INL/CON-24-76908-Revision-0

Rural Hybrid Generation & Microgrids: National Labs are Here to Help

March 2024

Changing the World's Energy Future

Megan Jordan Culler, Soumyadeep Nag, Justin J Welch, Michael Leitman

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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TECHADVANTAGE® 2024

NRECA® America's Electric Cooperatives

Lake Region Electric Cooperative (LREC)

- Distribution cooperative in western-central Minnesota
- Over 29,000 consumer-members composed of residential, commercial, industrial, and seasonal homes
- Headquartered in Pelican Rapids, Minnesota
- Territory includes rural farmland, forests, prairies, and 1,000+ lakes
- Maintains 5,600 miles of distribution lines
- Member of Great River Energy (GRE)

Wind-Solar Hybrid Project Details

- 2MW wind-solar hybrid project that is connected to the distribution grid
  - 2.3MW GE wind turbine
  - 500kW photovoltaic solar array
  - 2MW GE inverter which was sized to avoid backfeed or curtailment
- LREC has a 20-year Power Purchase Agreement (PPA) with Juhl Energy
- Also has a grid-enabled thermal storage (GETS) pilot using water 80-100 gallon water heaters to increase hybrid utilization

Renewable Energy & LREC

- The hybrid project is the largest, but not first renewable generating resource
- Member interest in clean, local, renewable energy beyond what GRE offers
- 2013 LREC erected a 35kW research and demonstration PV solar array
- An 18kW community solar array was later added
- GoWest Solar Program for LREC members

Members & Community

- High member satisfaction with the Hybrid Project
- Member participation with the GETS pilot and demand bill credit
- All around member savings and rate stabilization

What’s Next?

- LREC is looking to expand it’s DER resources to take advantage of an option from GRE to increase self-supply
  - Local renewable self-supply option increased from 5% of energy or energy needs to 10%
  - Switch to energy-charge only reductions; local renewables can not be used to reduce demand charges, previously allowed up to 5%
- Asked the National Labs to analyze optimized hybrid DER resources, including wind, solar, and battery storage
- Also asked labs to look at using batteries for energy arbitrage as an additional revenue stream, discharging them when MISO market pricing is high and charging them when market pricing is low.
- The Labs have significant capability and can offer a non-biased assessments across multiple hybrid technologies, can be the primary source of technical analysis or be used to supplement other due diligence activities.

Lab TA for Lake Region Electric Cooperative

Evaluation of benefits of additional Wind, PV, and battery from new contract.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Pacific Northwest
NATIONAL LABORATORY

INL Idaho National Laboratory

Outline

- Lab roles in LREC TA
- Project considerations
- Input Data
- Hybrid generation mixes
- Bill Calculations
- Battery dispatch strategies
- Economic analysis

Lab roles in LREC TA

DOE WETO → National Labs

NREL

- Determine optimal wind and solar configurations
- HOPP – Python based – Optimize size and layout

PNNL

- Determine economic metrics for the optimal configurations
- BSET – web-based tool for evaluating battery systems

INL

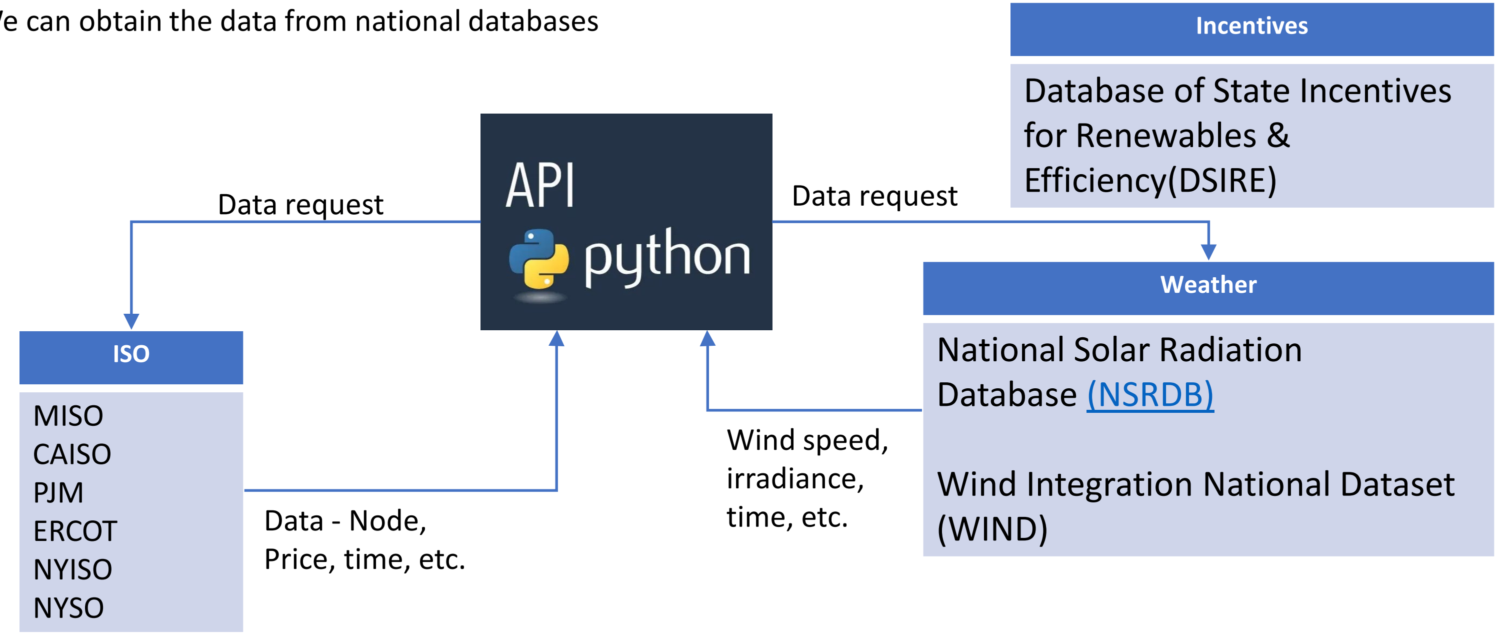
- Optimal battery operating strategy
- Contract and cooperative – defined – optimize savings

Project considerations

- Upper bounds: Need a large hybrid system to get significant value – it must be able to participate in MISO market to be profitable, (it must exceed local feeder demand)
  - All renewable resources will not exceed 10% of average annual energy purchases during preceding 36 months
  - Storage may not exceed hourly rate of discharge equal to 10% of the average hourly energy requirement during the preceding 36 months
- Storage will be charged/credited (for charge/discharge respectively) at MISO hourly LMP
- Renewables cannot be used to reduce peak demand, but can be used to offset energy purchases
- Storage and renewables are each discrete assets

Input Data

- Using Python application programming interface to collect required data
- Client can provide all data, or limited data (configuration and contract only)
- We can obtain the data from national databases



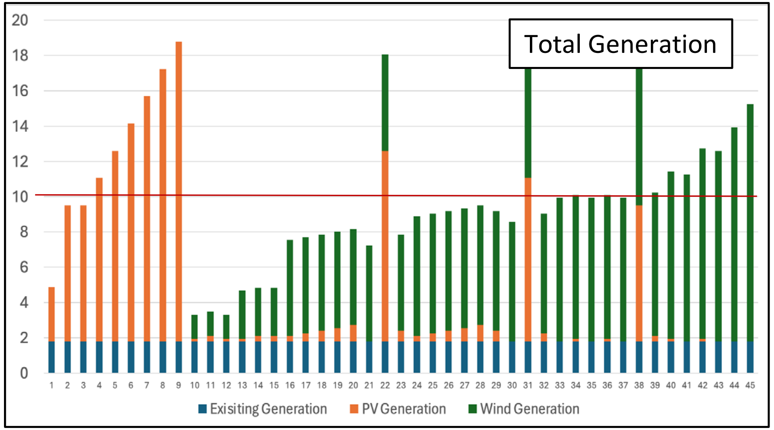
Hybrid Generation Mixes

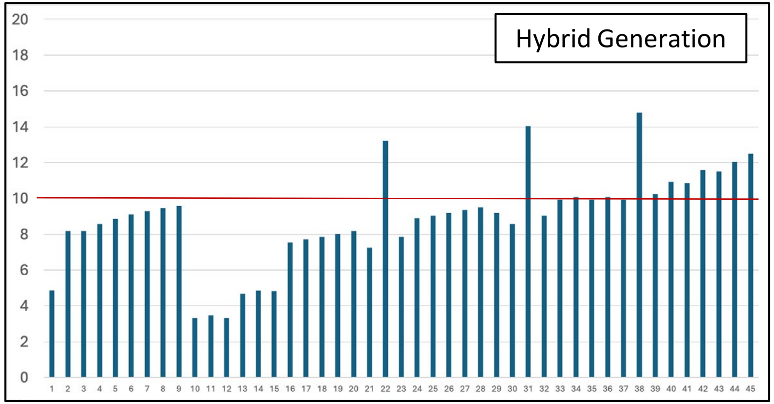
- Original system:
  - Wind: 2.0 MW
  - PV: 500.0 kW
  - Interconnection: 2.0 MW
  - Hybrid Capacity Factor: 32.4 %
  - Percentage of total demand: 1.8%
- Double system size:
  - Hybrid Capacity Factor: 32.4 %
  - Percentage of total demand: 3.3%

Credit: RADWIND Project Case Study on Lake Region Electric Cooperative, NRECA Research 2021

Generation Sweeps

- Ran 45 scenarios with different mixes of wind, PV and battery
- Generation was curtailed if in excess of maximum load from 2022 and battery was fully charged
- Selected cases with generation closes to 10% of annual demand





10% Demand System Size

- Both configurations are *in addition* to current generation assets
- Hybrid #1 (closest to 10%):
  - Wind: 6 turbines – 2MW
  - PV: 0.0 kW
  - Hybrid Capacity Factor: 33.6%
  - Percentage of total demand: 9.93%
- Hybrid #2 (slightly exceeds 10%):
  - Wind: 6 turbines – 2MW
  - PV: 500 kW
  - Hybrid Capacity Factor: 33.4%
  - Percentage of total demand: 10.07%

Credit: RADWIND Project Case Study on Lake Region Electric Cooperative, NRECA Research 2021

10% Demand System Size

- Hybrid #3 (more balanced system sizes):
  - Wind: 5 turbines – 2MW
  - PV: 3 MW
  - Hybrid Capacity Factor: 31.8%
  - Percentage of total demand: 9.5%
- Hybrid #4 (all systems closest w/o exceeding):
  - Wind: 5 turbines – 2MW
  - PV: 2 MW
  - Hybrid Capacity Factor: 32.4%
  - Percentage of total demand: 9.2%

Credit: RADWIND Project Case Study on Lake Region Electric Cooperative, NRECA Research 2021

Bill Calculation:
Energy and Demand Price and Contract Constraints

$$P_{GRd}(m) = \begin{cases} P_{Grd1}, & \text{if m} \in \text{[Jun Jul Aug]} \\ P_{Grd2}, & \text{if m} \in \text{[Jan Feb Dec]} \\ P_{Grd3}, & \text{otherwise.} \end{cases}$$

Peak Demand prices – seasonal variations

$$E_d(m) = \begin{cases} \overline{E}(m) + E_s(t), & \text{if } E_s(t) > 0 \;\&\; \text{t} = \text{coincident peak hour} \\ \overline{E}(m), & \text{otherwise.} \end{cases}$$

Peak Demand considering energy storage charging -

$$P_{GRe}(t) = \begin{cases} P_{pk}, & \text{if t} \in \text{[10am 8pm Mon-Fri]} \\ P_{opk}, & \text{otherwise,} \end{cases}$$

Energy prices – peak and off-peak

$$P(t) = \begin{cases} P_{Gre}, & \text{if } E_{net1} > 0 \text{ load} \\ P_{MISO}, & \text{if } E_{net1} < 0 \text{ source,} \end{cases}$$

Energy price based on determination of import or export

$$E_{net1}(t) = E(t) - E_r(t) - E_s(t),$$

Determine export or import

$$E_{net2}(t) = E(t) - E_r(t).$$

Excluding $E_s(t)$ to avoid double counting and billing E_s at P_{MISO}

Bill Calculation

Calculating the bill while considering system constraints

$$E_{net2}(t) = E(t) - E_r(t).$$

$$B = \sum_{m=1}^{12} \left\{ \sum_{t=1}^{24\times d_m} [E_{net2}(t)P(t) + E_s(t)P_{MISO}(t)] + E_d(m)(P_{GRd}(m) + P_{GRx}) \right\}$$

- We use Enet2 instead of Enet1 at P(t) because Es(t) – storage – is always charged or credited at PMISO
  - “Storage will be charged/credited (for charge/discharge respectively) at MISO hourly LMP”
  - Double consideration of Es is avoided
- Note: Peak demand Ed(m) used for demand charges and transmission charges

Strategies

Bill Savings and Battery Revenue

Seasonally varying price windows for charging, discharging and idle for the entire year. → **C**

Seasonally varying time windows for charging, discharging and idle for the entire year. → **B**

Fixed time windows for charging, discharging and idle for the entire year. → **A**

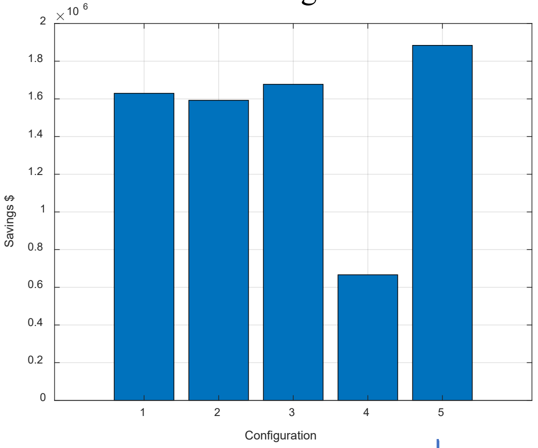
m = 1, 2, 3
1 = [Jun, Jul, Aug],
2 = [Jan, Feb, Dec],
and 3 = Otherwise

	Load sufficiency (base)	A	B	C
System-wide Mean savings	~$1.5M	base + $20k	base + $20k	base + $130k
Battery Revenue	~$12k	base - $3.6k	base - $3.3k	base + $3.8k

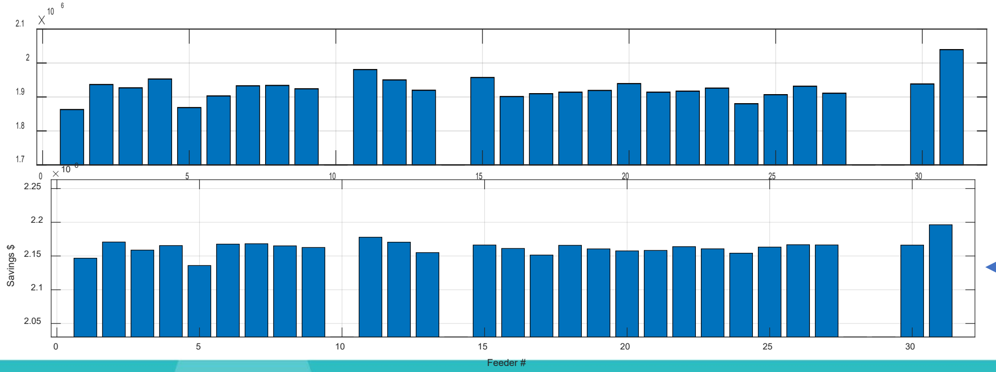
Savings analysis for different configurations and feeders – without storage

	Case summary	Case description
1	Balanced	wind_11500.000000kw_pv_3000.000000kw_battery_0.000000kwh
2	Balanced	wind_11500.000000kw_pv_2500.000000kw_battery_0.000000kwh
3	Wind only	wind_13800.000000kw_pv_0.000000kw_battery_0.000000kwh
4	Cost Prioritized	wind_4600.000000kw_pv_1000.000000kw_battery_0.000000kwh
5	PV only	wind_0.000000kw_pv_25000.000000kw_battery_0000.000000kwh

Mean Annual Savings over all feeder



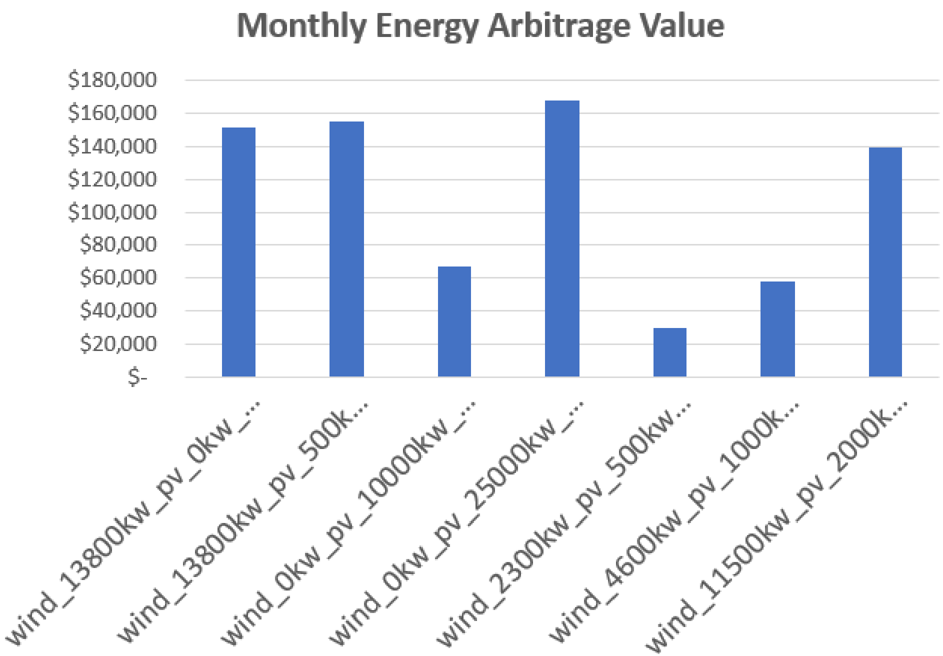
Annual Savings per feeder



Case 3 [31, 11, 12]

Case 5 [31, 11, 12]

Energy Arbitrage Validation



- Running a similar analysis in PNNL's Energy Storage Evaluation Tool, we find the greatest energy arbitrage value for the 25MW PV and 500 kW/2000 kWh battery system at about ~$170 k/mo.
- However, **all systems had a negative net present value**, given the assumed power costs.

Assumptions	
Base year	2022
ITC	30%
Battery type	Lithium-ion NMC
Discount rate	6.85%
Power cost of Wind + PV (paid via PPA)	~$4k/kW

Payback Periods – Battery Valuation

- All modeled systems had negative net present value, so payback periods all stretch longer than the assumed project lifetime (assumed to be 20 years)
- Lower power costs may make these systems more feasible (currently assume ~$4000/kW for the wind and PV)

Scenario			Results						
Wind	PV	Battery	System Cost	NPV	BCR	IRR	Annual Energy Arbitrage	Monthly Energy Arbitrage	Payback period (years)
13800 kW	0 kW	500 kW/2000 kWh	$57M	($20M)	0.62	0.3%	[redacted]	[redacted]	31
13800 kW	500 kW	500 kW/2000 kWh	$58M	($21M)	0.62	0.2%	[redacted]	[redacted]	31
0 kW	10000 kW	500 kW/2000 kWh	$41M	($19M)	0.52	-2.6%	[redacted]	[redacted]	51
0 kW	25000 kW	500 kW/2000 kWh	$101M	($47M)	0.53	-2.5%	[redacted]	[redacted]	50
2300 kW	500 kW	500 kW/2000 kWh	$12M	($4.8M)	0.60	-0.5%	[redacted]	[redacted]	34
4600 kW	1000 kW	500 kW/2000 kWh	$23M	($8.9M)	0.60	-0.3%	[redacted]	[redacted]	33
11500 kW	2000 kW	500 kW/2000 kWh	$55M	($21M)	0.61	-0.1%	[redacted]	[redacted]	33

Key Takeaways

- Collaborated with labs and the client within short time 3 months
- Successfully explored different Solar PV, Wind configurations and battery dispatch strategies
- Savings come primarily because of energy offsets from renewables
- Wind is more effective than solar (per kW of capacity) in reaching the 10% energy goal
  - Power cost of wind/solar makes or breaks scenarios
  - Regarding wind, community engagement is also a barrier (view)
- Battery capacity makes the biggest difference
- Battery dispatch strategy only made marginal differences
- Additional credits may be available to help justify battery investment

Justin Welch

Operations Director, INL Resilience Optimization Center

March 2024

National Laboratory Overview

Idaho National Laboratory

DOE National Laboratories

- Department of Energy owns 17 national laboratories spread across the United States
- Born during WWII
- Tackle critical scientific challenges of our time

National Labs are "Capability Machines" that rely on unique capabilities.

They innovate to solve multidisciplinary problems of national interest.

They do what Universities and Industry can't, won't or shouldn't do.

Research in the National Interest that maintains U.S. competitiveness and security

National Laboratory System

Example: Idaho National Laboratory Missions

Nuclear Energy

Lead laboratory for nuclear energy research, development, demonstration and deployment

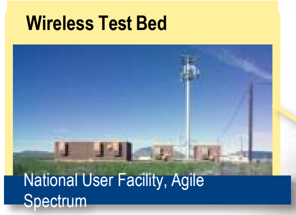
National Security

Solve urgent needs to secure the nation's critical infrastructures and prevent the illicit use of nuclear materials.

Clean Energy

Develop and advance clean, smart and secure energy systems essential to national security, economic prosperity, and environmental sustainability.

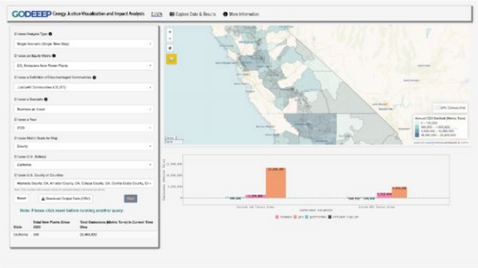
Stewardship of Unique National Security Capabilities



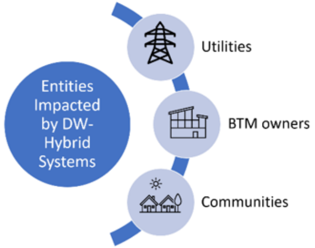
- **Full-scale real-world testing and demonstrations for deployment**
  (designed, built and operated by INL)
- **Integrated testing across multidisciplinary areas**
  (radiological, physical security, explosive, power, controls, cyber)
- **Rapid development through model, test, validate, and refine**
  (high fidelity, effects-based modeling, rapid testing and measurement)
- **Access to the full range of support services**
  (lineman, engineers, rad techs, fire fighters and security forces)
- **Ability to develop prototypes, manufacturing process and resolve uncertainty**

Example: PNNL Modeling and Analysis Tools

- **ESET – Energy Storage Evaluation Tool**
  - Suite of tools to model, optimize, and value energy storage systems
- **GridLAB-D**
  - Power distribution system simulation and analysis tool
  - Integrates with third-party data and tools
  - Useful for utility engineers, regulators, and other stakeholders
- **GoDEEEP Energy Justice Visualization and Impact Analysis tool**
  - Explore impacts to communities from energy policies, capacity expansion, grid operations, and more
- **Coming soon! WINDVALT – Distributed Wind Investment Analysis and Valuation Tool**
  - Assess costs and benefits of wind systems sited to meet local loads



GODEEEEP's EJ-VIA dashboard. Available now!



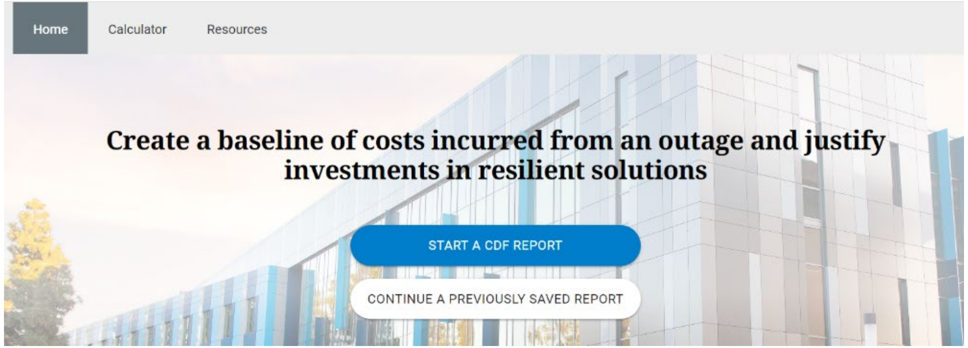
Example: NREL Capability: Resilience Metrics and Valuation

- NREL's research in resilience metrics and valuation helps with making resilient investment

Quantifying Social Burden in Energy System Resilience, NREL Webcast (2023)

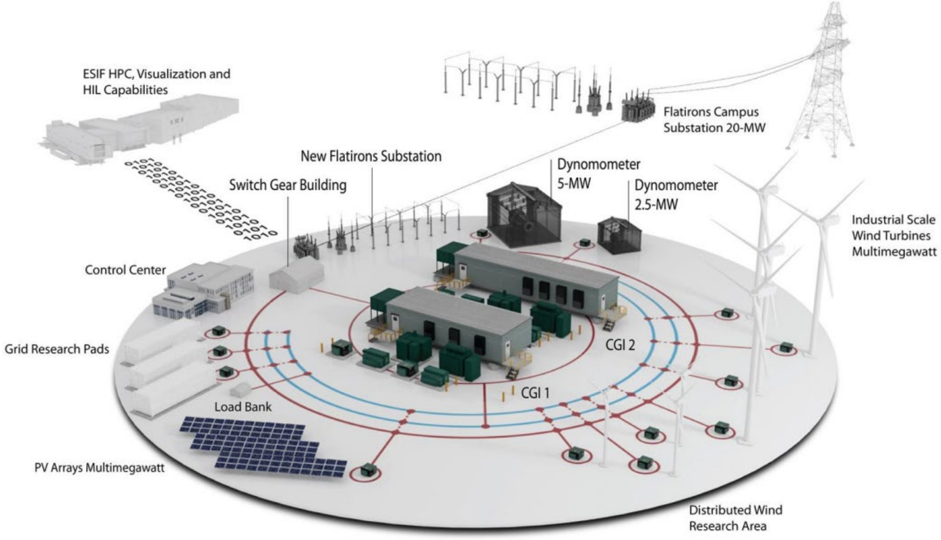
Figure 2. Resilience assessment methodology *NREL 2019*

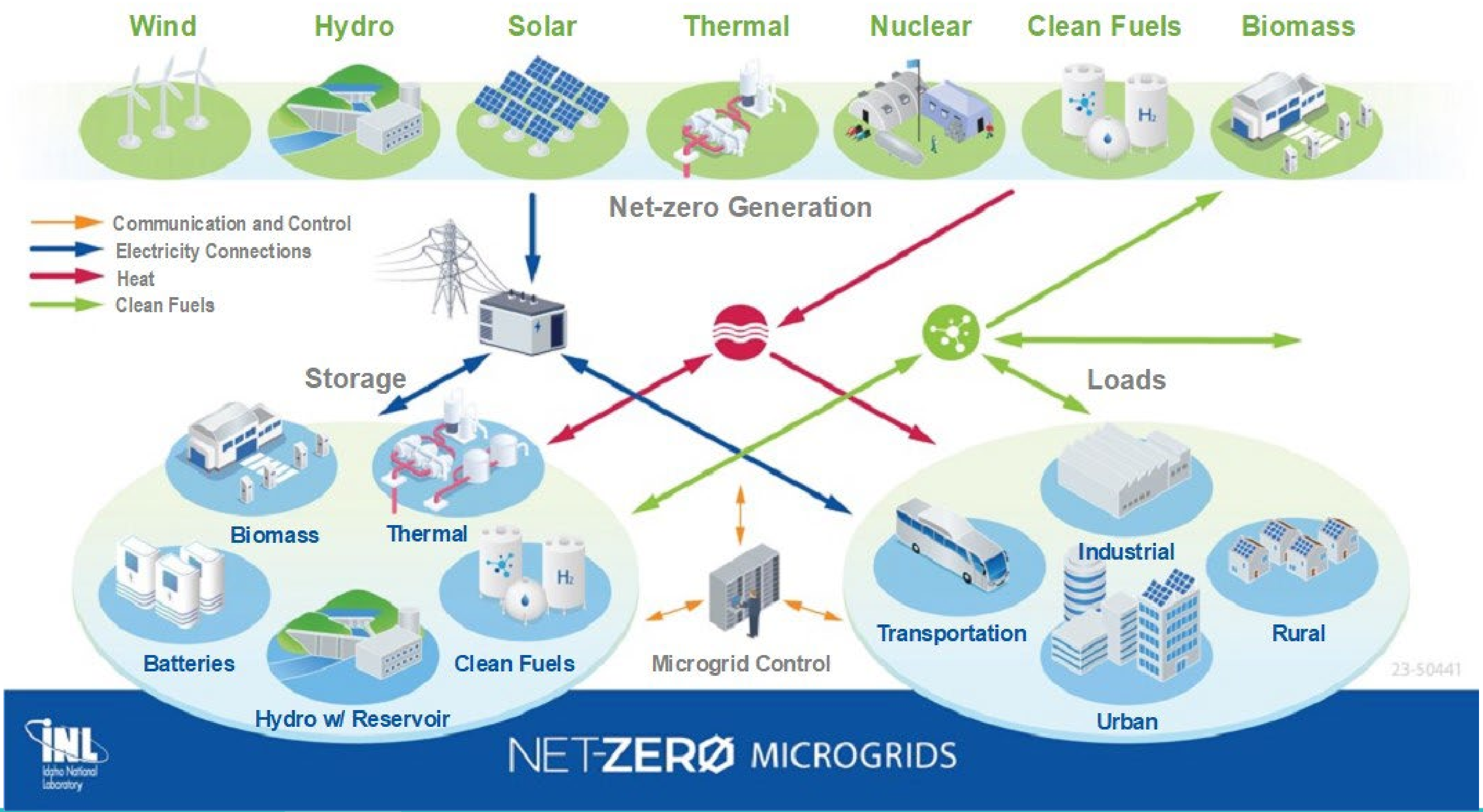
Customer Damage Function Calculator



Example: NREL Capability: Flatirons Campus Research Laboratories & Facilities

- National Wind Technology Center, testing facility for wind technologies and hybrid integration in Arvada, Colorado




Wind
Hydro
Solar
Thermal
Nuclear
Clean Fuels
Biomass
H_2
Net-zero Generation
Communication and Control
Electricity Connections
Heat
Clean Fuels
Storage
Loads
Biomass
Thermal
Batteries
Clean Fuels
Hydro w/ Reservoir
Microgrid Control
Transportation
Industrial
Rural
Urban
23-50441
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NET-ZERØ MICROGRIDS

How to Work with National Labs

- Partner to go after a funding opportunity announcement (FOA) together
  - Either party may be prime.
  - Data/Equipment may count towards cost share
  - Increase in opportunities that require industry partner
- Cooperative Research and Development Agreements (CRADA)
- Strategic Partnership Projects (SPP)
- Technical Assistance

Get technical assistance

- DOE offers technical assistance through a variety of programs, including:
  - Energy Transitions Initiative Partnership Project to help remote and island communities transform their energy systems and increase energy resilience
  - Energy Improvements in Rural or Remote Areas provides no-cost technical assistance to communities and organizations interested in energy improvements in rural or remote areas
  - Clean Energy to Communities Program offers three levels of technical engagement to support community clean energy goals
  - Communities Local Energy Action Program provides technical assistance to low-income, energy-burdened communities that are pursuing strategies to address environmental injustices or economic impacts
  - State, Local, and Tribal Government Technical Support Services are available from NREL when technical assistance is not available through existing federally supported programs
  - Federal Energy Management Program provides no-cost technical assistance and supports federal projects with technical and procurement expertise.
- Private companies also offer technical assistance and consulting for distributed wind projects
- DOD provides TA and training opportunities

The INL Technical Assistance Program (TAP)

- Designed to provide organizations with access to INL's world-class expertise, state-of-the-art facilities, and advanced research capabilities.
- Open to entrepreneurs, small business, local government and/or municipality
- The INL TAP program:
  - Provides assistance that is not otherwise commercially available in the region;
  - Supports up to 40 hours of INL technical assistance without charge to the recipient;
  - Authorized by federal law, and DOE has allocated limited funding for this support activity and provides policy guidance directing the screening and selection of projects.
- https://inl.gov/inl-initiatives/technology-deployment/

Energy Transitions Initiative Partnership Project (ETIPP)

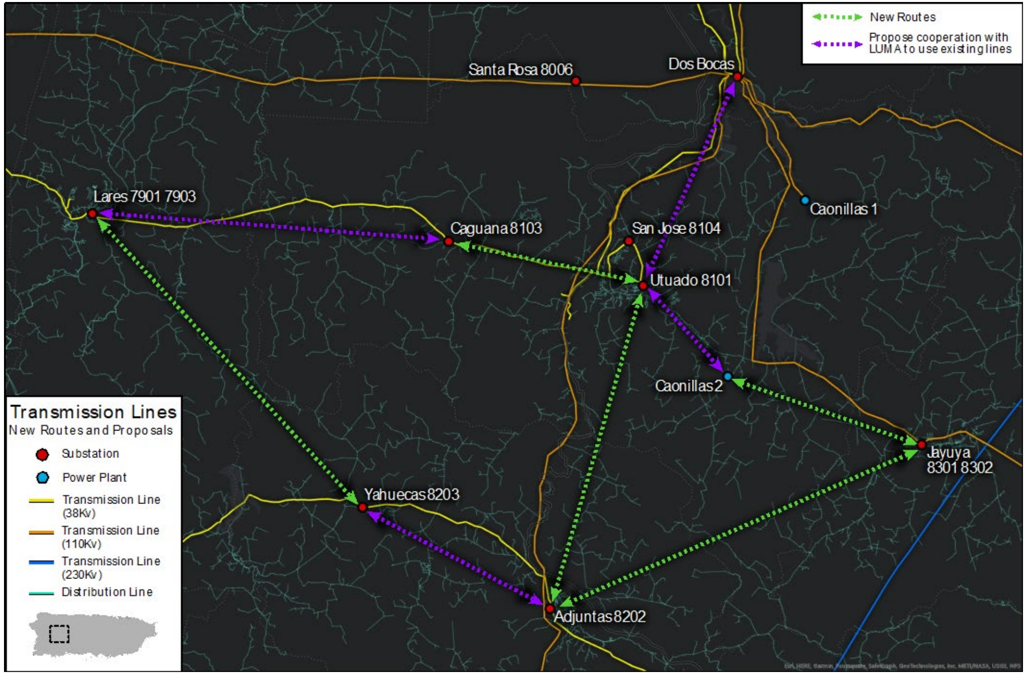
- Provides TA opportunities for remote and island communities.
- Assigns requests to labs with matching capabilities
- Support for project scoping, energy planning, and analysis projects:
  - Respond to the community's own energy priorities, goals, challenges, and opportunities.
  - Advance the community's ability to implement strategic, whole-systems solutions.
  - Develop replicable community energy transition approaches that can add value in neighboring communities, or those with similar characteristics.

- Types of community organizations eligible to apply include, but are not limited to:
  - Local governments (e.g., municipalities, counties, cities, towns)
  - Tribal organizations
  - Community-based nonprofits and nongovernmental organizations
  - Special purpose districts (e.g., school districts, water districts, sewer districts)
  - Municipal utilities and electric co-ops.

ENERGY TRANSITIONS INITIATIVE U.S. Department of Energy

- Learn More: https://www.nrel.gov/state-local-tribal/etipp-technical-assistance.html

The Cooperativa Hidroeléctrica de la Montaña, Puerto Rico



Project Overview

Develop a resilient power strategy for the Cooperativa's hydroelectric, solar, storage, transmission, and distribution assets to improve reliability during normal grid operations and bolster resilience during calamity for four neighboring towns.

ETIPP Technical Assistance (INL-lead)

- Resilience analysis (INL/NREL), recommendations, and cost estimates for transmission upgrades, battery storage (INL)
- Applying ReNCAT social burden analysis to optimize location of microgrids (SNL)
  - Engaging community to identify key services and infrastructure locations
- Evaluating potential for peak hydroelectricity generation during high rain events (INL)
  - Hurricanes Irene/Fiona—3.5+ days, Inez—2+ days

Interconnection Innovation E-Xchange (I2X)

- Goal: enable simpler, faster, and fairer interconnection of clean energy resources all while enhancing the reliability, resiliency, and security of our electric grid
- Funded by WETO, SETO
- Schedule “office hours” with i2X for initial consultation

https://www.energy.gov/eere/i2x/interconnection-innovation-e-xchange

Clean Energy to Communities (C2C)

C2C: Clean Energy to Communities
U.S. DEPARTMENT OF ENERGY

Objectives

- Close the gap between clean energy ambitions and real-world deployment
- Connect local governments, tribes, electric utilities, and community-based organizations with national laboratory experts and customized, cutting-edge analysis to achieve clean energy systems that are reflective of local and regional priorities

Eligibility:

- Projects that address cross-cutting system questions looking into the future that address resilience, large scale planning, clean energy transition social/economic/environmental impacts, etc.

Types of Partnerships

- In-depth (3 years) - Community teams composed of local governments, community-based organizations, and utilities
- Peer-Learning Cohorts (6 months) - Varies by cohort. Can include; tribal, city, town, and county governments; metropolitan and regional planning organizations, electric utilities, community-based organizations
- Expert Match (40-60 hours) - City, town, county, and tribal governments; metropolitan and regional planning organizations; community-based organizations; nongovernmental organizations; utilities; universities

Funding

- Varies with partnership type, but most awards are not provided directly to selected communities
- Only in-depth partnerships provide sub-contract funding

https://www.energy.gov/eere/clean-energy-communities-program

Communities Local Energy Action Program (LEAP)

Objectives

- Facilitate sustained community-wide economic and environmental benefits primarily through DOE's clean energy deployment work
- Assist participating communities in identifying specific resource opportunities to further project implementation

Eligibility:

- Low-income communities
- Energy-burdened communities that are experiencing either direct environmental justice impacts or direct economic impacts from a shift away from fossil fuels

Funding

- This is a competitive technical assistance opportunity
- Award is not provided directly to selected communities

https://www.energy.gov/communitiesLEAP/communities-leap

Office of Indian Energy Technical Assistance

Objective

- Provide technical assistance to advance tribal energy projects
- Address a specific challenge or fulfill a need that is essential to a current project's successful implementation
- The intended result is a tangible product or specific deliverable designed to help move a project forward

Eligibility

- Federally recognized Indian tribes, including Alaska Native villages
- Tribal entities —including Alaska Native regional and village corporations, intertribal organizations, and tribal energy development organizations
- Assistance must be requested at ie-ta@hq.doe.gov

Funding

- The Office of Indian Energy, DOE national laboratories, and other partnering organizations provide the technical assistance at no cost
- Current projects funded by DOE Office of Indian Energy grants receive highest priority. Priority will also be given to tribes that have previously submitted grant applications, but have not yet received awards

https://www.energy.gov/indianenergy/technical-assistance

Energy Storage for Social Equity Program

- 14 communities selected
- Assessment of energy storage to meet community needs
  - **Energy Access**—Energy storage, when integrated with a fuel source (fossil or renewable), can provide energy access.
  - **Energy Affordability**—Energy storage can reduce energy costs for consumers, increasing energy affordability.
  - **Decarbonization**—Energy storage can be integrated with renewable energy to provide clean energy in place of traditional fossil fuel systems.
  - **Environmental Impact**—Energy storage can replace peaker plants or backup generators to reduce pollution.
  - **Resilience**—Energy storage can be integrated with energy systems to provide energy that is accessible during extreme weather events.
  - **Social Impact**— Energy storage can serve as a community asset.
- Applications have closed

https://www.pnnl.gov/projects/energy-storage-social-equity-initiative/technical-assistance-program

Distributed Wind Network Activities

Network

The newly launched National Distributed Wind Network will serve as:

- An entry point for new stakeholders to DW
- A trusted source of fact-based information and technical assistance
- A clearinghouse for highlighting DW deployment efforts and identifying opportunities for collaboration

Resource Hub

The Distributed Wind Resource Hub on WINDExchange has tools and resources related to DW deployment, including:

- Educational fact sheets
- Curated slide decks
- Distributed Wind Guidebook

Webinar

Interested in learning more about the Network and the Resource Hub? Attend the webinar!

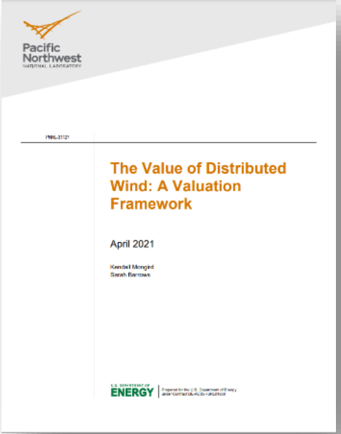
When: March 14th, 11-12 MT

Registration can be found here

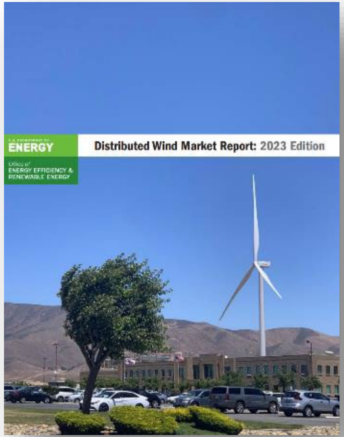
Additional Distributed Wind Resources

PNNL Distributed Wind Resources

Valuation Framework for Distributed Wind



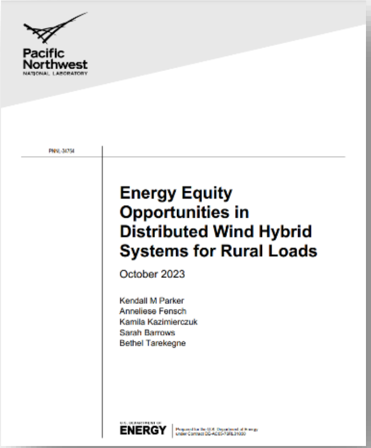
Distributed Wind Market Report & Database of Certified Small and Medium Wind Turbines



Distributed Wind Project Database

Training for Federal Agencies on Distributed Wind

Distributed Wind-Hybrid Energy Equity Framework



Coming soon: DW Mapping Tool!

Wind Energy Basics

Resource	Description
WINDExchange	Platform that shares wind energy information with communities to make wind development decisions, understand siting, permitting, and installation processes, and weigh costs and benefits.
What is Distributed Wind?	Highlights the various research, development, and deployment programs being run by the DOE’s Wind Energy Technologies Office.
How Distributed Wind Works	Learn how distributed wind works.
Distributed Wind Basics	Offers information on distributed wind (community wind and residential wind) and additional inputs on market condition and data.
Ten Things on Distributed Wind	Provides some key points and fun facts about the U.S. distributed wind market.
Utility-Scale Wind Basics	Offers relevant information on utility-scale land-based wind.
Small Community Wind Handbook	Guidance for the siting and development activities required to develop a wind project in a small community.
Large Community Wind Handbook	Guidance for the siting and development activities required to develop a wind project in a large community.

Wind Energy Basics

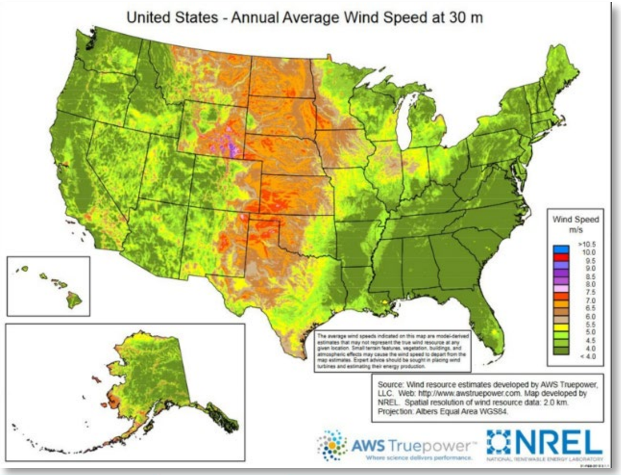
Resource	Description
Zoning and Permitting for Wind	Serves as a resource to facilitate the installation of distributed wind energy systems.
Distributed Wind Installers	List of distributed wind installers for consumers' reference but does not represent an endorsement of any installer.
Selecting, Implementing, and Funding Distributed Wind Systems in Federal Facilities	A free, on-demand training divided into modules. Only the financing module is hyper-specific to federal agencies.
Distributed Wind for Federal Agencies	A free, on-demand training that reviews wind resource assessment screening tools and other distributed wind tools and resources.
RADWIND	Rural Area Distributed Wind Integration Network Development (RADWIND) was a WETO-funded project led by NRECA Research to address barriers to the adoption of distributed wind by rural utilities. Its resources include project development guidance, case studies, and technical advisories.
Distributed Wind Installers Collaborative Case Studies	Case studies cover a variety of customers using distributed wind energy.
REPowering Schools	Provides programming and opportunities to engage and train a diverse and sustained renewable energy workforce.

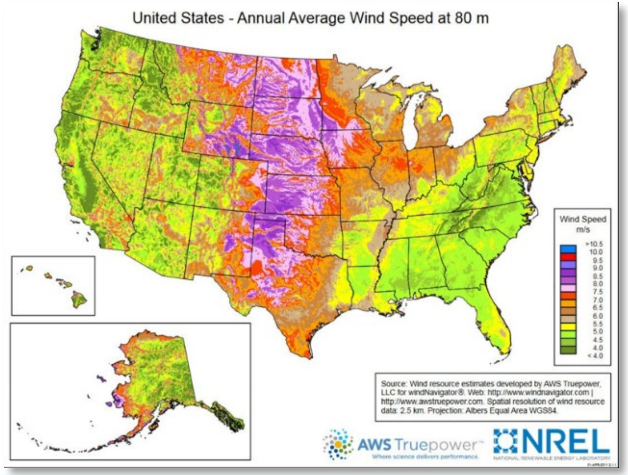
Data and Information

Resource	Description
Wind Technology Resource Center	Technical resources from DOE on wind energy research topics through publications, data, and analysis.
The U.S. Wind Turbine Database	Comprehensive dataset of U.S. wind turbine locations and characteristics that is updated quarterly.
Wind Energy Technologies Office Projects Maps	Details about the Wind Energy Technologies Office's research and development portfolio
Wind Energy Maps and Data	Existing wind capacity and the potential wind resources up to 140 meters above ground.
Wind Energy Technologies Office Publication and Product Library	Information about improving performance, lowering costs, and reducing market barriers for U.S. wind energy.
Distributed Wind Photo Gallery	Case studies to educate consumers on the many facets and opportunities within the distributed wind industry.
Distributed Wind Research—NREL	NREL's distributed and small wind research.
Distributed Wind Research—PNNL	PNNL's distributed and small wind research.
Distributed Wind Database	PNNL's distributed wind data from turbine manufacturers, operations and maintenance providers, state and federal agencies, and other stakeholders for projects installed in the United States.

Wind Resource Assessment

Resource	Description
WINDExchange	Wind energy resource assessment maps, data and trends.
Global Wind Atlas	Identifies high-wind areas for wind power generation.
DW-TAP API	Offers estimates of wind direction, wind rose, and wind speed.





Financial Analysis

Resource	Description
Cost of Renewable Energy Spreadsheet Tool (CREST)	Contains economic, cash-flow models designed to assess project economics, design cost-based incentives, and evaluate the impact of state and federal support structures on renewable energy.
System Advisor Model (SAM)	Free techno-economic software model that facilitates decision-making for people in the renewable energy industry.
Levelized Cost of Energy (LCOE) Calculator	Provides a simple way to calculate a metric that encompasses capital costs, operations and maintenance (O&M), performance, and fuel costs of renewable energy technologies.
Renewable Energy Integration and Optimization (REopt)	Techno-economic decision support platform used to optimize energy systems for buildings, campuses, communities, microgrids, and more.
Jobs and Economic Development Impact (JEDI)	Estimate the economic impacts of constructing and operating power generation and biofuel plants at the local and state levels.
Annual Technology Baseline (ATB)	Consistent, freely available, technology-specific cost and performance parameters across a range of research and development advancements scenarios, resource characteristics, sites, fuel prices, and financial assumptions for electricity-generating technologies, both at present and with projections through 2050.

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