Indicators for Local Energy Resilience

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Abstract

Communities can become more resilient by strengthening energy systems and helping to provide more reliable and affordable energy. A reliable energy supply allows businesses to serve their communities, homes to maintain habitable temperatures, and transportation systems to operate. Affordable energy can reduce low-income households' energy burdens and allow them to better prepare for and respond to hazards.[1] An energy supply accompanied by low levels of pollutants can mitigate health impacts such as asthma and other respiratory illnesses.

In this paper, we identify discrete dimensions of *local energy resilience*, our new term to describe the relationship between community resilience and various aspects of energy. We also develop indicators for these dimensions. The dimensions of and indicators for local energy resilience capture the social, economic, and environmental impacts of energy supply and consumption on community resilience.

Local government decision makers can use these dimensions and indicators as a starting point in considering how the local energy system affects community resilience. We provide information, where applicable, on how local governments can begin to collect data to track progress on each indicator.

[1] ACEEE defines a household's energy burden as the percentage of income it spends on home energy bills.

Introduction

Communities can become more resilient by strengthening energy systems and helping to provide more reliable and affordable energy. A reliable energy supply allows businesses to serve their communities, homes to maintain habitable temperatures, and transportation systems to operate. Affordable energy can reduce low-income households' energy burdens and allow them to better prepare for and respond to hazards. An energy supply accompanied by low levels of pollutants can mitigate health impacts such as asthma and other respiratory illnesses.

In past research, we defined *resilience* as a community's reduction of and preparation for risk. Using the formula described in the callout box to the right, we used prior thinking around risk to outline the components of resilience. Our report also established the potential value of using energy efficiency as a resilience strategy, drawing on its benefits related to emergency response and recovery, socioeconomic concerns, and climate change (Ribeiro et al. 2015).

The level of risk to a community is a function of the hazards it faces, its vulnerability to the damaging effects of those hazards, and its capacity to cope with those effects. The following formula summarizes the relationship among these variables:

$$\text{Risk} = \frac{\text{Hazards x Vulnerability}}{\text{Capacity to cope}}$$

Each factor in the equation impacts overall risk and therefore can affect a community's resilience. Hazards are threats a community is facing (e.g., flooding). Vulnerability is the susceptibility of a community to the effects of a hazard (e.g., buildings' exposure to the effects of flooding). Capacity to cope is the ability of a community to respond to the impacts of a hazard (e.g., ability to evacuate flooded areas and availability of insurance reimbursements for damages).

This paper goes a step further by identifying discrete dimensions of *local energy resilience*, our new term to describe the relationship between community resilience and various aspects of energy supply and consumption. For each of these dimensions we develop indicators that community stakeholders can use to understand how energy supply and consumption affect resilience.

Earlier Resilience Indicators

Our literature review indicates that most indicator systems do not focus on energy supply or consumption. In 2015, for example, Arup issued a *City Resilience Framework* to help local governments assess the extent of their community's readiness to face risk (Arup 2015). This research takes a broad approach to resilience, recognizing the unknown stresses and shocks communities may experience. The framework includes four categories of indicators: leadership and strategy, health and well-being, infrastructure and ecosystems, and economy and society. The indicators are crosscutting and holistic, but energy is not a major focus.

In an earlier study by Cutter, Burton, and Emrich (2010), "Disaster Resilience Indicators for Benchmarking Baseline Conditions," the authors quantitatively assess the disaster resilience of counties in the Southeast United States. They use variables related to social, economic, institutional, and infrastructure resilience as well as community capital; again, energy systems are not a focus.

Other indicator systems deal more with energy but limit their focus to the reliability of the electricity system (Willis and Loa 2015; Molyneaux et al. 2014). However as Ribeiro et al. (2015) show, energy considerations beyond reliability affect community resilience. For example, high energy burdens can prevent low-income households from being prepared for an unexpected event or emergency.

Applying Resilience Indicators

The dimensions of and indicators for local energy resilience that we introduce below capture the social, economic, and environmental impacts of energy supply and consumption on community resilience. They give a fuller understanding of the relationship between energy considerations and community resilience.

These indicators can help inform the activities of local government stakeholders who are interested in the role their energy systems can have in increasing community resilience. The local government staff who are charged with overseeing community resilience vary from city to city. For example, cities participating in 100 Resilient Cities have chief resilience officers to lead efforts, while others may be relying on multiagency teams to develop their resilience capacities (100 Resilient Cities 2016; Ribeiro and Jarrett 2016). These teams may include staff from sustainability offices, energy offices, and departments of health or emergency management.

We keep the focus on the local scale so that these indicators can better inform local governments' resilience strategies and activities. Even if some dimensions of energy supply and consumption are not within the jurisdiction of a particular community, the indicators capture activities that communities may be able to influence.

By developing a better understanding of the dimensions of local energy resilience and the indicators that can be used to assess them, local government staff can start to gauge how their local energy systems are contributing to their community's overall readiness to handle risk. Government staff can then use the indicators to establish a local energy resilience baseline and inform resilience planning processes. As communities track progress against these indicators over time, local governments may find the results valuable to policymaking efforts. Policymakers could use these findings to inform programs, set goals for particular indicators, and develop policies to increase local energy resilience.

As communities consider and potentially apply the indicators, the solutions they develop will likely incorporate renewable energy and energy storage. However, in our discussion of paths to resilience for each dimension, we limit our discussion to the role energy efficiency can play in increasing local energy resilience.

Community Resilience Dimensions and Indicators

Table 1 summarizes the dimensions of local energy resilience, indicators for each dimension, potential hazards associated with those dimensions, and energy efficiency solutions.

Table 1. Local energy resilience dimensions and indicators

Local energy resilience dimension	Indicator	Potential hazard	Energy efficiency solution that reduces vulnerability or increases capacity to cope
Energy infrastructure and reliability	Improvements in community-wide energy efficiency	Disruptions and outages	Reduce demand through efficiency
Transportation connectivity	Availability of, and access to, multiple transportation modes	Service disruptions to transportation modes	Location efficiency; multimodal transportation system
Distributed generation	Number of critical facilities served by efficient distributed energy	Loss of power at critical loads	Combined heat and power (CHP)
Thermal building performance	Building code stringency and compliance	Inability to shelter in place safely	Well-insulated buildings that maintain temperature
Urban heat island effect	Temperature gradient between urban area and surrounding rural areas	Stress on electric system	Energy efficiency to reduce system peak
Climate change	Levels of community-wide GHG emissions	Varied (climate change acts as a risk multiplier)	Reduce GHG emissions through efficiency measures
Particulate matter pollution	Levels of particulate pollutants	Chronic health issues	Reduce local pollution through efficiency measures
Energy burden	Proportion of household income spent on energy bills (especially for low-income households)	Inability to prepare for the unexpected (due to high burden)	Lower bills through energy efficiency
Energy bill stability	None	Inability to prepare for the unplanned (due to unexpected bill swings)	Reduce exposure to swings through energy efficiency

We loosely ordered the dimensions in table 1 according to physical, environmental, and socioeconomic components of local energy resilience. The initial dimensions, including transportation connectivity and distributed generation, focus on physical assets and infrastructure. The failure of these assets would lead to acute hazards, such as blackouts. Afterward, we discuss climate change and socioeconomic dimensions. The hazards associated with these tend to be more chronic than acute. Protracted exposure to these hazards can negatively affect a community and erode capacity to cope over time.

For most dimensions, we could have listed several hazards. To keep our discussion focused, though, we have concentrated on the primary hazard associated with each dimension. For example, when we discuss hazards associated with poor thermal building performance, we focus on exposure to temperature swings and the potential inability to shelter in place.

When discussing that dimension, we do not deeply explore hazards related to financial burdens or greenhouse gas emissions.

While we list each dimension separately as a discrete characteristic of local energy resilience, several are crosscutting. For example, efforts to improve thermal building performance by improving insulation could also reduce a household's or business's energy burden.

We discuss each dimension of local energy resilience in the sections that follow.

Energy Infrastructure and Reliability

Communities need a reliable energy supply for daily life. Energy infrastructure must maintain reliability through times of peak demand to ensure this steady energy supply. To this end, utilities have reserve margin requirements that set aside a designated amount of electricity capacity in excess of the forecast peak demand. However high and unpredictable levels of energy consumption due to weather extremes can strain infrastructure and overburden the reserve margins, leading to blackouts (York, Baatz, and Ribeiro 2016). For example, the polar vortex of 2014 caused demand for natural gas to increase sharply. Many of the natural gas pipelines were unable to support the demand, leaving households without power. Heat waves can have the same impact. In 2016, a heat wave in Southern California left some 5,300 households without power for several hours (Serna 2016). The Los Angeles Department of Water and Power reported that peak demand at that time was 50% higher than average (Serna 2016).

In the sections that follow, we discuss some of the ways blackouts can adversely affect communities. Without air conditioning or heating, temperatures in homes can increase or drop to dangerous levels (see Thermal Building Performance). Blackouts can also affect critical community services, including water treatment and distribution, communication, hospitals, and dispatch centers (see Distributed Generation).

Assessing Energy Infrastructure and Reliability

Utility system planners can use several frameworks to assess the reliability of the utility system. However the goal of this paper is to provide indicators assessing a community's contribution to each dimension of resilience. In this case, communities can contribute to increased reliability by increasing community-wide energy efficiency. Communities can partner with their local utility to gain access to natural gas and electricity consumption data, so that they can assess their progress over time.[2]

Paths to Greater Resilience

Reduce energy use through energy efficiency. Energy efficiency can alleviate stress on infrastructure by reducing energy use and lowering peak demand. In response to the

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[2] If data from the utility are unavailable, the Energy Information Administration has a database (EIA 861) that includes information on electricity retail sales in MWh (www.eia.gov/electricity/data/eia861/). This can be found by downloading the Sale to Ultimate Customer zip file and searching for the local utility in your community. Natural gas data are only available by state and can be found in the Natural Gas Monthly update by downloading table 18: Natural gas deliveries to all consumers by state. www.eia.gov/naturalgas/monthly/.

California energy crisis in 2000–01, there was a statewide effort to use energy efficiency and demand response to curb energy consumption. It literally helped keep the lights on (York, Kushler, and Witte 2007).

Target programs that reduce peak demand. Certain energy efficiency programs have a larger impact than others on reducing peak demand. For example, in colder climates, programs that target the thermal performance of buildings will do more to shave demand because of the energy required to heat a home. Demand response programs are another effective strategy for reducing demand (Nadel 2017).

TRANSPORTATION CONNECTIVITY

Communities with multiple modes of transportation, like public transit and bicycle sharing, provide residents options for getting around and leaving if need be. Localities with limited transportation connectivity can be worse off during emergencies or service disruptions. Residents may not be able to navigate their communities if the mode of transportation they depend on is unavailable. For example, many residents were unable to evacuate New Orleans shortly before Hurricane Katrina made landfall because they lacked access to cars (Hoffman 2009).

Transportation access is a concern for many low-income communities, who often do not have adequate transportation options. Members of low-income households can have difficulty visiting their doctors or picking up medication; Syed, Gerber, and Sharp (2013) found that 25% of low-income patients had missed or rescheduled doctors' appointments due to lack of transportation. According to a National Conference of State Legislatures report, people with disabilities and low-income respondents reported lack of transportation as one of their biggest barriers to employment (Rall 2015). Transportation-related costs, the second-largest expense for households in the United States, further burden low-income households (Vaidyanathan 2016). Costs are especially burdensome for low-income households in suburban areas who must rely on cars to get around (Sawhill 2012).

Assessing Transportation Connectivity

Communities can measure their transportation connectivity by using the Center for Neighborhood Technology's AllTransit index. It rates cities on a scale of 0–100 based on the number of bus routes and train stations within walking distance of households and the frequency of service (CNT 2017). Other indices also exist for walkable neighborhoods, commuting by bicycle, and commuting by walking.

Paths to Greater Resilience

Develop multimodal transportation. A community with multiple modes of transportation has alternatives if any one mode is unavailable. For example, when Washington, DC, launched Safe Track, an extensive maintenance plan for the District's transit system, Capital Bikeshare saw an increase in ridership of almost 10% (Lazo 2016). Following the collapse of a major section of I-85 in Atlanta, the Metropolitan Atlanta Rapid Transit Authority saw an increase of 73% in rider traffic on the city's rail lines (Landrum and Foody 2017).

Pursue location efficiency. Prioritizing location efficiency can help spur better connectivity. Compact communities are better equipped to handle multiple modes of transportation such as public transit, bicycling, and walking.

DISTRIBUTED GENERATION

Centralized sources, like large power plants, generate most of the electricity consumed in the United States. Transmission and distribution systems deliver energy from centralized sources to households and businesses. However distributed energy resources (DER), like combined heat and power (CHP) and distributed solar, have begun securing a foothold in the electricity system. These resources allow households and businesses to consume energy closer to the point of production. Centralized generation is a reliable source of electricity, but blackouts and brownouts occur even in the most reliable systems. During severe storms or large-scale emergencies, it is more likely that longer-term outages will occur. For example, during Hurricane Sandy, 8.5 million homes and businesses lost power during the height of the storm (Lacey 2014). Over 600,000 residents in Long Island waited more than two weeks for utilities to restore their power (Riddell 2013).

Power outages of any duration are especially problematic for critical community facilities, like hospitals and water treatment plants. If power is unavailable, hospitals can lose heating or air-conditioning, water pressure, the ability to sterilize equipment, refrigeration for medicine and food, and the use of elevators to transport patients to different floors (HPHSCC 2016). Outages can also affect police stations, 911 call centers, and community shelters. Distributed energy resources may be able to help these facilities avoid these outages and continue their operations.

Assessing Efficient Distributed Generation

Planners can assess whether efficient distributed energy systems serve the critical facilities in their communities. The ICF International CHP Installation Database lists each CHP installation in the United States.[3] Here you can find the capacity (kWh) of CHP installations within your city and the facilities served by these CHP systems (DOE 2016).

Paths to Greater Resilience

Increase the number of critical facilities served by CHP. CHP can continue providing power and thermal needs when the grid is down. It has proven its value during several extreme weather events. After Hurricane Sandy, CHP kept the heat and lights running in some multifamily buildings, kept Long Island's South Oaks Hospital in operation, and allowed the continuous treatment of wastewater at some wastewater treatment plants (Chittum 2012).

Put energy efficiency first. Communities can pursue renewable energy and storage solutions to provide backup power to critical facilities. Reducing energy consumption first, though, can help shave the load of a building. This more-efficient building will then require less storage and distributed generation to meet its critical load.

[3] The CHP Installation Database is available at doe.icfwebservices.com/chpdb/.

THERMAL BUILDING PERFORMANCE

Living in inefficient housing can expose families to temperature swings. During power outages, poorly insulated homes will lose heat in winter months and gain heat during the summer, quickly becoming unlivable for residing families (York, Baatz, and Ribeiro 2016). During a blackout from a heat wave, a single-family home can reach temperatures up to 90°F on the first day (Urban Green Council 2014). And during an extended winter outage, the temperature of a home can drop to 35°F after just three days without heating (Leigh et al. 2014). Even in moderate climates, indoor temperatures can fall enough to endanger the lives of people with preexisting health conditions or the elderly (Rudge and Gilchrist 2005).

A home that is well insulated, weatherized, and tight (meaning that air leaks are minimized) will maintain its temperature better than a home with poor insulation. During a power outage, well-insulated homes will better protect families from temperature swings, allowing them to shelter in place for a longer time.

A family living in an inefficient home will also pay more for electricity. More money spent on utility bills can leave households with less to money for other essentials, like food and water (see Energy Burden, below).

Assessing Thermal Building Performance

Assessing building energy code stringency is a way to begin evaluating building efficiency, including thermal performance. A stringent code may not translate to high-performing housing, though, because not all buildings may comply with codes (IMT and NRDC 2016). The City Energy Project, a collaboration between the Institute for Market Transformation and the National Resources Defense Council, provides a step-by-step methodology for conducting a baseline assessment of energy code compliance (IMT and NRDC 2016).

Paths to Greater Resilience

Improve thermal performance of buildings. Increasing energy efficiency in homes by improving their building envelopes is a core strategy to reducing occupant vulnerability to heat waves and cold snaps. There are many examples showing successful community-wide efforts to combat poor-quality housing, including the Weatherization Assistance Program (WAP).[4] Weatherization includes some of the lowest-cost building envelope improvements, like adding insulation or weather-stripping doors and windows.

[4] WAP is a Department of Energy–administered program aimed at improving the energy performance of low-income families' homes.

URBAN HEAT ISLAND (UHI) EFFECT

The UHI effect causes urban temperatures to be several degrees hotter than those in surrounding areas.[5] Urban heat islands can impact public health, energy consumption, and quality of life (Hewitt, Mackres, and Shickman 2014).

In cities with severe urban heat islands, more people may get sick or die during heat waves. Heat kills more people each year than any other weather-related hazard (EPA 2016b). More than 700 people died during the Chicago heat wave of 1995, and more than 100 lives were lost in 2006 during a weeklong heat wave in New York City. During these events, the risk of mortality was much greater in low-income neighborhoods where access to air-conditioning was scant (Rosenthal, Patrick, and Kristina 2014).[6]

Vulnerable populations are especially susceptible to the effects of urban heat islands. In response to heat waves, most households turn on air-conditioning to maintain habitable temperatures in their homes. However low-income households are less likely to have air-conditioning (EIA 2011), and if they do, it may be difficult to afford to run it as often as the average household does.

Urban heat islands can also increase energy consumption. According to Lawrence Berkeley National Laboratory (LBNL), UHI-related increases in air temperature are responsible for 5–10% of urban electricity demand (Berkeley Lab 2017). Greater demand exerts more stress on infrastructure and supply resources.

Assessing UHI

Communities can assess the UHI effect by finding the difference between data collected from two weather stations, one within a city and one outside it. Most of these data are available from websites. For example, Wunderground.com can provide temperatures reported by every weather station within a specified zip code.

Climate Central provides another source of UHI information; its online Summer in the City feature calculates the UHI effect in 60 of the largest US cities (Kenward et al. 2014).

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[5] Energy consumption, a predominance of dark, impermeable surfaces such as asphalt, roofs, and pavement, and sparse vegetation drive the UHI effect (Hewitt, Mackres, and Shickman 2014). Dark, impermeable surfaces absorb heat during the day—conventional asphalt can reach summertime temperatures of 120–140°F—and release heat during the evening, which increases nighttime temperatures. Transportation and other energy-consuming activities in cities, such as the use of air-conditioning, emit pollutants that help retain heat. Last, cities generally lack the benefits of vegetation, which provides natural cooling via shade from the tree canopy and the release of water vapor.

[6] Temperatures over 90°F are associated with dangerous levels of ozone pollution that can trigger asthma attacks, heart attacks, and other health impacts (Kenward et al. 2014). Children, adults with preexisting illness, and elderly people are the most vulnerable to the heat and the poor air quality associated with high temperatures.

Paths to Greater Resilience

Increase reflective surfaces. Light-colored, reflective surfaces (like cool roofs or cool pavements) reflect more heat than they store. They will stay cooler and will not exacerbate high ambient air temperatures.

Add vegetation. Trees can provide shade for buildings, which helps reduce cooling loads during hot days. They also cool the ambient air through evapotranspiration and provide an additional benefit by filtering rainwater (Kats and Glassbrook 2016). Communities can develop and incentivize new vegetation or preserve existing vegetation.

Reduce energy use through efficiency. Certain strategies to reduce energy consumption in both buildings and transportation can help mitigate the urban heat island effect. For example, location efficiency (see Transportation Connectivity) can help encourage a more compact community and reduce the need to drive. This would reduce pollutants that can contribute to warmer temperatures (see Local Area Pollution).

CLIMATE CHANGE

Climate change is a risk amplifier, increasing the magnitude of potential hazards already facing a community (DOD 2014). It can affect hurricanes, wildfires, droughts, heat waves, and other hazards. The increase in intensity and frequency of some weather-related hazards have been linked to higher temperatures (National Climate Assessment 2014). Princeville, North Carolina, recently had its second 100-year flood in 17 years. Some parts of southern Louisiana saw upward of 30 inches of rain in a span of three days during an August storm; this is roughly half of the state's average annual rainfall (Di Liberto 2016). Each of the first six months of 2016 set a record as the warmest since temperatures have been recorded (Lynch 2016).

Climate change can also have cascading effects across communities. For example, more-extreme storms can stress aging infrastructure and accelerate property damage. Those living in areas vulnerable to more extreme weather may have more difficulty getting insurance to cover their losses (Melillo, Richmond, and Yohe 2014). Hotter temperatures could amplify the urban heat island effect, leading to higher cooling needs and increased demand on energy systems. As a result, climate risk is a major—and increasing—issue of concern for communities (Ribeiro et al. 2015).

Assessing Greenhouse Gas Emissions

Communities can use EPA's Local Greenhouse Gas Inventory Tool to get an accurate accounting of their greenhouse gas emissions.[7] The tool is in a spreadsheet format and allows communities to scale and adjust inputs reflecting different characteristics and levels of activity (EPA 2015). ICLEI-USA has also developed ClearPath, another GHG inventory tool for communities.

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[7] This resource is not currently available on EPA's website.

Paths to Greater Resilience

Reduce energy use through energy efficiency. Communities can work to reduce energy waste in public buildings, private buildings, and transportation in order to avoid unneeded greenhouse gas emissions. While one community alone cannot reduce enough GHGs to reverse climate change, the collective action of cities can affect overall emissions (Zillman 2017). Cities around the globe account for two-thirds of energy demand and 70% of energy-related carbon dioxide emissions (IEA 2016).

PARTICULATE MATTER POLLUTION

Local area pollutants, like carbon monoxide, lead, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter (PM), can pose a severe health threat to communities (EPA 2016a). PM pollution, which affects more people than any other pollutant (Krzyzanowski and Gapp 2011), is a complex mixture of extremely small particles and liquid droplets suspended in the air (EPA 2017b). Particles that are smaller than 10 micrometers in diameter pose the most severe health threat because they can penetrate deep into the lungs (EPA 2016c).[8]

Both short-term and long-term exposure to PM can have acute and chronic health effects. Exposure to high concentrations of PM for a few hours can cause coughing, wheezing, heart attacks, and even death. Short-term exposure is more likely to affect people in at-risk populations, including infants, people over the age of 65, and those with preexisting health conditions (ALA 2016). Long-term exposure may shorten life expectancy by one to three years (Pope 2000).

The effects of PM on communities are not always evenly distributed. Low-income households are more likely to be exposed to environmental pollutants due to inefficient housing, outdated building materials, and fuel-burning appliances (Adamkiewicz et al. 2011).

Assessing Particulate Matter Pollution

Measurements for many local area pollutants, including PM, are widely available. EPA's Air Quality Index (AQI) displays data by state and zip code (if available) on pollutants such as PM2.5 (EPA 2017a). Data can be viewed in 20-minute intervals or by the daily average for the entire calendar year.

Paths to Greater Resilience

Reduce energy consumption through energy efficiency. Communities can help decrease PM pollution by lowering energy waste, thereby obviating some emissions from electricity generation and the transportation sector. The World Health Organization (WHO) recognizes increased energy efficiency in urban planning and in the power sector as a way to reduce air

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[8] Sources of outdoor PM include electricity generation, transportation, industrial activities, and burning of fuels such as oil, natural gas, coal, or organic matter. Exposure to PM and other pollutants is just as likely indoors as outdoor. PM can easily infiltrate poorly sealed and ventilated homes and it can also originate indoors from sources that include cooking, fireplaces, and space or kerosene heaters.

pollution, including particulates (WHO 2016). Energy efficiency programs can also reduce indoor PM for program participants.

ENERGY BURDEN

The median energy burden for US low-income households is more than double that of the average household (Drehobl and Ross 2016). A combination of low household income, high utility bills, and inefficient housing stock can drive energy burdens upward.

Low-income households with high energy burdens have limited flexibility to prepare for and respond to unplanned events. They have a limited disposable income from which to draw savings and have fewer resources to respond to an immediate disruption. High utility bills also compound affordability and livability problems for low-income households. For example, a household may not have the resources to keep air-conditioning running during a heat wave or to turn on the heat during a cold snap. And more income spent on energy bills means less money available for other essentials, like food and medicine.

High energy burdens can also have negative long-term effects on health and well-being that make it more difficult for households to cope with and recover from hazards. These effects include mental and physical problems due to thermal discomfort, inadequate lighting, unsafe housing conditions, and financial and social stress.

Assessing Energy Burdens

Measuring energy burdens at the city level can be challenging. To do so accurately, cities need to collect household-level data on annual energy bills and annual income, then divide each household's annual energy costs by annual income. Cities can then calculate the median or average energy burden in order to accurately depict the energy burdens in a given area. It is important to keep in mind that the average energy burden for a defined geographic area can be misleading. Certain groups, such as low-income households, renters, and the elderly, among others, face higher energy burdens than the average household.

ACEEE calculated energy burdens using 2011 and 2013 data from the *American Housing Survey* (AHS) data set developed by the US Census Bureau and US Department of Housing and Urban Development (Drehobl and Ross 2016). Although it compiles information for many metro areas, AHS does not have data for all metro areas. If AHS data are not available for a specific city or metro area, local officials can collaborate with their utilities to obtain household-level energy-use data or can explore other data collection possibilities.

Paths to Greater Resilience

Develop energy efficiency programs targeted to low-income households. Energy efficiency programs can support low-income households through energy and cost savings and a variety of other health, safety, and quality-of-life benefits (Cluett, Amann, and Ou 2016). Energy efficiency often requires high up-front capital, though, which is a barrier for low-income households that do not have funds on hand or access to credit. Local governments can help overcome this barrier by working with their utilities and/or using other resources to provide support for existing and new energy efficiency programs.

ENERGY BILL STABILITY

Hazards or fluctuations in energy demand may cause different retail energy bills to increase or decrease quickly. Retail electricity rates generally are regulated and not subject to substantial swings from month to month. Other energy prices, like gasoline prices or natural gas rates in some states, are more prone to swings. For example, during the cold snap caused by the polar vortex of 2014, the price of natural gas and other heating fuels rose due to a combination of surging demand and constraints on delivery. (Ladislaw 2014). Seasonal changes in demand can also lead to higher energy bills, with cooling requirements leading to increases in summer and heating requirements bringing increases in winter.

Bill swings can affect a community's capacity to cope with hazards. Most households are prepared for these fluctuations; higher-income households are often unaffected by volatility in their energy bills. However households that have a high energy burden are more at risk from stresses like the polar vortex (NRDC 2015).

Because low-income households may already be strained for necessities such as food, water, and medicine, an unpredictable rise in an energy bill can compound everyday affordability. According to a National Energy Assistance Survey distributed to a sample of low-income households, behaviors in response to high energy bills changed as follows: 23% turned off their heat or air-conditioning, 21% left their home for part of the day, 33% used a kitchen stove or oven to provide heat, and 24% went without food for at least one day (Choate and Wolfe 2011). Each of these outcomes can further compromise household resilience.

Assessing Energy Bill Stability

We have not determined an indicator or systematic measurement for community-wide energy bill stability. However communities with access to utility data can gauge past energy loads to gain a better understanding of peaks in energy bills.

Paths to Greater Resilience

Pursue energy efficiency strategies for low-income households. Energy efficiency can work to reduce consumer vulnerability to volatility. For example, a home retrofit will increase building efficiency and lower a home's energy demand, which can mitigate the magnitude of bill swings. However more research is needed to identify the impacts that energy efficiency can have in reducing the volatility of energy bills in different demographic groups.

Conclusions

We found that some resilience indicator efforts do not fully capture the effects that energy considerations have on community resilience. Existing indicators either focus on electricity reliability or do not focus on energy at all. Our new indicators capture the social, economic, and environmental impacts of energy supply and consumption on community resilience. For example, they reflect the role that efficient distributed energy systems can have in maintaining power at critical community facilities. They also address the impact of high energy burdens on the ability of low-income households to cope with unplanned events or emergencies.

The indicators can help inform the activities of local government stakeholders who are interested in the role their energy systems can have in increasing community resilience. Government staff can use the indicators to establish a local energy resilience baseline and inform resilience planning processes. As communities track progress over time, local governments may find the results valuable for informing programs, setting goals for particular indicators, and developing policies to increase local energy resilience. Policymakers can also learn how to use energy efficiency to increase local energy resilience.

We envision several other potentially valuable outgrowths of this paper. Exploring each dimension in detail could be a project unto itself. However some dimensions have been more thoroughly studied than others. For example, ample research exists on energy reliability, but less is available on energy bill swings. Further work could flesh out these under-researched dimensions. Also, case studies documenting how cities use these indicators would help disseminate best practices and lessons learned to other interested stakeholders. Our hope is that this effort will spur local governments to track their progress toward increasing local energy resilience and will help to increase consideration of energy efficiency in resilience planning.

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