our disaggregation process ensures matching of this capacity for the subset of reV project sites belonging to the same zone-class-bin. This matching is necessary for the disaggregated results to be consistent with the ReEDS investment decisions in terms of plant performance and interconnection costs.

Although downscaling is constrained as described previously, there is still some uncertainty in the land used for deployment within each zone-class-bin combination. This uncertainty applies to both the individual project sites and the portions of land used within those sites that could be used for deployment. In other words, downscaling introduces further uncertainties to our analysis. To quantify this uncertainty, we modeled three different land use preferences in the downscaling procedure:[21]

- The **Prefer Non-Federal Case** allocates capacity to non-federal lands first (up to the resource potential available on those lands) and only the remaining capacity is allocated to federal lands. This represents the minimum amount of federal land area that could be used while retaining consistency with the ReEDS deployment outcomes.

- The **Minimize Spur Lines Case** uses a downscaling process that ignores land ownership and, instead, allocates capacity to sites closest to points of interconnection (POIs; either substations or transmission lines) on the existing transmission network.

- The **Prefer Federal Case** is opposite the Prefer Non-Federal Case, where capacity is allocated to federal lands first with the remainder placed on non-federal lands. This represents a case where deployment is prioritized on federal lands while remaining consistent with the ReEDS investment choices.

2.4 Modeling Context and Limitations

The analysis approach is designed to serve the core objectives of this study: to estimate RE technical potential and future deployment on federal lands. There are several modeling limitations to the analysis given the complexities of RE deployment and federal land management. The estimated ranges are intended to partially address many uncertainties, but we

[21] In the Prefer Federal and Prefer Non-Federal cases, the priority ordering of land use among federal land administrators is as follows: DOE, BLM, USFS, DOD, FWS, Other Federal.

list the following key methodological limitations—in addition to the scope limitations described in Table 1—and context to appropriately interpret our results:

- The methodology was applied consistently for all locations in the CONUS, but further assessment is needed for any individual site given limited data availability and model resolution.

- The models and data are only available for locations in the contiguous United States. Alaska, Hawaii, and the U.S. territories have separate power grids, a smaller share of total U.S. electricity demand compared to the CONUS, and unique land use considerations. Future work would be needed to consider these factors to evaluate RE potential and deployment on federal lands in these locations.

- GIS data for federal land administration used in this analysis were compiled from multiple sources (Bureau of Land Management 2024; U.S. Forest Service 2024; Office of the Assistant Secretary of Defense for Energy, Installations, and Environment 2022; U.S. Fish & Wildlife Service 2024; U.S. Geological Survey 2014). These datasets were sourced directly from all agencies and represent the most authoritative and detailed publicly available datasets for each partner federal land administrator (BLM, USFS, DOD, FWS, and DOE). Nonetheless, many of these datasets are meant for representative purposes only and may be mapped at scales that do not precisely correspond to all legal land boundaries. Lands withdrawn from the BLM for military use are classified as DOD lands. DOE lands only include the five sites included in the Clean Up to Clean Energy Program; however, these five sites represent 93% of all DOE sites available in our source dataset (U.S. Geological Survey 2014). Some land units with multiple federal interests may have been duplicated across the source datasets, so there may be limited cases of misattribution, ownership or administration. In these cases of duplication, the assignment was made by giving priority to administrators in the following descending order: DOE, USFWS, DOD, USFS, BLM, Other Federal.

- The technologies evaluated in this study include UPV, land-based wind, and two types of geothermal (hydrothermal and EGS). Including other technologies (e.g., concentrating solar power, offshore wind, advanced geothermal systems) would increase the estimated renewable energy potential on federal lands. Note that the method considers each technology independently therefore the technical potential (in land area or capacity) of multiple technologies cannot be added due to overlapping land areas.

- The projected deployment results were developed within the context of scenarios that achieve 100% carbon-free electricity by 2035 and net zero economy by 2050. Scenarios with less ambitious emissions reductions could result in less deployment on federal and non-federal lands. Conversely, scenarios with higher demand growth or more-stringent emissions reductions target in specific states or regions could result in even more deployment than is envisioned in this study.

- The year indicated for the deployment estimates represents the date the capacity starts operating, e.g., the commercial operation date (COD). Achieving the labeled CODs would require project authorization (including permit and interconnection approvals) in advance of these dates. The current timeline from interconnection request to project CODs is about 5 years for new wind and solar project (Rand et al. 2024). We include estimated interconnection costs but do not model interconnection processes explicitly.

- The deployment estimates did not account for existing proposed or approved projects; the 30 GW of approved projects on BLM lands were not captured in our modeling or downscaling processes largely because of incomplete datasets available. Geothermal thermal resource potential estimates excluded existing geothermal leases and existing plants.

- Technical potential and deployment estimates were based on assumptions available at the time the study was performed; future regulations, policies, technologies, and other factors could alter these estimates.

3 Results

3.1 Technical Potential

We first present the technical potential, measured in terms of available land area, the corresponding developable capacity, and generation potential. Results of the Reference Access case are presented in Section 3.1.1, followed by the more-limited siting access cases in Section 3.1.2. Costs and economic considerations are presented in Section 3.1.3.

3.1.1 Reference Access

Figure 8 shows the portion of the total CONUS land area that is available for development in the Reference Access siting case. The potential developable land area is largest for UPV where 30% of the CONUS (582 million acres) is technically available for UPV development. Of that developable area, 44 million acres (7.6%) are on federal lands. The share of CONUS land available for wind development is smaller but still sizeable (21%; 404 million acres). The smaller relative amount of land available for wind development compared to UPV is largely because of airspace restrictions as well as greater setback requirements for wind.[22] However, the estimated amount of federal land area available for wind deployment (43 million acres) is nearly identical to that for UPV, resulting in federal lands comprising a larger share of total developable area for wind compared to UPV (10.5% vs. 7.6%). Figure 8 (bottom) also shows the total developable land areas for geothermal technologies (hydrothermal and EGS), which are smaller than those estimated for either UPV or land-based wind. We estimate the technical potential of hydrothermal and EGS on federal lands to be 12 million acres and 27 million acres, respectively. However, the geothermal resource is primarily located in the western half of the country and has strong spatial overlap with federal lands. In the Reference Access case, 19% and 14% of the developable land is federal for hydrothermal and EGS resources, respectively.

Figure 9 shows the geographic distribution of developable resource on federal lands. The percentage of each reV site (11.5 km by 11.5 km grid) with developable potential is shown. Only reV sites that overlap at least partially with federal lands are shown. Note there is some overlap in the developable land estimated for the technologies, which means the reported land areas cannot be summed across multiple technologies. Although it is possible to co-locate multiple generation technologies on the same land area, we do not estimate this potential; each of the technologies is modeled independently in the geospatial analysis.

[22] Setback requirements for wind turbines from structures, roads, railroads, and other infrastructures are often based on the maximum tip-height of the turbines. The assumed turbines (Lopez et al. 2025) have a maximum tip-height of 656 ft and a setback requirement of twice this height would be 1,312 ft. In contrast, most setbacks for UPV facilities require only 98 ft.

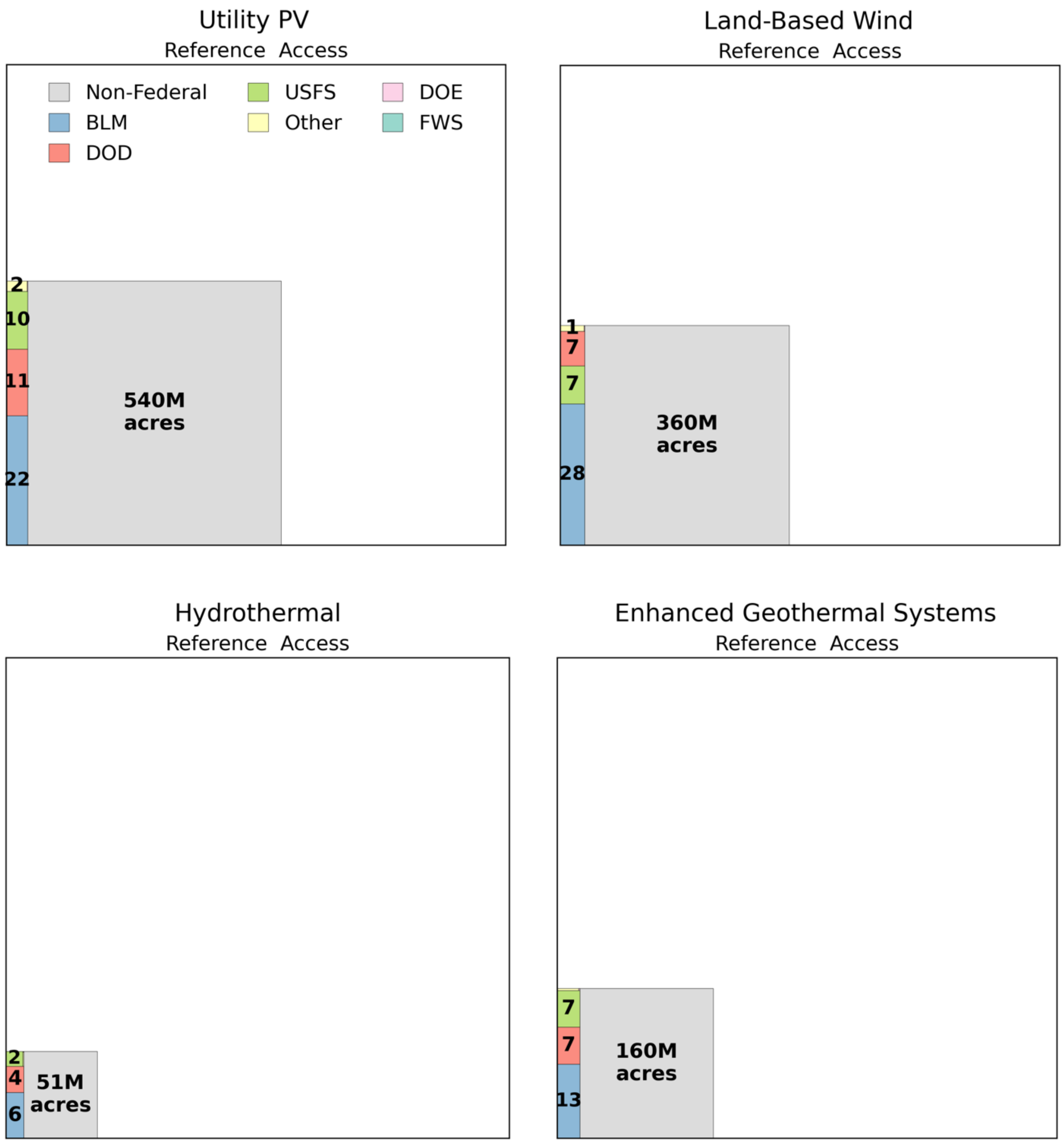

Figure 8. Developable land area

The outer squares are scaled to the area of the contiguous United States (1.91 billion acres). Values shown are rounded and may not sum exactly to totals described in the text. "Other" refers to federal land that is not administered by BLM, USFS, DOD, DOE, or FWS. The developable land areas cannot be summed between technologies because of overlaps.

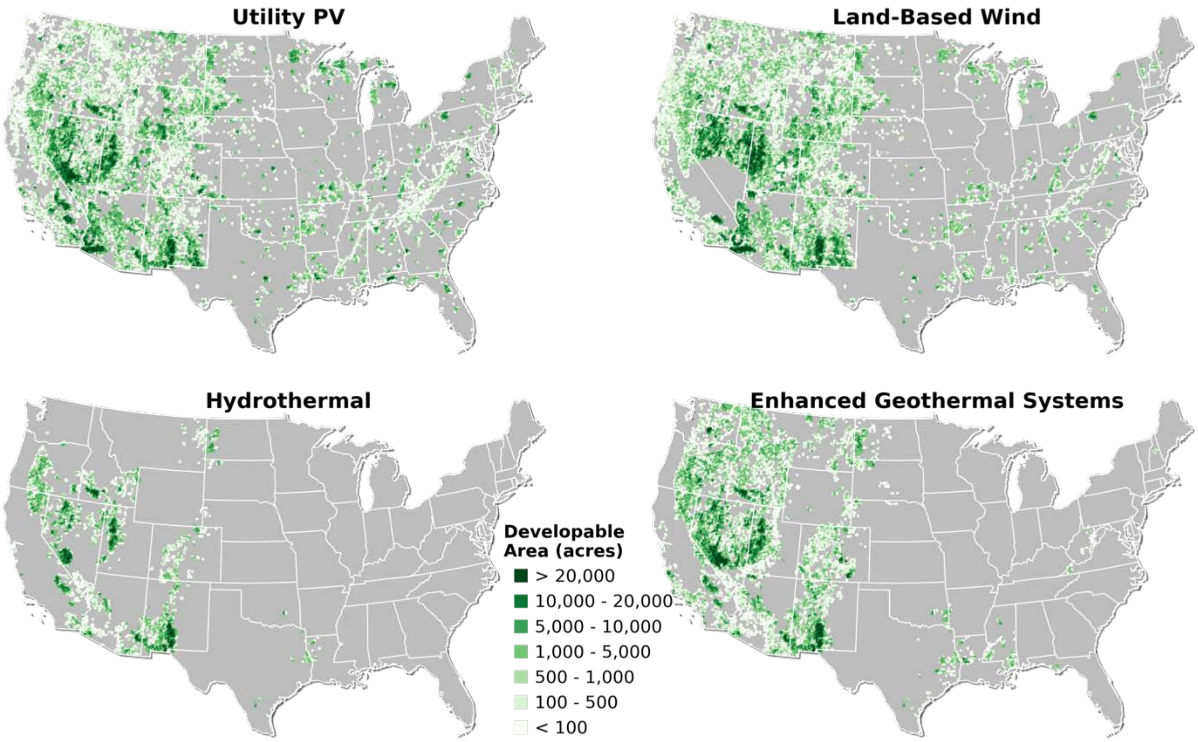

Figure 9. Developable federal land in acres for each (11.5 km) site

The previous discussion focuses on *total* land area, which differs from *direct* land area. A facility's lease area is similar to the total area and greater than the direct area, although lease areas can often exceed the total area. Total area refers to the land associated with the boundary of the RE facility, whereas direct area includes only the subset of that land that is disturbed (e.g., for access roads, electrical equipment, solar panels, turbine pads, and well pads). The remaining land could be available for other uses, such as livestock grazing or recreation but would be predicated on the land utilization intensity of the individual project. The share of total land area that is disturbed can vary by technology and project. For our analysis we assumed 90% of total land is directly utilized for UPV and 1.1% for geothermal. Given the common multiple uses of land around wind turbines, direct land use for wind cannot be simply assumed as a fraction of total land area. Instead, a direct land use factor of 2.3 acres/MW is assumed for land-based wind (Diffendorfer et al. 2019).[23] For rent calculation purposes, the BLM has established encumbrance factors of 5% for wind and 100% for solar to account for the extent of the use (BLM Solar and Wind Rule 2024). Total and direct land use estimates for the future scenarios are reported in Sections 3.2 and 3.3.

How much generation capacity can be installed on a given total area, which is referred to as the capacity density, also varies by technology and location. For UPV, the capacity density is uniformly assumed to be 43 MW_{DC}/km^2 (5.7 acres/MW_{DC}).[24] Capacity densities for wind can

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[23] For most sites, this represents less than 5% of total area.
[24] Unless otherwise noted, all capacity values are presented in alternating current (AC) terms. For UPV, we assumed an inverter loading ratio of 1.3; that is, 1.0 MW_{AC} (of the inverter) is equivalent to 1.3 MW_{DC} (of the PV panels).

vary depending on the interactions between terrain, siting factors, turbine layouts, balance-of-system costs, and wake losses. These factors are captured in the reV model (Stanley et al. 2022; Lopez et al., 2025) and result in typical capacity densities ranging from 4 MW/km^2 to 14 MW/km^2 (18–61 acres/MW). Location-varying capacity densities are also modeled for geothermal using the Geothermal Electricity Technology Evaluation Model (GETEM) in reV and typically range between 2.4 MW/km^2 and 2.7 MW/km^2 for hydrothermal and between 5.8 MW/km^2 and 8.8 MW/km^2 for EGS (Lopez et al. 2025). Capacity density is closely correlated with subsurface temperature, and the wide range of capacity densities for EGS relative to hydrothermal reflects its larger range in temperature estimates at the two depths (4 km and 6 km) where EGS was modeled.

Table 5 summarizes the capacity density and land use requirement assumptions used for our analysis.

Table 5. Land Use Assumptions

	Total: Land associated with the boundary of the RE facility	**Direct**: Disturbed land, including access roads and electrical equipment.
UPV	Space within the fenced area of the solar facility; capacity density = **43 MW_{DC}/km^2** or 5.75 acres/MW_{DC}[a,b]	Includes solar panels and disturbed area between panels; **90% of total** or 39 MW_{DC}/km^2[c]
Wind	Developable land within the wind facility extent; capacity density = **4.1-13.7 MW/km^2** or 18.0-60.3 acres/MW[d,e]	Includes wind turbine pads but not spacing between turbines; **0.0093 km^2/MW or 2.3 acres/MW**[d]
Hydrothermal	Space leased for subsurface development for a geothermal facility; capacity density = **2.4-2.7 MW/km^2** or 91.5-103 acres/MW[e,f]	Includes power plant and well pads; **1.1% of total**[f]
EGS	Space leased for subsurface development for a geothermal facility; capacity density = **5.8-8.8 MW/km^2** or 28.1-42.6 acres/MW[e,f]	Includes power plant and well pads; **1.1% of total**[f]

[a] Bolinger and Bolinger (2022), [b]Lopez et al. (2023), [c]Ong et al. (2013), [d]Diffendorfer and Compton (2014), [e]Lopez et al. (2025), [f]Cruce et al. (2020). Interquartile ranges for all reV sites are shown for wind and geothermal technologies.

Capacity densities for wind and geothermal are an output of the reV model. There are different methods to determine capacity density (Harrison-Atlas, Lopez, and Lantz 2022). For this analysis, we calculated capacity density on a per-reV site basis and accounted only for the developable land (lands remaining after exclusions are applied) in the denominator. This leads to higher capacity densities than many reports for wind but is a more accurate accounting for technical potential analysis. The uniform capacity density assumption for UPV leads to a one-to-one relationship between capacity potential and available land area, but the site-specific capacity densities for wind and geothermal are more complex. Nonetheless, comparing Figures 9 (land area) and 10 (capacity) shows an obvious relationship: having more developable land area leads to greater capacity potential.

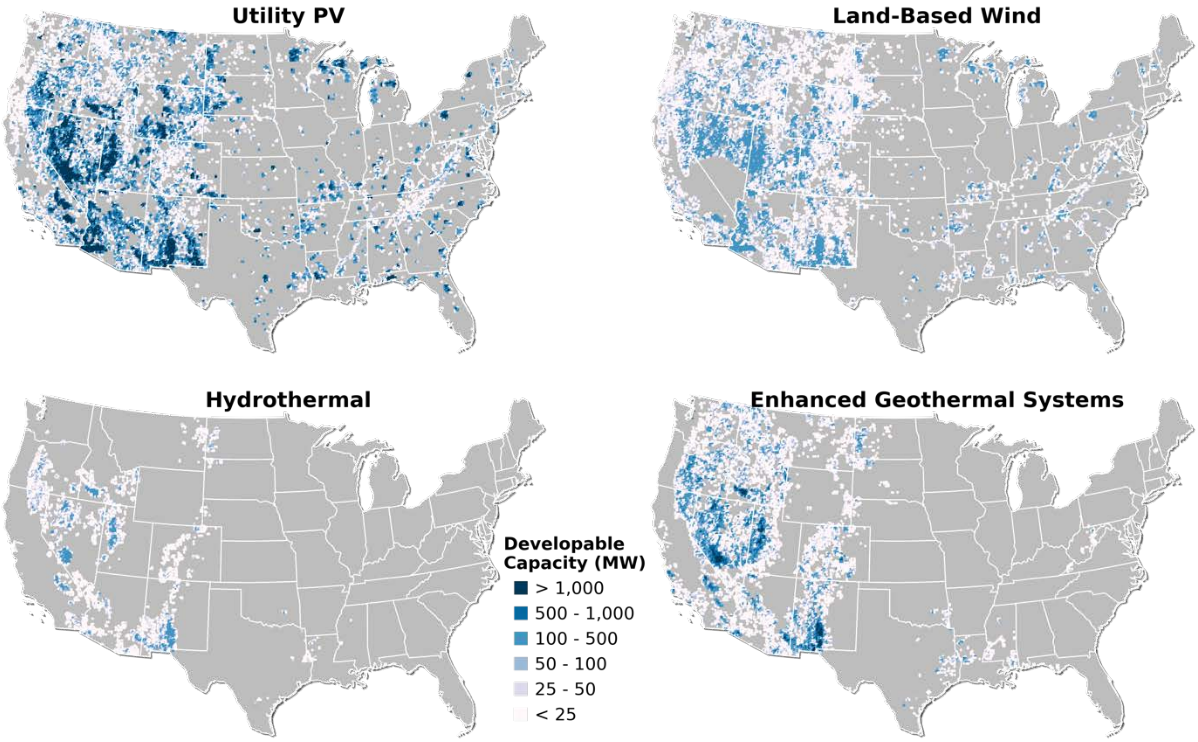

Figure 10. Developable capacity in MW on federal land for each (11.5 km) site

Figure 11 and Table 6 show the breakdown in developable land area and capacity by federal land administrator. The BLM possesses the greatest potential for all technologies, including approximately 2,800 GW of technical potential for UPV, 450 GW of wind potential, and nearly 600 GW of geothermal potential. The technical potential estimates are similar between USFS and DOD with 1,250 GW and 1,450 GW solar potential, respectively for the two agencies, and hundreds of GW potential for wind and geothermal. The technical potential for DOE is approximately 6 GW for UPV and is in the MW scale for other technologies. There is negligible technical potential on FWS land. Other federal land administrators possess additional technical potential.

As is clear from Figure 11, the capacity potential for UPV is much larger than the potential for the other technologies on federal lands because of UPV's greater capacity density. Across all federal lands, the technical potential for UPV is about 5,750 GW. Hydrothermal resources are most limited, yet there is still >130 GW of potential on federal lands. Success of EGS would expand the geothermal resource on federal lands by nearly an order of magnitude (more than 1,000 GW combined for hydrothermal and EGS). Land-based wind potential on federal lands is similar in magnitude to EGS (875 GW vs. 975 GW). As noted previously, these capacity potentials cannot be combined across multiple technologies given the spatial overlap of the assessed developable lands. Nonetheless, the results indicate there is a large amount of technical potential on federal lands among multiple RE technologies.

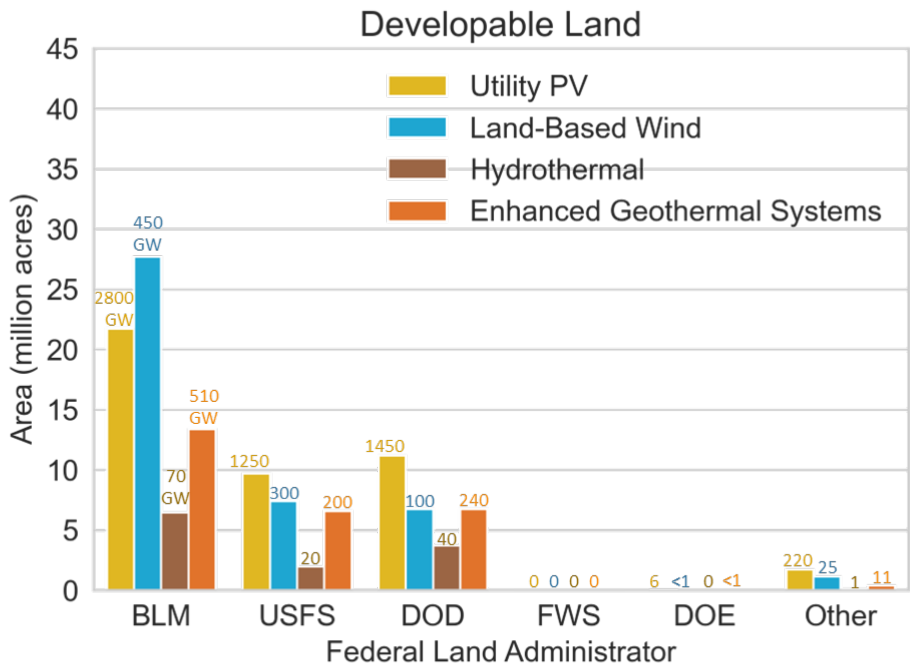

Figure 11. Developable area and capacity by federal land administrator and technology under Reference Access

The developable land areas and capacities cannot be summed between technologies because of overlaps. The bars refer to the total land area (y-axis) and the values on the top of each bar are the corresponding capacity potential (in GW units) for this land area.

Table 6. Technical Potential Under Reference Access

Land Administrator	Technology	Total area (million acres)	Capacity (GW)	Maximum Annual Generation (TWh)[a]
BLM	UPV	21.7	2,819	7,413
	Wind	27.7	452	1,071
	Hydrothermal	6.43	70	518
	EGS	13.4	512	3,815
USFS	UPV	9.67	1,256	2,873
	Wind	7.41	298	806
	Hydrothermal	1.96	21	157
	EGS	6.56	206	1,532
DOD	UPV	11.2	1,449	3,947
	Wind	6.72	96	249
	Hydrothermal	3.72	39	291
	EGS	6.71	244	1,817
DOE	UPV	0.0470	6.1	15
	Wind	0.0247	0.61	1.5
	Hydrothermal	0.00375	0.047	0.35
	EGS	0.0186	0.41	3.0
FWS	UPV	0.000104	0.013	0.031
	Wind	0.0000403	0.0018	0.0055
	Hydrothermal	0.00000289	0.000029	0.00022
	EGS	0.0000167	0.0004	0.003
Other Federal	UPV	1.70	220	538
	Wind	1.14	26	66
	Hydrothermal	0.102	1.1	8.4
	EGS	0.360	11	85
All Federal	UPV	44.3	5,751	14,785
	Wind	43.0	873	2,195
	Hydrothermal	12.2	131	975
	EGS	27.0	974	7,252
All CONUS (Federal + Non-federal)	UPV	582	75,613	181,072
	Wind	404	9,308	30,213
	Hydrothermal	63.0	671	4,997
	EGS	187	5,235	38,977

[a] Generation is based on projected 2035 technologies and site-specific capacity factors. Actual dispatch could result in lower generation values because of curtailment, non-economic dispatch, and degradation. Hydrothermal and EGS generation estimates assume an 85% capacity factor.

The technical potential capacity estimates do not reveal the resource quality. For RE technologies, power plant performance and costs can depend strongly on location. Figure 12 shows the annual capacity factor for all potential UPV and wind sites on federal lands and Figure 13 shows the distribution of capacity factors.[25] Locations in the southern latitudes—and especially southwestern locations—have higher UPV capacity factors due to greater insolation. Although there are regional variations in UPV capacity factors, UPV performance is relatively uniform compared to wind. Wyoming, Montana, the Dakotas, and New Mexico have the greatest

[25] Capacity factor is defined as the amount of electrical energy that can be produced over a period (e.g., per year) considering the availability of the resource and plant losses divided by the amount of electrical energy that could be produced if that plant was available and operating at full capacity for the entire period.

concentration of wind sites on federal lands with high capacity factor (>40%), but there are high capacity factor federal wind sites also in the Great Lakes region and spread throughout the country. The hourly dispatch of geothermal power plants is less dependent on the underlying resource[26] and therefore regional variations in capacity factors are not shown. Table 6 shows the annual generation potential for geothermal assuming 85% capacity factor in all locations.

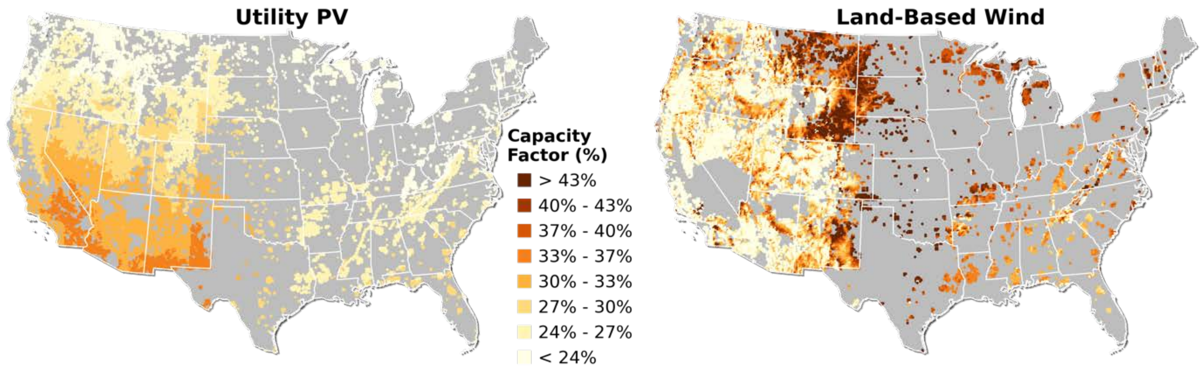

Figure 12. Land-based wind and UPV capacity factor for sites with federal land

Capacity factors are based on projected 2035 technologies from ATB 2024 Moderate case. The performance is estimated for 1998–2023 and 2007–2013 weather years for UPV and wind, respectively. Capacity factor is defined using AC capacity for both the numerator and the denominator.

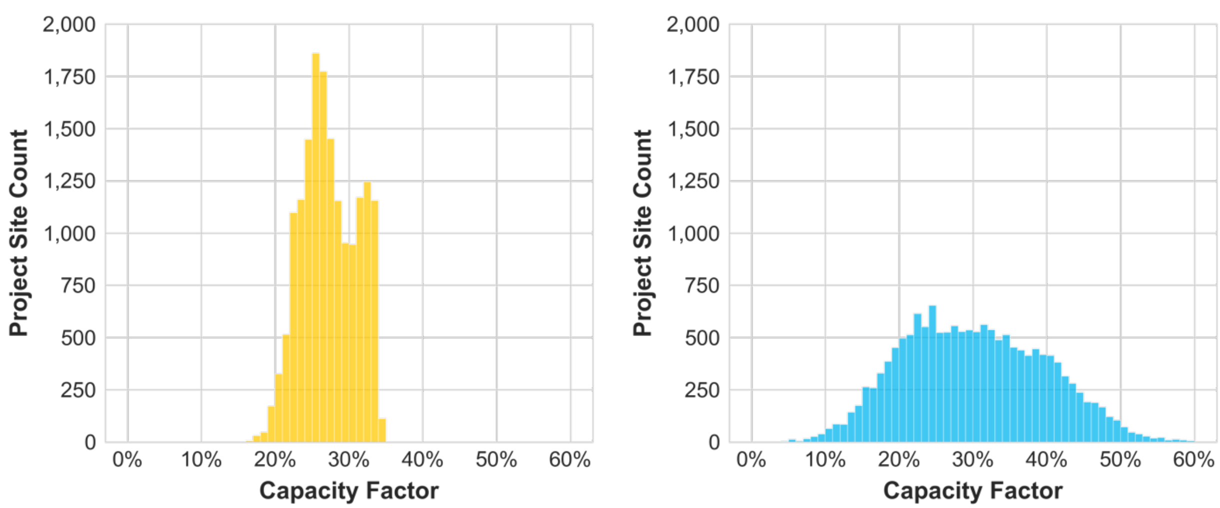

Figure 13. Land-based wind and UPV capacity factor distributions for all potential sites on federal lands

Capacity factors are based on 2035 technologies. Capacity factor is defined using AC capacity for both the numerator and the denominator.

[26] The amount of generation capacity of geothermal power plants is affected by ambient temperatures; therefore, geothermal plants can have different seasonal capacities and capacity factors. Geothermal power plants typically operate at or near their available capacity during any given hour because the variable operating costs are low.

3.1.2 Limited Access and Limited Private

The Limited Access siting case assumes more constraints to UPV and wind siting compared to Reference Access. As a result of these constraints, the developable land area for the CONUS (including both federal and non-federal land) is 53% lower (275 million acres vs. 585 million acres) for UPV (Figure 14) and 65% lower (140 million vs. 405 million acres) for land-based wind (Figure 15). The reduction is even starker for federal lands, where only 15 million acres and 1 million acres are available for UPV and wind development, respectively; only 5% of all developable land is federal for UPV under Limited Access and only 1% for wind.

The capacity potential estimates decline correspondingly to land area reductions under Limited Access. Figure 16 compares the differences in capacity potential between Reference Access and Limited Access. Table 7 summarizes the UPV and land-based wind technical potential estimates in terms of land area, capacity, and annual generation for each federal land administrator, all federal lands, and all CONUS land.

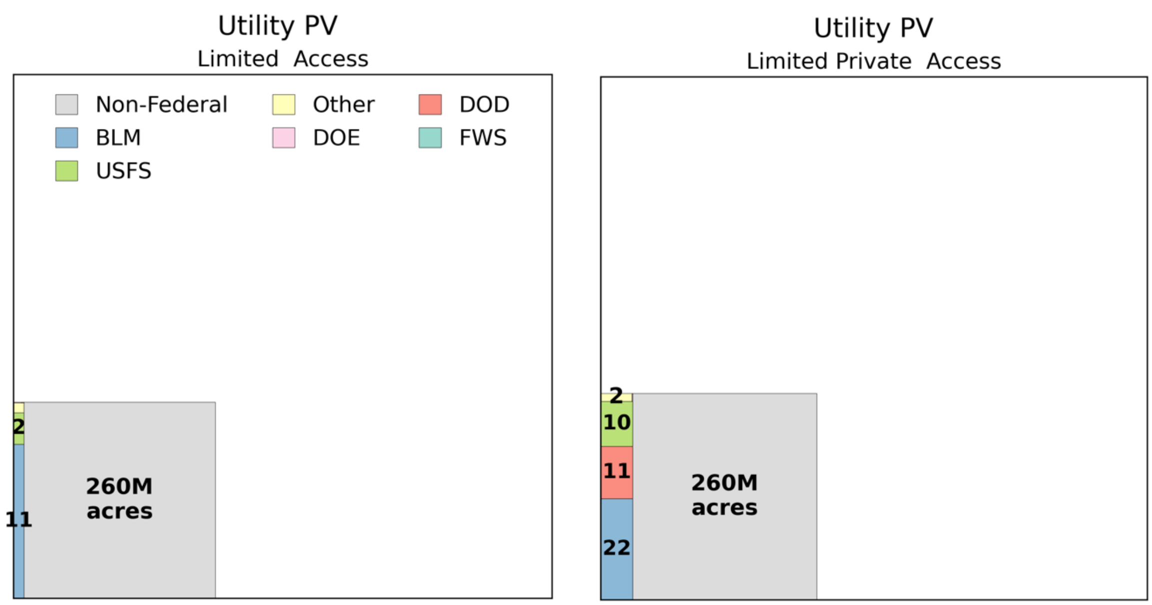

Figure 14. Developable land area for UPV under the more limited siting cases

The outer squares are scaled to the area of the contiguous United States (1.91 billion acres). "Other" refers to federal land that is not administered by BLM, USFS, DOD, DOE, or FWS. The developable land areas cannot be summed between technologies because of overlaps.

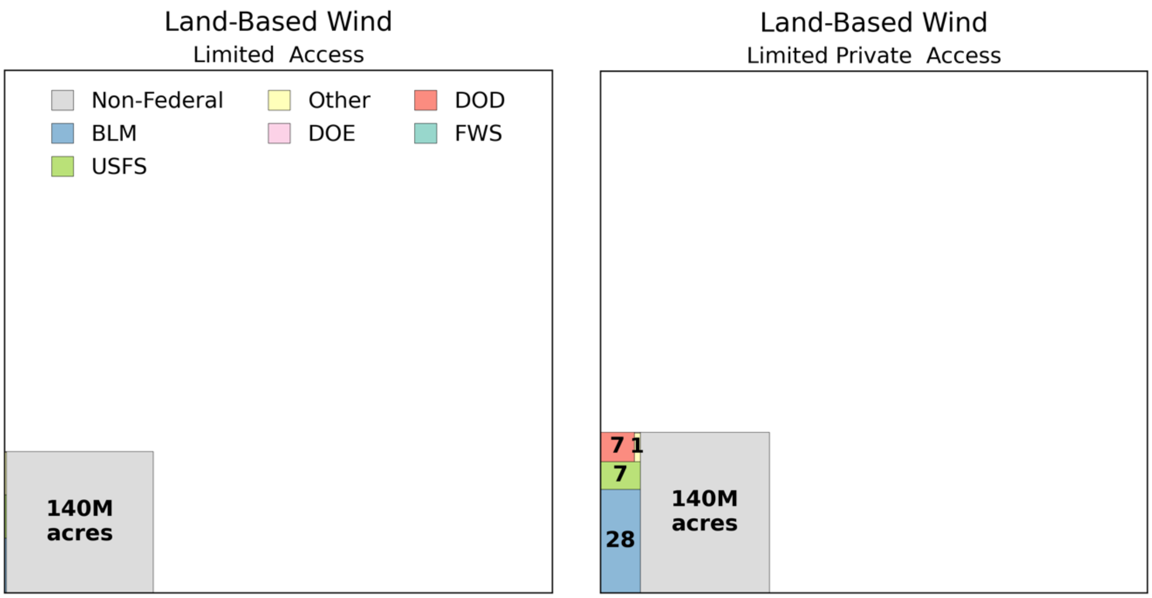

Figure 15. Developable land area for land-based wind under the more limited siting cases

The outer squares are scaled to the area of the contiguous United States (1.91 billion acres). "Other" refers to federal land that is not administered by BLM, USFS, DOD, DOE, or FWS. The developable land areas cannot be summed between technologies because of overlaps.

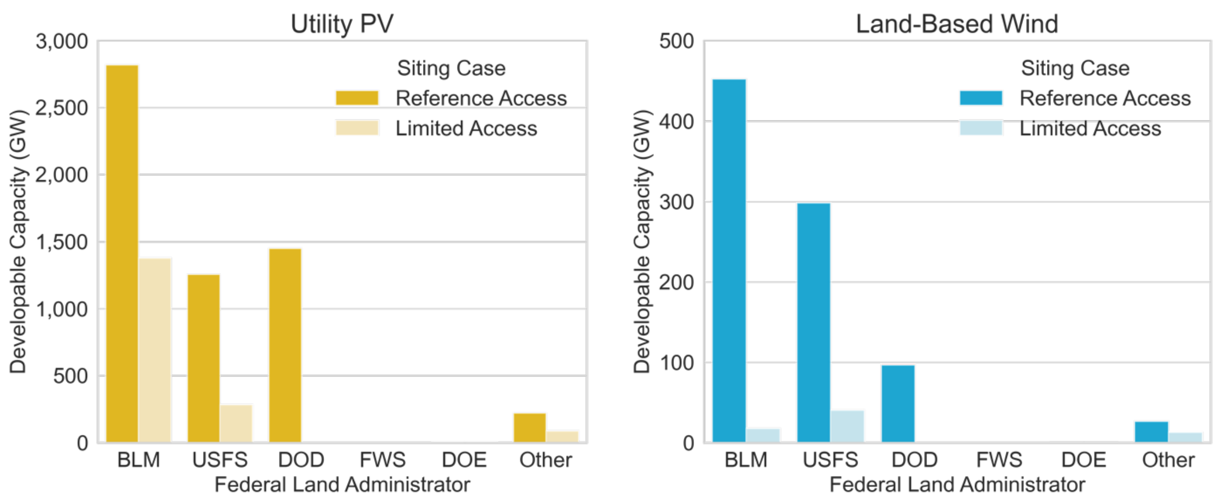

Figure 16. Capacity potential for UPV (left) and wind (right) across siting cases

The Limited Private siting case is a mix between the Reference and Limited Access cases; the RE technical potential on federal lands is from Reference Access (Table 6) and on non-federal lands is from Limited Access (Table 7). As a result, the share of total developable land that is federally administered is greatest in Limited Private. For UPV, 15% of developable land is federal under Limited Private and an even larger share (23%) of developable land is federal for wind. The bottom row of Table 7 shows the total technical potential across the CONUS for this siting case.

Table 7. Technical Potential Under Limited Access

Federal Land Administrator	Technology	Total area (million acres)	Capacity (GW)	Maximum Annual Generation (TWh)[a]
BLM	UPV	10.6	1,378	3,737
	Wind	0.576	18	47
USFS	UPV	2.17	282	592
	Wind	0.454	40	117
DOD	UPV	0.00854	1.1	3.0
	Wind	0.000106	0.017	0.070
DOE	UPV	0.0309	4.0	9.8
	Wind	0.0095	0.32	0.78
FWS	UPV	0.0000525	0.0068	0.016
	Wind	0.00000890	0.00011	0.00033
Other Federal	UPV	0.671	87	213
	Wind	0.445	13	32
All Federal	UPV	13.5	1,752	4,555
	Wind	1.48	71	197
All CONUS (Federal + Non-federal)	UPV	270	35,033	85,461
	Wind	142	4,195	13,989
Limited Private:[b] *All CONUS (Federal + Non-federal)*	UPV	301	39,028	95,684
	Wind	183	5,001	15,994

[a] Generation is based on projected 2035 technologies and site-specific capacity factors. Actual dispatch could result in lower generation values because of curtailment, non-economic dispatch, and degradation. Hydrothermal and EGS generation estimates assume an 85% capacity factor.

[b] The bottom row shows the results for the Limited Private siting case, which uses the technical potential from the Reference Access case for federal lands and the potential from the Limited Access for non-federal lands.

3.1.3 Supply Curves

reV estimates the levelized cost of energy (LCOE) for each site based on the capacity factor and assumed capital, operating, and financing costs.[27] RE supply curves show the LCOE as a function of cumulative technical potential capacity (GW) ordering the sites from lowest LCOE. Figure 17 shows supply curves for UPV and land-based wind on federal lands as assumed under Reference and Limited Access siting cases. Supply curves for geothermal technologies (Reference Access) are shown in Figure 18. LCOEs shown in Figures 17 and 18 are for projected 2035 costs based on the ATB 2024 Moderate case. "Site" LCOEs include infrastructure only within the plant boundaries and exclude interconnection costs, which include transmission spur lines, upgrades at the POI, and broader grid reinforcement costs. "All-in" LCOE adds these interconnection costs to the site LCOE.

[27] The ReEDS power sector model does not choose investments based on LCOEs; locations with higher LCOEs can be selected prior to ones with lower LCOEs because of differences in generation profiles, transmission congestion, or other system requirements (e.g., to meet state policy requirements). LCOEs and supply curves are displayed here to characterize the resource quality but do not translate directly to the deployment results presented in the following sections.

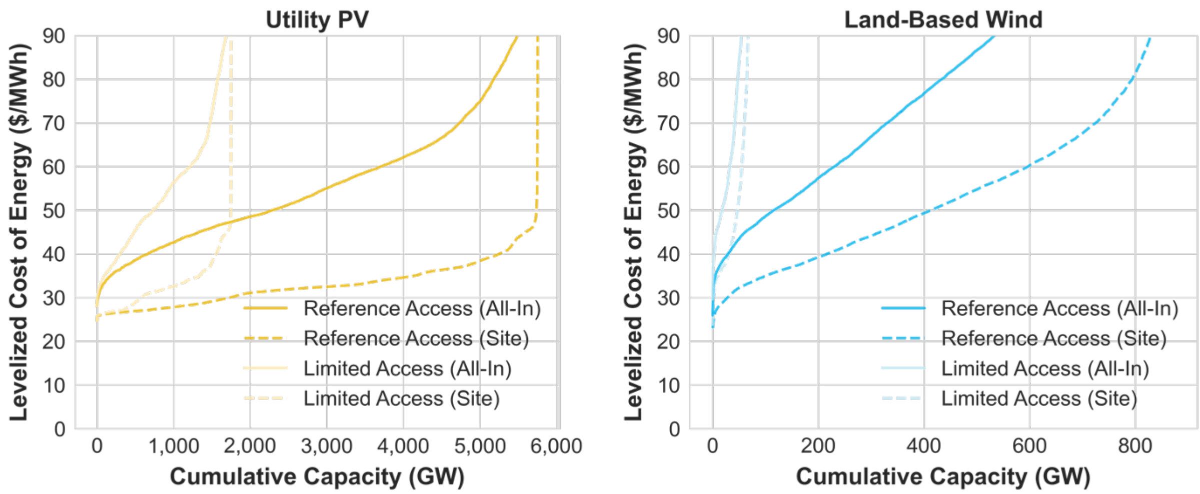

Figure 17. Federal land supply curves for UPV and wind using 2035 technology costs

ATB 2024 Moderate case is used for technology assumptions. All-in LCOEs include grid interconnection costs whereas Site LCOE excludes these costs. LCOEs are without federal tax credits.

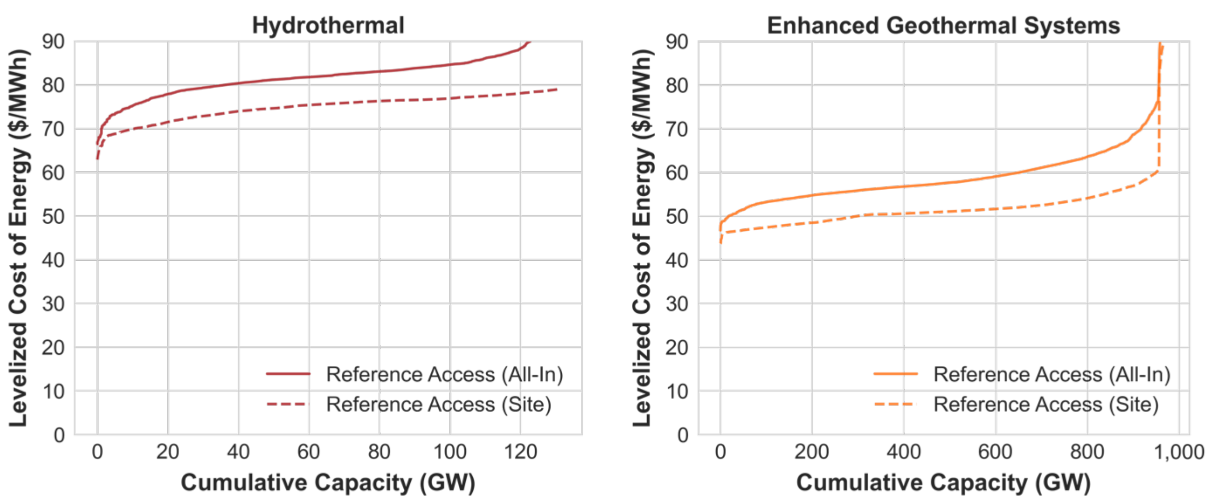

Figure 18. Federal land supply curves for geothermal technologies using 2035 costs

ATB 2024 Moderate case is used for technology assumptions. All-in LCOEs include grid interconnection costs whereas Site LCOE excludes these costs. LCOEs are without federal tax credits.

Site and all-in LCOEs start around $25/MWh for both UPV and wind, indicating there are RE sites on federal lands with very high-quality resources proximate to existing transmission infrastructure.[28] For UPV, the site LCOE supply curve has a relatively shallow slope—because of the uniform and high insolation on federal lands—leading to more than 5,500 GW of capacity available under $45/MWh under Reference Access. Under Limited Access, UPV site LCOEs

[28] Real 2022 dollars are used unless otherwise noted.

increase more rapidly but approximately 1,700 GW with LCOEs under $45/MWh remain available.

However, when considering interconnection costs, the UPV supply curves are much steeper. Using the same $45/MWh upper benchmark for all-in LCOE (instead of site LCOE) results in 1,300 GW and 480 GW of resource available for Reference and Limited Access, respectively. For many locations, interconnection costs are estimated to add $10–20/MWh to the LCOE for UPV. Note there is significant uncertainty in estimating interconnection costs—especially grid reinforcement costs—given the detailed power flow studies needed to assess existing transmission availability and required grid upgrades. We also do not consider how new transmission development could lower interconnection costs and the sensitivity of interconnection costs to processes and reforms (Rand et al. 2024).[29]

The wind supply curves follow a similar trend as UPV; however, the curves are much steeper because of the more varied wind resource quality across sites and the lower capacity density of wind. Under Reference Access, there is approximately 300 GW of developable wind capacity on federal lands under $45/MWh in terms of site LCOE and approximately 60 GW under $45/MWh in terms of all-in LCOE. Much smaller amounts of wind resource are available under Limited Access.

Geothermal LCOEs are typically higher than LCOEs for UPV, and wind and there is less overall variation in costs between geothermal sites.[30] LCOEs for hydrothermal start at about $65/MWh and we estimate about 40 GW of available hydrothermal resource below $80/MWh in all-in LCOE. EGS resources are more abundant and have lower costs with the best sites having an LCOE of about $45/MWh and nearly 650 GW of available capacity below $60/MWh in all-in LCOE. EGS is a newer technology with a handful of deployments compared with hydrothermal, which has been deployed in the United States since the 1970s.

3.2 National Deployment Projections

This section presents national-level results—generation, capacity, and land use—from the power sector modeling analysis. Section 3.3 downscales these results to estimate deployment on federal lands. All seven scenarios modeled in ReEDS achieve 100% carbon-free electricity starting in 2035 and assume increasing demand growth driven by electrification.

3.2.1 Generation

Achieving 100% by 2035 requires increasing generation from low- or zero-emissions technologies to replace the current fossil fuel-based generation and to meet new demands for electricity. Figure 19 shows how a majority of the annual electricity generated in the 100%

[29] Our method (Lopez et al. 2024) uses a geospatial-based approach to estimate these costs, which does not capture all factors that could affect interconnection costs. Because a large share of federal lands is remote from existing transmission infrastructure, our estimation method yields higher interconnection costs compared to regions near dense electrical infrastructure development. This method might overestimate high interconnection costs. Recent empirical studies (Seel and Kemp, n.d.) show increasing interconnection costs especially for RE projects. But we acknowledge this is an important uncertainty in our project cost estimates and future work is needed to assess the transmission and interconnection requirements for RE development on federal lands.
[30] LCOE is not used directly in ReEDS (see Footnote 27).

scenarios is from RE; 64%–86% of total generation is from RE in 2035, and RE generation ranges from 55% to 90% in 2050.[31] Narrowing the RE technologies to the three of focus in this study (UPV, land-based wind, and geothermal) the range in generation share is 50%–78% in 2035 and 42%–83% in 2050. Non-RE generation is from nuclear (10%–18% in 2035) and fossil with CCS (0%–13% in 2035). Note CCS and new (large and small) nuclear are allowed only in two of the scenarios (Many Options and CCS & Nuclear Favorable).[32] Other generation sources include hydrogen-based generation and imports from Canada.

In addition to the increase in RE generation *share* (compared with 21% in 2023), is a significant increase in the absolute amount of RE-based electrical energy. Figure 20 shows how total generation in 2035 ranges from 6,900 TWh to 7,500 TWh, which is a dramatic increase from 4,251 TWh in 2023 (EIA 2024). This increase in generation is needed to meet the much greater direct demand for electricity (Section 2.2.1); accommodate losses in storage, distribution, and transmission; and for hydrogen production and generation.[33] After 2035, growing direct and indirect demand for electricity leads to continued growth in total generation, which reaches approximately 10,000 TWh in 2050.

[31] RE generation includes generation from land-based and offshore wind, solar, geothermal, hydropower and biomass-based energy.

[32] Section 2.2.1 describes how the *net*-zero targets are defined, where fossil without CCS is required to be retired or upgraded to include CCS by 2035 and emissions from fossil-CCS technologies are required to be offset by BECCS. In the scenarios that allow BECCS, generation from BECCS is only approximately 1% in 2035, but such small amount of generation can offset emissions from a significant amount of fossil capacity (Mai et al. 2022). If considered within the 100% definition, other carbon dioxide removal technologies—such as direct air capture—can allow greater amounts of fossil generation and capacity (Denholm et al. 2022).

[33] The modeled scenarios include only electrolytic hydrogen production and electric sector use of hydrogen, which total 15–26 MMT in 2035. Hydrogen use outside the electricity sector would further increase demand for electricity generation. Conversely, other hydrogen production pathways that rely less on electricity would lower the demand for electricity.

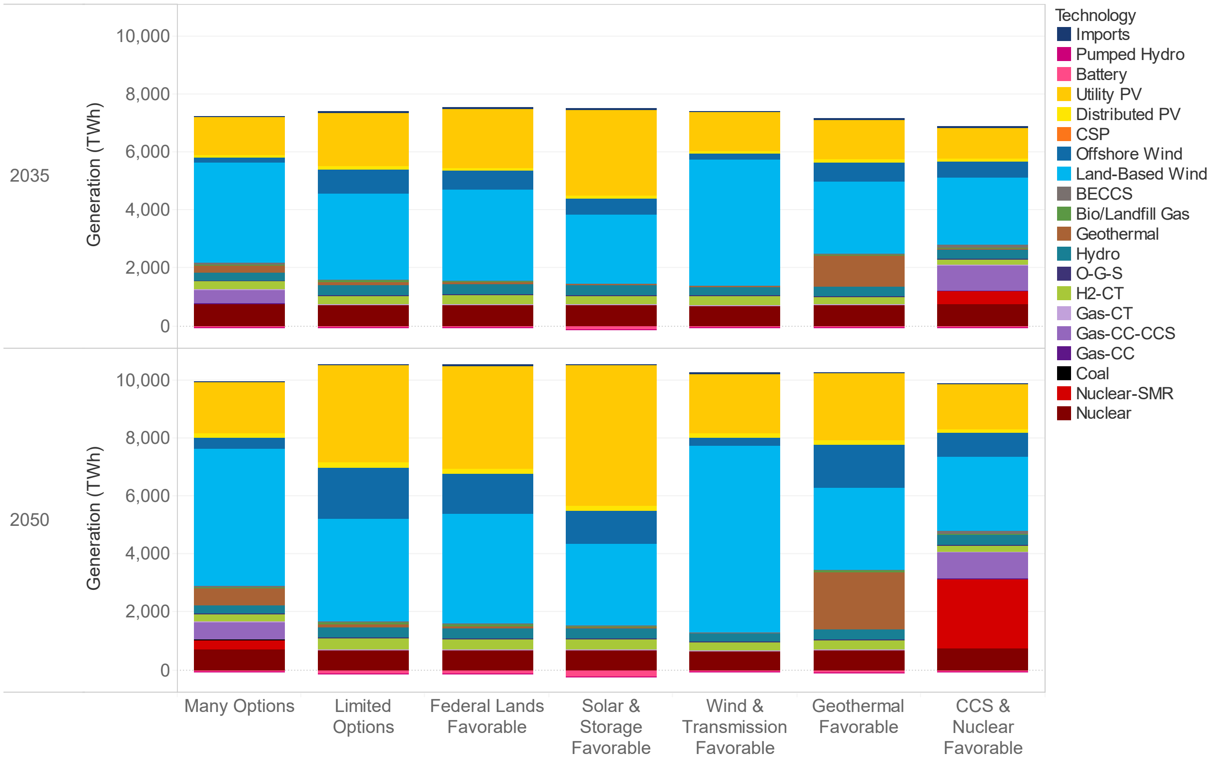

Figure 19. Annual generation by technology in 2035 (top) and 2050 (bottom)

PV = photovoltaic; CSP = concentrating solar power; BECCS = bioenergy with carbon capture and storage; OGS = oil-gas-steam; H2-CT = hydrogen combustion turbine; Gas-CT = natural gas combustion turbine; Gas-CC-CCS = natural gas combined cycle with carbon capture and storage; Gas-CC = natural gas combined cycle; SMR = small modular reactor (also referred to as small nuclear).

3.2.2 Capacity

The capacity needed to meet the 100% by 2035 target and the growing demand assumed in the scenarios is summarized in Figures 20 and 21. Solar and wind capacity are expected to have the most significant growth with TW-scale deployment of each technology class deployed by 2050 across all seven scenarios. UPV capacity estimates range widely from 607 to 1,795 GW in 2035 and 917 to 3,335 GW in 2050. Ranges in land-based wind deployment for the CONUS are also wide with 707–1,207 GW in 2035 and 749–1,979 GW in 2050. There is competition between UPV and wind deployment where scenarios with greatest UPV deployment tend to result in lower amounts of wind deployment and vice versa. Nonetheless, lower-end deployment estimates for these two technologies reflect dramatic growth from the current operating capacity (Figure 2).

Growth in storage capacity, primarily in batteries but also including expansion of pumped-storage hydropower capacity, is closely tied to the growth of solar capacity (Denholm et al. 2020). Under the Solar & Storage Favorable scenario, 400 GW of grid storage is deployed by 2035 with a large majority from 4- and 8-hour-duration batteries. In scenarios with less solar deployment, approximately 150 GW of storage capacity is developed, which still represents an increase from the ~44 GW operating today (U.S. Energy Information Administration 2024).

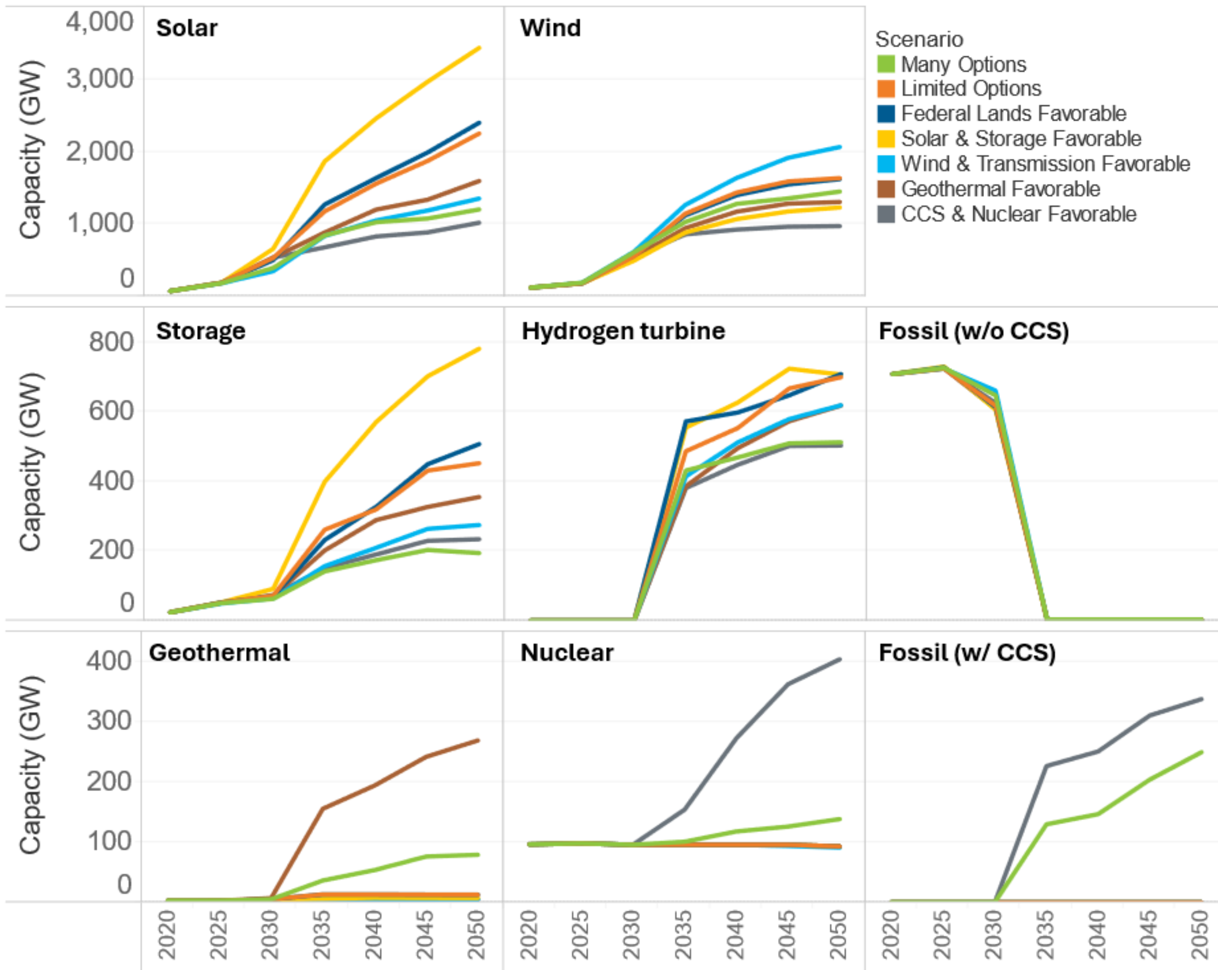

Figure 20. Installed capacity over time

Different scales are used. Solar includes UPV, distributed photovoltaics, and CSP. Wind includes land-based and offshore wind. Storage includes 4- and 8-hour duration batteries and pumped hydropower. Geothermal includes hydrothermal and EGS. Nuclear includes large and small nuclear. Hydrogen turbine includes hydrogen combustion turbines, both new and upgraded facilities. Fossil (w/ CCS) includes gas plants with CCS and BECCS. Fossil (w/o CCS) includes coal, natural gas, landfill gas, and oil-gas-steam plants.

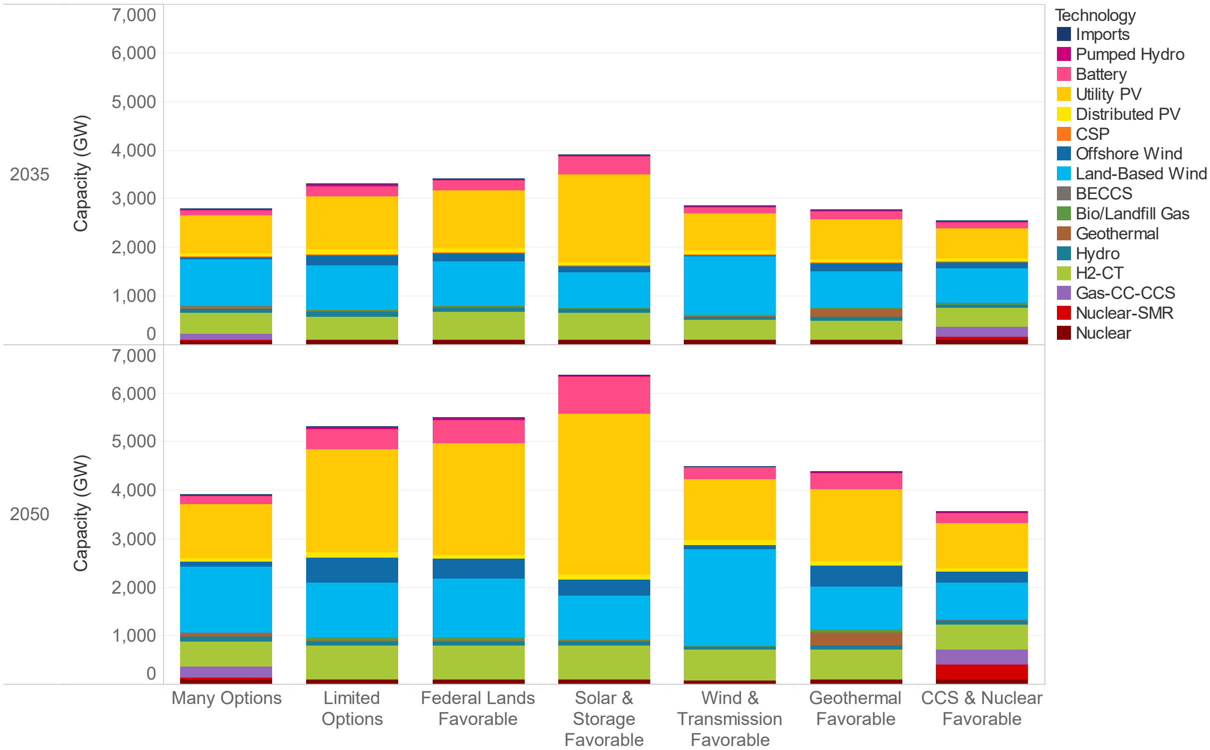

Figure 21. Installed capacity in 2035 (top) and 2050 (bottom)

Battery includes 4- and 8-hour-duration batteries. PV = photovoltaic; CSP = concentrating solar power; BECCS = bioenergy with carbon capture and storage; OGS = oil-gas-steam; H2-CT = hydrogen combustion turbine; Gas-CT = natural gas combustion turbine; Gas-CC-CCS = natural gas combined cycle with carbon capture and storage; Gas-CC = natural gas combined cycle; SMR = small modular reactor (also referred to as small nuclear).

Projected deployment of geothermal is highly sensitive to whether EGS is included in the scenarios. Without EGS, geothermal capacity is projected to range from 5 to 13 GW in 2035 without much further growth through 2050. These narrow ranges reflect the limited estimated hydrothermal resources available. Under the Many Options scenario, the inclusion of EGS expands total geothermal deployment to 36 GW in 2035 and 79 GW in 2050. Geothermal capacity estimates are much greater in the Geothermal Favorable scenario where more optimistic geothermal costs (combined with higher costs and deployment challenges for solar and wind) are used; 156 GW of geothermal capacity is installed by 2035 and 269 GW by 2050 under the Geothermal Favorable scenario with nearly all of that relying on EGS technologies. In addition to increasing the amount of projected geothermal capacity, EGS also expands the locations where geothermal is deployed (Figure 22). Although hydrothermal is deployed almost exclusively in California and neighboring states, EGS enables deployment to many other states and regions.

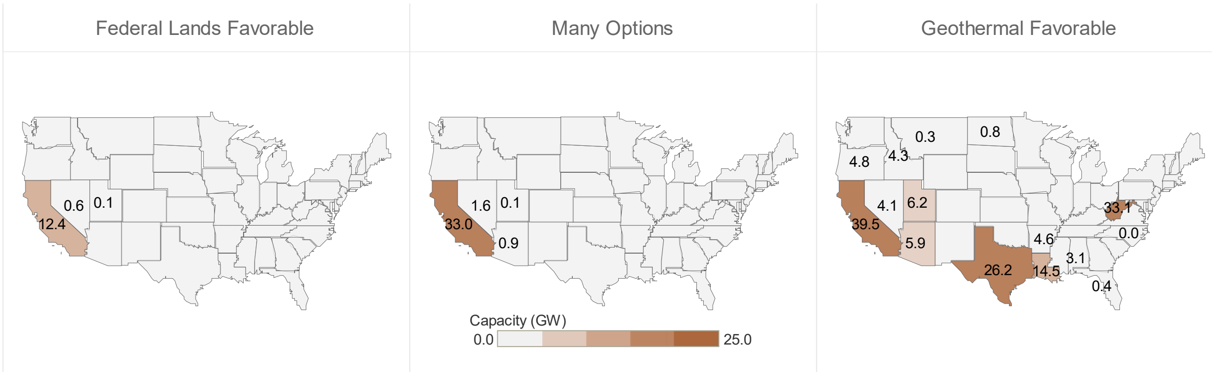

Figure 22. Geothermal installed capacity by 2035 under select scenarios

EGS is allowed only in the Many Options and Geothermal Favorable scenarios.

Figures 20 and 21 show the capacity deployment results for all technologies modeled in ReEDS. CCS and nuclear capacity are deployed in the Many Options and CCS & Nuclear Favorable scenarios. Unsurprisingly, the most significant development of these technologies is found in the CCS & Nuclear Favorable scenario where 350 GW of fossil with CCS and 400 GW of nuclear capacity are installed by 2050.[34] Capacity from hydrogen-based combustion turbines, which includes capacity from both new power plants and retrofits of existing natural gas power plants, grow significantly in all scenarios (500–700 GW by 2050) and replaces a large share of the existing fossil fuel capacity. As discussed in Section 3.2.1, reliance on electrolytic hydrogen in the scenarios increases the demand for electricity and associated generation capacity from UPV, land-based wind, geothermal, and other low-emissions resources. Scenarios with CCS and nuclear deployment result in smaller (but still significant) increases in UPV and wind deployment. Altogether, the scenarios are designed to capture the range in deployment of the technologies of interest (UPV, land-based wind, and geothermal) under 100% by 2035 futures, but a comparison of the broader impacts (e.g., costs) of the various decarbonization pathways is out of scope. Other studies (Denholm et al. 2022; Mai et al. 2022) discuss tradeoff between various technologies for achieving 100% clean electricity.

Despite the large increase in the amount of RE deployment in all scenarios, there remains substantial RE potential that is not developed. Most of the scenarios rely on less than 1% of the total geothermal technical potential (especially EGS), less than 5% of the UPV technical potential, and less than 25% of the wind technical potential. These shares are for the CONUS through 2050; some states and regions are projected to have greater utilization of the total developable resource. The share of available resources relied upon are typically greater in scenarios that assume the Limited Access or Limited Private siting cases.

The increase in RE deployment in the scenarios is accompanied by a need for transmission expansion. Figure 23 shows how total transmission capacity is projected to increase across all seven scenarios. At least a doubling of the 2020 transmission system is needed by 2050 across all

[34] This capacity includes existing capacity (for nuclear) and considers both new and retrofitted plants for fossil with CCS.

scenarios. Scenarios that rely more-heavily on wind generation (Wind & Transmission Favorable) result in the greatest amount of transmission expansion, with the 2050 transmission grid estimated to be 4.5 times the 2020 system in TW-mile units. Note inter-regional transmission expansion—including transmission expansion across the interconnection seams—is allowed only in two scenarios (Many Options and Wind & Transmission Favorable). Because a large majority (85%) of federal lands are in the Western Interconnection, which includes only approximately 20% of U.S. electricity demand, the absence of seam-crossing transmission limits the amount of deployment that could occur on federal lands. Under the Many Options and Wind & Transmission Favorable scenarios, seam-crossing transmission capacity grows to 66–86 GW by 2050 compared to the 1.8 GW operating today. DOE (2024e) and Bloom et al. (2022) study the potential for expanding such capacity. DOE (2024e) also evaluates additional scenarios that include a broader set of transmission expansion, including through widespread use of high-voltage direct current (HVDC) transmission.

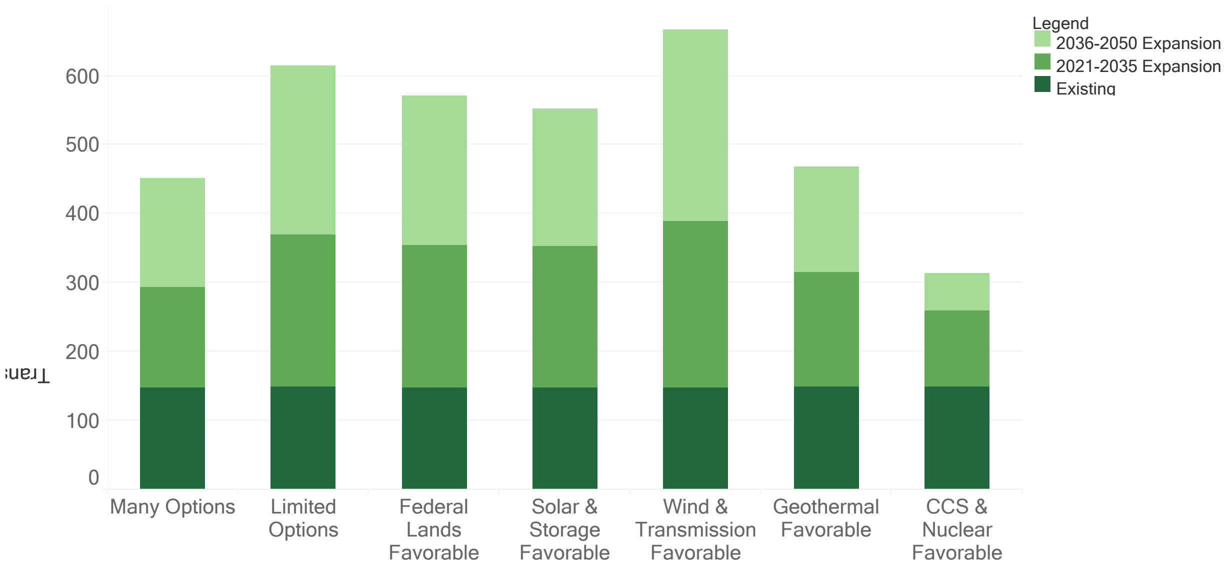

Figure 23. Transmission expansion

Transmission includes local, regional, and interregional transmission. Local refers to spur lines and local upgrades needed to interconnect new wind and solar power plants.

3.2.3 Land Use

Estimated total land use required for the projected UPV, wind, and geothermal deployment in the scenarios ranges from 22.5 to 45.2 million acres in 2035 and 26.1 to 74.7 million acres in 2050 (Figure 24, top).[35] A majority (45%–87% in 2050) of this land area is for wind power plants, including spacing between wind turbines. The total area comprises less than 4% of the CONUS land area. Direct land use required in the scenarios is much smaller (5.8–14.1 million acres in

[35] Although not a focus of this study, the scenarios also include offshore wind deployment that is modeled to occur on federal waters. Assuming a capacity density of 4 MW/km^2, the resulting offshore wind development totals 3-14 million acres of total area in 2035 and 5-32 million acres in 2050. As with land-based wind, areas that are directly disturbed in offshore wind facilities are much smaller than the total area of the facility.

2035), comprising less than 0.75% of the CONUS land area (Figure 24, bottom). Direct land use is largest for UPV because approximately 90% of the area within the project fence line would be covered by solar panels, electrical equipment, and access roads. The much smaller amount of direct land use compared to total land use, particularly for wind and geothermal power plants, reveals co-use opportunities. Other impacts of the projected deployment—such as noise, viewsheds, and wildlife interactions—are not quantified in our analysis but are partially accounted for in our assumed siting exclusions (Section 2.1).

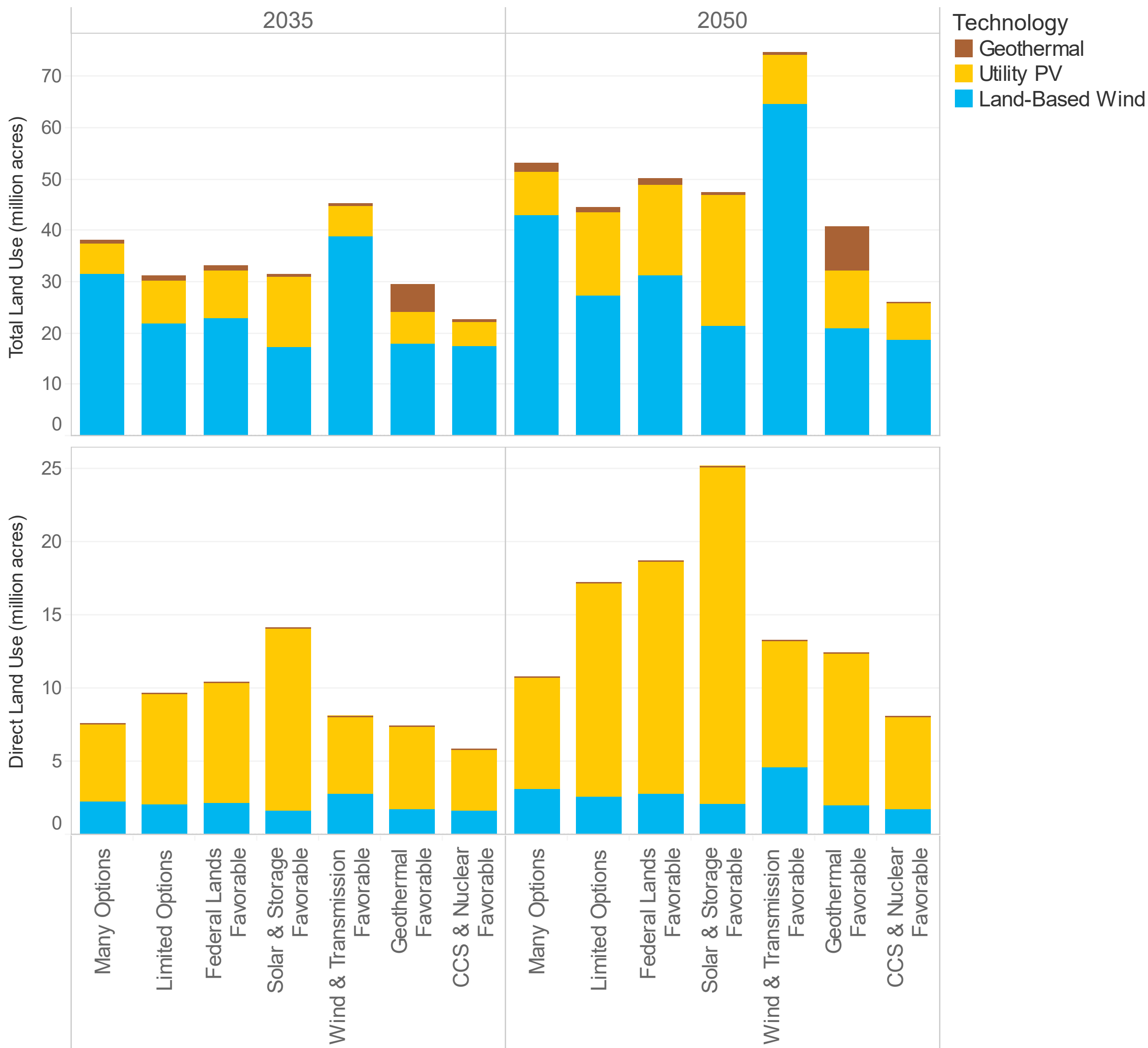

Figure 24. Total (top) and direct (bottom) land use from UPV, wind, and geothermal in 2035 (left) and 2050 (right)

Land use and related impacts can be highly localized making them difficult to contextualize or compare between competing energy-related and non-energy uses of land. However, broad comparisons prove useful for understanding the overall scale of energy development in these scenarios. [36] Examples of other direct land-uses across the CONUS (on federal and non-federal lands) include 4 million acres of land currently disturbed for coal production, 11 million acres dedicated to railroads, and 68 million acres of urbanization. For additional context, examples of total land use—which encompass areas that theoretically could, and often do, allow multiple uses—include livestock grazing and feed is estimated to be 781 million acres across the CONUS and 20.5 million acres of federal lands leased for oil and gas development.

3.3 Federal Lands Deployment Projections

The CONUS-wide deployment results (Section 3.2) were downscaled to produce deployment estimates on federal lands, which are presented in this section. Estimates were produced across several scenarios and downscaling assumptions to capture the wide range of possibilities; none of the results represent predictions. Deployment results can be disaggregated at multiple resolutions—including by federal land administrator, technology, and year—as summarized in the following subsections.

3.3.1 Total Deployment on Federal lands

Table 8 presents the total combined UPV, land-based wind, and geothermal deployment estimates on all federal lands in the CONUS across all seven power sector scenarios and the three land use preference downscaling cases. The years shown in the table and in the following figures indicate the year when the capacity is operating to fulfill all the generation requirements estimated in the power sector scenarios. To achieve these commercial operating dates would require permit authorization prior to the dates, possibly by approximately 5 years, depending on whether interconnection agreements are also approved. Tables showing the deployment estimates on federal lands broken out for the individual RE technologies are included in Appendix C.

[36] Denholm et al. (2022) provide additional context and examples of other major land uses.

Table 8. Total RE Capacity on All Federal Lands

Power Sector Scenario	Downscaling Preference	Installed UPV, Wind, Geothermal Capacity (GW)[a]				
		2030	**2035**	**2040**	**2045**	**2050**
Many Options	Prefer Non-Fed	26	55	72	85	93
	Min Spur Lines	31	62	82	96	106
	Prefer Fed	47	84	109	123	134
Limited Options	Prefer Non-Fed	20	51	66	85	100
	Min Spur Lines	23	60	74	94	111
	Prefer Fed	31	72	89	114	130
Federal Lands Favorable	Prefer Non-Fed	110	231	329	402	465
	Min Spur Lines	115	247	344	424	490
	Prefer Fed	131	270	373	456	533
Solar & Storage Favorable	Prefer Non-Fed	28	81	106	147	195
	Min Spur Lines	34	97	131	182	218
	Prefer Fed	58	128	173	239	269
Wind & Transmission Favorable	Prefer Non-Fed	30	60	88	103	116
	Min Spur Lines	32	67	93	112	128
	Prefer Fed	41	78	104	126	139
Geothermal Favorable	Prefer Non-Fed	20	33	46	58	65
	Min Spur Lines	22	38	50	65	74
	Prefer Fed	30	49	63	79	89
CCS & Nuclear Favorable	Prefer Non-Fed	20	26	28	29	32
	Min Spur Lines	22	31	34	36	40
	Prefer Fed	31	40	43	46	50

[a] The years indicate when the estimated capacity begins operating assuming prior approval of siting authorizations.

Figure 25 shows the federal land deployment estimates graphically for 2035 and 2050 and reveals four groups of scenarios. The CCS & Nuclear Favorable and Geothermal Favorable scenarios result in the lowest amount of RE capacity deployed on federal lands in 2035 (26–49 GW). Conversely, the Federal Lands Favorable scenario includes 231–270 GW of installed capacity and the Solar & Storage Favorable scenario includes 81–128 GW. The three central scenarios result in deployment levels intermediate between these outcomes (51–84 GW).

The broad range reflects variability across power sector scenarios and downscaling uncertainties. Scenarios with greater overall RE deployment in the CONUS typically also result in greater deployment on federal lands. Except for the Federal Lands Favorable scenario, all other scenarios result in 2%–5% of total deployed capacity located on federal lands in 2035 (Figure 26), which is consistent with the current share of 3.7% (Figure 2). The share of deployed capacity on federal lands is much greater (11%–12.5%) in the Federal Lands Favorable scenario where we assume higher siting pressures on private lands compared to federal lands. This share is similar to the percentage of current oil and natural gas production on federal lands (12% for oil, 11% for natural gas).

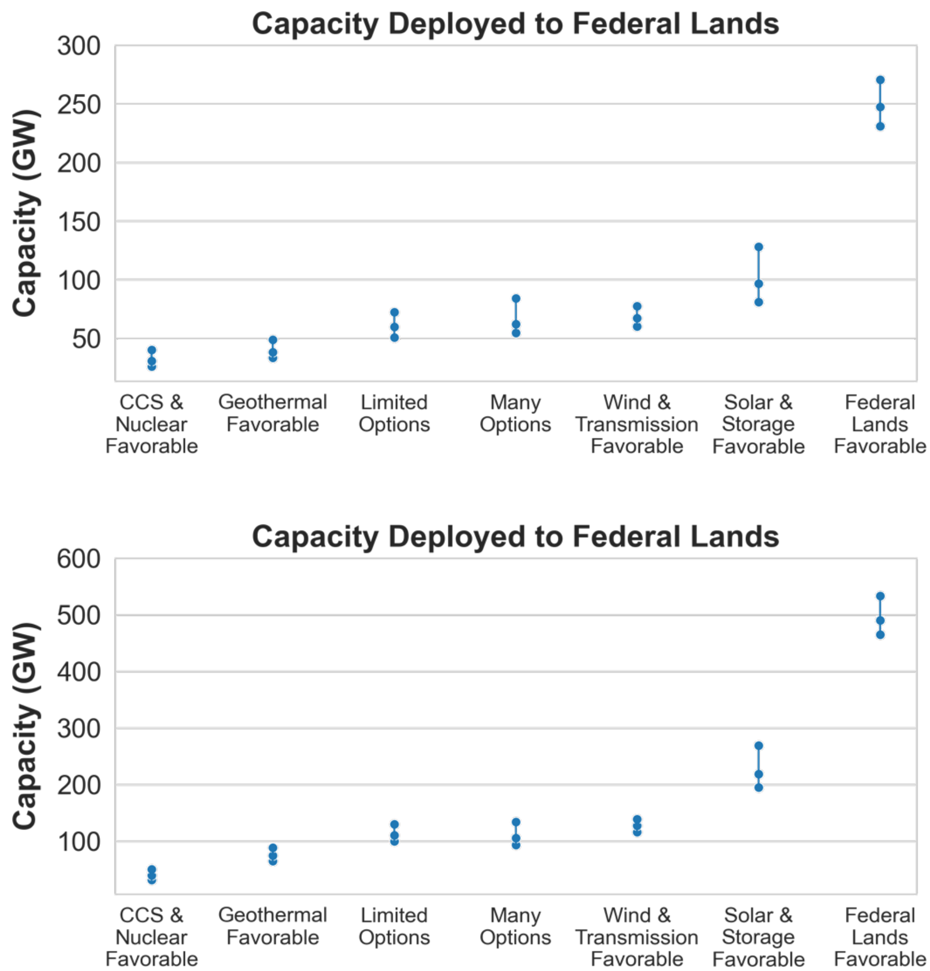

Figure 25. UPV, wind, and geothermal deployment on all federal lands in 2035 (top) and 2050 (bottom)

The markers reflect results across the three downscaling preference cases.

Downscaling assumptions can also affect the estimated deployment. Solar deployment is most sensitive to choice of downscaling prioritization because solar resources tend to be more uniform between nearby locations in contrast to the more site-specific resource quality of wind and geothermal. Figure 25 shows the large range (~50 GW in 2035) between the Prefer Federal and Prefer Non-Federal land use preference assumptions in the Solar & Storage Favorable scenario. In contrast, this range is much narrower (~15 GW in 2035) in the Geothermal Favorable and Wind & Transmission Favorable scenarios.

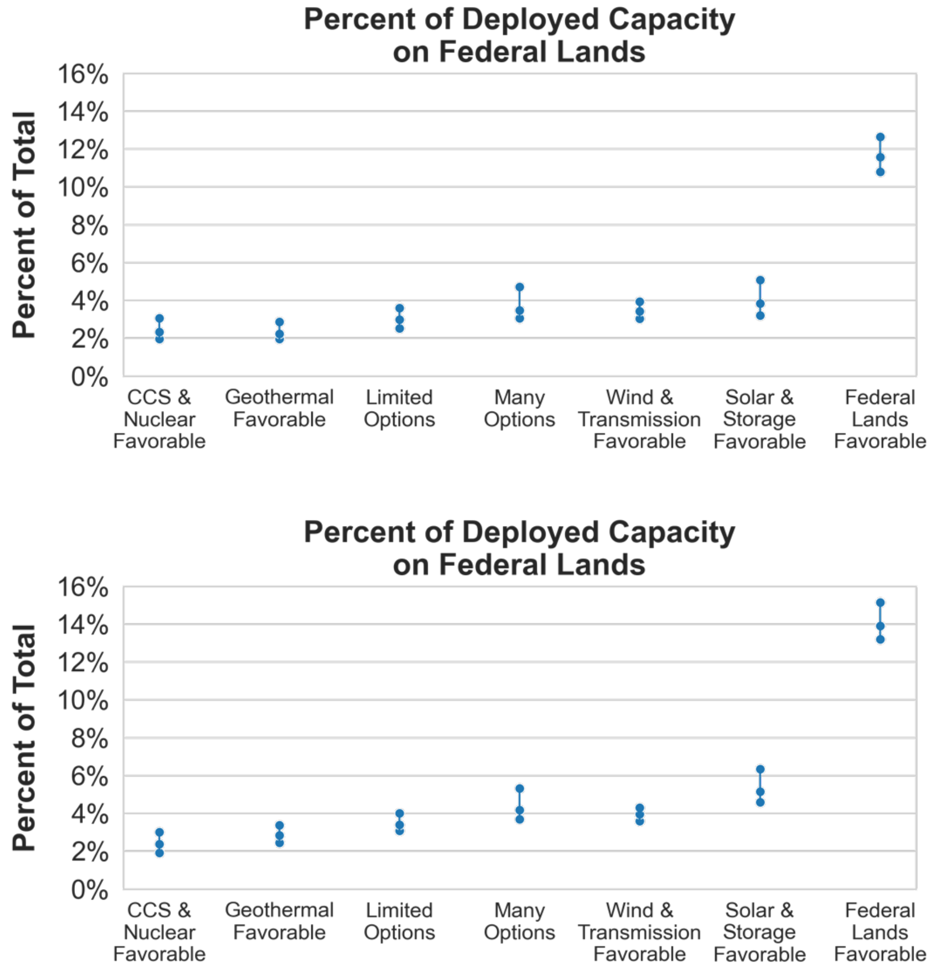

Figure 26. Share of total RE deployment on federal lands in 2035 (top) and 2050 (bottom)

The markers reflect results across the three downscaling preference cases.

Figures 25 and 26 also show results for 2050, where the same general trends found for 2035 apply although the overall installed capacity estimates are higher. In 2050, 32–89 GW of RE are installed on federal lands in the lowest two scenarios, 93–139 GW in the central three scenarios, 195–269 GW in the Solar & Storage Favorable scenario, and 465–533 GW in the highest scenario. These estimates reflect a slightly higher reliance on federal lands where across nearly all cases 2%–6% of total RE capacity is located on federal lands—and this share increases to 13%–15% in the Federal Lands Favorable scenario. These higher percentages indicate that as more renewable energy is deployed and fewer non-federal sites remain, federal lands may be increasingly needed. However, the increase is slight and within the uncertainty ranges reflected by the land use preference assumptions reflecting the large technical potential for renewable energy on both federal and non-federal lands.

3.3.2 Example Federal Land Administrator and Technology Breakdown

The federal land deployment estimates can be disaggregated by technology and land administrator. Figure 27 shows the technology breakdown in deployed capacity in 2035 for the seven power sector scenarios (all assuming the Prefer Federal Land downscaling case). As with the CONUS wide results (Section 3.2), deployment on federal lands is approximately evenly split between UPV and land-based wind in most cases. In general, there is greater UPV *capacity* than land-based wind on federal lands but *annual generation* is more evenly split between the two technologies because of wind's typically higher capacity factors.

Geothermal capacity on federal lands is lower than that of wind and UPV in all scenarios in 2035. Except for the Geothermal Favorable scenario, geothermal capacity is less than 4.7 GW, but the share of total geothermal capacity located on federal lands (up to 35% in 2035) is higher than that for UPV and wind extending historical trends (Figure 2). In the Geothermal Favorable scenario where EGS is deployed, geothermal capacity on federal lands is similar to the amount of wind capacity (10.4 GW and 15 GW in 2035, respectively), but annual generation from geothermal is greater than both wind and UPV because of the high capacity factor of geothermal power plants (85%).

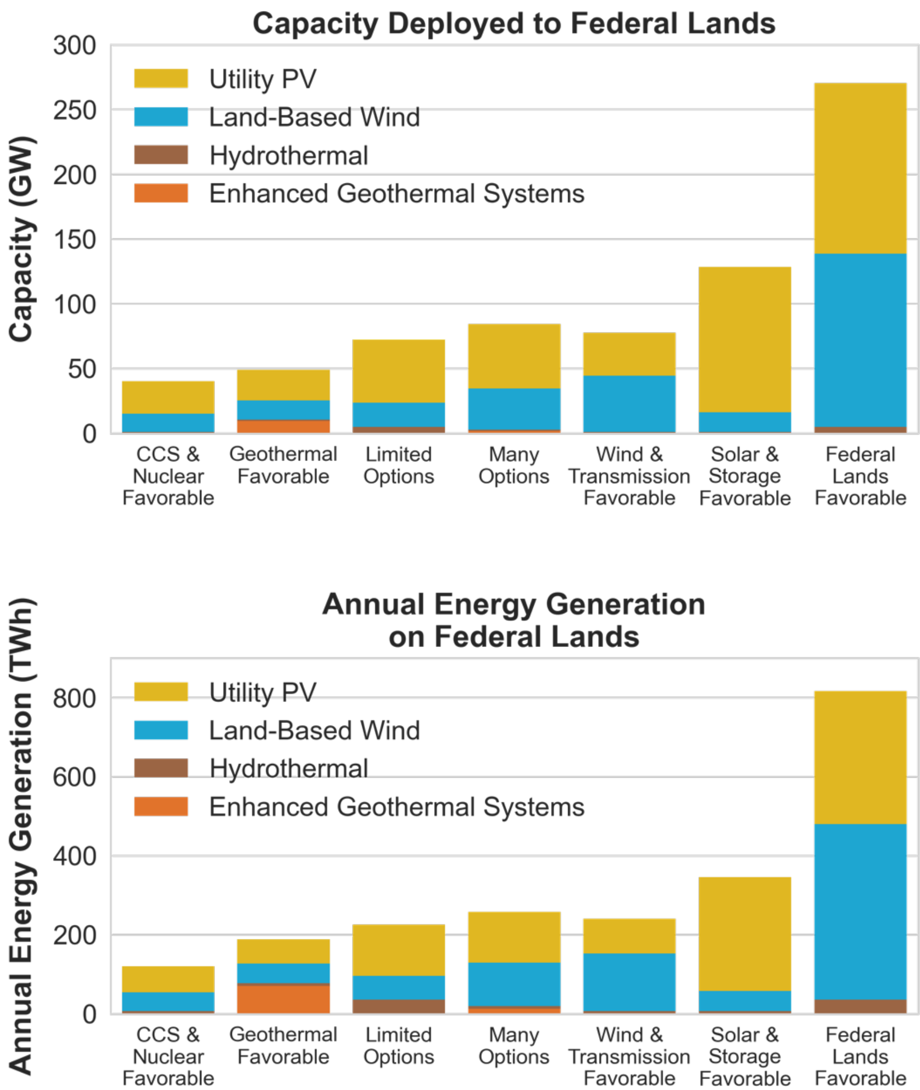

Figure 27. Capacity deployed on all federal lands (top) and associated annual generation (bottom) in 2035 by technology

The Prefer Federal downscaling case is shown in the figure. Generation is based on projected 2035 technologies. Actual dispatch could result in lower generation values because of curtailment, non-economic dispatch, and degradation.

Figure 28 shows the capacity deployed by federal land administrators over all modeled years. For most scenarios, BLM experiences the most significant amount of RE development over all years, followed by USFS and DOD, in different orders depending on the scenario. The Federal Lands Favorable scenario breaks this pattern, showing more installed RE capacity on USFS and DOD lands in the long term. Deployment on DOE and FWS land is limited in all projections (< 625 MW and <2 MW through 2050, respectively). In Figure 28, these two administrators are included in the "All Other Federal" category, along with federal land administrators other than the BLM, USFS, and DOD.

Results from the downscaling analysis can also be used to identify locations managed by each federal land administrator; Appendix D presents RE deployment estimates for BLM field offices, national forests and grasslands administered by USFS, and DOD bases.

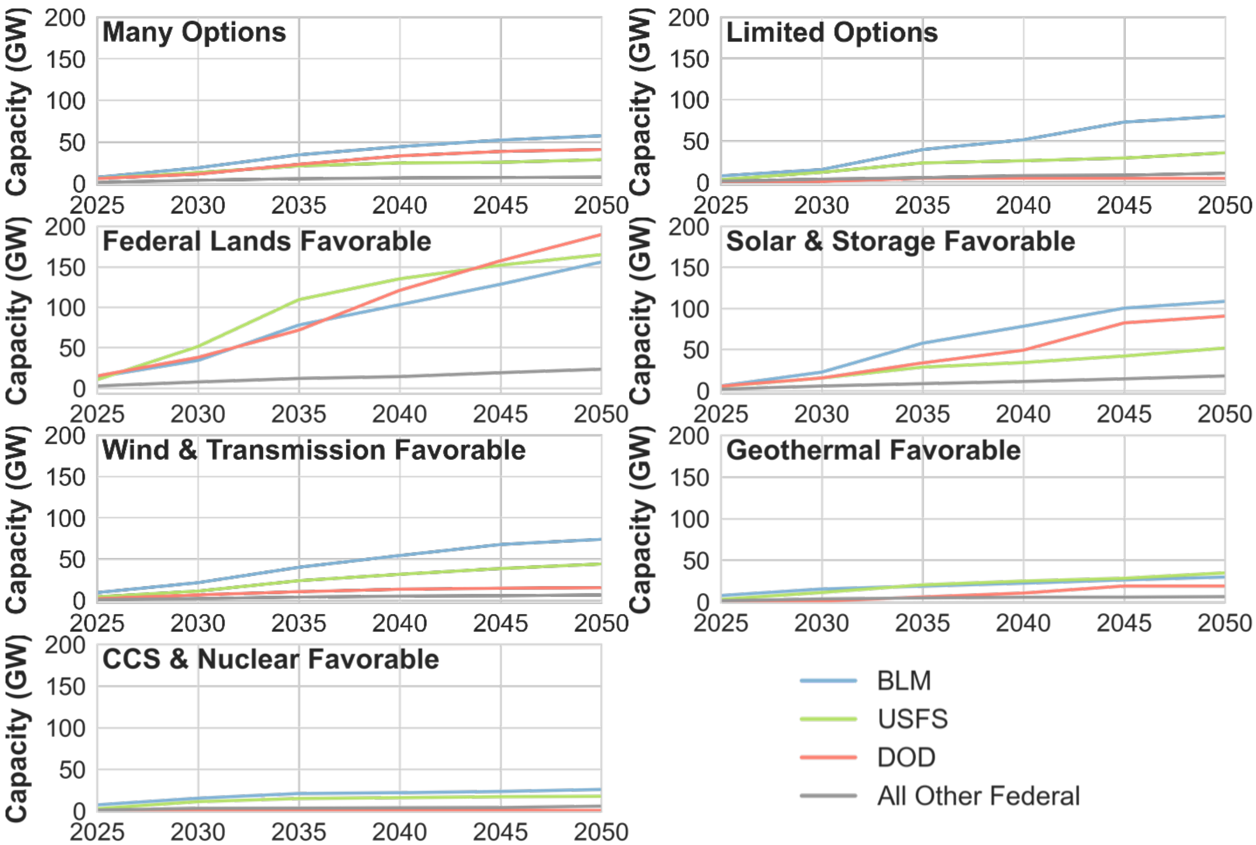

Figure 28. Combined UPV, wind, and geothermal deployed over time by federal land administrator

The High land use preference case is shown in the figure. All Other Federal includes DOE, FWS, and other federal lands.

There are also differences between federal land administrators in terms of the primary technologies deployed in the future scenarios. Figure 29 shows how deployment by 2035 on BLM land is dominated by UPV in most scenarios, whereas wind deployment is largest on USFS land. Across federal lands, geothermal deployment is most significant on DOD sites, although either UPV or wind capacity can be greater than geothermal for DOD in many of the scenarios. A mix of technologies are used on other federal lands.

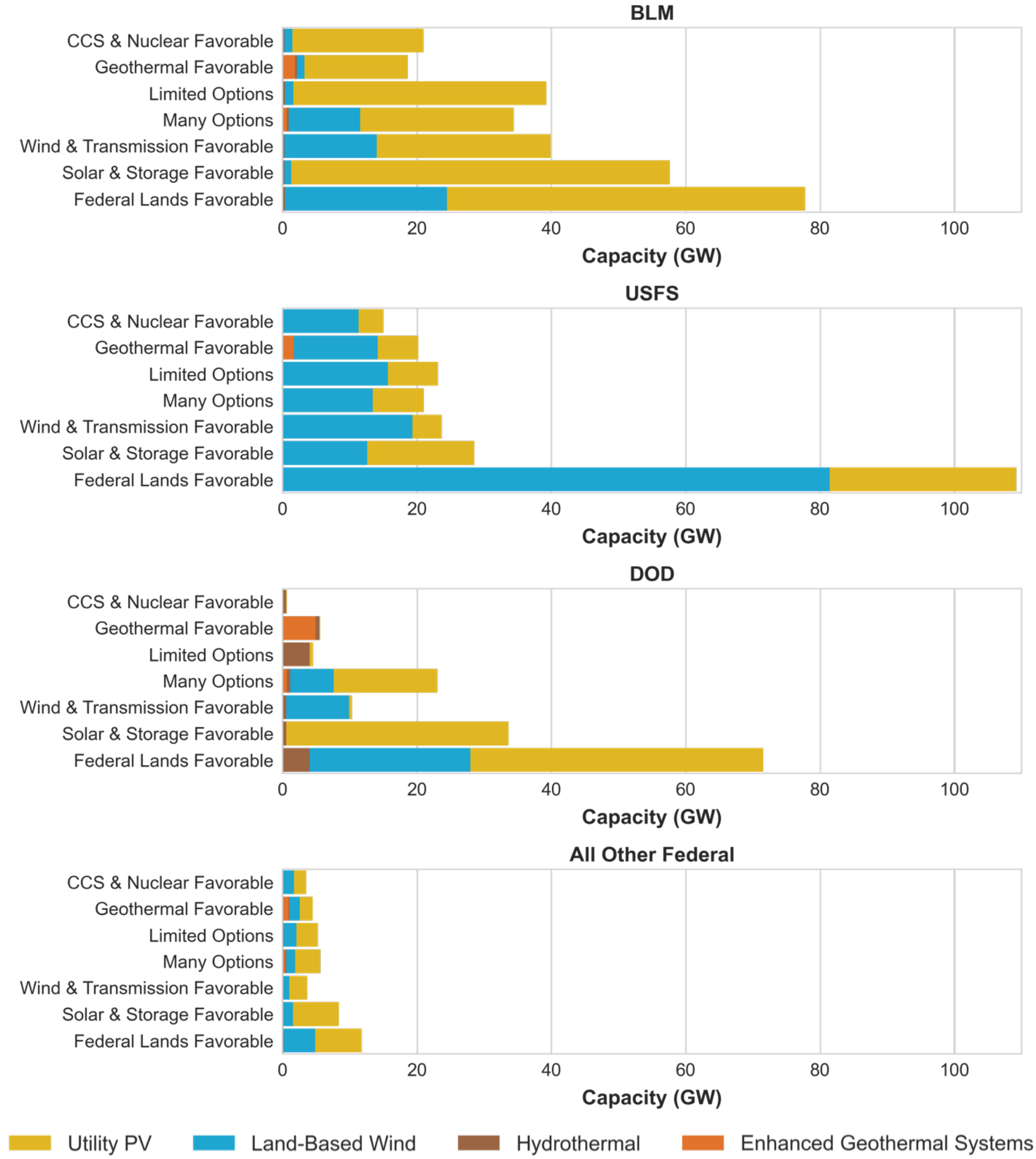

Figure 29. Capacity deployed by 2035 across federal land administrators

The Prefer Federal downscaling case is shown in the figure.

3.3.3 Federal Land Use

Table 9 presents the total land area associated with the deployed capacity from Table 8. The reported total areas, which are based on the amount of capacity deployed and the technology- and site-specific capacity densities, apply to all federal lands and for all three RE technologies (UPV, land-based wind, and geothermal).

Table 9. Total Land Area on All Federal Lands

Power Sector Scenario	Land Use Preference[a]	Total Land Area (thousand acres)[a]				
		2030	**2035**	**2040**	**2045**	**2050**
Many Options	Prefer Non-Fed	828	1325	1786	2036	2199
	Min Spur Lines	899	1412	1905	2162	2371
	Prefer Fed	1124	1680	2197	2450	2745
Limited Options	Prefer Non-Fed	274	837	968	1102	1215
	Min Spur Lines	301	919	1035	1186	1305
	Prefer Fed	425	1074	1215	1398	1516
Federal Lands Favorable	Prefer Non-Fed	2133	4353	6129	7235	7862
	Min Spur Lines	2217	4527	6280	7455	8109
	Prefer Fed	2414	4800	6609	7750	8522
Solar & Storage Favorable	Prefer Non-Fed	314	745	954	1252	1622
	Min Spur Lines	368	881	1158	1547	1818
	Prefer Fed	624	1189	1544	2044	2266
Wind & Transmission Favorable	Prefer Non-Fed	963	1646	2301	2661	2922
	Min Spur Lines	1009	1758	2381	2793	3075
	Prefer Fed	1223	1938	2565	2980	3268
Geothermal Favorable	Prefer Non-Fed	275	488	682	904	977
	Min Spur Lines	299	543	734	979	1095
	Prefer Fed	426	705	926	1192	1315
CCS & Nuclear Favorable	Prefer Non-Fed	270	328	350	345	368
	Min Spur Lines	295	373	406	412	438
	Prefer Fed	422	509	538	546	577

[a] The years indicate the dates when the estimated capacity begins operating assuming siting authorizations are approved prior to the dates.

Figure 30 shows the total and direct land areas in 2035 for RE development on federal lands. In most scenarios, total land use on federal lands is between approximately 325,000 and 2,000,000 acres, which represents less than 0.5% of all federal lands and less than 5% of estimated *developable* federal lands. Direct land use on federal lands is lower, between 110,000 and 815,000 acres; less than approximately 0.2% of all federal lands is disturbed in most of the scenarios. Total and direct land use is greatest in the Federal Lands Favorable scenario, where up to nearly 4.8 million acres (~1.2% of federal lands) and 1.23 million acres (~0.3%) are required. As with the national results, wind-heavy scenarios result in higher total land use, whereas solar-heavy scenarios drive higher direct land use.

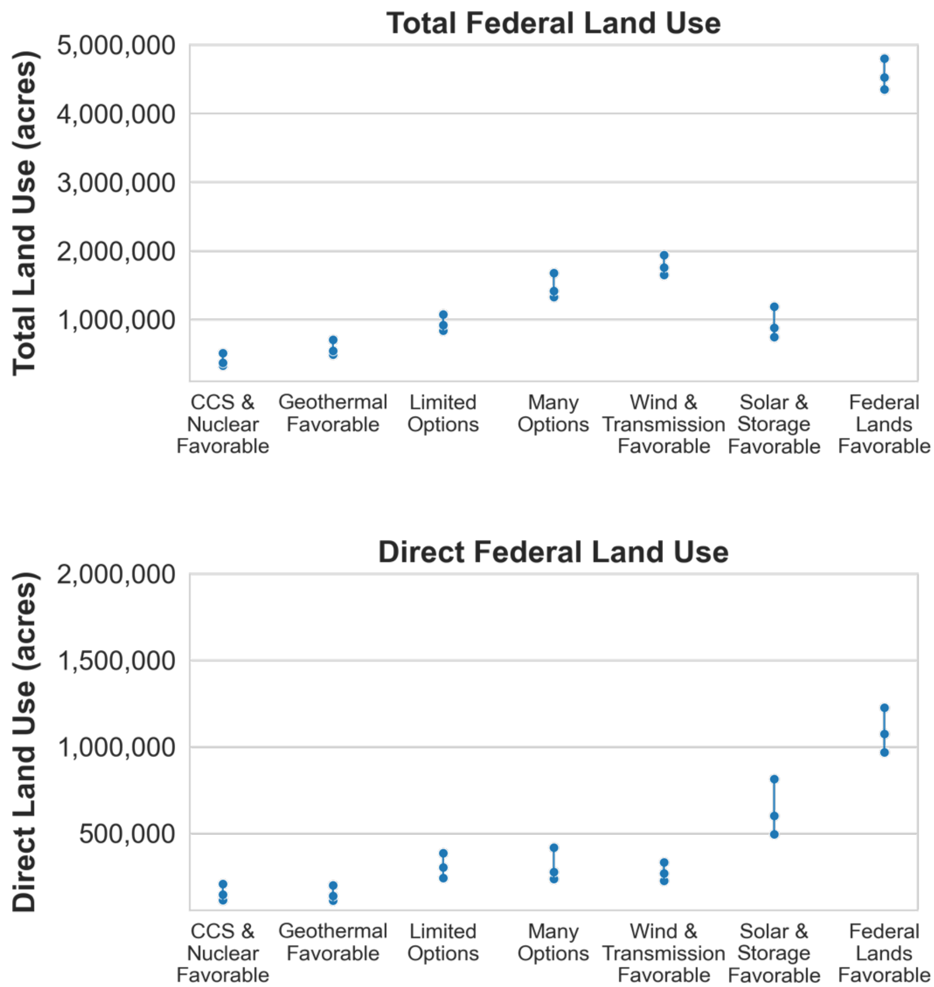

Figure 30. Total (top) and direct (bottom) land use in 2035 on all federal lands

The markers reflect results across the three downscaling preference cases.

4 Conclusion

The purpose of this study is to estimate RE technical potential on federal lands in the CONUS and to project RE capacity that could be developed on federal lands under multiple decarbonization scenarios. In addition, we also estimated the total and direct land use for RE under these scenarios. The RE technologies examined in this study include utility PV, land-based wind, and geothermal.

Using siting perspectives from BLM, USFS, FWS, DOE, and DOD, we estimated the technical potential on federal lands for UPV to be 5,750 GW, for land-based wind to be 875 GW, and for hydrothermal geothermal and EGS to be 130 GW and 975 GW, respectively. Of all federal land administrators, BLM has the highest RE technical potential, followed by USFS and DOD. DOE, FWS, and other federal land administrators have relatively modest RE technical potential. When modeling a limited-siting case, we estimate the technical potential on federal lands to decline by 70% (to 1,750 GW) for UPV and by 96% (to 70 GW) for wind, compared to the reference siting case.

The RE technical potential on federal lands is great, but only a small portion of the potential would be needed or developed to meet future energy demands. To estimate RE deployment, we created seven scenarios that achieve 100% carbon-free electricity by 2035 and assume net-zero-greenhouse gas emissions by 2050. Across the seven scenarios, the three RE sources that we focus on in this study (i.e., UPV, land-based wind, and geothermal) compose 50%-78% of total generation in 2035 and 42%–83% in 2050. The 2050 generation share from *all* RE technologies (i.e., the three of focus in this study plus offshore wind, distributed PV, CSP, hydropower, and biopower) is 55%–90% in 2050, compared to 21% in 2023. To achieve these generation levels requires significantly increasing capacity deployment. Across the seven scenarios, UPV capacity increases to 607–1,795 GW by 2035 and 917–3,335 GW by 2050 across the CONUS. Wind capacity estimates are 707–1,207 GW in 2035 and 749–1,979 GW in 2050. Geothermal capacity estimates are 5–156 GW in 2035 and 5–269 GW in 2050.

The national-scale results were downscaled to estimate RE development on federal lands. The combined capacity of UPV, wind, and geothermal on federal lands ranges from 26 GW in the lowest estimate to 270 GW in the highest deployment one. The three central scenarios include 51 GW to 84 GW of RE on federal lands in 2035, and achieving those 2035 commercial operating dates would entail prior permit authorizations, potentially by about 5 years beforehand. Six of seven scenarios found 2%–5% of total CONUS-wide RE capacity on federal lands in 2035. The Federal Lands Favorable scenario models 11%–12.5% of these three technologies being deployed on federal lands in 2035. RE deployment on federal lands is estimated to increase after 2035, although, as with 2035 estimates, there are wide-ranging projections depending on scenario (32 GW to 533 GW).

We parsed the federal land deployment estimates by generation type and land administrator. Using the “Prefer Federal Land” downscaling case, ~25 GW to 130 GW UPV, and ~10 GW to 130 GW wind is deployed across the seven scenarios. In six of seven scenarios, geothermal capacity is less than 5 GW; however, in the Geothermal Favorable scenario it ranges from 10.4 GW to 15 GW in 2035 across the three downscaling cases. For most scenarios, more RE is deployed on BLM lands than other federal lands by 2035, with USFS and DOD second and third, depending on scenario. RE deployment is relatively small on DOE and FWS lands in all scenarios. Of the three RE technologies, UPV is dominant on BLM lands and wind on USFS lands by 2035, and geothermal is deployed on DOD more than on other federal lands.

In most scenarios in 2035, the three RE technologies' total federal land use ranges from 325,000 to 2,000,000 acres; this is less than 0.5% of all federal land area and less than 5% of developable federal lands. Direct federal land use is 110,000–815,000 acres. Less than 0.2% of all federal lands are disturbed in most scenarios. In the Federal Lands Favorable scenario, total land use is 4.8 million acres, and direct land use is 1.23 million acres.

This study provides a screening of federal lands for RE deployment, and further site-specific work is required to determine viability of areas and site-specific locations. Policies, regulations, and directives from multiple federal land administrators change with time, as do the priorities of various stakeholders. This study's results should be updated periodically to capture these and other changing dynamics.

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Appendix A: Multiagency Collaboration

The U.S. Department of Energy (DOE) and National Renewable Energy Laboratory (NREL) coordinated with partner federal agencies and land administrators throughout the 1-year duration of the study as well as the White House Council on Environmental Quality (Figure A-1). Partnering land administrators reviewed and provided recommendations on NREL's model assumptions and data inputs, suggested geospatial data sets to assist in NREL's estimation of renewable energy technical potential by location, and provided input on power sector scenarios. Table A-1 lists the individual participants of the study.

Table A-1. Study Participants

The primary point(s) of contact for each federal land administrator and the core team members of the study are shown in bold. Acronyms are defined following the table.

Department of Energy (DOE)	
Andy Adams, EERE-GTO	Becca Jones-Albertus, EERE-SETO
Carla Frisch, OP	Sean Porse, EERE-GTO
Keith Benes, OP	Marie Monis, EM
Steve Bruno, MA	**Davie Nguyen**, OP
Angela Guiliani, EERE (former)	Tamika Taylor, MA
Sarah Jensen	**Raphael Tisch**, EERE-WETO
Kendra Kostek, EERE	Craig Zamuda, MA (former)
Kelsey Landau, OP (on detail to CEQ)	
Department of Interior (DOI), Bureau of Land Management (BLM)	
Jeremy Bluma	Sara Moffat
U.S. Department of Agriculture (USDA), U.S. Forest Service (USFS)	
Jennifer Edmonds	Will Pedde
Leah Hurley	**Reggie Woodruff**
Katherine Van Massenhove	
DOI, Fish and Wildlife Service (FWS)	
Trish Adams	Erin Strasser
Bud Cribley	Ben Thatcher
Anna Joy Lehmicke	**Tom Wittig**
Katie Powell	
Department of Defense (DOD)	
Michelle Byman	Michael Jones
Susan Call	Andrew D. Knox
Christopher Fields	Bronwyn Pascal
John Michael Forrest	Stephanie Rice
Bernard Given	Steven J. Sample
Mathew Haupt	Christin Schliemann
Yamil Hernandez	Judith Willis
Rebecca Isacowitz	

White House, Council on Environmental Quality (CEQ)	
Ana Unruh Cohen, CEQ	Steve Hardegen, CEQ
Michael Drummond, CEQ	Mark Pituch, CEQ
Jordan Eccles, CEQ	
DOI, U.S. Geological Survey (USGS)	
Jay Diffendorfer	Bethany Straw
National Renewable Energy Laboratory (NREL)[a]	
Akriti Bhargava	Aaron Levine
Carishma Gokhale-Welch	Gian Porro

[a] The study authors are not listed on this table but are all core contributors to the study.

EERE = Energy Efficiency and Renewable Energy; GTO = Geothermal Technologies Office; SETO = Solar Energy Technologies Office; WETO = Wind Energy Technologies Office; EM = Office of Environmental Management; MA = Office of Management; OP = Office of Policy

Appendix B: Additional reV assumptions

Old Growth Forests

The old growth forests dataset used in our modeling of siting constraints was derived from a combination of two source datasets: an official, spatially-coarse inventory from the USFS (U.S. Forest Service 2024) and a high-resolution, unofficial source from an independent research study (DellaSala et al. 2022). This combination provided the best achievable balance of spatial resolution and alignment with official government inventories.

The first dataset we used was the "Mature and Old Growth Forest" layer available from the USFS Climate Risk Viewer (v1.0.2), which included estimates of mature and old growth forest acreage for firesheds across the U.S. (U.S. Forest Service 2024) Standard errors were also provided for these estimates, indicating their degree of uncertainty. These data were available at the resolution of individual firesheds across the US, which are roughly on the scale of 20 to 40 km square. These data were derived from Forest Inventory and Analysis plot estimates by the USFS. Although these data represent the official inventory of old growth forests by the USFS, they were too coarse to use in modeling site-level constraints for renewable energy.

As a result, we integrated a second gridded dataset that estimated the presence of mature and old growth forests using satellite imagery, remote sensing, and spatial analysis methods (DellaSala et al. 2022). This dataset was available at the resolution of 30m by 30m (DellaSala 2022), which was more suitable for representing site-level exclusions.

As noted by (U.S. Forest Service and Bureau of Land Management 2024), the federal inventory dataset and the DellaSala (2022) dataset have substantial differences. Because of these differences, the USFS advised NREL that their preference was to use their fireshed-level dataset; however, this was infeasible for our modeling purposes. As a result, we performed an assessment of the degree of alignment between the two datasets. To do so, we calculated the total acreage of mature and old growth forest from DellaSala (2022) then assessed if that acreage fell within the 95% confidence interval of the USFS estimate for the same fireshed. We found that across the CONUS, the two datasets were consistent for 78% of all firesheds.

Based on these results, and with agreement from USFS, we proceeded to use the mature and old growth presence from the DellaSala (2022) dataset, but only within firesheds where the total acreage was within the 95% confidence interval of the USFS estimate. In addition, we spatially filtered the dataset to include only mature and old growth forest areas on USFS or BLM lands.

Recreational Opportunity Spectrum (ROS)

Recreation Opportunity Spectrum (ROS) is a framework used by the USFS for planning and managing recreation opportunities across the lands they manage. Under the ROS framework, the USFS zones lands within National Forests and Grasslands based on their degree of remoteness, access, development, and visitor activity levels. Each National Forest and National Grassland has been subdivided into ROS zones, which can span the following 6 classes (from high to low remoteness/activity): Primitive, Semi-Primitive Non-Motorized, Semi-Primitive Motorized, Roaded Natural, Rural, and Urban. ROS is closely tied to both Scenic Integrity Objectives (SIO) and Visual Quality Objectives (VQO), which define how a given visual landscape should be managed and the degree to which it should be preserved to prevent human modification (U.S. Forest Service n.d.; U.S. Forest Service 1990).

USFS advised NREL that, in practice, ROS maps for individual forests and grasslands would be used by the local land managers to guide decisions about the compatibility of new renewable energy installations with existing management goals on those lands. As such, ROS boundaries would provide a suitable proxy for identifying the portions of USFS lands which should be excluded from our modeling of potential renewable energy development.

Unfortunately, ROS boundary datasets are maintained by the individual national forest and grasslands offices, which total 174 separate units (U.S. Forest Service 2016). Within the scope of this study, it was not feasible to collect these data directly from the individual USFS offices. Therefore, as an alternative, NREL performed geospatial analysis to develop modeled ROS zones for all 174 forest and grasslands following the official protocol published by the USFS and using input datasets from the USFS, BLM, and others.

For this ROS modeling effort, we used the "National Recreation Opportunity Spectrum (ROS) Inventory Mapping Protocol", which is intended to provide standardized guidance to USFS staff involved in ROS inventory mapping (Hill 2017). We implemented the portions of the protocol that did not require local knowledge or manual adjustments, which include Steps 1 through 5. Step 6 of the protocol is intended to resolve small areas, generally by merging them with larger neighboring zones that share similar characteristics. Because this step requires manual decision-making that was not possible at the scale of our analysis, we applied a simplified alternative to resolve small areas: by consolidated areas below the thresholds defined in Step 5 into the largest neighboring area within 200 m. We did not perform Step 7, which is required to distinguish between Roaded Natural, Rural, and Urban ROS classes; thus, our output dataset included four ROS classes: Primitive, Semi-Primitive Non-Motorized, Semi-Primitive Motorized, and a combined Roaded Natural/Rural/Urban class.

Our input datasets for this modeling effort included roads datasets from the USFS and BLM (U.S. Forest Service 2024d; 2024e; Bureau of Land Management 2024e; 2024f), trails datasets from the USFS and BLM (U.S. Forest Service 2024f; 2024e; Bureau of Land Management 2024g), and roads datasets from OpenStreetMap (Geofabrik 2024). We did not account for waterways or other over water use, railroads, or aviation facilities, nor did we model ROS by season.

We performed a visual comparison of a small sample of actual ROS boundaries available from a select number of National Forests. The comparison data were primarily available from USFS Region 3 (U.S. Forest Service 2024g), which encompasses Arizona, New Mexico, and portions of western Oklahoma and the Texas panhandle. With some exceptions, this comparison showed that the boundaries and categorization of the modeled ROS zones aligned well with actual ROS zones. Actual ROS zones were typically more spatially refined (e.g. more detailed, narrower, more sub-divisions), which is to be expected given the degree of local knowledge applied by managers in the development of those boundaries. Gross misclassification of zones was most common at the higher end of the remoteness spectrum (e.g., confusion between Primitive and Semi-Primitive Non-Motorized).

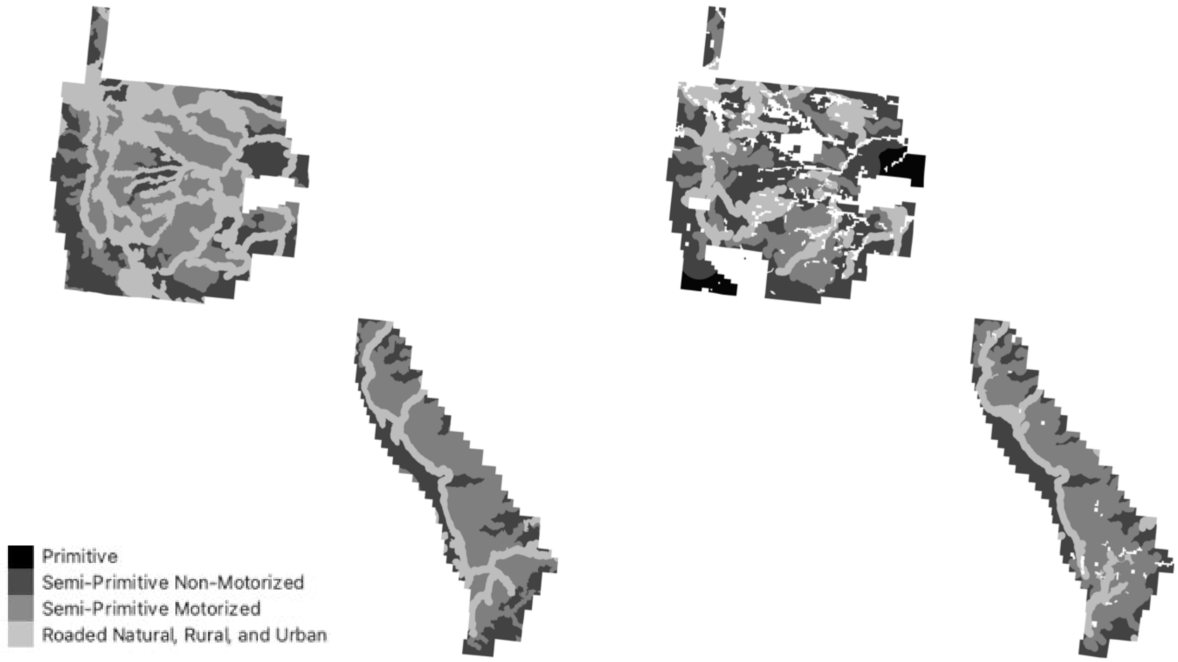

Figure B-1. Comparison of actual ROS zones (left) to modeled ROS zones (right) for portions of Lincoln National Forest in New Mexico

Figure B-2. Comparison of actual ROS zones (left) to modeled ROS zones (right) for portions of Carson National Forest in New Mexico

In our technical potential modeling, we excluded USFS lands categorized as Primitive, Semi-Primitive Non-Motorized, and Semi-Primitive Motorized in our modeled ROS dataset. The exclusion of these categories was determined based on their alignment to Scenic Integrity

Objectives (SIO) levels of Very High, High, and Moderate (U.S. Forest Service, n.d.) and guidance from the USFS. As such, we only modeled renewable energy potential within USFS lands modeled as Roaded Natural/Rural/Urban, which aligns to SIO levels of Low to Very Low.

Department of Interior Ridgelines

For ridgelines, we used a definition provided to us in a past correspondence with the Department of the Interior: "Areas within 660 feet of the top of the ridgeline, where a ridgeline is at least 150 feet of vertical elevation gain with a minimum average slope of 10 percent between ridgeline and base." To identify terrain features meeting these criteria, we performed geomorphometric and spatial analysis on the USGS 3DEP 1/3 arc-second bare-earth Digital Elevation Model (DEM) (U.S. Geological Survey 2023).

As a first step, we used the Geomorphons algorithm from WhiteboxTools (Lindsay 2023) with the following parameters to identify ridges and valleys:

Parameter	Setting
Search Distance	45 pixels
Skip Distance	10 pixels
Threshold	1.0 degree
Flatness Threshold Distance	0 pixels
Classify Geomorphons	True
Convert Elevation to Residuals	False

In the output raster, we combined pixels classified as either "ridges" or "peaks" into a single "ridges" class. We then removed all features not classified as either "ridges" or "valleys". Then, we applied morphometric cleanup operations to remove small gaps within and between features, including a binary closing (with a 2-pixel radius, disk-shaped footprint) and removal of holes smaller than 16 pixels.

Using the ridges and valleys from this geomorphometric analysis, we then performed additional filtering on the ridge features to retain only those pixels meeting the criteria of our ridgeline definition. For each pixel classified as a ridge, we identified the nearest pixel identified as a valley. We then calculated the distance between each ridge/valley pixel pair (i.e., run), their difference in elevation (i.e., rise), and the slope (i.e., rise over run). These values were then filtered to remove ridges with a slope less than 10 percent or a rise less than 150 ft (Figure B-3).

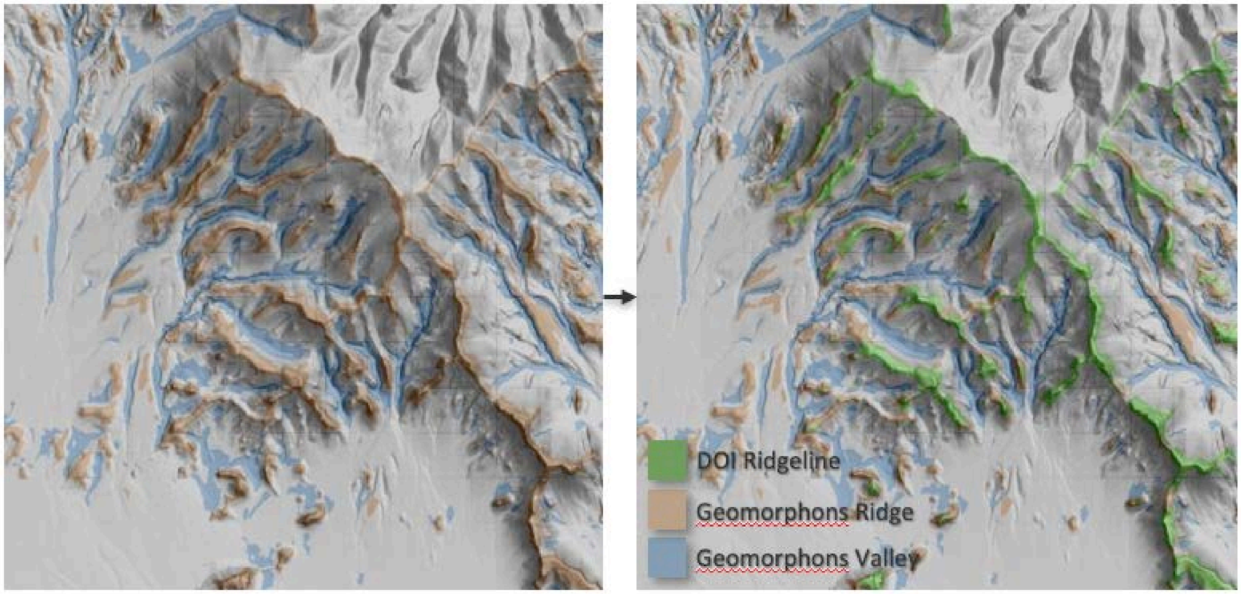

Figure B-3. Maps showing ridges and valleys derived via Geomorphons algorithm (left) and the portions of ridges meet the DOI criteria for ridgelines (right)

Finally, we vectorized the remaining features and applied a morphometric cleanup to the resulting polygons, consisting of a binary closing (using buffers at a radius equal to 2 pixels) and geometric simplification using the Douglas-Peucker algorithm (to a tolerance equal in size to 1/10 of pixel). We treated the resulting polygons as ridgelines.

General Siting Exclusions

Table B-1. Land-Based Wind General Siting Exclusions

Dataset	Reference Access	Limited Access	Source
Airport and heliport setbacks (variable)	x	x	Federal Aviation Administration (AIS 2022); Lopez et al. (2024)
Airport footprints	x	x	"Airports and Heliports" (2010)
Risk of Adverse Impact to Military Operations and Readiness (RAIMORA)	x	x	Kiernan (2016)
U.S. Department of Defense (9-km) and Next Generation Weather Radar (NEXRAD) radar setback (4-km)	x	x	Official-use-only communication with NORAD
U.S. Department of Defense and NEXRAD radar line-of-sight exclusion		x	Lopez et al. (2024)
Intercontinental ballistic missile silo setback (3.7-km)	x	x	"ICBM Sites" (2019)

Dataset	Reference Access	Limited Access	Source
Risk of adverse impact on military operations and readiness areas (RAIMORA)	x	x	Kiernan (2016)
Sagebrush Core and Growth habitat on federal lands *		x	Doherty et al. (2022)
Karst Depressions	x	x	Jones et al. (2021)
FEMA 100-year floodplains *	x	x	Federal Emergency Management Agency (2024)
Bat Hibernacula Setback	Priority 1, 2	Priority 1, 2, 3	Lopez et al. (forthcoming)
National Land Cover Dataset Water, Woody/Herbaceous Wetlands	x	x	U.S. Geological Survey (2021)
Lesser Prairie Chicken core habitat		x	“Conserving the Lesser Prairie-Chicken | U.S. Fish and Wildlife Service” (2023)
FWS National Wetlands Inventory	x	x	U.S. Fish and Wildlife Service (n.d.)
American Farm Trust Conservation Lands	x	x	American Farmland Trust (2023)
BLM Areas of Critical Environmental Concern	x	x	Bureau of Land Management (2022b)
National Forest Service Inventoried Roadless Areas	x	x	U.S. Forest Service, Geospatial Service and Technology Center (2001)
National Conservation Easement Database (Gap Analysis Project [GAP] Status 1, 2)	x	x	National Conservation Easement Database (2017)
Protected Areas Database (GAP Status 1, 2)	x	x	United States Geological Survey (2024)
Oil and gas well footprints (One well equals one 90-m x 90-m pixel.)	x	x	Oak Ridge National Laboratory (2019)
Railroads	x	x	U.S. Census Bureau (2021)
Roads	x	x	Homeland Security Infrastructure Program (2018)
Building structures	x	x	Microsoft (2018)
Transmission right-of-way	x	x	Oak Ridge National Laboratory et al. (2022); Lopez et al. (2021); Microsoft (2018)

Dataset	Reference Access	Limited Access	Source
Oil and gas pipeline right-of-way	x	x	Federal Communications Commission and Oak Ridge National Laboratory (2018)
Urbanized areas	x	x	U.S. Census Bureau (2018)
Existing solar PV facilities	x	x	Fujita et al. (2023)
Wind facility bans or moratoriums	x	x	Lopez et al. (2022)
Wind facility height limits (exceeding current turbine height assumption)	x	x	Lopez et al. (2022)
Oil and gas pipeline setback	220 m	400 m	Lopez et al. (2022)
Railroad setback	220 m	400 m	Lopez et al. (2022)
Road setback	220 m	400 m	Lopez et al. (2022)
Structure setback	220 m	400 m	Lopez et al. (2022)
Transmission setback	400 m	1,000 m	Lopez et al. (2022)
Water setback	220 m	400 m	Lopez et al. (2022)
Slope exclusion(s)	>25%	>13%	Jarvis et al. (2008)
Elevation (>9,000 ft.) and mountainous landforms	x	x	Karagulle et al. (2017)

Table B-2. Utility PV General Siting Assumptions

Dataset	Reference Access	Limited Access	Source
Intercontinental ballistic missile silo setback (3.7-km)	x	x	"ICBM Sites" (2019)
Runways	x	x	"Airports and Heliports" (2010); U.S. Department of Transportation (2024)
Bat hibernacula setbacks	805 m	805 m	Lopez et al. (forthcoming)
National Land Cover Dataset Water, Woody/Herbaceous Wetlands	x	x	U.S. Geological Survey (2021)
Lesser Prairie Chicken core habitat		x	"Conserving the Lesser Prairie-Chicken | U.S. Fish and Wildlife Service" (2023)
Sagebrush Core and Growth habitat on federal lands		x	Doherty et al. (2022)
FEMA 100-year floodplains	x	x	Federal Emergency Management Agency (2024)
FWS National Wetlands Inventory	x	x	U.S. Fish and Wildlife Service (n.d.)

Dataset	Reference Access	Limited Access	Source
Nationally Significant Agricultural Lands	10% available	5% available	Conservation Science Partners and American Farmland Trust (2016)
Simulated Conservation Reserve Program Lands	x	x	Lopez et al. (2024)
American Farm Trust Conservation Lands	x	x	American Farmland Trust (2023)
BLM Areas of Critical Environmental Concern	x	x	Bureau of Land Management (2022b)
National Forest Service Inventoried Roadless Areas	x	x	U.S. Forest Service, Geospatial Service and Technology Center (2001)
National Conservation Easement Database (GAP Status 1, 2)	x	x	National Conservation Easement Database (2017)
Protected Areas Database (GAP Status 1, 2)	x	x	U.S. Geological Survey (USGS) Gap Analysis Project (GAP; 2022)
Big game migration corridors	50% available	x	Kauffman et al. (2020); Kauffman, Lowrey, Beck et al. (2022); Kauffman, Lowrey, Berg et al. (2022)
Existing wind turbine pads (45.7 m) setback	x	x	Hoen et al. (2023)
Oil and gas well footprints	x	x	Oak Ridge National Laboratory (2019)
Railroads	x	x	U.S. Census Bureau (2021)
Roads	x	x	Homeland Security Infrastructure Program (2018)
Building structures	x	x	Microsoft (2018)
Transmission right-of-way	x	x	Oak Ridge National Laboratory et al. (2022); Lopez et al. (2021)
Oil and gas pipeline right-of-way	x	x	Federal Communications Commission and Oak Ridge National Laboratory (2018)
Solar existing bans or moratoriums	x	x	Lopez et al. (2022)
Oil and gas pipeline setback	30 m	76 m	Lopez et al. (2022)
Property line setback	15 m	46 m	Lopez et al. (2022)
Rail setback	30 m	76 m	Lopez et al. (2022)
Road setback	30 m	76 m	Lopez et al. (2022)
Building structure setback	61 m	152 m	Lopez et al. (2022)

Dataset	Reference Access	Limited Access	Source
Transmission setback	30 m	76 m	Lopez et al. (2022)
Water setback	30 m	76 m	Lopez et al. (2022)
Slope exclusion	>10%	>5%	Jarvis et al. (2008)
Elevation (>9,000 ft.) and mountainous landforms	x	x	Karagulle et al. (2017)
DOI-criteria ridgelines		x	See description of methodology included above.
Contiguous area filter (8,100 m^2)	x	x	Endogenous

Appendix C: RE Deployment on Federal Lands by Technology

This appendix provides additional detail regarding the RE deployment estimates on all federal lands in the CONUS. The information provided is similar to Table 8 in Section 3.3.1 of the report, which provides the deployed capacity estimates by year for total RE across power sector scenarios and land use preference downscaling cases. In this case, we have provided this same information broken out for each of the technologies: UPV (Table C-1), wind (Table C-2), and geothermal (Table C-3). Geothermal estimates include both hydrothermal and EGS technologies. Note that our methods and data imperfectly capture the locations of some existing facilities and we do not consider projects that have been proposed or are currently under development. As a result, these estimates could underestimate RE capacity on federal lands for the near term. This applies particularly to geothermal where there is currently 2.62 GW of operating capacity on federal lands compared to the 1 GW estimated for all scenarios through 2030. Current operating facilities for UPV and wind on federal lands total 4.85 GW and 1.46 GW, respectively.

Consistent with Table 8, the years shown in these tables refer to when the capacity is operational. Achieving these commercial operating dates would require authorization of permits and interconnection agreements prior to the years shown in the table. Each table shows deployed capacity estimates rounded to the nearest gigawatt. As a result, the sum of values for a given power sector scenario, downscaling case, and year across Tables C-1, C-2, and C-3 may not equal the total shown in Table 8.

Table C-1. Total UPV Capacity on All Federal Lands

Power Sector Scenario	Downscaling Preference	Installed UPV Capacity (GW)[a]				
		2030	**2035**	**2040**	**2045**	**2050**
Many Options	Prefer Non-Fed	7	25	31	35	39
	Min Spur Lines	11	30	39	44	48
	Prefer Fed	24	50	62	69	72
Limited Options	Prefer Non-Fed	9	29	42	60	74
	Min Spur Lines	11	37	50	70	85
	Prefer Fed	18	49	64	89	104
Federal Lands Favorable	Prefer Non-Fed	35	96	159	216	269
	Min Spur Lines	39	111	172	236	292
	Prefer Fed	52	132	199	266	333
Solar & Storage Favorable	Prefer Non-Fed	19	67	89	128	176
	Min Spur Lines	25	82	112	163	199
	Prefer Fed	48	112	153	219	247
Wind & Transmission Favorable	Prefer Non-Fed	8	19	34	39	46
	Min Spur Lines	9	25	38	47	56
	Prefer Fed	15	33	46	59	65
Geothermal Favorable	Prefer Non-Fed	9	11	13	15	19
	Min Spur Lines	11	15	17	21	25
	Prefer Fed	18	23	26	30	35
CCS & Nuclear Favorable	Prefer Non-Fed	9	12	13	15	17
	Min Spur Lines	11	17	19	21	25
	Prefer Fed	19	25	27	30	34

[a] The years indicate when the estimated capacity begins operating assuming prior approval of siting authorizations.

Table C-2. Total Wind Capacity on All Federal Lands

Power Sector Scenario	Downscaling Preference	Installed Wind Capacity (GW)[a]				
		2030	**2035**	**2040**	**2045**	**2050**
Many Options	Prefer Non-Fed	18	28	36	38	42
	Min Spur Lines	20	30	37	39	44
	Prefer Fed	22	32	39	40	47
Limited Options	Prefer Non-Fed	10	18	20	20	21
	Min Spur Lines	10	18	20	20	21
	Prefer Fed	11	19	21	21	22
Federal Lands Favorable	Prefer Non-Fed	74	131	165	182	192
	Min Spur Lines	75	132	167	184	194
	Prefer Fed	77	134	169	186	196
Solar & Storage Favorable	Prefer Non-Fed	8	13	17	18	19
	Min Spur Lines	8	14	18	18	19
	Prefer Fed	10	15	19	19	20
Wind & Transmission Favorable	Prefer Non-Fed	21	40	54	63	70
	Min Spur Lines	23	42	54	64	71
	Prefer Fed	25	43	57	67	74
Geothermal Favorable	Prefer Non-Fed	10	14	16	16	17
	Min Spur Lines	10	14	16	16	17
	Prefer Fed	11	15	17	17	18
CCS & Nuclear Favorable	Prefer Non-Fed	10	13	14	14	14
	Min Spur Lines	10	13	14	14	14
	Prefer Fed	11	14	15	15	15

[a] Years indicate when the estimated capacity begins operating assuming prior approval of siting authorizations.

Table C-3. Total Geothermal Capacity on All Federal Lands

Power Sector Scenario	Downscaling Preference	Installed Geothermal Capacity (GW)[a]				
		2030	**2035**	**2040**	**2045**	**2050**
Many Options	Prefer Non-Fed	1	2	6	12	12
	Min Spur Lines	1	3	7	13	15
	Prefer Fed	1	3	7	14	16
Limited Options	Prefer Non-Fed	1	4	4	4	4
	Min Spur Lines	1	5	5	4	4
	Prefer Fed	1	5	5	5	5
Federal Lands Favorable	Prefer Non-Fed	1	4	4	4	4
	Min Spur Lines	1	5	5	4	4
	Prefer Fed	1	5	5	5	5
Solar & Storage Favorable	Prefer Non-Fed	1	1	1	1	1
	Min Spur Lines	1	1	1	1	1
	Prefer Fed	1	1	1	1	1
Wind & Transmission Favorable	Prefer Non-Fed	1	1	1	0	0
	Min Spur Lines	1	1	1	1	1
	Prefer Fed	1	1	1	1	1
Geothermal Favorable	Prefer Non-Fed	1	8	17	27	30
	Min Spur Lines	1	9	17	28	32
	Prefer Fed	1	10	20	32	36
CCS & Nuclear Favorable	Prefer Non-Fed	1	1	1	0	0
	Min Spur Lines	1	1	1	1	1
	Prefer Fed	1	1	1	1	1

[a] Years indicate when the estimated capacity begins operating assuming prior approval of siting authorizations.

Appendix D: RE Deployment on Federal Lands by Land Unit

As discussed in Section 3.3.2, the downscaled RE deployment estimates can also be summarized to land units relevant to individual federal land administrators. This appendix presents downscaled results for BLM field offices, USFS National Forests and Grasslands, and DOD military installations, ranges and training areas (MIRTA).

The results presented in this section focus on land units that frequently had RE deployment across our modeled scenarios—suggesting an insensitivity to modeling assumptions—and ranked highly in total RE deployment across multiple scenarios. We limited the land units to those with a non-zero amount of deployed RE capacity in more than half of our modeled scenarios (i.e., capacity > 0 MW in at least four of the seven scenarios). We then ranked the land units within each scenario based on their total deployed RE capacity (including UPV, wind, and geothermal). Finally, we calculated a composite rank for each land unit from its average rank across all applicable scenarios.

Tables D-1, D-2, and D-3 list the top 25 land units based on those composite ranks. All results are for 2035 and use the downscaled results from the Prefer Federal land use preference.

Table D-1. Top BLM Field Offices Based on Modeled RE Deployment by 2035.

	Field Office	Mean Rank	Scenario Count	Deployed RE Capacity (MW)			
				Min	Median	Mean	Max
1	Salt Lake	3.1	7	1782	3209	4903	9706
2	Roswell Field Office	3.7	7	1924	3540	3501	4831
3	Lake Havasu Field Office	4	7	1740	3262	3618	5861
4	Las Vegas Field Office	4.3	7	725	4020	4483	8952
5	Kingman Field Office	4.7	7	1297	2860	3132	5163
6	Vernal	6.4	7	70	3709	3328	6205
7	Vale Malheur Field Office	8	7	639	1219	1737	3587
8	Sierra Front Field Office	8.9	7	430	1842	1919	3736
9	Lower Sonoran Field Office	9	7	913	1762	1496	1922
10	Tucson Field Office	12.7	7	591	1040	1047	2129
11	Humboldt River Field Office	13	7	110	824	995	2095
12	Hassayampa Field Office	14.5	4	275	1010	976	1608
13	El Centro Field Office	14.7	7	250	597	764	2023
14	Four Rivers Field Office	16	7	42	812	675	892
15	Stillwater Field Office	16.3	7	64	838	959	2704
16	Needles Field Office	17.2	6	566	590	596	658
17	Ridgecrest Field Office	19.3	7	42	264	689	2743
18	Palm Springs/S. Coast Field Office	21.1	7	91	177	271	906
19	Safford Field Office	21.7	7	138	212	243	423
20	Spokane Wenatchee Field Office	22.4	7	54	216	252	670
21	Ukiah Field Office	24.5	6	27	148	267	817
22	Fillmore	25.1	7	26	27	383	1107
23	Casper Field Office	25.6	7	32	45	249	714
24	Lander Field Office	26.1	7	2	894	1256	3481
25	Barstow Field Office	27.2	6	19	64	241	1156

Table D-2. Top USFS National Forests and Grasslands Based on Modeled RE Deployment by 2035

	National Forest or Grassland	Mean Rank	Scenario Count	Deployed RE Capacity (MW)			
				Min	Median	Mean	Max
1	Mark Twain National Forest	1.4	7	1707	3905	4228	8981
2	Ocala National Forest	3.8	6	748	1465	3814	13891
3	Talladega National Forest	5.1	7	427	1891	1866	3606
4	Francis Marion National Forest	5.3	7	710	1295	1467	2489
5	Lyndon B. Johnson National Grassland	7.7	7	910	995	1203	1768
6	Daniel Boone National Forest	9.2	6	234	995	1541	5009
7	Sumter National Forest	10.4	7	207	1256	1322	3386
8	Oconee National Forest	13.6	7	419	713	694	1153
9	Chattahoochee National Forest	14	7	260	266	925	3363
10	Ouachita National Forest	15.3	7	196	570	708	1925
11	Sam Houston National Forest	15.6	7	389	476	565	1014
12	Holly Springs National Forest	16	7	229	343	655	2180
13	George Washington National Forest	16.3	7	186	360	638	2353
14	Huron National Forest	16.8	6	13	701	1041	3429
15	Hiawatha National Forest	18	7	23	373	1250	5360
16	Kisatchie National Forest	19.1	7	50	328	594	2252
17	Shasta National Forest	20	7	66	273	531	1425
18	Chippewa National Forest	21.2	6	168	299	327	514
19	Manistee National Forest	22.9	7	89	89	826	4400
20	Lolo National Forest	22.9	7	188	402	332	453
21	Tahoe National Forest	23	4	79	419	577	1392
22	Jefferson National Forest	25	7	58	209	444	1966
23	Cleveland National Forest	25	4	0	1034	875	1432
24	William B. Bankhead National Forest	25.3	7	87	87	357	1382
25	Redbird Purchase Unit	25.8	5	37	94	496	2004

Table D-3. Top DOD MIRTA Based on Modeled RE Deployment by 2035

	MIRTA	Mean Rank	Scenario Count	Deployed RE Capacity (MW)			
				Min	Median	Mean	Max
1	Fort Bliss	2.4	5	580	3661	2814	4568
2	Joint Base Lewis-McChord	3.2	4	2266	2530	2691	3439
3	Edwards Air Force Base	4.1	7	88	415	2452	9630
4	Avon Park AF Range	4.2	4	438	3546	2831	3795
5	Choc Mt Air Gnry Rng	7.3	7	106	510	518	1288
6	Naval Air Weapons Station China Lake	7.7	7	234	234	597	1507
7	Fort Knox	8.5	4	145	490	1372	4362
8	Joint Base McGuire-Dix-Lakehurst	9	7	11	138	708	2291
9	Nevada Test and Training Range	9.8	4	0	1415	1276	2274
10	Eglin Air Force Base	9.8	4	3	1602	2463	6647
11	Letterkenny Army Depot	10.2	4	91	887	841	1498
12	Nellis Air Force Base	11.2	5	46	231	267	503
13	NG Camp Ravenna Joint Military Training Center	11.2	4	156	551	663	1396
14	Target B-16	11.9	7	86	86	226	611
15	Marine Corps Air Ground Combat Center Twentynine Palms	12.2	4	27	625	649	1320
16	Creech Air Force Base	13.8	4	6	354	267	354
17	NG TS Ethan Allen Range	14.5	4	164	232	266	436
18	Target 101 Shade Tree	15.3	7	22	46	103	291
19	Tooele Army Depot	15.4	7	39	39	188	1007
20	NG CTC Fort Custer Trng Center	16.8	4	41	399	411	805
21	Orchard Combat Training Center	17.5	4	58	155	167	299
22	NG MTA Camp Edwards	17.6	7	14	14	49	125
23	Joint Base Charleston	18.2	4	22	194	158	222
24	Fallon Range Complex	18.4	7	33	33	33	33
25	Vandenberg Main Base	18.6	7	2	2	65	220