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Microgrid Hardening Design Toolkit User Guide

Software v0.29

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ABSTRACT

Microgrid Hardening Design Toolkit helps microgrid stakeholders assess community-specific natural hazard risks to microgrid components and provides mitigation strategies to reduce those risks. Using census tract location inputs and the Federal Emergency Management Agency (FEMA) Risk Index dataset, the tool provides a ranked list of the highest risk hazards for a selected community and hazard-specific mitigation options for microgrid components. It also provides risk twin communities with similar hazard risk profiles and includes a radar-chart to visually compare risk profiles across communities. The toolkit is expected to help users quickly understand community-specific hazard risks and make decisions for microgrid hardening.

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ACRONYMS AND TERMS

Acronym/Term	Definition
CAIDI	Customer Average Interruption Duration Index
EAGLE-I	Environment for Analysis of Geo-Located Energy Information
EALS	Expected Annual Loss Score
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standards
GUI	graphical user interface
NRI	National Risk Index
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

1. INTRODUCTION

Natural hazards such as extreme weather and natural disasters can pose risks to the electric grid and the people relying on it. One method of improving electrical system resilience and reliability is to develop microgrid systems for co-located electricity generation and usage, to have the ability to access islanded electrical generation during times when the main grid may be experiencing outages or other disruptions. However, microgrid components can also be susceptible to damage and downtime from extreme weather and natural disaster impacts. Therefore, taking mitigative actions to harden the microgrid against certain risks can help improve its resilience during natural disasters to maintain access to energy-dependent critical services as well as reduce economic burden on electrical customers who might otherwise bear costs of outages and/or costs of repair for microgrid equipment damage.

The Microgrid Hardening Design Toolkit was developed to provide a way to aggregate, visualize, and rank risks of different natural hazards on microgrid components based on census tract location, since weather patterns are site-specific. The tool builds on the Federal Emergency Management Agency (FEMA) National Risk Index (NRI) dataset to describe various hazards and risks in different locations across the country for specific microgrid components and equipment. The tool also provides mitigative design approaches and operational actions that can be taken to proactively reduce the highest-risk hazards.

This tool may be useful to stakeholders involved in microgrid development, by indicating a prioritization of risks related to natural hazards and extreme weather events to specific system components, which may provide a starting point for developing solutions for system hardening.

1.1. Software Installation

Download **CommunityRiskExplorer_V0.29.exe** from the website. No installation is required.

1.2. Software Overview

The Microgrid Hardening Design Toolkit GUI **Error! Reference source not found.**□ . The interface consists of two main parts: an interactive map and information panels. The following sections describe the interactive map that displays the U.S. communities, the natural hazard risk information provided in the panels, and the natural hazard data sources used in this toolkit.

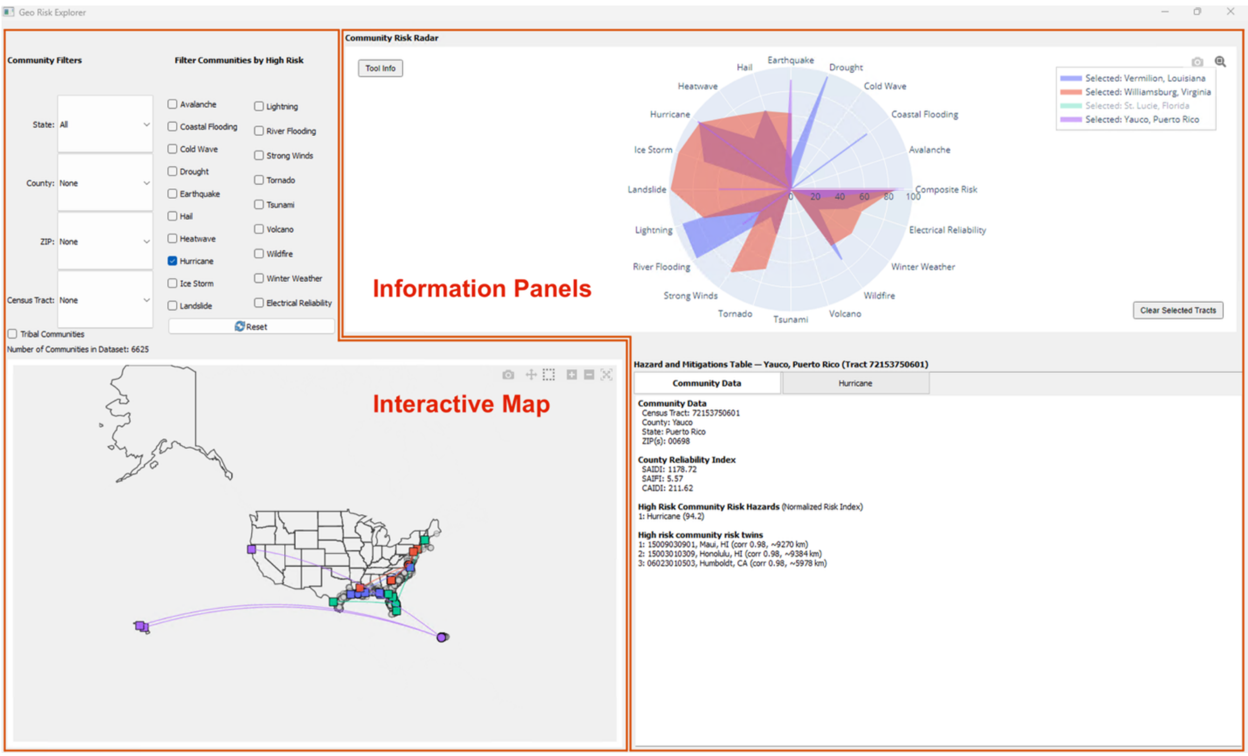

Figure 1-1. Microgrid Hardening Design Toolkit GUI.

2. INTERACTIVE MAP

Figure 2-1. Interactive map. Each point represents centroid of the U.S. Census Tracts, including the 50 states, Washington D.C., and five territories (American Samoa, Guam, Mariana Islands, Puerto Rico, and the Virgin Islands).

The interactive map shown in Figure 2-1 displays points representing communities across the United States at the census tract level, including the 50 states, Washington D.C., and five territories (American Samoa, Guam, Mariana Islands, Puerto Rico, and the Virgin Islands) [1]. Each point corresponds to the centroid of a census tract. In this section, the associated map tools, user interactions, and filters are introduced.

2.1. Map Tools

The interactive map provides various tools, as shown below.

2.1.1. Download plot as PNG

 Users can export plot as PNG.

2.1.2. Pan

 Users can click and drag the map to navigate.

2.1.3. Box select

 Drag to select an area to zoom in.

2.1.4. *Zoom in/out*

Zoom in/out centered on the current view.

2.1.5. *Reset*

Reset to default view.

2.2. User Interactions

2.2.1. *Hovering over a community*

Hover over a community to view its county, state, and census tract GEOID as shown in Figure 2-2.

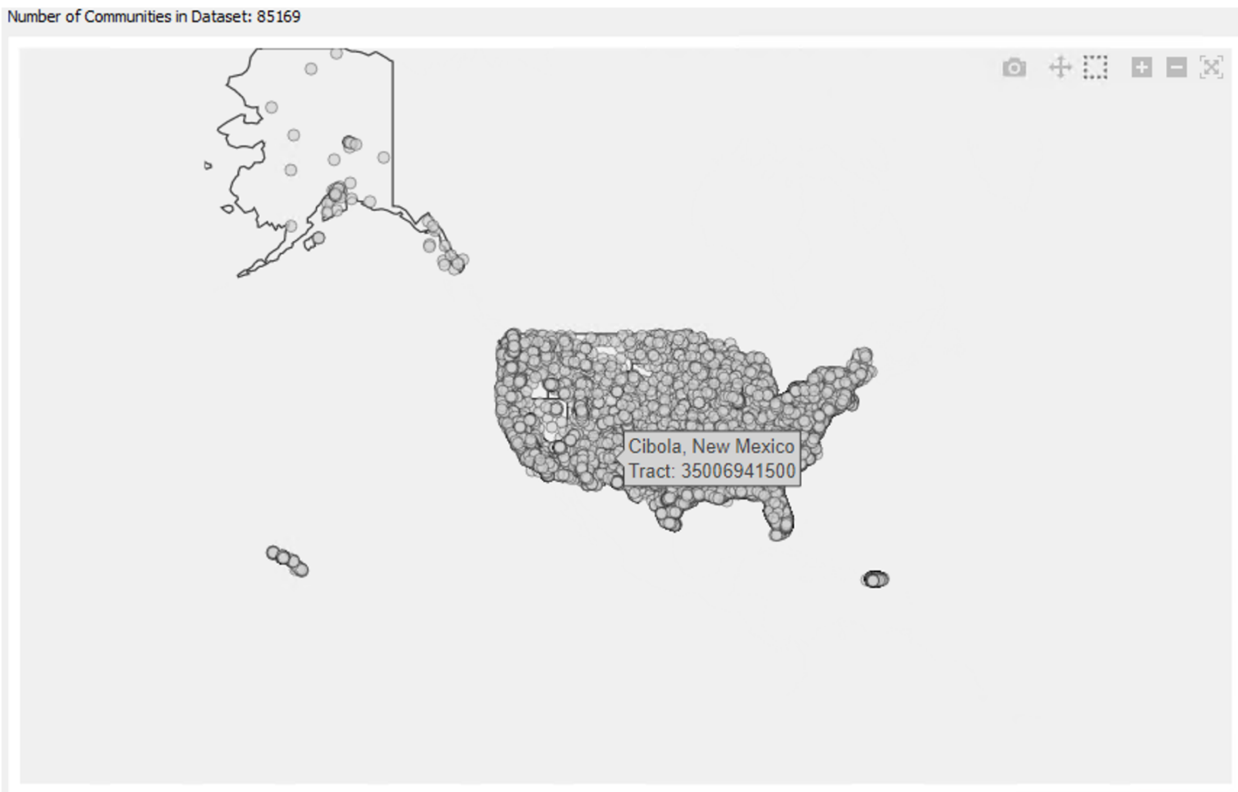

Figure 2-2. Hover over a community to view its county, state, and census tract GEOID.

2.2.2. *Clicking on a community*

Click on a community to permanently display its and its risk twins (see 3.1.4. Top 5 Community Risk Twins for details about risk twins.) on the map as shown in Figure 2-3. The circular marker represents the selected community, and the square markers indicate its risk twins. Multiple communities can be selected. The markers on the map can be cleared using the ‘Reset’ or ‘Clear Selected Tracts’ buttons.

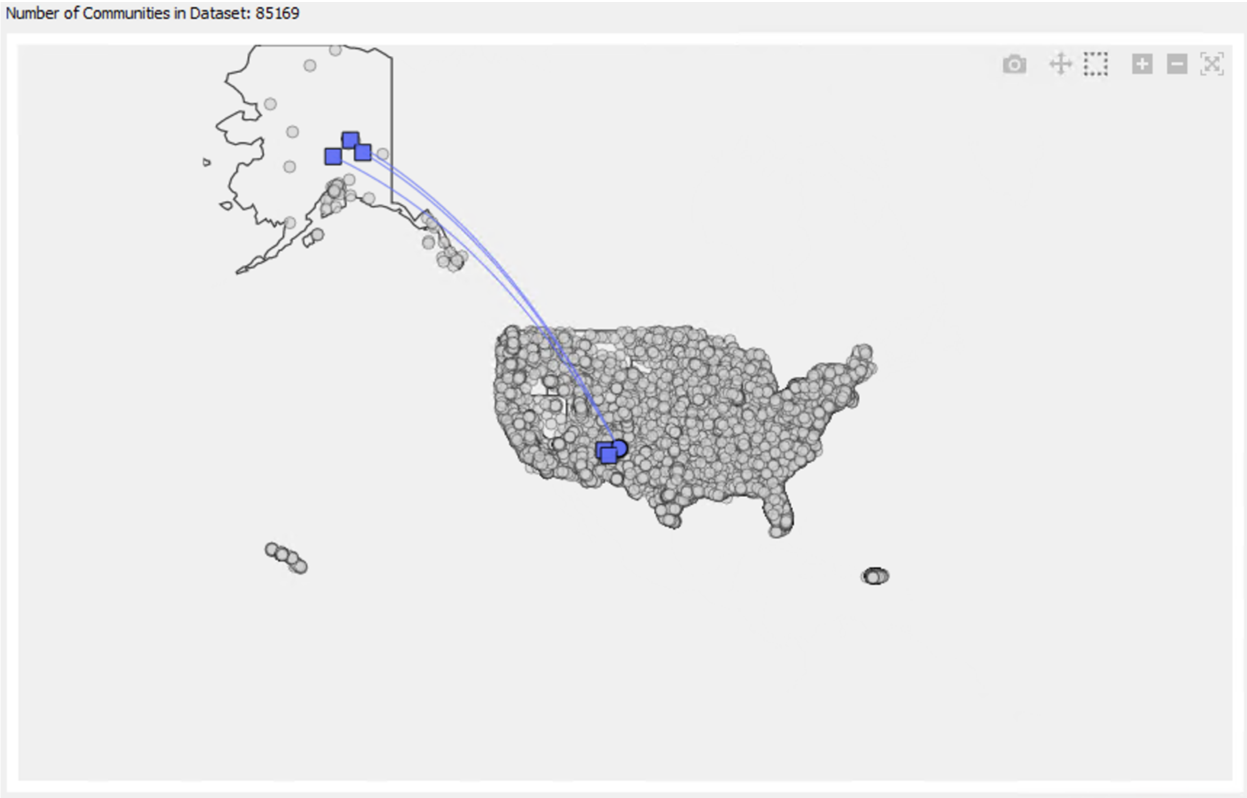

Figure 2-3. Click on a community to permanently display it and its risk twins on the map.

2.3. Community Filters

Use filters to display communities that satisfy specific criteria. The filters shown in Figure 2-4 and their corresponding criteria are explained in detail in this section. Filters can be cleared at any time using the reset button.

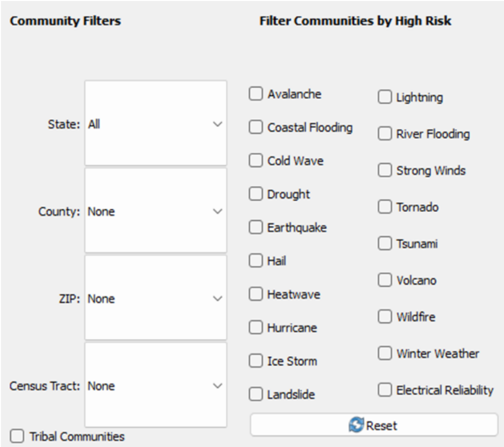

Figure 2-4. Community filters and a reset button.

2.3.1. Filter by State

Use the State filter to narrow communities to a U.S. state, district, or territory. The list includes 1) the 50 U.S. states, 2) District of Columbia, and 3) U.S. territories (American Samoa, Guam, Mariana Islands, Puerto Rico, and the Virgin Islands)

2.3.2. Filter by County

Use the County filter to narrow communities to a specific county. If a State filter is selected, the County list shows only counties within that state. If no State is selected, the County list shows all counties.

2.3.3. Filter by ZIP Code

Use the ZIP Code filter to narrow communities to a specific ZIP code. If a State and/or County filter is selected, the ZIP code list shows only ZIP codes within the selected State and/or County. If no State and/or County is selected, the ZIP code list shows all ZIP codes.

2.3.4. Filter by Census Tract

Use the Census Tract filter to narrow communities to a specific Census tract. If a State, County and/or ZIP is selected, the list shows only tracts associated with the selected State, County, and/or ZIP. If no State, County, or ZIP is selected, the list shows all Census tracts.

2.3.5. Filter by Tribal Status of Communities

Use the Tribal Communities filter to show communities with tribal status. The tribal status of each community was determined using the NRI tribal dataset.

2.3.6. Filter by Hazard Type

Use this filter to find communities that are at higher risk for a specific hazard. The Microgrid Hardening Design Toolkit uses the 18 natural hazard types evaluated by FEMA in [1]. The definitions of the 18 hazard types are provided in Section 4. Definitions of Natural Hazard Types.

The FEMA Expected Annual Loss (EAL) is a risk metric that quantifies the average monetary loss per year a community can expect due to natural hazards, expressed in U.S. dollars. The Expected Annual Loss Score (EALS) indicates the community's national percentile rank relative to all communities at the same level [1]. Therefore, a higher score indicates a greater risk.

The Hazard filter displays the communities where the EALS is greater than 90. For example, selecting Drought shows communities with drought-induced EALS > 90.

2.3.7. Filter by Electrical Reliability

Use this filter to find communities with low electrical reliability. This filter displays the communities with the Composite Electrical Reliability Index Score greater than 42.22. The Composite Electrical Reliability Index Score integrates SAIDI and SAIFI into a single metric. The log-scaled SAIDI and SAIFI values are min-max normalized, averaged with equal weights, and then scaled to a 0-100 range. Higher SAIDI or SAIFI values indicate lower electrical reliability. Therefore, a higher Composite Electrical Reliability Index Score also indicates lower electrical reliability.

The threshold of 42.22 corresponds to the national average of all county-level Composite Electrical Reliability Index Scores, computed using the Environment for Analysis of Geo-Located Energy Information (EAGLE-I) dataset [2].

3. COMMUNITY HAZARD RISKS AND MITIGATION

The Microgrid Hardening Design Toolkit provides details for each community shown on the interactive map. These details introduced in this section, include geographic information about the community, electrical reliability, natural hazard induced risk profiles, radar chart visualizations of those risk profiles, and recommended mitigation actions.

3.1. Community Data

Click on a community on the interactive map to retrieve Community Data as shown in Figure 3-1.

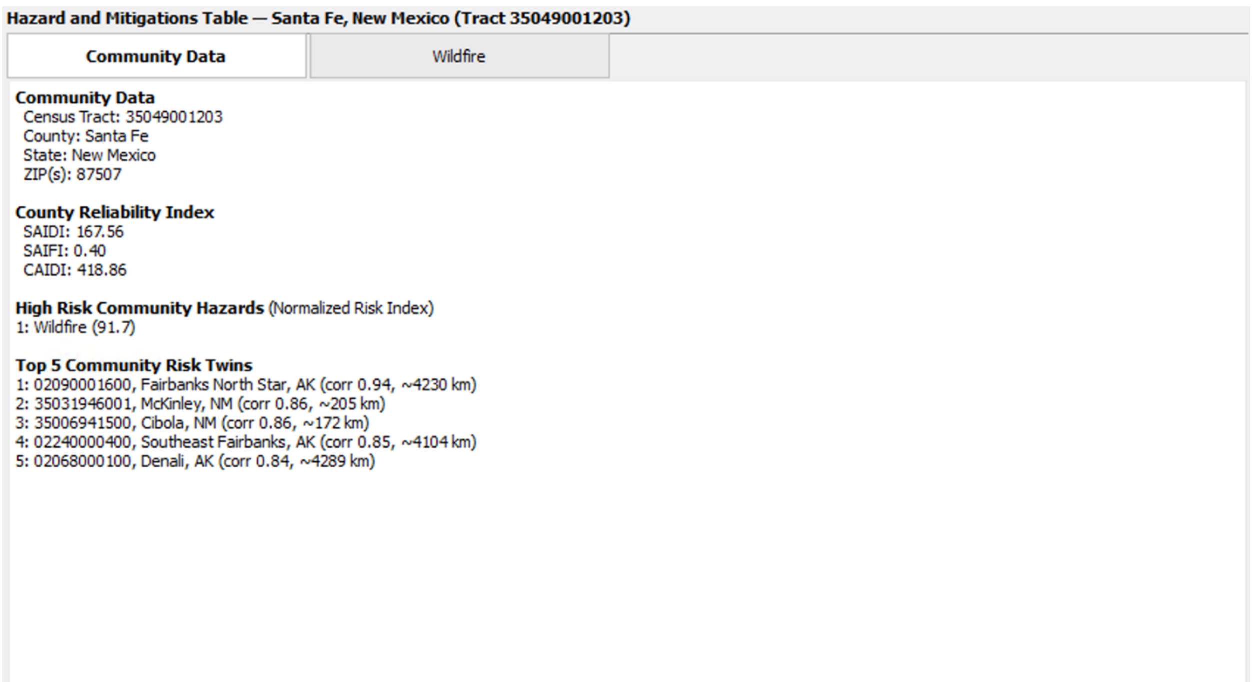

Figure 3-1. View 'Community Data' tab to see geographic information, electrical reliability, high-risk hazards, and risk twins for the selected community.

3.1.1. Community Data

View 'Community Data' to find the following geographic identification information of a community.

- FIPS census tract code
- County
- State
- ZIP codes within the community

3.1.2. County-Level Electrical Reliability Index

View 'County Reliability Index' to find the following electrical reliability indices of a community.

- System Average Interruption Duration Index (SAIDI)
- System Average Interruption Frequency Index (SAIFI)
- Customer Average Interruption Duration Index (CAIDI)

These electrical reliability indices are computed at a county level using the Environment for Analysis of Geo-Located Energy Information (EAGLE-I) dataset [2].

3.1.3. High Risk Community Hazards

View 'High Risk Community Hazards' to find the hazard types with EALS values greater than 90 for the selected community. The list displays the following:

- Type of hazard
- FEMA EALS of the hazard

3.1.4. Top 5 Community Risk Twins

View 'Top 5 Community Risk Twins' to find community risk twins of the selected community. Community risk twins refer to communities that exhibit similar patterns across high-risk hazard types with the selected community. This similarity between two communities is quantified as a correlation score, calculated as the Pearson correlation coefficient using FEMA EALS for each hazard type. The following attributes of the top five community risk twins are shown in the list.

- Census tract GEOID
- County
- State
- Correlation score
- Distance from the selected community

The correlation score is defined on a -1 to 1 scale. A positive correlation means community patterns move in the similar trend, while a negative correlation means they move in opposite trends. Values closer to 1 indicate stronger similarity, meaning hazards that are high or low in one community tend to be high or low in the other. Values closer to –1 indicate stronger dissimilarity, meaning hazards that are high in one community tend to be low in the other community, and vice versa. Therefore, the five communities with the highest correlation scores are selected as risk twins.

Communities that are geographically adjacent tend to be more correlated because of the localized nature of many types of weather patterns and natural disasters. To avoid risk twins being limited to neighboring communities, only the community with the highest correlation score per county is selected. In addition, twins located within 100 miles of the selected community are excluded. Additionally, twins with correlation scores under 0.5 are excluded.

Communities that are highly correlated in their risk patterns are likely to face similar hazard driven damage to microgrid components. Therefore, risk twin information can be used to predict potential impacts on a selected community's microgrid and to reference or benchmark mitigation strategies that have proven effective in its risk twin communities.

3.2. Mitigation Data

Click on a community to retrieve mitigation data associated with the high-risk hazards. Next to the 'Community Data' tab, high risk community hazard tabs listed in 3.1.3High Risk Community Hazards are displayed as shown in Figure 3-2. Each hazard tab provides mitigation options for microgrid components that are at risk due to the selected hazard. The information is organized into the following categories and presented in a tabular format.

- Systems and subsystems at-risk due to the corresponding hazard

- Mitigation strategies

Hazard and Mitigations Table — Santa Fe, New Mexico (Tract 35049001203)

Community Data | **Wildfire**

Systems at-risk	Subsystems at-risk	Mitigations
Energy Generation and Storage Assets	Combined Heat and Power Systems	Shutdown protocols: Implement protocols to de-energize the system when nearby wildfires are detected to help prevent damage to the system and surrounding infrastructure.
	Solar Photovoltaic Systems	Siting: Select solar panel locations away from areas with high wildfire risk.
		Environmental management practices: Implement a vegetation management plan to prevent overgrowth of nearby vegetation.
		PV module design: Select panels rated to be more fire-resilient (i.e., select Class A or B modules even when only Class C modules are required by regulation). Select modules with thicker backsheets to help improve fire resistance.
		Fire-resistant containment: Use fire-resistant containers to store electrical equipment (e.g., inverters, batteries).
		Underground cabling: Use underground wiring where possible.
		Barriers: Install non-combustible screens or barriers in front of or behind the PV system to prevent fire spread.
		Roof mounting design: Increase the gap between PV systems and the roof on which they are mounted (ideally at least a one-foot gap) to prevent fire spread under the PV system.
		Islanding: Proactively island microgrids during wildfire events to prevent cascading failures and support localized power generation for evacuation centers
	Wind Turbines	Coatings: Use fire-protective coatings to prevent ignition of the turbine and fire spread.
		Barriers: Install a non-combustible barrier near the nacelle (e.g., made of fiber-reinforced polymer) to prevent ignition and fire propagation on the turbine
		Automatic disconnection system: Install a system that fully deactivates the turbine's mechanical systems and electrically isolates the tower to prevent fire damage and propagation. Ensure the system provides total isolation between the component affected by the fire and the rest of the wind turbine, and includes a safety device to prevent reconnection before intended.
		Automatic extinguishing system: Install fire detection and extinguishing systems inside the nacelle to enable early detection and extinguishment
	Battery Energy Storage Systems	Sprinkler protection: Implement water-based fire protection to help control fires (whether a wildfire or a battery fire induced by wildfire heat) and lower battery temperature to help prevent thermal runaway induced by high temperatures.
		Venting: Provide adequate battery venting and ventilation to help maintain safe battery temperatures when exposed to wildfire heat
		Siting: Select a battery location with adequate distance from combustibles.
	Underground Cables	Low vulnerability

Figure 3-2. Mitigation table for a selected community.

Users can display mitigation strategies for the systems or subsystems of interest by applying the filter next to 'Systems at-risk' or 'Subsystems at-risk' columns shown in. See Figure 3-3 for the available filtering options. List of systems and subsystems covered in the tool is given in Table 1.

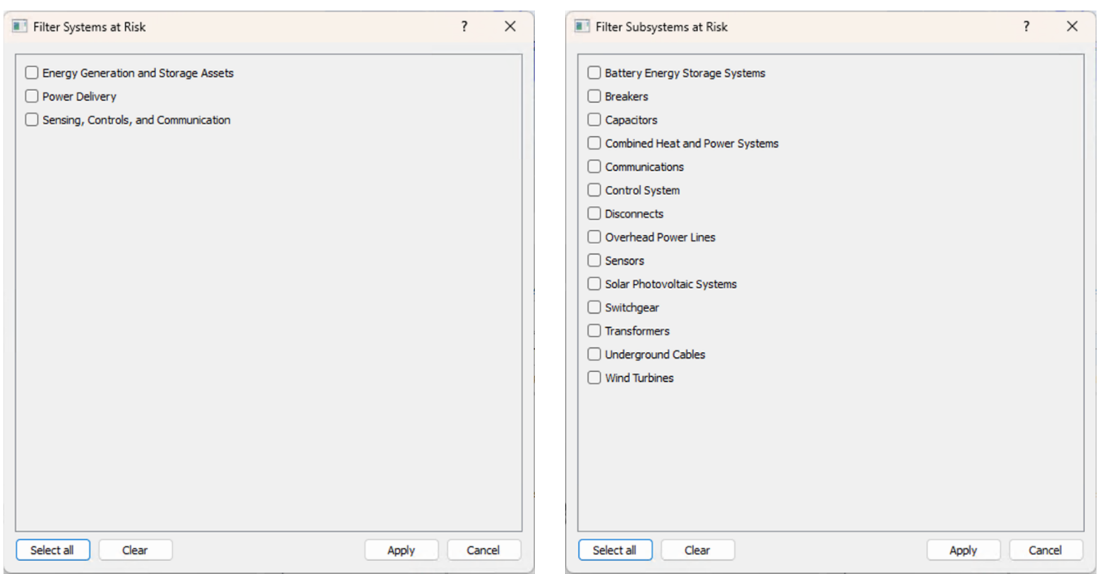

Figure 3-3. Filtering options for the mitigation table display.

Table 1. List of systems and subsystems covered in the tool

System	Subsystem
Energy Generation and Storage Assets	Battery Energy Storage Systems
	Combined Heat and Power Systems
	Solar Photovoltaic Systems
	Wind Turbines
Power Delivery	Breakers
	Capacitors
	Disconnects
	Overhead Power Lines
	Switchgear
	Transformers
	Underground Cables
Sensing, Controls, and Communication	Communication
	Control System
	Sensors

3.3. Community Risk Radar Chart

The radar chart visually illustrates a community's hazard-risk pattern across multiple hazard types, showing which hazards pose relatively higher or lower risk. This section describes how to plot the risk radar chart, use the radar chart tools, and interpret the results.

3.3.1. Plotting the Radar Chart

Hover over the community to display the community risk radar chart as shown in Figure 3-5. The following scores are provided in a radar chart. These scores are defined on a 0-100 scale, with higher values indicating greater risk.

- Composite FEMA EALS
- FEMA EALS for each hazard type
- Composite Electrical Reliability Index Score

The composite EALS represents the national percentile of the composite EAL, which is the sum of EALs across all hazard types. The Composite Electrical Reliability Index Score integrates SAIDI and SAIFI into a single metric. The log-scaled SAIDI and SAIFI values are min-max normalized, averaged with equal weights, and then scaled to a 0-100 range.

Click on a community to permanently plot the radar chart. Multiple communities can be selected, and the tool visualizes comparisons between them as shown in Figure 3-5. Users can hide and show a community's plot by clicking its name in the legend.

Note that plotting too many communities simultaneously can reduce clarity due to overlapping layers. In particular, when five or more communities are displayed, lower layers are obscured. Therefore, it is recommended to limit the number to no more than four at a time.

3.3.2. Radar Chart Tools

Community risk radar chart provides various tools.

3.3.2.1. Download plot as PNG

 Users can export plot as PNG.

3.3.2.2. Zoom

 Users can drag select and zoom in. Double click to zoom back out.

3.3.2.3. Reset

Clear Selected Tracts

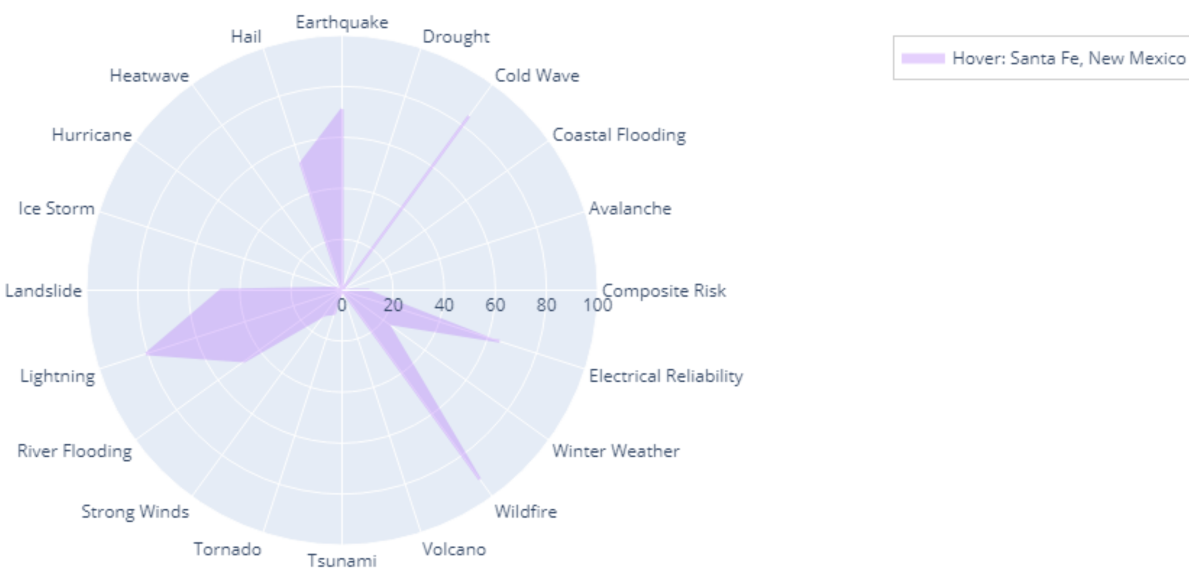

Figure 3-4. Community Risk Radar Chart when hovering over a community.

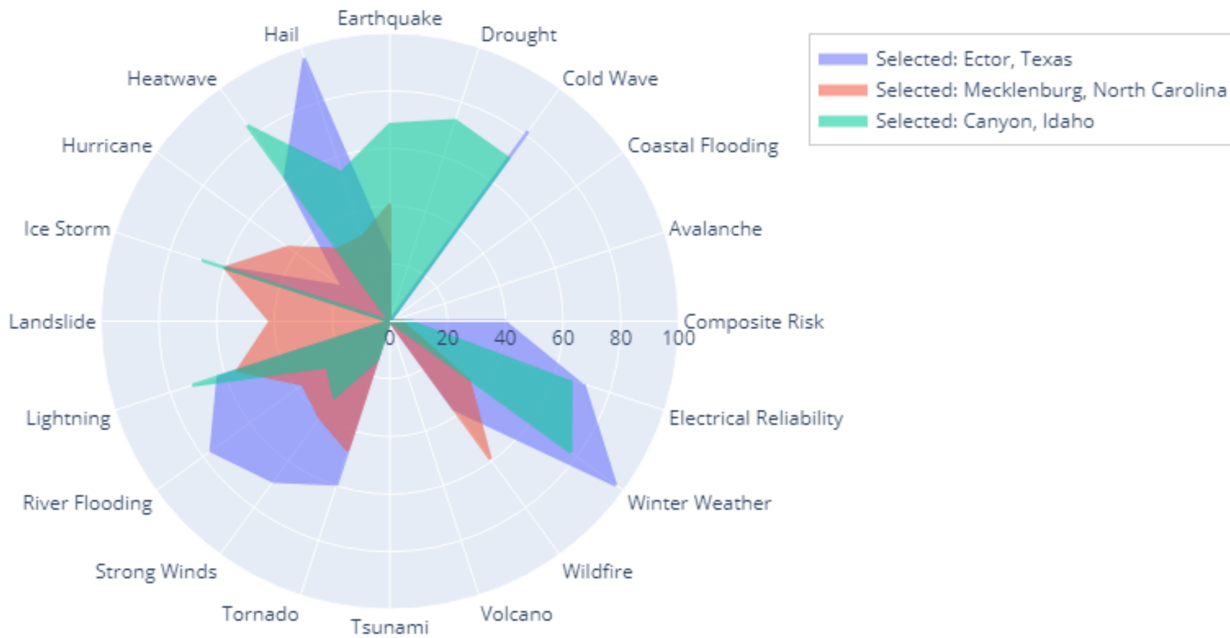

Figure 3-5. Community Risk Radar Chart.

3.3.3. Interpreting the Radar Chart

The community risk radar chart shown in Figure 3-5 visually illustrates a community's hazard-risk pattern across multiple hazard types, showing which hazards pose relatively higher or lower risk. This helps identify communities that should be more alert to specific hazards and supports prioritizing attention and mitigations. When multiple communities are plotted together, the chart enables quick comparison of risk profiles, showing similarities and differences across communities. The overlapping area shows the similarity in the risk pattern between communities, providing a visual measure of their "risk twinness". Therefore, the close two communities are as risk twins, the larger the overlap, the more disparate their patterns, the smaller the overlap.

4. DEFINITIONS OF NATURAL HAZARD TYPES

Microgrid Hardening Design Toolkit uses the same definitions of natural hazards (e.g., natural disasters and extreme weather events) as the FEMA NRI [4]. These definitions are included below (verbatim) for ease of use of this guide.

Table 2. Selected Natural Hazard Types

Hazard Name	Description
Avalanche	A mass of snow in swift motion traveling down a mountainside.
Coastal Flooding	When water inundates or covers normally dry coastal land as a result of high or rising tides or storm surges.
Cold Wave	A rapid fall in temperature within 24 hours and extreme low temperatures for an extended period. The temperatures classified as a Cold Wave are dependent on the location and defined by the local NWS weather forecast office.
Drought	A deficiency of precipitation over an extended period of time resulting in a water shortage.
Earthquake	A shaking of the earth's surface by energy waves emitted by slowly moving tectonic plates overcoming friction with one another underneath the earth's surface.
Hail	A form of precipitation that occurs during thunderstorms when raindrops, in extremely cold areas of the atmosphere, freeze into balls of ice before falling towards the earth's surface.
Heat Wave	A period of abnormally and uncomfortably hot and unusually humid weather typically lasting two or more days with temperatures outside the historical averages for a given area. The temperatures classified as a Heat Wave are dependent on the location and defined by the local NWS weather forecast office.
Hurricane	A tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph). The Hurricane data also include tropical storms for which wind speeds range from 39 to 74 mph.
Ice Storm	A freezing rain situation (rain that freezes on surface contact) with significant ice accumulations of 0.25 inches or greater.
Landslide	The movement of a mass of rock, debris, or earth down a slope.
Lightning	A visible electrical discharge or spark of electricity in the atmosphere between clouds, the air, and/or the ground often produced by a thunderstorm.
Riverine Flooding	When streams and rivers exceed the capacity of their natural or constructed channels to accommodate water flow and water overflows the banks, spilling into adjacent low-lying, dry land.
Strong Wind	Consists of damaging winds, often originating from thunderstorms, that are classified as exceeding 58 mph.
Tornado	A narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground and is visible only if it forms a condensation funnel made up of water droplets, dust, and debris.

Hazard Name	Description
Tsunami	A wave or series of waves generated by an earthquake, landslide, volcanic eruption, or even a large meteor hitting the ocean and causing a rise or mounding of water at the ocean surface. A Tsunami can travel across the open ocean at about 500 mph and slow down to about 30 mph as it approaches land, causing it to grow significantly in height.
Volcanic Activity	Occurs via vents that act as a conduit between the Earth’s surface and inner layers, and erupt gas, molten rock, and volcanic ash when gas pressure and buoyancy drive molten rock upward and through zones of weakness in the Earth’s crust.
Wildfire	An unplanned fire burning in natural or wildland areas, such as forest, shrub lands, grasslands, or prairies.
Winter Weather	Consists of winter storm events in which the main types of precipitation are snow, sleet, or freezing rain.

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[3] R. Darbali-Zamora, M. Louie, J. Choi, and J. D. Flicker, "Quantification of Harsh Environments, At-Risk Microgrid Components, and Hardening Technologies," Sandia National Laboratories, Publication in Progress.

[4] Federal Emergency Management Agency, "National Risk Index." Feb. 16, 2025. doi: 10.23719/1531998.

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