nature portfolio

Peer Review File

Extreme typhoon events trigger long-lasting power outages and require demand-side solutions to enhance energy resiliency

Corresponding Author: Dr Yanxue Li

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Dr Li,

First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "Long-duration power outages triggered by extreme typhoon events: characterization and demand-side mitigation strategies". It has now been seen by 3 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to
• address these criticisms (that is, either to incorporate the suggestions or provide a compelling argument why the point made by the reviewer is not valid, or relevant to the editorial threshold as outlined below)
AND
• meet our editorial thresholds as outlined below,
then we would be happy to look at a substantially revised manuscript. In the following, we list our main editorial concerns.

****
*Provide novel and fully supported insight into the recovery process following the extended power outage caused by a typhoon and the performance of demand-side solutions to reduce outages.
*Provide a comprehensive overview of the related literature and methodological details, including definitions of terms, choices of typhoons, and representatives.
*Provide techno-economic assessment of mitigation strategies and specifically address the capital cost of solutions.
****

When resubmitting, please provide a point-by-point response to the reviewers' comments. Please submit your responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and any completed checklist:

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Alessandro Rubino, PhD
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Martina Grecequet, PhD
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Communications Earth & Environment
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(https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

This is an interesting and absolutely essential topic. I hope my suggestions will help improve the work. Here are my comments:

1-The knowledge gap and the novelty of the work need to be explained more clearly.
2-The definition of the resiliency indexes is a bit vague and could be clarified further.
3-Please provide an explanation of the figures before presenting them in manuscript.
4-I suggest defining specific indexes (e.g., Uncovered Power/Total Power, or any other relevant metric you might have in mind). Then, compare these indexes in a table before and after applying the scenarios.
I leave an example work as follow. Please see how they defined some resiliency factors.
https://www.sciencedirect.com/science/article/pii/S0301479720300281
Table S2. Resilience indicators used in this study in Supplementary data

Reviewer #2 (Remarks to the Author):

This paper gives some historical data on equipment outaged, customers outaged and recovery in several Japanese typhoons, and discusses the roles of customer electrification, batteries (including EVs), and fuel cells in maintaining some

level of resilience during and after typhoons.
The data presented has some value, and the overall idea motivating the paper that changes on the customer side can aid recovery and increase resilience is sound. Some of these remedies might be cost-effective, and overall the paper makes some good points in its discussion. The paper shows an exponential form of recovery from typhoons in Japan and provides links to the data used.

However, I also think that some key issues are missing from the discussion and data:

(1) For any distributed energy source, including PV, battery, diesel generator, and fuel cell, a critical issue in its use for resilience in a blackout is whether the house or business, or certain key circuits or devices therein, can be islanded from the grid. There are two reasons for this: First, the distribution system cannot be safely repaired while it is energized by distributed sources. Thus the islanding must not only be done, it must be done provably to the distribution utility for worker safety. Second, many inverters are grid following and require the grid voltage to operate. For these reasons, distributed energy resources may not be operable during a blackout. This issue, not the "unreliability" of PV, could be a reason that the paper data shows low PV during a typhoon.
This issue has a strong component of regulation and design standards and the installed capability and wiring arrangements of the customers.
The paper should describe the regulations and practices for this issue in Japan, and its impact on using DERs. I note that discussion of the particular Japanese context and Japanese solutions is of value to other countries facing similar problems and opportunities.

(2) The paper does not properly address the cost of the solutions it discusses.
The proposed solutions in the paper have very different capital costs, and the paper should at least state approximate ranges or orders of magnitude of costs in order to place the solutions in their rational context. For example, I suspect that fuel cells are relatively expensive.

(3) Related to the cost issue, but no less significant, is the issue of whether the solutions are for typhoon resilience only or are also viable and economical to be used under normal conditions.
While some solutions are backup during blackout only, others are productive solutions for normal use. This makes a huge difference to homes and businesses actually investing in solutions.
Leveraging an EV or PV for a blackout that is already economically justified for regular use is an entirely different proposition than buying backup power only for emergencies.
For example, if one considers only backup power for the typhoon, the cheapest and perhaps best solution is a diesel generator. (It only runs occasionally, so burning the fossil fuel is a limited concern.) However, it is not a good power source everyday.
The paper must discuss this issue of the economic practicality and use of the solution beyond backup power during a typhoon, and also include some assessment of diesel generators, as they are one of the relatively cheap currently deployed backup power solutions.

Some more comments on details follow:

"Furthermore, the power capacity of distributed generation is constrained, necessitating the prioritization of critical electricity-dependent demands over regular operational management during prolonged outage events." I very much agree.

In Figure 2,
"color band presents two days experience typhoon event (12 hour ahead and 36 hours after peak outage event)" the time period of the band seems arbitrary ... surely to provide useful information it should begin when outages start to accumulate at a high rate (or less usefully, but much better than 12 hour ahead and 36 hours after peak outage event, when winds pick up) and should end when outage rate drops, or winds die down.

"However, because typhoons often come with heavy rainfall, we did not examine role of rooftop photovoltaic systems cannot reliably provide power, the role of rooftop photovoltaics system during recovery from extreme weather events."
Photovoltaics may sometimes underperform during the high winds and rain (note that in the cases studied in Fig 2, PV only sometimes decreased) but could play a key role in the recovery after the storm during daylight hours, especially if the critical loads are segregated.
Providing refrigeration, communication, and heating and cooling during daylight hours may be sufficient to sustain life during emergencies.
Note that if the roof remains intact, residential PV can survive well.

"Although EV storage capacities range from 20 kWh to 80 kWh, the actual electricity available depends on the state of charge of battery storage system. Therefore, it needs to consider power availability constraints and priorities of the critical electricity demands under extended power outage events"
Note that for typhoons and hurricanes, there is usually substantial advance warning, so that homes and businesses could charge their battery sources.

I do not mind so much occasional substandard or awkward english from authors who do not write english as a native, but the author list includes Americans who should have read and corrected the mistakes in english in the paper. The mistakes are not pervasive, but are sufficiently present to be distracting.

Ian Dobson
Iowa State University

Reviewer #3 (Remarks to the Author):

Review of manuscript entitled “Long duration power outages triggered by extreme typhoon events: characterization 2 and demand side mitigation strategies” by Li et al.

To be published in Communications Earth & Environment a paper needs to meet several general criteria:
•The conclusions are novel
•The paper provides strong evidence for the main conclusions
•The underlying data are generated and processed at a state-of-the-art level, including tracking of uncertainties
•The manuscript is important to scientists in a specific sub-field of the Earth, environmental or planetary sciences.
In general, to be acceptable, a paper should meet these criteria and represent an advance in understanding that is expected to influence thinking in the field.

In my opinion, this manuscript, in its present form, does not meet the criteria above.

Although the study is relevant as a case study for Japan under typhoon constraints, I consider that the work is not yet convincing nor representative for other communities. The main points and further information and evidence required to strengthen the conclusions are below.

The authors claim to “characterize widespread power outages induced by historical typhoon events in Japan”. However, they do not define/justify the expression “historical typhoon events in Japan” when using data from 6 typhoons occurring between 2018 and 2022. It is not clear how these events are internationally representative.

There is a bulk of new research on extreme weather events and energy sector that was not included in the introduction. Additionally, the introduction is too general, broad and vague; it does not identify the gap in the literature that may be investigated through the study of 6 events occurring in Japan. It should be more focused to define what is meant by “long duration power outages” in Japan and how the study may be novel and relevant for the scientific community.

Graphic abstract
The image is very appellative; however, it must also have scientific rigor. As it is well known, for the integration of rooftop solar panels the installation must be performed on the southern facades or roofs. Therefore, the image must be corrected in order to have all the solar panels heading South and the shadows compatible with the North-South direction. The present image has incompatible shadows (they are not all on the same direction) and the solar panels are not all heading South. Since the authors refer that "did not examine role of rooftop photovoltaic systems" (ln 153-157), this graphical abstract is also misleading.

The numbering of Typhoons should be explained, usually they are chronologically numbered, but in this case no. 19, for example, occurred after no. 24. As stated above, more information should be given on the choice and representativeness of the events.

Ln 108-109 – “Because typhoons are accompanied by heavy rainfall, generation from solar PV often declines significantly during outages.” This sentence should be further discussed as it does not seem to agree with results on figure 2.

Ln 116 and Figure 3 – Some information is missing regarding the graphs, namely regarding the time of occurrence of the events. It is not mentioned what time = 0 refers to, nor the duration of the typhoons is indicated.

Ln 124 – As the authors refer “…shows that the severity and recovery duration of outage events present regional variations”. Therefore, additional information must be given to characterize the events and establish the conclusions. It should be different if the events occur in a highly demographic, urban, region or in a larger rural area. It should be different if the typhon has long or short duration, if it is stationary or not. In addition to “regional intrinsic resilience characteristics”. The “increased number of affected customers” per se is not the relevant measure if the previous criteria are not considered.

Therefore, the framework for this study and its results (ln 135-137) should be better presented in the introduction and the abstract.

Finally, this kind of study - with mitigation strategies - should include a technical-economic approach.

Figures
Figure 2 – please revise the xlabels caption. There is some problem with the last xTick caption in every panel (After 12 Sept is not 30 Aug, the same in all panels). The “peak outage event” is highlighted with a red dot.
Figures 2, 3 and 4 – The xlabels should be harmonized. Since all panels have the same labels, xlabels could be omitted in panels 1 to 3 and ylabels could be omitted in panels 2,3,5 and 6, for better reading.
Figure 3 – the caption should be more explicit: it is not clear in the figure when is “before, during, and after each power outage”. A note should highlight that the scales are different amongst panels. The symbols should have a caption.
Figure 5 – all acronyms should be described in the caption.

Figure 6 – please improve the ylabel “number”. Please indicate if you represent number of family-homes. Please explain what “Group1 n1=136, Group 2 n2=131” means. Please refer to how these families are representative of Japan society in these regions.

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Version 1:

Decision Letter:

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Dear Dr Li,

Your manuscript titled "Long-duration power outages triggered by extreme typhoon events: characterization and demand-side mitigation strategies" has now been seen by our reviewers, whose comments appear below. In light of their advice, we are delighted to say that we are happy, in principle, to publish a suitably revised version, under the condition that you fully implement reviewer 3's requests for more information within the manuscript (as opposed to the response to reviewers), including details of your methodology and classifications.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewer 3. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Martina Grecequet, PhD
Senior Editor,
Communications Earth & Environment
@CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The current version of the manuscript can be considered accepted. My comments have been addressed effectively.

Reviewer #2 (Remarks to the Author):

The authors have responded substantially towards the reviewer comments.

Reviewer #3 (Remarks to the Author):

Review of manuscript entitled "Long duration power outages triggered by extreme typhoon events: characterization and demand side mitigation strategies" by Li et al.

It is very important to characterize and understand energy disruption mechanisms due to extreme weather events. I read this manuscript with great interest. However, the manuscript still lacks quantification, grounding and discussion of the new results to justify its publication on this high impact journal.

The authors have adequately addressed some of the comments raised, replied and improved the manuscript. Nevertheless, in some cases, the replies have not been incorporated in the manuscript. In my opinion, these aspects and evidence are required to strengthen the quality of the manuscript. Finally, the novelty and relevance of this study should be clearly stated.

Abstract – The text in the abstract needs to be more specific. Generic expressions should be avoided. For example: "In Part I, we characterize widespread power outages induced by historical typhoon events in Japan. Using collected real world datasets, we illustrate the failure causes and recovery processes associated with extended power outages. Those outages present similar recovery curves, with full recovery requiring a relatively long time." Reading this sentence, the reader does not identify the factors that characterize widespread power outages due to typhoons; nor the failure causes, nor the recovery processes – an abstract should objective and highlight the novelty and results of the study. This comment applies to seveal sentences in this manuscript.

Reply to Q2 – on the use of the term "historical typhoon events in Japan". This information should be included in the manuscript.
It is important to highlight that the generic sentence "Climate change is contributing to the increasing frequency and intensity of extreme weather events globally." needs to be written carefully and using a reference. Recent research has shown that the frequency of some extreme weather events is not increasing – only their intensity has been increasing. Thus, when applied to this study and to severe typhons, a scientific article reference should be included.

Additionally, while it is reasonable to choose the "six typhoons because they had maximum wind velocities exceeding 40 m/s and caused substantial impacts on Japan's power infrastructure, leading to widespread outages.", it is not necessarily a way to characterize them as historical typhons. Either there is a climatological assessment (with a scientific reference) to confirm how these events have been considered historical events, or the justification is given through the data availability, as stated in this reply. It should be noted that the text written in this manuscript is dubious and allows confusion between the criteria to consider an extreme typhon. As stated in Figure 1 “Examined typhoon events that trigger widespread power outages” – so, the impacts are the criteria. The reader of this manuscript should clearly understand how rare and extreme these six events were without the need to consult further literature or links. Therefore, how representative these events are should be clear to the reader. Please rephrase lines 105-106, explaining which were the criteria for choosing these 6 events.

According to the Japan Meteorological Agency, the typhoons in Table 1 fall within two different categories – Typhoon (Maximum wind speed <44m/s), Very Strong Typhoon (44m/s ≤ Maximum wind speed < 54m/s). None of them was classified as a Violent Typhoon (54m/s ≤ Maximum wind speed). Please consider rephrasing the text when “Super typhoons” are mentioned, since these were not addressed here.

Figure 1 – units are missing.
Table 1 – A sentence could be added to the caption “typhoons are numbered according to the order in which they occur each year” to identify the events from the official list. Column 1 should have in the title “Name of extreme event (Number)”

Figure 2 and reply to Q5 – On their reply authors mention that “While there are moments during typhoons when solar PV systems can still generate power, overall, the generation is notably lower compared to normal weather conditions”. As previously stated, this is not in full agreement with this figure. Additional information should be given to what data are represented by the “solar PV generation profiles” – and this will justify that these are not affected by the occurrence of the analyzed typhoons in some locations. Further discussion is missing on lines 111-112.

Ln 126-128 – Please explain this sentence. It is not clear how the correlation and its significance are computed.

Ln 132-134 – Please explain this conclusion: “The recovery process for the Tokyo grid demonstrates a long tail characteristic, likely due to the extensive area it serves and the large number of customers.” This manuscript lacks characterization of the grid on the different considered (Fig 1) regions. Many factors may affect the recovery process and these should be discussed. Please discuss how the recovery process for the Tokyo (No.15 Typhoon) compares with Kansai grid (No.21 Typhoon).

Ln 235-236 – Please explain how the PV values on Table 3 were computed and what the relation is with Figure 2.

Ln 242 – “Incorporating battery storage effectively increases the load cover ratio, providing increased opportunity to meet critical energy demand.” As mentioned above, such general sentences should be avoided, an effort should be made to quantify and references should be added.

Ln 247 – damage on energy systems occurs even when typhoons are not categorized as super typhoons.

Ln 249-250 – please add a reference to this statement – it is the increasing in intensity of extreme events more than the frequency that causes increasing severe disruption on systems.

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Manuscript: COMMSENV-24-1920
Title: Long-duration power outages triggered by extreme typhoon events: characterization and demand-side mitigation strategies

Reviewer #1 (Remarks to the Author):
This is an interesting and absolutely essential topic. I hope my suggestions will help improve the work. Here are my comments:

Q1- The knowledge gap and the novelty of the work need to be explained more clearly.
Answer: Thank you for your constructive feedback. In end of literature review work, we revised the main contribution (tracked version page 3 from line 72) as follows:
This knowledge gap still exists, although many studies have explored the energy resilience of building energy systems, they primarily rely on simulation work that focuses on either the supply or demand side. This is partly due to the scarcity of high-resolution data on real-world grid operations and consumer demand patterns. The implications of growing building electrification on energy resilience, as well as the ability and effectiveness of various demand-side solutions to enhance this resilience, are not well understood. Furthermore, the power generation ability of distributed generation is constrained, necessitating the prioritization of critical electricity-dependent demands over regular operational management during prolonged outage events. However, limited research has been conducted to effectively ensure the provision of critical demand energy services during the recovery process following extreme event outages. Results can inform strategies for enhancing infrastructure resilience and provide valuable insights into the effectiveness of demand-side solutions.

Q2- The definition of the resiliency indexes is a bit vague and could be clarified further.
Answer: Thank you for pointing out the need for clearer definitions of the resiliency indexes (in Page 14, from line 221). We evaluate the resiliency performance using the self-load cover ratio index, which is calculated by dividing the on-site generation by the home energy demand during a power outage period. This index provides a measure of how effectively on-site energy generation can meet demand when external power sources are unavailable.

Q3- Please provide an explanation of the figures before presenting them in manuscript.
Answer: Thank you for your suggestion regarding the presentation of the figures. We provide further explanation before the figure is introduced in the text to help readers understand its relevance, detailed changes have been marked in the manuscript.

Q4- I suggest defining specific indexes (e.g., Uncovered Power/Total Power, or any other relevant metric you might have in mind). Then, compare these indexes in a table before and after applying the scenarios.

I leave an example work as follow. Please see how they defined some resiliency factors.
https://www.sciencedirect.com/science/article/pii/S0301479720300281
Table S2. Resilience indicators used in this study in Supplementary data

Answer: Thank you for pointing it out. In method part (page 20), we added the description about how to calculate load cover ratio. And further analyze resilience performance of hybrid PV and battery systems in Result part.

Thank you again for helping us enhance the quality of our presentation.

Reviewer #2 (Remarks to the Author):

This paper gives some historical data on equipment outage, customers outage and recovery in several Japanese typhoons, and discusses the roles of customer electrification, batteries (including EVs), and fuel cells in maintaining some level of resilience during and after typhoons.

The data presented has some value, and the overall idea motivating the paper that changes on the customer side can aid recovery and increase resilience is sound. Some of these remedies might be cost-effective, and overall the paper makes some good points in its discussion. The paper shows an exponential form of recovery from typhoons in Japan and provides links to the data used.

However, I also think that some key issues are missing from the discussion and data:

Q1: For any distributed energy source, including PV, battery, diesel generator, and fuel cell, a critical issue in its use for resilience in a blackout is whether the house or business, or certain key circuits or devices therein, can be islanded from the grid. There are two reasons for this: First, the distribution system cannot be safely repaired while it is energized by distributed sources. Thus the islanding must not only be done, it must be done provably to the distribution utility for worker safety. Second, many inverters are grid following and require the grid voltage to operate. For these reasons, distributed energy resources may not be operable during a blackout. This issue, not the "unreliability" of PV, could be a reason that the paper data shows low PV during a typhoon.

This issue has a strong component of regulation and design standards and the installed capability and wiring arrangements of the customers.

The paper should describe the regulations and practices for this issue in Japan, and its impact on using DERs. I note that discussion of the particular Japanese context and Japanese solutions is of value to other countries facing similar problems and opportunities.

Answer: Thank you for your constructive feedback. The causes of power outage triggered by typhoon events are presented in Table 2, distribution network failures (support pole and overhead line) are primary reasons. Then we analyzed performances of demand-side solutions in improving energy resilience during typhoon event days. We further analyzed the energy resilience performance of PV and battery system during typhoon event days.

According to literature review, the capacity of diesel generator is relatively large for a single family (analyzed objective) and levelized cost is relatively high. We choose to focus on analyzing solar PV, battery, electric vehicle and fuel cell systems. We also compare their costs in discussion part. Typhoons are often accompanied by heavy rainfall. Through analysis of measured data, it has been found that heavy rainfall is the primary factor reducing PV generation.
Climate change is contributing to the increasing frequency and intensity of extreme weather events globally. Understanding the impact of recent severe typhoons can help other countries prepare for and mitigate the effects of such disasters on their power infrastructures. Many countries rely on large-scale power grids that are vulnerable to extreme weather. Lessons learned from Japan's experiences can inform international strategies for infrastructure resilience and demand-side solutions.

Q2: The paper does not properly address the cost of the solutions it discusses.
The proposed solutions in the paper have very different capital costs, and the paper should at least state approximate ranges or orders of magnitude of costs in order to place the solutions in their rational context. For example, I suspect that fuel cells are relatively expensive.
Answer: Thank you for pointing out the costs of the solutions. In discussion part, we add the approximate levelized cost of distributed technologies after conducting literature review work. We also found that fuel cells offer advantages in terms of levelized cost of electricity due to their high efficiency, long lifespan, and low fuel cost, even at smaller capacities. We highlight that "Electrical vehicles can serve dual purposes but involve higher costs due to vehicle prices and battery capacities. While micro-CHP technologies commonly used for backup power, they have higher operating costs and environmental impacts, fuel availability may be constrained during extreme events. Integrating PV systems with home battery storage enhances reliability in meeting critical household energy demands during prolonged outage periods. Customers need to consider these costs carefully to make informed investment decisions that increase home energy security." (Page 18 from line 294)

Q3: Related to the cost issue, but no less significant, is the issue of whether the solutions are for typhoon resilience only or are also viable and economical to be used under normal conditions.
While some solutions are backup during blackout only, others are productive solutions for normal use. This makes a huge difference to homes and businesses actually investing in solutions.
Leveraging an EV or PV for a blackout that is already economically justified for regular use is an entirely different proposition than buying backup power only for emergencies.
For example, if one considers only backup power for the typhoon, the cheapest and perhaps best solution is a diesel generator. (It only runs occasionally, so burning the fossil fuel is a limited concern.) However, it is not a good power source everyday.
The paper must discuss this issue of the economic practicality and use of the solution beyond backup power during a typhoon, and also include some assessment of diesel

generators, as they are one of the relatively cheap currently deployed backup power solutions.

Answer: Thank you for your suggestion.

Firstly, we further analyzed the energy resilience performances of hybrid PV and home battery systems. The detailed load cover ratios under examined typhoon event days are presented in Table 3. (Page 15 and 16, from line 244)

After conducting a literature review and market survey, we found that the capacity of diesel generators is relatively large for a single-family home. Fuel cells offer advantages in terms of levelized cost of electricity due to their high efficiency, long lifespan, and low fuel cost, even at smaller capacities. Therefore, for the micro-CHP system, we chose to analyze the energy resilience performance of home fuel cells. We added descriptions as follows (Page 17 from line 287):

"Energy resilience can be enhanced by investing in distributed energy resources, levelized costs of electricity for solar PV, home battery storage, and electric vehicles vary by region and electricity market. Their estimated values are as follows: electric vehicles at 0.30 \$/kWh [58,59], solar PV system at 0.05 \$/kWh [60] and home battery storage at 0.25 \$/kWh [61]. The levelized costs for rooftop PV systems are lower than market electricity prices. The levelized costs for micro-CHP units are based on several factors, including generator lifespan, efficiency, installed capacity and fuel cost. The estimated levelized costs for home fuel cell and diesel generator are 0.25 \$/kWh [62], 0.40 \$/kWh [63], respectively. While micro-CHP technologies commonly used for backup power, they have higher operating costs and environmental impacts, fuel availability may be constrained during extreme events. Integrating PV systems with home battery storage enhances reliability in meeting critical household energy demands during prolonged outage periods. Customers need to consider techno-economic performances of these solutions carefully to make informed investment decisions that increase home energy security.

Some more comments on details follow:

"Furthermore, the power capacity of distributed generation is constrained, necessitating the prioritization of critical electricity-dependent demands over regular operational management during prolonged outage events." I very much agree.

Answer: Thanks for your positive comment.

In Figure 2,

"color band presents two days experience typhoon event (12 hour ahead and 36 hours after peak outage event)" the time period of the band seems arbitrary ... surely to provide useful information it should begin when outages start to accumulate at a high rate (or less usefully, but much better than 12 hour ahead and 36 hours after peak outage event, when winds pick up) and should end when outage rate drops, or winds die down.

Answer: Thank you for your insightful comment. We revised Figure 2 and its caption. The color band represents the 48 hours period starting from the initial increased power outages.

"However, because typhoons often come with heavy rainfall, we did not examine role of rooftop photovoltaic systems cannot reliably provide power, the role of rooftop photovoltaics system during recovery from extreme weather events." Photovoltaics may sometimes underperform during the high winds and rain (note that in the cases studied in Fig 2, PV only sometimes decreased) but could play a key role in the recovery after the storm during daylight hours, especially if the critical loads are segregated.
Providing refrigeration, communication, and heating and cooling during daylight hours may be sufficient to sustain life during emergencies.
Note that if the roof remains intact, residential PV can survive well.
Answer: Thank you for your insightful comment. We further analyzed the energy resilience performances of hybrid PV and home battery systems. The detailed load cover ratios under examined typhoon event days are presented in Table 3. We found that "Results indicate that standalone PV systems are unreliable for meeting home energy demand during typhoon events. Adding battery storage effectively increases the load cover ratio, providing increased opportunity to meet critical energy demand. However, fully meeting total electricity demand remains challenging when PV generation significantly decreases. (Page 15 from line 244)

"Although EV storage capacities range from 20 kWh to 80 kWh, the actual electricity available depends on the state of charge of battery storage system. Therefore, it needs to consider power availability constraints and priorities of the critical electricity demands under extended power outage events"
Note that for typhoons and hurricanes, there is usually substantial advance warning, so that homes and businesses could charge their battery sources.
Answer: Thank you for your valuable feedback. In the current market, electric vehicles offer a wide range of storage capacities, on average 40 kWh. We consider these factors to better address energy resilience of mobile battery storage with different available storage capacities.

I do not mind so much occasional substandard or awkward english from authors who do not write english as a native, but the author list includes Americans who should have read and corrected the mistakes in english in the paper. The mistakes are not pervasive, but are sufficiently present to be distracting.
Answer : Thank you for pointing out, the language have been checked by a native English speaker.

Ian Dobson
Iowa State University

Thank you again for helping us enhance the quality of our presentation.

Reviewer #3 (Remarks to the Author):
Review of manuscript entitled "Long duration power outages triggered by extreme

typhoon events: characterization 2 and demand side mitigation strategies” by Li et al.

To be published in Communications Earth & Environment a paper needs to meet several general criteria:
•The conclusions are novel
•The paper provides strong evidence for the main conclusions
•The underlying data are generated and processed at a state-of-the-art level, including tracking of uncertainties
•The manuscript is important to scientists in a specific sub-field of the Earth, environmental or planetary sciences.
In general, to be acceptable, a paper should meet these criteria and represent an advance in understanding that is expected to influence thinking in the field.
In my opinion, this manuscript, in its present form, does not meet the criteria above.

Q1: Although the study is relevant as a case study for Japan under typhoon constraints, I consider that the work is not yet convincing nor representative for other communities. The main points and further information and evidence required to strengthen the conclusions are below.
Answer: Thank you for your valuable insights. Our study focuses on analyzing the impacts of typhoon events on large-scale power grids and the performance of various distributed technologies in enhancing home energy resilience. We investigate long-duration power outages triggered by extreme typhoons, examining the recovery process and underlying causes of failures. Given that residential energy demand follows similar load curves and critical loads are consistent across regions, the energy resilience performance of these technologies can serve as a reference for strengthening home energy resilience in other areas.

Q2: The authors claim to “characterize widespread power outages induced by historical typhoon events in Japan”. However, they do not define/justify the expression “historical typhoon events in Japan” when using data from 6 typhoons occurring between 2018 and 2022. It is not clear how these events are internationally representative.
Answer: Thank you for your feedback. In our study, we use the term "historical typhoon events in Japan" to refer to significant typhoons that occurred between 2018 and 2022. We selected these six typhoons because they had maximum wind velocities exceeding 40 m/s and caused substantial impacts on Japan's power infrastructure, leading to widespread outages. The recent nature of these events ensures that we have access to high-quality, detailed data, which is crucial for accurately analyzing the effects on large-scale power grids. Climate change is contributing to the increasing frequency and intensity of extreme weather events globally. Understanding the impact of recent severe typhoons can help other countries prepare for and mitigate the effects of such disasters on their power infrastructures. Many countries rely on large-scale power grids that are vulnerable to extreme weather. Lessons learned from Japan's experiences can inform international strategies for infrastructure resilience and disaster response.
Route information about typhoon events is as follows:

https://www.data.jma.go.jp/yoho/typhoon/route_map/index.html

Q3: There is a bulk of new research on extreme weather events and energy sector that was not included in the introduction. Additionally, the introduction is too general, broad and vague; it does not identify the gap in the literature that may be investigated through the study of 6 events occurring in Japan. It should be more focused to define what is meant by "long duration power outages" in Japan and how the study may be novel and relevant for the scientific community.

Answer: Thank you for your feedback. We have revised the discussion, contribution and research gap in end of literature review part as follows (Page 3 from line 72).

This knowledge gap still exists, although many studies have explored the energy resilience of building energy systems, they primarily rely on simulation work that focuses on either the supply or demand side. This is partly due to the scarcity of high-resolution data on real-world grid operations and consumer demand patterns. The implications of growing building electrification on energy resilience, as well as the ability and effectiveness of various demand-side solutions to enhance this resilience, are not well understood. Furthermore, the power generation ability of distributed generation is constrained, necessitating the prioritization of critical electricity-dependent demands over regular operational management during prolonged outage events. However, limited research has been conducted to effectively ensure the provision of critical demand energy services during the recovery process following extreme event outages. Results can inform strategies for enhancing infrastructure resilience and provide valuable insights into the effectiveness of demand-side solutions.

Q3: Graphic abstract: The image is very appellative; however, it must also have scientific rigor. As it is well known, for the integration of rooftop solar panels the installation must be performed on the southern facades or roofs. Therefore, the image must be corrected in order to have all the solar panels heading South and the shadows compatible with the North-South direction. The present image has incompatible shadows (they are not all on the same direction) and the solar panels are not all heading South. Since the authors refer that "did not examine role of rooftop photovoltaic systems" (ln 153-157), this graphical abstract is also misleading.

Answer: Thank you for your insightful comment. We revised the Graphic figure, all solar panels are heading south. We also further analyzed the ability and effectiveness of solar PV and battery technologies in improving home energy load cover ratios.

Q4: The numbering of Typhoons should be explained, usually they are chronologically numbered, but in this case no. 19, for example, occurred after no. 24. As stated above, more information should be given on the choice and representativeness of the events.

Answer: These examined typhoons originated in the Pacific, typhoons are numbered according to the order in which they occur each year.

Detailed information about typhoon events is as follows:

https://www.data.jma.go.jp/yoho/typhoon/route_map/index.html

Q5: Ln 108-109 – "Because typhoons are accompanied by heavy rainfall, generation from solar PV often declines significantly during outages." This sentence should be further discussed as it does not seem to agree with results on figure 2.

Answer: Thank you for your insightful comment. In Figure 2, we present the aggregated data of solar PV generation during typhoon events, which might not fully illustrate the periods of significantly reduced generation due to heavy rainfall and dense cloud cover. While there are moments during typhoons when solar PV systems can still generate power, overall, the generation is notably lower compared to normal weather conditions. To address this discrepancy, we have conducted a more detailed analysis of the capability and effectiveness of solar PV and home battery systems in improving the home energy cover ratio during typhoon-induced outages. We utilized hourly rooftop PV generation data from a 5 kWp system and typical residential energy demand profiles to simulate the load cover ratios under typhoon conditions. (Page 15 from line 244)

Q6: Ln 116 and Figure 3 – Some information is missing regarding the graphs, namely regarding the time of occurrence of the events. It is not mentioned what time = 0 refers to, nor the duration of the typhoons is indicated.

Answer: Thank you for pointing this out. We apologize for the oversight. In Figure 3, time = 0 corresponds to the onset of the typhoon's impact on the power grid—specifically, when power outages begin to occur. We have updated the figure and its caption to clearly indicate this reference point. Additionally, we have included the duration of each typhoon event on the graph to provide a more comprehensive understanding of the timeline (Page 8 from line 129).

" The x-axis begins at the moment the typhoon starts affecting the power grid. Initially, the number of customers experiencing outages rises sharply, reaching a peak that represents the maximum impact of the typhoon. After this peak, the number of affected customers gradually decreases as power restoration efforts proceed, eventually returning to normal levels once all services are fully reinstated.

Q7: Ln 124 – As the authors refer "…shows that the severity and recovery duration of outage events present regional variations". Therefore, additional information must be given to characterize the events and establish the conclusions. It should be different if the events occur in a highly demographic, urban, region or in a larger rural area. It should be different if the typhon has long or short duration, if it is stationary or not. In addition to "regional intrinsic resilience characteristics". The "increased number of affected customers" per se is not the relevant measure if the previous criteria are not considered.

Therefore, the framework for this study and its results (ln 135-137) should be better presented in the introduction and the abstract.

Answer: We appreciate your thoughtful suggestions. In our study, the super typhoon events we examined affected large-scale regions encompassing both highly populated urban areas and extensive rural areas. We acknowledge that factors such as population density, urbanization level, typhoon duration, and whether a typhoon is stationary can significantly influence the impact on power infrastructure and the subsequent recovery process (Page 8, form line 141).

"A comprehensive comparison of those scenarios shows that the severity and recovery duration of outage events present regional variations, which could come from regional intrinsic resilience characteristics and the varying number of customers at the grid edge. As shown in Table 2, the main cause of power outages is distribution network disruption. The recovery process for the Tokyo grid demonstrates a long-tail characteristic, likely due to the extensive area it serves and the large number of customers."

Q8: Finally, this kind of study - with mitigation strategies - should include a technical-economic approach.

Answer: Thank you for your valuable feedback. Understanding the techno-economic performance of these solutions allows homeowners, policymakers, and utility companies to make informed investment decisions. We discussed the technical-economic performances of demand solutions in improving energy resilience during long-duration power outage triggered by extreme weather events (Page 17 from line 287).

"Energy resilience can be enhanced by investing in distributed energy resources, levelized costs of electricity for solar PV, home battery storage, and electric vehicles vary by region and electricity market. Their estimated values are as follows: electric vehicles at 0.30 \$/kWh [58,59], solar PV system at 0.05 \$/kWh [60] and home battery storage at 0.25 \$/kWh [61]. The levelized costs for rooftop PV systems are lower than market electricity prices. The levelized costs for micro-CHP units are based on several factors, including generator lifespan, efficiency, installed capacity and fuel cost. The estimated levelized costs for home fuel cell and diesel generator are 0.25 $/kWh [62], 0.40 $/kWh [63], respectively. EVs can serve dual purposes but involve higher costs due to vehicle prices and battery capacities. While micro-CHP technologies commonly used for backup power, they have higher operating costs and environmental impacts, fuel availability may be constrained during extreme events. Integrating PV systems with home battery storage enhances reliability in meeting critical household energy demands during prolonged outage periods. Customers need to consider techno-economic performance of these solutions carefully to make informed investment decisions that increase home energy security."

Figures
Figure 2 – please revise the xlabels caption. There is some problem with the last xTick caption in every panel (After 12 Sept is not 30 Aug, the same in all panels). The "peak outage event" is highlighted with a red dot.
Answer: Thank you for pointing this out. We revised the xlabel, the "peak outage event" is highlighted with a red dot.

Figures 2, 3 and 4 – The xlabels should be harmonized. Since all panels have the same labels, xlabels could be omitted in panels 1 to 3 and ylabels could be omitted in panels 2,3,5 and 6, for better reading.
Answer: Thank you for pointing this out. We revised these figure according to your suggestions.

Figure 3 – the caption should be more explicit: it is not clear in the figure when is "before, during, and after each power outage". A note should highlight that the scales are different amongst panels. The symbols should have a caption.
Answer: Thank you for pointing this out. We revised the caption and ensured that the x-axis scale is consistent.

Figure 5 – all acronyms should be described in the caption.
Answer: Thank you for pointing this out. All acronyms have been described in the caption.

Figure 6 – please improve the ylabel "number". Please indicate if you represent number of family-homes. Please explain what "Group1 n1=136, Group 2 n2=131" means. Please refer to how these families are representative of Japan society in these regions.
Answer: Thank you for pointing this out. We revised the caption and ylabel for Figure 6(a).
Figure 6 Distributions of measured daily electricity loads for representative single-family homes. (a): Group 1: Electrical heat pump supplies hot water (136 families), Group 2: Fuel cell meets hot water needs (131 families). (b): load profile for Group 1, (c) load profile for is Group 2, (d): critical home lighting and (e): refrigerator electricity demand, red dashed lines and shaded band indicate standard deviations of average load at various time, respectively.

Thank you again for helping us enhance the quality of our presentation.

Manuscript: COMMSENV-24-1920A

Title: Extreme typhoon events trigger long-lasting power outages and require demand-side solutions to enhance energy resiliency

Reviewer #3 (Remarks to the Author):

Review of manuscript entitled "Long duration power outages triggered by extreme typhoon events: characterization and demand side mitigation strategies" by Li et al.
It is very important to characterize and understand energy disruption mechanisms due to extreme weather events. I read this manuscript with great interest. However, the manuscript still lacks quantification, grounding and discussion of the new results to justify its publication on this high impact journal.
The authors have adequately addressed some of the comments raised, replied and improved the manuscript. Nevertheless, in some cases, the replies have not been incorporated in the manuscript. In my opinion, these aspects and evidence are required to strengthen the quality of the manuscript. Finally, the novelty and relevance of this study should be clearly stated.

Q1: Abstract – The text in the abstract needs to be more specific. Generic expressions should be avoided. For example: "In Part I, we characterize widespread power outages induced by historical typhoon events in Japan. Using collected real world datasets, we illustrate the failure causes and recovery processes associated with extended power outages. Those outages present similar recovery curves, with full recovery requiring a relatively long time." Reading this sentence, the reader does not identify the factors that characterize widespread power outages due to typhoons; nor the failure causes, nor the recovery processes – an abstract should objective and highlight the novelty and results of the study. This comment applies to seveal sentences in this manuscript.
Answer: Thank you for your insightful feedback. According to the attached abstract provided by editors and format (no more than 150 words), we revised the abstract to make it more specific and informative.

As climate change intensifies, the adverse impacts of extreme weather events on energy supply systems will increase. Here, we collected energy grid utility datasets to illustrate causes and recovery processes of extended power outages induced by typhoon events in Japan. We also assessed the performance of demand-side solutions to enhance home energy resilience using household load profiles. We show that power outages present similar recovery curves, with full restoration times highly dependent on maximum wind velocities and affected regions. Ensuring a 24-hour self-energy supply is essential to mitigate outage impacts. Further, our results highlight the importance of off-grid energy storage or production in sustaining critical household energy loads under extended outage conditions. Building electrification scenarios challenges meeting increased demand under power outages. Building electrification and resiliency should be designed in tandem to improve energy security. Findings shed light on the effectiveness of demand-side solutions in enhancing Japan's home energy resilience.

Q2: Reply to Q2 – on the use of the term "historical typhoon events in Japan". This information should be included in the manuscript.
It is important to highlight that the generic sentence “Climate change is contributing to the increasing frequency and intensity of extreme weather events globally.” needs to be written carefully and using a reference. Recent research has shown that the frequency of some extreme weather events is not increasing – only their intensity has been increasing. Thus, when applied to this study and to severe typhons, a scientific article reference should be included.
Answer: Thank you for your suggestion. We revised the sentence of “Climate change is contributing to the increasing frequency and intensity of extreme weather events globally.” And added relevant references. “Climate change has increased the intensity of extreme weather events, such as typhoons, snowstorms, and heatwaves [1-3].”

1 Murakami, H., Levin, E., Delworth, T. L., Gudgel, R. & Hsu, P. C. Dominant effect of relative tropical Atlantic warming on major hurricane occurrence. Science 362, 794-799 (2018).

2 Guo, X. et al. Intensification of future subsurface marine heatwaves in an eddy-resolving model. Nature Communications 15, 10777, doi:10.1038/s41467-024-54946-z (2024).

3 Insua-Costa, D. et al. Extraordinary 2021 snowstorm in Spain reveals critical threshold response to anthropogenic climate change. Communications Earth & Environment 5, 339, doi:10.1038/s43247-024-01503-7 (2024).

Q3: Additionally, while it is reasonable to choose the “six typhoons because they had maximum wind velocities exceeding 40 m/s and caused substantial impacts on Japan's power infrastructure, leading to widespread outages.”, it is not necessarily a way to characterize them as historical typhons. Either there is a climatological assessment (with a scientific reference) to confirm how these events have been considered historical events, or the justification is given through the data availability, as stated in this reply. It should be noted that the text written in this manuscript is dubious and allows confusion between the criteria to consider an extreme typhon. As stated in Figure 1 “Examined typhoon events that trigger widespread power outages”

– so, the impacts are the criteria. The reader of this manuscript should clearly understand how rare and extreme these six events were without the need to consult further literature or links. Therefore, how representative these events are should be clear to the reader. Please rephrase lines 105-106, explaining which were the criteria for choosing these 6 events.

Answer: Thank you for pointing out. We added the following description in the revised manuscript:

This study selected six typhoon events based on their wind velocities exceeding 40 m/s and the widespread power outages they caused, supported by reported recovery data. Table 1 provides detailed information on these typhoon events and induced power outage events affecting four electrical companies.

Q4: According to the Japan Meteorological Agency, the typhoons in Table 1 fall within two different categories – Typhoon (Maximum wind speed <44m/s), Very Strong Typhoon (44m/s ≤ Maximum wind speed < 54m/s). None of them was classified as a Violent Typhoon (54m/s ≤ Maximum wind speed). Please consider rephrasing the text when "Super typhoons" are mentioned, since these were not addressed here.

Answer: Thank you for pointing out. We revised the "Super typhoons" as "Typhoon events"

Q5: Figure 1 – units are missing.

Answer: Thank you for pointing out. We added units for Figure 1 (a).

Q6: Table 1 – A sentence could be added to the caption "typhoons are numbered according to the order in which they occur each year" to identify the events from the official list. Column 1 should have in the title "Name of extreme event (Number)"

Answer: Thank you for helping improve the clarity of the table. We added the sentence: "Typhoons are numbered according to the order in which they occur each year". Additionally, we revised the title of Column 1 to "Name of Extreme Event (Number)" to align with your recommendation.

Q7: Figure 2 and reply to Q5 – On their reply authors mention that "While there are moments during typhoons when solar PV systems can still generate power, overall, the generation is notably lower compared to normal weather conditions". As previously stated, this is not in full agreement with this figure. Additional information should be given to what data are represented by the "solar PV generation profiles" –

and this will justify that these are not affected by the occurrence of the analyzed typhoons in some locations. Further discussion is missing on lines 111-112.

Answer: Thank you for your insightful feedback. We understand the need for clarity regarding the "solar PV generation profiles" in Figure 2. To address this, we provided additional information about the data represented by these profiles.

Q8: Ln 126-128 – Please explain this sentence. It is not clear how the correlation and its significance are computed.

Answer: Thank you for pointing out, we revise the content as follows: The scenarios analyzed for the Chubu (Typhoons No. 24 and No. 19) and Kyushu (Typhoons No. 10 and No. 14) grids indicate that higher maximum wind velocities are associated with longer recovery durations. However, the increased number of affected customers does not appear to impact recovery durations, in consist with previous work.

Q9: Ln 132-134 – Please explain this conclusion: “The recovery process for the Tokyo grid demonstrates a long tail characteristic, likely due to the extensive area it serves and the large number of customers.” This manuscript lacks characterization of the grid on the different considered (Fig 1) regions. Many factors may affect the recovery process and these should be discussed. Please discuss how the recovery process for the Tokyo (No.15 Typhoon) compares with Kansai grid (No.21 Typhoon).

Answer: Thank you for your insightful comment. The service areas of the Kansai and Tokyo

Q10: Ln 235-236 – Please explain how the PV values on Table 3 were computed and what the relation is with Figure 2.

Answer: Thank you for pointing out. The hourly generation profiles of a 5.0 kWp rooftop PV system over two days (the day before and the day of the typhoon event) were computed by scaling the monitored PV load profiles (illustrated in Figure 2) according to solar PV capacity connected to the power grid (reported in Table 1).

Q11: Ln 242 – “Incorporating battery storage effectively increases the load cover ratio, providing increased opportunity to meet critical energy demand.” As mentioned above, such general sentences should be avoided, an effort should be made to quantify and references should be added.

28,7

Answer: Thank you for your feedback. Incorporating battery storage effectively increases the load cover ratio, providing increased opportunity to meet critical energy demand. Case studies have shown that 5.0 kWp battery storage systems can increase the load coverage ratio by 25-50% in certain disruption scenarios. This improvement enhances the reliability of the lighting and refrigeration energy supply (as illustrated in Figure 6), approximately 30% of daily electricity consumption.

Q12: Ln 247 – damage on energy systems occurs even when typhoons are not categorized as super typhoons.
Answer: Thank you for pointing out. We revised the content accordingly.

Q13: Ln 249-250 – please add a reference to this statement – it is the increasing in intensity of extreme events more than the frequency that causes increasing severe disruption on systems.

Answer: Thank you for your suggestion.

It is the increase in intensity of extreme events more than the frequency that causes increasing severe disruption on systems[11,57].

11 Xu, L. et al. Resilience of renewable power systems under climate risks. Nature Reviews Electrical Engineering 1, 53-66, doi:10.1038/s44287-023-00003-8 (2024).

57 Harrington, L. J., Schleussner, C.-F. & Otto, F. E. L. Quantifying uncertainty in aggregated climate change risk assessments. Nature Communications 12, 7140, doi:10.1038/s41467-021-27491-2 (2021).

Thank you again for helping us enhance the quality of our presentation.