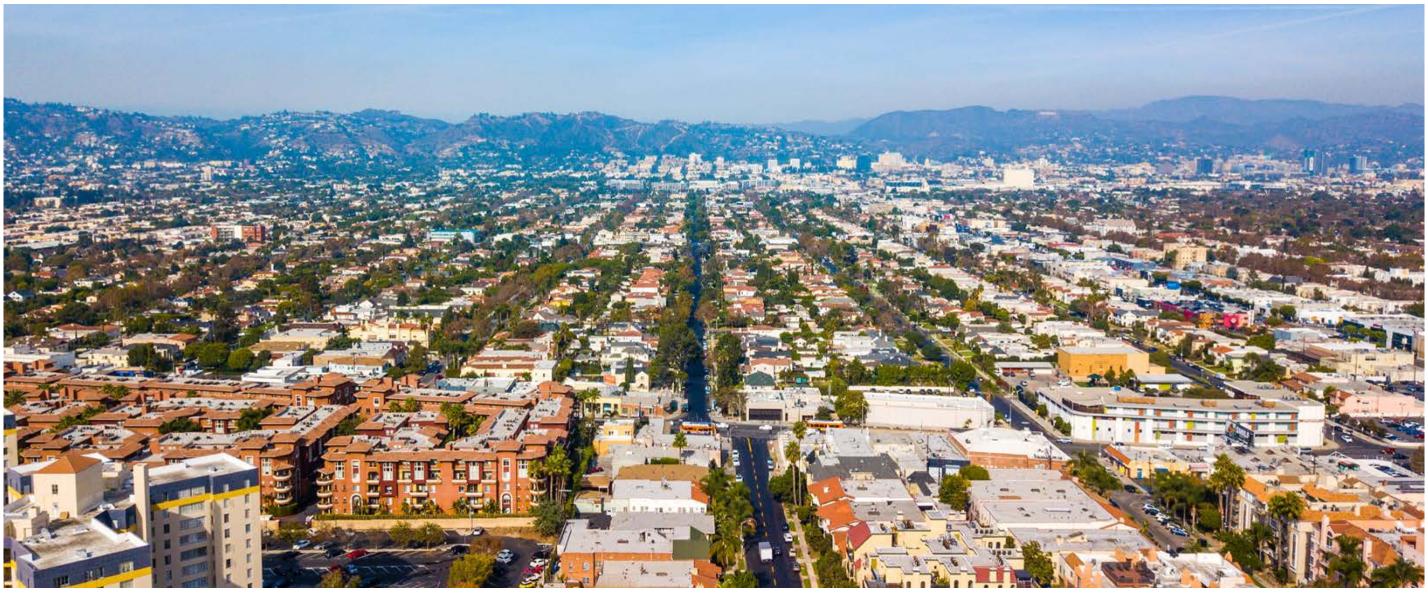
LA100 EQUITY STRATEGIES



Chapter 12. Distribution Grid Upgrades for Equitable Resilience and Solar, Storage, and Electric Vehicle Access

FINAL REPORT: LA100 Equity Strategies

Bryan Palmintier, Sherin Ann Abraham, Kwami Senam Sedzro, Jane Lockshin, Gayathri Krishnamoorthy, Kapil Duwadi, Patricia Romero-Lankao, Nicole Rosner, and Greg Bolla

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LA100 EQUITY STRATEGIES

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Preface

The Los Angeles 100% Renewable Energy Study, or LA100, revealed that although all communities in Los Angeles will share in the air quality and public health benefits of the clean energy transition, increasing equity in participation and outcomes will require intentionally designed policies and programs. The LA100 Equity Strategies project was specifically designed to help Los Angeles identify pathways to such policies and programs in the form of equity strategies. The project aimed to do this by incorporating research and analysis to chart a course toward specific, community-prioritized, and equitable outcomes from the clean energy transition outlined in the LA100 study.

The Project Partners

The Los Angeles Department of Water and Power (LADWP), the National Renewable Energy Laboratory (NREL), and the University of California Los Angeles (UCLA) partnered on the LA100 Equity Strategies project to develop strategies for engaging communities, funding equitable technology and infrastructure investments, expanding existing programs, and designing new programs and policies to improve equity by incorporating what community members themselves know is needed to achieve a more equitable energy future.

The Project Approach

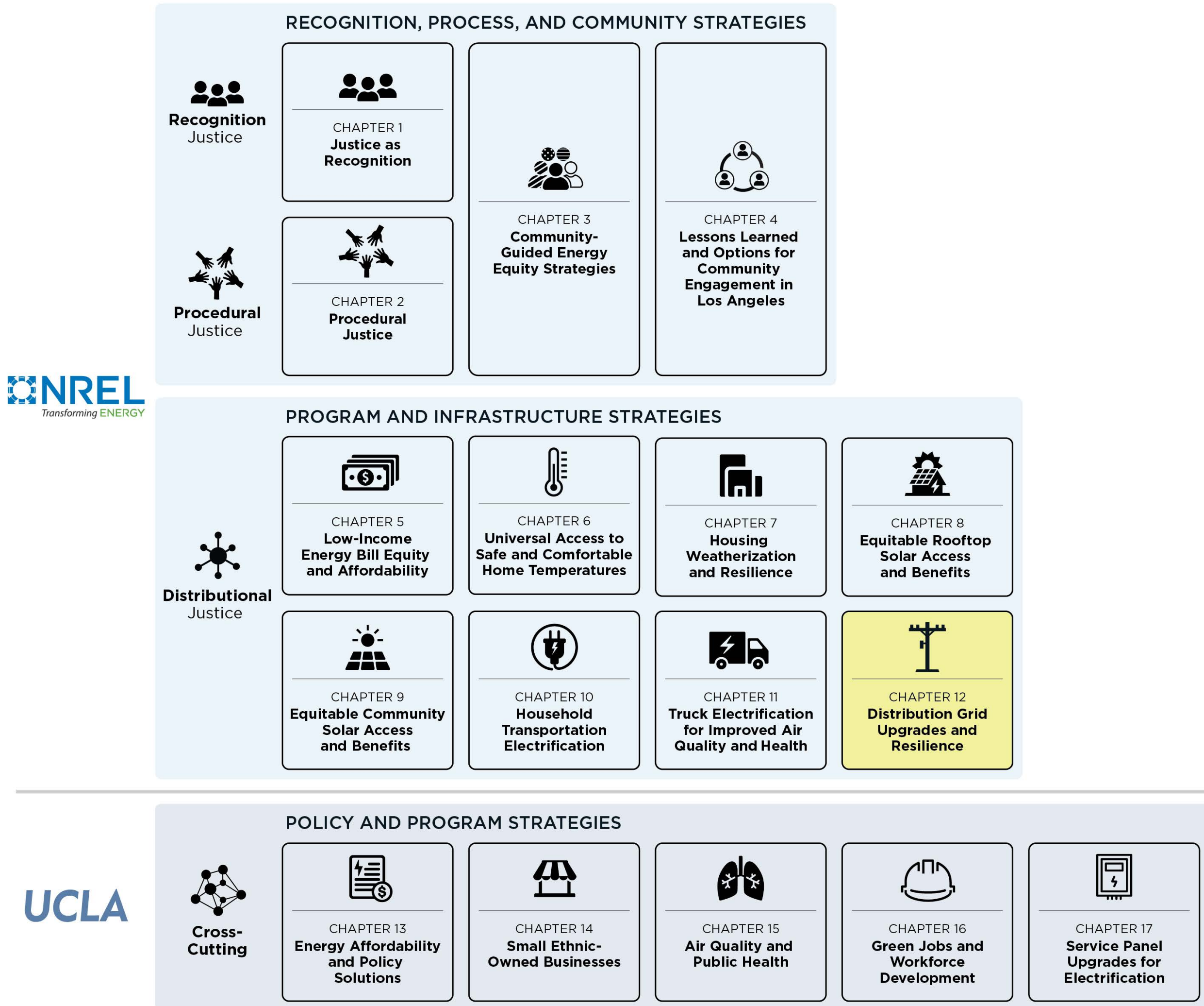
LA100 Equity Strategies employs a unique mixed-methodological approach utilizing three distinct—but connected—research efforts. Through these efforts, NREL and UCLA developed a range of strategy options for increasing equity in LA's transition to 100% clean energy.

A Project Summary

To get a high-level overview of the project, you can dive into the executive summary, interactive data visualizations, and more on the LA100 Equity Strategies website at maps.nrel.gov/la100/equity-strategies.

The Full Report

NREL's final full report for the LA100 Equity Strategies project encompasses seventeen chapters. The first twelve chapters, authored by NREL, are organized around the three tenets of justice. Chapters 1–4 address recognition and procedural justice, while Chapters 5–12 address distributional justice. The final five chapters, authored by UCLA, provide crosscutting policy and program strategies. Each chapter provides data, methods, insights, and strategies to help LADWP make data-driven, community-informed decisions for equitable investments and program development.



NREL Chapters

UCLA Chapters

List of Abbreviations and Acronyms

A	amp, a unit of electric current
DAC	disadvantaged community
DER	distributed energy resource
dGen	Distributed Generation Market Demand model
DISCO	Distribution Integration Solution Cost Options model
EMF	electromagnetic fields
ERAD	Equity and Resiliency Analysis for Distribution model
EV	electric vehicle
HVAC	heating, ventilation, and air conditioning
kV	kilovolt, a unit of electric potential
kW	kilowatt, a unit of electric power
LADWP	Los Angeles Department of Water and Power
LMI	low and moderate income
NREL	National Renewable Energy Laboratory
PUMA	Public Use Microdata Area
PV	photovoltaics
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SCADA	supervisory control and data acquisition
V	volt, a unit of electric potential

Executive Summary

The LA100 Equity Strategies project integrates community guidance with robust research, modeling, and analysis to identify strategy options that can increase equitable outcomes in Los Angeles' clean energy transition. As Los Angeles transitions toward clean energy, existing distribution grid infrastructure will need to be updated and expanded to support reliable service during routine operations, enable interconnection with distributed energy resources and electrified loads, and provide access to energy-related services during disasters. This chapter focuses on equity in distribution grid upgrades, reliability, and resilience in Los Angeles.

Specifically, NREL performed grid upgrade and resilience analyses using a detailed model of the distribution grid and income-differentiated household load profiles, electric vehicle (EV) adoption patterns, distributed solar adoption, and grid reliability to explore two key questions to inform how the City of Los Angeles can ensure a resilient and reliable distribution grid for all communities during the clean energy transition:

- Where can distribution system upgrades can be prioritized to enable equitable access to, and adoption of, clean energy technologies?
- How can Los Angeles provide equitable, resilient access to electricity-related services (e.g., health care, food) during disaster events like earthquakes and flooding?

The electric distribution system is the "last mile" of the grid, linking the multistate bulk power system with customers; new loads, including EVs; and distributed energy resources, such as customer and community solar and storage. This analysis focuses on the 4.8-kilovolt (kV) system, including service transformers that represent the utility-side of the grid connection for most residential customers. Chapter 17 looks at the customer-side of the grid connection with a focus on electric panel upgrade needs. The transition toward clean energy can put additional stress on the distribution system from distributed energy resources and electrification—especially EVs and increased use of electricity for heating, cooling, cooking, and hot water. This stress, measured here as the number of equipment overloads and voltage violations, correlates strongly to grid reliability and therefore is used as a proxy for understanding additional upgrades needed and to help ensure equitable access to electrification and distributed energy resources. NREL also conducted community resilience analysis to examine customer-level access to both electricity and a larger range of services, such as hospitals and grocery stores during a disaster. This analysis explicitly considers equity to understand differences in current resilience and resilience strategies to effectively improve critical services access for all Angelenos.

Research was guided by input from the community engagement process, and associated equity strategies are presented in alignment with that guidance.

Community Guidance

Guidance from the LA100 Equity Strategies Steering Committee, listening sessions with community members co-hosted with community-based organizations, and community meetings included the following:

> **South LA Resident:**
>
> "I need to find someone with an upgrade of electric because…we have blockage [outages] all the time when somebody hits a [utility] post and the electricity go off and it cause problem in my home now that I cannot wash [clothes] and watch a TV at the same time. My electric goes off…they have these accidents, these people hit these posts [utility poles], then your electric's out for two hours or so, and it messes up your appliance…your appliance be off and…it's a mess."

- Invest in infrastructure capacity for all Angelenos by understanding that barriers to accessing clean, energy efficient technologies arise from multiple intersecting sociodemographic factors. For example, consider the citywide infrastructure and investments needed to ensure new clean technologies, such as EVs, will be available for all Angelenos to access and use.
- Redress historical and ongoing neighborhood neglect: outdated infrastructure needs remediation and attention to safety and health concerns.
- Develop strategies to upgrade the grid and electrical capacity (i.e., panels) of existing housing stock in Los Angeles without further burdening low- and moderate-income communities, particularly in historically disenfranchised neighborhoods.
- Guarantee access to safe and comfortable shelter during disaster events, such as heat waves and fires, particularly when access to cooling and grid reliability in participants' homes is compromised. Community members often stated that they relied on spaces outside their homes to provide a safe and comfortable environment.
- Provide safety upgrades to residential electrical infrastructure in disadvantaged communities (DACs). In buildings with older electrical systems, outages have additional impacts, such as causing safety risks and negatively affecting home appliances.

Distributional Equity Baseline

An analysis of distributional equity in electric power distribution systems infrastructure reliability found that DACs and mostly Hispanic communities experience more *frequent* power interruptions than non-disadvantaged, mostly non-Hispanic communities. No statistically significant difference was found in the *duration* of power interruptions across communities (Figure ES-1).

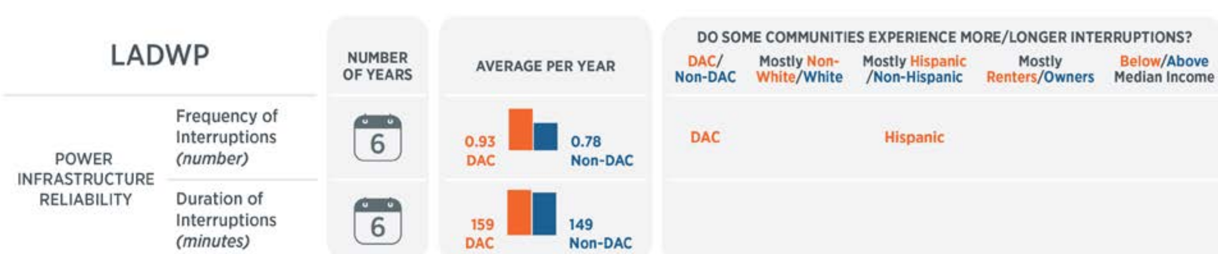


Figure ES-1. Statistical analysis of LADWP customer electric outage metrics (2015–2020)

In addition, DACs are less than one-half as likely to have underground distribution lines compared to non-DAC areas (12.6% versus 26.7% of lines undergrounded). Underground lines offer reliability, aesthetic, and other benefits.

Key Findings

- Grid reliability challenges are unequally distributed and disproportionately impact DACs. Modeled levels of grid stress—overloads and voltage challenges that provide a forward-looking proxy for lower reliability—are an average of 14% higher in regions of the city with significant DAC representation.[1] This is expected to worsen to 25% by 2035. (Figure ES-2).
- Grid stress represents a key challenge to supporting significantly higher loads from electrification and widespread integration of distributed solar and storage. To overcome these challenges, substantial increases in distribution capacity are needed.

Distribution grid equity metrics include:

- Risk of power outages and grid stress (overloads and voltage challenges) by disadvantaged community status and neighborhood.
- Ability for low- and middle-income (LMI) customers to install electrified appliances, EVs, solar, storage, and other technologies without grid or service transformer limitations.
- Access to critical services during disasters by disadvantaged community status and neighborhood.

[1] Specifically for census Public Use Microdata Areas (PUMAs) where 75% or more of the representative neighborhoods are classified as DACs versus those with fewer DACs.

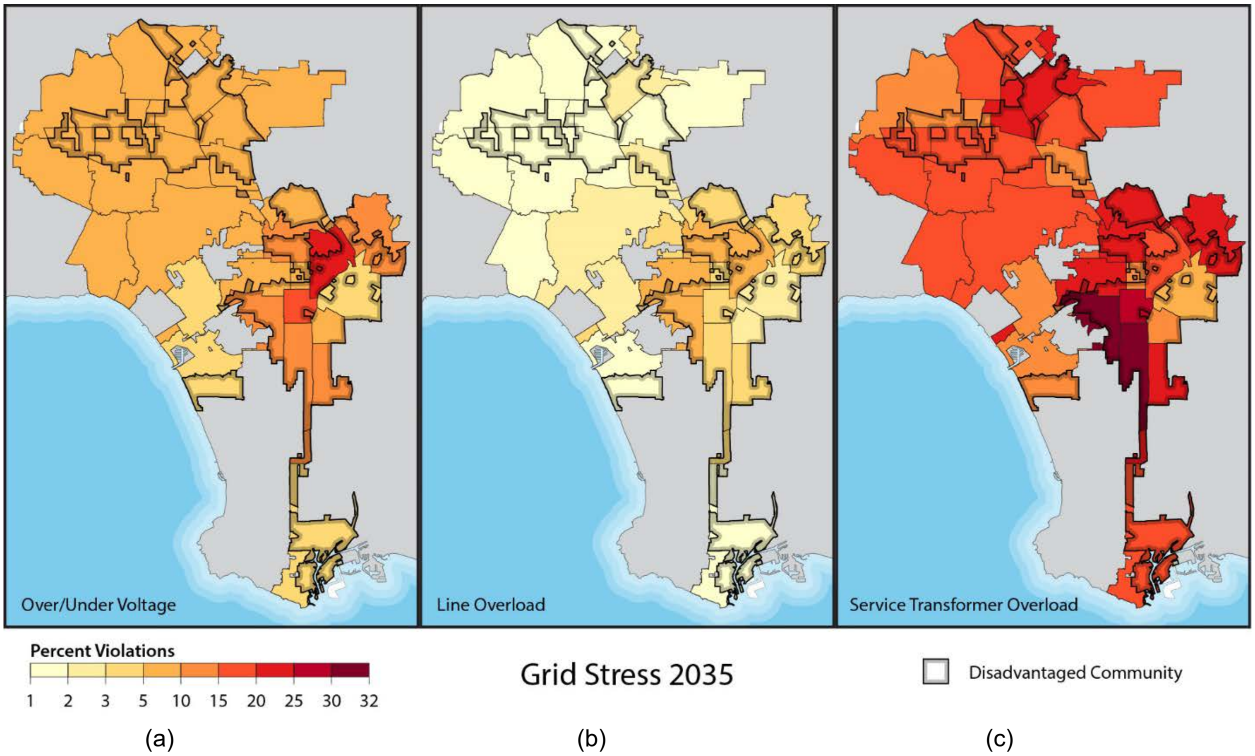


Figure ES-2. Grid stress level estimates for 2035-Equity case showing (a) over/under voltages, (b) line overloads, and (c) service transformer overloads

The level of grid stress is significantly higher in 2035 than in 2019

- Grid limitations could limit the success of other clean energy equity programs. In some cases, service transformer or grid upgrade costs may be borne by the customer, creating an additional barrier to adoption for customers, especially those with lower incomes. In other cases, required grid upgrades may be delayed, which could in turn delay other programs that seek to increase electrification, solar, and storage.
- Access to critical services—grocery, hospitals, emergency shelters, convenience stores, and banking—varies considerably among neighborhoods, even without disaster events. Although DACs have generally lower access to services such as groceries, hospitals, and convenience stores, they generally have higher access to emergency shelters and banking. These trends continue during disasters. Both DAC and non-DAC neighborhoods see significant reductions in service access during simulated disaster events, though the impacts vary considerably by service and neighborhood, resulting in some neighborhoods having very low service access. Residential electricity access is also reduced for most DAC and all modeled non-DAC neighborhoods during disaster events (Figure ES-3).
- Implementing resilience strategies such as microgrids that use future solar and storage resources already estimated to be installed and adding backup power (e.g. additional solar + storage) to 50% of critical infrastructure can significantly improve service access during disasters. If targeted for communities with initially lower resilience, such approaches could help provide more equitable service access during disaster events (Figure ES-3).

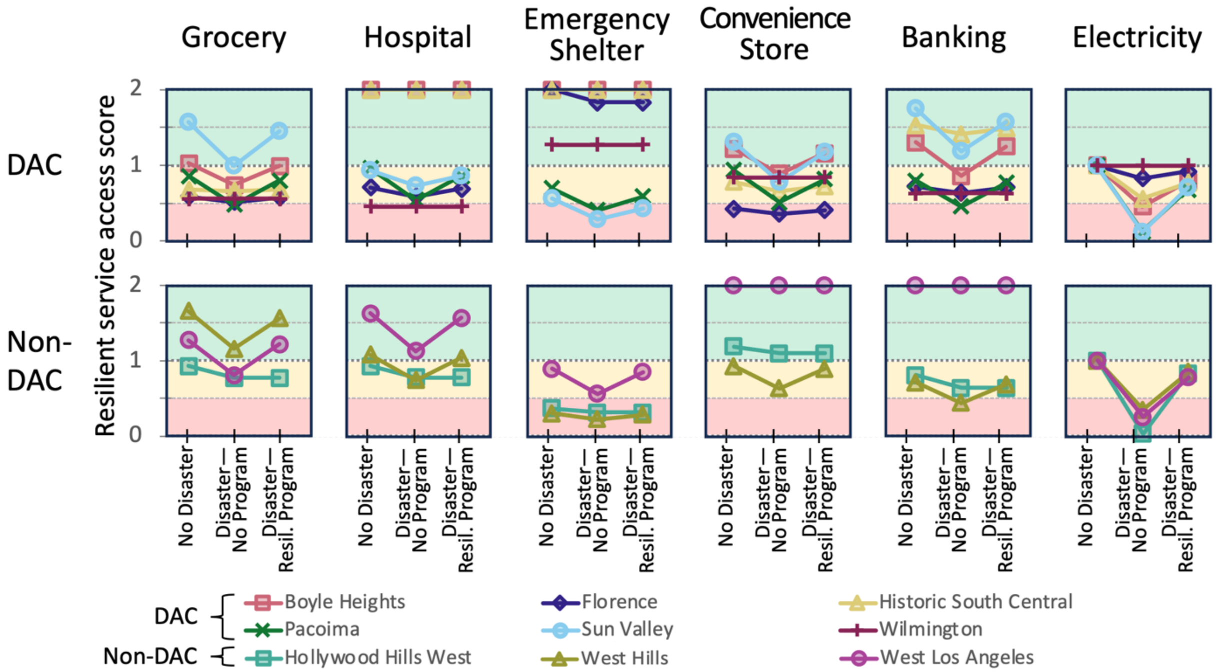


Figure ES-3. Modeled community-level resilient service access score for six critical services for residents of nine neighborhoods before and during disaster events in 2035

For each neighborhood-service combination, three access levels are shown as a series of points: No disaster, during a disaster with no resilience program, and during a disaster with a resilience program that combines microgrids using solar + storage already estimated to be installed and backup power at 50% of critical service facilities.

Resilience scores on the y-axis are normalized by median system-wide access for each critical service relative to normal operations (no-disaster event scenario). Values in the top green bands are at or above the system-wide no-disaster level (≥1), those in the yellow band have reduced service access between 50% and 100% of the system-wide no-disaster average, and those in the bottom red band are below 50% for the system-wide no-disaster average.

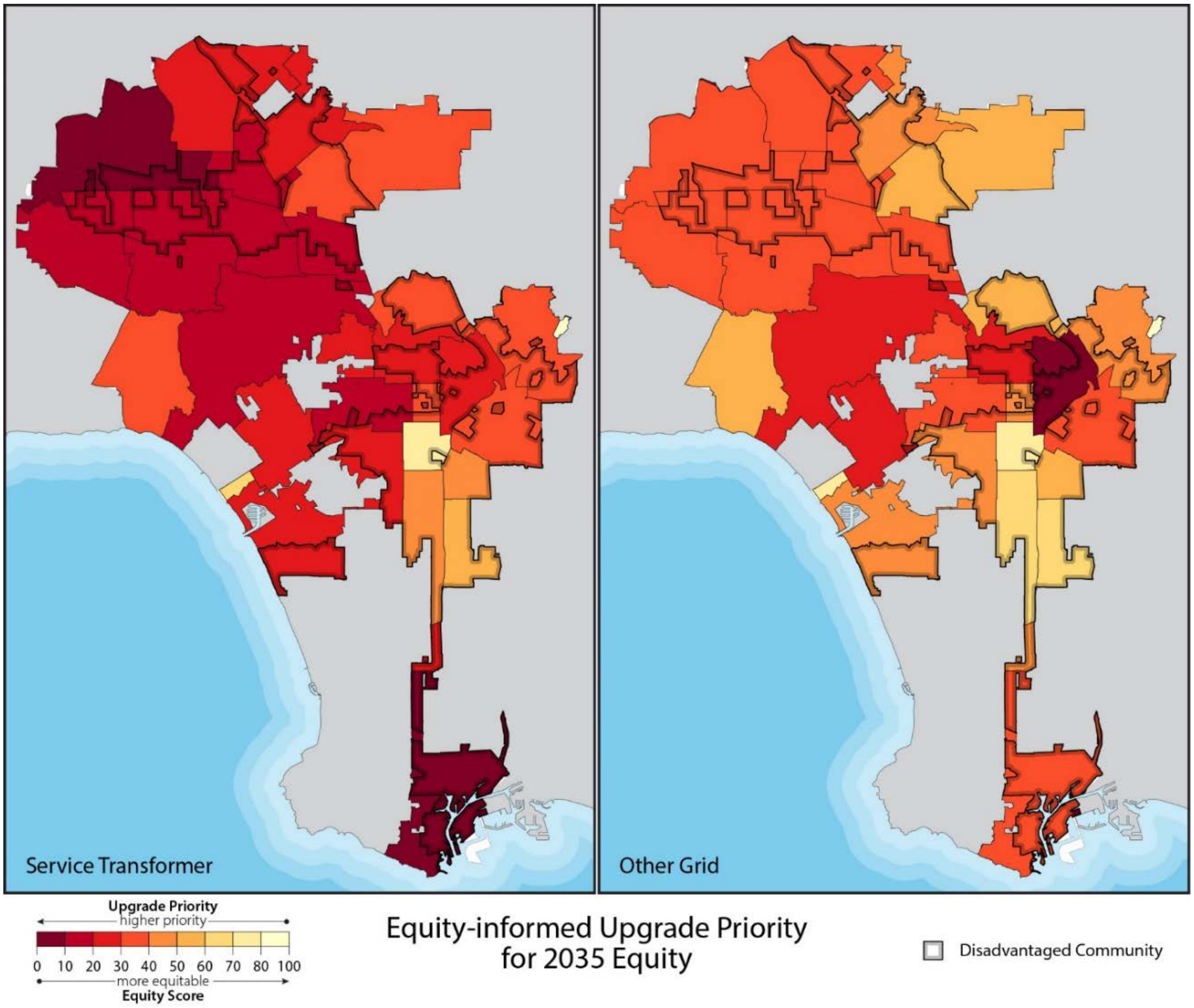
Equity Strategies

Modeling, analysis, and community engagement identified the following strategies for achieving more equitable outcomes in the distribution of benefits and burdens for distribution grid reliability and resilience in LA's transition to clean energy.

- Incorporate equity as a priority when planning grid infrastructure investments. For instance, incorporating sociodemographic data—including income and race—and DAC status into other grid evaluation metrics can highlight areas of inequity to correct. And, upgrade priority can be boosted for regions with larger differences in grid stress or other indicators between DAC and non-DAC neighborhoods. Figure ES-4 shows an example of this approach highlighting a prioritization that combines grid stress with grid (in)equity.
- Upsize transformer capacity by a factor of 2–3+ when replacing service transformers to cover not only traditional growth trends but also higher load increases and high-capacity services needed with electrification. This is especially important for customers with existing 60-amp (A)–100 A service projected to need to grow to 150 A–200 A. This can help prevent grid connections from being a barrier to equitable technology adoption and can also avoid the need to replace transformers again

before end of life, as might happen if ongoing transformer replacements do not fully consider these future higher load levels.

- Coordinate grid upgrade programs with other programs—such as those aimed at increasing equity in cooling, EVs, home electrification, and electric panel upgrades—so that the grid does not create a barrier for deployment. For example, this could include programs that cover any service transformer upgrade costs for low- to moderate-income customers, along with programs to support additional grid upgrades that might also be needed.
- Consider increased investment in underground distribution lines in non-flood-prone portions of DACs.
- Implement community-specific resilience strategies for equitable service access during earthquakes, floods, and other disasters. This includes targeted programs to prioritize resilient electricity upgrades, including on-site backup power (such as solar + storage), for critical emergency services in neighborhoods with traditionally low non-disaster service access. Additional programs could target backup power, such as solar and storage, for mobility-impaired low- to moderate-income community members.
- Collaborate with community-based organizations for preparedness, education, and support programs (Chapter 3). Efforts that work in collaboration with trusted community-based organizations could prove more effective for preparedness, particularly in DAC neighborhoods.



(a) (b)

Figure ES-4. Equity-informed upgrade priorities for (a) service transformer and (b) other grid components for the 2035 equity scenario at the Public Use Microdata Area level across the in-basin LADWP grid

Higher scores are lower priority because they indicate a combination of lower grid stress and/or higher equity.

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1 Introduction

As Los Angeles transitions toward clean energy, existing and aging distribution grid infrastructure will need to be updated and expanded to support routine operations, enable interconnection with distributed energy resources (DERs) and electrified loads, and provide access to energy-related services during disaster events. The objective of the modeling and analysis effort reported here is to inform planning for an equitable[2] and fair distribution grid by exploring three questions:

- How can the City of Los Angeles ensure a resilient and reliable distribution grid for all communities within Los Angeles in the clean energy transition?
- Which distribution system upgrades are required to enable equitable access to, and adoption of, clean energy technologies?
- How can Los Angeles provide equitable access to critical services during disaster events?

1.1 What is the Electric Distribution System? How Does it Look Today?

The electric distribution system is the local part of the grid—the portion within neighborhoods that provides a vital link between the large-scale bulk power system and building loads, distributed solar, distributed storage, and electrified transportation. In addition, the distribution grid provides the key grid link for the DERs that are expected to provide significant in-basin[3] capacity in support of Los Angeles' clean energy goal.

The Los Angeles Department of Water and Power (LADWP) electric distribution system contains two utility voltage levels: (1) the larger 34.5-kilovolt (kV) subtransmission circuits that serve the dual purpose of connecting the transmission system to local distribution substations and directly serving larger customers (generally >500 kilowatts (kW)) and (2) the 4.8-kV local distribution system to service smaller loads. Because most residential customers (both single-family and multifamily customers) are connected to the 4.8-kV system, this analysis primarily considers the 4.8-kV system. In addition, residential customers have a secondary or service voltage, which is typically in the 120-volt (V)–480-V range, that is not captured in detail in this analysis, but Chapter 17 considers the customer portion of this low-voltage system.

As seen in Figure 1, the current system has reliability equity challenges, including a higher system average interruption frequency index (SAIFI) in DACs and predominantly Hispanic neighborhoods. Specifically, DACs and mostly Hispanic communities experience more *frequent* power interruptions than non-disadvantaged, mostly non-Hispanic communities. No statistically

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[2] Energy equity or justice "refers to the goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system." (Baker, DeVar, and Prakash 2019, p9).

[3] In this report, "in-basin" refers to the Los Angeles Basin.

significant difference was found in the *duration* of power interruptions across communities. In addition, DACs are less than one-half as likely to have underground distribution lines compared to non-DAC areas (12.6% versus 26.7% of lines undergrounded), as seen in Figure 2.

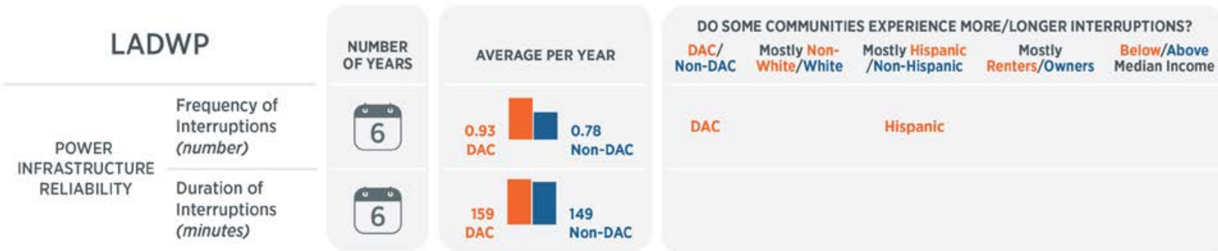

Figure 1. Statistical analysis of LADWP customer electric outage metrics (2015–2020)

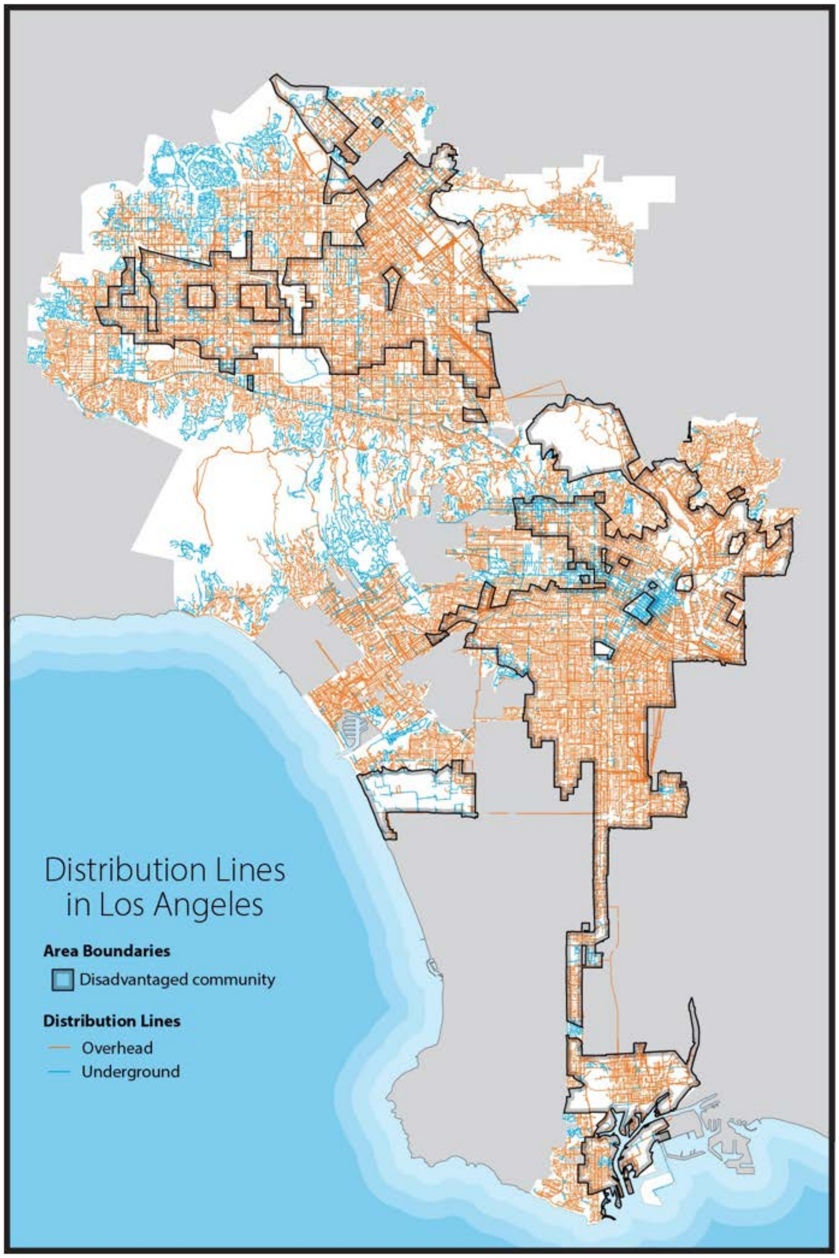

Figure 2: Underground and overhead distribution lines in Los Angeles

LADWP is already undertaking a multiyear effort to address a backlog of aging equipment maintenance through the Power Supply Reliability Program[4] and other programs, although these programs do not directly consider equity and may only partially address electrification and DER needs. With climate-related disaster events expected to become more common with climate change, it is also critical to consider the resilience of the distribution grid and related services during emergencies. Currently, LADWP is prioritizing electricity hardening options such as on-site storage for a range of city facilities for both emergency services and to provide resilience

[4] "Power System Reliability Program," LADWP, http://prp.ladwp.com/.

hubs to offer shelter and other services to residents. However, this program does not explicitly consider equity or other services beyond municipal services.

1.2 Barriers to Equitable Interactions With the Distribution Grid

The wide range of barriers to participating in the clean energy transition that disadvantaged community (DAC) members might face can be thought of as a series of closed doors (Figure 3). For example, consider installing rooftop solar. Potential barriers may include the high up-front cost of solar, low roof structural integrity, inadequate home electric panel or internal wiring, and challenges with the grid itself. This analysis focuses on the grid itself, and other challenges—or doors—are covered in other chapters.[5] We divide the grid upgrade analysis into two elements: (1) the connection from homes to the grid with a focus on potential overloading of the service transformers, as in some situations customers might be expected to pay for some of or all service transformer upgrade costs and (2) the larger distribution grid itself, where upgrade costs are typically covered by the utility.

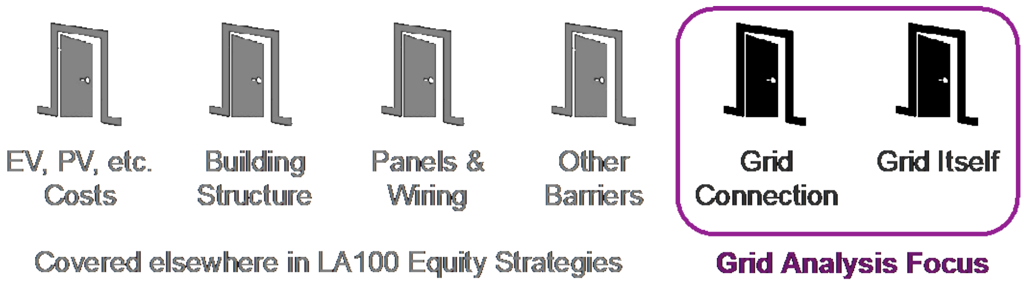

Figure 3. The barriers for a DAC member participating in the clean energy transition may be visualized as a series of closed doors

This chapter considers ways to open the doors associated with the two grid-related elements. Other chapters address other barriers.

1.3 Resilient Access to Electricity and More During Disaster Events

Access to electricity-related services during disaster events such as earthquakes or flooding is a significant additional challenge for DACs. This analysis explores options for improving community energy resilience during disaster events. Our modeling considers more than just whether customers can keep their lights on by also looking at customer-level access to a range of critical services during disaster events.

[5] Specifically, the chapters on electricity rates and affordability (Chapter 5), solar adoption (Chapter 8), and electric service panel upgrades (Chapter 17) explore these other barriers in detail.

2 Summary of Community Guidance

As described in detail in Chapter 1 and Chapter 2, the LA100 Equity Strategies project team conducted extensive community engagement to identify community guidance on needs, priorities, and equity strategies from the local perspective. Employing qualitative methodology to code and categorize community-grounded data, this approach was applied to reveal the findings most relevant to distribution grid reliability and resilience. The following list summarizes this community guidance:[6]

- *Invest in infrastructural capacity—from building-scale to urban-scale, that lowers barriers to accessing and using clean energy efficient technologies*: Invest in infrastructural capacity for all Angelenos by understanding that barriers to accessing clean, energy efficient technologies arise from multiple intersecting sociodemographic and built-environment factors. For example, consider that distribution grid infrastructure and service transformer investments will be needed to ensure new clean technologies such as electric vehicles (EVs) will be available for all Angelenos to access and use. This includes investing in public infrastructure and making upgrades to single-family and multifamily homes.
- *Upgrade and maintain aging infrastructure for safety and efficiency*: Redress historical and ongoing neighborhood neglect by remediating outdated infrastructure. A few engaged residents were particularly concerned with safety and health dangers related to transmission lines in their community in South LA.[7]
- *Develop affordable strategies for grid and home electrical capacity upgrades that do not further burden low- or moderate-income Angelenos*: Develop strategies to upgrade the grid and electrical capacity (i.e., panels) of existing housing stock in Los Angeles without further burdening low- or moderate-income communities, particularly, as one resident noted, "neighborhoods that have been disenfranchised historically and are now expected to get up to speed to be part of the energy revolution." Another resident specifically mentioned the older housing stock in South LA (Leimert Park), which is from the late 1920s, and noted that most houses still have old electrical panels that would require upgrades to use any of the new energy efficient technologies being proposed.[8]
- *Support the development and maintenance of publicly accessible resilience spaces for safe and comfortable shelter during disaster events*: Residents often stated that in disaster events such as heat waves and fires, when access to cooling and grid reliability in their homes is compromised, they rely on spaces outside their homes to provide a safe and comfortable environment. These spaces include offices and employment locations, shopping malls, coffee shops, parks, and libraries (when they are open and accessible).
- *Invest in local capacity building and knowledge sharing about safe, efficient practices Angelenos use in their homes during extreme weather*: Provide the educational tools needed to foster and value local expertise by developing a space for Angelenos to share community knowledge and practices.

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[6] Additional quotes from engaged residents, can be found in Section A.7 in the appendix.
[7] The potential health risks of living near transmission lines have been the subject of intense debate. Reports from a wide range of credible sources "have all concluded that insufficient scientific evidence exists to warrant the adoption of specific health-based EMF [electromagnetic field] mitigation measures" (PG&E 2006), such as those from transmission lines.
[8] This assessment is supported by the panel upgrade needs estimated in Chapter 17.

- *Prioritize upgrading critical electrical infrastructure in neighborhoods with older housing stock to prevent local blackouts and their negative effects*: In buildings with older electrical systems, outages have additional impacts such as negatively affecting home appliances. In relation to outages, two reasons for local blackouts in participants homes were identified:
    - **Rain:** One resident commented on a series of outages she experienced during two days of continuous rainfall.
    - **Infrastructural Accidents and Electrical Capacity:** Another resident commented on a need for an upgraded electrical system in her neighborhood and in her home because of accidents where neighborhood electrical posts have been hit and her house has experienced a 2-hour power outage.

3 Modeling and Analysis Approach

The grid upgrade and resilience analyses build on a detailed electrical engineering model of the distribution grid and National Renewable Energy Laboratory (NREL)-modeled, Los Angeles-specific, income-differentiated household load profiles, EV adoption patterns and charging profiles, and distributed solar adoption and production.[9] Scenario details can be found in Section A.2 of the appendix. For the distribution grid analysis, the baseline (2019) estimates are scaled to match LADWP historical load patterns as described in Section A.1 of the appendix.

Infrastructure upgrade analysis provides insight into the variation across Public Use Microdata Areas (PUMAs) of grid impacts and costs needed to mitigate grid stress introduced by changing loads and equitable adoption of and access to solar, storage, and EVs. These impacts are analyzed for DACs and non-DACs to understand any differences. This analysis informs PUMA-level prioritization for infrastructure upgrade investments to ensure equitable access to reliable power.

The second part of this analysis considers equitable access to electricity and social services during resilience events, such as earthquakes and flooding. The analysis reported here includes income, DAC status, and other equity metrics to evaluate access to critical services during such events, compute aggregated community energy resilience scores, and assess which resilience strategies are most effective at boosting critical services access.

3.1 Modeling Approach Background

Both analyses use distribution grid feeder[10] models from the original LA100 study (Palmintier et al. 2021) as a starting point. The forecasted electricity consumption, EV and distributed solar and storage adoption and use, along with their time-series demand and generation profiles are estimated at the census-tract scale for representative customers. As described in Section A.1 of the appendix, a multistep process is then used to map these parameters to corresponding feeders and then customer locations.

This analysis considers two scenarios: a 2019 baseline and a 2035 equity scenario. The 2019 baseline scenario represents the present state of the system, and corresponding analyses and metrics assess the health of the present grid and existing inequities. The 2035 equity scenario uses projections of load changes due to electrification and adoption of DER technologies to look at equity-centric impacts on the distribution grid. To ensure the spatial load patterns better reflect on-the-ground conditions, the 2019 forecasted loads are scaled to match 2019 supervisory control and data acquisition (SCADA) data from LADWP at the feeder level. The same scaling multipliers are also applied for 2035. Section A.2 of the appendix includes additional scenario details and load and DER assumptions.

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[9] See Chapters 6, 7, 8, and 10 for methodologies and modeling details.

[10] Here, each feeder is the "last mile" portion of the distribution grid that connects dozens to hundreds of customers to a distributing substation. This report considers only the 4.8kV system, which connects to smaller loads (up to about 500kW) and therefore includes most housing in the city.

3.2 Equitable Distribution Grid Upgrade Priorities and Grid Upgrade Analysis Methodology

This analysis combines forward-looking reliability analysis and demographic data to help inform planning strategies to achieve an equitable distribution grid. As described in this section, this assessment uses projected grid stress as a proxy for reliability under a combination of increased load from electrification and equitable adoption and use of DERs.

A combination of increasing load, aging equipment, and large amounts of DERs can impact the reliability of the distribution system, potentially leading to outages. Past reliability performance is typically measured with metrics like system average interruption duration index (SAIDI) and SAIFI, but future reliability is difficult to predict, in part because it requires significant amounts of failure rate and condition data that are not available. Therefore, this work considers *grid stress* as a proxy for reliability prediction. Specifically, we define grid stress as line and transformer overloading along with out-of-range equipment voltages, because these elements tend to be strongly correlated with equipment failure and outages on the grid. These grid stress elements can be simulated for both current and future systems using physics-based distribution power flow analysis, which is commonly used for engineering analysis.

To run physics-based power flow analysis and determine grid stress, distribution feeders across the in-basin LADWP service territory are modeled in OpenDSS. Power flow simulations are then run using OpenDSS/PyDSS, with automation provided by the Distribution Integration Solution Cost Options (DISCO)[11] tool (Horowitz et al. 2019; Wang et al. 2022). Using DISCO upgrade analysis, the feeder-level grid stress, infrastructure upgrades, and costs to alleviate grid stress are determined for the 2019 baseline scenario and the 2035 equity scenario. Figure 4 summarizes this workflow for conducting equitable distribution grid upgrade analysis.

[11] https://github.com/NREL/disco

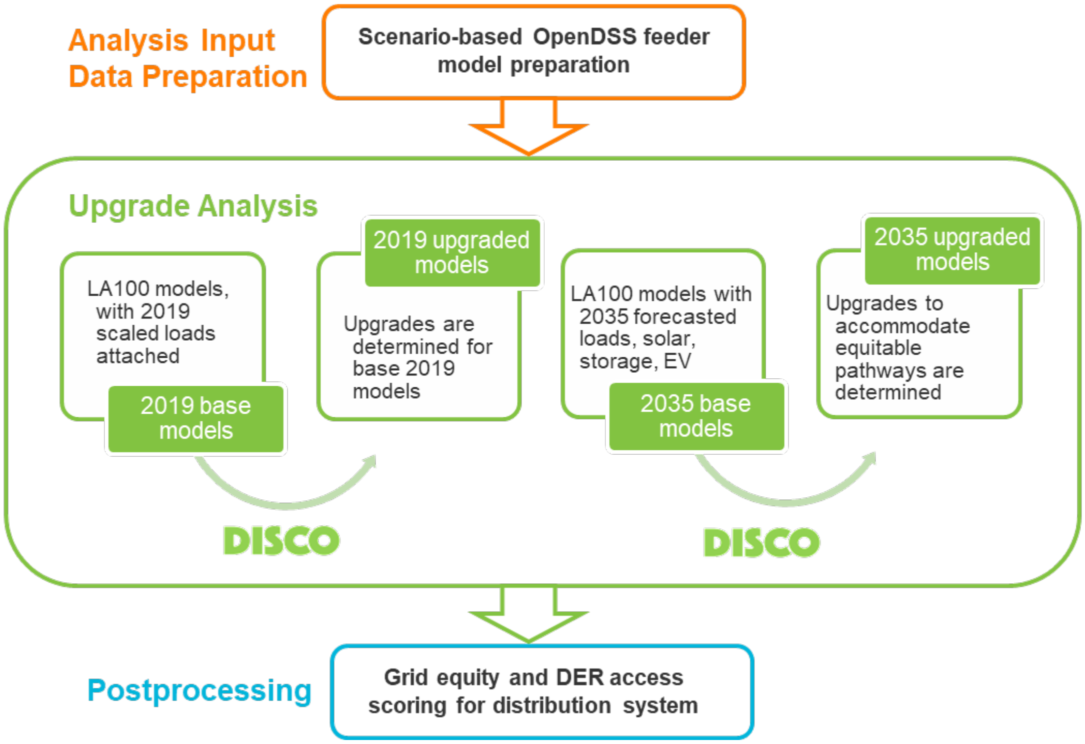


Figure 4. Equitable distribution grid upgrade analysis workflow

The first level of translation from the feeder-level analysis involves computing the *grid stress score* for individual census tracts, which is a combination of undervoltages, overvoltages, service transformer overloads, and line overloads. This is performed by first mapping feeder-level results to the census tract so they can be combined with demographic data available at that resolution. A high grid stress score implies high limits imposed by the grid. When analyzing the scenarios for 2035, a *DER adoption score* for each census tract is also estimated to capture the level of DER adoption in each census tract, for individual technologies like EV, solar, and storage. As seen in Figure 5, the grid stress score and the DER adoption score can be combined to arrive at a census-tract level *DER access score*.

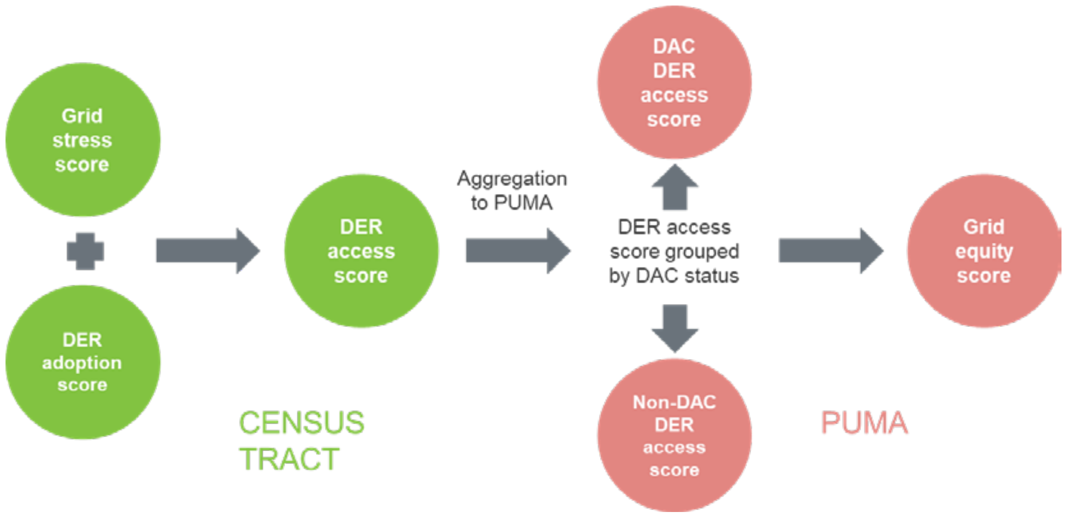


Figure 5. Process to determine a grid equity score for each PUMA in the LADWP service territory by combining the DER adoption and grid stress scores computed at the census-tract level

Traditionally in distribution system planning, grid reliability and costs are used to determine where infrastructure investments are going to be made (i.e., sites with the highest number of violations and poor reliability are prioritized to provide access to reliable power). Therefore, the DER access score represents a traditional, engineering-only assessment of how to prioritize grid investments. In a business-as-usual case, only objectives of reliability and decarbonization are considered. However, this approach does not consider any demographic metrics and does not assess equitable access to DERs.

To perform an equity-focused analysis, the census-tract level DER access score is aggregated by DAC status for each of 30 regions—corresponding to census-defined Public Use Microdata Areas (PUMAs)—in the LADWP territory. Doing so provides the DAC DER access score and non-DAC DER access score by region. The difference between these reflects the inequity within each region. By combining the mean DER access score (technical) and demographic inequity within a region, a combined grid equity score for each region can be computed. This grid equity score captures not only the technical needs but also provides a measure of equity with regard to grid stress and DER adoption for the distribution grid. Regions with a lower grid equity score correspond to those with higher priority for infrastructure investments when planning for the transition toward an equitable distribution grid.

3.3 Equitable Access to Electricity-Enabled Service During Resilience Events

In addition to grid stress during routine operations, we also estimate the equity of access to energy-related services during simulated disaster events for earthquakes and flooding. As described in this section, we use a social burden metric to compare access to a range of services.

3.3.1 Neighborhood Selection

We conduct the resilience analysis for nine neighborhoods in LADWP's in-basin service territory selected for their diversity across several quantitative and qualitative metrics.

Quantitatively, we consider five key metrics: DAC status, SAIFI, SAIDI, median income, and percentage of underground cable length. To ensure diversity, a stratified sampling approach is used by dividing all tracts into three categories for each metric separated by *mean - standard deviation* and *mean + standard deviation*. As a result, all the tracts within +/- one standard deviation of the mean fall into the middle group, and those higher or lower fall into the other two groups respectively. Then, samples are drawn separately for each of the three groups to ensure sufficient coverage of the lower and higher tails of the ranges for these values. Doing so identifies 56 tracts that are then expanded to their corresponding neighborhoods (there are multiple tracts per neighborhood). This results in 65 neighborhoods that include some or all of 252 tracts. We further down selected to nine neighborhoods based on priorities identified in on-the-ground observations, stakeholder listening sessions, and a semiquantitative typology of neighborhood types (Romero-Lankao, Wilson, and Zimny-Schmitt 2022). Doing so results in the selection of the nine neighborhoods for comparative analysis: Boyle Heights, Florence, Historic South Central, Hollywood Hills West, Pacoima, Sun Valley, West Hills, West Los Angeles, and Wilmington. The selected neighborhoods cover 92 census tracts and 167 distribution feeders. Section A.4 in the appendix includes details about the neighborhood selection process and neighborhood data.

3.3.2 Resilience Analysis Methodology

As shown in Figure 6, the resilience analysis first estimates the baseline resilience (i.e., access to critical services) of the selected neighborhoods. Then, various resilience strategies are applied, and resilience is evaluated again to identify the most promising strategies. As described in Section 3.3.3, the resilience scores are based not only on whether electricity can be provided to customers but more importantly on customer access to critical services.

Figure 6. Community energy resilience modeling workflow

The community energy resilience evaluation uses NREL's Equity and Resiliency Analysis for Distribution System tool (ERAD) (Duwadi et al. In Review), which builds a community graph database to capture a simplified, connectivity-only representation of the distribution grid to model whether supply, storage, and control are sufficient to keep loads—critical and otherwise—powered, without conducting power flow analysis. A range of resilience events (represented through probabilistic equipment damage scenarios for earthquakes and flooding) are then applied by taking randomized samples of possible equipment failures for each. These in turn are used to compute customer-level access to critical services, which are then aggregated to compute a community energy resilience score. This process is repeated after various upgrade strategies to identify different patterns of backup generation and microgrids that result in the highest equitable resilience outcomes. In this analysis, upgrade strategies include:

1. **Microgrid**: This strategy adds microgrid controllers to portions of the grid that may be isolated during a disaster, or islands, so they can use future DERs (notably solar and storage) already estimated to be installed[12] within the island to provide power without a connection to the larger grid.
2. **Critical Backup**: This strategy randomly assigns 50% of the critical services to have additional access to generic on-site backup power. In a low-carbon future this could be solar photovoltaics (PV) + storage or more traditional fuel-based backup power that seldom operates.
3. **Microgrid + Backup**: This strategy combines the previous two approaches and tends to provide the highest during-disaster service access.

Section A.4 of the appendix provides additional methodology details.

3.3.3 Equitable Grid Resilience Metrics

In the community energy resilience analysis, we evaluate customer access to a set of six critical services across a range of resilience scenarios. As seen in Figure 7, we measure the level of access each community member has to electricity, as well as a selection of other critical services—hospitals, grocery stores, emergency shelters, banking, and convenience stores—under a set of disaster scenarios. Access is defined as a function of distance to the set of facilities that are operational during the simulated disaster. The access of a household to the critical service is proportional to the inverse of the distance from the house to the nearest facility for that service that still has power. As described in detail in Section A.4 of the appendix, these individual scores are then aggregated across the community and across resilient event scenarios to build the community-scale resilience score.

[12] For simulations, this focused on customer adopted solar + storage, while additional community-scale storage included in conjunction with community solar (Chapter 9) and/or through LADWP's new Community Energy Storage Program could also contribute and further this strategy. For resilience during disasters where connections to the larger grid may be damaged, however, the presence of storage alone may be insufficient unless these resources include sufficient grid-forming inverters, isolation switches are added, and consideration is given to balancing supply and demand and ensuring island stability. Because the strategy builds on existing distributed generation, we refer to these additional controls as the key enablers of a microgrid.

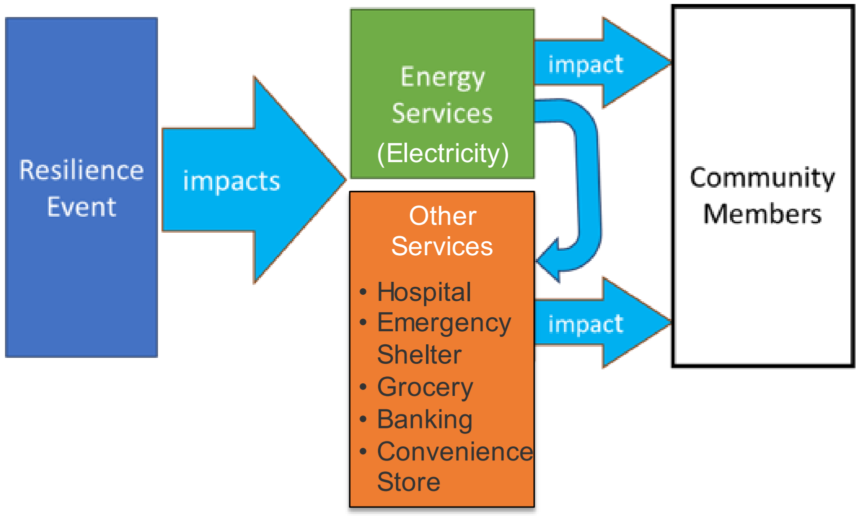


Figure 7. A resilience event can impact both electric service and the power to other critical services

Collectively, the distance-based individual community member access to operational services provides a measure of individual resilience, which is then aggregated to the community level to provide a neighborhood-wide metric.

4 Modeling and Analysis Results

4.1 Distribution Grid Upgrades for Equitable Reliability and Solar, Storage, and EV Access

Equitable distribution grid upgrade prioritization was conducted by PUMA region for feeders across the LADWP in-basin service territory. Results for the baseline 2019 distribution grid show there is already widespread grid stress—voltage stress, line overloads, and transformer overloads—and therefore substantial need for grid upgrades to the current system.

The 2035 high-grid-stress equity scenario expands this analysis using future load and DER estimates from (1) NREL-modeled building load growth including electrification, increased adoption of electric heating and cooling technologies, and general demand increase, (2) NREL-modeled electrified transportation, and (3) NREL-modeled customer adoption of solar and storage. Programs designed to encourage equitable adoption of these technologies are assumed to be in place.[13] As seen in Figure 8, the levels of growth estimated by 2035 result in significant grid stress throughout much of the city. Without any grid changes, the lowest regions' grid stresses in 2035 are roughly close to the highest level of grid stress seen in 2019. The highest regional grid stresses in 2035 are roughly 3×, 11×, and 7× higher than 2019 highs for voltage stress, line upgrades, and service transformer upgrade needs respectively.

Overall, in 2019 DACs experience roughly 1.5× more overloaded service transformers, lines, and voltage violations compared to non-DACs; this result demonstrates inequity in the distribution grid today, and this disparity is amplified in 2035 due to electrification.

Additional results, including maps for 2019, can be found in Section A.5 of the appendix.

[13] Section A.2 of the appendix describes the specific scenarios from these sources used here.

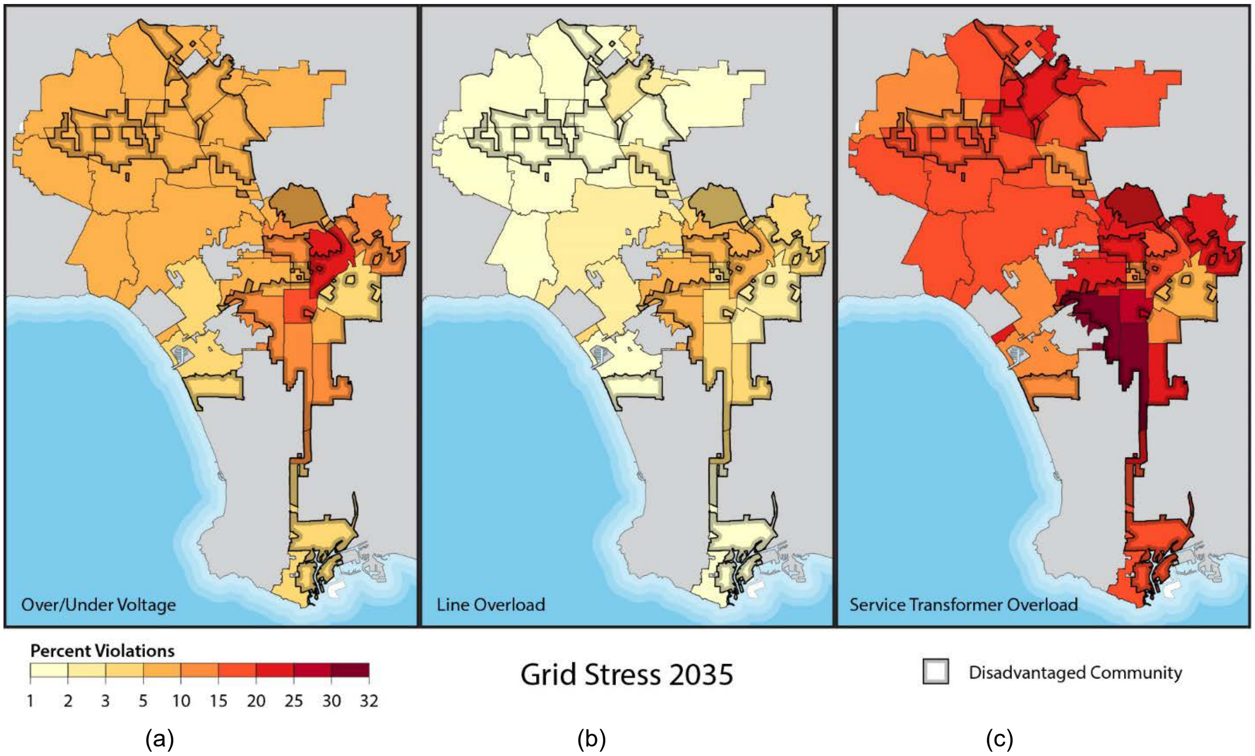


Figure 8. Grid stress level estimates for 2035-Equity case showing (a) over/under voltages, (b) line overloads, and (c) service transformer overloads

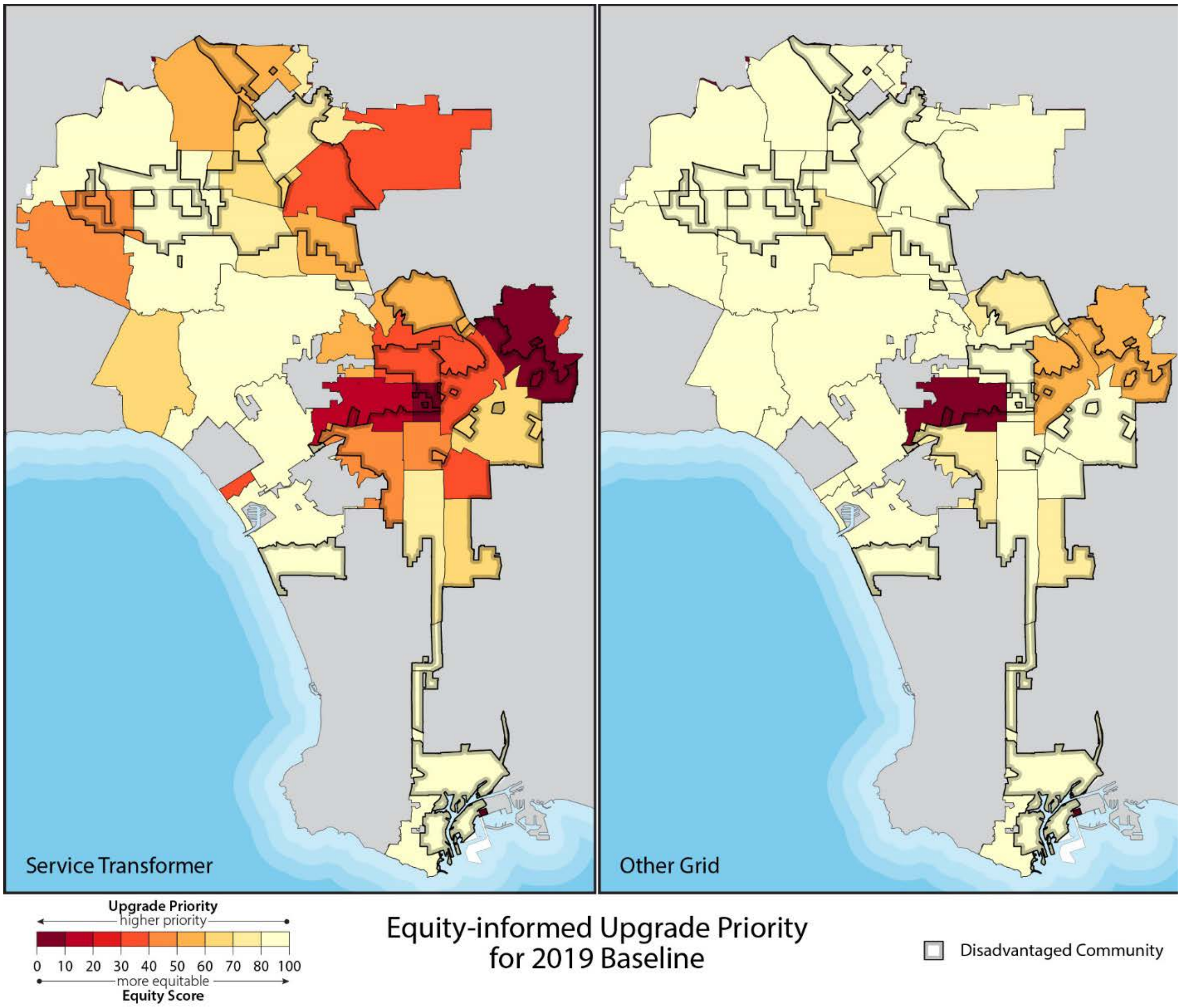
When grid stress results and DER adoption levels are combined with DAC status as described in Section 3.2, we arrive at the equity-informed upgrade priorities. These priorities are divided between service transformer upgrades and other grid upgrades. In some cases, customers may be expected to pay for their service transformer upgrades while larger grid upgrades are generally covered by LADWP. As a result, these upgrade needs might warrant different approaches or program designs to ensure equitable solutions. LADWP's recently announced Project PowerHouse provides an example of an equity-oriented program that covers the costs of power infrastructure upgrades for 100% affordable housing and permanent supportive housing units.[14]

Figure 9 (page 17) and Figure 10 (page 18) show the prioritization of upgrades based on grid equity for the baseline 2019 grid and for 2035 respectively. These values have been normalized to a zero to 100 scale by year, with zero as the lowest equity and hence highest priority. They show that the service transformer priority patterns differ from other grid upgrades and that these patterns differ over time. The 2019 equity-informed upgrade priority areas primarily reflect areas of deferred upgrades and low DER adoption levels, with some additional priority given to areas facing higher local variation in upgrade need between DAC and non-DAC tracts. These priorities can inform the sequencing of upgrades for the ongoing Power System Reliability Program[15] or

[14] "L.A. Water & Power Commissioners Unanimously Approve New Energy Services Policy Changes to Speed Construction, Lower Costs for 100% Affordable Housing Developments and Permanent Supportive Units," LADWP, March 14, 2023, https://www.ladwpnews.com/l-a-water-power-commissioners-unanimously-approve-new-energy-services-policy-changes-to-speed-construction-lower-costs-for-100-affordable-housing-developments-and-permanent-supportive-units/.
[15] "Power System Reliability Program," LADWP, http://prp.ladwp.com/.

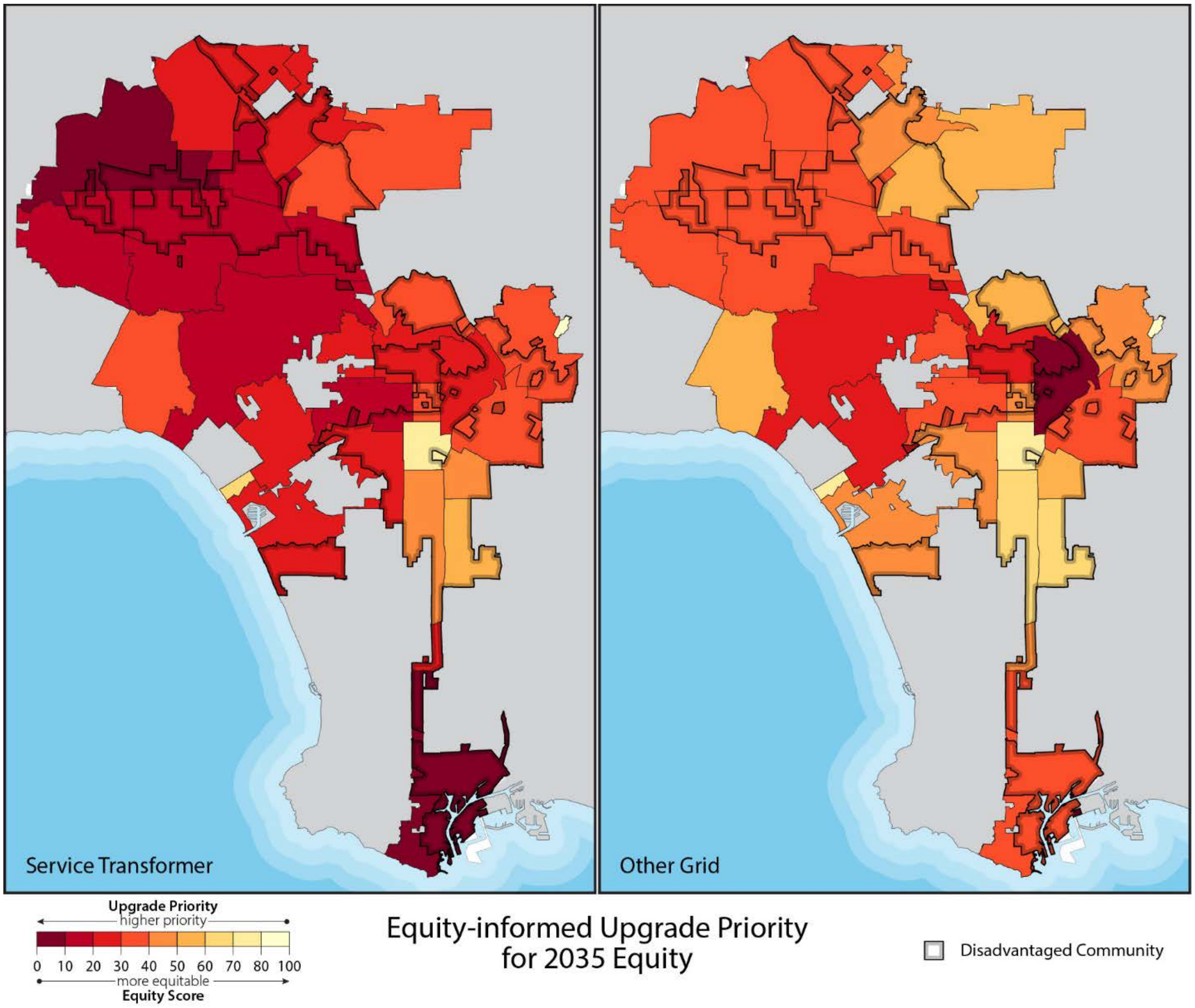
other programs to better support near-term equity. In 2019 (Figure 9), areas with low grid equity scores for service transformers are more uniformly widespread than for other upgrades. For service transformers, upgrade priorities are concentrated from the northeast to northwest of downtown, notably around Koreatown and in the roughly triangular region surrounding Mount Washington from El Sereno to Glassell Park to Eagle Park. These areas seem to combine high inequity in grid stress and DER adoption, and hence greatest need for equitable service transformer upgrades. For other grid upgrades in 2019, the region extending west from Koreatown to the outskirts of Beverly Hills shows the highest priority. Before looking ahead to 2035, it is important to note that these results are normalized for each year from zero (lowest equity, higher priority) to 100 (highest equity, lower priority). In 2019, the overall grid stress is much lower. As a result, the level of stress corresponding to a high priority area in 2019 is actually lower than that found in even lower priority areas in the 2035 scenario.

The 2035 results (Figure 10) reflect significant additional grid needs to support equitable electrification, load growth, and increased DER adoption. Service transformer upgrades are a high priority through much of the city, especially in the far south toward the harbor (including San Pedro, Wilmington, Harbor City, and parts of Harbor Gateway) along with the far northwest (including Northridge, Chatsworth and Porter Ranch). Other grid upgrade needs are somewhat lower priority, but still widespread, with the highest priority northwest of downtown (including portions of Westlake, Pico-Union, Silver Lake, Echo Park, Elysian Park, and Elysian Valley)



(a) (b)

Figure 9. Equity-informed upgrade priority, determined by the normalized grid equity score for (a) service transformer and (b) other grid components for the baseline 2019 in-basin LADWP grid



(a) (b)

Figure 10. Equity-informed upgrade priority for (a) service transformer and (b) other grid components for the 2035 equity scenario at the PUMA level across the in-basin LADWP grid

Demand from electrification and DER growth by 2035 show considerably higher grid stress than for 2019, such that lower priorities in 2035 might correspond to the same scale of investment needed in higher-priority areas for 2019.

In many cases, the upgrades indicated for the baseline system—which are shown for 2019 but are expected to take around a decade to rollout—can help alleviate the need for further upgrades in 2035. However, this is only possible if they are sufficiently oversized to accommodate the expected significant additional growth in load and/or DERs. If such growth is not taken into account, a costly second set of upgrades might be needed to manage the large growth. This speaks to a need to carefully consider the amount of capacity headroom specified for near-term equipment upgrades, particularly for service transformers, and to potentially increase this headroom.

Older buildings and lower-ampacity customers—which tend to be more prevalent in DAC communities (Chapter 17)—may see much higher load growth under equity-oriented programs than customers with newer homes or who already have a larger set of home equipment and correspondingly larger service connections. For example, equity-oriented programs that enable the addition of electrified HVAC (heat pumps), electrified cooking and domestic hot water, and EV chargers in homes that currently have primarily only plug loads and lighting, might see much higher proportional increases from 2019 to 2035 than customers who already have air conditioning and other large electric loads. A current rule of thumb—based on subject matter expert input received during the original LA100 study—is to replace equipment that sees 125% of rated loading with larger equipment such that post-upgrade loading is only 75% of rating. This represents a 1.6× size increase, which would likely be too small for a highly electrified future. A service panel upgrade analysis done as part of the LA100 Equity Strategies project (Chapter 17) suggests that over 50% of DAC customers and over 30% of non-DAC customers have 100A or less service today, often only 60A, but they are estimated to need 150–200A service to accommodate future needs. This implies a 2.0–3.3× capacity increase may be appropriate when sizing replacement transformers, particularly those that currently serve customers with low-amperage service.

4.2 Equitable and Resilient Access to Electricity-Related Services During Disaster Events

We conduct a community energy resilience assessment across nine neighborhoods—six DAC and three non-DAC neighborhoods—from the LADWP in-basin service territory using the approach described in Section 3.3. This selection of neighborhoods covers 167 distribution feeders and 92 census tracts. The selected neighborhoods and demographic data for them are listed in Table A-1 in the appendix.

Figure 11 (page 22) shows the normal, no-emergency-event levels of access to a range of critical services for DAC and non-DAC communities as a radar plot. Each of the spokes of these radar plots captures access to one service. The range for each value is normalized so that 1.0 represents the median, no-event access among all nine neighborhoods studied. These results show that prior to a disaster event, three of six modeled DAC neighborhoods (Wilmington, Pacoima, and Florence) and one of three non-DAC neighborhoods (Hollywood Hills West) have lower access to most services than system-wide median access levels. Although DACs have generally lower access to services such as groceries, hospital, and convenience stores, they generally have higher access to emergency shelter and banking.

Figure 12 (page 23) shows the corresponding results for community-level resilient service access scores during disaster events without any resilience-oriented programs in place.[16] In these results, it is assumed electricity to customers or services is only available if grid substations and distribution equipment are sufficiently intact to provide electricity or if they have generation on-site. At the neighborhood level, these results show that while both DAC and non-DACs see severe reductions in service access during the simulated disaster event scenarios, the impacts are not uniform by service or area. The most uniformly impacted service is electricity, with nearly all areas experiencing significant disruptions. Two DACs (Sun Valley and Pacoima) and two

[16] Note that in this analysis, PV and storage adopted by customers for economic reasons as captured in Chapter 8 are assumed to be grid-following (as is standard today) and therefore are not available during a disaster unless a microgrid controller is available to provide required coordination.

non-DACs (Hollywood Hills West and West LA) have the lowest remaining electric service, covering less than half their customers.

Among other services, two of six DACs (Pacoima and Sun Valley) and two of three non-DACs (Hollywood Hills West and West Los Angeles) show large decreases in services to levels below 1.0 for three or more services; this result is in part due to their proximity to fault lines or water bodies (see Section A.4 in the appendix for fault locations relative to neighborhoods). Furthermore, even with more modest decreases, the lower pre-disaster service access for Boyle Heights, brings three of its services below 1.0, joining already lower Florence and Wilmington for a total of five of six DACs with low during disaster service access.

Historic South Central and Boyle Heights maintain much of their already high access to emergency shelter and hospital services during disaster events, while West Los Angeles maintains its high access to convenience store and banking services. Although Wilmington experiences some of the lowest overall access to critical services, it has minimal degradation of services during the modeled disasters because Wilmington is farther from the recently active fault zones[17] used in scenarios and has limited flood-prone areas.

Service access during disaster events can be improved through a range of resilience strategies. Here, we consider three:

1. **Microgrid**: Adding microgrid controllers[18] to enable use of existing DERs (including additions estimated in 2035) located on isolated islands of the electric grid that otherwise would be unpowered: In this strategy, critical services would have power if they are part of an island with sufficient generation and a microgrid controller.
2. **Backup:** Implementing a critical infrastructure backup power program that provides 50% of critical service facilities (randomly selected in this analysis) with on-site backup generation (e.g., solar + storage).
3. **Microgrid + Backup:** Implementing a program that combines the first two strategies and enables critical service backup generation to join other DERs in powering islanded microgrids.

Of these three strategies, the third one—the *backup + microgrid* strategy shown in Figure 13 (page 24)—offers the best resilience improvement in both earthquake and flooding event scenarios; however, as seen in Figure 15 and described in Section A.6 in the appendix, in general, enabling microgrid formation through switching and control using existing DERs such as solar and storage is more effective than only providing backup generation units for critical services. Microgrids alone are comparable to site-specific backup for critical services and also support residential electricity. Although the backup + microgrid program makes all nine

[17] As described in detail in Section A.4 of the appendix, the earthquake scenario results are from four simulated events that occurred close to historically recorded earthquakes with a magnitude of >5.5 from 1965 to 2016 using USGS data. These all happen to fall in the northern part of the city. There are other potentially active fault zones throughout the city include offshore to the southwest that could more severely impact Wilmington and other southern neighborhoods.

[18] Grid-forming modes are included for sufficient inverters, isolation switches, supply/demand balance, and island mode stability.

neighborhoods more energy resilient, the impact of this program on electricity access is largest in non-DAC neighborhoods, where access goes from some of the lowest electricity access scores to some of the highest.

For simplicity, the remainder of this discussion focusses on the backup + microgrid scenario. Figure 13 shows the resilience scores with this program applied for all communities. With this program in place, none of the seven affected neighborhoods fully return to their pre-disaster electricity access levels, although most services are recovered.

A spatial comparison of results for no event, during a disaster with no program, and during a disaster with the backup + microgrid program are shown as maps in Figure 14. In this figure, a combined neighborhood score combines[19] weighted scores across all five critical services and residential electricity. These results show how the northern modeled neighborhoods (Pacoima, West Hills, Sun Valley, and Hollywood Hills West) are generally the hardest hit by the simulated disasters with very low combined neighborhood scores during a disaster without a resilience program (All Hazard map), given their proximity to historical fault lines and flood zones. Service access is notably improved for most of these regions with the backup + microgrid program. The exception is Pacoima, which still has low combined service access even with the program in place. The results for Pacoima do show improvement with the resilience program, but it still has uniformly low disaster-with-program access, largely due to lower pre-disaster (no event) access.

[19] Using the 2-norm or square root of the sum of the squares

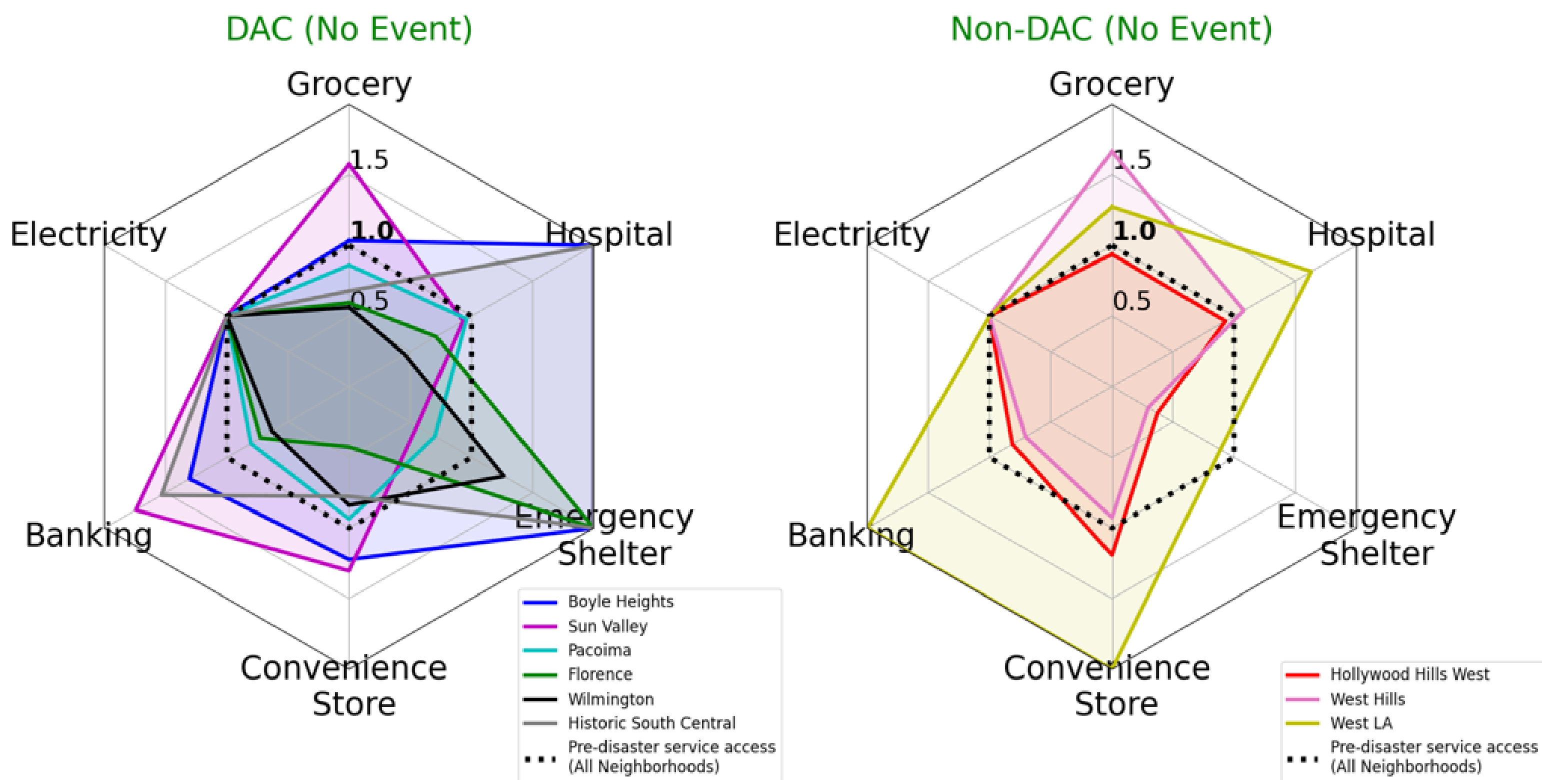


Figure 11. Median DAC and non-DAC normalized 2035 community-level resilient service access scores along six critical service axes during routine grid operations (no event)

These resilience scores are normalized such that the median system-wide access to each service has a score of 1.0 as emphasized by the bold dotted hexagon. Values within this hexagon show lower service access than the system-wide baseline.

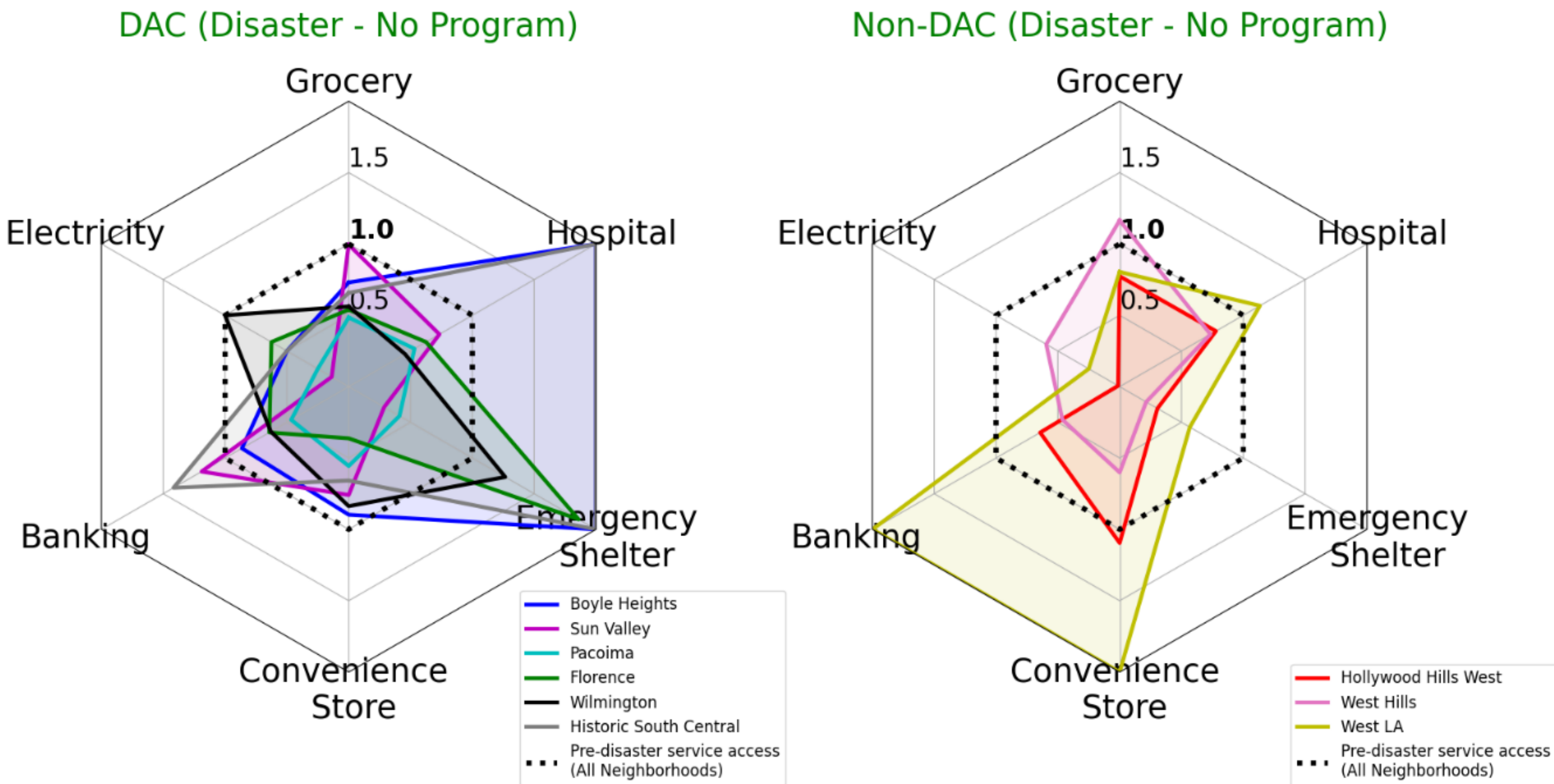


Figure 12. Normalized 2035 post-event community-level resilient service access scores across earthquake and flooding scenarios when there is no resilience-focused program in place.

Resilience scores are normalized along six critical service axes by median system-wide access to critical services in normal operations (no-event scenario). Values within the bold dotted hexagon show lower post-event service access than the system-wide, no-event reference. As described in detail in Section A.4 of the appendix, the earthquake scenario results are from four simulated events located close to historically recorded earthquakes with a magnitude >5.5 from 1965 to 2016 using United States Geological Survey (USGS) data. These all happen to fall in the northern part of the city. There are other potentially active fault zones throughout the city, including offshore to the southwest that could more severely impact Wilmington and other southern neighborhoods.

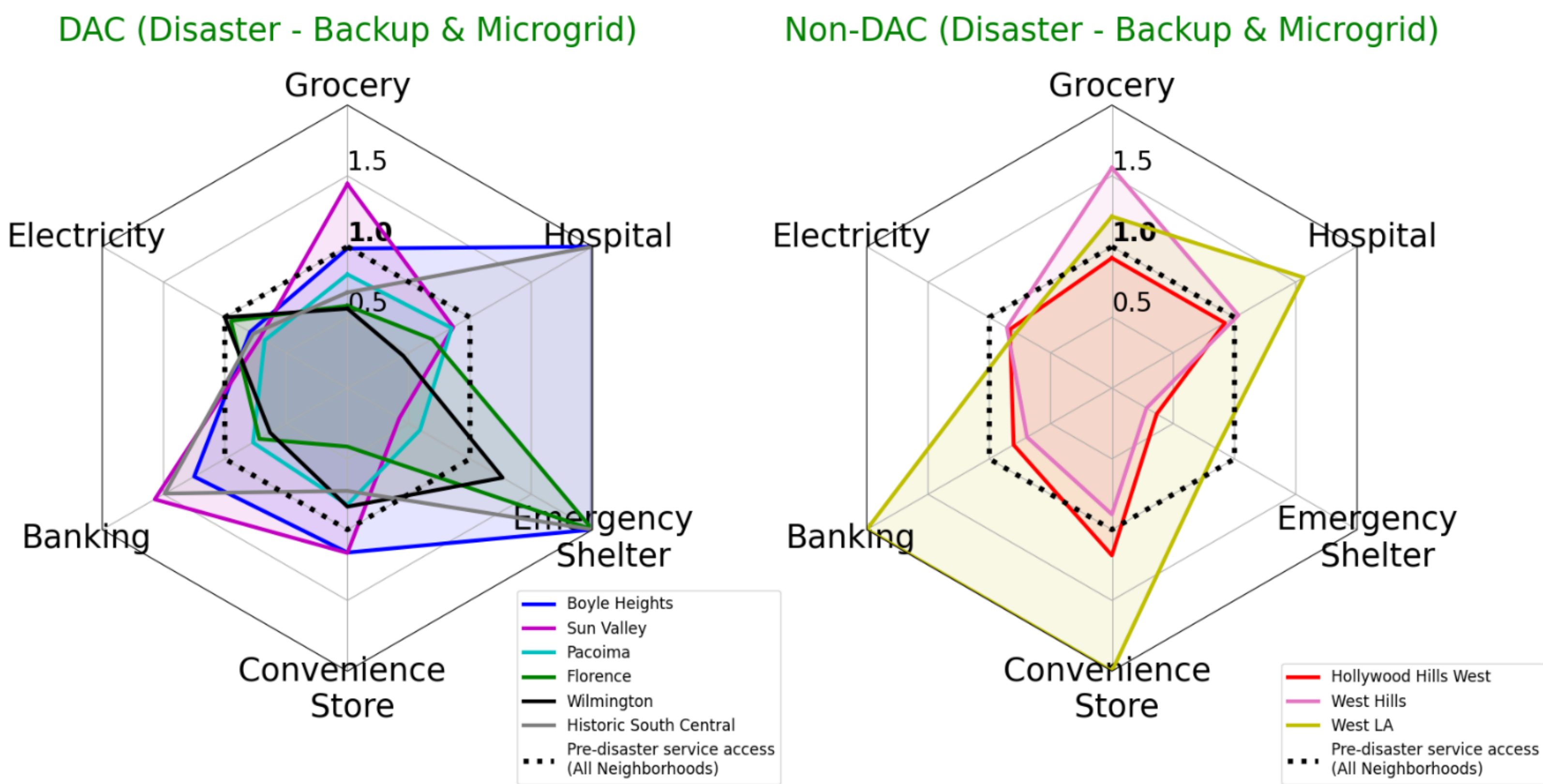


Figure 13. Normalized 2035 post-event community-level resilient service access scores with backup + microgrid and DER resilience strategy

Results show the medians for DAC and non-DAC and cover the same selection of earthquake and flooding events as other post-event results. Resilience scores are normalized along six critical service axes by median system-wide access to critical services in normal operations (no-event scenario); as a result, values within the bold dotted hexagon show lower post-event service access than the system-wide, no-event reference.

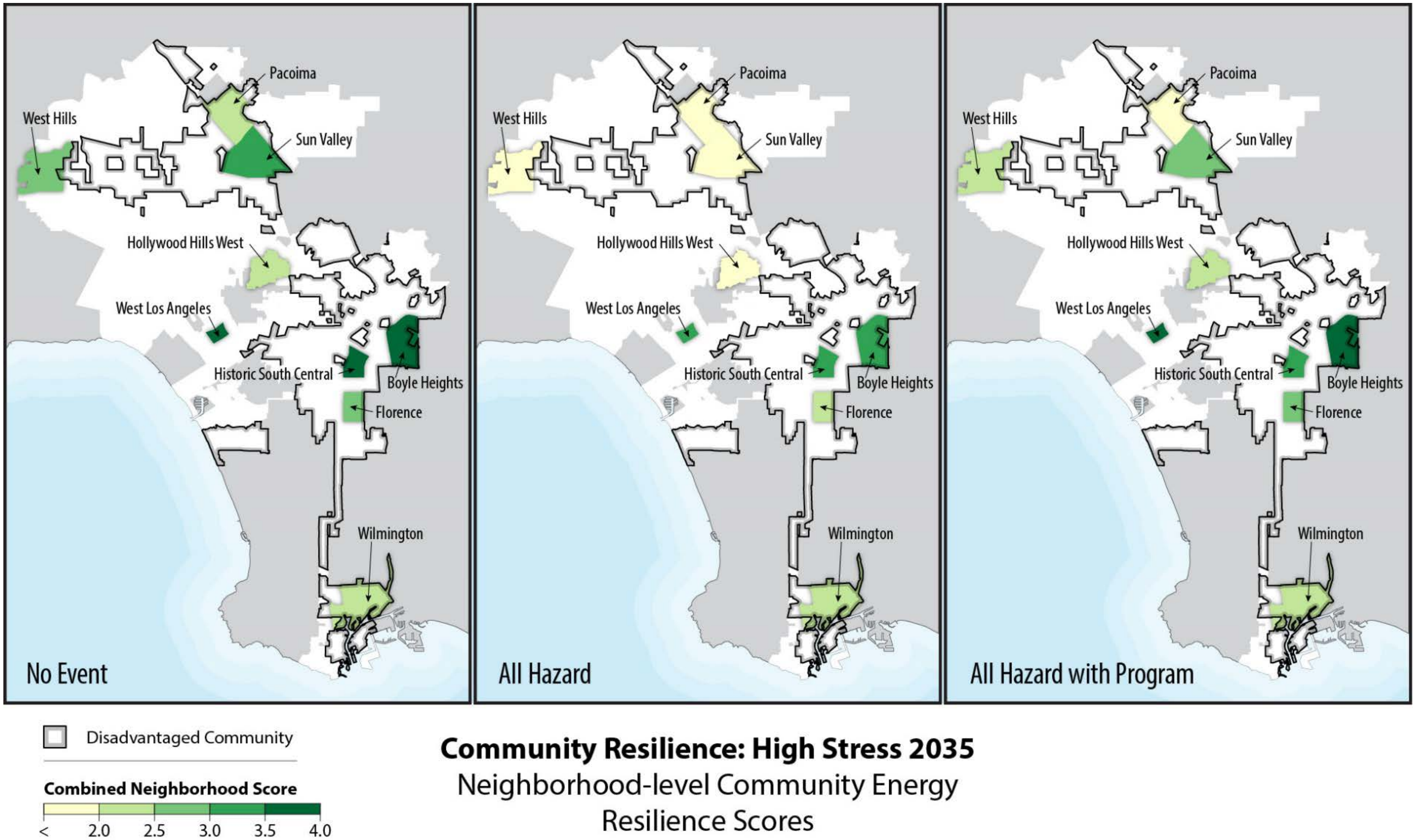


Figure 14. 2035 pre- and post-disaster neighborhood aggregate resilience scores with and without the backup + microgrid resilience strategy

Higher scores and darker greens indicate higher multiservice access (better).

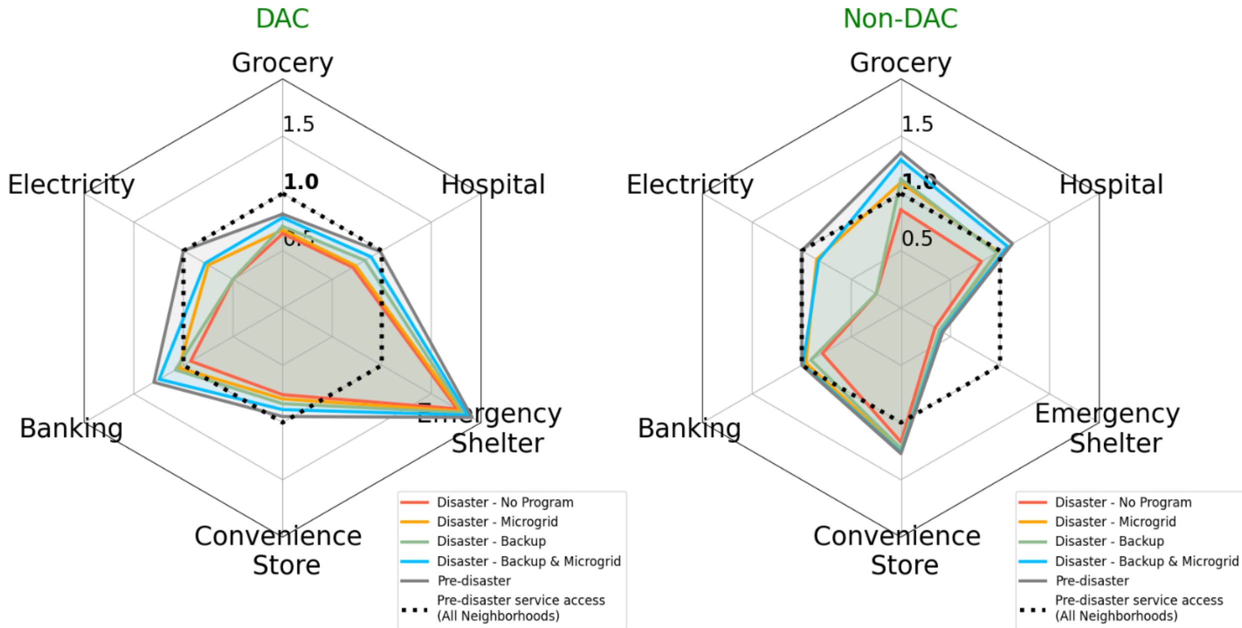


Figure 15. Comparison of resilience strategies for 2035 using normalized pre- and post-disaster-event community-level resilient service access scores across all modeled disaster scenarios

Resilience scores are normalized along six critical service axes by median system-wide access to critical services in normal operations (no-disaster event scenario). Values within the bold dotted hexagon reference show lower post-event service access than the system-wide, no-event reference.

Figure 16 provides a summary of these results by neighborhood and service. Overall, DAC neighborhoods have more access to emergency shelters and banking but less access to groceries, hospitals, and convenience stores in all disaster scenarios (with and without resilience programs). Further, disaster scenarios without resilience programs reduce access to electricity in all neighborhoods. Microgrid programs, using existing distributed generation assets (including those expected to be installed in 2035), increase electricity access though typically not to pre-disaster levels. Backup programs, which consists of providing on-site backup generation to a randomly selected 50% of critical service facilities, provides some improvement to community energy resilience in both DAC and non-DAC neighborhoods by bolstering these services' ability to operate even without grid-supplied electricity. *In combination, both programs see cross benefits. Backup generation located at critical service facilities, if combined with microgrid controls, can also provide additional generation (and storage) to nearby services without backup and can directly support nearby customer electricity. Similarly, the microgrid program can support critical services that do not have on-site backup while also reducing the generation and storage capacity needed at critical service facilities that do have on-site backup.*

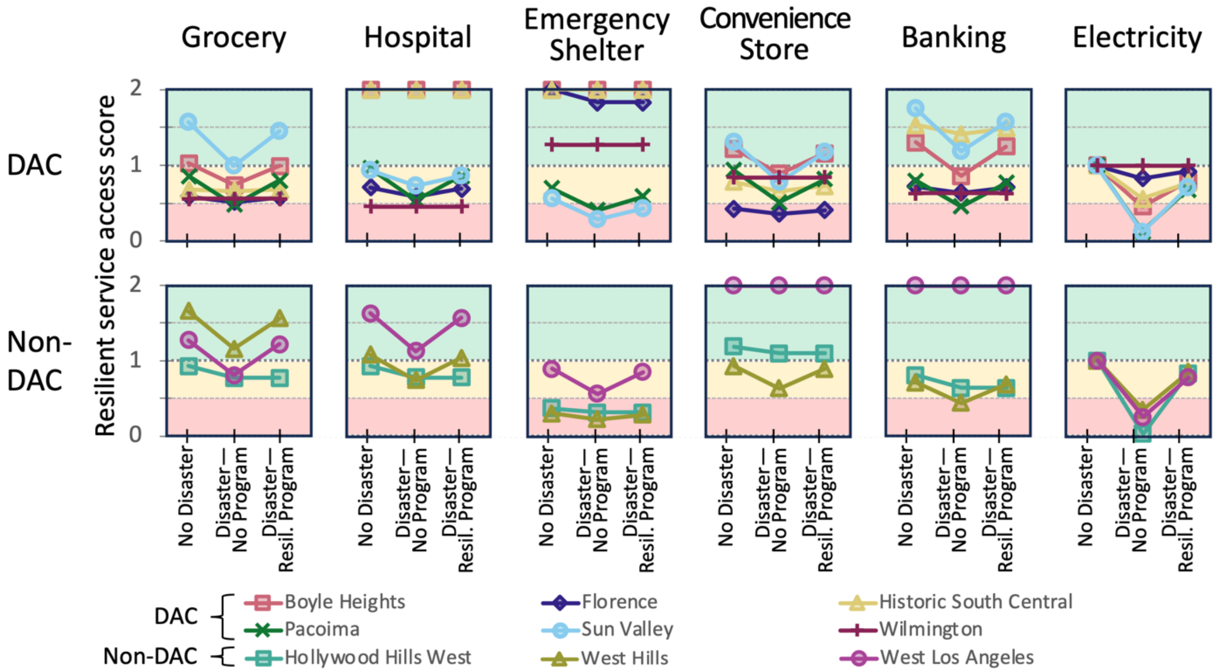


Figure 16. Modeled normalized community-level resilient service access to six critical services for residents of nine neighborhoods before and during disaster events in 2035

For each neighborhood-service combination, three access levels are shown as a series of points: No disaster, during a disaster with no resilience program, and during a disaster with a resilience program that combines microgrids using solar and storage already estimated to be installed and backup power at 50% of critical service facilities.

Resilience scores on the y-axis are normalized by median system-wide access for each critical service relative to normal operations (no-disaster event scenario). Values in the top green bands are at or above the system-wide no-disaster level (≥1), those in the yellow band have reduced service access between 50% and 100% of the system-wide no-disaster average, and those in the bottom red band are below 50% for the system-wide no-disaster average.

To improve pre-disaster access to critical services, community planners can consider increasing relevant service facilities in or near neighborhoods that have the lowest per-service access currently, and the lowest expected access in 2035. This would improve both the day-to-day lives of Angelenos and provide a higher critical service access pre-disaster starting point. For disasters, strategically equipping critical service facilities with on-site backup generation can significantly improve access to services and can be prioritized by the set of critical services that are most likely to have the lowest service access during disasters in each neighborhood. For residential electricity during disasters, the distribution grid can be upgraded with isolation switches and controllers, including grid-forming controllers, to enable microgrid operations. This also provides additional electricity options for critical services.

In addition to the backup and microgrid programs modeled in detail, additional distribution hardening and community or household backup generation kits could be considered based on neighborhood situations. For example, Florence, Historic South Central, and Hollywood Hills West had some of the lowest improvements in service access as a result of the modeled resilience programs during disasters, so might benefit from such alternatives. There may also be differences within neighborhoods due to a combination of demographics and localized disaster effects. In some cases, particularly for low-to-moderate income, mobility-impaired people or those with energy-dependent life-sustaining health needs, individual customer solutions may be needed to enable equitable service access.

Section A.5 of the appendix describes additional results from the community energy resilience analysis, including the distribution of access scores and neighborhood-level figures. Section A.6 of the appendix describes additional results from the community energy resilience analysis, including the distribution of access scores and neighborhood-level figures.

5 Equity Strategies Discussion

Modeling results demonstrate that DACs experience higher grid stress, which could restrict clean energy and technology adoption, access, and use and could also reduce grid reliability. Some neighborhoods—a mix of DACs and non-DACs—also have lower access to critical services during disaster events, suggesting targeted resilience-focused programs may be warranted to provide more equitable access to critical services during disasters. The transition toward clean energy is an opportunity to overcome these disadvantages and provide a more equitable future grid for all Angelenos. Specific strategy options for LADWP and the City of Los Angeles to do so include:

- *Incorporate equity as a priority when planning grid infrastructure investments:* For instance, incorporating sociodemographic data— including income and race—and DAC status into other grid evaluation metrics can highlight areas of inequity to correct. And, upgrade priority can be boosted for regions with larger differences in grid stress or other indicators between DAC and non-DAC neighborhoods. This will also require more neighborhood-scale considerations for load, electrification, and DER trends rather than assuming historical trends of larger load growth and therefore more technology uptake in wealthier neighborhoods will continue. If equity-informed programs succeed in increasing access to electrification, EVs, and DERs for all Angelenos, current approaches to proactively upgrade feeders in anticipation of load growth would need to extend to more DACs to prevent the grid from presenting a barrier to equitable technology access. Incorporating equity metrics into upgrade prioritization, by using metrics such as grid stress (measured in line and transformer overloading and out-of-range equipment voltages), level of anticipated DER adoption, and demographic data (Section 3.2 and Section A.2 in the appendix) is important to overcoming the inequities seen in current and projected grid stress and corresponding reliability (Section 4.1 and Section A.1 in the appendix).
- *Upsize transformer capacity by a factor of 2–3+ when replacing service transformers:* Already, service transformers are sized with some anticipation of future growth when they are replaced due to age, overload, or as part of programs such as the Power System Reliability Program. However, electrification of cooking and water heating and increased adoption of air conditioning, heat pumps, EVs, solar, and storage can all drive a need for significantly larger service transformers. For instance, an historically appropriate 1.6× size increase would likely be too small for a highly electrified future. Instead, 2.0–3.3× capacity increases may be appropriate when sizing replacement transformers, particularly those serving customers with existing low-amp (60–100A) service projected when estimates predict the vast majority of customers will need to grow to 150–200A. Alternatively, in some cases it may be more appropriate to replace a single service transformer with two (or more) units and rework the secondary (low-voltage) connections accordingly. It may also be possible to combine transformer size increases with other grid overhauls such as a feeder transition to 12kV.
- *Coordinate grid upgrade programs with other programs so that the grid does not create a barrier for deployment*. A wide range of programs for the equitable transition to a clean energy future—such as those aimed at increasing equity in cooling, EVs, home electrification, and electric panel upgrades—will require increased capacity on the electric distribution grid overall and for service transformers in particular. As a result, in order for such programs to succeed, they will need to be coordinated with grid and service transformer upgrades. Additionally, integrated program design enables multiple customer-facing and grid upgrade efforts to occur simultaneously and take advantage of synergies such as streamlined customer engagement, application paperwork, and permitting. In particular, programs to reduce or eliminate service transformer upgrade costs for low- and moderate-income

customers may be needed so technical, interconnection cost, and permitting challenges do not impede equitable technology access.

- *Consider increased investment in underground cables in DACs:* Underground cables offer benefits in the form of reliability (Fenrick and Getachew 2012), more visually appealing environments, and higher resilience to most non-flood disaster events, yet are significantly less prevalent in DACs (Figure 2). Outside flood-prone areas and where possible, overhead lines should be considered for replacement with underground lines, particularly during grid capacity upgrades in DACs. And undergrounding efforts should also include upsizing efforts as already described. To reduce the costs associated with undergrounding, such efforts could be combined with other large-scale grid projects such as 12kV transitions, feeder capacity expansion, or concentrated service transformer upgrades.
- *Implement community-specific resilience strategies for equitable service access during disasters:* The community resilience analysis (Section 4.2 and Section A.5 in the appendix) shows neighborhood-level variation to critical energy-requiring service access day-to-day and during disaster events such as earthquakes or floods. Modeling identifies resilience strategies including bosting no-disaster service access, adding backup generation (e.g., additional PV + storage) at critical infrastructure, and using microgrid controls to coordinate existing distributed generation, including customer and community DERs to enable intentional islanding[20] of parts of the distribution grid with grid-forming inverters, and/or corresponding automated switch gear. Such need is further amplified by community guidance (Section 2 and Section A.7 in the appendix). Rather than uniform efforts across the city, achieving equity for all Angelenos requires targeted service and location specific efforts in neighborhoods that currently have low service access and resilience scores.
- *Prioritize resilient electricity options for critical emergency services and at-risk community members within DACs:* During disaster events, providing backup power for critical infrastructure including fire and police departments, healthcare, food, and communication—such as through on-site solar and storage—can increase service access. This is especially critical within neighborhoods such as Pacoima that already have lower service access. Having resilient electricity for emergency services within DACs can create more equitable community resilience. Further, providing resilient electricity options to at-risk community members who may struggle to travel out of the home, such as seniors and those who require electricity for medical equipment such as ventilators or oxygen concentrators, can reduce emergency room visits, morbidity, and mortality (Molinari et al. 2017).
- *Collaborate with community-based organizations for preparedness education and support programs:* Preparation represents a key aspect of successful responses to emergency, disaster, and resilience situations. Yet due to eroded trust, lack of accessible information such as language barriers, and/or other factors, traditional education and support programs from LADWP or the City of Los Angeles may not effectively reach all Angelenos. Efforts that work in collaboration with trusted community-based organizations could prove more effective for preparedness, particularly in DAC neighborhoods. For example, the existing semi-formal network of health promoters or promotores (Center for the Study of Social Policy and First 5 LA 2019) could be provided resilience training and education materials to help share key ideas more widely with community members. Promotores who participated in LA100-ES community engagement activities expressed interest in expanding their knowledge of energy-related technologies and resilience strategies to inform their local networks.

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[20] Intentional islanding is the term for allowing a portion of the distribution grid to operate when not connected to the rest of the grid. This requires switches to isolate from the larger grid and some form of control scheme, such as a microgrid controller and/or grid forming inverters, to balance supply and demand.

Table 1 summarizes the expected benefit and cost (where known) of each strategy, as well as the timeline for implementation (short or long term), the party responsible for implementing the strategy, and metrics for measuring the success of the strategy. Figure 17 and Figure 18 provide a summary of findings, modeling results and equity strategies for distribution grid upgrades and resilience, respectively.

Table 1. Equity Strategy Benefit, Cost, Timeline, Responsible Party, and Metrics for Evaluation

Equity Strategy	Benefit/Impact	Cost	Timeline	Responsible Party	Evaluation Metrics
Incorporate equity as a priority when planning grid infrastructure investments	Reduce grid stress, increase reliability, and prevent the grid from presenting a barrier to clean energy adoption in DACs Increase transparency and ability to monitor progress toward grid equity	Neutral	Start now, keep long term	LADWP	Grid stress (undervoltages, overvoltages, service transformer overloads and line overloads).Reliability (e.g., SAIDI and SAIFI) in DACs versus non-DACs Number of grid evaluation metrics capturing DAC or low-to-moderate income status
Upsize transformer capacity by a factor of 2–3+ when replacing service transformers	Reduce grid barriers to clean energy adoption. Avoid need up upgrade transformers twice	Medium now; cost reduction in long run	Start now, keep long term	LADWP	Average capacity increase for service transformer replacements, including as a function of DAC versus non-DAC, and for customers with <100A service vs. >100A service. Number of repeated replacements to increase capacity of the same service transformer in much less than expected life (e.g. in ≤10 years)
Coordinate grid upgrade programs with other programs so that the grid does not create a barrier for deployment	Ability for other clean energy programs to meet objectives without grid restrictions Reduce cost barriers for low- and moderate-income communities customers and streamline customer engagement, application paperwork, and permitting	Low; may save money overall by enabling other programs to succeed	Start now, keep long term	LADWP	Percent of programs that impact net load that either include distribution grid upgrades or have a complementary distribution grid program. Average service transformer upgrade cost for low- and moderate-income customers who participate in clean energy programs or otherwise adopt EVs, electrification, solar, or storage. Percentage reduction in application and permitting time vs. separate, un-coordinated program participation.

Equity Strategy	Benefit/Impact	Cost	Timeline	Responsible Party	Evaluation Metrics
Consider increased investment in underground cables in DACs	Increase reliability, improve aesthetics, and increase resilience to most disaster events	High	Long term	LADWP	Percentage of circuit-miles that are underground in DAC vs. non-DAC neighborhoods. DAC parity (26.7% to match current non-DAC) means 977 underground miles of the total 3,658 miles of distribution lines in DACs, an increase of 517 miles or 43 miles/year through 2035.)
Implement community-specific resilience strategies for equitable service access during disasters	Increase equity in access to critical services	High	Medium term	LADWP and others	Normalized resilience scores by service and neighborhood. Number of critical services with >0.75 access scores during disaster events by DAC status
Prioritize resilient electricity options for critical emergency services and at-risk community members within DACs	Increase access to critical services and increased community resilience in DACs	High	Start now, keep long term	LADWP	Percentage of facilities for each critical service serving each neighborhood with clean backup power. Percentage of at-risk community members with clean, backup-ready power
Collaborate with community-based organizations for preparedness education and support programs	Increase preparedness in DACs. Overcome trust and information access barriers	Low	Short term	LADWP, community-based organizations	Number of *promotores* trained Number of community members reached

Baseline Equity

- Disadvantaged communities and mostly Hispanic communities experience more frequent power interruptions.
- Customer costs to upgrade utility transformers, when modernizing service size for electrification, integration of solar, storage, EVs, etc., can be a key barrier.
- Disadvantaged community census tracts are less than one-half as likely to have underground distribution lines compared to non-DAC areas (12.6% versus 26.7% of lines undergrounded).

Community Solutions Guidance

- Update aging electric equipment to improve reliability in DAC neighborhoods.
- Support low- and moderate-income households in upgrading their electrical panels and service connections so they can access and use air conditioning, heat pumps, EVs, solar, storage, or upgraded appliances.

Modeling & Analysis Key Findings

- The consequences of poor grid reliability do not impact all communities equally and disproportionally impact DACs.
- Average grid stress is 14% higher in regions of the city with significant DAC fractions today. Without upgrades this is expected to worsen to 25% higher by 2035.
- Service transformer and other grid upgrades are needed to support expected EVs, electrification, solar, and storage.

Equity Strategies

- Incorporate equity as a priority when planning grid infrastructure investments
- Upsize transformer capacity by a factor of 2-3+ when replacing service transformers
- Coordinate grid upgrade programs with other programs so that the grid does not create a barrier for deployment.

Figure 17. Grid upgrade equity strategies

Baseline Equity	Community Solutions Guidance	Modeling & Analysis Key Findings	Equity Strategies
• Social burden (effort to access critical services) during disasters is worse in some communities than others.	• Guarantee access to safe & comfortable shelter during extreme events. • Address underlying causes of blackout risks and their negative impacts on home environments. • Expand outreach and awareness about resources and options in emergencies. • Prioritize community members with energy-related health needs and seniors in emergency situations.	• Even before disasters, DACs have generally lower access to groceries, hospital, and convenience stores, but generally higher access to emergency shelter and banking. • Service access is significantly reduced during disasters, though the impacts vary widely. Northern neighborhoods are more impacted due to proximity to active fault-lines and low-lying areas • Microgrids using expected solar and storage, and backup power at half of critical facilities boosts service access 0-30% depending on neighbohood.	• Implement community-specific resilience strategies for equitable service access during disasters • Prioritize resilient electricity options for critical emergency services and at-risk community members within DACs • Collaborate with community-based organizations for preparedness education and support programs • Consider increased investment in underground cables in DACs

Figure 18. Grid resilience equity strategies

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Appendix: Distribution Grid Reliability and Resilience Modeling and Analysis Methodology and Detailed Results

A.1 Methodology Details: Data Preparation

To develop high spatial resolution, bottom-up customer-level load forecasts, as seen in Figure A-1, NREL modeled data at a census-tract resolution and mapped these data first to feeders and then to distribution service transformers. Secondary (low-voltage: 120–480V) line modeling was not included. Instead, all NREL-modeled modeled building loads, EV charging, distributed solar generation, and storage were modeled as being connected directly to the low side of service transformers.

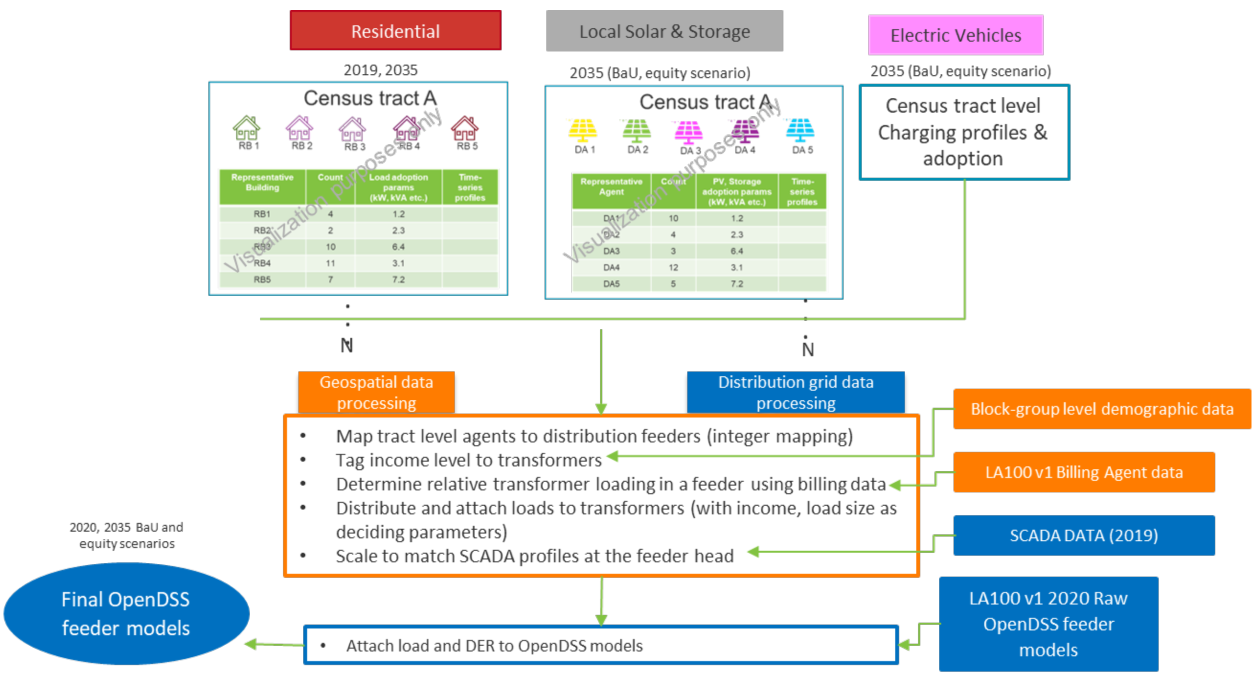

Figure A-1. Simplified schematic of the feeder preparation workflow

NREL-modeled data consisted of agent tables at the tract level, where each agent type corresponds to a row. For example, the building agents represent a unique combination of building type (e.g., single-family detached home), vintage (e.g., 1970s), tenure (e.g., renter occupied), and income level. In addition, each agent type row contains a count of the number of occurrences of that agent type.

NREL modeled approximately 50,000 residential building agents, each with a unique combination of building, building system, and household characteristics and associated energy loads.[21] The distribution grid analysis mapped building agents to census tracts and then to feeders based on spatial proportions, and subsequently mapped to transformers within feeders,

[21] Distribution gird analysis used the expanded agent list developed by the dGen team to account for additional buildings that appeared in the lidar data but were missing from the detailed building simulation results.

based on income level, transformer capacity, phase count (single-phase versus three-phase), and size of load. Modeled building load time-series data for 2019 was attached to corresponding agents and finally scaled to match 2019 SCADA data. Where feeder-level SCADA data were unavailable, substation transformer bank data were used where available, and where not, neighboring feeder scaling estimates were used instead. We also use SCADA data at the agent level to attach time-series reactive power to this model.

Because the building stock is assumed to be static, the building type to tract and therefore feeder mapping is static, allowing the assignment to be done once and then reused for additional years and scenarios. In addition, the same base weather year (2012) and calendar structure was used for all scenarios. This allowed reusing the feeder-specific load time-series scaling factors developed for 2019 to adjust for spatial differences in 2035. For example, if the modeled 2019 load for a feeder was 10 MW at a given time point, but the corresponding SCADA data were only measured at 6 MW, the scaling factor of 3/5 was applied to both 2019 and 2035 modeled building loads at that point in time. If the 2035 raw modeled building loads at that point were 15 MW, applying the same scaling factor would result in using 9 MW in the 2035 modeling.

Because commercial and industrial loads were not simulated in detail as part of LA100-ES, we reused the commercial and industrial data from the original LA100 project at a feeder level and assigned it proportionally to transformers based on the billing data mapping to the agent commercial load classification in NREL's Distributed Generation Market Demand (dGen) model. These results were then scaled based on a combination of the known fraction of commercial and industrial versus residential annual energy (from billing data) applied to the SCADA data to estimate the non-residential load.

Once the base building load was assigned for all feeders, years, and scenarios, next solar, storage, and EV loads were added. PV adoption is available from the dGen model at the building-agent-type level, making it readily assignable to corresponding loads. The installed solar capacity in 2019 was adjusted to match historical data and adjusted in 2035 using the load max power (not time-series) scale difference between 2019 simulated and 2019 SCADA data at the dGen agent level. The solar time series was translated from capacity to power production based on irradiance data matched to the weather data used in the building simulations. All new solar and storage installations were assumed to use smart inverters consistent with California Rule 21 and IEEE 1547-2018. Specifically, they were modeled as using a combination of Volt-VAR *and* Volt-Watt inverter controls, consistent with LADWP's planned requirements. See Palmintier et al. 2021 Appendix A for specific curves.)

For EVs, detailed charger location, customer assignment, and charge event data were not available. So, we started with the tract-level summary of charging events for both commercial and residential chargers and the tract-level number of residential level-1 and level-2 residential chargers provided by the LA100-ES transportation team. Even this level of data was not available for commercial chargers, so for commercial charging, the maximum number of simultaneous charging events by type (i.e., level-1, 120V AC; level-2, 208–240V AC, or level-3 DC fast charge) was multiplied by a scaling factor to estimate the number of corresponding commercial chargers in the feeder. Chargers were then assigned to service transformers based on transformer phasing, load type, and amount of distributed solar and storage capacity at that transformer. With the charging infrastructure in place, actual EV charging events were then randomly assigned to charging stations for corresponding charger types, customer types, and time periods. This included translating the two typical day (weekend and weekday) time series to match a full 8760 hourly time series by duplicating the weekend day for all Saturdays, Sundays, and widely celebrated national holidays.

Throughout this process, pre- and post-assignment checks were conducted to verify intended behavior (e.g., not having large loads mistakenly assigned to smaller transformers) and to confirm the total demand by type and spatial location was preserved.

With this, the data preparation was complete, and feeder models were ready to run for analysis.

A.2 Methodology Details: Scenario Data Used for Distribution Grid Analyses

The distribution analysis uses 2019 data as a representation of the current system, rather than a more recent year, due to complete data availability—including 2019 SCADA data—and to remove the impacts of the COVID-19 pandemic.

The 2035 grid scenario attempts to capture the highest grid stress across the solar and storage, vehicle electrification, and residential building scenarios. For behind-the-meter PV, this includes the highest PV adoption scenario, which assumes strong programs to enable DER adoption among renters and multifamily building residents (Chapter 8). EV adoption and charging estimates follow the equity scenario adoption patterns for 2035 (Chapter 10). Building loads assume the higher business-as-usual load levels that do not include substantial DAC efficiency deployment. These higher building loads represent additional potential grid stress and are consistent with the load patterns used in the highest behind-the-meter PV adoption scenario (higher energy consumption makes PV adoption more economically attractive).

A.3 Methodology Details: Equitable Distribution Grid Upgrades for Reliability and Solar, Storage, and EV Access and Use

As introduced in Section 3.2, the equitable distribution grid upgrade analysis aims to assess equity in future grid reliability and grid access for adopting DERs, EVs, and other new technologies. This is done by computing current and 2035 grid stress as a proxy for reliability and then estimating distribution system infrastructure upgrade needs and planning strategies to achieve an equitable distribution grid.

In the upgrade cost analysis, distribution grid violations and necessary infrastructure improvements are determined, and associated costs are estimated, to ensure the distribution system does not experience problems such as overloaded equipment or poor voltages. Distribution feeders are modeled using OpenDSS for power flow with automation provided by the DISCO[22] tool. The analysis includes power flow simulations that capture the physics of electricity flowing through wires and other equipment and identification of grid stress in terms of voltage violations and thermal overloads. First, the DISCO analysis is run to estimate stress in the 2019 baseline model year; and then, the analysis is run again to identify impacts of estimated 2035 load and EV and solar and storage deployment. Finally, the grid impacts of both years are

[22] https://github.com/NREL/disco

postprocessed and evaluated by DAC and non-DAC census tracts. The results are then aggregated to the PUMA level to suggest priorities for infrastructure investments to ensure DACs are not left behind. The analysis uses a total of 580 distribution feeders from throughout the LADWP in-basin service territory with 10+% of distribution feeders in the DAC and non-DAC groups for all in-basin PUMAs (average of 40% feeder coverage across all PUMAs).

A.4 Methodology Details: Equitable and Resilient Access to Electricity-Related Services During Disaster Events

As described in Section 3.3, the equitable resilience analysis looks at individual customer access to critical services during disaster events. This analysis is conducted on the nine neighborhoods described in Section 3.3.1. Table A-1 shows the list of neighborhoods selected for analysis along with the corresponding values of selection metrics. As described in Section 3.3.1, the selection process attempted to find a mix of neighborhoods that represented a wide range of combinations across these metrics.

Table A-1. Summary of Selected Resilience Analysis Neighborhoods and Metrics

Neighborhood	SAIFI (times/ year)	SAIDI (minutes/ year)	Median Annual Income ($)	Percentage Underground Cable Length	DAC Status	Qualitative Energy Access Ranking
Boyle Heights	1.33	144	45,820	14.8	DAC	low
Florence	1.07	126	36,010	6.0	DAC	low
Historic South Central	1.06	156	36,410	17.6	DAC	very low
Hollywood Hills West	1.04	297	128,991	42.3	Non-DAC	very high
Pacoima	0.49	76	63,170	11.9	DAC	middle
Sun Valley	0.74	132	59,230	10.4	DAC	middle
West Hills	1.07	217	103,200	36.5	Non-DAC	high
West Los Angeles	0.85	142	115,200	26.0	Non-DAC	high
Wilmington	1.01	146	58,870	15.0	DAC	very low

Section 3.3.2 describes the equitable resilience analysis process, and Section 3.3.3 provides an overview of the corresponding metrics. This section provides additional details on these metrics.

Community-Member-Level Composite Access-Based Score (CCAS)

We first define a community-member-level composite access-based score that reflects a customer's level of access to critical services, such as energy, health, and food services. Specifically, the score for each customer is combined as a sum of the customer's level of access to each critical service. In its unweighted form used here, the contribution of each critical service facility to the access of a household is proportional to the inverse of the distance from the house to the facility.

To assess neighborhood-level metrics, customer-level scores for various disaster events are aggregated while maintaining visibility of equity metrics and resilience strategy performance (i.e., every neighborhood has a community-member-level composite access-based score). The neighborhood resilience metric is the median of its corresponding community-member-level access-level scores.

Disaster Modeling and Scenario Development Approach

We evaluate earthquake and flooding scenarios to understand the impact on community members' access to critical services and how resilience programs such as microgrids, backup energy sources for critical infrastructure, or a combination of both would improve such access. The Equity and Resiliency Analysis for Distribution (ERAD) tool leverages fragility curves (gathered from multiple scientific journals and conferences as described in (Duwadi et al. In Review) to translate disaster intensity (e.g., earthquake intensity at a given location, water level for flooding) to failure probability for a given distribution system asset type. A fragility curve is a probability distribution that maps the intensity of disaster to damage level or failure probability for a given asset type. Figure A-2 shows an example of a fragility curve for different asset types at different peak ground acceleration magnitudes during an earthquake event.

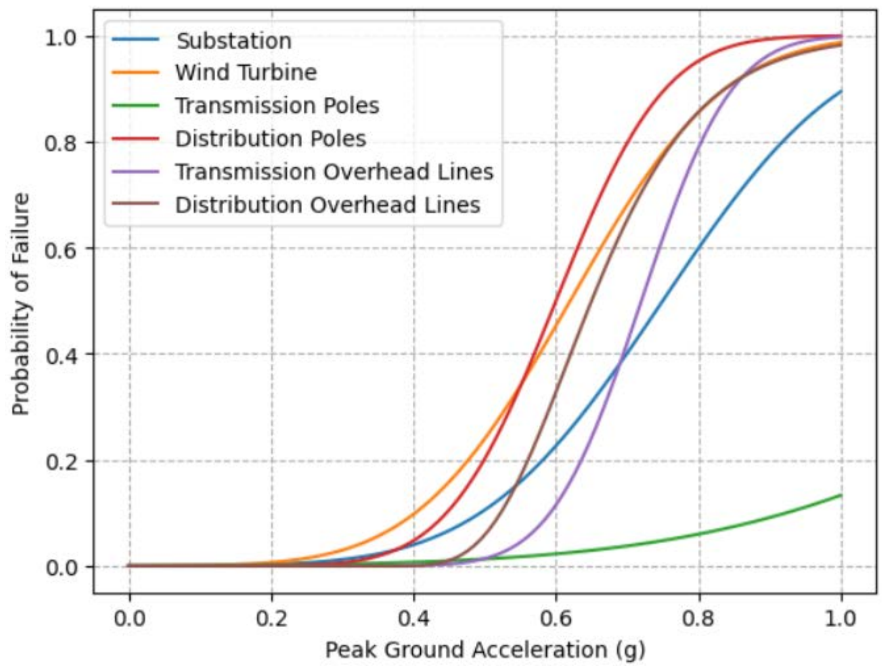

Figure A-2. Fragility curves for different assets under earthquake event

Earthquake Modeling

In developing earthquake scenarios, we carefully select the epicenter location and earthquake magnitude to differentiate impact on assets. All assets would survive in a faraway or very low magnitude earthquake, and all assets would be destroyed in a very high magnitude or nearby earthquake.

We choose four earthquake scenarios for the simulation, each with epicenters on historically active fault lines near our selected neighborhoods and with a magnitude of 6.0 (not big enough to destroy everything but also not small enough that all assets would survive). Figure A-3 (page 43) shows the location of the simulated earthquake epicenters, nearby fault lines and historical earthquake epicenters. The earthquake scenarios are selected based on historically recorded earthquakes with a magnitude >5.5 from 1965 to 2016 using USGS data. As seen in Figure A-3, these all happen to fall in the northern part of the city. There are other potentially active fault zones throughout the city, including offshore to the southwest that could result in different earthquake impacts, particularly for Wilmington and other southern neighborhoods that are far from the selected epicenters. Also, a larger earthquake, even if farther away, could have different impacts.

Each of the selected scenarios is run with 40 Monte Carlo samples to capture a range of outcomes on the probability distributions. For each scenario-sample combination, we simulate all neighborhoods in base case 2019 and high stress 2035 under the following conditions:

1. **Pre-Disaster:** a scenario where critical infrastructure and the distribution grid are operating normally
2. **Earthquake Scenario:** a simulated earthquake scenario where asset impacts are determined by fragility curves and earthquake intensity. This could cause electricity access interruption to customers as well as critical infrastructure.
3. **Post-Earthquake Microgrid Program:** a simulated post-earthquake microgrid program. After an earthquake, multiple islands would be formed that might not have access to electricity from the substation. In this scenario, microgrid controllers are added to each island that has sufficient solar and storage. This solar and storage matches the high estimates for 2035 adoption as described in Section A.2 without any additional resilience-driven installation. A microgrid is considered viable if the sum of generating resource capacity is greater than or equal to sum of total load capacity (100%) multiplied by a load factor of 0.5 and coincidence factor of 0.4. This approach can directly improve community members' electricity access and might also provide electricity to nearby critical services that are also part of the microgrid.
4. **Post-Earthquake Backup Program:** a simulated backup energy source allocation program. Allocating additional backup energy resources (diesel generator, energy storage, etc.) would allow critical infrastructure to provide services, thereby improving community members' access to those services. For backup, we randomly select 50% of critical infrastructure to have a backup energy resource in each sample.
5. **Post-Earthquake Microgrid + Backup Program:** a simulated microgrid + backup program that combines the other two programs. In this program, the additional backup energy resources sited on the premises of a critical service facility can also contribute to a microgrid, if applicable.

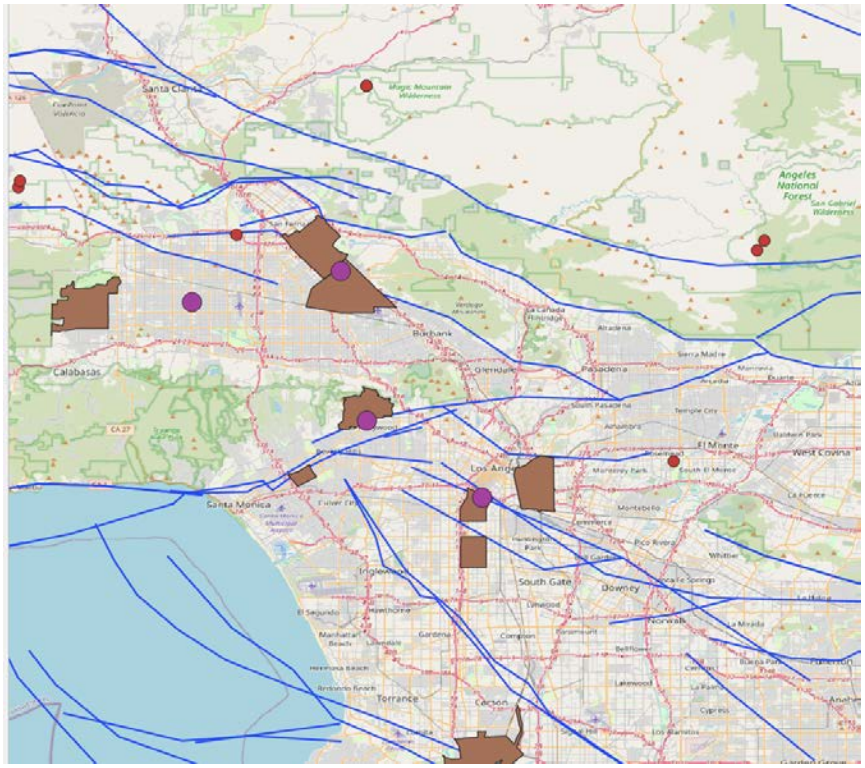

Figure A-3. Earthquake simulation model

Larger, purple dots represent earthquake epicenters used in these simulations. Smaller, red dots show historical earthquake epicenters covering all earthquakes ≥5.5 magnitude from 1965 to 2016 from the United States Geological Survey ("Significant Earthquakes, 1965–2016," USGS, https://www.kaggle.com/datasets/usgs/earthquake-database). There are other potentially active fault zones including offshore to the southwest that could result in different impacts, particularly for southern neighborhoods.

Blue lines represent fault lines from the United States Geological Survey as captured by CalOES GIS Data Management ("Earthquake Faults and Folds in the USA," California Governor's Office of Emergency Services, https://hub.arcgis.com/maps/CalEMA::earthquake-faults-and-folds-in-the-usa/).

Brown polygons are simulated neighborhoods. Base-map OpenStreetMap contributions are used under the Open Database License.

Flooding Modeling

To model the flooding scenario, we use typical historical water level measurements during flooding season: flow (measured in 1,000 cubic feet per second) and level (measured in feet from the ground surface). Figure A-4 shows the physical sensors (green dots) measuring water levels and the flooding polygon considered for the simulation.

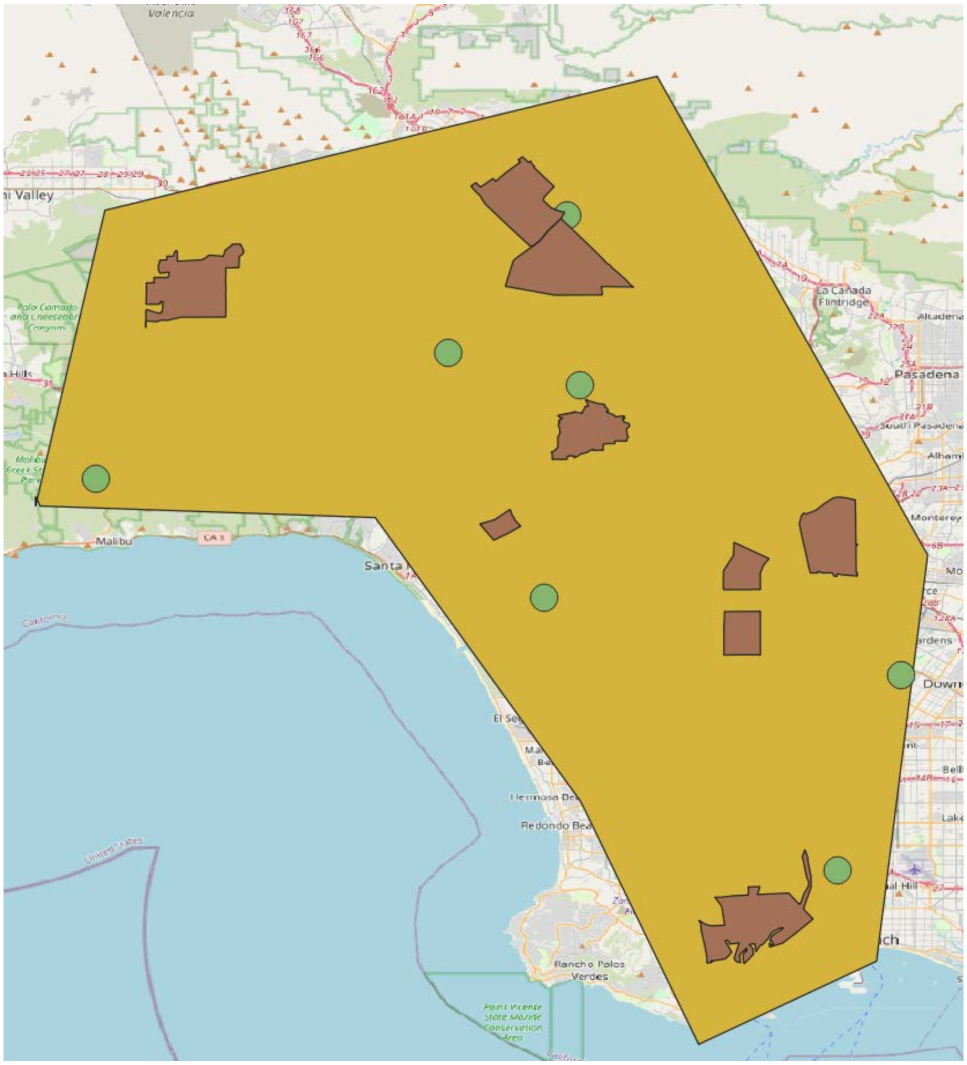

Figure A-4. Flood simulation model

The bigger outer polygon is used as input for flooding modeling. Brown smaller polygons are the neighborhoods simulated. Green dots are physical sensors measuring water levels. Base-map OpenStreetMap contributions are used under the Open Database License.

Each scenario is again run 40× to capture sufficient samples for the probability distribution. As with earthquake modeling, we model pre-disaster flooding, post-flooding microgrid program, post-flooding backup program, and post-flooding microgrid + backup program scenarios for all neighborhoods in base case 2019 and high stress 2035.

Equity-Based Energy Resilience Score and Community Resilience Indicator

Equity is analyzed through the following process:

1. The distribution (e.g., histogram) of community-member-level composite access-based scores disaggregated by DAC status is computed for each group of disaster events (e.g., all earthquake events). Doing so helps analysts understand the strengths and weaknesses of various resilience strategies and the patterns of disparity for resilience.

2. Distributions are then combined across scenario groups using a risk-weighted average that not only accounts for disaster event likelihood but also considers the level of impact. By maintaining the distribution of community-member-level access-based scores and DAC status in this step, we can evaluate the overall performance of resilience strategies in various ways.
3. We then use the median to statistically summarize the community-level resilient service access scores for each service category.
4. Then resilience score distributions are combined by equity group (i.e., DAC status) to arrive at each group's equity-based energy resilience score.
5. The resulting group-level energy resilience scores are normalized across all groups using the community-wide median as a reference.[23] Table A-7 reports the full neighborhood-level resilience results for 2035 high grid-stress case.

Aggregated community energy resilience scores allow evaluation of resilience strategies across the service territory. A good resilience resource allocation solution is one that increases both the equity-based energy resilience score and community resilience indicator values.

While it is critical to keep service access values in a composite resilience metric, we also introduce an aggregate resilience score that can be computed at the customer, neighborhood, or community level. The aggregate resilience score enables a holistic comparison of resilience of different customers, neighborhoods, or communities. This aggregate resilience score is expressed as the Euclidian norm of per-service access scores. Table A-3 shows how demographic groups (DAC and non-DAC) compare in terms of aggregate resilience score and per-service access scores.

Table A-4 shows how neighborhoods' aggregate resilience score and per-service access scores compare during routine situations without a disaster event. It also includes the pre-event coefficient of variation of access to critical services. This is an inverse measure of access equity. The lower the coefficient of variation, the higher the equity of access. Results show that the highest pre-disaster inequity is in access to emergency shelter services, with a coefficient of variation of 0.64. Access to electricity, with a coefficient of variation of 0, is the most equitable in pre-disaster conditions, as only households with grid connections are modeled. This equity indicator can help prioritize resilience investments for both normal operation and disaster conditions.

Table A-5 reports neighborhoods' post-disaster aggregate resilience scores and per-service access scores during a disaster, assuming there is no resilience-oriented program in place. Like in Table A-4, we compute the coefficient of variation as an inequity indicator. Results show that overall access inequity has increased from 0.24 in the pre-disaster conditions to 0.36 in post-

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[23] The reported aggregated scores are normalized for comparison. In most cases, this normalization was based on the population-level median. That is the median of all simulated households from all neighborhoods was set to 1.0, such that values above 1.0 indicated higher service access (better) while those less than 1.0 correspond to lower access (worse). This approach is used for all results with neighborhood-service or finer resolution. For summaries that combine across neighborhoods, such as those by event or program, results are normalized by the median of neighborhood medians.

disaster conditions, which is equivalent to a decrease in equity of access to critical services. The highest post-disaster inequities are in access to electricity, emergency shelter, and hospital services, with a coefficient of variation of 0.80, 0.79, and 0.60 respectively. Access to groceries, with a coefficient of variation of 0.30, is the most equitable in post-disaster conditions.

Table A-6 provides the results during a disaster when the critical backup + microgrid program is applied. The table shows how the post-disaster access inequity decreases from 0.36 to 0.27.

A.5 Additional Results: Equitable Distribution Grid Upgrades for Reliability and Solar, Storage, and EV Access and Use

Figure A-5 and Figure A-6 show the underlying grid stress results at the PUMA level for 2019 and 2035, respectively. In addition, Table A-2 contains the underlying full numeric results for grid stress, equitable grid score and DER access inequity. Here, DER access inequity shows the local variation between DACs and non-DACs within a PUMA. Equitable Grid score is a combination of grid stress results, DER adoption levels, and the local inequity observed in a PUMA.

Table A-2. Complete Numeric Results for Equitable Upgrade Analysis

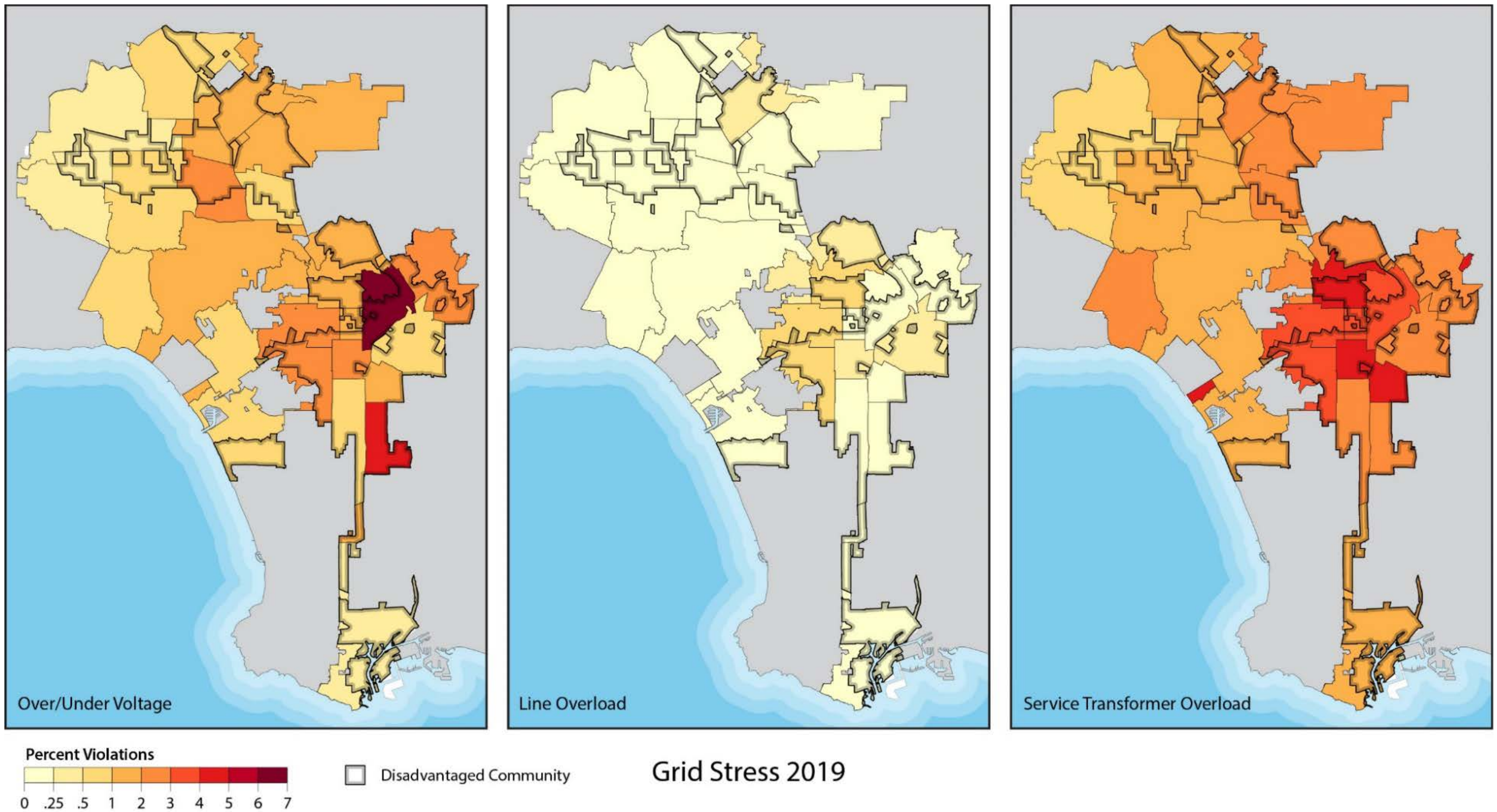
[a] Indicates disadvantaged community.

		Grid Stress (higher=worse)						Equitable Grid Score (higher=more equitable)				DER Access Inequity within a PUMA			
		Service Transformer Overloads (% of transformers)		Over/Under Voltages (% of nodes)		Line Overloads (% of lines)		Service Transformers		Other Grid Upgrades		Service Transformers		Other Grid	
PUMA	**Representative Neighborhoods**	**2019**	**2035**	**2019**	**2035**	**2019**	**2035**	**2019**	**2035**	**2019**	**2035**	**2019**	**2035**	**2019**	**2035**
3705	Chatsworth[a], Northridge, West Hills, Northridge[a], Porter Ranch, North Hills[a], Winnetka[a], Canoga Park[a], Chatsworth Reservoir	0.86	14	0.47	7.2	0.01	1.3	95	0	99	31	0.04	4.4	0.01	1.4
3706	Granada Hills, Mission Hills[a], Sylmar[a], North Hills, Granada Hills[a], Northridge	1.5	17	0.54	8.6	0.01	1.1	51	22	97	34	0.69	0.48	0.11	2.3
3707	Arleta[a], Pacoima[a], Sylmar, Lake View Terrace[a], Hansen Dam	2.4	21	1.6	7.5	0.27	2.1	74	24	92	44	0.04	7.1	0.22	8
3708	Sun Valley[a], Sunland, Valley Glen[a], Lake View Terrace, Tujunga, Shadow Hills, Pacoima[a]	2	18	1.2	7.3	0.03	1.6	37	32	88	50	1	0.59	0.4	0.25
3720	Griffith Park[a], Hollywood Hills[a], Atwater Village[a]	3	21	1.5	6.2	0.42	3.6	58	36	76	54	0.4	0.22	0.7	1
3721	North Hollywood[a], Valley Village, Sun Valley[a], Toluca Lake, Valley Glen[a]	2.3	14	0.83	6.2	0.09	2.3	60	14	95	33	0.4	2.9	0.16	2.1
3722	Valley Glen[a], Sherman Oaks, Van Nuys[a], Valley Village	1.9	18	2.5	7	0	1.2	73	11	72	38	0.25	2.5	0.87	1.3

PUMA	Representative Neighborhoods	Grid Stress (higher=worse)						Equitable Grid Score (higher=more equitable)				DER Access Inequity within a PUMA			
		Service Transformer Overloads (% of transformers)		Over/Under Voltages (% of nodes)		Line Overloads (% of lines)		Service Transformers		Other Grid Upgrades		Service Transformers		Other Grid	
		2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035
3723	Panorama City[a], Mission Hills, North Hills[a], Van Nuys[a], Arleta[a], Arleta	1.6	21	1.2	6.6	0	1.5	61	18	94	31	0.61	2.7	0.1	6.4
3724	Tarzana[a], Sepulveda Basin, Encino, Reseda[a], Northridge, Lake Balboa[a], Encino[a], Van Nuys[a], Woodland Hills, North Hills	1.3	17	0.61	8.3	0.03	1.7	89	15	98	36	0.01	2.9	0.04	2.3
3725	Woodland Hills, Winnetka[a], Canoga Park[a], Tarzana, West Hills[a]	0.93	19	0.5	6.6	0.01	1.1	43	13	95	37	1.1	1.7	0.19	1.5
3726	Pacific Palisades	3	18	1	7.6	0.17	1.8	69	34	97	51	0	0	0	0
3727	Beverly Crest, Brentwood, Sherman Oaks, Encino, Bel-Air, Studio City[a], Pacific Palisades, Hollywood Hills, Valley Village, Toluca Lake	1.6	15	1.9	6.3	0.08	2.8	80	19	92	28	0.23	0.62	0.22	2.4
3728	Venice	4.3	24	1.9	8.3	0.13	3	34	67	93	79	0	0	0	0
3729	Century City, Mar Vista, Westwood, Sawtelle, Cheviot Hills, West Los Angeles, Rancho Park, Palms[a], Beverly Crest, Brentwood	1.7	14	0.9	4.9	0.15	2.2	82	22	94	28	0.22	0.08	0.21	2.5
3730	Carthay, Beverly Grove, Pico-Robertson, Mid-Wilshire[a], Mid-City[a], Windsor Square, Hancock Park, Fairfax, Harvard Heights[a], Beverlywood, Koreatown[a], Arlington Heights[a]	3.7	20	2.7	8.4	0.73	6.5	17	14	0	32	0.85	6.8	3.1	7.6
3731	Hollywood, Fairfax, Hollywood Hills West, Beverly Grove, Hollywood Hills	2.8	17	1.1	7.1	0.33	3.8	55	22	95	38	0	0	0	0

PUMA	Representative Neighborhoods	Grid Stress (higher=worse)						Equitable Grid Score (higher=more equitable)				DER Access Inequity within a PUMA			
		Service Transformer Overloads (% of transformers)		Over/Under Voltages (% of nodes)		Line Overloads (% of lines)		Service Transformers		Other Grid Upgrades		Service Transformers		Other Grid	
		2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035
3732	East Hollywood[a], Hollywood Hills, Hollywood[a], Los Feliz, Silver Lake, Larchmont, Silver Lake[a], Hancock Park, Los Feliz[a]	4.9	21	1.6	10	0.64	6.4	31	22	83	29	0.15	1.2	0.43	4.7
3733	Pico-Union[a], Koreatown, Koreatown[a], Westlake[a], Harvard Heights[a]	3.92	15	1.5	6.8	0	4.3	9.9	35	90	47	1.4	2.1	0.36	0.38
3734	Pico-Union[a], Westlake[a], Los Feliz, Silver Lake, Westlake, Echo Park[a], Elysian Park[a], Elysian Valley[a]	3.8	19	7	21	0.13	6.4	38	21	54	0	0.2	3.1	0.94	14
3735	Atwater Village[a], El Sereno[a], Highland Park, Eagle Rock, Lincoln Heights[a], Montecito Heights[a], Glassell Park[a], Cypress Park[a], Mount Washington[a]	2.5	24	2.2	13	0.05	4.4	0	36	53	43	1.4	3.4	1.5	6.1
3736	Highland Park	4.3	24	2.2	6.4	0	4.8	37	100	92	100	0	0	0	0
3744	Downtown[a], Chinatown[a], Boyle Heights[a], Lincoln Heights[a], Central-Alameda[a], Historic South-Central[a]	2.4	7.9	0.87	3	0.35	2.2	62	31	97	37	0.57	1.1	0.04	0.13
3745	Historic South-Central[a], Central-Alameda[a], South Park[a]	4.2	14	1.3	7	0	2.7	34	41	95	52	0	0	0	0
3746	Exposition Park[a], Pico-Union[a], Jefferson Park[a], Adams-Normandie[a], Harvard Heights[a], University Park[a], Arlington Heights[a]	4.1	25	2.1	16	0.38	4.9	49	76	92	77	0	0	0	0
3747	Hyde Park[a], West Adams[a], Baldwin Hills/Crenshaw[a], Leimert Park[a], Mid-City[a], Jefferson Park[a], Beverlywood[a], Arlington Heights[a]	3.6	32	2.6	14	0.73	8	41	30	70	48	0.07	0.14	0.81	3.7
3748	Westchester[a], Playa Vista, Del Rey, Venice, Playa del Rey[a]	1.7	15	0.87	3.4	0.04	1.6	86	25	98	44	0	0	0	0

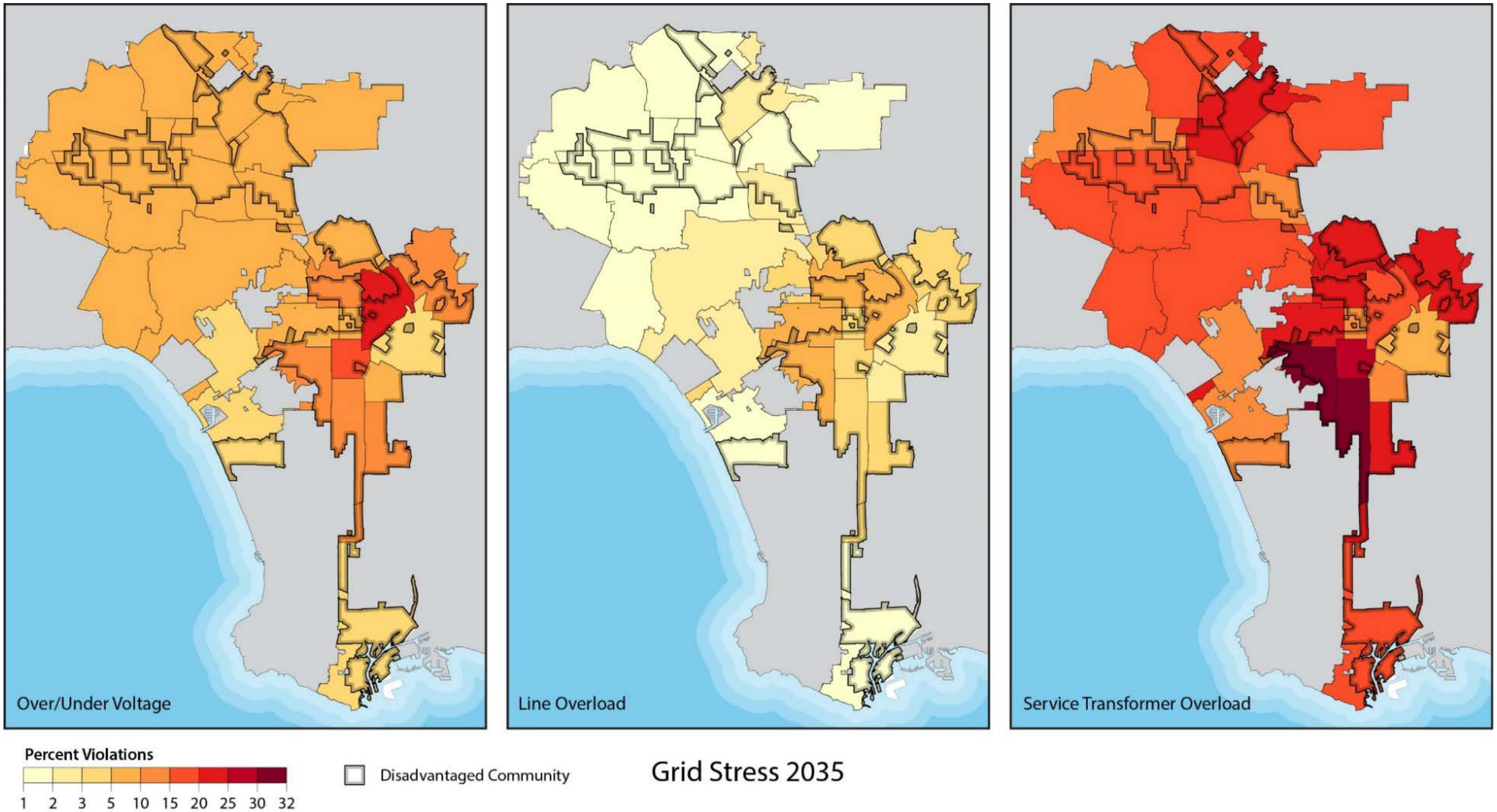
PUMA	Representative Neighborhoods	Grid Stress (higher=worse)						Equitable Grid Score (higher=more equitable)				DER Access Inequity within a PUMA			
		Service Transformer Overloads (% of transformers)		Over/Under Voltages (% of nodes)		Line Overloads (% of lines)		Service Transformers		Other Grid Upgrades		Service Transformers		Other Grid	
		2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035	2019	2035
3750	Vermont Square[a], Manchester Square[a], Gramercy Park[a], Vermont Knolls[a], Harvard Park[a], Chesterfield Square[a], Vermont-Slauson[a], Vermont Vista[a], Harbor Gateway[a]	2.1	31	0.94	11	0.03	4.4	74	42	98	67	0	0	0	0
3751	Green Meadows[a], Florence[a], Broadway-Manchester[a], Watts[a]	3	23	4.1	12	0.03	4.3	70	55	79	67	0	0	0	0
3758	Harbor Gateway[a]	1.3	23	1.4	14	0	4.3	98	28	97	45	0	0	0	0
3767	Harbor Gateway[a], Wilmington[a], Harbor City[a], San Pedro[a]	1	16	0.47	4.8	0.03	1.6	100	5.9	100	31.2	0.01	9.8	0.01	9



(a) (b) (c)

Figure A-5. PUMA-level grid stress metrics estimates for current (2019) base case for (a) over/under voltages, (b) line overloads, and (c) service transformer overloads

Note color scale difference compared to 2035.



(a) (b) (c)

Figure A-6. PUMA-level grid stress level estimates for 2035-Equity case for (a) over/under voltages, (b) line overloads, and (c) service transformer overloads

Figure 8 is duplicated for easier comparison with the 2019 results.

The level of grid stress is significantly higher in 2035 than in 2019. Note difference in scale from the 2019 figures.

As can be seen in Figure A-5, in 2019, neighborhoods surrounding South Central see high overloaded transformers, those near Koreatown, Mid-Wilshire experience higher line overloads and those around Northwest Downtown experience higher voltage issues. On average, DACs observe roughly 1.5× more overloaded service transformers and 2× more overloaded lines and 2× more voltage violations, as compared to non-DACs.

Figure A-6 shows the grid stress experienced for the 2035 equity scenario. In 2035, there is a significant overall increase in grid stress. On average, grid stress in service transformers is 8.5× higher than in 2019 and the stress for other parts of the distribution grid is 7.5× higher. In particular, neighborhoods north and west of downtown (stretching from Exposition Park to Silver Lake and Elysian Valley) see the most anticipated 2035 voltage challenges. These areas partially overlap with the estimated regions of the worst line overloads that cover an arc from Hyde Park through Mid-City to Silver Lake and Elysian Valley. Significant service transformer overloads are seen throughout the city, with the highest levels in a rough triangle south and west of downtown stretching from Harbor Gateway to Mid-City to Pico-Union.

A.6 Additional Results: Equitable and Resilient Access to Electricity-Related Services During Disaster Events

Access to Critical Services Post-Disaster and Impact of Resilience Programs

This section provides a breakdown of the equitable resilience results by type of disaster event and neighborhood. It also highlights the effect of mitigation strategies on neighborhood resilience. In general, enabling microgrid formation through switching, control, and using existing DERs such as solar and storage is more effective than only providing backup generation units. But when the backup generation program is combined with the post-disaster microgrid formation strategy, close to pre-disaster levels of access to critical services are restored for all neighborhoods.

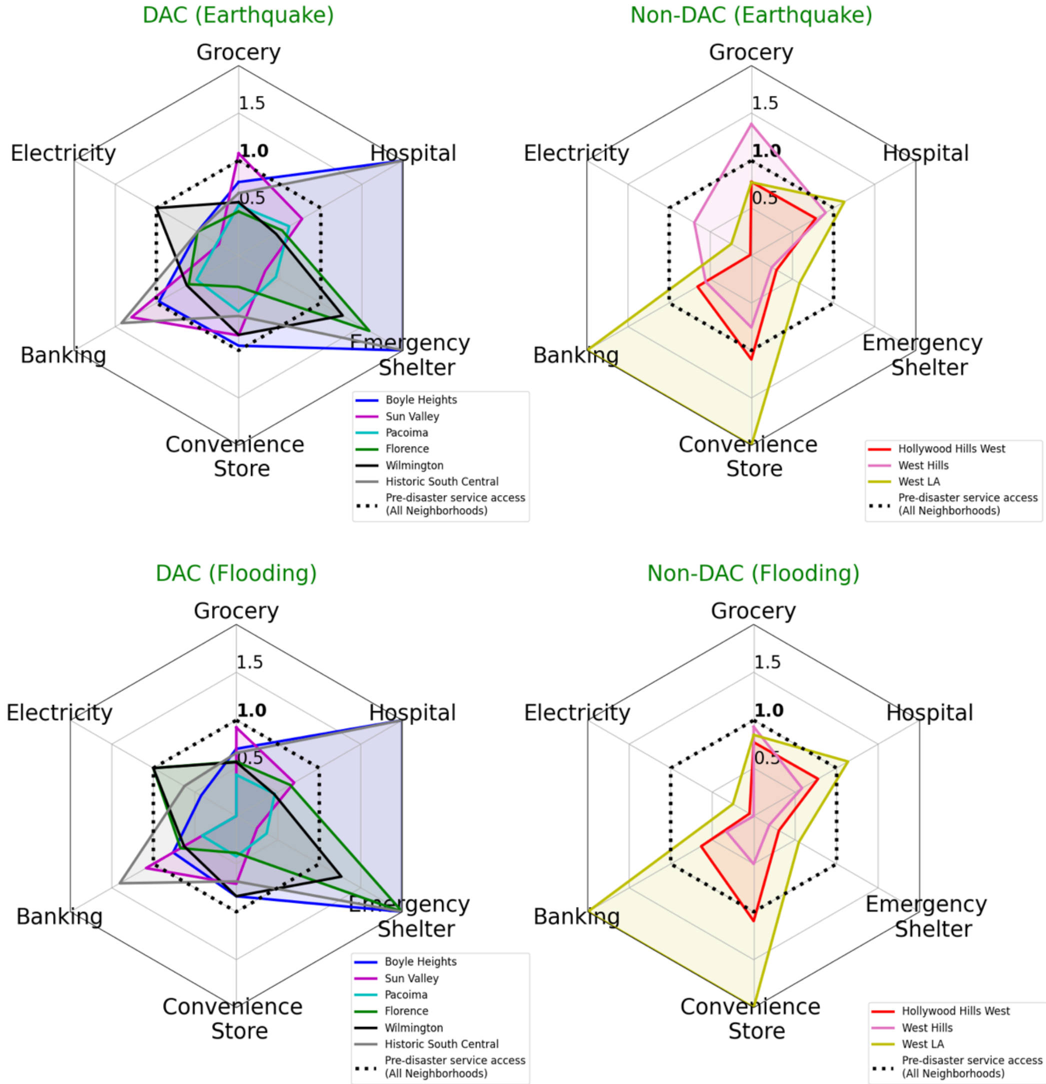


Figure A-7. 2035 post-earthquake and post-flooding (no resilience strategy) equitable access scores

See averages and additional notes in Figure 12.

As seen in Figure A-7, earthquake and flooding events have similar impacts on five of the nine neighborhoods evaluated. In Sun Valley, Pacoima, and West Hills, flooding causes greater reduction in access to electricity. In Florence, the earthquake scenarios cause greater reduction in access to electricity.

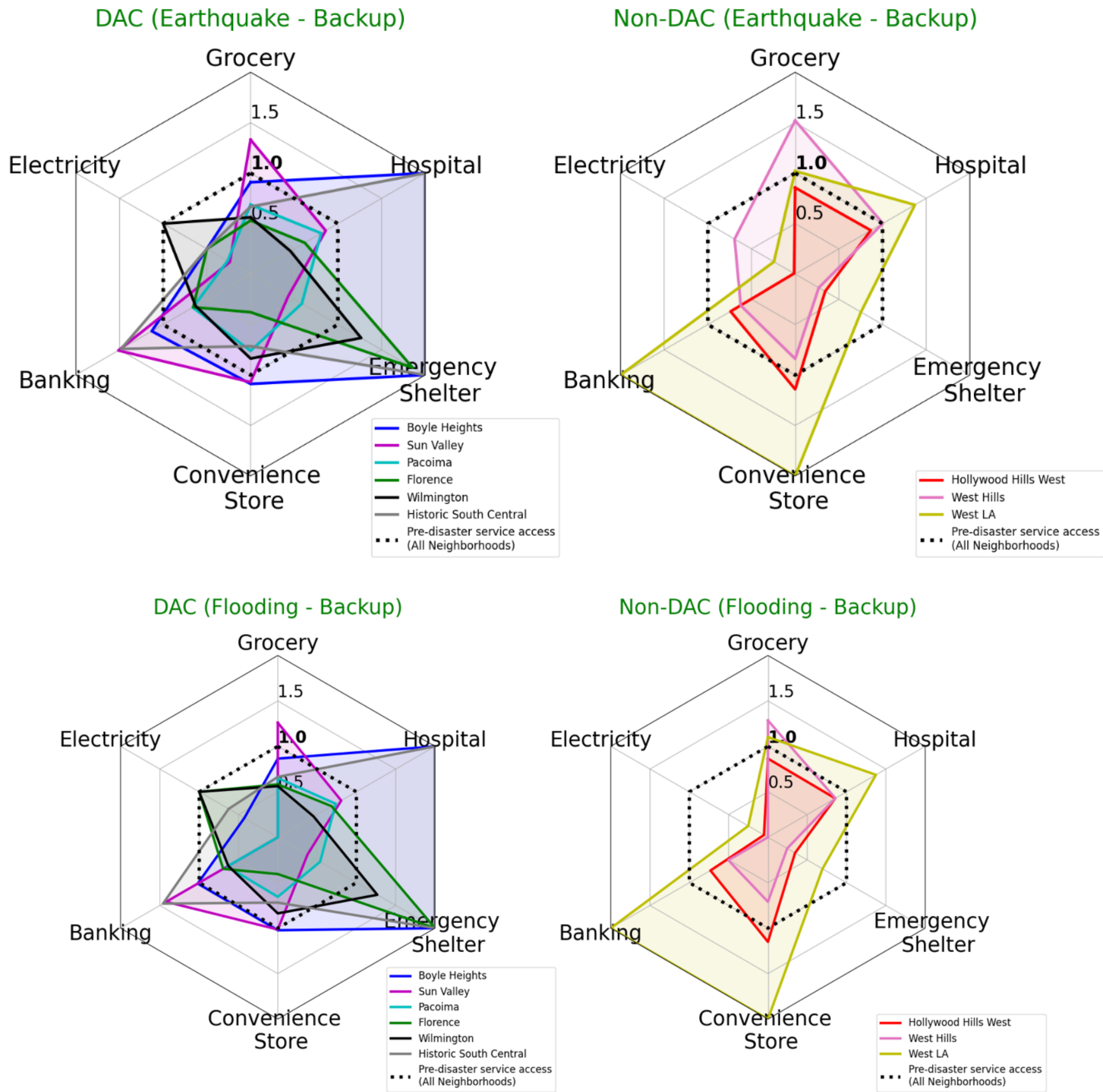


Figure A-8. 2035 Post-event equitable access scores with backup generators added to 50% of critical service facilities

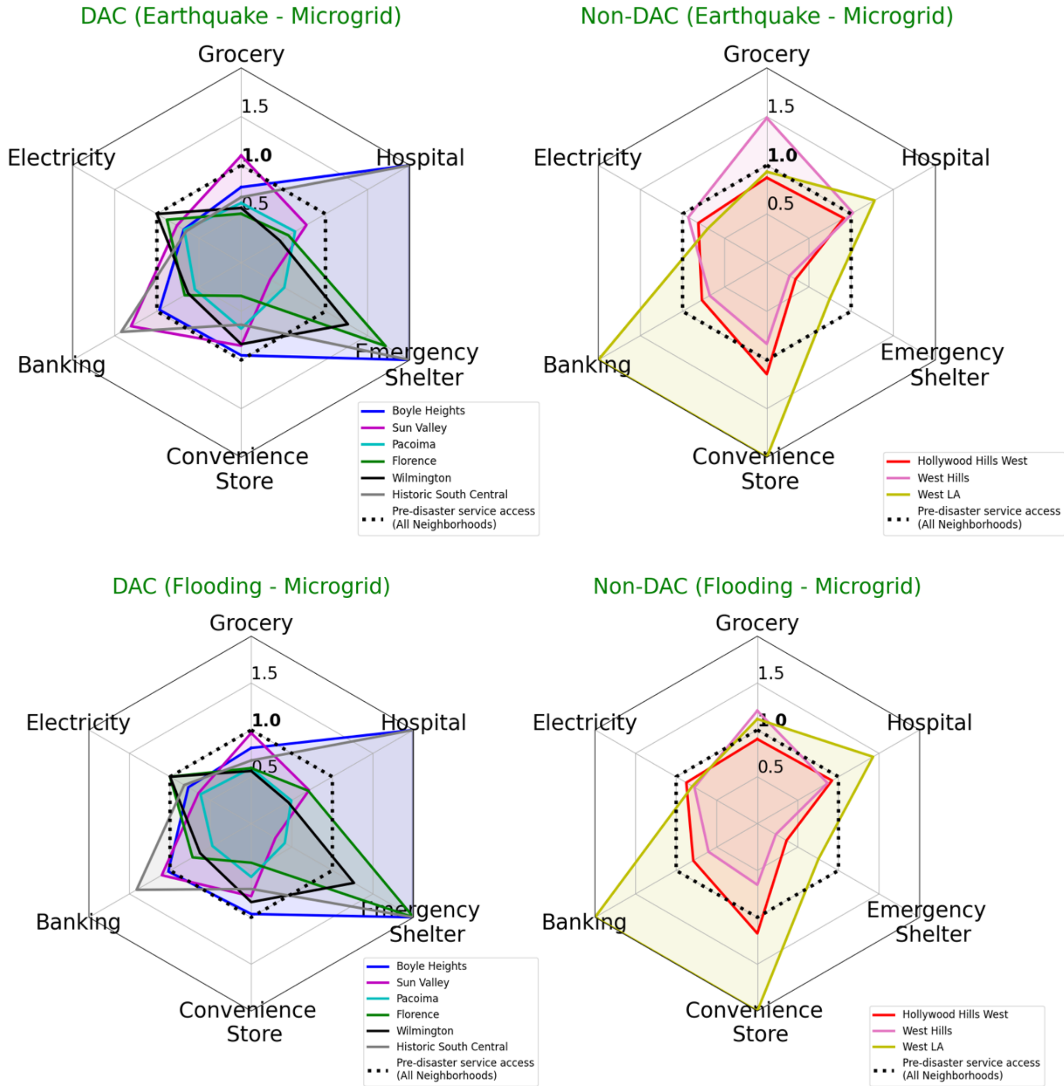


Figure A-9. 2035 Post-event equitable access scores with microgrid controllers added that use estimated existing customer solar + storage installations

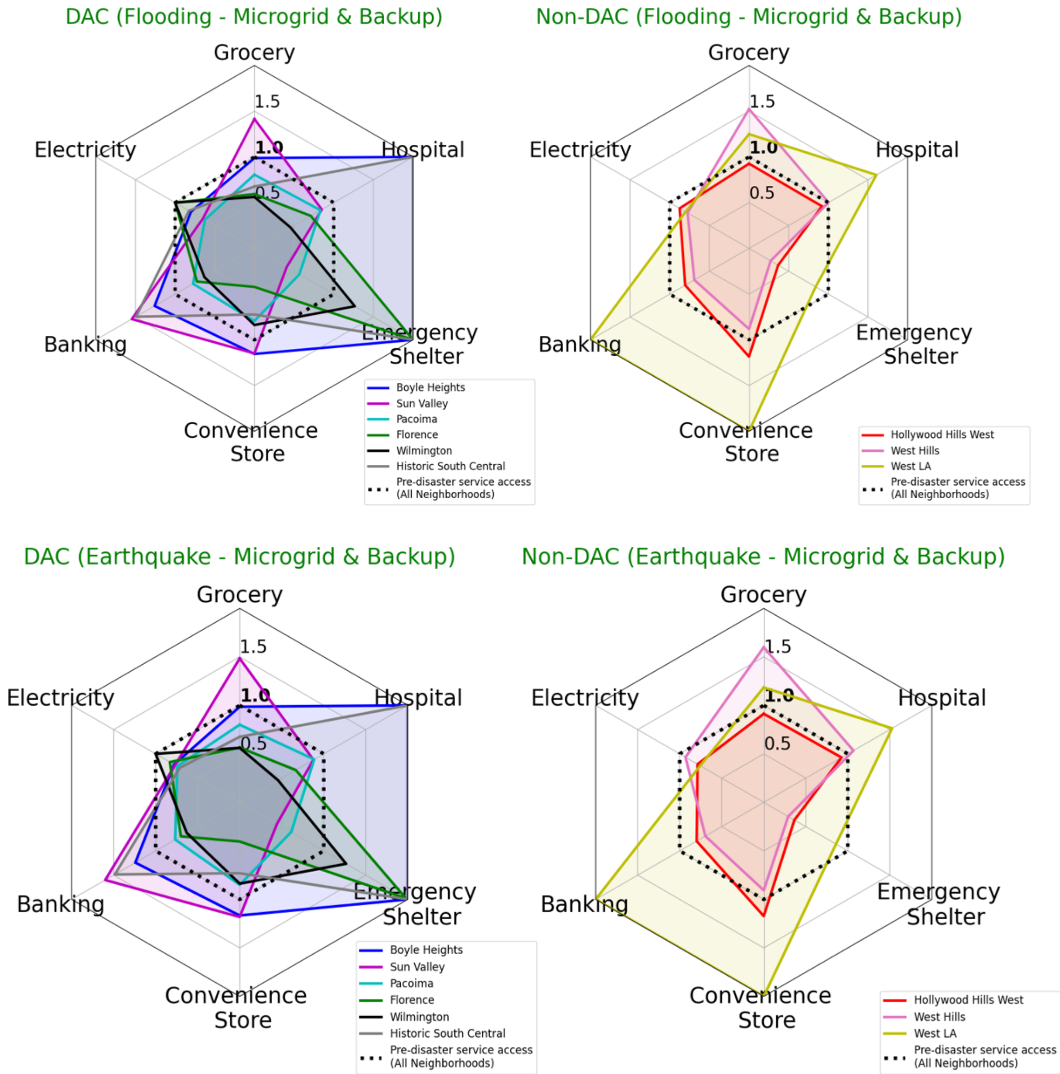


Figure A-10. 2035 post-event equitable access scores with microgrid controllers added that use projected customer solar + storage and new backup generation sited for 50% of critical service facilities

See averages and additional notes in Figure 12.

Figure A-8 through Figure A-10 highlight benefit of the microgrid + backup program that combines the ability of microgrids to support both residential electricity and critical facilities with the further service-only improvement from the critical facility backup program to significantly increase post-disaster access to critical services. Microgrids alone are somewhat less effective for services while backup-only solutions only support services and provide little to no resilience improvement for customer electricity. The results also indicate that microgrid programs tend to be more effective in flooding scenarios than in earthquake events.

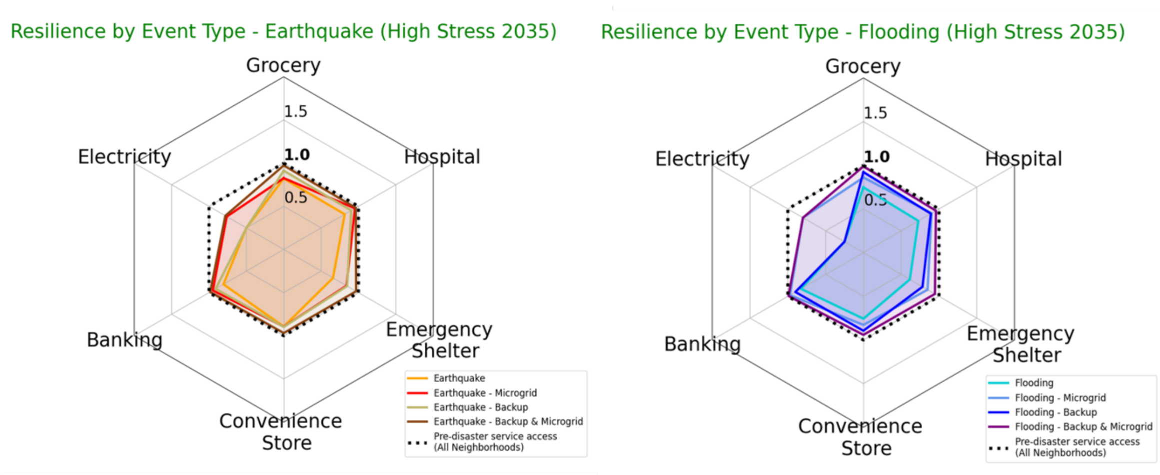


Figure A-11. 2035 post-event equitable access scores by event type and resilience strategy

The microgrid + backup program yields the most post-disaster resilience improvement and is as effective in flooding as in earthquake scenarios (Figure A-11). Neighborhoods generally have less access to electricity during flooding events than during simulated earthquake events.

Distribution of Access to Critical Services Pre-, Post-Disaster and Impact of Resilience Programs

Figure A-12 to Figure A-15 show a series of data-rich overlaid violin plots that illustrate the distribution of access for individual loads in DAC (top) and non-DAC neighborhoods (bottom). Unlike the radar plots above, which collapse these complex distributions into a single number (the median), these figures maintain the details of how individual household's access to services is distributed. For example, wider sections of the violin indicate larger fractions of the population at that access level, while narrower sections indicate few households have that level of access.

The plots display the normalized access for a critical service. The normalized access is scaled such that the median access score for that service across all neighborhoods in the pre-disaster scenario is assigned a value of 1.0. Portions of the distribution >1.0 then represent households with greater than average access, while those <1.0 have lower access for that service. All data are limited to a max access level of 2.0 to prevent outliers from distorting the scale. Any data >2.0 are included at 2.0 in its corresponding distribution; doing so reveals underlying patterns such as whether most households have similar levels of access, whether this access varies widely, and whether it might be multimodal, with one or more groups of households having high access and others cluster having lower access.

Each violin then captures three different conditions for this normalized access for the particular service in that combination of scenario year and DAC status: (1) the No-disaster reference, shown in gray, (2) the during-disaster case with no program, shown in a lighter/brighter color, and (3) the during-disaster case with the backup + microgrid program implemented. The probability distribution for no-disaster reference is plotted symmetrically about the vertical center line, and the two disaster cases are plotted to the left and right of the line for the no-program and backup + microgrid program respectively. The width of the no-disaster violin is exaggerated by 2× so it can be directly compared to the two single-sided disaster violins. As a result, the household distributions of all three cases can readily be compared: left vs. right to see the effectiveness of the microgrid + backup program and each side to the gray no-disaster reference to see how the disaster compares to no-disaster access.

For example, in Figure A-12, the dark yellow distribution (left of the axis) represents access for individuals when a simulated earthquake occurs, and no program is implemented, while the dark brown (right of the access) represents access for individuals when a simulated earthquake occurs and both backup and microgrid programs are implemented. In this case, the gray portion of DAC grocery access is widest around 1.0 showing that a large number of households have the average grocery access among the total studied population with no disaster. The portion of the wider gray section that extends up to around 1.5, shows that many households have higher than average grocery access, while another wider portion around 0.5 shows that another cluster of DAC households have about half the normal access level to groceries. The wider portion of the yellow distribution around 0.7, shows that without a resilience program in place, most of the population shifts from a bit above average to noticeably below average access to groceries during simulated earthquake events; the fact that the bottom of the yellow distribution does not noticeably extend below the lowest gray bulge suggests those with lower access are not significantly impacted further in their grocery access; and the somewhat wider yellow distribution around 0.5 compared to the gray reference shows that more households have fallen to this lower level of grocery access during the simulated earthquake. Looking at the right half of the same stacked violin shows that with the microgrid + backup program in place, the household distribution of access to groceries has been restored to no-disaster levels, as the dark brown distribution closely resembles that of the underlying gray reference. Note that the reference electricity access appears as a gray horizontal line at 1.0 because all households in this study represent LADWP customers who are expected to have electricity in non-disaster times.

All violins approximate the actual distribution as a kernel density, similar to a smoothed histogram, to better estimate the underlying distribution. However, this kernel density can introduce some artifacts to bring the smooth shape back to zero beyond the maximum value of 1.0 (for electricity) or 2.0 (for other services). The individual plotted sample values are the average for each household across the Monte Carlo samples for the corresponding case. For most services, where the underlying metric is distance-based and therefore continuous, this results in smoother results. However, because electric service is modeled as having only two states—on (1.0) or off (0.0)—there are larger "lumps" around 1.0 and 0.0. In some cases, there are also higher electric service distributions at other values such as 0.5 or 0.25, when only some of the Monte Carlo samples result in a loss of electric service.

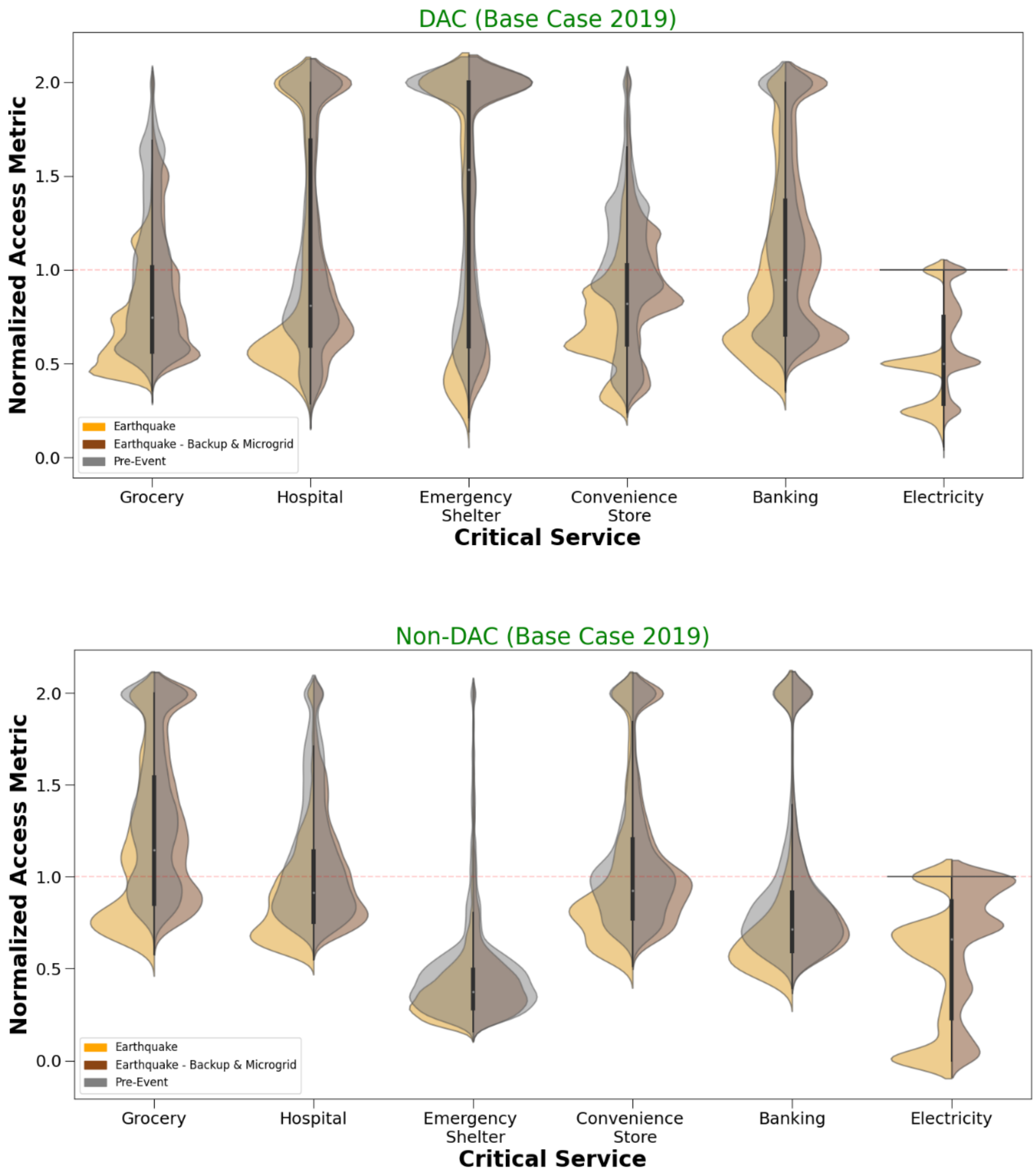
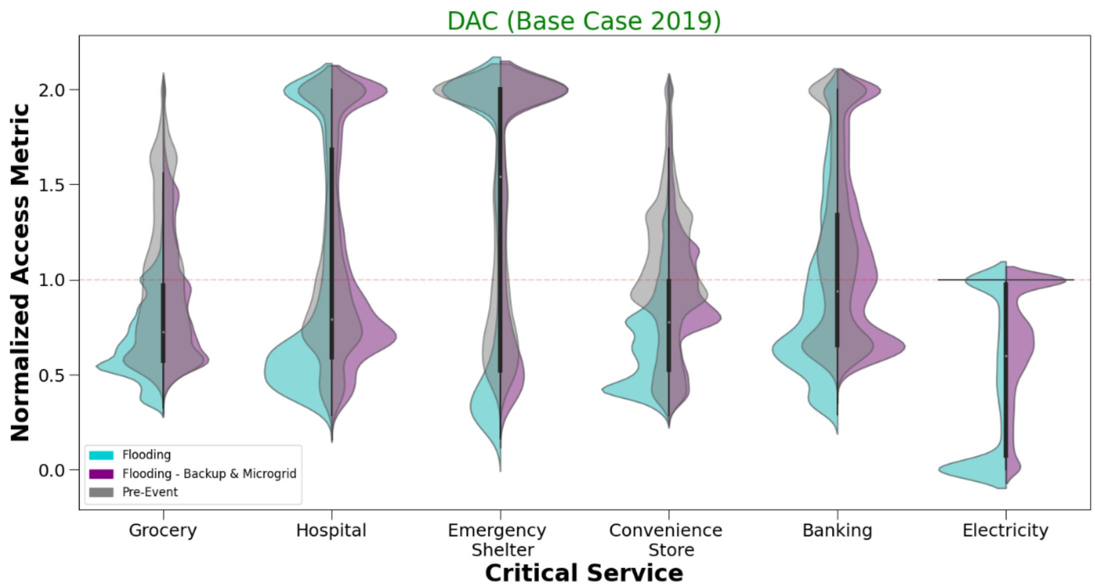


Figure A-12. Distribution of 2019 pre- and post-earthquake equitable access scores and effect of backup + microgrid resilience strategy

The normalized access is scaled such that the median access score for that service across all neighborhoods in the pre-disaster scenario is assigned a value of 1.0. Values >1.0 represent households with greater than average access. The width of the no-disaster violin is exaggerated by 2× so it can be directly compared to the two single-sided disaster violins.



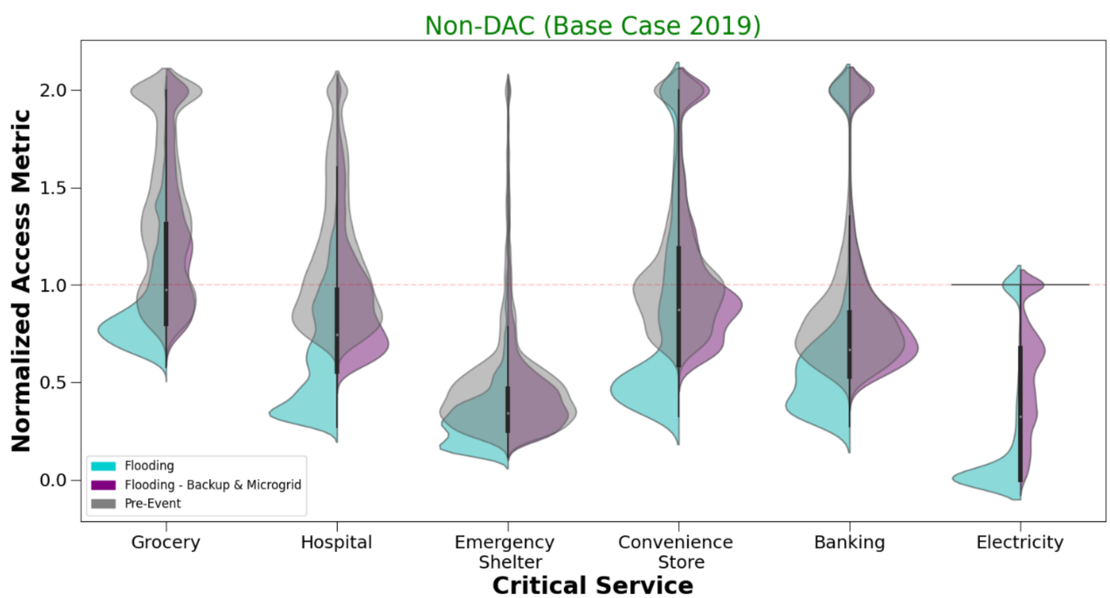


Figure A-13. Distribution of 2019 pre- and post-flooding equitable access scores and effect of backup + microgrid resilience strategy

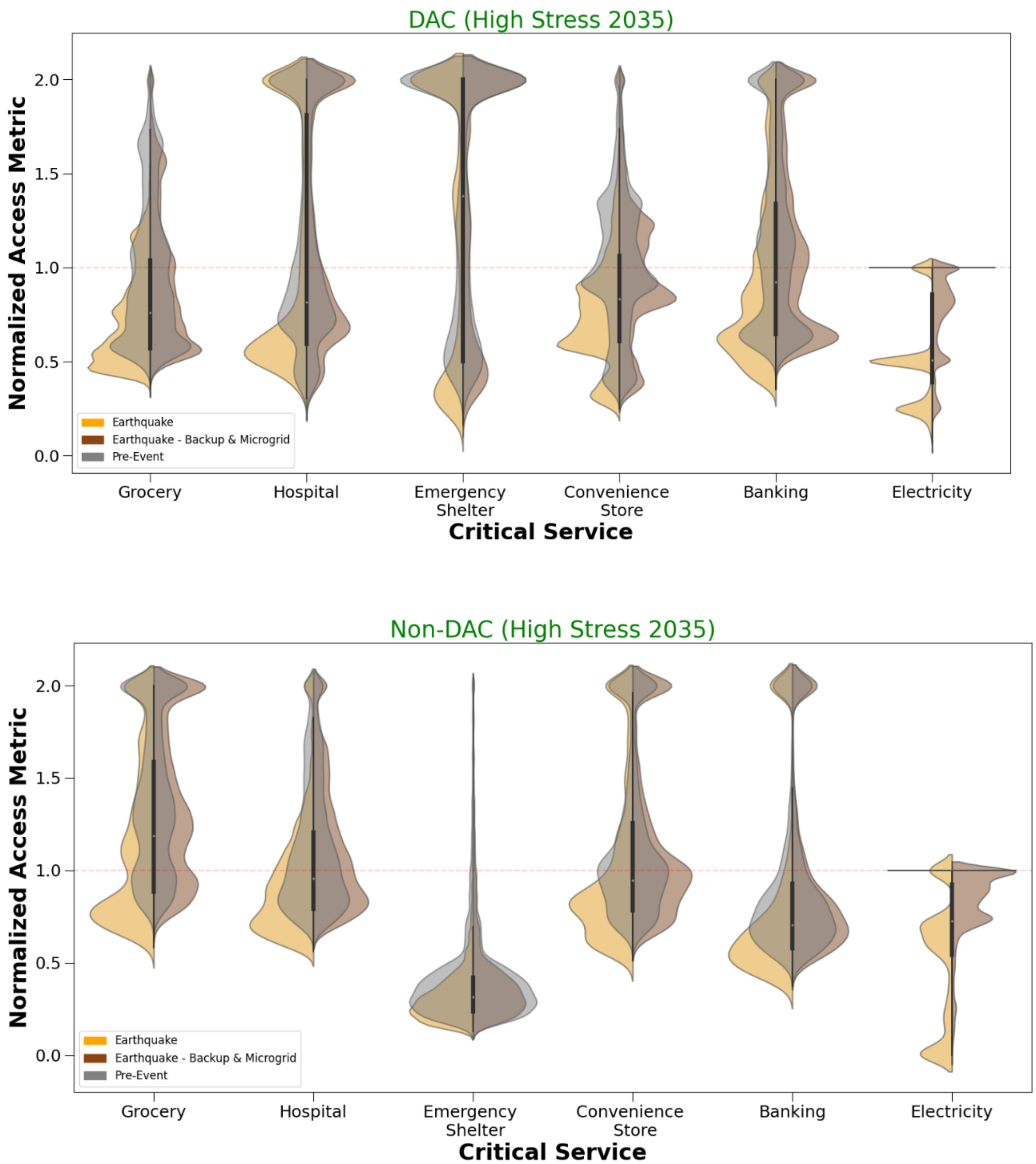


Figure A-14. Distribution of 2035 pre- and post-earthquake equitable access scores and effect of backup + microgrid resilience strategy

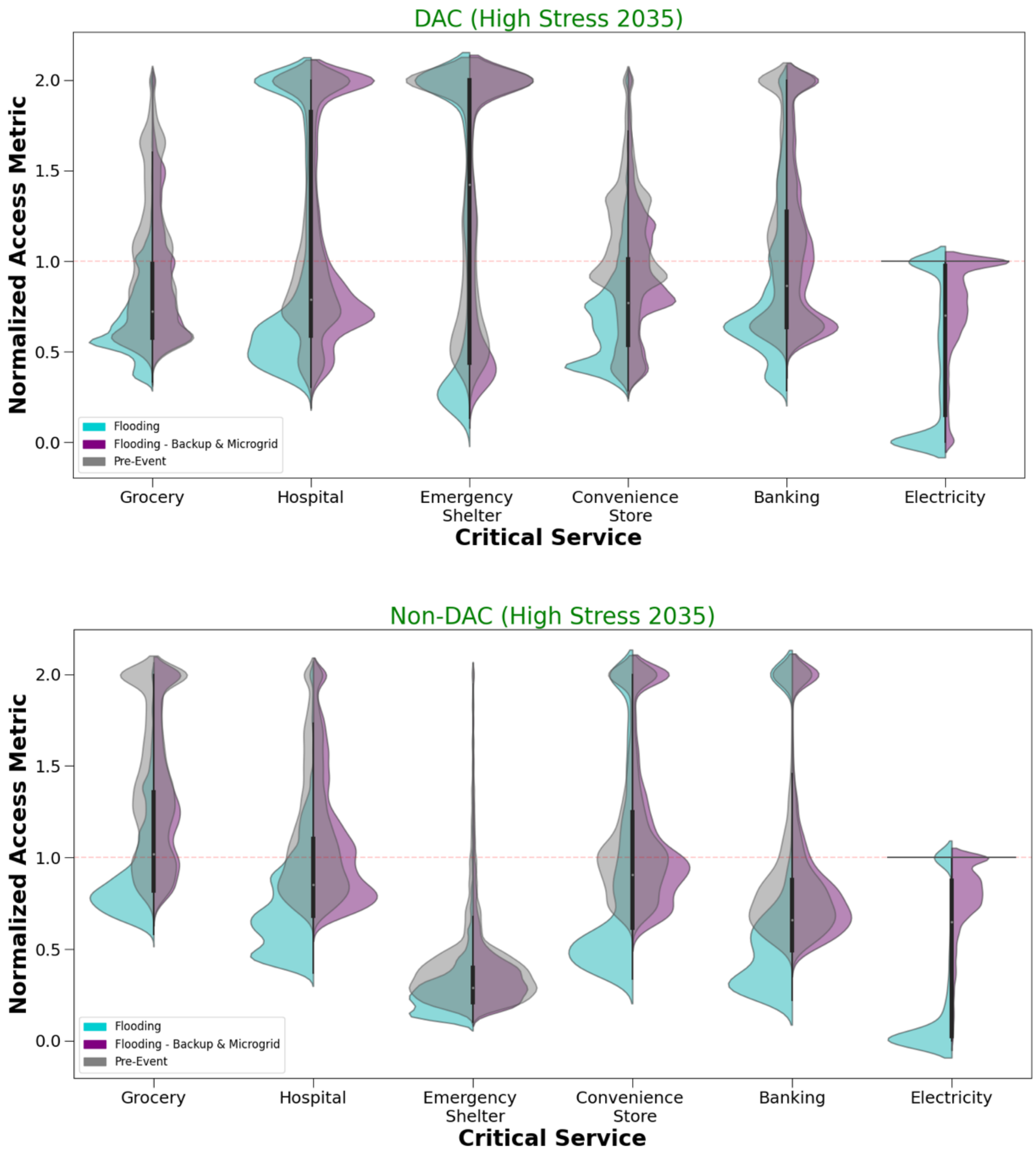


Figure A-15. Distribution of 2035 pre- and post-flooding equitable access scores and effect of backup + microgrid resilience strategy

Equitable Resilience Summary Tables

Table A-3 through Table A-7 provide various summaries of the resilience results. Table A-3 combines across neighborhoods to compare demographic groups. Note that here the use of the Euclidian norm (square root of sum of the squares) to summarize can mask inequities within the demographic groups when one or a few neighborhoods have relative high access scores.

Table A-4 through Table A-6 compare neighborhood results for pre-disaster, disaster without program, and disaster with the microgrid + backup program. Finally, Table A-7, provides complete neighborhood results for all services, events, and program combinations.

As shown throughout this report, community energy resilience is multidimensional. But a single metric is needed to compare resilience among demographic/geographic groups, or resilience by event type. To this end, these tables use the aggregate resilience score, which is the Euclidian norm of per-service access scores, each critical service being an axis of the Euclidian space.

Table A-3. 2035 Aggregate Service Access Scores by Demographic Group and Event Type

Demographic Group	Event	Per-Service Access Score						Aggregate Service Access Score
		Grocery	Emergency Shelter	Convenience Store	Banking	Hospital	Electricity	
DAC	None	0.89	1.52	0.99	1.09	0.97	1.00	2.69
	Earthquake[a]	0.68	1.35	0.73	0.82	0.68	0.50	2.05
	Flooding	0.64	1.41	0.65	0.71	0.66	0.33	1.97
Non-DAC	None	1.34	0.35	1.03	0.79	1.05	1.00	2.39
	Earthquake[a]	1.07	0.29	0.86	0.63	0.88	0.59	1.87
	Flooding	0.84	0.25	0.62	0.50	0.70	0.03	1.38

[a] Earthquake results include four simulated events located close to historically recorded earthquakes from 1965 to 2016, which all happen to fall in the northern part of the city. There are other active fault zones throughout the city and offshore that could more severely impact Wilmington and other southern neighborhoods.

Table A-4. 2035 Pre-Event Aggregate Service Access Scores by Neighborhood

Neighborhood	Per-Service Access Score						Aggregate Service Access Score
	Grocery	Emergency Shelter	Convenience Store	Banking	Hospital	Electricity	
Boyle Heights[a]	1.03	2.00	1.22	1.30	2.00	1	3.64
Florence[a]	0.59	2.00	0.43	0.72	0.71	1	2.56
Historic South Central[a]	0.68	2.00	0.78	1.53	2.00	1	3.52
Hollywood Hills West	0.93	0.37	1.19	0.81	0.93	1	2.22
Pacoima[a]	0.86	0.70	0.94	0.80	0.96	1	2.16
Sun Valley[a]	1.57	0.56	1.30	1.75	0.93	1	3.07
West Hills	1.66	0.30	0.93	0.71	1.08	1	2.53
West Los Angeles	1.27	0.89	2.00	2.00	1.63	1	3.75
Wilmington[a]	0.56	1.27	0.84	0.63	0.46	1	2.06
Coefficient of Variation	**0.40**	**0.64**	**0.41**	**0.45**	**0.47**	**0.00**	**0.24**

[a] DAC neighborhood

Table A-5. 2035 Post-Event (No Program) Aggregate Service Access Scores by Neighborhood

Neighborhood	Per-Service Access Score						Aggregate Service Access Score
	Grocery	Emergency Shelter	Convenience Store	Banking	Hospital	Electricity	
Boyle Heights[a]	0.74	2.00	0.89	0.86	2.00	0.46	3.21
Florence[a]	0.52	1.83	0.36	0.64	0.59	0.83	2.28
Historic South Central[a]	0.66	2.00	0.66	1.41	2.00	0.56	3.34
Hollywood Hills West	0.77	0.31	1.10	0.64	0.78	0.03	1.71
Pacoima[a]	0.48	0.41	0.51	0.46	0.54	0.13	1.09
Sun Valley[a]	1.00	0.29	0.78	1.19	0.73	0.12	1.91
West Hills	1.16	0.22	0.63	0.44	0.74	0.35	1.63
West Los Angeles	0.81	0.56	2.00	2.00	1.13	0.25	3.21
Wilmington[a]	0.56	1.27	0.84	0.63	0.46	1.00	2.06
Coefficient of Variation	**0.30**	**0.79**	**0.55**	**0.57**	**0.60**	**0.80**	**0.36**

[a] DAC neighborhood

Table A-6. 2035 Post-Event Aggregate Service Access Scores by Neighborhood with Critical Backup + Microgrid Program

Neighborhood	Per-Service Access Score						Aggregate Service Access Score
	Grocery	Emergency Shelter	Convenience Store	Banking	Hospital	Electricity	
Boyle Heights[a]	0.99	2.00	1.16	1.25	2.00	0.79	3.54
Florence[a]	0.58	1.83	0.41	0.71	0.69	0.92	2.38
Historic South Central[a]	0.68	2.00	0.73	1.49	2.00	0.77	3.44
Hollywood Hills West	0.77	0.31	1.1	0.64	0.78	0.83	1.90
Pacoima[a]	0.8	0.59	0.82	0.77	0.86	0.68	1.86
Sun Valley[a]	1.45	0.43	1.17	1.57	0.86	0.71	2.71
West Hills	1.56	0.28	0.89	0.69	1.04	0.85	2.36
West Los Angeles	1.22	0.85	2.00	2.00	1.57	0.78	3.64
Wilmington[a]	0.56	1.27	0.84	0.63	0.46	1.00	2.06
Coefficient of Variation	**0.39**	**0.69**	**0.43**	**0.47**	**0.50**	**0.12**	**0.27**

[a] DAC neighborhood

Table A-7. Full Neighborhood-Level Resilience Results for 2035 High Grid-Stress Case

Neighborhood	Service	No Event	No Program			Microgrid			50% Critical Backup			Microgrid + 50% Critical Backup		
			Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average
Boyle Heights[a]	Electricity	1.00	0.50	0.43	0.46	0.68	0.78	0.73	0.50	0.43	0.46	0.78	0.80	0.79
	Grocery	1.03	0.77	0.70	0.74	0.78	0.81	0.79	0.91	0.87	0.89	0.99	0.99	0.99
	Hospital	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Emergency Shelter	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Convenience Store	1.22	0.95	0.84	0.89	0.95	0.96	0.96	1.09	1.02	1.06	1.17	1.15	1.16
	Banking	1.30	0.97	0.76	0.86	0.97	1.02	1.00	1.13	1.02	1.08	1.24	1.26	1.25
Florence[a]	Electricity	1.00	0.50	1.00	0.83	0.88	1.00	0.94	0.50	1.00	0.75	0.83	1.00	0.92
	Grocery	0.59	0.46	0.57	0.52	0.50	0.59	0.55	0.53	0.58	0.56	0.57	0.59	0.58
	Hospital	0.71	0.53	0.65	0.59	0.56	0.70	0.63	0.62	0.68	0.65	0.67	0.71	0.69
	Emergency Shelter	2.00	1.59	2.00	1.83	1.71	2.12	1.91	1.86	2.00	1.98	1.98	2.00	2.00
	Convenience Store	0.43	0.33	0.39	0.36	0.34	0.42	0.38	0.38	0.40	0.39	0.40	0.42	0.41
	Banking	0.72	0.61	0.67	0.64	0.67	0.72	0.70	0.66	0.70	0.68	0.70	0.72	0.71
Historic South Central[a]	Electricity	1.00	0.50	0.63	0.56	0.65	0.83	0.74	0.50	0.63	0.56	0.71	0.83	0.77
	Grocery	0.68	0.66	0.66	0.66	0.67	0.67	0.67	0.67	0.66	0.67	0.68	0.68	0.68
	Hospital	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Emergency Shelter	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Convenience Store	0.78	0.64	0.68	0.66	0.64	0.70	0.67	0.71	0.72	0.72	0.73	0.72	0.73
	Banking	1.53	1.42	1.40	1.41	1.42	1.41	1.42	1.48	1.46	1.47	1.49	1.49	1.49
Hollywood Hills West	Electricity	1.00	0.01	0.05	0.03	0.82	0.88	0.85	0.01	0.05	0.03	0.79	0.88	0.83
	Grocery	0.94	0.78	0.77	0.77	0.87	0.90	0.89	0.86	0.87	0.86	0.91	0.93	0.92
	Hospital	0.93	0.78	0.78	0.78	0.91	0.92	0.92	0.87	0.86	0.86	0.93	0.92	0.92
	Emergency Shelter	0.37	0.31	0.30	0.31	0.34	0.36	0.35	0.34	0.35	0.34	0.36	0.37	0.37

Neighborhood	Service	No Event	No Program			Microgrid			50% Critical Backup			Microgrid + 50% Critical Backup		
			Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average
	Convenience Store	1.19	1.10	1.10	1.10	1.15	1.17	1.16	1.14	1.15	1.15	1.17	1.18	1.18
	Banking	0.81	0.66	0.63	0.64	0.77	0.79	0.78	0.74	0.73	0.74	0.80	0.81	0.80
Pacoima[a]	Electricity	1.00	0.26	0.00	0.13	0.68	0.63	0.65	0.26	0.00	0.13	0.74	0.63	0.68
	Grocery	0.86	0.53	0.43	0.48	0.61	0.59	0.60	0.69	0.65	0.67	0.80	0.81	0.80
	Hospital	0.96	0.62	0.46	0.54	0.64	0.49	0.57	0.81	0.74	0.77	0.89	0.83	0.86
	Emergency Shelter	0.70	0.45	0.37	0.41	0.51	0.41	0.46	0.59	0.54	0.56	0.61	0.57	0.59
	Convenience Store	0.94	0.59	0.42	0.51	0.68	0.57	0.62	0.76	0.66	0.71	0.85	0.79	0.82
	Banking	0.80	0.51	0.41	0.46	0.55	0.48	0.51	0.66	0.64	0.65	0.77	0.77	0.77
Sun Valley[a]	Electricity	1.00	0.24	0.00	0.12	0.76	0.65	0.71	0.24	0.00	0.12	0.77	0.65	0.71
	Grocery	1.57	1.08	0.92	1.00	1.10	0.97	1.03	1.33	1.26	1.30	1.48	1.41	1.45
	Hospital	0.93	0.77	0.70	0.73	0.77	0.71	0.74	0.86	0.81	0.83	0.88	0.85	0.86
	Emergency Shelter	0.56	0.32	0.25	0.29	0.34	0.30	0.32	0.43	0.38	0.41	0.44	0.41	0.43
	Convenience Store	1.30	0.84	0.71	0.78	0.85	0.78	0.81	1.07	1.01	1.04	1.18	1.15	1.17
	Banking	1.75	1.30	1.09	1.19	1.31	1.10	1.20	1.51	1.42	1.47	1.60	1.55	1.57
West Hills	Electricity	1.00	0.69	0.00	0.35	0.93	0.78	0.85	0.69	0.00	0.35	0.93	0.78	0.85
	Grocery	1.66	1.38	0.93	1.16	1.49	1.20	1.35	1.52	1.29	1.40	1.60	1.52	1.56
	Hospital	1.08	0.90	0.58	0.74	1.02	0.87	0.94	1.00	0.86	0.93	1.07	1.00	1.04
	Emergency Shelter	0.30	0.25	0.19	0.22	0.27	0.23	0.25	0.27	0.25	0.26	0.29	0.27	0.28
	Convenience Store	0.93	0.76	0.50	0.63	0.83	0.65	0.74	0.84	0.71	0.77	0.91	0.88	0.89
	Banking	0.71	0.56	0.33	0.44	0.68	0.60	0.64	0.62	0.50	0.56	0.70	0.69	0.69
West LA	Electricity	1.00	0.24	0.25	0.25	0.70	0.80	0.75	0.24	0.25	0.25	0.76	0.80	0.78
	Grocery	1.27	0.77	0.85	0.81	0.93	1.12	1.02	1.02	1.10	1.06	1.18	1.25	1.22
	Hospital	1.63	1.13	1.14	1.13	1.28	1.43	1.35	1.37	1.37	1.37	1.53	1.61	1.57

Neighborhood	Service	No Event	No Program			Microgrid			50% Critical Backup			Microgrid + 50% Critical Backup		
			Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average	Earthquake[b]	Flood	Disaster Average
	Emergency Shelter	0.89	0.59	0.54	0.56	0.75	0.75	0.75	0.75	0.69	0.72	0.86	0.84	0.85
	Convenience Store	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Banking	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Wilmington[a]	Electricity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grocery	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
	Hospital	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
	Emergency Shelter	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
	Convenience Store	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	Banking	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63

[a] DAC neighborhood
[b] Earthquake results include four simulated events located close to historically recorded earthquakes from 1965 to 2016, which all happen to fall in the northern part of the city. There are other active fault zones throughout the city and offshore that could more severely impact Wilmington and other southern neighborhoods.

A.7 Additional Community Member Feedback

This section provides verbatim comments from community members of the listening sessions that are relevant to the equity strategies for the distribution grid.

Invest in Infrastructural Capacity—from Building-Scale to Urban-Scale—that Lowers Barriers to Accessing and Using Clean Energy Efficient Technologies

> I think…most of the problem is with the homes in South LA, you know the electrical is outdated so I hear from a lot of neighbors, they can't even run their computers because now computers are too fast and the electrical can't get out that [current]. So, with all these [new energy efficient technologies]—going with electrical stoves, I'm gonna assume that they're gonna be new—so how is that gonna work? I think a program has to be done to encourage the owners or something to upgrade…like when we did [this transition] with the landscaping…they got a program so if they took out their grass to decrease water, something like that. Because it's just terrible what neighbors go through.—South LA Resident

Upgrade and Maintain Aging Infrastructure for Safety and Efficiency

> I'm thinking about just kind of equity and intentionality and thoughtfulness in infrastructure. And so, what [LA]DWP can do to support a vision of a, of a healthy community, like the last question is, for example, like, I see, at least in my community, we still have things like high tension power lines, right? And so when we are looking at the infrastructure necessary to facilitate renewable energy, we are implementing, creating infrastructure, or even going in and remediating and fixing infrastructure that's outdated in ways that supports the renewable energy efforts but not necessarily at the environmental impact expense disproportionately in inner cities. And to me that's also about public health, when we have public health, adverse health outcomes associated with these types of infrastructure. So just being mindful that, again, we're not adding to that, and that we're going and we're thinking thoughtfully about how this can, these efforts can be combined with going into what high tension power lines or other not optimal infrastructural structures and correcting those and doing something better than what already exists.— South LA Resident

Develop Affordable Strategies for Grid and Home Electrical Capacity Upgrades that Do Not Further Burden Low- and Moderate-Income Angelenos

> I don't have air conditioning…The bills [are too high], but obviously I would like to...I would like to have that in my house because one needs air conditioning, especially now that it has been very hot. I have a little dog—we couldn't go out. Where I used to spend a lot of time was on the beach, but because of the [price of] gas [instead]…I would hang around in the area. I would go to other people's houses [to access air conditioning], sadly, because we didn't qualify for those [cooling] programs.— Pacoima Resident

Support the Development and Maintenance of Publicly Accessible Resilience Spaces for Safe and Comfortable Shelter During Disaster Events

- Oh, [in extreme heat] I just blast the AC [everyone laughs]. I mean I close the door, blast the AC, and think about the electric bill later, because it's so hot I can't sleep. During the day I try to go to a cold spot, like a coffee shop or the parks where there's a lot of trees. There's not much I can do because it's so hot.— East LA Resident
- When it's too hot? Um, well, I come here [Boyle Heights Arts Conservatory and Resilience Hub] because there's really good AC and I work. So, luckily, I have a job where there's AC. But for my puppies I have to make sure the AC is running for them, at home. But I try to maintain and manage what I definitely do is make sure that during the day—I lived in Vegas, for a while, so I can deal with like if there's 116 to 110 on a normal day, on average, so you learn how to manage your AC units so that they don't blow or they don't cause any problems where your electrical bill is crazy. Because the reality is, if it's 105 degrees here you just have to cool your house down to like 95. And it does make a big difference. So you just put your AC to 95 or 85 and it actually works really well. Same thing with my car. I do that, I don't put it all the way down to low because it doesn't really function that way. And then at night you drop it down to at least 10 degrees cooler than…the temperature outside. So that way at least you maintain some type of cool house…and keeping the curtains closed during the day, that really helps, and keeping the doors closed, so that way the puppies don't get exhaustion from heat. And it does, just having your AC controlled…really does work.— East LA Resident

Prioritize Upgrading Critical Electrical Infrastructure in Neighborhoods With Older Housing Stock To Prevent Local Blackouts and Their Negative Effects

> I need to find someone with an upgrade of electric because…we have blockage [outages] all the time when somebody hits a [utility] post and the electricity go off and it cause problem in my home now that I cannot wash [clothes] and watch a TV at the same time. My electric goes off…they have these accidents, these people hit these posts [utility poles], then your electric's out for two hours or so, and it messes up your appliance…your appliance be off, and you know, it's a mess.— South LA Resident

A.8 Data Sources and Assumptions

Table A-8. Summary of Grid Reliability and Resilience Modeling Data Sources

Data	Source	Description	Resolution	Data Year
Electrical distribution grid models	LA100 study (with limited updates)	Existing OpenDSS feeder models will be used, potentially with limited priority updates	Feeder	2018
LADWP power reliability metrics	LADWP	SAIDI/SAIFI additional metrics welcome (e.g., customer-oriented metrics)	Distribution station/census tract	2015–2020
Disadvantaged communities (DACs)	CalEnviroScreen 4.0	DACs are identified as tracts with the highest 25% CalEnviroScreen Scores	Census tract	2021
LADWP electrical infrastructure cost database	LA100 (with limited updates)	Unit costs for electrical equipment to evaluate cost of distribution grid upgrades	Utility-managed components	2020
Electrical loads	NREL residential buildings and transportation modeling	Hourly building loads, EV charging profiles	By building and household type and census tract	2020, 2035
Rooftop solar and storage adoption	NREL local solar and storage modeling	Time-series profiles from agents generated in dGen	Census tract	2020 (existing), 2035
SCADA data	LA100/LADWP	Scales and matches loads placed at the transformer	Feeder / circuit / distribution station / distribution station bank / receiving station	2019 (to avoid COVID anomaly)

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