



Assessing the household burdens of infrastructure disruptions in Texas during Winter Storm Uri

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Abstract

In February 2021, severe winter weather conditions associated with Winter Storm Uri triggered an energy infrastructure failure in Texas. Most Texans lost electricity, some lost potable water, natural gas, and suffered other infrastructure-related service disruptions that had profound household consequences. Although several studies have documented the disparities in terms of the types and extent of disruptions Texans experienced during Uri, there is little information about the impact of these disruptions in terms of their burdens on households. Guided by the Capabilities Approach framework, a survey of Texan households was conducted to identify the outage characteristics and capability losses for different household types, as well as the *burdens* that those disruptions posed to households using both objective and subjective measures. Our results indicate that households that endured longer and constant electricity outages suffered more severe impacts across all measures, including more disrupted household capabilities, increased time, and financial costs to cope during the outages, as well as greater declines in reported life satisfaction. We found that low-income households, households with children, and households with disability challenges suffered more severe objective burdens during the storm, although subjective results for these households were mixed. Households with members over the age of 65 fared better in terms of objective measures, yet suffered more in terms of subjective well-being. Moreover, households that had prior experience with a prolonged outage reported significantly smaller reductions in well-being during the storm than other households, despite not showing any difference in objective measures. Ultimately, our results offer context-specific, post-event information about the impacts and needs of different types of households during Uri that are important for informing emergency management and community resilience planning.

Keywords Household burdens · Capabilities approach · Community resilience · Infrastructure disruptions · Disaster resilience

1 Introduction

Winter Storm Uri included three arctic weather systems that swept across the USA from February 10 to 20, 2021, bringing severe winter weather conditions to almost three-quarters of the nation. Millions of Americans experienced frigid temperatures, historic snowfall, and dangerous ice accumulations, creating a dire situation for many residents who were left scrambling to meet their basic needs (Bogel-Burroughs et al. 2021; Dolce 2021). The storm caused particularly severe impacts on the state of Texas. For the first time in recorded history, all 254 counties in the state were placed under a winter storm warning by the National Weather Service (Villarreal 2021). Texas was not only hit especially hard by the storm, but was caught unprepared for a winter storm of this magnitude (Bogel-Burroughs et al. 2021; Cavanagh 2021). Ultimately, the storm has been blamed for 246 official deaths in Texas (Aldhous et al. 2021).

The severe impacts and high death toll in Texas during Uri were, in part, because the storm triggered an energy infrastructure failure, the worst in state history and the largest in the U.S. since the 2003 Northeast Blackout (Electric Choice, n.d.). The winter weather conditions, infrastructure failures, increased energy demand, and fuel limitations during the storm, all led to deteriorated power grid conditions, causing load shedding and rolling blackouts across the Electric Reliability Council of Texas (ERCOT) service area (University of Texas at Austin 2021). ERCOT had originally announced that Texans would experience “rolling outages” that would leave households without power for 45 min at a time (Ferman et al. 2021); ultimately, however, the power demand so greatly exceeded generation capacity that many Texans were without power for days at a time (Busby et al. 2021). According to a University of Houston study, 69% of Texans lost electrical power, and about half of Texans lost access to running water (Watson et al. 2022). Other infrastructure-related impacts of the storm include difficulty obtaining food or groceries, the loss of internet service, and difficulty obtaining bottled water.

The infrastructure disruptions caused by Uri were not experienced equally by households across the ERCOT service territory. For example, in the City of San Antonio, official power outage durations ranged from non-existent to two-and-a-half days long (CPS Energy 2021; Paalcios 2021). Impacts in rural areas of Texas were reported to be particularly severe, where households are often less able to depend on resources and services in nearby communities (Houston Advanced Research Center 2021). Sociodemographic disparities in power and water outages associated with Uri were also found in Texas. For example, Grineski et al. (2023) found that longer power outage durations were associated with being Black, having children, and renting one’s residence. Flores et al. (2023) found that counties with relatively high Hispanic residents tended to endure more severe power outages and that Black respondents were more likely to report outages lasting longer than one day. Moreover, Lee et al. (2022) revealed significant disparities in the extent and duration of outages experienced by low-income and minority groups in Harris County, Texas.

Infrastructure disruptions like those experienced during and after Uri have severe well-being consequences for households, which typically depend upon energy, water, and other infrastructure services (e.g., lighting and running water) and the capabilities they enable (e.g., the ability to cook food and access drinking water) to meet their critical needs. Additionally, because households have varying needs, preferences, and abilities, the impacts of similar infrastructure disruption types may have drastically different impacts for diverse populations (i.e., power outages of similar durations may be particularly severe and acute for some, and yet a matter of inconvenience for others) (Cutter et al. 2003; Obolensky et al.

2019). When considering the disparities in the duration and extent of infrastructure disruptions suffered by Texans during Uri, the resulting burdens of outages on households are even more likely to be unequal. While several studies that have documented the disparities among Texans in terms of the types and extent of disruptions experienced during Uri (e.g., Lee et al. 2022), there is little information about the consequent impacts of these outages on different types of households.

This research, therefore, seeks to empirically examine the disparate impacts of power outages (and associated infrastructure disruptions) in Texas on households' abilities to meet basic needs (i.e., being healthy and feeling safe) during Winter Storm Uri. Guided by the Human Capabilities Approach (Sen 2001), discussed in more detail in the next section, a survey of Texan households was conducted to identify the capability losses experienced by different households, as well as the *burden* that those disrupted capabilities had on household outcomes in terms of both objective and subjective measures. The objective measures include the number of disrupted household capability types reported, as well as the increased time and financial costs incurred by households to adapt to reported disruptions. To capture subjective impacts, we assess household well-being (i.e., reported life satisfaction) during the outages as well as changes in life satisfaction scores from before the outage to during Winter Storm Uri.

We also examine the role of prior experience with power outages in mitigating household outcomes. Unlike other major outage events in recent years, Uri is distinct because of the diverse range of prior outage experiences among the population of Texas. While the state's southern and coastal regions have experienced multiple outages in recent years (e.g., Hurricane Ike and Hurricane Harvey) (Hoffman et al. 2009; Lee and Hodge 2017) the 2021 power outages were at an unprecedented scale, affecting portions of the population that have not experienced prolonged outages in recent memory (Ferman et al. 2021). By comparing the responses of people with varying levels of prior outage experience, a more accurate measure of the true household burdens of disruptions on households caught off-guard by Winter Storm Uri is possible, informing other places and contexts where investments in resilience planning have not been a priority.

In particular, the following research questions guided our data collection and analysis:

1. What capabilities were disrupted during Winter Storm Uri and which type of disruptions were most impactful to households?
2. How did the disruption of capabilities (and the outcomes associated with adapting to these disruptions) differ based on outage duration and characteristics?
3. How did the household outcomes associated with adapting to capability disruptions differ across vulnerable household types?
4. What role (if any) did prior outage experience have in mitigating household losses?

Although the types of capabilities disrupted will likely vary across households, we hypothesize that the most impactful disruptions will be associated with lifeline energy services for households related to water, food, and medicine. We also expect to find that longer-duration outages will be associated with a greater number of household capabilities lost and will also be associated with greater burdens—both objective and subjective—as households work to mitigate disruptions to these capabilities. We also expect that socially vulnerable households (e.g., households with elderly, poor households, or households with disabled members) will report more significant burdens related to disrupted household capabilities than comparatively less-vulnerable households. Finally, we expect that prior

outage experience may mitigate the household consequences of disruptions, as households with prior outage experience may have undertaken preparatory measures (e.g., purchasing a generator or having excess food on hand) or have developed greater adaptive capacity because of this prior outage experience.

2 Literature review

2.1 Capabilities approach

The capabilities approach (CA) to human development is a widely-recognized theory for understanding the process of human development and well-being (Sen 2001). It has been utilized by organizations such as the United Nations to compare and assess human development progress across nations (United Nations Development Programme 2022). The CA offers a way to measure well-being as what people are able to do with the resources they have. This is an alternative perspective compared with many traditional economic metrics of development that tend to focus on measures of income as a proxy for well-being. In this way, the CA emphasizes that people differ in their ability to transform resources into actual achievements. A key aspect of the CA is the concept of *capabilities*—what people have the ability to do and become, or the portfolio of possibilities that are available to an individual or household to achieve a life they consider valuable. Universally valued measures of basic capabilities include good health, access to knowledge, and a decent standard of living, among others (Nussbaum 2001). These capabilities are influenced by *resources* (e.g., entitlements, rights, or financial resources) and how individuals can use those resources to enable capabilities through *conversion factors*. Conversion factors can be personal, social, or environmental factors (e.g., mobility, health, infrastructure, social norms) that enable or inhibit the portfolio of capabilities available to a person (Sen 1992). For instance, if a person is disabled or has limited access to healthcare services, they are likely at a comparative disadvantage in terms of the capabilities they are able to achieve, such as being healthy or getting from place to place. Therefore, unequal conversion factors lead to different abilities to transform resources into capabilities. Capabilities that are realized through individual choice are referred to as *functionings* (Sen 2001). A simple example is the capability to eat all kinds of food yet choosing to be a vegetarian for health reasons. The decision (or choice) to be vegetarian to achieve a healthy lifestyle would be considered a *realized capability* or *functioning*. Ultimately the CA emphasizes the importance of capabilities, as they reflect the real opportunities or freedoms that people have to choose from. Ultimately, people that have a lot of resources and appropriate conversion factors will have more opportunities to live a life they value. Figure 1 summarizes the general capabilities approach framework, which may be applied to a diverse range of contexts and applications (see, e.g., Day et al. 2016).

2.2 Capabilities approach applied to infrastructure disruptions

Drawing on previous literature which applies the CA to infrastructure services at the household level, we have adapted Fig. 1 to show how infrastructure disruptions can impede household capabilities and functioning, shown in Fig. 2. Our framework



Fig. 1 The Capabilities Approach Framework indicating the theorized relationship between resources, capabilities and functionings (adapted from Robeyns 2005)

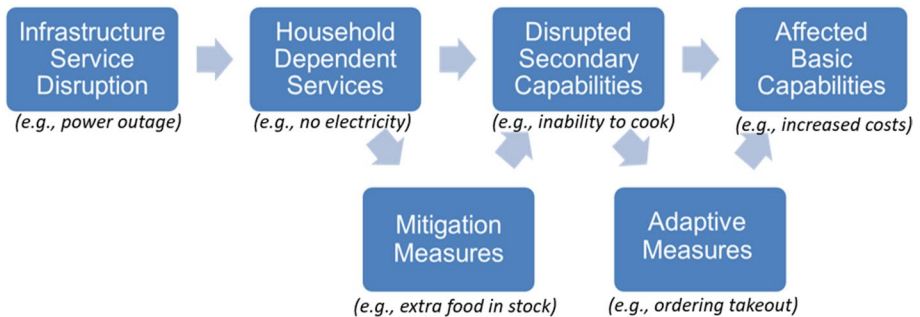


Fig. 2 Capabilities Approach framework applied to infrastructure disruptions at the household level indicating the relationship between infrastructure resources, household responses, and capabilities

incorporates insights from Day et al. (2016) which used the CA to understand how electricity-dependent household services relate to specific and contextual household activities (e.g., cooking, and bathing), referred to as secondary capabilities, and energy poverty. We also drew from Dargin and Mostafavi (2020) who applied the CA to inform subjective well-being impacts (i.e., measures of emotional well-being) of infrastructure disruptions in Houston, Texas following Hurricane Harvey in 2017. They found varying self-reported well-being impacts (i.e., feelings of anxiousness or helplessness) related to general infrastructure disruption types (i.e., transportation, food, solid waste) across households with different demographic characteristics. Also, previous work by the authors of this study has used the CA framework to study the impact of infrastructure disruptions on households in Puerto Rico (Clark et al. 2022) as well as utilized the CA to inform the development of an equity-focused social burden metric that seeks to quantify the burden of post-event adaptations taken by households to maintain their capabilities and fulfill important functionings (Clark et al. 2023).

Figure 2 helps to illustrate how the CA may be applied to infrastructure disruptions specifically, where the portfolio of capabilities typically available to households is constrained during infrastructure disruptions as infrastructure services and thus important household capabilities are likely reduced. For example, during a power outage, many households lose the ability to refrigerate food which reduces the ability of a household to safely store food. If the ability to safely store food is reduced, the basic capabilities of

maintaining good health may also be diminished. Some households, perhaps with previous outage experience and sufficient financial resources may be able to take pro-active measures to mitigate or reduce the impacts, such as purchasing a generator or keeping more food and water in stock. Also, many households will take adaptive measures to cope with the disruptions they experience, such as ordering takeout or buying bottled water to cope with the inability to cook or access clean drinking water in their home as they usually would.

Therefore, the CA applied to the context of infrastructure disruptions suggests that households with more resources (e.g., higher income) and appropriate conversion factors (e.g., are healthy, own a car, live in proximity to services) will have a greater ability to undertake mitigation measures prior to an event as well as adaptive behaviors during events that will help to alleviate burden during disruptions. Conversely, the lack of resources and conversion factors will likely reduce the ability of households to take proactive mitigation measures and may limit their adaptive capacity. While there are a multitude of conversion factors that may be relevant to the experiences of different people during disruption events, a body of existing literature has identified particular population demographics and characteristics that are frequently associated with a reduced ability to adapt or prevent human suffering when faced with disaster events, also referred to as *social vulnerability* (see, e.g., Cutter et al. 2003; Fatemi et al. 2017; Singh et al. 2014). These measures of vulnerability, including household income, education, access to a vehicle, racial and ethnic minority status, age, and English proficiency, can be thought of as specific personal and societal resources and conversion factors that may impact households' outcomes during disruption events such as power outages. These factors may impact households' outcomes in a variety of ways—'vulnerable' households may require additional goods or services to maintain the same health and well-being outcomes as 'non-vulnerable' households, have relatively few resources to fall back on compared to their non-vulnerable peers, have access to less-quality goods and services that are more prone to disruption during extreme events, face more challenges in undertaking adaptive behaviors than their peers, or may otherwise struggle to maintain capabilities, compared to their peers.

Other important factors that may impact households' outcomes from an infrastructure disruption are outage duration and prior experience. Outage duration has been linked to increased severity of consequences, as previous studies have found that longer-duration outages were associated with more severe impacts on households and communities (Stock et al. 2023). Conversely, prior experience has been associated with less severe outage consequences, as studies have found that the knowledge gained through previous outages can help households act effectively and engender resilience during disruptions (Heidenstrom and Kvarnlof 2018; Abi Ghanem et al. 2016). In the context of the CA, we would expect that longer periods of time without access to home energy services and important conversion factors result in more burdens to households. Also, because knowledge and experience would be considered important personal conversion factors in CA (Robeyns and Byskov 2023), we would expect to see households that have had the opportunity to build up their knowledge and experience through prior outage experience will report less burdens as a result of Winter Storm Uri, due to more proactive mitigation measures and knowledge of effective adaptation strategies.

Overall, this theoretical framing of the CA was used to inform the design of our survey questions, as well as determine appropriate ways to measure objective and subjective burdens that households experienced during Uri.

3 Methodology

3.1 Research design

Qualtrics, an online survey company, was hired to conduct a digital survey of Texan households. Qualtrics operates by sending surveys to individuals who had been previously recruited to complete online surveys in exchange for monetary compensation. By design, the individuals recruited as participants were intended to provide a representative sample of Texan households residing within the Electric Reliability Council of Texas (ERCOT) service area in terms of race and income. Screening questions were included at the outset of the survey to prevent potential participants that (a) were less than 18 years old, (b) did not live in the ERCOT service area of Texas, (c) had not experienced a power outage during Winter Storm Uri in February 2021 from taking the survey.

The survey was conducted between September 24, 2021, and October 29, 2021 (6–7 months following the February 2021 event). During this period Qualtrics gathered over 3000 survey responses. Qualtrics conducted quality assurance checks on these responses (e.g., looking for respondents who finished the survey abnormally fast, possible bots, duplicate responses, ambiguous text, etc.) (see *Response Quality*, n.d.) and eliminated all but 1049 responses. Further quality assurance checks were conducted by the research team on these 1049 responses to eliminate duplicate responses and speeders (i.e., individuals who finished the abnormally quickly). Duplicate responses were identified based on a combination of personal characteristics (i.e., age, gender, and racial and ethnic identity) and household characteristics (i.e., zip code, number of people in household, and language spoken in household). Of the duplicate responses identified based on personal and household characteristics, 38 originated from individual IP address and 112 originated from an IP address associated with two or more survey responses (i.e., 112 were duplicates down to the IP addresses). Speeders were defined as respondents who completed the survey in 40% or less of the median time taken to complete the survey (i.e., those individuals who completed a survey with a median duration of 21 min in fewer than 9 min) (Bhavsar 2018). After eliminating a total of 150 duplicate responses and 67 speeders, 832 responses remained and were used for analysis.

Figure 3 provides a dot density map of the geographic distribution of the 832 respondents included in the final analysis. Each household is represented by a single dot, with the color of the dot reflecting the duration of time the household was without power, including households that reported no power outage ('no outage', $n=96$), but did report other infrastructure disruption types in their homes, including water ($n=48$) and natural gas ($n=15$). The distribution of responses largely reflects the population density across the state, with a high number of responses from the Dallas—Fort Worth Metropolitan Area, Houston, San Antonio, and Austin. Even within these clusters of responses, there was a wide range in the duration of outages reported.

3.2 Survey questions

In the survey, participants were first asked about their personal and household characteristics (e.g., yearly income, race of household, household size, etc.). They were then asked if they experienced a power outage during Winter Storm Uri; only those who specifically

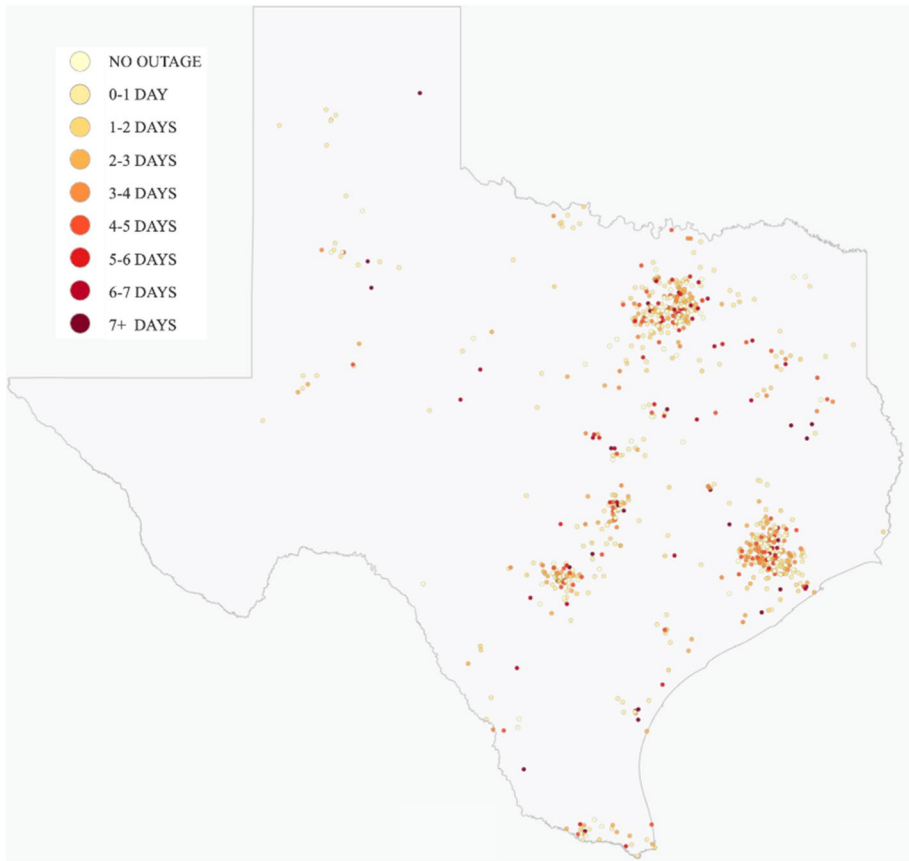


Fig. 3 Dot density map of the geographic distribution of the 832 respondents included in the final analysis. The color of the dot indicates the duration of power outage reported by each household

indicated that they had by answering ‘yes’ were allowed to continue.¹ They were next asked to identify characteristics of the outage they experienced (i.e., duration and if it was constant or intermittent), and if they had ever experienced a significant power outage before Uri. Respondents were also provided a list of eleven important household capabilities (e.g., ability to access food or water, ability to heat their home, ability to cook food, etc., see full list in Fig. 4) and asked to identify which (if any) were disrupted by the outage. They could also add up to two additional ‘other’ disrupted capabilities that they felt were not reflected by the choices included in the provided list. Respondents were then asked to identify which of the disrupted capabilities had ‘significant impacts’ on their household’s health and well-being and estimate the additional time and money their household spent to mitigate the

¹ While eligibility for participation in this study included participants having experienced a power outage in their home because of Winter Storm Uri, when explicitly asked about their experiences of power outages during Uri, 96 households reported that they did *not* experience any power outage in their homes. These households did, however, report disruptions to water and natural gas as a result of disruptions to the electrical system, so their households were impacted by power outages, albeit indirectly.

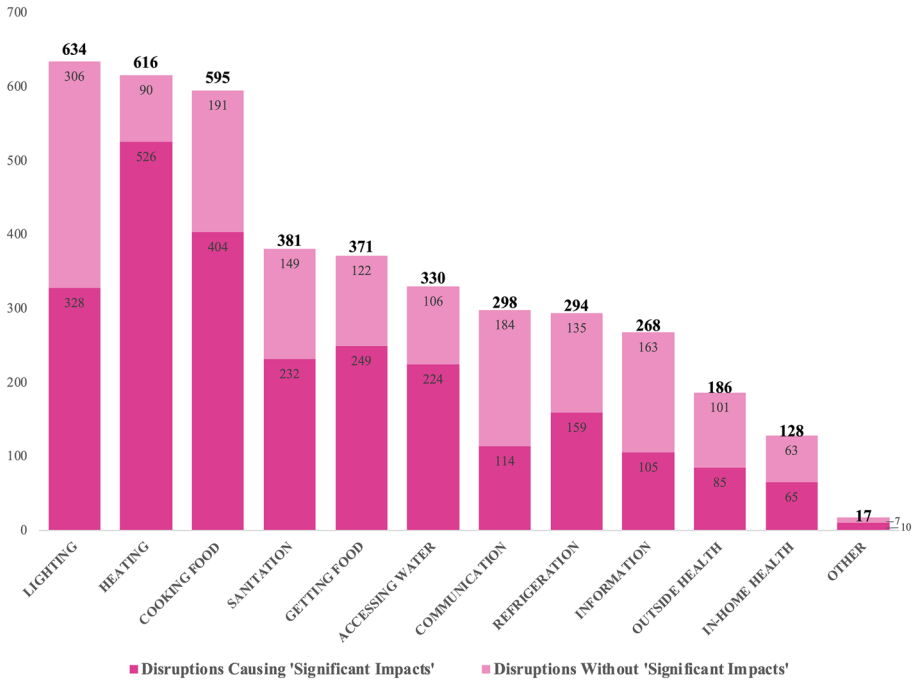


Fig. 4 Number of households that reported disruptions to each capability type, in order of most reported disruptions types to least reported. The lighter bar indicates the number of households that reported capabilities as being disrupted but having relatively little impact on the household’s health and well-being, while the darker bar indicates the number of households that reported capabilities as being disrupted and having a significant impact on the household’s health and well-being. The counts inside each bar indicate the number of households reporting each level of impact, while the counts outside the end of the lighter bar indicate the total number of households reporting each type of disruption

disruptions to these capabilities. Respondents were also asked to evaluate the impact of the disruptions during Uri on their overall well-being by using a scale of 0 (“worst possible life” to 10 “best possible life”) to indicate their satisfaction with their lives both before and during the outage.

3.3 Sample demographics

The demographic characteristics of respondents were compared to those of the total population of Texas, using the 2019-American Community Survey (ACS) 5-year estimates, where analogous demographic data could be found (U.S. Census Bureau 2019). When possible, survey questions were adapted from demographic questions used by the U.S. Census Bureau, facilitating the ease of comparison with ACS data for key demographic indicators such as age and gender. It is, however, important to note that respondents were asked to answer most questions on behalf of their household, whereas ACS questions typically ask respondents to provide information about the individual members of their household. As a result, many demographic questions (i.e., education and race) are not directly comparable to the individual-oriented ACS data. Specifically, respondents were asked “What is the highest level of schooling that someone *in your household* has received?” [emphasis

Table 1 Comparison of sample household demographics to those of all Texan households (U.S. Census Bureau 2019)

	Count Sample (<i>n</i> = 832)	Percent Sample (%)	Count Texas Households (<i>n</i> = 9,985,126)	Percent Texas Households (%)	
Household size (Table C11016, 2019 ACS 1-year estimates)	1-person household	127	2,559,502	25.6	
	2-person household	271	3,148,563	31.5	
	3-person household	156	1,610,569	16.1	
	4-person household	149	1,426,957	14.3	
	5-or-more-person household	125	1,239,535	12.4	
	<i>Prefer not to respond</i>	4	0.5		
Educational level (highest education achieved) (Table C15003, 2019 ACS 1-year estimates)	Grade School	29	1,436,483	7.7	
	Some Secondary School	191	1,445,905	7.7	
	High School Graduate (or GED)	297	4,734,422	25.2	
	Some College	196	5,379,207	28.7	
	Bachelor's Degree (4-Year College)	113	3,750,797	20.0	
	More than a Bachelor's Degree	0	2,025,736	10.8	
	<i>Prefer not to respond</i>	6	0.7		
		77	9.3	592,805	5.9
Household income (Table B19001, 2019 ACS 1-year estimates)	Less than \$10,000	70	762,129	7.6	
	\$10,000–\$19,999	118	867,309	8.7	
	\$20,000–\$29,999	106	869,432	8.7	
	\$30,000–\$39,999	91	801,749	8.0	
	\$40,000–\$49,999	79	775,885	7.8	
	\$50,000–\$59,999	148	2,274,524	22.8	
	\$60,000 to \$99,000	60	1,545,073	15.5	
	\$100,000–\$149,999	56	1,496,220	15.0	
	More than \$150,000	27	3.2		
	<i>Prefer not to respond</i>				

Table 1 (continued)

Race & ethnicity (Table B02001, 2019 ACS 1-year estimates)	Count Sample (<i>n</i> = 832)	Percent Sample (%)	Count Texas Households (<i>n</i> = 9,985,126)	Percent Texas Households (%)
White—Not Hispanic/Latinx	352	42.3	11,929,568	41.1
White—Hispanic/Latinx	144	17.3	9,343,758	32.2
Black or African American—Not Hispanic/Latinx	123	14.8	3,442,881	11.9
Black or African American—Hispanic/Latinx	23	2.8	111,041	0.4
Asian	44	5.3	1,446,073	5.0
Other	125	15.0	2,722,560	9.4
<i>Prefer not to respond</i>	<i>21</i>	<i>2.5</i>		

Italic values indicate types of missing data for each variable

added] as compared to ACS questionnaires, which ask respondents “What is the highest degree or level of school [each] person [in the household] has completed?”. For ‘Race & Ethnicity’ respondents were asked “In terms of race, which of the following do members of your household primarily consider themselves to be?”, and “Do any members of your household identify as Hispanic or Latino?”. Table 1 compares select sample demographics with all Texan households; race and ethnicity types used in the survey are listed in the last row.

The demographics of the collected sample, shown in Table 1, are considered reasonably representative of the Texan population in terms of income, education, household size, and race. Respondents’ median household yearly income was slightly lower than that reported by the ACS (between \$40,000–\$49,000 and \$50,000–\$59,000, respectively); the median household educational attainment of respondents was the same of that as Texas overall, with some college education; the median household size of survey respondents was three individuals, while the median for Texas is two people; and the proportion of the sample that identified as a racial or ethnic minority (defined here as all respondents who identified as either Hispanic/Latino or non-White) was similar to the Texas population (57.7 and 58.9%, respectively).

3.4 Analysis

Our data analysis is organized according to our four research questions, with additional methodological detail provided as needed, specific to each section. Section 4.1 includes summary statistics describing the household capabilities disrupted and the ranking of these disrupted household capabilities in terms of impact on households’ health and well-being. In the subsequent sections (Sects. 4.2 through 4.4), statistical methods were used to explore the individual relationships between independent variables relevant to each of the research questions and six key household outcomes, both objective and subjective. The objective measures included in the analyses were (1) the total number of capability disruption types reported, (2) the number of capability disruption types reported as having a “significant impact” on households’ health and well-being, (3) the number of disruption types resulting in additional time, and (4) the number of disruption types resulting in additional money spent. Subjective measures included in the analysis were (1) reported life satisfaction, or well-being, during the outage on a scale of 0–10, and (2) the reported *change* in well-being from before the outage to during the outage, calculated based on the difference in reported life satisfaction before the outage and during the outage (both on a scale of 0 to 10). While the former offers insight into life satisfaction, or well-being, during the outage in an absolute sense, the latter offers insight into the change in life satisfaction, or well-being, specifically because of the outage. Student’s t-tests were first performed to determine whether there were significant differences in the means of these six household outcome measures between two categorical groups, based on the independent variable of interest. Differences in the quantitative means of two or more categorical groups were further explored using ANOVA and Tukey’s Honest Significant Difference (HSD) tests. Differences in the quantitative means of ordinal independent variables and household outcomes were examined using Spearman’s rank-order correlation, with Spearman’s rho value indicating monotonic relationship between these variables (i.e., that an increase in variable corresponds to an increase in the other, without regard to the linearity of the relationship). These tests were conducted in R, using the packages “aov,” and “stats” for analysis (Dag et al. 2018; R Core Team 2021).

4 Results

4.1 Disrupted capabilities and household outcomes

4.1.1 Prevalence and relative impact of disrupted capabilities

Survey respondents identified the household capabilities that were disrupted by the power outages and indicated which of these disrupted capabilities most significantly impacted their households' health and well-being. On average, households reported 4.9 household capabilities being disrupted and reported an average of 3.0 disruptions as having 'significant impacts' on their households' health and well-being. Figure 4 summarizes both the frequency that each capability type was reported as being disrupted as well as the frequency of these disruptions being reported as having 'significant impacts' on households' health and well-being.

Three specific capabilities stood out in terms of the overall prevalence of disruption: more than two-thirds of households reported disruptions to *lighting* (76%), *heating* (74%), and *cooking* (72%). In comparison, the fourth-most common disruption, *sanitation*, was only reported as being disrupted by 46% of households. Only fourteen households reported disruptions to 'other' capabilities (corresponding to a total of 17 'other' disrupted capabilities); these included disruptions to internet access and cell phone communication, challenges in caring for pets and livestock, additional challenges posed to the household due to COVID-19, lack of toilet paper, running generators, inability to drive on roads due to weather conditions, a lack of water and restoration needed due to pipes bursting.

In addition to being the most prevalent disruptions overall, disruptions to *heating*, *cooking*, and *lighting* were the most frequently reported 'significantly impactful' disruptions, with 63% of households, 49% of households, and 40% of all respondents reporting that these disrupted capabilities had 'significant impacts' on their households' health and well-being. When constrained to exclusively consider the households impacted by power outages, the disproportionate impact of heating disruptions becomes even more evident, as 85% of households that experienced these kinds of disruptions indicated that they resulted in significant impacts on their households' health and well-being. Disruptions to cooking food, accessing water, and accessing food were also particularly impactful for affected households: approximately two-thirds of respondents experiencing these disruptions indicated that they were "significantly impactful" for their households. In contrast, disruptions to *information* and *communication* were relatively prevalent but less likely to be impactful for affected households: while disruptions to these capabilities were not infrequent (reported by 268 and 298 respondents, respectively), less than four in ten affected households (39 and 38%) reported that these disruptions had significant impacts on their household's health and well-being. The 'other' capability disruption types reported to have significant well-being impacts were challenges due to not having internet (could be considered a communication issue), CPAP machines (could be considered an in-home health issue), running generators, inability to drive on roads due to weather conditions, a lack of water and restoration needed due to pipes bursting (could be considered an issue with accessing water), and the need to keep livestock warm and ensure that they had access to water.

4.2 Additional time and monetary costs

For each of the disrupted capabilities that had a “significant impact” on their household, respondents were asked to estimate the additional time spent adapting to the disruption over the course of the outage. Eighty-five percent of households ($n = 705$) reported one or more disrupted capabilities requiring additional time, with affected households reporting an average of 3.6 disruptions that required additional time to address. On average, households spent approximately 2.3 h additional hours per impacted capability, corresponding to a total of 10.8 h per household over the duration of the outage. While disruptions to lighting and cooking were reported by many households, they resulted in the fewest additional hours per affected household of any disrupted capability type (2.1 and 1.8 h, respectively). In contrast, while ‘other’ disruptions were the rarest, they were also the most time-intensive disruptions: the ten households queried spent an average of 4.6 h addressing these ‘other’ needs. Particularly time consuming ‘other’ needs were related to water pipes that burst, keeping livestock alive, the lack of internet, and challenges related to COVID.

While disruptions to household capabilities were slightly less likely to incur additional monetary costs, three-quarters of households ($n = 628$) reported spending additional money to adapt to one or more disrupted capabilities caused by Winter Storm Uri. On average, these affected households experienced 3.3 disruptions that required additional money to address, with the average disruption costing households approximately \$38 over the duration of the outage. Disruptions to information and lighting were associated with the lowest monetary burdens (an average of approximately \$21 and \$23, respectively), while disruptions to food-related capabilities such as accessing food and cooking had comparatively high monetary costs (an average of approximately \$56 and \$39, respectively). ‘Other’ disruptions requiring additional money were very rare ($n = 8$) but were associated with the highest monetary costs on a per-household basis (affected households reported an estimated \$61 on average to address ‘other’ disruptions). Particularly costly ‘other’ disruptions included burst water pipes, the lack of hot water, and challenges related to COVID.

4.3 Household outcomes based on outage characteristics

4.3.1 Reported outage characteristics

For respondents experiencing a power outage in their home ($n = 736$), they were asked to provide information about both the *duration* of the outage from the point in time households first lost power to the point in time when their power was fully restored and the *nature* of the outage. In particular, respondents were asked to indicate whether the outage was (a) constant, meaning the power did not come back between when it first went out and when it was completely restored; (b) intermittent with short (< 1 h) periods of power; (c) intermittent with medium-length (1–4 h) periods of power; or (d) intermittent with long (4+ hour) periods of power. Figure 5 summarizes the duration and nature of outages reported.

Just under half of respondents (47%) reported an outage lasting less than two full days, with more than one in three respondents (34%) reporting that the total time from when power first went out to when it was fully restored was less than 24 h. Although most households reported relatively short outages—the median outage duration was between one and two days, and some 62% of respondents reported an outage of less than three days—more than one in four households (26%) reported an outage lasting more than 3 days, with 10%

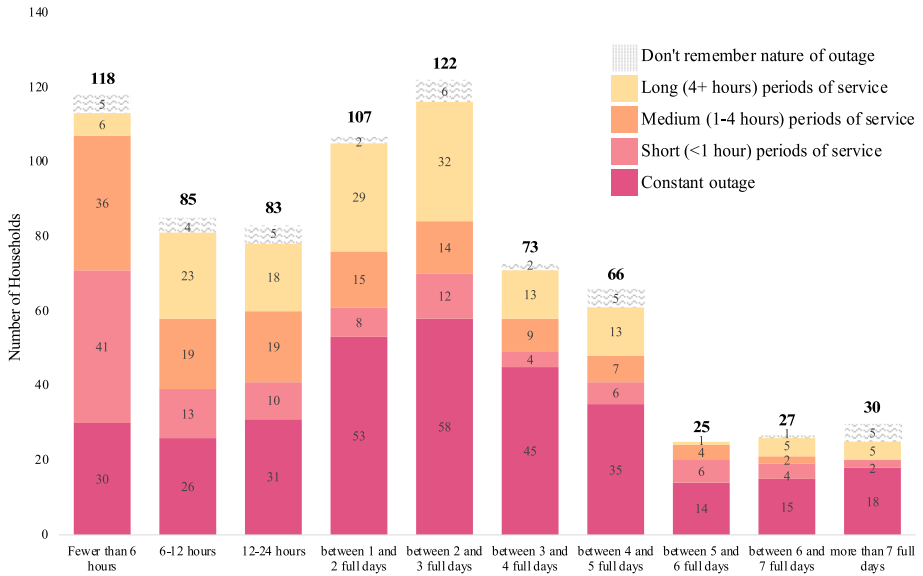


Fig. 5 Duration and nature of power outages experienced by respondents

of households reporting an outage that lasted five or more days. These disruptions varied in nature; while almost 5% of respondents could not remember whether they experienced constant outages, slightly less than half (44%) reported constant outages, while slightly more than half (51%) reported intermittent periods of power. Interestingly, households that experienced outages lasting less than a full day were particularly likely to report some period of power, as only about one-third of households with outages lasting less than a day (32%) reported that these outages were constant (Fig. 5).

4.3.2 Household outcomes and disruptions to household power

While eligibility for participation in this study included participants having experienced a power outage in their home because of Winter Storm Uri, when explicitly asked about their experiences of power outages during Uri, 96 households reported that they did *not* experience any power outage in their homes. These households did, however, report disruptions to water and natural gas because of disruptions to the electrical system, so their households were impacted by power outages, albeit indirectly. The inclusion of households that did not experience a power outage in their homes during Uri (but did experience other types of infrastructure disruptions like water and natural gas interruptions) presented an opportunity to test for statistically significant differences in household outcomes between households that had experienced a power outage of any kind ($n=736$) and those that had not ($n=96$). The results are summarized in Table 2. For objective outcomes, households that lost power reported more disrupted capabilities on average (5.1 vs. 3.5, $p < .001$) and more disruptions with ‘significant impacts’ (3.1 vs. 2.4, $p < .01$) than households reporting other infrastructure disruption types. Subjectively, households that lost power also reported lower life satisfaction during the outage (3.7 vs. 4.5 on a scale of 0–10, $p < .01$) and greater decreases in life satisfaction from before the outage to during the outage (an average decrease in 3.6 points vs. 2.2 points, $p < .001$) than other households.

Table 2 Differences in household outcomes based on whether households lost power

Household Outcomes	No Outage <i>n</i> = 96		Outage <i>n</i> = 736		<i>t</i> -test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Count Disrupted Capabilities	3.51	2.85	5.14	2.53	5.32	0.0000***
Count 'Significant Impact' Disrupted Capabilities	2.43	2.12	3.08	2.11	2.84	0.0052**
Count Disrupted Capabilities Requiring Additional Time	2.73	2.41	3.10	2.41	1.41	0.1601
Count Disrupted Capabilities Requiring Additional Money	2.49	2.63	2.52	2.55	0.12	0.9025
Well-being During Outage	4.47	2.77	3.66	2.71	-2.70	0.0080**
Change in Well-being from Before to During Outage	-2.23	3.13	-3.75	3.54	-4.39	0.0000***

* denotes $p < .05$, ** denotes $p < .01$, *** denotes $p < .001$

Table 3 Results of Spearman's testing between outage duration and household outcomes

Household Outcomes	rho	<i>p</i> value
Count Disrupted Capabilities	0.38	<0.0001***
Count 'Significant Impact' Disrupted Capabilities	0.18	<0.0001***
Count Disrupted Capabilities Requiring Additional Time	0.18	<0.0001***
Count Disrupted Capabilities Requiring Additional Money	0.14	<0.0001***
Well-being During Outage	-0.30	<0.0001***
Change in Well-being from Before to During Outage	-0.29	<0.0001***

*** denotes $p < .001$

For households reporting that they did lose power, Spearman's testing indicated highly significant correlations between outage duration and all six household outcomes (Table 3). Outage duration was positively correlated with all objective measures and was most strongly correlated with the total number of disrupted capabilities ($\rho=0.38$); outage duration was negatively correlated both with reported life satisfaction during the outage ($\rho=-0.30$) and the change in life satisfaction from before the outage to during the outage ($\rho=-0.29$).

4.3.3 Household outcomes and nature of power outage

Among the households that experienced a power outage ($n=736$), slightly more than half experienced rolling outages with intermittent periods of power ($n=376$), less than half experienced continuous outages ($n=325$), while relatively few could not remember ($n=35$). For households that could recall the nature of the outage ($n=701$), student's *t* tests were performed to identify differences between the household outcomes of those that experienced continuous outages and those that experienced intermittent outages (Table 4). Households with constant outages reported a greater number of disrupted capabilities (5.6 vs. 4.8, $p < .001$), more disruptions resulting in 'significant impacts' (3.3 vs. 2.9, $p < .01$),

Table 4 Differences in household outcomes based on nature of outage (constant or intermittent)

Household Outcomes	Constant <i>n</i> =325		Intermittent <i>n</i> =376		t-test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Count Disrupted Capabilities	5.64	2.57	4.76	2.40	4.67	0.0000***
Count 'Significant Impact' Disrupted Capabilities	3.26	2.10	2.89	2.04	2.36	0.0185*
Count Disrupted Capabilities Requiring Additional Time	3.45	2.54	2.88	2.26	3.10	0.0020**
Count Disrupted Capabilities Requiring Additional Money	2.83	2.71	2.30	2.37	2.73	0.0064**
Well-being During Outage	3.18	2.77	4.00	2.61	-4.03	0.0001***
Change in Well-being from Before to During Outage	-4.42	3.63	-3.28	3.33	-4.32	0.0000***

* denotes $p < .05$, ** denotes $p < .01$, *** denotes $p < .001$

Table 5 Differences in household outcomes based on nature of power outage

Household Outcomes	No Outage <i>n</i> = 96		Constant Out- age <i>n</i> = 325		Short Service Periods <i>n</i> = 106		Medium Ser- vice Periods <i>n</i> = 125		Long Service Periods <i>n</i> = 145		Don't Remem- ber <i>n</i> = 35		<i>p</i> value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Count Disrupted Capabilities	3.51	2.85	5.64	2.57	4.26	2.50	4.51	2.30	5.32	2.31	4.60	2.71	0.0000***
Count 'Significant Impact' Disrupted Capabilities	2.43	2.12	3.26	2.10	2.55	1.86	2.83	1.91	3.19	2.23	3.51	2.78	0.0012**
Count Disrupted Capabilities Requiring Additional Time	2.73	2.41	3.45	2.54	2.81	2.30	2.58	2.14	3.19	2.30	2.23	2.38	0.0012**
Count Disrupted Capabilities Requiring Additional Money	2.49	2.63	2.83	2.71	2.24	2.27	2.05	2.09	2.56	2.65	2.14	2.55	0.0318*
Well-being During Outage	4.47	2.77	3.18	2.77	4.35	2.57	4.22	2.46	3.56	2.71	4.49	2.65	0.0000***
Change in Well-being from Before to During Outage	-2.23	3.13	-4.42	3.63	-2.61	3.29	-2.95	3.00	-4.06	3.49	-2.49	3.82	0.0000***

* denotes $p < .05$, ** denotes $p < .01$, *** denotes $p < .001$

more disruptions requiring additional time (3.5 vs. 2.9, $p < .01$), and more disruptions requiring additional money (2.8 vs. 2.3, $p < .01$) than households that had power at least some of the time. Households with constant outages also reported lower life satisfaction scores (3.2 vs. 4.0, $p < .01$) and greater decreases in life satisfaction during the outages than those who received intermittent periods of power (an average decrease of 4.4 points vs. 3.2 points, $p < .001$).

Subsequent testing further categorized respondents into five groups based on the nature of outages: households that experienced *no* outages ($n=96$), *constant* outages ($n=325$), intermittent outages with *short* periods of service lasting less than one hour ($n=106$), intermittent outages with *medium* periods of service between one and four hours ($n=125$), and intermittent outages with *long* periods of service lasting more than four hours ($n=145$); results of these tests are seen in Table 5. These test results highlight the differences in outcomes between those who had experienced no outages and those who had experienced constant outages. Households who experienced constant outages reported more disrupted capabilities (5.6 vs. 3.5, $p < 0.001$), more disruptions causing ‘significant impacts’ (3.3 vs. 2.4, $p < 0.01$), and lower life satisfaction scores during the outage (3.2 points vs. 4.5 points on a scale of 0–10, $p < 0.001$) than households that did not experience outages. There were also statistically significant differences between those who experienced constant outages and those who experienced medium or short periods of service across several household outcomes. Households that experienced constant outages experienced more disrupted capabilities (5.6 vs. 4.5 $p < 0.001$), more disruptions requiring additional time (3.5 vs. 2.6, $p < 0.01$) and additional money (2.8 vs. 2.1, $p < 0.05$), and lower life satisfaction scores during the outage (3.2 points vs. 4.2 points on a scale of 0–10, $p < 0.001$) than those who experienced intermittent outages with medium periods of service. Households that experienced constant outages also experienced more disrupted capabilities (5.6 vs. 4.3, $p < 0.001$), more disruptions causing a ‘significant impact’ on their household (3.3 vs. 2.6, $p < 0.001$) and lower life satisfaction scores during the outage (3.2 points vs. 4.4 points on a scale of 0–10, $p < 0.001$) than their peers that experienced intermittent outages with short periods of service.

4.4 Household outcomes and social vulnerability

While there are many different indices that may be used to identify vulnerable populations, one that is frequently used is the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI), which uses social factors measured in the U.S. Census and ACS to create a composite index that measures social vulnerability to disasters in four key dimensions: (1) *Socioeconomic Status*, (2) *Household Characteristics*, (3) *Racial & Ethnic Minority Status*, and (4) *Housing Type & Transportation* (ACS 2020; Flanagan et al. 2018). Drawing from indicators in both the 2018 and the 2020 SVI, eleven metrics were selected for analysis. The list of indicators included in this analysis are included in Table 6.

For each indicator of social vulnerability listed in Table 6, household outcomes across the six measures were analyzed to determine whether there were significant differences in outcomes based on household vulnerability status. The results of these analyses, as well as supplemental correlation and ANOVA analyses, are discussed in greater detail below, categorized by the four vulnerability themes.

Table 6 Social vulnerability indicators included in the analysis as well as the number and percent of households in sample meeting both vulnerable (V) and (NV) classifications of each indicator

Vulnerability theme	Indicator	Classification	Count	Percent (%)
Socioeconomic status	Household high school diploma or ged status	One or more people with at least GED equivalent	(NV) 797	95.8
		Nobody in household has GED equivalent	(V) 29	3.5
	Household relation to poverty line (size-adjusted)	<i>Prefer not to Respond</i>	–	0.7
		Above 150% poverty line	(NV) 473	56.9
Household characteristics	Household relation to poverty line (size-adjusted)	Below 150% poverty line	(V) 328	39.4
		<i>No Response</i>	–	3.7
	Presence of adults aged 65 + in household	No Adult(s) aged 65 + in household	(NV) 599	72.0
		Adult(s) aged 65 + in household	(V) 233	28.0
	Presence of children under age 18	No children under 18	(NV) 493	59.3
		One or more children under 18	(V) 339	40.7
	Single parent household	Two-Parent Household	(NV) 234	28.1
		Single-Parent Household	(V) 99	11.9
	Disability in household	<i>Prefer not to Respond</i>	–	0.7
		<i>Not Applicable (No Children Present)</i>	–	59.3
In-home medical device	No	(NV) 503	60.5	
	Yes	(V) 285	34.3	
English skill level	<i>Prefer not to Respond</i>	–	5.3	
	No	(NV) 660	79.3	
Racial and ethnic minority status	Yes	(V) 156	18.8	
	<i>Prefer not to Respond</i>	–	1.9	
Racial and ethnic minority status	Racial or ethnic minority	Household members speak English 'very well'	(NV) 767	92.2
		Household members speak English less than 'very well'	(V) 65	7.8
	Racial or ethnic minority	Not Racial or Ethnic Minority	(NV) 352	42.3
		Racial or Ethnic Minority	(V) 459	55.2
		<i>Prefer not to Respond</i>	–	2.5

Table 6 (continued)

Vulnerability theme	Indicator	Classification	Count	Percent (%)
Housing and transportation	Vehicle access	Household has access to one or more vehicles	(NV) 757	91.0
		Household does not have access to a vehicle	(V) 66	7.9
		<i>Prefer not to Respond</i>	– 9	1.1
Vulnerable housing		Housing type is not mobile home or large apartment	(NV) 540	64.9
		Housing type is mobile home or large apartment	(V) 259	31.1
		<i>Could not be determined</i>	– 33	4.0
Overcrowding		2 or fewer people per bedroom	(NV) 780	93.8
		More than 2 people per bedroom	(V) 48	5.8
		<i>Could not be determined</i>	– 4	0.5

Household status in relation to 150% of poverty line was calculated using both the reported household size and annual income of the household. For each household, the midpoint of the provided income range was compared to 150 of the United States Department of Health and Human Services (US HHS) poverty guideline for the number of people living in the household; if the household’s estimated income was below 150 of the poverty guideline, the household was classified as being below 150 of the poverty line. English skill level was determined based on respondents’ answers to the question about the English skill level of their household. Households that responded either “Extremely well” or “very well” were classified as speaking English “very well”; households that responded, “moderately well”, “slightly well”, or “not well at all” were classified as speaking English “less than very well”. Overcrowding was calculated based on both the reported household size and the number of bedrooms in the home; households with more than two people per bedroom were classified as “overcrowded”.

Italic values indicate types of missing data for each variable

Table 7 Differences in household outcomes based on socioeconomic vulnerability indicators

	Household Outcomes		Vulner- able <i>n</i> = 29		Not Vulnerable <i>n</i> = 797		<i>t</i> -test statistic	<i>p</i> value
			Mean	SD	Mean	SD		
Household high school diploma or ged status	Count Disrupted Capabilities		4.38	2.40	4.97	2.62	-1.30	0.2018
	Count 'Significant Impact' Disrupted Capabilities		3.38	2.11	3.00	2.12	0.96	0.3465
	Count Disrupted Capabilities Requiring Additional Time		2.48	2.01	3.08	2.43	1.56	0.1283
	Count Disrupted Capabilities Requiring Additional Money		2.41	2.11	2.53	2.57	-0.29	0.7759
	Well-being During Outage		4.38	2.99	3.74	2.71	1.14	0.2645
	Change in Well-being from Before to During Outage		-2.10	3.51	-3.62	3.52	2.29	0.0291*
	Household Outcomes		Vulnerable <i>n</i> = 328		Not Vulnerable <i>n</i> = 473		<i>t</i> -test statistic	<i>p</i> value
			Mean	SD	Mean	SD		
Household income relative to 150% of poverty line	Count Disrupted Capabilities		5.08	2.72	4.82	2.53	1.34	0.1808
	Count 'Significant Impact' Disrupted Capabilities		3.16	2.25	2.85	2.00	2.05	0.0405*
	Count Disrupted Capabilities Requiring Additional Time		3.23	2.49	2.92	2.36	1.73	0.0835
	Count Disrupted Capabilities Requiring Additional Money		2.72	2.69	2.38	2.46	1.79	0.0741
	Well-being During Outage		3.97	2.95	3.58	2.56	1.93	0.0535
	Change in Well-being from Before to During Outage		-3.59	3.72	-3.61	3.41	0.05	0.9622

* denotes $p < .05$

Table 8 Results of Spearman’s correlation testing between household income and household outcomes

Household Outcomes	All Household Incomes $n = 805$		Incomes Below \$100,000 $n = 689$	
	rho	p value	rho	p value
Count Disrupted Capabilities	0.02	0.5563	0.04	0.2687
Count ‘Significant Impact’ Disrupted Capabilities	−0.04	0.2593	−0.03	0.4017
Count Disrupted Capabilities Requiring Additional Time	0.04	0.2701	0.05	0.2317
Count Disrupted Capabilities Requiring Additional Money	0.02	0.6698	0.03	0.4375
Well-being During Outage	0.05	0.1475	−0.02	0.6038
Change in Well-being from Before to During Outage	−0.07	0.0515	−0.12	0.0021*

* denotes $p < .05$

4.4.1 Socioeconomic status

The results of t tests for differences in household outcomes based on socioeconomic indicators of vulnerability can be seen in Table 7. Of the outcome variables tested, the only statistically significant difference found for households with a high school diploma or GED equivalent and those without, was in the change in well-being from before the outage to during the outage. The more educated households reported greater decreases in well-being than households without a high school diploma or GED status (a decrease of 3.6 points vs. a decrease of 2.1 points on a scale of 0–10). The only statistically significant difference between households above and below 150% of the poverty line was in the count of ‘significant’ disruptions, with households below the poverty line reporting 0.3 more disruptions causing significant impacts on their health and well-being than their counterparts (3.2 vs. 2.9).

Additional Spearman’s correlation tests were conducted to further evaluate the relationship between income and household outcomes (Table 8). There were no statistically significant correlations between household income and the six household outcomes during Winter Storm Uri across all households for whom income data was provided ($n = 805$). However, analysis restricted to households earning below \$100,000 ($n = 689$) revealed a negative correlation between the change in life satisfaction from before the outage to during the outage ($\rho = -0.12$). This suggests that in households earning under \$100,000, higher income households were associated with greater declines in life satisfaction during the outages.

4.4.2 Household characteristics

Household outcomes were compared to identify differences between (a) households with one or more members aged 65 or above and those without, (b) households with one or more members aged 17 or below and those without, (c) households with children headed by a single parent and households with children headed by two parents, (d) households one or more members reporting a chronic illness or disability and those without, and (e) households that speak English ‘less than well’ and those that speak English ‘well’; households that declined to respond to these questions were excluded from analysis. Results of t -tests

Table 9 Differences in household outcomes based on household characteristics

Household Outcomes	Vulnerable <i>n</i> = 233		Not Vulnerable <i>n</i> = 599		<i>t</i> -test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Presence of adults aged 65 or above						
Count Disrupted Capabilities	4.64	2.45	5.07	2.67	-2.25	0.0249*
Count 'Significant Impact' Disrupted Capabilities	2.47	1.68	3.21	2.24	-5.18	0.0000****
Count Disrupted Capabilities Requiring Additional Time	2.43	2.17	3.30	2.46	-5.00	0.0000****
Count Disrupted Capabilities Requiring Additional Money	1.81	2.17	2.80	2.64	-5.52	0.0000****
Well-being During Outage	3.64	2.43	3.80	2.84	-0.77	0.4396
Change in Well-being from Before to During Outage	-4.02	3.14	-3.40	3.66	-2.46	0.0141*
Household Outcomes						
Vulnerable <i>n</i> = 339		Not Vulnerable <i>n</i> = 493		<i>t</i> -test statistic		<i>p</i> value
Mean		Mean		SD		
Presence of children under age 18						
Count Disrupted Capabilities	5.04	2.79	4.88	2.49	0.85	0.3967
Count 'Significant Impact' Disrupted Capabilities	3.26	2.27	2.83	2.00	0.00	0.0047****
Count Disrupted Capabilities Requiring Additional Time	3.47	2.46	2.77	2.34	4.06	0.0001****
Count Disrupted Capabilities Requiring Additional Money	3.10	2.66	2.12	2.40	5.45	0.0000****
Well-being During Outage	4.03	3.00	3.56	2.51	2.37	0.0180*
Change in Well-being from Before to During Outage	-3.49	3.70	-3.63	3.41	0.56	0.5743

Table 9 (continued)

Household Outcomes		Vulnerable n=99		Not Vulnerable n=234		t test statistic	p value
		Mean	SD	Mean	SD		
Single parent household (among households with children)							
Count Disrupted Capabilities		4.71	2.80	5.18	2.78	-1.40	0.1640
Count 'Significant Impact' Disrupted Capabilities		3.12	2.21	3.30	2.27	-0.68	0.4964
Count Disrupted Capabilities Requiring Additional Time		3.40	2.39	3.48	2.48	-0.27	0.7857
Count Disrupted Capabilities Requiring Additional Money		3.09	2.46	3.11	2.75	-0.07	0.9474
Well-being During Outage		4.65	3.24	3.80	2.88	2.24	0.0264*
Change in Well-being from Before to During Outage		-2.58	3.79	-3.84	3.61	2.83	0.0052**
Household Outcomes							
Household Outcomes		Vulnerable n=285		Not Vulnerable n=503		t-test statistic	p value
		Mean	SD	Mean	SD		
Disability in household							
Count Disrupted Capabilities		5.32	2.71	4.77	2.54	2.80	0.0052**
Count 'Significant Impact' Disrupted Capabilities		3.10	2.17	2.93	2.09	1.09	0.2755
Count Disrupted Capabilities Requiring Additional Time		3.34	2.58	2.93	2.34	2.26	0.0244*
Count Disrupted Capabilities Requiring Additional Money		2.91	2.82	2.36	2.42	2.78	0.0056**
Well-being During Outage		3.78	2.83	3.78	2.68	-0.02	0.9850
Change in Well-being from Before to During Outage		-3.40	3.55	-3.70	3.48	1.16	0.2460

Table 9 (continued)

Household Outcomes	Vulnerable <i>n</i> =65		Not Vulnerable <i>n</i> =767		<i>t</i> test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
English skill level						
Count Disrupted Capabilities	4.63	2.63	4.98	2.62	-1.02	0.3121
Count 'Significant Impact' Disrupted Capabilities	2.75	2.12	3.03	2.12	-1.00	0.3215
Count Disrupted Capabilities Requiring Additional Time	3.49	2.21	3.02	2.43	1.64	0.1043
Count Disrupted Capabilities Requiring Additional Money	2.77	2.49	2.50	2.56	0.84	0.4055
Well-being During Outage	3.97	2.98	3.74	2.71	0.61	0.5431
Change in Well-being from Before to During Outage	-3.08	3.72	-3.61	3.51	1.12	0.2666

* denotes $p < .05$, ** denotes $p < .01$, *** denotes $p < .001$

Table 10 Differences in household outcomes based on racial or ethnic minority status

	Household Outcomes				t-test statistic	p value
	Vulnerable <i>n</i> = 459		Not Vulnerable <i>n</i> = 352			
	Mean	SD	Mean	SD		
Racial or ethnic minority						
Count Disrupted Capabilities	5.05	2.66	4.85	2.55	1.12	0.2645
Count 'Significant Impact' Disrupted Capabilities	3.24	2.12	2.69	2.09	3.72	0.0002****
Count Disrupted Capabilities Requiring Additional Time	3.35	2.41	2.67	2.37	4.05	0.0001****
Count Disrupted Capabilities Requiring Additional Money	2.83	2.60	2.13	2.46	3.96	0.0001****
Well-being During Outage	3.77	2.76	3.69	2.67	0.45	0.6547
Change in Well-being from Before to During Outage	-3.36	3.73	-3.95	3.22	2.43	0.0153*

Households with members identifying as Non-White or White-Hispanic or Latino are considered vulnerable whereas households identifying as White-Not Hispanic or Latino are categorized as non-vulnerable, consistent with the CDC's definition of racial and ethnic minority status in the SVI 2020

* denotes $p < .05$, **** denotes $p < .001$

for differences in household outcomes based on household characteristics consistent with vulnerability can be seen in Table 9.

Households with members aged 65 and above experienced *fewer* disrupted capabilities (4.6 vs. 5.1), *fewer* disrupted capabilities causing ‘significant impacts’ (2.5 vs. 3.2), *fewer* disruptions requiring additional time, and *fewer* disruptions requiring additional money (1.8 vs. 2.8) than households without elderly members. However, despite having lower objective burdens, households with members aged 65 and above experienced *greater* decreases in well-being from before the outage to during the outage than their counterparts (a decrease of 4.0 vs. a decrease of 3.4).

In contrast, households with members aged 17 and younger experienced more disruptions resulting in ‘significant impacts’ (3.3 vs. 2.8) more disruptions requiring additional time (3.5 vs. 2.8), and more disruptions requiring additional money (3.1 vs. 2.1) than households without children. However, households with children reported *greater* life satisfaction scores during the outages than those without (4.0 vs. 3.6 on a scale of 0–10). There were no differences in the objective outcomes of households based on number of parents, but single-parent households reported both higher well-being during the outages than dual-parent households (4.7 vs. 3.8 on a scale of 0–10) and smaller decreases in well-being from before the outage to during the outage (2.6 points vs. 3.8 points) than dual-parent households.

Households with a disability reported more disrupted capabilities (5.3 vs. 4.8, $p < .01$), more disrupted capabilities resulting in additional time (3.3 vs. 2.9, $p < .05$), and more disrupted capabilities requiring additional money (2.9 vs. 2.4, $p < .01$) than their counterparts. There were no statistically significant differences across the key outcomes of households when compared by English proficiency.

4.4.3 Race and ethnic minority status

Consistent with the CDC’s definition of racial and ethnic minority status in the SVI 2020, households that identified *Non-White (any race) or White—Hispanic or Latino* were categorized as being vulnerable, while households that identified as *White—Not Hispanic or Latino* were categorized as not being vulnerable. The results of t tests for differences in household outcomes based on racial and ethnic minority status can be seen in Table 10. Households categorized as being racial and ethnic minorities reported more disruptions resulting in significant impacts (3.2 vs. 3.7, $p < .001$), more disruptions requiring additional time (3.4 vs. 2.7, $p < .001$), and more disruptions requiring additional money (2.8 vs. 2.1, $p < .001$) than non-minority households. However, racial and ethnic minority households reported *smaller* declines in well-being from before the outage to during the outage (a decrease of 3.4 vs. 4.0 points on a scale of 0–10, $p < .05$) than white, non-Hispanic households.

Additional ANOVA testing further identified differences in household outcomes based on specific racial and ethnic identities. This analysis included comparison across the following racial and ethnic groups: White—Not Hispanic or Latino, White—Hispanic or Latino, Black or African American—Not Hispanic or Latino, Black or African American—Hispanic or Latino, Asian, American Indian or Alaska Native, Native Hawaiian or Pacific Islander, Other, and *prefer not the answer*. Results of these tests indicated that there were statistically significant differences between different racial and ethnic groups in all

Table 11 Testing for differences in household outcomes based on racial and ethnic identities

	White—Not Hispanic or Latino <i>n</i> = 352		White—Hispanic or Latino <i>n</i> = 144		Black or African American—Not Hispanic or Latino <i>n</i> = 123		Black or African American—Hispanic or Latino <i>n</i> = 23		American Indian or Alaska Native <i>n</i> = 33		Asian <i>n</i> = 44		Other <i>n</i> = 86		Native Hawaiian or Pacific Islander <i>n</i> = 6		Prefer not to answer <i>n</i> = 21	<i>p</i> value	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
Household Outcomes	4.85	2.55	5.16	2.70	4.28	2.40	5.30	2.32	6.00	2.85	5.50	2.78	5.27	2.72	5.67	2.80	4.43	2.68	0.0268 *
Disrupted Capabilities	2.69	2.09	3.22	2.08	2.93	1.88	3.17	2.35	3.94	2.59	3.57	1.84	3.28	2.25	3.67	3.67	3.10	2.19	0.0275 *
'Significant Impact' Disrupted Capabilities	2.67	2.37	3.68	2.41	2.54	2.10	4.13	1.98	3.64	3.09	3.64	2.78	3.56	2.28	2.50	1.38	3.10	2.32	0.0001 ***
Requiring Additional Time																			

Table 11 (continued)

	White—Not Hispanic or Latino <i>n</i> = 144		Black or African American—Not Hispanic or Latino <i>n</i> = 123		Black or African American—Hispanic or Latino <i>n</i> = 23		American Indian or Alaska Native <i>n</i> = 33		Asian <i>n</i> = 44		Other <i>n</i> = 86		Native Hawaiian or Pacific Islander <i>n</i> = 6		Prefer not to answer <i>n</i> = 21		<i>p</i> value		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
Household Outcomes	2.13	2.46	3.03	2.77	2.12	1.94	4.13	2.34	3.42	2.98	2.99	2.93	2.60	2.00	0.89	2.33	2.20	0.0002***	
Disrupted Capabilities Requiring Additional Money	3.69	2.67	3.72	2.59	4.07	2.72	3.57	3.23	3.21	2.89	2.93	3.92	2.87	4.17	2.14	4.43	3.09	0.7197	
Well-being During Outage	-3.95	3.22	-3.35	3.65	-2.82	3.61	-3.65	3.84	-3.73	3.98	-4.32	3.93	-3.45	3.86	-3.00	3.03	-1.86	3.05	0.0312*
Change in Well-being from Before to During Outage																			

* denotes *p* < .05, *** denotes *p* < .001

measures except for well-being during the outage; the results of ANOVA tests can be seen in Table 11.

The results of Tukey's HSD tests further underscored the differences between White—Not Hispanic or Latino respondents and other racial and ethnic groups: White—Not Hispanic or Latino respondents reported fewer disruptions resulting in 'significant impacts' than American Indian or Alaska Native respondents (2.7 vs. 3.9, $p < .05$), fewer disruptions resulting in additional time than Other respondents (2.7 vs. 3.6), $p < .001$, and fewer disruptions resulting in additional time than Black or African American—Hispanic or Latino respondents (2.7 vs. 4.1, $p < .001$) or White—Hispanic or Latino respondents (2.7 vs. 3.7, $p < .001$). There were also statistically significant differences between the outcomes of Black or African American respondents and those of other respondents that were generally classified as Racial or Ethnic Minorities. Black or African American—Non Hispanic or Latino respondents reported fewer disruptions than Native Hawaiian or Pacific Islanders (4.3 vs. 5.7, $p < .05$), fewer disruptions requiring additional time than White—Hispanic or Latino respondents (2.5 vs. 3.7, $p < .001$), and fewer disruptions requiring additional money than Black or African American—Hispanic or Latino respondents (2.1 vs. 4.1, $p < .001$).

4.4.4 Housing and transportation

As seen in Table 12, households living in mobile homes or large apartment buildings reported more disrupted capabilities (5.3 vs. 4.8, $p < .05$), more disruptions resulting in 'significant impacts' (3.4 vs. 2.9, $p < .001$), and more disruptions requiring additional money to adapt (2.9 vs. 2.4, $p < .01$) than households living in non-vulnerable housing structures such as unattached single-family homes. Households in crowded housing conditions reported more disruptions requiring additional money (3.4 vs. 2.5, $p < .05$) than households living in non-crowded conditions, but no other significant differences were seen between the two groups. There were no statistically significant differences in household outcomes based on vehicle access.

5 Prior outage experience

5.1 Household outcomes and prior outage experience

As shown in Table 13, there were no statistically significant differences in objective measures between households with prior outage experience ($n = 483$) and those with no prior outage experience ($n = 349$). There were, however, statistically significant differences between household outcomes in terms of subjective measures. Households with prior outage experience reported higher levels of life satisfaction during the outage than their counterparts (4.0 vs. 3.5, $p < 0.01$) and reported smaller decreases in life satisfaction (a decrease of 3.3 points vs. a decrease of 4.0 points, $p < 0.01$).

Further testing to identify additional differences in outcomes between households that had never experienced prior outages ($n = 349$), households who had previously experienced *short-term outages* lasting less than a day ($n = 289$), *medium-term outages* lasting between one day and a week ($n = 143$), and *long-term outages* lasting more than one week ($n = 32$) can be seen in Table 14. Results of Tukey's HSD testing specifically indicated that there were statistically significant differences in the outcomes of households that had previously experienced long-term outages and those that had never experienced outages. Households

Table 12 Differences in household outcomes based on housing type and transportation vulnerability indicators

Household Outcomes	Vulnerable <i>n</i> = 259		Not Vulnerable <i>n</i> = 540		<i>t</i> -test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Vulnerable housing						
Count Disrupted Capabilities	5.30	2.62	4.84	2.58	2.36	0.0189*
Count 'Significant Impact' Disrupted Capabilities	3.40	2.14	2.87	2.11	3.31	0.0010***
Count Disrupted Capabilities Requiring Additional Time	3.29	2.52	2.97	2.36	1.68	0.0941
Count Disrupted Capabilities Requiring Additional Money	2.90	2.67	2.36	2.50	2.69	0.0075**
Well-being During Outage	3.51	2.80	3.86	2.70	-1.68	0.0942
Change in Well-being from Before to During Outage	-3.71	3.69	-3.55	3.48	-0.60	0.5490
	Vulnerable <i>n</i> = 66		Not Vulnerable <i>n</i> = 757		<i>t</i> -test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Vehicle access						
Count Disrupted Capabilities	4.83	2.77	4.97	2.60	-0.39	0.6980
Count 'Significant Impact' Disrupted Capabilities	3.05	2.20	3.01	2.12	0.13	0.8944
Count Disrupted Capabilities Requiring Additional Time	2.67	2.76	3.10	2.39	-1.24	0.2198
Count Disrupted Capabilities Requiring Additional Money	2.47	3.06	2.53	2.52	-0.16	0.8722
Well-being During Outage	3.56	2.90	3.76	2.71	-0.53	0.5999
Change in Well-being from Before to During Outage	-2.89	3.76	-3.66	3.51	1.58	0.1172
	Vulnerable <i>n</i> = 48		Not Vulnerable <i>n</i> = 780		<i>t</i> -test statistic	<i>p</i> value
	Mean	SD	Mean	SD		
Overcrowding						
Count Disrupted Capabilities	5.04	2.57	4.95	2.62	0.23	0.8166
Count 'Significant Impact' Disrupted Capabilities	3.13	2.18	3.00	2.12	0.38	0.7067
Count Disrupted Capabilities Requiring Additional Time	3.48	2.71	3.04	2.39	1.11	0.2740
Count Disrupted Capabilities Requiring Additional Money	3.40	3.02	2.47	2.52	2.08	0.0427*
Well-being During Outage	4.27	2.90	3.71	2.71	1.30	0.1979
Change in Well-being from Before to During Outage	-2.90	3.51	-3.63	3.52	1.41	0.1634

* denotes $p < .05$, ** denotes $p < .01$, *** denotes $p < .001$

Table 13 Differences in household outcomes based on prior outage experience

Household Outcomes	No Prior Experience		Prior Experience		t-test statistic	p value
	Mean	SD	Mean	SD		
Count Disrupted Capabilities	5.09	2.67	4.85	2.57	-1.27	0.2040
Count 'Significant Impact' Disrupted Capabilities	3.09	2.08	2.95	2.15	-0.93	0.3534
Count Disrupted Capabilities Requiring Additional Time	3.12	2.51	3.01	2.35	-0.64	0.5212
Count Disrupted Capabilities Requiring Additional Money	2.54	2.56	2.51	2.56	-0.21	0.8395
Well-being During Outage	3.45	2.60	3.97	2.80	2.77	0.0057***
Change in Well-being from Before to During Outage	-3.95	3.48	-3.29	3.54	2.68	0.0075**

** denotes $p < .01$

Table 14 Differences in household outcomes based on the duration of prior outage experiences

Household Outcomes	No Prior Outage <i>n</i> =349		Prior Outage Lasting Hours <i>n</i> =289		Prior Outage Lasting Days <i>n</i> =143		Prior Outage Lasting Weeks <i>n</i> =32		<i>p</i> value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Count Disrupted Capabilities	5.09	2.67	4.81	2.37	5.10	2.74	4.41	3.24	0.3674
Count 'Significant Impact' Disrupted Capabilities	3.09	2.08	2.86	2.02	3.10	2.23	2.84	2.67	0.4924
Count Disrupted Capabilities Requiring Additional Time	3.12	2.51	2.91	2.29	3.34	2.45	2.63	2.21	0.2180
Count Disrupted Capabilities Requiring Additional Money	2.54	2.56	2.34	2.43	2.81	2.76	2.63	2.52	0.3623
Well-being During Outage	3.45	2.60	3.88	2.69	3.83	2.95	5.06	2.95	0.0116*
Change in Well-being from Before to During Outage	-3.95	3.48	-3.31	3.49	-3.73	3.60	-2.00	3.64	0.0101*

that had previously experienced an outage lasting a week or longer reported significantly higher life satisfaction during Winter Storm Uri than their inexperienced peers (5.1 vs. 3.5 on a scale of 0–10, $p < 0.05$), which also corresponded to relatively small decreases in well-being from before the outage to during the outage compared to those who had never experienced an outage (a decrease of 2 points vs. a decrease of 4 points on a scale of 0–10, $p < 0.05$). There were no other statistically significant differences in household outcomes based on the duration of prior outages.

6 Discussion and conclusion

Our analysis reveals some interesting insights into the impacts of infrastructure disruptions in Texas associated with Winter Storm Uri. Informing the first research question, we found that the most prevalent reported capability disruptions (i.e., to lighting, heating, and cooking) also were most reported as having the most significant impacts on households' overall well-being, albeit a slightly different order (i.e., heating, cooking, and lighting). This aligns somewhat with what we expected, although water services and health related challenges were not among the top capabilities for which households reported as being particularly impactful, which could be in part because only a small portion of our sample reported water service disruptions in their home. We did however see a few respondents mention water related issues and inability to use a CPAP machine as particularly impactful 'other' disruption types that were significant to their household. It is important to note that the 'other' disruption types, reported by less than 2% of respondents, were disproportionately likely to have significant household consequences, as four of the fourteen respondents who indicated 'other' disruptions also reported these disruptions as the most significant disruption experienced by their household. When reported, these 'other' disruptions were also both particularly likely to incur additional time burdens and were associated with the highest time costs of any disrupted activity type. In contrast, while disruptions to lighting and cooking were prevalent, they both were associated with relatively low time costs on a per-household basis. 'Other' disruptions were not only associated with relatively high time costs, but were also associated with the greatest monetary burdens of any activity type. Overall, disruptions to food-related activities such as accessing food, cooking, and refrigeration resulted in some of the highest household burdens, particularly in terms of monetary burdens, as these disruptions were both very prevalent and among the most cost-intensive disruptions reported.

Analysis related to our second research question confirmed hypotheses regarding the relationships between outage characteristics—both in terms of duration and continuousness—and household outcomes. Longer-duration outages were associated with higher burdens across all key household outcome measures, including the count of disrupted capabilities, the number of disruptions causing significant impacts on households, as well as the number of disruptions causing additional time and monetary burdens. Longer-duration outages were also negatively associated with reported life satisfaction during the outage and change in reported life satisfaction from before the outage to during the outage. There also were statistically significant differences between household outcomes based on the nature of outages, as households that experienced constant outages experienced more significant burdens than households with intermittent outages across all measures tested, both objective and subjective. The sensitivity of both the objective and subjective measures to the duration of outages suggests that reducing the length of outages would help to mitigate a

variety of household burden types. The sensitivity of these measures to the continuity of the outages highlights the importance of being able to periodically attend to needs, even if only for a short period of time. Our results also indicate that power outages were more burdensome by objective and subjective measures when compared to other types of infrastructure service disruptions reported during Uri, including water and natural gas disruptions.

Analysis related to our third research question generally supported the hypothesis that socially vulnerable households (defined by the CDC's SVI) experienced more severe burdens than comparatively less vulnerable households, but only for vulnerability groups and only for some measures of household outcomes. We found that impoverished households, households with minority status, households with children, households with members having a disability, as well as households residing in mobile homes or large apartment buildings reported the worst burdens in terms of objective measures. Interestingly, many of these household types, although suffering in terms of objective measures, reported less severe declines in well-being. In fact, lower income and less educated households, households with children, households with a disability and households with minority status all fared better in terms of subjective well-being when compared to other households. Most surprising is that households with seniors, despite experiencing less severe objective outcomes than households without elderly members, reported bigger declines in well-being during the storm.

These findings are seemingly counter-intuitive. The CA would suggest that more vulnerable groups may be more challenged to adapt or cope with these disruptions, which should be reflected by both objective and subjective measures. Yet many of our statistically significant results indicate that despite relatively high objective burdens, many vulnerable households suffered less subjectively. This may be explained by the theory of hedonic adaptation, or the tendency of people to quickly return to a stable level of happiness despite major positive or negative events; it is a process that can reduce the affective impact of emotional events (Graham and Oswald 2010). According to the theory, those who have lived a disadvantaged life, in general, may be less sensitive or emotionally affected by the occurrence of an extreme or disastrous event than others who are more well-off. If the theory holds, more wealthy and higher educated households may subjectively report greater declines in reported life satisfaction, as the event was more shocking and deviated more significantly from their typical life experience. On the other hand, a more vulnerable or disadvantaged household may subjectively report less severe well-being consequences from the same event because they are desensitized from chronic stressors and shocks that impact their lives fairly routinely. Without recognizing this relationship between measures of subjective well-being and infrastructure disruptions, one might report greater burdens experienced by more wealthy or privileged households, when in fact, the decline is relative to a baseline-level of experienced well-being prior to the event. This finding also underscores the limitations of the use of subjective measures alone in assessing impacts of disaster events, since these measures may not only lack consideration of social equity but also may unintentionally encourage unequitable strategies for mitigating burden. Moreover, future research should take greater considerations for important groupings of capability losses and social vulnerability indicators. For instance, households with children or elderly members may be particularly burdened if they also lack access to a personal vehicle and are considered low-income. That is, socially vulnerable populations are often disadvantaged in more than one way, and taking these multiple disadvantages into consideration with capability losses may reveal more meaningful results.

Analysis related to our fourth research question indicated that prior outage experience may have yielded some benefits for households, albeit only in certain capacities. Prior

outage experience did not reduce the impact of the outages in terms of objective household outcomes, but it did offer some benefits in terms of subjective household outcomes during the storm. Previous outage experience of any kind resulted in higher levels of life satisfaction during the outages associated with Uri, which also corresponded to smaller declines in reported life satisfaction during the storm. Households that had prior experience with an outage lasting a week or more experienced the greatest subjective well-being benefits compared to households that had never experienced a prior outage. Although prior experience did not result in households being better positioned to mitigate the impacts of an outage—or at least not of an outage associated with a storm the scale of Uri—it did, perhaps, engender greater emotional capacity to cope with the uncertain nature of the situation.

These results reveal key insights for emergency management, resilience planners, infrastructure managers, and households. They suggest that interventions related to supporting or enabling residents to cook, light their homes, and most significantly stay warm (or cool in the case of an outage during a heat event) are important interventions to safeguard health and well-being outcomes during future outages. At the community or neighborhood level, providing accessible heating (and cooling) shelters (a.k.a. resilience hubs) with backup power systems that also offer ways for residents to access potable water, refrigerate and cook food, as well as maintain sanitary conditions, could help mitigate the most significant burdens experienced by households. For individual homes, keeping plenty of warm blankets, flashlights, a stockpile of food and water, as well as sanitation products (e.g., cleansing wipes) may help families and households better cope. These results could also inform the prioritization of critical loads or load-shedding decisions for power utilities or other infrastructure managers during outages, that in general, do not incorporate community/household level needs or preferences. For example, facilities that provide services related to food preparation or storage should be categorized as part of a community's critical energy load and considered a priority in resilient infrastructure investments. Also, strategies that perhaps allow vulnerable households to utilize a particular threshold or limit of electricity that would enable the most basic capabilities (i.e., heating, cooking, lighting) to be achieved without shutting off power altogether may be a way to reduce significant household impacts, while keeping energy demand under control. Because longer, continuous power outages were found to cause higher burdens on households, utilizing rolling outages that limit the duration that households go without power will also be an important strategy for mitigating household impacts. Mobile electric generators may also be a worthwhile investment for some communities, so that local decisions may be made to prioritize power for the most critical community-level needs.

Moreover, our findings suggest that some indicators of social vulnerability (i.e., households that are impoverished, have children, identify as a minority, and have members with disabilities) were more relevant than others in predicting household burden during Uri. On the other hand, households with elderly members, which are often assumed to have increased social vulnerability, showed significantly reduced objective burdens when compared with other households. Other vulnerability indicators, like access to a personal vehicle and English proficiency had no statistically significant effect on the household outcomes examined in this analysis. These findings suggest that ex-ante indicators of social vulnerability may not be well suited to predict ex-post or experienced burdens on households and communities to disaster events, which in this case reveal more nuanced and context-specific results.

These findings also have important implications for resilience and disaster research scholarship. This research advances scholarship within the human development and human capabilities arenas because it extends a very widely used and rich framing of human

development and well-being, most used to understand effective ways to alleviate poverty, to the context of measuring household burdens of infrastructure disruptions in both objective and subjective ways. In this way, our work serves as a model for operationalizing the capabilities approach for use in understanding how the provision of infrastructure services (or lack thereof) influences the ability of a household to thrive. Although our proposed work here is focused on disruption situations, this work may also inform critical infrastructure system planning more generally to address issues related to food insecurity/food deserts, energy poverty, and/or access to clean water.

Future studies using the CA as a lens for understanding and quantifying the social burdens experienced by households during infrastructure outages are currently being planned in other cases and contexts. Ultimately, we hope to gather insights from a variety of disaster event types and locations to inform a generalizable hierarchy of household needs, for different household types, to help inform priorities for resilient infrastructure investment and community resilience planning efforts.

Author's contribution SKEP, SSC, and MAS contributed to the conception and design of the study. Material preparation, and initial data preparation performed by SP, with data preparation finalized by SH. Primary analysis performed by SH, with supplemental analysis performed by SP. A preliminary draft of the manuscript was written by SH, with guidance from SC, SP, and MS. The manuscript was supplemented and revised by SP and SC. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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