Local Power: Comparing County-Level Renewable Energy Potential to Consumption Using the SLOPE Platform

National Renewable Energy Laboratory

Christiana Ivanova, Megan Day

Summary of Findings

Wide-scale deployment of renewable energy technologies could significantly reduce greenhouse gas emissions and mitigate the effects of climate change. Many communities have ambitious clean energy goals with targets for locally generated renewable energy. To inform state and local clean energy planning, analysts from the Joint Institute for Strategic Energy Analysis (JISEA) and National Renewable Energy Laboratory (NREL) used data from NREL's State and Local Planning for Energy (SLOPE) platform to compare annual technical generation potential of renewable energy technologies to modeled electricity consumption in every county of the contiguous United States. Annual costs were calculated to produce a 20% share of electricity consumed annually from each technology to examine the local cost effectiveness of a diversified mix of generation sources. For example, combining distributed and utility-scale wind and solar generation can offset the need for storage and nonintermittent fossil resources to achieve high deployment of renewables. This county-level analysis provides insight into where local renewable energy generation could cost-effectively match annual electricity consumption.

Snapshot

With full build-out of technical generation potential (i.e., development of all suitable land or rooftop area), 75% of counties in the contiguous United States could produce a median value of:

- 48% of modeled 2020 local residential electricity consumption using residential rooftop photovoltaics (PV)
- 35% of modeled 2020 commercial and industrial electricity consumption from commercial and industrial rooftop PV
- 40% of modeled 2020 total electricity consumption from rooftop PV (residential, commercial, and industrial rooftop PV combined).

A comparison of 2020 levelized costs of locally generating renewable energy equal to 20% of 2020 county-level electricity consumption indicates that local generation of land-based, large-scale wind energy has the lowest median cost. Of all counties in the contiguous United States with the potential to deploy each of the following technologies, 75% have the potential to locally produce 20% of 2020 electricity consumption for a median cost of:

- $2.7 million from land-based wind
- $3.3 million from PV
- $5.1 million from commercial rooftop PV
- $6.3 million from concentrating solar power (CSP)[1]
- $8.2 million from residential rooftop PV.

These findings demonstrate the potential for locally deploying cost-effective renewable energy technologies for local consumption.

JISEA Joint Institute for Strategic Energy Analysis

1 44% of the 3,108 counties analyzed have the potential to generate electricity by deploying new CSP.

Local Clean Energy Deployment to Achieve Climate Goals

The desire to mitigate the effects of climate change is driving many local governments to set greenhouse gas emissions reduction and renewable energy targets. Within the United States, more than 180 cities and towns, 14 counties, and 10 states and territories have committed to transitioning to 100% renewable energy (Sierra Club 2022).

Local and state goals, combined with the cost-competitiveness of utility-scale renewable energy technologies, led to renewables surpassing coal as the second-most prevalent energy source of U.S. electricity generation in 2020 (EIA 2021) (Figure 1).

Comparing generation potential and levelized costs across wind and solar energy technologies can help inform state and local energy planners seeking to prioritize local renewable energy generation. The State and Local Planning for Energy (SLOPE) platform—developed by the U.S. Department of Energy (DOE) and NREL—delivers jurisdictionally resolved potential and projection data on energy efficiency, renewable energy, and sustainable transportation to enable data-driven state and local energy planning.

This study uses SLOPE data on wind and solar technical generation potential, energy consumption, and levelized cost of energy to demonstrate how SLOPE can inform energy planning at the county, state, and national levels within the contiguous United States.

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Learn more at **maps.nrel.gov/slope**

Methodology

SLOPE provides jurisdiction-specific maps and downloadable data on energy consumption, renewable energy generation and energy efficiency potential, energy costs, and transportation energy and electrification projections, as well as demographic and commercial buildings data.[2] For instance, SLOPE delivers county-level residential rooftop PV generation potential (NREL 2021a) (Figure 2).

This study focuses on solar and wind energy technologies, as they have the highest technical generation potential. NREL analysts compared SLOPE data on in-county utility PV, residential

2 "SLOPE: State and Local Planning for Energy," NREL, https://maps.nrel.gov/slope.

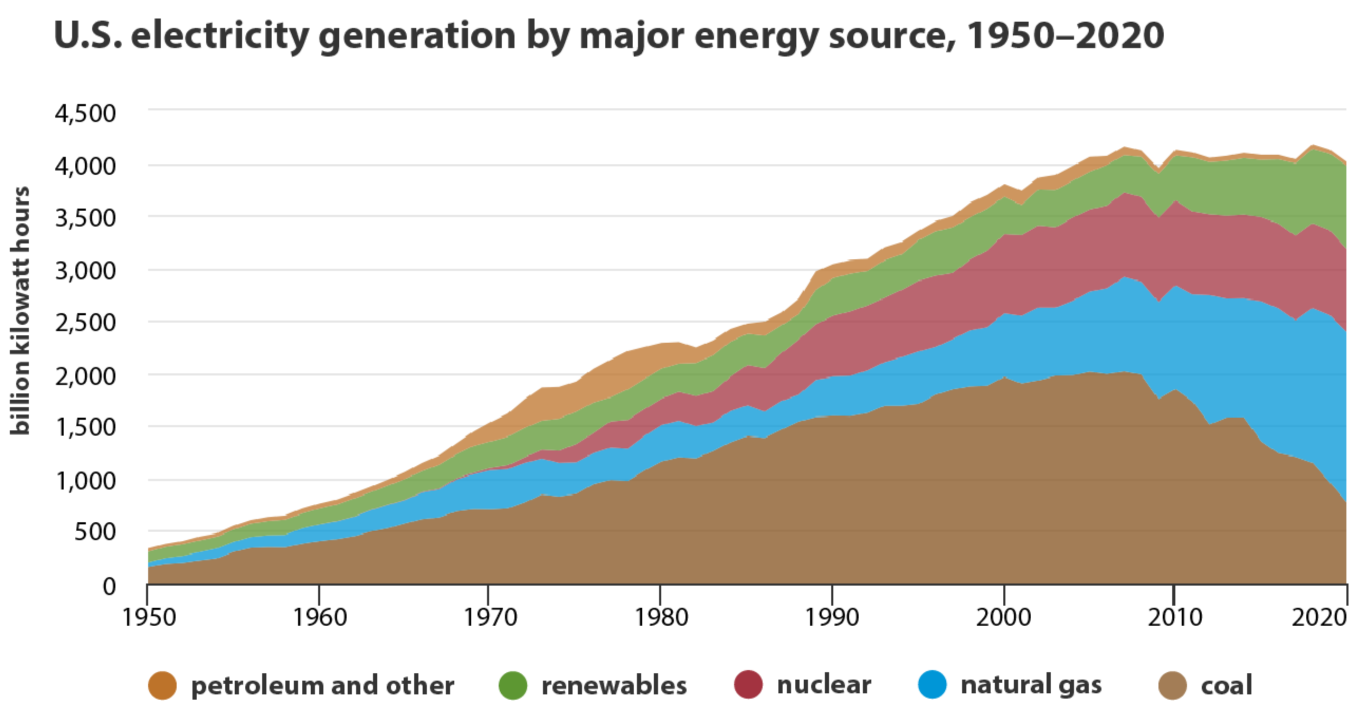

Figure 1. U.S. electricity generation by major energy source, 1950–2020. Electricity generation from utility-scale facilities. Source: EIA 2021

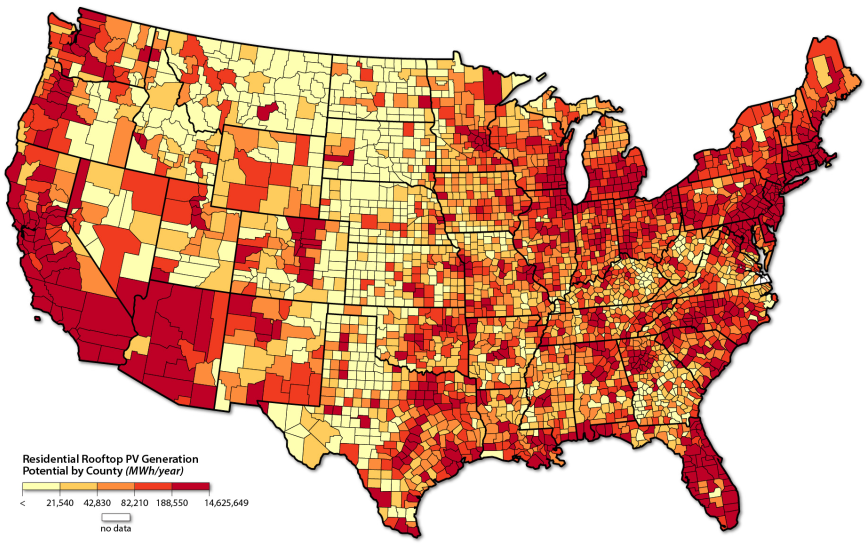

Figure 2. Annual technical generation potential of residential rooftop PV at the county level
Source: NREL 2021a. MWh = megawatt-hours.

rooftop PV, commercial rooftop PV,[3] land-based wind, and CSP generation potential and costs with electricity consumption within each county in the contiguous United States.[4]

Consumption is defined as the modeled consumption in megawatt-hours (MWh) of electricity and/or natural gas[5] in 2020 (NREL 2021b). Technical generation potential is the modeled maximum generation (MWh) per year that can be produced by a given technology based on "resource, system performance, topographic limitations, and environmental and land-use constraints, not market conditions"[6] if all suitable land (for utility PV, land-based wind, and CSP) or rooftop area (for residential and commercial PV) is used. Estimates are calculated using NREL's Renewable Energy Potential (reV) model.[7] We do not account for generation from existing renewable energy facilities. Technological specifications are consistent with representative technologies in NREL's Annual Technology Baseline (NREL 2021c).

This study explored the following research questions:

1. What percentage of local, combined electricity and natural gas energy consumption could be locally produced by wind and solar technologies?
2. Within each county and state, what percentage of annual residential electricity consumption could be produced by residential rooftop PV? What percentage of commercial electricity consumption could be produced by commercial rooftop PV?
3. Within each county and state, how does rooftop PV generation potential compare with annual electricity consumption?
4. How much would it cost to locally produce 20% of annual electricity consumption from wind and solar technologies?

Calculating Local Clean Energy Potential to Match Consumption

This study uses the term coverage to refer to the percentage of county-, state-, or national-level energy consumption that could be produced using local renewable energy technologies (Equation 1).

SLOPE data used in this analysis include:

- Annual technical generation potential by county and state for utility PV, residential rooftop PV, commercial rooftop PV, and land-based wind.
- Energy consumption sectors: residential, commercial, industrial.
- Energy consumption types: electricity and natural gas.

Equation 1

$$\text{Coverage (\%)} = \frac{\text{Modeled Annual Technical Generation Potential (MWh)}}{\text{Modeled Electricity and/or Natural Gas Consumption (MWh)}}$$

Equation 2

$$\text{Coverage Cost (\$)} = \text{Coverage (X\%)} \times \text{Modeled Electricity and/or Natural Gas Consumption (MWh)} \times \text{Modeled LCOE (\$/MWh)}$$

3 Modeled technical generation potential for commercial PV includes build-out on rooftops of both commercial and industrial buildings.

4 SLOPE also provides location-specific generation potential from new hydropower development, but this potential is not mapped to county jurisdictions and is therefore not included in this analysis.

5 SLOPE Net Electricity and Natural Gas Consumption data in metric million British thermal units (MMBtu) are converted to megawatt-hours for this analysis.

6 "SLOPE: State and Local Planning for Energy: Energy Generation: Utility PV," NREL, https://maps.nrel.gov/slope/data-viewer?layer=energy-generation.utility-pv.

7 "reV: The Renewable Energy Potential Model," NREL, https://www.nrel.gov/gis/renewable-energy-potential.html.

Calculating Cost of Coverage

Levelized cost of energy (LCOE) is the modeled cost to generate electricity ($/MWh), considering technology capital costs, operation and maintenance costs, and performance and capacity factors. Local conditions are also considered, including labor markets and interconnection costs (NREL 2021d).

In this study, coverage cost is defined as the dollar amount required to achieve a level of coverage (e.g., 20%) of county-, state-, or national-level annual consumption using local renewable energy generation from a given technology. Coverage cost is reported as modeled costs for one year. (Equation 2).

Only counties with nonzero technical generation potential for a given technology are included in the coverage cost calculations.[8] This study does not consider the value of other energy services, such as flexibility, bill offsetting, or storage, which may factor substantially into the overall value of a given technology.

Results: Renewable Energy Potential to Match Annual Consumption

Research Question 1: *What percentage of local, combined electricity and natural gas energy consumption could be locally produced by wind and solar technologies?*

This scenario explores the potential of local wind and solar generation to produce sufficient electricity to accommodate both current electricity consumption and increased electricity consumption from electrifying natural gas end uses, such as heating and cooking. Efficiencies in conversion are not considered. Full build-out of utility PV potential in each county in the contiguous United States generates a median value of 4,435% of combined electricity and natural gas consumption in that same county. County-level residential rooftop PV has the lowest potential to match combined electricity and natural gas consumption at a median value of 9% (Table 1).

Research Question 2: *Within each county and state, what percentage of annual residential electricity consumption could be produced by residential rooftop PV? And what percentage of commercial electricity consumption could be produced by commercial rooftop PV?*

Full build-out of residential rooftop PV on all suitable rooftops has a higher potential to match local annual residential electricity consumption than commercial PV has to match commercial electricity consumption. For 75% of counties[10] across the contiguous United States, full build-out of residential rooftop PV has the potential to produce 38%–62% of residential electricity consumed annually with a median coverage potential of 48%, whereas commercial PV has the potential to produce 21%–55% of commercial electricity consumed with a median coverage potential of 35% (Figure 3).

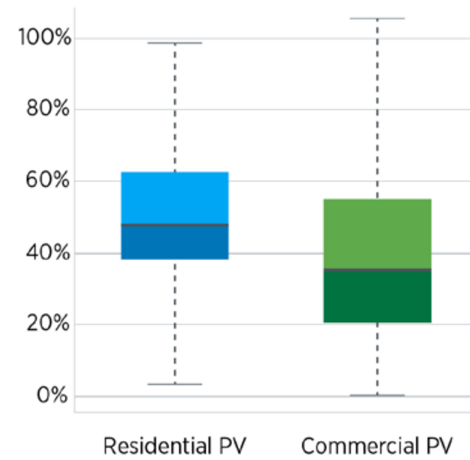

Figure 3. County-level coverage potential of residential electricity consumption using residential rooftop PV (left) and commercial electricity consumption using commercial rooftop PV (right). Outliers are excluded from the box plots; only coverage values from 0% to 100% are shown.

Research Question 3: *Within each county and state, how does rooftop PV generation potential compare with annual electricity consumption?*

Table 1. Exploring End-Use Electrification: Median County-Level Coverage of Combined Electricity and Natural Gas Consumption

	Utility PV	Residential Rooftop PV	Commercial Rooftop PV	Land-Based Wind	CSP
Median	4,435%	9%	11%	637%	0%[a]
Q1–Q3	971%–15,658%	5%–13%	6%–17%	163%–2,174%	0%–3,962%

Q1–Q3 represents the 75% of counties represented in each metric corresponding to those captured in the center range of results between the first and third quartiles of data.

a Of the 3,108 counties evaluated across the 48 contiguous states, 1,757 counties have no technical generation potential for CSP, as it requires high direct normal solar irradiance.[10] Twenty states have no technical generation potential for CSP across all counties.

8 Counties and states with a technical generation potential of 0.0 MWh and therefore a potential to produce 0% of electricity consumed for a given technology yield a coverage cost of $0.00, implying these technologies are free when in fact they are impossible to deploy.

9 Areas with direct normal irradiance of greater than or equal to 5 kWh/m2/day are considered viable for CSP (Lopez et al. 2012).

10 The 75% of counties represented in each metric correspond to those captured in the center range of results between the first and third quartiles of data.

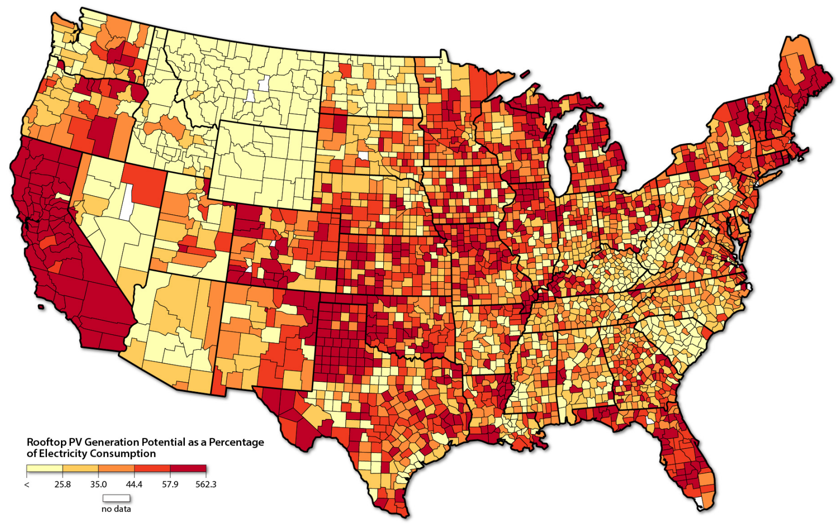

Figure 4. County rooftop PV technical generation potential as a percentage of county electricity consumption (2020). Differences across state lines often reflect high industrial electricity consumption in counties with low rooftop PV generation potential (as in counties in Nevada and Wyoming).

For 75% of counties across the contiguous United States, full build-out of residential and commercial rooftop PV potential produces 28%–54% of modeled 2020 electricity consumption. The median coverage potential is 40%, and some counties reach potential coverage as high as 562% (Figure 4). This approach assumes generation can be shared across buildings and sectors to match electricity consumed but not across county jurisdictional boundaries. Enabling this assumption of power sharing would require implementation of virtual net metering or similar policies.

More-uniform levels of coverage across counties within a state may result in seemingly stark differences in coverage across state boundaries, such as between Colorado and Wyoming. Uniform distribution within low-coverage states for total rooftop PV may reflect geographically larger, less populous counties, with less rooftop area and high levels of industrial electricity consumption.

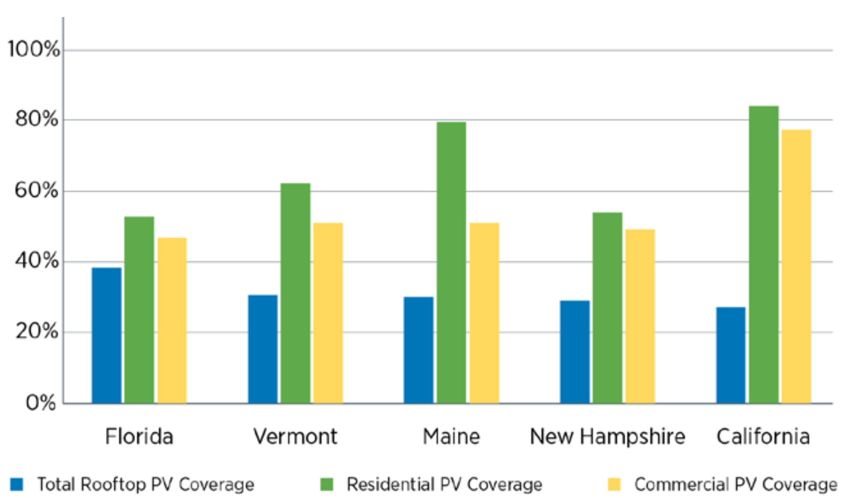

Figure 5. Top-five states' potential coverage of electricity consumption using residential and commercial rooftop PV.

Florida's rooftop PV technical generation potential is 38% of annual state electricity consumption, the highest of the 48 contiguous states, followed by Vermont, Maine, New Hampshire, and California (Figure 5). For the top-five states, full build-out of residential rooftop PV has the potential to produce a larger percentage of residential electricity consumption than commercial rooftop PV could produce for commercial electricity consumption. Though the New England states have lower solar resource, they yield higher coverage than states with abundant solar resource (e.g., Texas) due to their higher density population. Despite being one of the highest solar resource states in the contiguous United States, Texas ranks 37th of the 48 states in rooftop PV potential compared to electricity consumption (NREL 2021e). Such results highlight the advantage of using local SLOPE data to determine needs and opportunities in energy planning rather than relying on national-level trends.

Between states and among counties, differences in modeled technical generation potential, population size, building stock, and consumption patterns may lead to different deployment opportunities for rooftop PV. For instance, New Hampshire's residential rooftop PV technical generation potential is 54% of annual residential electricity consumption. The state's commercial rooftop PV technical generation potential is 49% of commercial electricity consumption. Individual counties within New Hampshire have the combined rooftop PV technical generation potential equal to 41%–83% of electricity consumption (Figure 6).

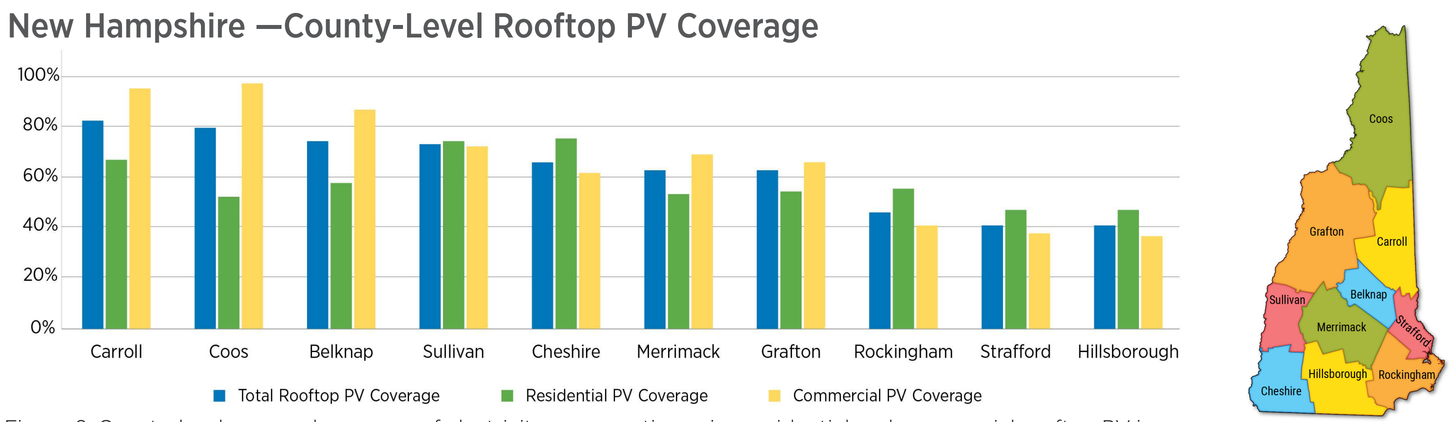

Figure 6. County-level map and coverage of electricity consumption using residential and commercial rooftop PV in New Hampshire. Total rooftop PV covers all sectors' electricity consumption, residential PV covers residential electricity consumption, and commercial PV covers commercial and industrial electricity consumption.

Results: Renewable Energy Costs for Local Consumption

Research Question 4: *How much would it cost to locally produce 20% of annual electricity consumption from wind and solar technologies?*

Utility-scale PV and wind technologies have the lowest modeled minimum LCOE and capital cost averaged across all counties in the contiguous United States; rooftop PV has next-lowest LCOE and capital cost, and CSP is the most expensive technology (Table 2).

Land-based wind could provide the lowest-cost local generation to produce 20% of local electricity consumption. Seventy-five percent of counties in the contiguous United States with the potential to deploy land-based wind could generate enough electricity to match 20% of electricity consumption for $1.2–$7.5 million per year using land-based wind, with a median cost of $2.7 million per year. Utility PV is the second-lowest cost, and 75% of counties utility-PV generation potential could match 20% of electricity consumption for $1.3–$8.9 million per year, with a median coverage cost of $3.3 million per year, followed by commercial PV at $2.1–$13.8 million per year, with a median $5.1 million per year, and CSP at $2.5–$17.5 million per year, with a median of $6.3 million per year. Residential PV is the most expensive technology, at a modeled coverage cost for 75% of counties of $3.3–$21.9 million per year, with a median cost of $8.2 million per year.

Residential and commercial rooftop PV have the widest range of coverage costs, indicating that the price of deployment to produce local annual electricity consumption varies greatly depending on local characteristics. Utility PV and land-based wind have the lowest median coverage costs as well as the smallest range of potential coverage costs across counties, indicating that conditions for utility-scale wind and solar deployment are more homogenous across the United States than they are for rooftop PV or CSP (Figure 7).

At the state level, Texas and California have the most expensive potential annual coverage costs of all technologies. The most expensive technology option is CSP in Texas, which has a modeled coverage cost of $8.4 million per year, followed by residential PV at a modeled cost of $8.2 million per year. Vermont, Rhode Island, and Maine have the lowest potential coverage costs for all technologies except CSP. The lowest-cost technology is utility PV in Vermont, with a modeled annual coverage cost of $61.25 million per year. High coverage costs within a state can be attributed to higher potential coverage, larger populations, and higher consumption, even if the localized LCOE for a given technology is lower, or vice versa.

Table 2. Average County-Level Minimum LCOE and Capital Cost, 2018

Technology	LCOE ($/MWh)	Capital Cost ($/MW)
Utility PV	$44.15	$1,085,440
Residential PV	$108.68	N/A[a]
Commercial PV	$68.66	N/A
Land-based wind	$38.68	$1,530,092
CSP	$112.45	$7,600,502

a Capital costs are currently not available for residential or commercial PV in SLOPE.

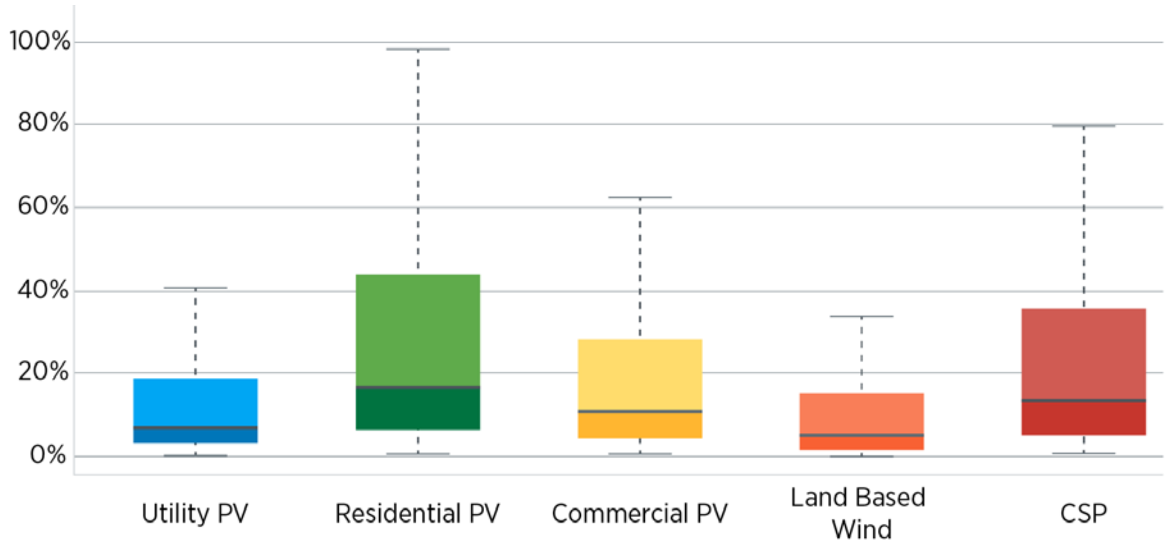

Figure 7. County-level annual coverage cost ($) ranges for 20% of electricity consumption by technology. Outliers are excluded from the box plots.

Conclusion

This study explored the potential of locally deployed wind and solar energy technologies to match modeled annual county- and state-level energy consumption in terms of technical generation potential and cost. At the national level across the 3,108 counties analyzed in the contiguous United States—and for most within-boundary state and county-level generation—utility PV and land-based wind as modeled by SLOPE have higher technical generation potential and are more cost-effective than rooftop PV. Rooftop PV is often the only option for customer-sited generation and may make financial sense at the household level.

All counties in the contiguous United States have the potential to generate electricity by deploying new rooftop PV, 98% of counties could deploy new utility-scale PV or wind, and 44% could deploy CSP. Most jurisdictions could produce more local electricity to match consumption per dollar invested by locally deploying new utility-scale solar or wind facilities than by outfitting all suitable buildings with rooftop PV.

Across the 3,108 counties studied, land-based wind had the lowest median coverage cost to produce 20% of annual local electricity consumption, followed by utility PV, commercial PV, CSP, and residential PV.

State- and national-level trends in coverage and coverage cost do not always hold true at the county level, which emphasizes the importance of using local data to inform local investment prioritization and energy planning.

The coverage potential of a technology to produce local energy consumption is not solely determined by technical generation potential, as some less-populated or low-resource states have high coverage. Coverage cost can be driven by population size and consumption levels rather than technology costs or technical generation potential. For instance, states with high resource availability and low LCOE for a given technology may have high coverage costs because of larger populations or higher consumption.

Using such insights from SLOPE data, local and state energy planners, developers, and utilities can target cost effective, localized renewable energy investments.

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The potential for PV to meet local energy demand depends on population size and energy consumption. Photo by Werner Slocum, NREL 64436

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