

The social factors shaping community microgrid operation

Received: 15 May 2023

Accepted: 18 July 2024

Published online: 31 July 2024

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When extreme weather events result in power blackouts, the critical electricity needs of a community can continue to be met by utilizing localized energy resources. The collective setup of these resources is referred to as a microgrid. Here, we carry out a survey to study the preferences of 1021 US residents on how the finite energy stored in a community microgrid should be rationed amongst various participating households during prolonged blackouts. Particularly, a differentiated service paradigm—where certain consumers can pay more to avail of higher energy quotas—received support from over 91.8% of respondents, despite the zero-sum nature of such rationing. We also report that respondents were receptive to selling between 42–53% of their stored energy to the microgrid should they own personal backup devices—what we call willingness-to-sell—balancing self-preservation and monetary compensation. Studying the factors influencing the responses on the fairness of differentiated service (for consumers) and willingness-to-sell (for storage owners), we identify for policymakers and businesses that an energy-as-a-service model is socially acceptable for community microgrids.

Electricity is a necessity in a functioning modern society. During climate-related emergencies including floods, wildfires, heatwaves, or winter storms, blackouts often occur due to demand-related stress or physical damage to the power distribution system (e.g., Puerto Rico Hurricane Maria 2017¹, Australia bushfires 2019², Texas winter freeze 2021³, Henan floods 2021⁴). Such power outages can disrupt the fundamental needs of the populace, e.g., heating/cooling, food, and communication. Supply chains for fuels such as petrol and diesel can also be affected due to the damage to critical transport infrastructure. Given that the availability of energy resources is critical for life preservation and recovery efforts in the aftermath of a disaster, microgrids are a widely-regarded solution to provide uninterrupted power to critical loads^{5–8}. Microgrids energize portions of the grid from the bottom up by coordinating locally available power generators (photovoltaic systems and diesel generators), storage units (community battery banks and vehicle-to-grid installations), and electrical loads^{9,10}. In exchange for a guarantee of a low-amperage uninterrupted power access, a community of residents can opt in to pay for a microgrid

setup through a localized levy to finance the installation of backup devices and associated supporting infrastructure¹¹.

As extreme weather events become increasingly frequent, and microgrid technologies become more mature, power sector vendors are expanding their portfolios in the microgrid space^{12–15}. This makes microgrids increasingly affordable, efficient, accessible, and mainstream. Further, governments such as that of California are investing significantly in community microgrid ventures¹⁶. For these to succeed in practice, businesses need to consider, apart from the technical aspects, the social implications behind how energy is managed within a microgrid during blackouts. Particularly, it is important to recognize that a community microgrid is limited by the overall energy storage capacity present (in the form of batteries or diesel fuel) and cannot provide power indefinitely. At the same time, major blackouts from extreme weather events can last several days or even weeks (Texas winter freeze 2021 - over 2 days³, Australia bushfires 2019 - up to 10 days², Puerto Rico Hurricane Maria - 84 days¹). Note that during a blackout, some consumers might be willing to pay large sums of

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money to continue to use electricity, which necessarily comes at an expense to others, given the scarcity of available energy. However, such a practice that views energy as a paid service may not be socially acceptable. Recognizing that continued energy access is a matter of life and death, microgrid operators should ensure equity and fairness in how the stored energy is rationed amongst the consumers. Otherwise, the viability of a market-based mechanism within the community would become questionable.

Surveys have been extensively conducted to elicit consumers' willingness-to-pay (WTP) for uninterrupted power supply (US^{17–19}, Europe²⁰, Ghana²¹, India^{22,23}, Indonesia²⁴). While these studies are directly related to the economic considerations in microgrid planning, they do not inform us on how such a microgrid should indeed be operated. Given that energy could be critical for survival during extreme weather events, and that perceived fairness of the payment and energy-use framework has been documented^{25,26} to have an impact on WTP for backup services (which can be viewed here as a proxy for societal acceptance of such services), it is essential to study the preferences of the populace thorough a survey, and identify the factors that influence them. Therefore, the primary goal of this study is to identify consumer preferences towards a differentiated service paradigm for community microgrids, where those who pay more receive a higher consumption quota. Our first hypothesis (H1) is that respondents will be against a conventional market-based system where certain residents could pay more to use more electricity during blackouts, depleting the share of others. Since some residents might be willing to pay significantly high prices to continue receiving backup power during contingencies, the expectation is that survey responses would skew towards favoring equal energy-use quotas for all residents. It is worth noting that prior studies (e.g., ref. 17) that conducted surveys to estimate WTP for backup services did not inform respondents on the inherent limit of overall backup energy available; it may therefore not be possible to extrapolate the results (e.g., reported critical electricity amperes) to design energy-use quotas in practice. Other studies (e.g., ref. 27) have considered how fairness indicators can be included in regulating energy consumption in the microgrid paradigm, but did not discuss how the values of these indicators are ascertained in practice.

In addition to community resources such as centralized battery storage and diesel generators, microgrid operators can tap into distributed resources that already exist within the community during blackouts. For instance, rooftop renewable generation and household battery storage are now commercially available, e.g., Tesla SolarRoof and PowerWall²⁸, which can offset utility consumption and reduce bills under normal circumstances. Several electric vehicle manufacturers (e.g., Ford F-150 Lightning^{29,30}) also enable vehicle-to-grid services to obtain monetary compensation from utilities for services such as peak shifting³¹. These technologies currently offer the capability of powering up a house for a few days during blackouts. Nonetheless, while the technical feasibility of integrating distributed storage resources is sound, the amount of

energy that microgrid operators can retrieve from these resources depends on the willingness of consumers to share. Regrettably, this crucial factor has not been considered in previous studies, potentially leading to overestimation of available energy resources. The second goal of our study is therefore to elicit the amount of stored energy these consumers are willing to sell (termed here as willingness-to-sell (WTS)). The WTS would be a hedged trade-off between the expected blackout duration, available personal storage capacity, and thereby the perceived surplus. This yields our second hypothesis (H2) that respondents would make a rational decision based on self-preservation, duly reducing their WTS when the personal storage capacity reduces, or when the blackout is expected to last longer. Ultimately, the goal is to estimate the amount of stored energy that the residents are willing to sell, and how it varies with the expected blackout duration, contributing towards more accurate estimates of consumer participation and informing calculations on leveraging such participation for the reduction in centralized storage^{32,33}. Finally, we wish to study the interdependence between the responses relating to H1 and H2, so as to ensure that the designed energy-use framework is socially acceptable both from the consumer and supplier perspectives.

In this work, we analyze the results of a survey of US respondents to elicit their preferences on energy management in a community microgrid during blackouts. We find (a) strong support for a differentiated service paradigm where consumers can pay more to secure higher energy quotas (91.8% of respondents), and (b) a strong inclination to sell from personal energy storage (91.4% of respondents), with the mean WTS ranging between 42–53% of the available storage. We also observe that while the WTS is proportional to the storage capacity of the resource owned, it increases when the perceived blackout duration is longer. Our findings enable microgrid manufacturers and electricity retailers to develop and implement an energy-use framework that is socially and economically fair under energy-scarcity situations, accelerating community acceptance and deployment.

Results

To ascertain the preferences of individuals on the fairness of a differentiated service paradigm and the WTS for resource owners, we conducted a web-based survey of 1021 respondents from the US. The survey first explains to the respondents the consequences of prolonged blackouts, and the capabilities and limitations of a community microgrid in providing backup power. It then elicits the respondents' preferences on how energy quotas for different residences served by the microgrid should be set up. Finally, it poses questions on WTS in the hypothetical scenario that the respondent owns one of the following storage resources: Ford F-150 electric vehicle, Tesla PowerWall, or portable diesel generator. Each of these devices has a different utility under normal circumstances—transportation, offsetting energy consumption, and camping respectively—but can be used during blackouts to power up a residence. The framework of the survey is shown in Fig. 1. Further details and the

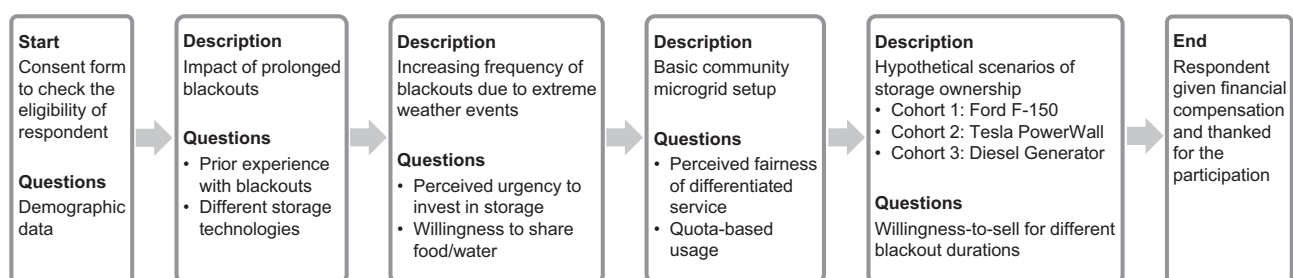


Fig. 1 | Framework of the web-based survey. The survey elicits respondent perceptions on the fairness of a differentiated service scheme for energy rationing in a community microgrid, and their willingness to sell stored energy during a blackout.

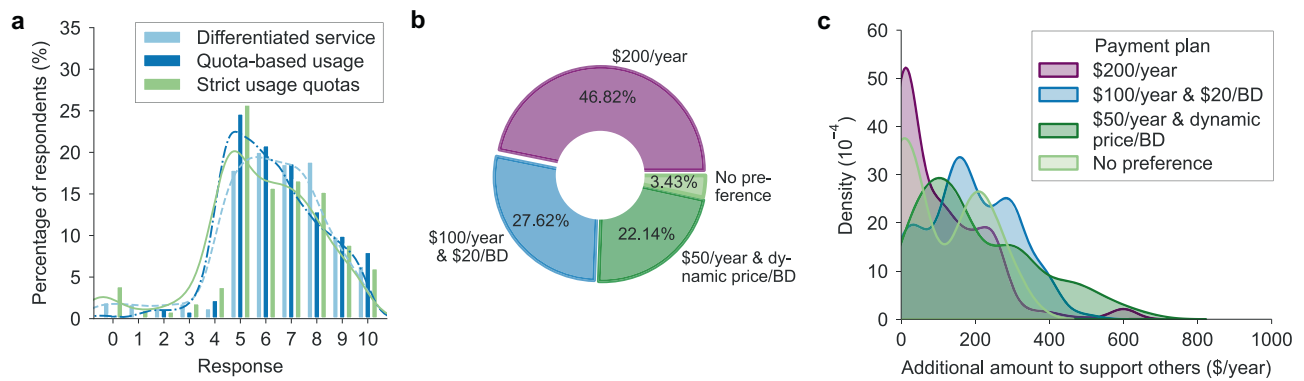


Fig. 2 | Survey responses pertaining to a differentiated service paradigm for community microgrids. **a** Histogram showing the preference of respondents on the fairness of differentiated service, quota-based usage, and whether usage quotas should be strictly enforced during a blackout. Here, the responses are on a Likert scale from 0 to 10, where a larger number indicates stronger support. **b** Responses on the payment plan perceived to be the most fair for availing of backup service

from the community microgrid, where the choices differ in the fixed cost per year (USD(\$)/year) and variable cost (\$/blackout day (BD)). **c** Density plots showing the probability distribution of the additional amount of money that respondents are willing to pay per year towards providing backup for economically weaker residents in the community. Responses are grouped according to the responses from (b), where values above \$1000 are capped at \$1000.

survey questionnaire are given in Methods and Supplementary Information.

Fairness in differentiated service

The overall energy stored in a microgrid is determined by the installed centralized battery capacity and the fuel tank capacity associated with the diesel generator. We study how this energy should be apportioned to the various participating residences by eliciting responses on a Likert scale on the respondents' support for a scenario where the quota allocated depends on the amount paid beforehand. This is in contrast to the scenario where each resident gets an equal quota and pays an equal price for the backup service. The responses are given in Fig. 2a, where over 91.8% of the respondents indicate support for the differentiated service paradigm for the participating residences, with a response greater than or equal to 5 (mean = 6.595, s.d. = 2.065 on a Likert scale from 0 to 10). The propositions that residents who use less power (e.g., by judicious use of energy) should receive energy for longer, and that backup power supply should be terminated immediately for residents who exhaust their quotas during the course of the blackout, also received strong support. Directly contradicting hypothesis H1, these results indicate that the respondents view emergency energy backup as similar to non-emergency services and support a traditional market paradigm—although this could perhaps change if respondents experience more frequent or more severe blackouts.

In exchange for receiving backup power during blackouts, we presented respondents with the following yearly payment options in the expectation of 10 blackout days per year: (i) a one-time yearly payment of USD(\$ 200, (ii) a reduced one-time payment of \$100 with additional \$20 per blackout day (i.e., \$100–300 per year), or (iii) a lower one-time charge of \$50 with dynamic pricing between \$20–40 per blackout day (i.e., \$50–450 per year). For context, the average monthly electricity bill in the continental US ranged from \$84–187 in 2022 depending on the state³⁴, and a 2020 study reported a median WTP of \$43 per blackout day¹⁷. Referring to Fig. 2b, amongst the respondents who indicated a particular preference, over half favored the plans with variable annual cost, suggesting that they expect that blackouts would be less frequent in reality and therefore wish to reduce their upfront monetary commitment towards power backup. The results are not region-specific, remaining largely consistent for respondents from the western and eastern parts of the US; see Supplementary Fig. 6. We also investigated the choice of respondents who endured blackouts exceeding one day (see Supplementary Fig. 7). Interestingly, this set showed a clear inclination towards the plan with a

fixed annual cost of \$200. This suggests that, as more individuals experience prolonged power outages, fixed-cost payment options are likely to become more attractive. Based on the above options, we then presented the maximum yearly amounts that the respondents have committed to the community microgrid (\$200, up to \$300, up to \$450, and \$200 for those who expressed no particular preference), and then asked them how much more per year they are willing to pay to subsidize economically weaker residents of the community (see Fig. 2c). Despite different committed amounts, we find that most respondents are willing to pay a median value between \$50 and \$150 per year. Furthermore, our investigation reveals an intriguing phenomenon where respondents who are hesitant to pay a higher upfront annual cost are willing to pay more to support others, as depicted by Fig. 2c. To explain this observation, we instead studied the correlation between the latter value and the maximum yearly amount they committed to paying for backup, as this was also displayed in the survey question for each payment plan. Here, a Spearman test revealed a statistically significant relationship (p -value $\approx 0 < 0.05$) suggesting a potential anchoring effect; those committed to paying more for the backup service also volunteered higher amounts to help their community.

Willingness to sell stored energy

Given the limited nature of stored energy, the microgrid operator may contract resource owners (e.g., those who own battery storage, diesel generators, etc.) to purchase any available surplus to supplement the existing resources in the microgrid. Such an arrangement can also serve to reduce the centralized battery size and significantly reduce the capital cost for the microgrid infrastructure. Notably, while the participation of individual resource owners towards mitigating generation deficits for monetary compensation is already a mainstream practice in power grids (termed as ancillary services), the decision-making process in selling energy to a microgrid during a blackout involves the conflicting objective of self-preservation. An accurate estimate of the fraction of community residents that are willing to participate in such a contract, and their WTS, would be valuable due to the earlier reasons. From our survey, about 91.4% of the respondents were interested in selling surplus energy in the hypothetical scenario that they owned a storage resource (mean = 6.414, s.d. = 1.860 on a Likert scale from 0 to 10); see Fig. 3a. Furthermore, Fig. 3b shows that the WTS responses were strongly correlated to how fair the respondents found the differentiated service paradigm (linear regression slope = 0.322, p -value of T-test ≈ 0). This suggests that respondents who believe in the market-based energy-consumption framework

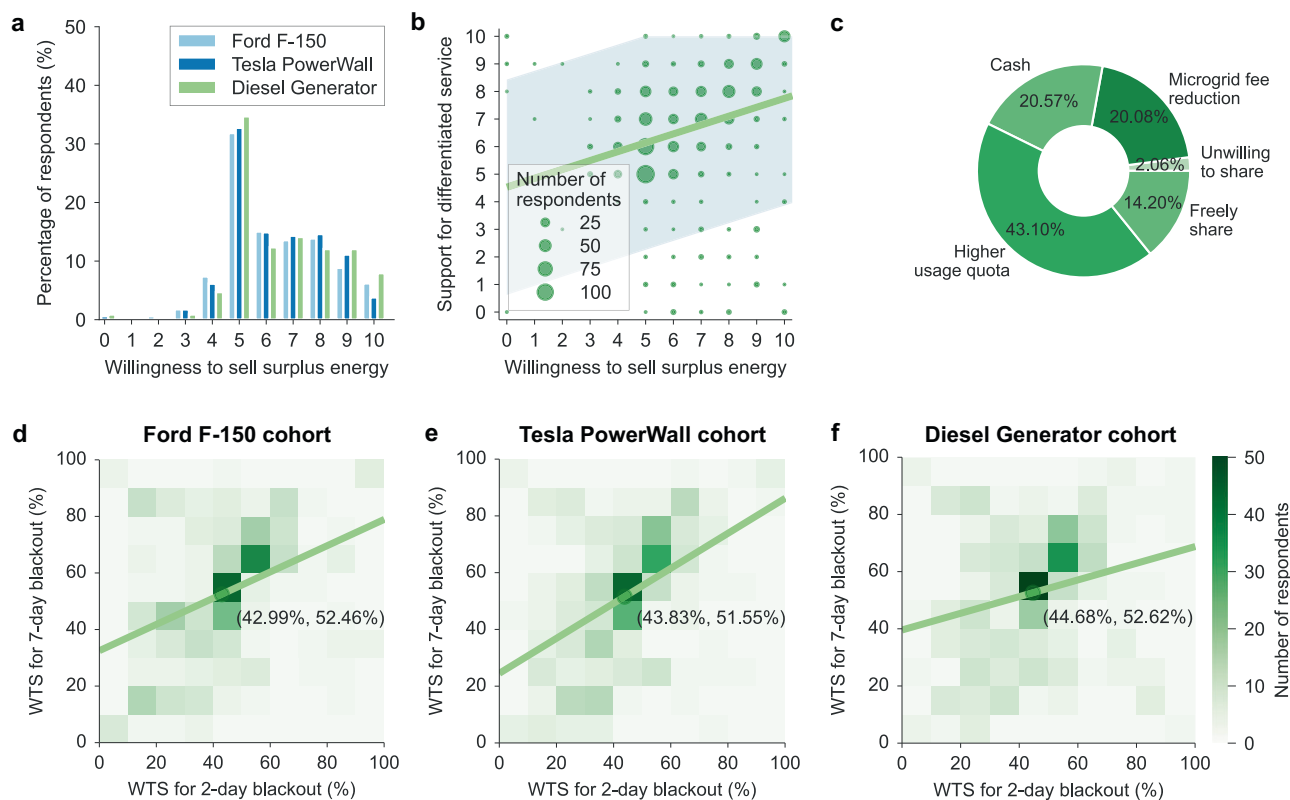


Fig. 3 | Survey responses on willingness-to-sell (WTS). **a** How willing the respondents are to participate in a contract where they sell energy to the microgrid from personal storage in exchange for a payment. Here, the responses are on a Likert scale from 0 to 10, where a larger number indicates higher willingness. **b** Correlation between the respondents' willingness to participate in a selling contract with their support for differentiated service. Here, the solid line is the result of a linear regression, with the shaded area representing the prediction interval with 95% confidence. The size of the circles represents the number of respondents. **c** Preferences on the nature of payment for selling energy to the microgrid. **d–f** Heat map of the WTS for an anticipated 2-day blackout versus a 7-day blackout for the three cohorts. Here, the solid line is the result of a linear regression, and the coordinates indicate the mean WTS.

Table 1 | Summary of the respondents' willingness-to-sell (WTS) for different blackout durations

	Response on WTS of different cohorts					Linear regression (2 days vs 7 days)			KS test for change in WTS (2 days vs 7 days)
	Blackout	Lowest	Median	Highest	s.d.	Slope	Intercept	p-value	p-value
Cohort 1: Ford F-150	2 days	5%	45%	95%	0.187	0.464	32.51%	≈ 0	Cohort 1 - Cohort 2: 0.992
	7 days	5%	55%	95%	0.224				
Cohort 2: PowerWall	2 days	5%	45%	95%	0.168	0.617	24.53%	≈ 0	Cohort 2 - Cohort 3: 0.999
	7 days	5%	55%	95%	0.226				
Cohort 3: Diesel Gen	2 days	5%	45%	95%	0.175	0.292	39.59%	≈ 0	Cohort 3 - Cohort 1: 0.978
	7 days	5%	55%	95%	0.216				

p-values of linear regression are based on two-sided T-test. The KS test is also two-sided.

under scarcity are also more likely to participate in selling to the same market, should they own a storage resource. In exchange for such residence-to-microgrid energy sharing, both higher energy quotas and monetary returns appear acceptable; see Fig. 3c.

To determine WTS and how it is impacted by the capacity of personal storage as well as the perceived surplus (based on anticipated blackout duration), the respondents were divided randomly into one of 3 cohorts. In each, the respondents were presented with the hypothetical scenario that they owned a Ford F-150 electric vehicle (cohort size 339), Tesla PowerWall (cohort size 342), or portable diesel generator (cohort size 340). These devices were explained to have different energy storage capacities, and that they could power a typical US residence for 10, 3, or 2 days, respectively. Given the differences in storage capacity amongst the cohorts, we designed the questions on WTS to report in percentages of the overall storage capacity. The

results are shown in Table 1, where the indicated percentages correspond to the mid-points of the intervals selected by the respondents in the survey. Surprisingly, opposite to our second hypothesis where we initially supposed a reduction in WTS when blackouts are anticipated to be longer, the survey results for each cohort indicate that the WTS increases when the blackout duration increases from 2 to 7 days; see Fig. 3d–f. In other words, these results are inconsistent with H2. Note that this is despite reminding the survey respondents that their own stored energy would decrease should they choose to sell to the microgrid. This could perhaps be due to two reasons: (i) a desire to obtain more revenue by selling more energy during a longer blackout, or (ii) a willingness borne out of responsibility to help the rest of the community during a worsening predicament. To delve into this aspect further, we conducted a Spearman test to examine the correlation between the increase in WTS and the participants' willingness to allow

their neighbors to charge their electronic devices during a blackout. The outcome of the test revealed a negative correlation of -0.098 ($p = 0.0017$), which challenges the hypothesis that the increase in WTS is driven by a sense of communal responsibility. Further, we analyzed the increase in WTS for respondents who opted for reductions in fees, cash incentives, and increased energy quotas as compensation mechanisms. The results show a notable 7.64% increase in average WTS for this group, with a statistically significant difference in the paired sample test (p -value ≈ 0). This analysis suggests that the primary motivation behind the increased WTS is the individual's desire to obtain additional revenue.

For each cohort, we conducted the paired sample test to check whether the blackout duration had a statistically significant effect on the WTS responses. Here, the p -values ≈ 0 , indicate that a statistically significant difference does exist. We further confirm this positive correlation using linear regression; see Table 1. These observations also hold when all the cohorts are considered together, as seen from Supplementary Fig. 8. To determine whether the increase in WTS for longer blackout durations is dependent on the available storage capacity, we conducted two-sample Kolmogorov–Smirnov (KS) tests to compare the distributions of the WTS difference for a 2-day versus 7-day blackout. For the cohort combinations taken pairwise in cyclic order, the p -values were respectively 0.992, 0.999, and 0.978 (all $\gg 0.05$), indicating that the capacity does not have a statistically significant impact on WTS decisions. This is also evident from the probability distributions of the responses given in Supplementary Fig. 9. It should however be noted that since the WTS values were reported in percentages of the overall storage capacity, the actual WTS would be proportional to the storage capacity, meaning that this section of results is in accordance with hypothesis H2. In fact, when the respondents were broadly asked if they would sell more energy during a blackout if they had a larger capacity, they overwhelmingly agreed (from Supplementary Fig. 5f, mean = 6.759, s.d. = 1.740 on a Likert scale from 0 to 10). Overall, this suggests that WTS estimates from the survey may be broadly applicable to different storage device types and models. We further inquired about the price at which respondents would be willing to sell their energy to the microgrid (refer to Supplementary Fig. 5h). The results indicate that a majority of respondents who expect compensation prefer a higher price than the normal electricity price.

Relationships to demographic data

Finally, we analyze the survey responses in the context of the demographic data of the respondents. Referring to Table 2, we find that the responses on the fairness of differentiated service and WTS both

exhibit significant positive correlations to the income of the respondents. An implication here is that the section of the population with relatively higher financial capacity to invest in, and be the most likely to own storage resources, is more inclined to participate in buying and selling energy from community microgrids. The results also suggest that relatively older, more educated individuals tend to view a differentiated service paradigm as less fair, and have a lower WTS. Individuals with these demographic characteristics could potentially have increased awareness or experience of the consequences of a blackout, resulting in a more risk-averse stance. Despite a positive correlation between income and education level ($\rho = 0.136$, p -value ≈ 0 in Spearman test), their effects on perceived fairness and WTS diverge, which is presented as opposite signs of their coefficients in the linear regression. Along similar lines, we find a negative correlation between blackout experience and the perceived fairness of differentiated service. This implies that individuals who have experienced longer blackouts are less inclined to support the market-based mechanism. Additionally, we find that sex, ethnicity, and employment status do not have much bearing on either the perceived fairness of differentiated service or the WTS. It is worth mentioning here that the same demographic factors—age, income, and education level—have been found to influence WTP decisions in other studies as well^{17,19–21,35}.

While our results broadly indicate that the respondents overwhelmingly prefer a market-based or capitalistic approach to transact energy during blackouts, a majority of respondents nevertheless express empathy with other residents in the community. Specifically, they would (i) be willing to share food with neighbors during blackouts (mean = 6.934, s.d. = 1.841 on a Likert scale from 0 to 10), or (ii) allow them to charge electronic devices in their homes (mean = 6.831, s.d. = 1.985), should they have backup power available; see Supplementary Figs. 3b and 5a). We also observe that these two preferences are correlated (see Supplementary Fig. 10), which reveals that respondents' empathy is reflected consistently across the various survey questions; the response trends on the fairness of differentiated service and WTS are therefore realistic.

Discussion

While a microgrid entails participants buying and selling backup energy during blackouts, its operation differs significantly from the conventional market paradigm. That is, energy is a scarce commodity and could be critical for survival during long blackouts. Despite this key difference, our research finds that US residents generally prefer a market-based system where consumers can pay more to use more energy during a blackout, and residents are rewarded for storing and sharing energy. Survey respondents also continue to support such a differentiated service paradigm when the blackouts are expected to be more severe and longer. This contradicts our hypothesis H1 that people would prefer equal usage quotas for all residents. This finding suggests that while community microgrids could arguably be viewed as a community service, it may be socially acceptable to implement a market mechanism (with some subsidies for economically weaker residents). With regard to residence-to-microgrid energy transactions, the results are partly inconsistent with hypothesis H2 that the WTS decision-making process rationally leans towards self-preservation. While our results show that the amount of energy the respondents are willing to sell is proportional to the available storage capacity, they also show that a substantial number of respondents prefer to sell more to gain higher monetary compensation even at the cost of increasing personal risk of losing backup power, suggesting that they do not actually expect to remain without power for extended periods of time. We also uncover that respondents are willing to sell their excess energy at a price higher than the regular rate. Diverse reimbursement plans such as microgrid fee reductions, cash incentives, and increased usage quotas, can be considered effective incentives to engage customers in selling their surplus energy. These findings carry important

Table 2 | Linear regression of the perceived fairness of differentiated service and willingness-to-sell (WTS) with demographic data

Demographics	Perceived fairness of differentiated service		WTS for 2-day blackout	
	Coefficient	s.e.	Coefficient	s.e.
Income	0.372*	0.083	0.316*	0.069
Age	-0.021*	0.011	-0.029*	0.009
Education	-0.094*	0.047	-0.240*	0.039
Blackout experience	-0.193*	0.077	0.084	0.064
Not full-time employed	-0.222	0.329	-0.515	0.276
Female	0.143	0.133	0.027	0.111
Hispanic	-0.250	0.157	0.050	0.131
Constant	7.351*	0.489	4.897*	0.410

s.e. standard error.

*Statistically significant, i.e., p -value of two-sided T -test is below 0.05.

implications for developing successful business models for community microgrids, as well as for policymaking and regulation. In fact, considering that more distributed storage is now available, and that community microgrids at present rely largely on bulk investment into centralized storage/generation, the use of a market framework for distributed storage/generation can alleviate investment costs. This makes greenfield community microgrid projects more economically and technically viable.

We note that the results presented in this work relate to respondents from the continental US. However, the following observations suggest that the results could be more broadly applicable. While prior studies have noted statistically significant correlations between the blackout experience and the willingness-to-pay (WTP) for uninterrupted backup (e.g., Ghana²¹, India²³), we did not observe similar correlations of the blackout experience with the perceived urgency to invest into backup solutions and WTS (*p*-values of Spearman test are respectively 0.278 and 0.832). This could perhaps be due to the fact that in the present survey, the consequences of long blackouts were explained in detail to the respondents, mitigating the impact of a lack of personal experience (similar findings were previously reported in the context of WTP¹⁷). Overall, this implies that surveys regarding community microgrid energy management can be carried out on a general populace, and not necessarily from those previously affected by long blackouts, to obtain meaningful results. Note that there is the possibility that the WTS responses could be affected by the hypothetical bias as not all respondents currently own a storage device, especially given that the community microgrid concept has not yet proliferated in the continental US. Moreover, the attitudes of individuals toward fairness and willingness to share may change over time. Yet, it is essential that the outcome of WTS research—an energy-use framework for community microgrids—should be palatable even to a naïve populace to enjoy broad societal acceptance.

Overall, microgrids are required for life preservation and recovery in times of crises such as climate emergencies and war. Heretofore, electrical engineers often assume that the various elements of a microgrid are fully controllable and optimizable, except in the instance of direct human interventions such as demand response. However, even for distributed storage, there is a human element of ownership and decision-making involved that is particularly complex due to energy scarcity. In reality, as we have shown, WTS is not 100%, which makes WTS an important question that has not been formerly considered. The next step would be to develop a socially acceptable market mechanism for community microgrids during blackouts. Establishing such an operational philosophy is fundamental to developing a sustainable business model for microgrids, and more broadly, the energy-as-a-service model during blackouts and emergencies.

Methods

Survey design

Prior work on WTP estimation suggests that the respondents express accurate preferences when they are educated on the consequences of a blackout¹⁷. Therefore, the survey begins with a detailed description of the consequences of extreme weather events and the blackouts that result thereof. The survey follows up with questions to gauge the respondents' experience with electricity blackouts including blackout duration, the electric loads they consider essential during a blackout, and their (planned) ownership of backup solutions. Since one of the goals of the survey is to elicit preferences on WTS that relates to electrical energy in community microgrids, we included questions to understand whether respondents are generally willing to share other essential items such as food and water with their neighbors, or allowing them to charge essential electronic devices, e.g., cell phones, during blackouts.

The next part of the survey describes a community microgrid and explains its capabilities. The respondents are then informed on the

zero-sum nature of energy consumption during a blackout, and are presented with questions to determine their preferences on how usage quotas should be set up. Here, to avoid inducing a bias for/against a quota-based usage system, the questions presented both scenarios: (i) if a resident uses energy frugally, they should be able to be guaranteed backup for longer, and (ii) if a resident reaches the end of their quota, their backup should be cut off even if the blackout is ongoing.

Finally, the survey elicits responses on WTS by introducing the hypothetical scenario that the respondent owns (randomly selected), one of the following devices: (i) a Ford F-150 electric vehicle for travel needs, (ii) a Tesla PowerWall solar array with battery storage for offsetting electricity consumption, or (iii) a diesel generator for camping. The survey describes how these devices can alone power up a typical US household for respectively 10/3/2 days, even if the community microgrid runs out of energy. A key component of the WTS decision-making process being the available storage capacity which directly influences the amount of energy surplus beyond personal use, we selected the cohort storage devices with the above significantly-different capacities. We also study the other key component: the expected blackout duration—which is balanced against the storage capacity—by eliciting the respondents' WTS under two scenarios: a blackout expected to last 2 days, and then, one that is expected to last 7 days. To avoid bias in the WTS responses by anchoring the responses to a baseline, we did not provide the actual storage capacity in kWh of each device, nor did we elicit the WTS in terms of kWh. Instead, the WTS choices were in percentages of the overall available personal storage. Furthermore, in regard to the preferred compensation for energy sold to the microgrid, we did not ask respondents to report the expected amount, e.g., in \$/kWh, or indeed provide the actual investment cost of the storage devices for any of the cohorts. The underlying reasoning is that each of these devices serves a different primary purpose in a resident's life, namely, transportation and ancillary services for the Ford F-150, reduction of electricity consumption for PowerWall, and camping for the diesel generator. That these devices can also be used to provide energy during a blackout is incidental, and therefore WTS decisions should not be made on the basis of recouping the respective investment costs.

Data

The survey was hosted on Qualtrics and administered through Amazon Mechanical Turk, where we recruited 1,021 unique respondents. To be eligible to participate, respondents had to be at least 18 years of age and have been living in the continental US for the past 5 years. The survey was approved by the Institutional Review Board of the National University of Singapore, and informed consent was obtained from all survey respondents before they started the survey. The responses were collected in February 2024. Approximately 70% of our respondents have experienced blackouts lasting more than half a day, and 24% have endured outages lasting over a day in the past five years. These are generally consistent with the current US blackout situation, as evidenced by data from the US Energy Information Administration (EIA) showing an average of over eight hours of power interruptions for US residents in 2020³⁶. Notably, specific states like Texas, Connecticut, and Oklahoma experienced considerably longer outages, averaging 23.8, 21.2, and 51.5 hours, respectively³⁷. More details about the survey including demographic information of the participants are given in Supplementary Information.

Analyzing survey results

The family of distributions of the responses obtained from our survey was generally unknown, which suggested the use of non-parametric tests for analysis. For analyzing the correlations between ordinal variables obtained from the survey, e.g., responses on fairness and WTS, we used the Spearman Test. When correlations were observed, we also employed linear regression to fit the relationship between the

variables under study. To analyze the impact of the blackout duration on the WTS, we employed the paired two-sample test to check whether the WTS for the same respondent changes when the perceived blackout duration is longer. Meanwhile, analyzing the impact of storage capacity involved comparisons across the different cohorts. Therefore, we used the two-sample KS test to compare the distributions.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The raw data obtained from the survey has been presented in Supplementary Figs. 1 to 5, and are also available at ref. 38.

Code availability

The code for obtaining the plots in the study are available at ref. 38.

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Acknowledgements

The research was conducted at Future Resilient Systems at the Singapore-ETH Center, which was established collaboratively between ETH Zurich and the National Research Foundation Singapore. This research is supported by the National Research Foundation Singapore (NRF) under its Campus for Research Excellence and Technological Enterprise (CREATE) program.

Author contributions

G.R., Y.Y., and J.C.-H.P. conceived the study. G.R. and Y.Y. generated the figures and performed the analyses. G.R., Y.Y., and J.C.-H.P. wrote the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41467-024-50736-9>.

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Peer review information *Nature Communications* thanks Hoang Phong Le, Sunhee Baik and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. A peer review file is available.

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