

Supplementary Information for
**The social factors shaping community microgrid
operation**

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This Supplementary Information include: Supplementary Note 1, Supplementary Figures 1-10, and Supplementary References.

Supplementary Note 1: Survey questionnaire

To understand the preferences of residents towards how energy should be distributed amongst participating households in a microgrid system during blackouts, we recruited 1,021 unique participants through Amazon Mechanical Turk. The respondents were then provided a link to the survey which was hosted on Qualtrics. The survey consists of the following 6 steps:

- Step 1:** A consent form is displayed (see Section 1.1), following which the demographic questions are asked (see Section 1.2);
- Step 2:** The participant is asked a set of questions to gauge their prior experience on blackouts, and their knowledge on any distributed energy resources (Section 1.3);
- Step 3:** The participant is informed on the consequence of a blackout and is asked questions on willingness to invest in backup solutions and share other resources with neighbors during a blackout (Section 1.4).
- Step 4:** The participant is informed on the community microgrid concept and the limited nature of stored energy, and is asked questions to determine the fairness of differentiated service in community microgrids (Section 1.5);
- Step 5:** The participant is introduced to the capability of one of three personal energy storage resources (Ford F-150, Tesla PowerWall, and a diesel generator) and is asked questions about their willingness to trade energy from their storage resource in exchange for payment (Section 1.6).
- Step 6:** The participant is awarded a payment of \$1.0 and thanked for their participation (Section 1.7).

1.1 Consent form

The consent form consists of the following text:

Welcome to this study investigating the expectations of people on energy backup during power grid blackouts. You are eligible to participate in the study at this time if you are:

- 1. 18 years of age or older; and*
- 2. live in the continental United States (i.e., all states except Hawaii) for the past 5 years.*

The questionnaire asks about your background and your experiences with power grid blackouts in the past. This is followed by questions to record your perceptions on how a backup system should be set up, as well on your willingness to share personal energy resources with the community. This survey is anonymous, i.e., it does not contain individually identifiable data from you. Your participation is voluntary, and you may close the survey at any point.

The questionnaire is expected to last on average 10 minutes. An amount of \$1 will be paid upon successful completion of the survey.

This research is conducted by Gurupraanesh Raman and Jimmy Chih-Hsien Peng at the National University of Singapore, and has been approved by the Institutional Review Board (IRB). For questions about the rights of research participants, you may contact the IRB at irb@nus.edu.sg.

If you have any questions, suggestions or concerns, please feel free to reach out to the project manager Gurupraanesh Raman at elegpr@nus.edu.sg or the faculty advisor Jimmy Chih-Hsien Peng at jpeng@nus.edu.sg.

*Please do not complete the survey more than once. Upon finishing the survey you will receive a completion code. The payment of \$1 will be made once you've entered that code in the space provided. **Please do not close the browser with your MTurk account.** If you read this consent form, and would like to participate in this study, press the button below!*

1.2 Demographic questions

1. *What is the sex listed on your birth certificate?*

- (a) *Male*
- (b) *Female*

2. *What is your ethnicity?*

- (a) *Hispanic*
- (b) *Non-Hispanic*

3. *What is your age?*

[Empty field to be filled by a number]

(if age is less than 18, participant is not eligible and is thanked and exits the survey)

4. *What is your highest completed level of education?*

- (a) *Less than high school*
- (b) *High school graduate or equivalent (e.g., GED)*
- (c) *Some college*
- (d) *2 year degree (i.e. Associate's degree)*
- (e) *4 year degree (i.e. Bachelor's degree)*
- (f) *Masters or Professional degree (i.e. MBA, MPP, etc)*
- (g) *Doctoral Degree*

5. *What best describes your employment situation?*

- (a) *Full-time employed*
- (b) *Part-time employed*
- (c) *Unemployed*
- (d) *Caregiver (e.g., children, elderly) or homemaker*
- (e) *Retired*
- (f) *Full-time student*
- (g) *Other*

6. *What was your yearly personal income in 2021 (include salary, interests, returns on investments, etc)?*

- (a) *Less than \$30,000*
- (b) *\$30,000 - \$59,999*
- (c) *\$60,000 - \$99,999*
- (d) *\$100,000 - more*

7. *Do you currently or in the past 5 years owned an automobile such as a car, minivan, or a pickup truck?*

- *Yes*
- *No*

8. *Have you been living in the continental United States for the past 5 years?*

- *Yes*
- *No*

(if "No" selected, participant is not eligible and is thanked and exits the survey)

1.3 Questions on prior experience with blackouts

During a blackout, you lose power to your residence. The buildings and other residences in your locality will also likely lose power, and blackouts can last several days. Your fundamental needs such as ventilation, heating/air-conditioning, lighting and water pumps will not function. You will not be able to charge your electronic devices, and mobile service may be affected during blackouts over 3 days long, as the power supply to communication infrastructure continues to be interrupted. If you are working from home, you may not be able to do so, and you might therefore not get paid by your employer.

1. *What is the longest blackout that you have encountered in the past 5 years?*
 - (a) *0-3 hours*
 - (b) *3-12 hours*
 - (c) *12-24 hours*
 - (d) *1-3 days*
 - (e) *More than 3 days; enter number of days* [Field to enter number].
2. *Can you please confirm if you did experience a **blackout lasting more than half a day** in the past 5 years?*
 - (a) *Yes, I did*
 - (b) *No, I didn't*
3. *What electrical appliances do you consider essential during a blackout? Check all that apply:*
 - (a) *Heating*
 - (b) *Fan or air-conditioning*
 - (c) *Cell phone*
 - (d) *Consumer electronics, e.g., laptop, iPad, TV*
 - (e) *Water pump*
 - (f) *Radio*
 - (g) *Healthcare equipment*
 - (h) *Others* [Field to enter text]
 - (i) *None of the above*
4. *Which of the following technologies do you have any knowledge about? Check all that apply:*
 - (a) *Portable diesel generator*
 - (b) *Solar photovoltaic (PV) arrays*
 - (c) *Battery storage, e.g., Tesla PowerWall*
 - (d) *Electric-Vehicle-to-grid (V2G) technology, e.g., Ford F-150 Lightning*
 - (e) *None of the above*
5. *Do you plan on installing any backup solutions for your home in the next 5 years? Check all that apply:*
 - (a) *Portable diesel generator*
 - (b) *Solar photovoltaic (PV) arrays*
 - (c) *Battery storage, e.g., Tesla PowerWall*
 - (d) *Electric vehicle*
 - (e) *Other power backup device* [Field to enter text]
 - (f) *None of the above*
6. *Are you planning to buy an electric vehicle in the next 5 years?*
 - (a) *Yes*
 - (b) *No*
 - (c) *Undecided*

1.4 Questions on the baseline community spirit:

Extreme weather events such as heatwaves, hurricanes, and winter storms are becoming more frequent and severe in recent years. These can all lead to blackouts by stressing the power grid or damaging some of its critical components. Depending on the severity of the extreme weather event, the blackout can last up to 10 days in the continental United States. During this time, your residential neighborhood will not have any access to electricity.

1. *How urgent do you think it is for you to personally invest in backup solutions such as battery storage, electric vehicles, or other technologies in anticipation of blackouts in the next 5 years?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled as “Not at all necessary” and “10” is labeled as “Definitely necessary”]

2. *How willing are you to share food and/or drinking water with your neighbors, if they are in need, as neighboring supermarkets or convenience stores may not be able to remain open without power?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Not at all willing” and “10” is labeled as “Definitely willing”]

3. *To what extent do you agree with the statement: “I will NOT share any food and/or drinking water with my neighbors during a blackout”?*

(a) *Mostly disagree*

(b) *Mostly agree*

(The responses for the questions 1.4.2 and 1.4.3 are cross-validated for consistency. Inconsistent responses are discarded.)

1.5 Questions on the fairness of differentiated service:

*Suppose your local community comes together to pay a vendor to install a setup that would provide backup supply during blackouts caused by extreme weather events. This would consist of a large diesel generator, diesel storage, and a battery bank. Each participating resident pays into this setup called a **community microgrid** through a fee, and in exchange, receive backup power for limited critical needs. The overall energy stored in the microgrid is fixed, and the backup can only last until the battery is drained and the stored diesel fuel runs out. Remember that a blackout can last as long as 10 days and transporting in diesel fuel in the short term is likely difficult due to damage to road infrastructure from the extreme weather event.*

1. *One of the residents wants to pay more beforehand and be entitled to use more of the stored energy during the blackout. This would reduce the quota of energy backup for the other residents who pay less. Do you think this is fair?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely unfair” and “10” is labeled as “Completely fair”]

2. *This is an attention check question. Please select the option that is equal to 0.*

[Likert scale with values: 0, 1, ..., 10]

(If the respondent fails to select the correct answer, their response is discarded)

3. *If a resident conserves energy during a blackout (e.g., by reducing lights, turning down the heating/air conditioning, etc.), do you agree that they should be guaranteed backup for longer until they fully utilize their quota?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely disagree” and “10” is labeled as “Completely agree”]

4. *Do you agree that a resident should stop receiving backup once they finish their allocated energy quota even if the blackout is still ongoing?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely disagree” and “10” is labeled as “Completely agree”]

5. Do you agree with the statement: “A resident, who has exhausted his/her allocated energy quota during a blackout, should be cut off from receiving further backup”?

- (a) Mostly agree
- (b) Mostly disagree

(The responses for questions 1.5.4 and 1.5.5 are cross-validated for consistency. Inconsistent responses are discarded.)

6. For receiving backup from the community microgrid, what type of payment mechanism do you find the most fair? The anticipated blackout duration for your locality is 10 days per year.

- (a) You pay a fixed price of \$200 per year which is pre-determined based on the severity of blackouts in your region. You don't pay anything more for energy used during the blackout.
- (b) You pay a charge of \$100 per year upfront to pay for the microgrid installation and get charged \$20 per day of blackout experienced during the year, i.e., you may pay a total charge between \$100 and \$300.
- (c) You pay a charge of \$50 per year upfront to pay for the microgrid installation, and the price for energy during a blackout is determined daily by the microgrid operator depending on the energy availability. This price could go anywhere from \$20 to \$40 per day, i.e., you may pay a total charge between \$50 and \$450.
- (d) I don't have any preference among the above.
- (e) I have another suggestion [Field to enter text]

7. Some residents may not have the financial capacity to pay into the community microgrid. You have already agreed to pay [\$200/up to \$300/up to \$450] (depending on the choice made for Question 4) per year for receiving backup. How much more are you willing to pay per year towards providing backup for these residents? Enter the amount in \$ starting from 0.

[Field to enter \$ amount]

1.6 Questions on willingness-to-sell:

You have now paid into the community microgrid in exchange for a promise of backup to essential devices in your household such as heating and cooling when blackouts occur. The microgrid can provide you with guaranteed backup for 2 days when a blackout occurs.

Respondents are split into 3 cohorts and are accordingly shown one of the following three texts:

- In addition, during the blackout, you happen to own a Ford F-150 electric vehicle for your travel needs. During a blackout, you can connect the electric vehicle to its charger unit in your garage and use it to power up essential parts of your home. Note that the Ford F-150 alone can power a typical American household for up to 10 days, and can continue to power your home even if the community microgrid runs out of stored energy.
- In addition, during the blackout, you happen to own a Tesla PowerWall Solar Array and Battery Bank that you use to reduce your electricity bills under normal circumstances. During a blackout, you can use it to power up essential parts of your home. Note that the Tesla PowerWall alone can power a typical American household for up to 3 days, and can continue to power your home even if the community microgrid runs out of stored energy.
- In addition, during the blackout, you happen to own a diesel generator that you normally use for camping. During the blackout, you can turn on the generator and use it to power up essential parts of your home. Assume that you have enough stored diesel fuel to power your home for 2 days, and note that the generator can continue to power your home even if the community microgrid runs out of stored energy.

Display the following questions:

1. We would like to ask you the following question to make sure you understand the scenario. If you share energy with the community microgrid/neighbors: (Check all that apply)

- (a) *Your own stored energy would **increase***
- (b) *Your own stored energy would **decrease**, but you get a payment in return*
- (c) *Your neighbors would be able to access energy backup for a **shorter** duration*
- (d) *Your neighbors would be able to access energy backup for a **longer** duration*

(If the second and the fourth choices are not selected, the following information will be displayed:

“Incorrect. The stored energy is limited. Therefore, sharing your energy with your neighbors will **decrease** your own stored energy but can help them to get backup for a **longer** duration. Please go back to revise your answers!”)

2. *Assuming that you have electricity backup during the blackout while your neighbor does not, how willing are you to let your neighbor charge their essential electronic devices (e.g., cell phones) in your house?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Not at all willing” and “10” is labeled as “Definitely willing”]

3. *The operator of your community microgrid wants to pay you and other residents like you for sharing some of the stored energy from the [F-150/PowerWall/diesel generator] to the rest of the community during a blackout. This allows you to sell surplus stored energy, while all residents will be able to receive power backup for longer. This could be valuable to their survival. How willing would you be to accept such a contract?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely unwilling” and “10” is labeled as “Definitely willing”]

4. *To what extent do you agree with the statement: “I will NOT share/sell any stored energy with my neighbors during a blackout, even though this could be valuable to their survival”?*

[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely disagree” and “10” is labeled as “Completely agree”]

(The responses for the questions 1.6.3 and 1.6.4 are cross-validated for consistency. Inconsistent responses are discarded.)

5. *This is an attention check question, please select the option that is equal to 3.*

[Likert scale with values: 0, 1, ..., 10]

(If the respondent fails to select the correct answer, their response is discarded)

6. *Say the utility tells you that the blackout is expected to last for 2 days. While the microgrid itself is likely sufficient to provide backup for all residents throughout this 2-day blackout, the blackout duration can sometimes be longer or shorter depending on the speed of repair of the power grid. Remember that your [F-150/PowerWall/diesel generator] can power your individual home for an additional [10/3/2] days. What percentage of your stored energy are you willing to share with the community microgrid in exchange for a suitable payment, so that the backup duration for all residents can be increased?*

[Likert scale with values: 0 – 10%, 11% – 20%, ..., 91% – 100%]

7. *Assume that the utility tells you that the blackout is expected to last for 7 days instead. This means that the microgrid will likely run out of stored energy at some point after 2 days. Remember that your [F-150/PowerWall/diesel generator] can power your individual home for an additional [10/3/2] days. What percentage of your stored energy are you now willing to share with the community microgrid in exchange for a suitable payment?*

[Likert scale with values: 0 – 10%, 11% – 20%, ..., 91% – 100%]

8. *How much do you agree with the statement: “If I had more personal energy storage, I would be willing to sell more energy to the community microgrid”?*

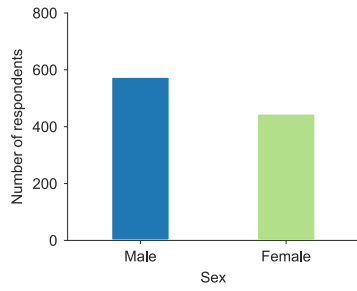
[Likert scale with values: 0, 1, ..., 10, where “0” is labeled at “Completely disagree” and “10” is labeled as “Completely agree”]

9. If you are willing to share some of your stored energy to the community microgrid, what nature of payment would you prefer in exchange? Select the most preferred choice.
- (a) Not applicable, not willing to share
 - (b) Reduction in fee for the community microgrid (given as yearly cash/rebate) irrespective of whether a blackout occurs
 - (c) Cash for stored energy you shared during the blackout
 - (d) Higher energy quota during the blackout, i.e., you can use more energy during the blackout
 - (e) No expected compensation, will freely share to help the local community
 - (f) Other compensation [Field to enter text]
10. Sharing energy means your own stored energy will be less during the blackout. This increases your risk of running out of power during a long blackout. What is the **minimum suitable price** you would expect the community microgrid to pay you for you to consider sharing some of your stored energy with the community microgrid? Select the most preferred choice.
- (a) Not applicable, not willing to share
 - (b) Freely share to help the local community
 - (c) Average electricity price under normal circumstances
 - (d) 2 times average electricity price under normal circumstances
 - (e) 3 times average electricity price under normal circumstances
 - (f) 4 times average electricity price under normal circumstances
 - (g) 5 times average electricity price under normal circumstances
 - (h) No preference
 - (i) Other compensation [Field to enter text]

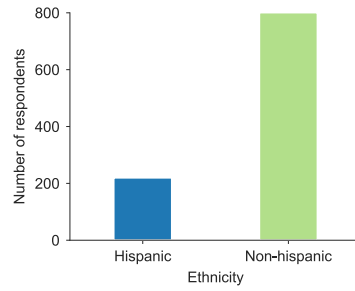
1.7 Closing message and compensation

*This is the end of the study. Thank you for your participation. Please make note of the following 7-digit code. You will input it through Mechanical Turk to indicate your completion of the study. **Then click the button on the bottom of this page to submit your answers. You will not receive credit unless you click this button.***

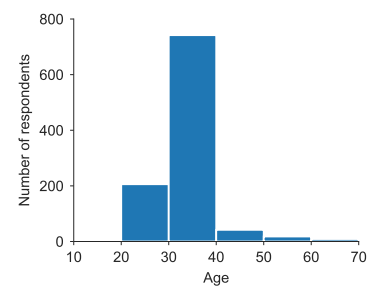
7-Digit Code: [code appears]



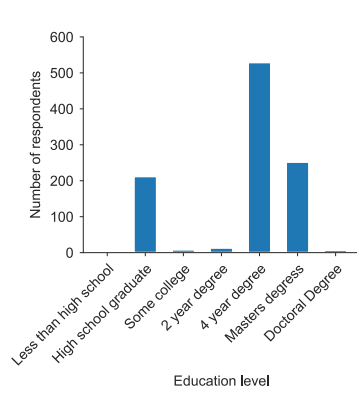
(a) Sex (Question 1.2.1)



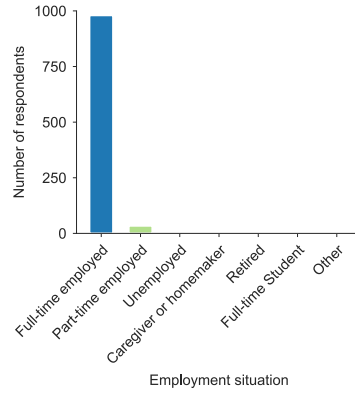
(b) Ethnicity (Question 1.2.2)



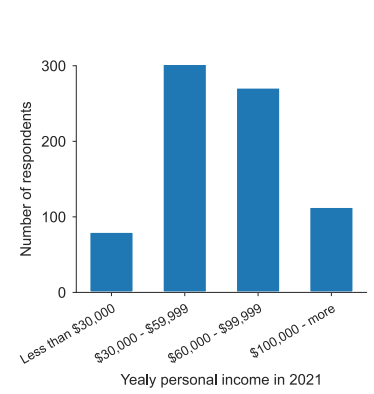
(c) Age (Question 1.2.3)



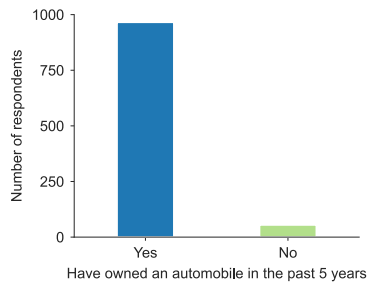
(d) Education level (Question 1.2.4)



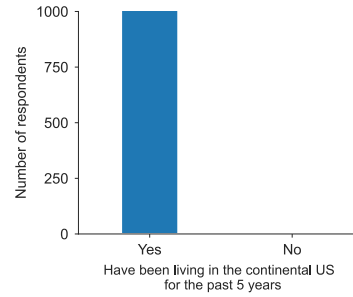
(e) Employment situation (Question 1.2.5)



(f) Yearly personal income (Question 1.2.6)

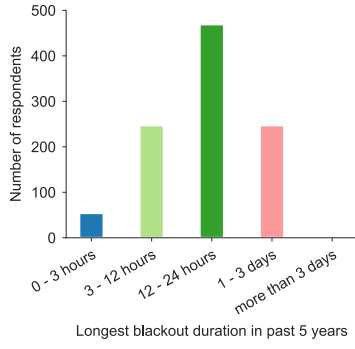


(g) Automobile ownership (Question 1.2.7)

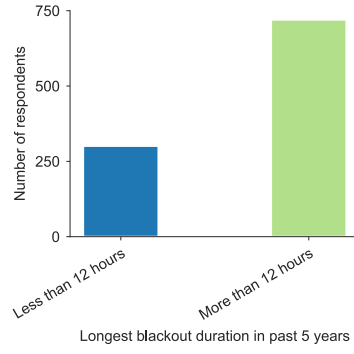


(h) Residential status in the US (Question 1.2.8)

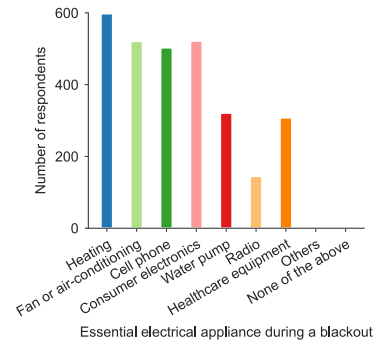
Supplementary Fig. 1. Raw data obtained from the survey for the demographic questions (questions were listed in Section 1.2 of Supplementary Note 1).



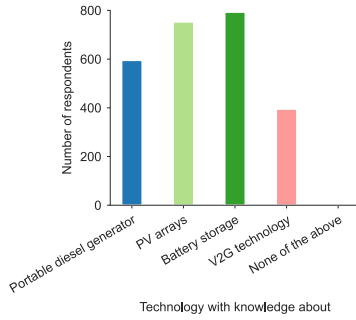
(a) Longest blackout experienced (Question 1.3.1)



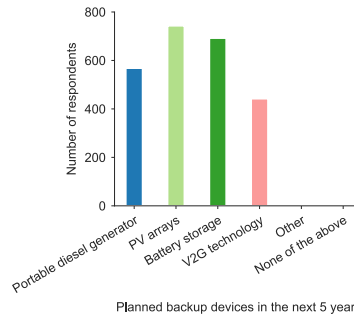
(b) Longest blackout experienced (Question 1.3.2)



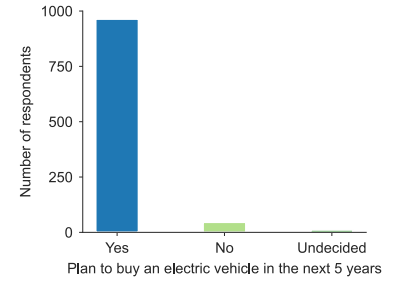
(c) Electrical appliances deemed essential (Question 1.3.3)



(d) Technologies with a priori knowledge (Question 1.3.4)

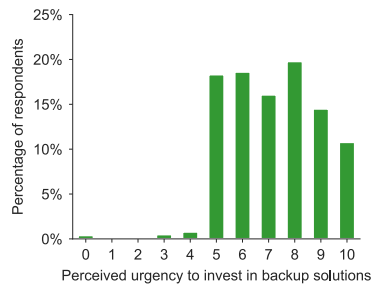


(e) Planned installation of backup devices (Question 1.3.5)

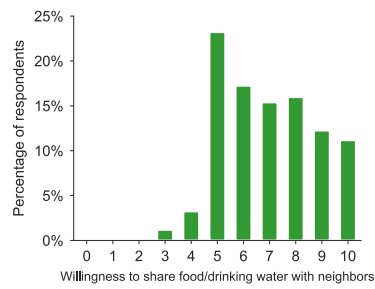


(f) Planned ownership of electric vehicle (Question 1.3.6)

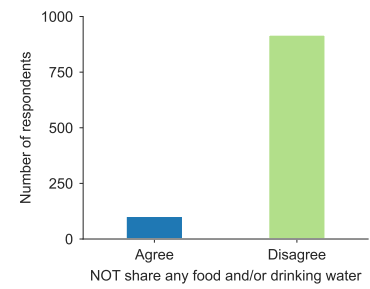
Supplementary Fig. 2. Raw data obtained from the survey for the questions on prior experience with blackouts (questions were listed in Section 1.3 of Supplementary Note 1).



(a) Perceived urgency to invest in backup solutions (Question 1.4.1)

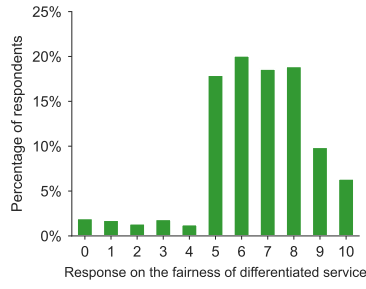


(b) Willingness to share food or water with neighbors (Question 1.4.2)

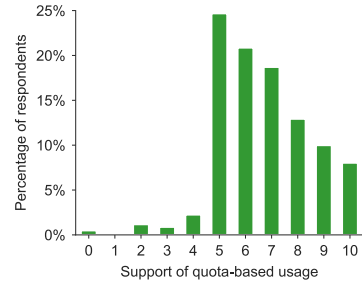


(c) Unwillingness to share food or water with neighbors (Question 1.4.3)

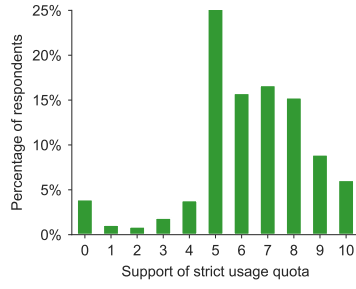
Supplementary Fig. 3. Raw data obtained from the survey for the questions on the baseline community spirit (questions were listed in Section 1.4 of Supplementary Note 1).



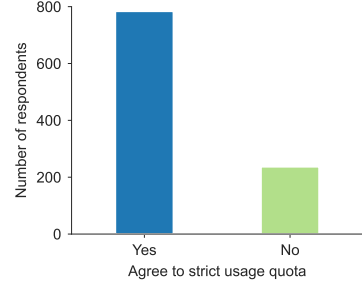
(a) Perceived fairness of differentiated service (Question 1.5.1)



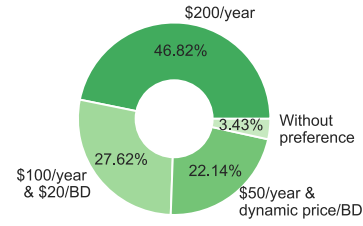
(b) Perception on quota-based energy use (1.5.3)



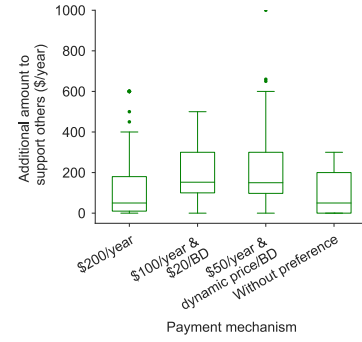
(c) Perception on strict usage quotas (Question 1.5.4)



(d) Perception on strict usage quotas (Question 1.5.5)

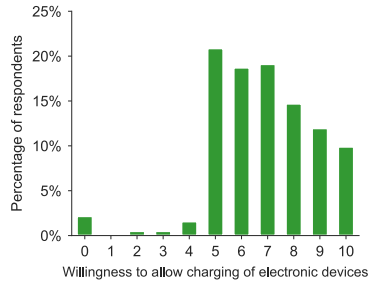


(e) Perception on the fairness of various payment plans (Question 1.5.6)

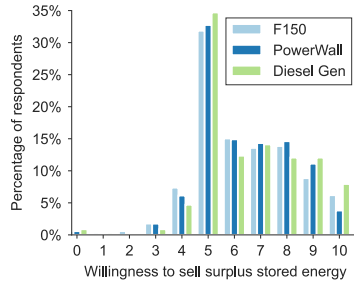


(f) Willingness to subsidize economically weaker residents (Question 1.5.7)

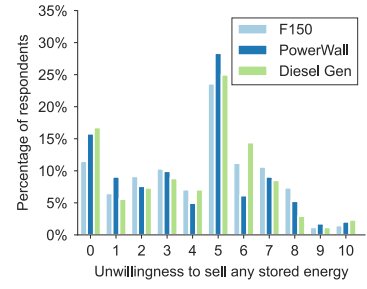
Supplementary Fig. 4. Raw data obtained from the survey for the questions on the fairness of differentiated service (questions were listed in Section 1.5 of Supplementary Note 1). The responses to the attention check question 1.5.2 are not included, as all qualified participants must choose “0”. In (f), the central mark, bottom, and top edges of each box plot represent the median, 25th, and 75th percentiles, respectively. Outliers, if any, are marked as individual points. Note: BD refers to blackout day.



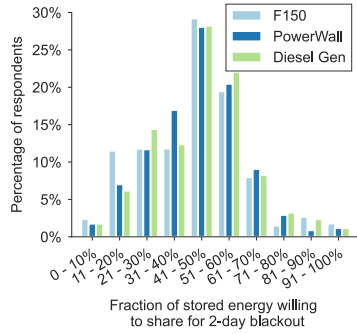
(a) Willingness to allow neighbors to charge essential electronic devices (Question 1.6.2)



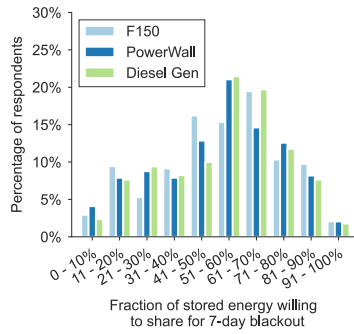
(b) Willingness to sell stored energy (Question 1.6.3)



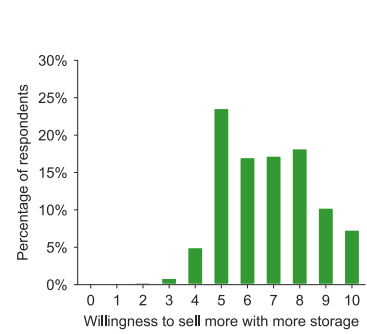
(c) Unwillingness to sell stored energy (Question 1.6.4)



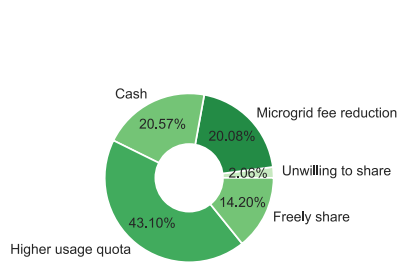
(d) WTS for a 2-day blackout (Question 1.6.6)



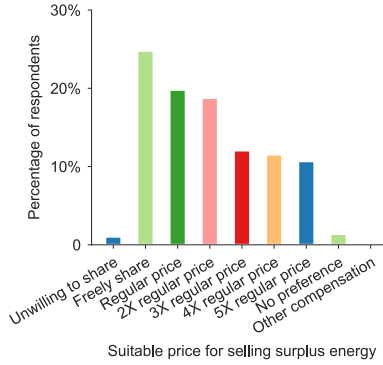
(e) WTS for a 7-day blackout (Question 1.6.7)



(f) Willingness to sell more energy based on personal storage capacity (Question 1.6.8)

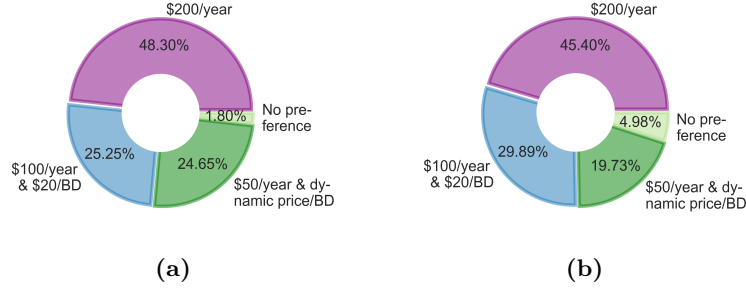


(g) Preferred nature of payment (Question 1.6.9)

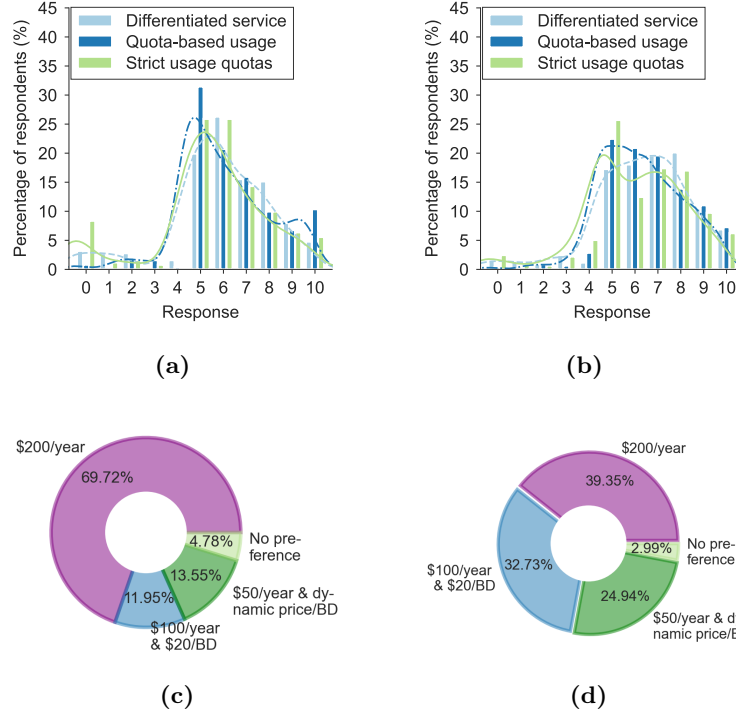


(h) Minimum suitable price for selling stored energy (Question 1.6.10)

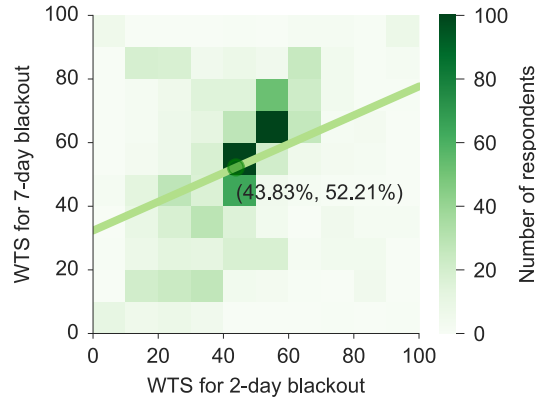
Supplementary Fig. 5. Raw data obtained from the survey for the questions on willingness-to-sell (WTS) (questions were listed in Section 1.6 of Supplementary Note 1). The responses to questions 1.6.1 and 1.6.5 are not included, as all qualified participants must choose “b,d” and “3”, respectively.



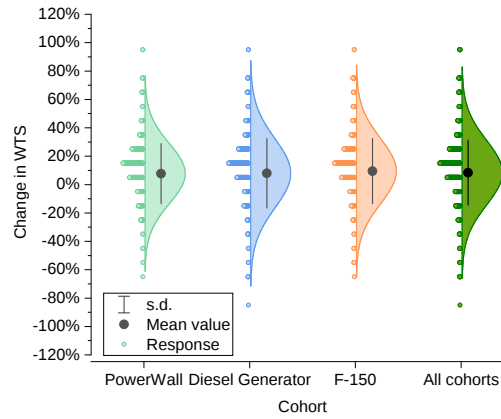
Supplementary Fig. 6. Payment plan choices for respondents located in (a) the western US and (b) the eastern US, separated by the meridian $90^{\circ}0'0''\text{W}$ that approximately bisects the US population, as per the US census 2020 [1]. The Western group comprises 49% of respondents, while the Eastern group comprises 51%, closely reflecting the current population distribution in the US. Our analysis revealed similar payment plan choices in both groups. Note: BD refers to blackout day.



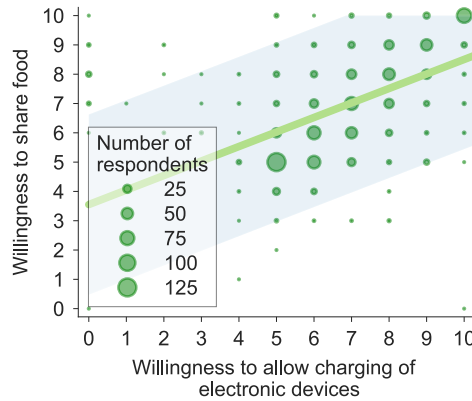
Supplementary Fig. 7. Survey responses pertaining to a differentiated service paradigm for community microgrids, shown on the basis of blackout experience. (a) and (b) show the preference of respondents on the fairness of differentiated service, quota-based usage, and strict usage quotas during blackouts, respectively for respondents who have experienced blackouts longer than a day (24.6% of respondents), and less than a day (75.4%). (c) and (d) show the payment plan choices of respondents who have experienced blackouts longer than a day and less than a day, respectively. Note: BD refers to blackout day.



Supplementary Fig. 8. Heat map of the willingness-to-sell (WTS) for an anticipated 2-day blackout versus a 7-day blackout, considering all cohorts together. Here, the solid line is the result of a linear regression, and the coordinates indicate the mean WTS.



Supplementary Fig. 9. The distribution of change in willingness-to-sell (WTS) for a 2-day blackout vs a 7-day blackout for the different cohorts.



Supplementary Fig. 10. Correlation between the willingness to allow neighbors to charge small electronic devices and the willingness to share food with neighbors during an emergency. Here, the linear regression fit is shown as a solid line, with the shaded area representing the prediction interval with 95% confidence. The size of the circles represents the number of respondents.

Supplementary References

- [1] Position of the geographic center of area, mean and median centers of population: 2020. <https://www.census.gov/library/visualizations/2020/geo/geographic-center-2020.html>. Accessed on 2023-10-27.