The Contribution of Distributed Solar to Reliability, Grid Resilience, and Community Resilience

A Report for SolarPlus Northwest

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Preface

SolarPlus Northwest is a regional, collaborative effort led by a diverse group of stakeholders in Oregon and Washington with the goal of tripling the amount of solar energy installed in both states by 2019. This project builds upon work undertaken by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and the Solar Energy Technologies Office (SETO). Current efforts are working towards accelerating growth to achieve 500 MW of combined installed solar in both states, with a special focus on directing the benefits of solar projects to low-income communities of color, who are often the most vulnerable to electrical disruptions and weather-related disasters.

While the SolarPlus initiative is focused on developing strategies that accelerate solar market growth and increase the economic benefits of solar, a strong emphasis is placed on enabling projects in the region that increase both community resilience and grid resilience, as well as educating stakeholders on how distributed solar can contribute to a resilient energy system. In both Oregon and Washington, SolarPlus stakeholder groups are contributing to measures that will enhance resiliency through emergency preparedness, specifically through the planning of a resilience roadshow and workshops with local utilities, community members, and businesses in Q3 and Q4 of 2018. The role of this report is to establish a framework around community resilience, grid resilience, and reliability within the context of distributed solar energy systems. The work from this report will be used as a definitions guide for resilience roadshows, workshops, and other related policy work at the local and state levels.

Project partners

Washington Department of Commerce
Spark Northwest
Bonneville Environmental Foundation
Front and Centered
Northwest Energy Coalition
Renewable Northwest
Verde
Avista Corporation
Washington State University Energy Program
Puget Sound Energy
Seattle City Light
Snohomish Public Utility District
Oregon Solar Energy Industries Assoc.
Solar Installers of Washington
Bonneville Power Administration
Energy Trust of Oregon
Oregon Department of Energy
Oregon Public Utility Commission
Washington Utilities and Transportation Commission

Executive Summary

Power outages caused by extreme weather have increased in recent years, causing damage to the electrical grid and intensifying known hazards and risks. In the event of a natural disaster, traditional emergency response management has depended on the transport of fuel into communities to power generators for the length of the outage. As the energy transition from thermal sources to renewables continues, distributed renewables (mainly solar) have shown the potential to resiliently and reliably power communities, and in many cases, do so more effectively than thermal generators, all while decreasing carbon emissions and decreasing communities' dependence on the transport of fuels. The goals of this report are as follows:

1. Establish baseline definitions for grid resilience, reliability and community resilience
2. Investigate the potential for distributed solar energy to enhance or increase grid resilience, reliability, and community resilience

From a regulatory standpoint, resilience and reliability actions are often performed under the same umbrella. However, it is important to make a distinction between the two concepts. While grid reliability aims to reduce the probability of common, low-impact power interruptions, the concept of resilience acknowledges that high-impact outages will eventually occur, and aims to reduce damage and recover promptly. Although reliability measures taken by regulatory entities often passively improve resilience, establishing straightforward resilience metrics is necessary to enhance system resilience in a targeted manner. Where grid resilience and reliability are focused on impacts to the larger transmission and distribution system, community resilience measures focus on human and critical infrastructure recovery at the local scale. Distributed solar has been found to enhance grid reliability, grid resilience, and community resilience by increasing utility cost savings, reducing peak loads, improving the accuracy and response times to outages with smart inverter technology, as well as increasing a community's adaptability and independence following a disturbance. The path towards decarbonization in Washington and Oregon should focus on the critical role of distributed renewables to enhance grid reliability, grid resilience, and community resilience. Policymakers and regulators must consider the value that distributed solar technology adds to power systems when its contribution towards resilience and reliability is taken into account.

Introduction

Across the country, weather-related electricity outages continue to increase due to recent changes in climate and a spike in extreme weather events. 2017 was a record-breaking year for extreme weather events in the United States[1], which are now the nation's leading cause of power outages, costing the economy $20-55 billion annually[2]. In Oregon, residents experienced record-breaking heat waves, wildfires, and snow storms[3], posing risks to communities and their energy systems. The Cascadia Subduction Zone earthquake is perhaps Oregon's biggest threat to electric system resilience and reliability. It is estimated that the Willamette Valley could experience a post-earthquake outage of 1-3 months, and the coast could be without electricity for up to 6 months[4].

The threat of a large-scale earthquake and increased extreme weather events due to climate change is exacerbating the stressors that cause damage to the electricity grid. Society's energy demands are also changing, causing a shift in the energy system landscape. The transition from traditional energy sources to renewables is also changing the way we think about structuring the grid. Utilities have begun to address strategies to increase the grid's reliability and resilience, sparking a national conversation on the issue. A number of government reports and private entities have attempted to define electric system resilience, how it relates to reliability, and methods to build community resilience with distributed renewable resources.

Background

In late 2017, U.S. Department of Energy (DOE) Secretary Rick Perry submitted a request to the Federal Energy Regulatory Commission (FERC) to rewrite energy market regulations to subsidize coal and nuclear plants[5]. Secretary Perry claimed that this subsidy was necessary to prevent immediate threats to grid resilience and reliability, caused by upcoming retirements of coal and nuclear plants across the country. Early retirements of conventional power plants are the effect of changes in the market, as the costs of running coal plants are now more expensive than the costs of running renewable plants[6]. In January 2018, however, FERC issued an order rejecting DOE's request for rulemaking in a proceeding, stating that DOE failed to provide evidence to back the claims that retiring coal and nuclear plants threatened grid reliability and resilience[7]. Within the order, FERC requested that grid operators evaluate the resilience of the

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[1] National Oceanic and Atmospheric Administration. (2018). *2017 was 3rd warmest year on record for U.S.*

[2] Campbell, R. J. (2012, August). *Weather-related power outages and electric system resiliency*. Washington, DC: Congressional Research Service, Library of Congress.

[3] National Weather Service. (2017). *Portland 2017 Weather In Review*.

[4] Oregon Seismic Safety Policy Advisory Commission. (2013). *The Oregon Resilience Plan*.

[5] U.S. Department of Energy. (2017). *Grid Resiliency Pricing Rule*.

[6] Marcacci, S. (2017). Utilities Closed Dozens Of Coal Plants In 2017.

[7] Federal Energy Regulatory Commission. (2018). *Order 162 Terminating Rulemaking Proceeding*.

bulk power system and submit information on their concerns in order for grid resilience to be examined holistically.

FERC's grid resiliency docket (No. AD18-7-000) was open for comments from grid operators until May 9th, 2018; however, it sparked an ongoing nationwide conversation on what grid resilience and reliability truly mean. This document, prepared for the Washington and Oregon SolarPlus initiative, draws upon current literature to define grid reliability, resilience, and community resilience, with a focus on how each can be enhanced by developing the grid with distributed solar energy.

Background definitions

Resilience has been an established concept in various fields of study for decades, but it was not until recently that the energy and infrastructure community adopted it as a strategic objective[8]. The definition of resilience stems from its root, *resilio*, meaning to leap or spring back. While reliability has a variety of established metrics, there are currently no accepted metrics for resilience. As momentum continues to build to push for the transition to renewables, knowing these metrics and using them to define resilience and reliability is crucial when advocating for the development of distributed renewable sources like rooftop solar. The following definitions from FERC, the North American Electric Reliability Corporation (NERC), and The National Institute of Standards and Technology (NIST) establish a baseline definition for the concepts covered in this paper.

Resilience: The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event[8].

Reliability: The ability of a system to meet the daily electricity needs of end-use customers even when unexpected equipment failures or other factors reduce the amount of available electricity[9].

Community resilience: The ability of a community to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions[10].

Grid resilience, community resilience, and reliability are conceptualized by the tri-venn diagram in Figure 1. Utilities, communities, and local governments should strive to create power systems that fall in the center bracket of this diagram. Incorporating features that enhance each concept

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[8] Vugrin, E., Castillo, A., & Silva-Monroy, C. (2017). *Resilience Metrics for the Electric Power System: A Performance-Based Approach* (No. SAND--2017-1493). Sandia National Laboratories.

[9] North American Electric Reliability Corporation (NERC). (2013). *Frequently Asked Questions.*

[10] National Institute of Standards and Technology. (2016). *Community Resilience Planning Guide for Buildings and Infrastructure Systems.*

ensures that the system not only covers the bases when it comes to grid reliability standards, but that it sets the bar high for resilience standards yet to be established. Although these concepts are very much interrelated, small variations between their purposes require different planning methods and metrics. This paper focuses on the contribution of distributed solar to enhancing each of these concepts. Reliability, grid resilience, and community resilience are each defined. The potential for distributed solar to increase each concept is analyzed. Finally, two case studies are presented that provide an example of power systems that include features that increase reliability, grid resilience, and community resilience.

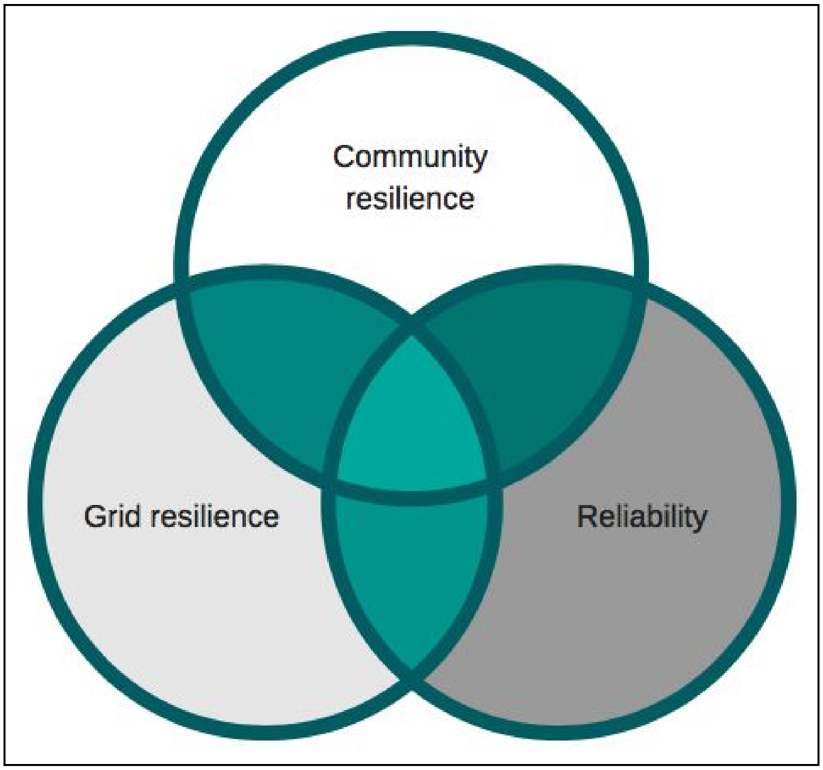

Figure 1. The relationship between reliability, grid resilience, and community resilience, shown in a tri-venn diagram.

Distributed solar energy is a form of decentralized electricity produced at or near the point of consumption, either with a rooftop solar photovoltaic (PV) system or ground-mounted PV array[11] . It is usually connected to the local utility distribution grid. Distributed solar energy systems have been found to enhance grid and community resilience on a number of levels, while also ensuring long-term reliability[12]. Although reliability metrics have been established—mainly by NERC—there are currently no formal grid resilience definitions, metrics, or analysis methods. Using current research on electric system resilience as a guide, this document aims to provide a

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[11] Solar Energy Industries Association (SEIA). (2018). *Rooftop Solar*.

[12] Ansari, O. A., Safari, N., & Chung, C. Y. (2016, November). Reliability assessment of microgrid with renewable generation and prioritized loads. In *Green Energy and Systems Conference (IGSEC), 2016 IEEE* (pp. 1-6). IEEE.

definition of grid resilience within the context of distributed solar, as well as community resilience and reliability. The document is organized as follows:

I. Defining and measuring grid reliability
    A. Reliability of distributed solar
II. Defining grid resilience and current research on metrics and analysis
    A. Distributed solar for grid resilience
III. Defining community resilience
    A. Distributed solar for community resilience (Borrego Springs and Living Cully case studies)

I. Defining and measuring reliability

Grid reliability is an essential, longstanding concept within the electricity infrastructure community. Reliability ensures that the grid supplies a continuous, uninterrupted supply of power to end users. In simple terms, it means keeping the lights on in a consistent manner. NERC is in charge of promoting the reliability and adequacy of bulk power transmission in all North American electric utility systems by developing standards for power system operation, assessing resource adequacy, and providing educational and training resources for power system operators.

NERC defines power system reliability by separating it into two core concepts:

1. **Adequacy:** The ability of the electricity system to supply the electrical demand and energy requirements of the end use customers at all times, taking into account scheduled and reasonably expected unscheduled outages.
2. **Security:** The ability of the bulk power system to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements, while avoiding uncontrolled large-scale blackouts or damage to equipment[9].

Methods for quantifying reliability are almost universally accepted and established within the electric power system community. Because over 90% of grid disturbances occur on the distribution side, most reliability indicators are customer-focused[13]. For example, a resource's capacity value is one measure of its ability to reliably meet customer demand. This metric is useful because it allows us to quantify the contribution of renewable generation to the reliability

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[13] Silverstein, A., Gramlich, R., & Goggin, M. (2018). *A Customer-focused Framework for Electric System Resilience*. Grid Strategies.

of the bulk power system. There are various techniques for estimating a system's capacity value and quantifying the level of adequacy and security[14].

Reliability is generally concerned with common, expected disturbances to the grid. Most disruptions are characterized as high frequency, low consequence events that occur on a daily basis, such as fallen trees or squirrels interrupting distribution lines. Measures taken to ensure every day, long term system reliability are crucial for sustaining any form of electricity generation.

As energy sources continue to transition from conventional fossil fuels to renewables, and the penetration of distributed resources increases, it is important as always to consider the question of system reliability. It is of increasing importance to not only understand how distributed solar can compare with conventional sources, but also how it can potentially enhance grid reliability.

A. Reliability of distributed solar

Solar energy is Oregon's largest potential renewable energy resource[15]. As of this year, 462 MW of solar are installed in the state[16]. The statewide cumulative installed PV capacity has more than doubled in one year. Because of the significant increases in solar installations, there have been many investigations into the ability of distributed solar generation to reliably meet customer demand. On a local scale, distributed solar can potentially increase overall electric system reliability. A study completed by FERC in 2007 looked into the potential benefits and drawbacks of distributed generation (DG), including solar, finding that DG contributes the following benefits:

- Cost savings via peak load reduction[17];
- Ancillary services (reactive power and voltage support)[18];
- Improved power quality;
  and
- More accurate and reduced response times to outages (smart inverter technology has faster frequency response than traditional thermal plants)[19].

When implemented on a large scale, distributed solar generation has the potential to alter peak load forecasts in a given area, potentially saving utilities a significant amount of money. In the

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[14] National Renewable Energy Laboratory. (2012). *Comparison of Capacity Value Methods for Photovoltaics in the Western United States*.

[15] Oregon Department of Energy. (2012). *Oregon State Energy Assurance Plan* (pp. 22-23).

[16] Solar Energy Industries Association. (2018). *Oregon Solar Spotlight*.

[17] California ISO. (2018). *2017-2018 Transmission Plan*.

[18] Improves the system's ability to respond to changes in generation and demand with smart inverter-based resources.

[19] Federal Energy Regulatory Commission. (2007). *The potential benefits of distributed generation and rate-related Issues that may impede their expansion*.

State of California's 2017-2018 Transmission Plan, 41 transmission projects were either cancelled or revised due to considerable amounts of residential solar power and energy efficiency improvements changing local area load forecasts. The estimated cost savings outlined in the California transmission plan are approximately $2.6 billion[17].

One of the biggest goals of maintaining reliability is reducing the amount of unanticipated downtime for end-users. PV solar projects have been shown to have significantly less unexpected downtime than traditional power plants. While the average coal plant in the US is down 6.5% of the year for unscheduled maintenance[20], the average solar project is expected to have unexpected downtimes of 1% on average[21].

While this paper focuses on the strengths of distributed solar for electric system reliability, it is important to note that no single resource can provide all of the required grid services to maintain reliability. A diverse resource portfolio increases reliability, makes sense economically, and provides a platform for ambitious greenhouse gas reduction targets.

II. Defining grid resilience

While reliability encompasses many of the everyday risks that face electric systems, a changing hazard landscape has caused the critical infrastructure and power grid community to recognize that reliability measures alone are not enough to manage emerging risks. Reliability metrics do not account for the outage information needed when low-probability, high consequence disturbances like storms, earthquakes, or cyber attacks occur. Historical data used for reliability calculations will no longer be suitable for measuring future potential outages because emerging threats differ significantly from historical precedents[8]. The U.S. Department of Homeland Security (DHS) Critical Infrastructure Task Force was one of the first entities to recommend the integration of resilience as a strategic objective in 2006. The DHS task force advocated for the integration of critical infrastructure resilience into "systems level investment strategies"[22]. The recommendation sparked resilience initiatives throughout local and national governments as well as the private sector.

Although grid resilience has no formally agreed to metrics or analytical methods, they are currently under development, with discussions underway at almost every level of government. Power system organizations have led the grid resilience discussions, formulating definitions, metrics, comparing the concept to reliability, and identifying existing and new technologies to increase the resilience of distribution systems. The following definitions of grid resilience are the most widely accepted within the utility and critical infrastructure community:

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[20] North American Electric Reliability Corporation. (2014). *2014 Summer Reliability Assessment*.

[21] Banke, B. (2010). Solar electric facility O&M now comes the hard part, Part 3. *Renewable Energy World North America Magazine*, *2*(1).

[22] US Department of Homeland Security. (2006). *Report of the Critical Infrastructure Task Force*.

“A system that acknowledges that outages will occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from experience to improve performance in the future.” - National Academy of Sciences[23]

“Measures taken to reduce damage from outages and hasten restoration and recovery to shorten outage durations.” - Silverstein et al., 2018[13]

“The ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.” - National Infrastructure Advisory Council, 2010[24]

Resilience actions are often performed under the umbrella of reliability, but it is important to make a distinction between the two concepts. While grid operators already work to try and ensure grid reliability and aim to reduce the probability of power interruptions, the concept of resilience acknowledges that outages will eventually occur and aims to reduce damage and recover quickly. Although reliability measures taken by NERC often improve resilience, establishing resilience metrics is necessary to further enhance system resilience in a targeted manner.

Increasing grid resiliency reduces the time and resources needed to supply power to critical facilities and return the entire system to normal operations[25]. A system’s level of resilience should be based on outcome-focused abilities that fall under the following categories:

1) **Robustness** - the ability to absorb shocks and continue operating;
2) **Resourcefulness** - the ability to effectively manage a disaster as it unfolds;
3) **Rapid Recovery** - the ability to return services back to normal as quickly as possible; and
4) **Adaptability** - the ability to incorporate lessons learned from past events to improve overall resilience[24].

Grid resilience is not an end goal, but rather an ongoing process that is continually being updated to adapt to changes in the natural, social, and technological environment. The Edison Electrical Institute, who has created a repository of resilience studies, programs, and policies, notes that no single solution exists to make all systems more resilient; rather, “utilities and their

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[23] National Academy of Sciences. (2017). *Enhancing the Resilience of the Nation's Electricity System*. The National Academies Press.

[24] Department of Homeland Security. (2010). *A Framework for Establishing Critical Infrastructure Resilience*. National Infrastructure Advisory Council.

[25] National Renewable Energy Laboratory. (2014). *Distributed Solar for Electricity System Resiliency*. US Department of Energy.

regulators must look at the full menu of options and decide the most cost-effective measures to strengthening the grid"[26].

When defining resilience metrics, it is important to decide which characteristics of the grid are being considered. In general, resilience metrics should be simple to calculate, enable retrospective and forward-looking analyses, and also be highly informative and consistent. In its 2015 Quadrennial Energy Review, Sandia National Laboratories (SNL) presented the Resilience Analysis Process, one of the first frameworks to develop performance-based resilience metrics for the power grid[27]. SNL's review defined the following criteria for developing resilience metrics:

- **Metrics should be centered around low-probability, high-consequence disturbances**, often referred to as "catastrophes".
- **Metrics should be based on the performance of power systems instead of their attributes**. Because of the high level of detail that performance-based metrics encompass, their use is maximized for baseline assessments, response and recovery activities, and planning and investment efforts. For example, an attribute-based metric usually relies on surveys that result in general numerical scores (indices) for resilience attributes, while a performance-based metric relies on quantitative data based on actual infrastructure outputs, such as the number of critical loads that experience an outage, or the critical customer energy demand not served.
- **Metrics should quantify the consequences that occur after grid disturbances** (for example, electricity not delivered as a result of the outage, utility revenue lost, cost of recovery to the utility, etc).
- **Metrics should reflect the uncertainties that drive response and planning activities**. These uncertainties include disruption conditions, damage to the grid, demand from the affected population, time required for response, and more[27].

SNL's Resilience Analysis Process (Watson et al) is not a strict procedure, but rather a flexible framework that gives operators an opportunity to customize metrics for a particular system. The process is as follows:

1. **Define resilience goals**
    a. Example: Improving a local electric grid's resilience to increasing natural disasters
2. **Define consequence and resilience metrics**
    a. Example: Focusing metrics on monetary loss due to outages. Metrics could include loss of utility revenue, cost of recovery, or avoided outage cost.
3. **Characterize hazards**

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[26] Edison Electrical Institute. (2014). *Before and After the Storm*.

[27] Watson, J., Guttromson, R., & Silva-Monroy, C. (2015). *Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States*. Sandia National Laboratories.

    a. Example: Identifying that earthquakes are largest hazards of concern.
4. **Determine level of disruption**
    a. Example: Identifying which substations will be nonfunctional in the event of an earthquake, and identifying the steps needed to bring it back online as fast as possible.
5. **Collect data via system model or other means**
    a. Example: Gathering data from the utility's outage management system and gathering power disruption estimates.
6. **Calculate consequence and resilience metrics**
    a. Example: Using the utility system model to estimate the monetary loss due to an outage.
7. **Evaluate resilience improvements**
    a. Example: Repeating the last six steps with a resilience improvement in the system model such as the addition of islanding capability and increased behind-the-meter solar infrastructure.

A. Distributed solar for grid resilience

An important aspect of distributed solar is its ability to potentially increase grid resilience. Distributed PV solar, or rooftop "behind the meter" solar, is electricity produced by individual households, businesses, or communities in close proximity to the point of use[11]. Traditionally, the grid has been powered by thermal resources generated at locations far away from the point of consumption. Electricity is transported by long transmission lines to a local substation where it is converted to lower-voltage electricity, which is then distributed to the users. The grid has relied on this system for decades. An aging infrastructure system and rapid changes in climate are making the current centralized system more vulnerable to increasing extreme weather events and cyber-security threats.

A Grid Strategies report published by Silverstein et al. identified that the key to increasing grid resilience is transitioning from centralized transmission power to more decentralized distributed generation[13]. In order to do this, regulators must incorporate intelligent grid solutions throughout the system, including energy storage, demand response, and smart inverters, and update policies to align economic interests among utilities and ratepayers.

When a disturbance occurs within the current centralized transmission system, a large chunk of the grid can lose power, causing large-scale outages. During the disturbance, critical infrastructure (such as hospitals and fire stations) are powered by fuel generators. Rooftop solar, possibly in conjunction with with battery storage, has the potential to provide extensive resiliency benefits, as well as increase the value of the system and increase electric bill savings

[28,29]. A study completed by the National Renewable Energy Laboratory (NREL) in 2014 found that putting a value on the resilience provided by PV solar systems that include battery storage almost doubles the net present value compared to a traditional standalone PV system[28]. This increase is shown in Figures 2 and 3. Operating within a microgrid also reduces the effects of disturbances and allows communities to potentially power themselves through a large-scale outage.

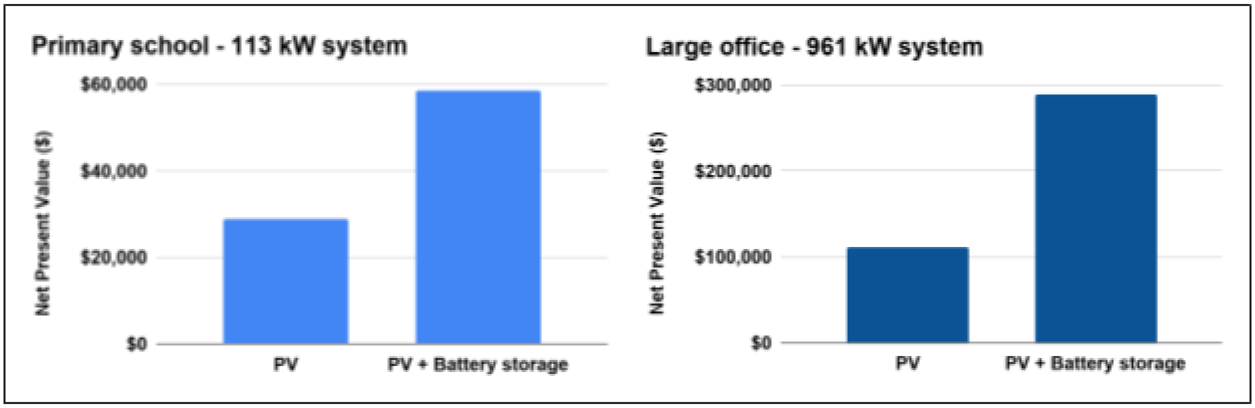

Figure 2. The increasing value of two different PV systems before and after battery storage was implemented into the system is displayed. Net present value was more than doubled in each system after placing a value on the resilience provided by battery storage systems. Data obtained from NREL[28].

Rooftop solar provides resiliency benefits when the system:
1) is designed to fully disconnect or “island” itself from the grid during a disturbance;
2) is implemented with battery storage; and
3) can provide localized power to essential facilities when the grid is down.

In order to maximize a solar system’s level of resilience, it should be equipped with a battery storage system, a multifunctional inverter, and operate on its own during a disturbance. Current operating standards require grid-connected solar PV systems to automatically disconnect from the grid during a power outage for safety reasons; however, instead of operating while isolated from the grid during the power outage, most rooftop PV systems completely cease production and are unable to provide standalone power[25]. Because of this, efforts to increase the resilience of distributed PV systems have been focused on the development of microgrids, which are able to island themselves from the larger grid and supply consistent localized power during an outage.

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[28] National Renewable Energy Laboratory. (2018). *Valuing the Resilience Provided by Solar and Battery Energy Storage Systems*.

[29] California Energy Commission. (2013). *Borrego Springs Microgrid Demonstration Project*. San Diego Gas and Electric.

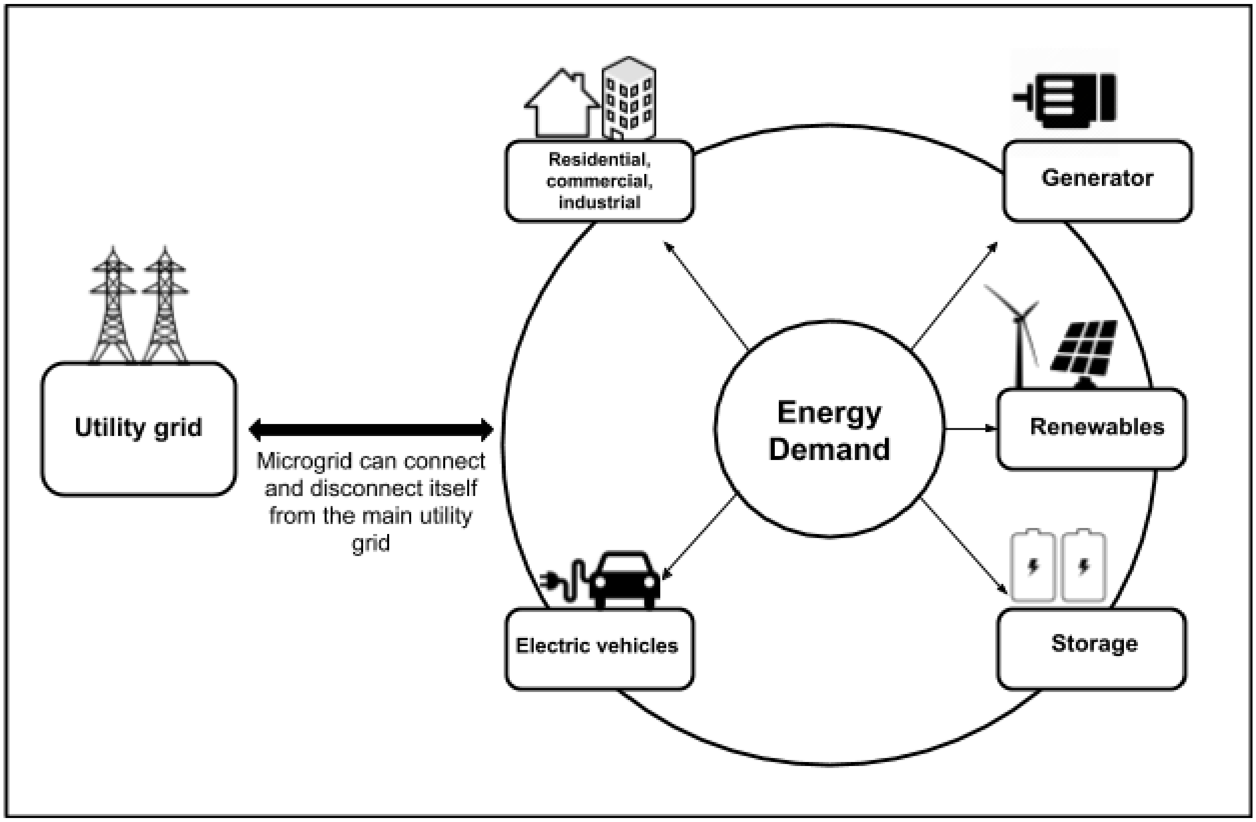

Figure 3. The concept of a microgrid is illustrated. Together, residential, commercial, and industrial customers are able to disconnect from the main grid by monitoring, controlling, and balancing energy demand with distributed energy sources.

A microgrid is a group of interconnected loads and distributed energy resources that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid, enabling it to operate in both grid-connected or island-mode[30]. During disasters, microgrids have proven to provide extensive resilience benefits to communities who were previously reliant on the larger centralized, fuel-powered system during outages[31]. Microgrids are an essential characteristic of community resilience, discussed in the final section of this report.

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[30] The Role of Microgrids in Helping to Advance the Nation’s Energy System | Department of Energy. (2018).

[31] Walton, R. (2015). SDG&E microgrid uses solar, storage to avoid outage in small town.

III. Defining community resilience

Resilience is best put into practice when it is planned for by communities from the bottom-up. Traditional state level emergency management tends to focus on top-down planning, with a heavy reliance on shipping fuels to communities in the wake of a catastrophe[32]. However, emerging climate hazards impose localized risks that affect communities inequitably. This requires community members to create resilience and adaptation plans tailored to their community's specific vulnerabilities and needs. It also requires utilities to be adaptive and to work closer with communities to understand their concerns. Community resilience is a relatively new concept in the critical infrastructure community. Like grid resilience, community resilience has no widely accepted definitions or metrics, but it is commonly discussed in current literature. Communities themselves cannot prevent natural hazards from shutting off power, but they can plan as best as they can to mitigate risk, protect human life and critical assets, and to operate and recover after a disaster.

Often times community resilience is discussed without an understanding of what defines a "community". The definition of community resilience is subjective and can have a variety of meanings in practice. For this level of work, the NIST definition of a community applies:

> A place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town city, or county. It is within these places that people live, work, find security, and feel a sense of belonging[33].

Communities must begin to consider energy system resilience because of the vital role that the power system plays in our everyday lives. Electricity is the foundation of all critical systems in our modern world. Following a disaster, the biggest challenges that face communities relate to restoring power to critical facilities, and ensuring reliability once power is restored. Both of these challenges have serious implications for rebuilding and recovering economic activity[32]. Because of this, resilience planning must begin from the ground-up with the needs of community members in mind.

Community resilience differs from larger concepts of power system and grid resilience because of its focus on the vulnerabilities and risks specific to a community. There is no strict overarching guide for improving community resilience because planning strategies are fluid and vary from community to community. The City Club of Portland provides a general definition of community resilience:

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[32] Rubado, L., Iplikci, J., & Engel, B. (2018). Community Resilience Board Learning Paper. Energy Trust of Oregon.

[33] National Institute of Standards and Technology. (2016). *Community Resilience Guide for Buildings and Infrastructure Systems*.

> A resilient community, city, or region understands its strengths and vulnerabilities and has developed capabilities to plan for and mitigate the impact of a major earthquake or other disaster, rapidly restore itself to a state of basic well being, and rebuild to achieve even greater resilience[34].

While grid resilience and reliability are solely focused on damage to the larger power grid, community resilience focuses on human and critical infrastructure recovery[35]. Conversations around this concept incorporate equity and social justice into planning, focusing on frontline communities who are usually the most impacted by local disturbances. Disasters affect everyone, but the effects are disproportionate. Historically disadvantaged communities (low-income, people of color, immigrants, and the elderly) are more vulnerable than others, and must be put at the front and center of all community resilience planning.

A community's level of resilience depends heavily on social, economic, and institutional variables[36]. Resilient community infrastructure must provide benefits and critical needs to as many people as possible. This may mean choosing a safe, commonly known community space for residents to gather during an emergency that will have power[37]. Deciding on this location requires collaborative planning and investment in distributed solar and battery storage. The gathering space can then island from the grid or operate within a neighborhood microgrid, acting as a fully operating center for refuge for the entire community. Much of the technology that has been proven to enhance community resilience is either already on the market or currently being developed and tested in pilot projects. Where past efforts have focused on deploying diesel generators, future efforts may build more resilience by deploying solar plus batteries, which are not dependent on delivery of fuel.

A. Distributed solar for community resilience

Distributed solar has been shown to enhance community disaster resilience, increase cost savings, provide local economic benefits, and reduce overall carbon emissions. Community resilience planning must acknowledge the long-term climate change uncertainties we face, and bolster communities with power systems that not only reduce greenhouse gas emissions, but better protect families, neighborhoods, and businesses from extreme hazards. Distributed solar systems should be thought of less as a feature or option to enhance community resilience, but as a vital source of power for communities when a catastrophe occurs. Distributed solar with storage has proved time after time that it can not only provide reliable power to communities during emergencies, but that it can also bring economic and social benefits to those who need it

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[34] City Club of Portland. (2017). Big Steps Before the Big One: How the Portland area can bounce back after a major earthquake. *City Club of Portland Bulletin.*

[35] Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American journal of community psychology*, *41*(1-2), 127-150.

[36] Norris, F. (2008). *Defining Resilience for Communities and Organizations*. National Academies.

[37] Valdez, Jaimes. (2018, July 25). S. Dean, Interviewer)

most. The following two case studies showcase ways in which distributed solar is being implemented to increase community resilience.

Borrego Springs Microgrid

The Borrego Springs, California, solar project is the nation's first microgrid to provide power to an entire community during an extended outage, while operating in complete isolation from the grid[38]. The microgrid was an existing utility circuit in San Diego Gas & Electric (SDG&E) service territory, serving 615 customers with a peak load of 4.6 MW. In February 2015, SDG&E was awarded a $5 million grant from the U.S. DOE and California Energy Commission to expand the microgrid, integrate smart grid technology, and enable it to "island" from the grid. In May 2015, the microgrid successfully islanded from the grid and provided power to all of Borrego Springs for over 9 hours during planned maintenance. The city relied solely on the microgrid as the county's transmission lines were previously damaged by lightning. At the completion of the funded demonstration project, the combined power provided by the microgrid (from rooftop-solar in the community and utility-scale solar from a nearby facility) was about 30 MW, with a battery storage of 1.5 MW[29,31].

Living Cully Community Energy Plan

The Cully neighborhood in Northeast Portland, Oregon, is one of the largest and most diverse neighborhoods in the city, yet it is also one of the most underdeveloped. The community has some of the highest poverty rates and lowest incomes in the city. New developments are pushing out residents who are already extremely vulnerable to climate-related disasters. Living Cully, a community-wide collaboration between Habitat for Humanity, Hacienda CDC, and Verde, works to bring environmental funding directly into the community as a tool to build local wealth and economic resilience. The Living Cully Community Energy Plan is a neighborhood-scale energy plan that addresses the climate crisis by creating a blueprint for investments in distributed solar, community energy education, and home weatherization. One pilot in particular is focused on developing community owned distributed solar to increase community resilience. As of 2018, Living Cully is currently planning to construct a 78 kW rooftop solar plus storage installation at a local church. The church is a recognized community institution that will serve as a fully functioning gathering place for the neighborhood in the event of a disaster when the neighborhood's power goes out. The project received funding from Pacific Power's Blue Sky Renewable Energy Program, and Living Cully is partnering with Neil Kelly Solar to permit and install the project[39].

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[38] Walton, R. (2015). Inside the nation's first renewables-plus-storage microgrid.
[39] Living Cully. (2018). *Living Cully Community Energy Plan*. Portland, Oregon.

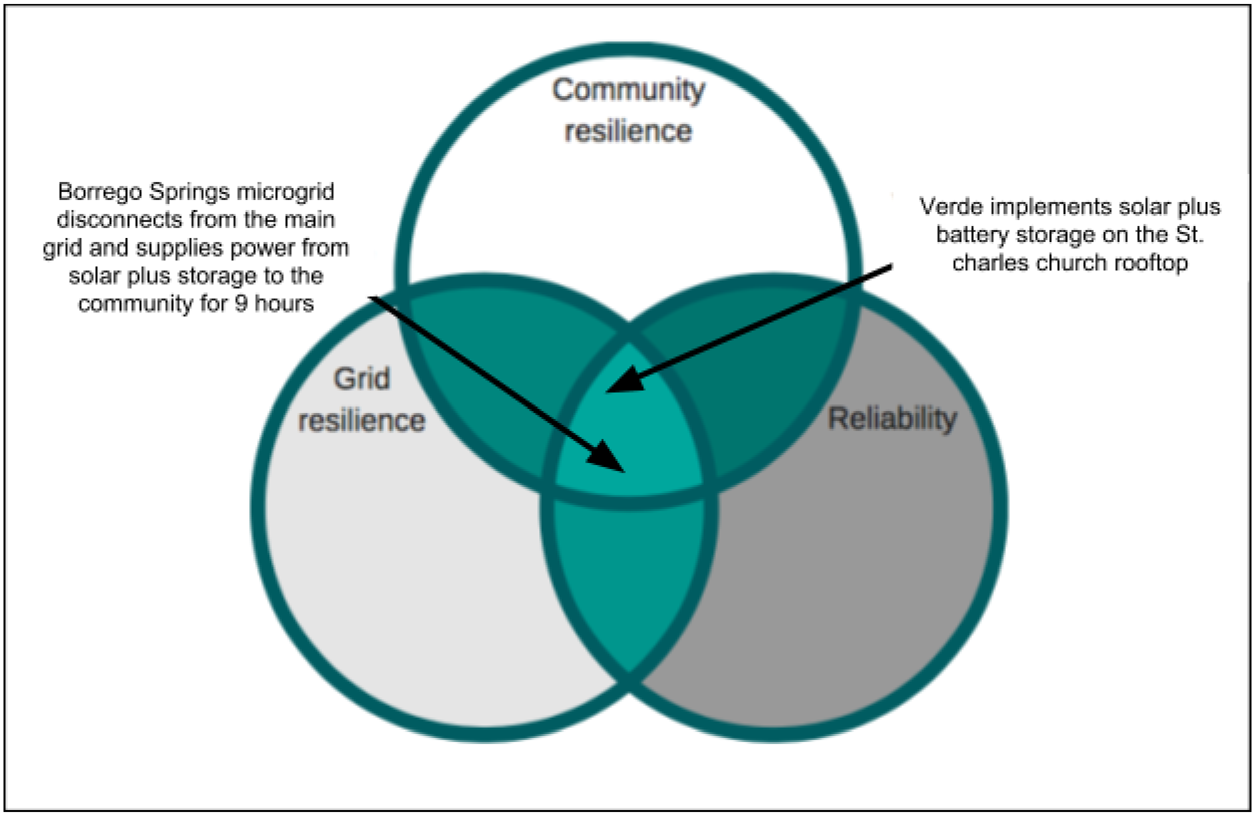

Figure 4. The two examples of communities using distributed solar for resilience used in this paper are conceptualized within the tri-venn diagram of community resilience, grid resilience, and reliability.

Projects that implement distributed solar often end up enhancing all three concepts discussed in this paper. In Figure 4, the two case studies previously discussed are placed within the tri-venn diagram of community resilience, grid resilience, and reliability. The Borrego Springs example is placed in the lower half of the center section of the diagram because it employed resilient technology (microgrid with battery storage) to reliably power the community for over 9 hours. The features of the Borrego Springs microgrid emphasize grid resilience and reliability, and reduce the community's reliance on the larger centralized power system. Because the project was developed by outside entities, community resilience was achieved more as a by-product of the microgrid. The Living Cully project, however, is placed higher up in this section towards community resilience. The project is centered around the community's needs, and the goal of implementing solar plus storage on the community church is to power and empower residents in the event of a disaster. In this example, the project is developed by community members for community members.

Conclusion

Despite the damages that disturbances may bring, they provide a unique opportunity for policymakers, regulators, and communities to anticipate them and adopt transformative and innovative planning strategies. Community resilience, grid resilience, and reliability measures all stem from the same goal: ensuring that power systems are ready and able to rapidly respond to disturbances. A resilient grid is one that is able to sustain and recover from high-impact, low-frequency events. A reliable grid aims to reduce the number and duration of high-frequency, low-impact power interruptions. A resilient community is one that not only minimizes impacts to humans and infrastructure during a disaster, but one that protects and empowers those who are most vulnerable by taking advantage of resilient technologies that provide co-benefits.

Moving forward, as Oregon and Washington continue on the path towards decarbonization, the role of distributed solar in enhancing reliability, grid resilience, and community resilience is vital. In the road ahead, Pacific Northwest communities will be bolstered with resilient, reliable, clean electricity systems. Reaching this goal will require government support for local, bottom-up planning efforts that are already making headway on building strong and resilient communities.