ENERGY RESILIENCE IN BUSHFIRES AND EXTREME WEATHER EVENTS

Final Report of the

ESKIES project

August 2023

Collaboration on Energy and Environmental Markets

UNSW SYDNEY

About the authors

The UNSW **Collaboration on Energy and Environmental Markets (CEEM)** undertakes interdisciplinary research in the design, analysis and performance monitoring of energy and environmental markets and their associated policy frameworks. CEEM brings together UNSW researchers from a range of faculties, working alongside a number of Australian and international partners. CEEM's research focuses on the challenges and opportunities of clean energy transition within market-oriented electricity industries.

Effective and efficient renewable energy integration is key to achieving the energy transition and CEEM researchers have been exploring the opportunities and challenges of market design and policy frameworks for renewable generation investment, and investment in the necessary flexible resources to facilitate its integration, for 20 years.

As distributed energy resources (DER) such as solar PV, batteries and demand response are deployed at increasingly high penetrations, their successful integration into electricity industries will be critical. CEEM studies emerging markets, regulatory approaches and business models for DER integration, and their technical, economic and social outcomes.

More details of this work can be found on the CEEM Website: www.ceem.unsw.edu.au
We welcome comments, suggestions, questions and corrections on this report and all our work in this area.

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Australian Government

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Disclaimer

While the authors have made every effort to ensure the information provided here is correct and useful, we accept no liability for any errors or inaccuracies. Readers are advised to obtain independent advice before investing in solar, batteries, generators or other distributed energy resources.

Although funding for this project has been provided by both the Australian and New South Wales Governments, the material contained herein does not necessarily represent the views of either Government.

Abbreviations

Abbreviation	Term
1-P	Single phase
3-P	Three phase
ac	Alternating current
BCRRF	Bushfire community recovery and resilience fund
BESS	Battery energy storage system
BEV	Battery electric vehicle
dc	Direct current
DER	Distributed Energy Resource
DNSP	Distribution network service provider
DOD	Depth of discharge
EV	Electric vehicle
GHG	Greenhouse gas
ICE	Internal combustion engine
kVA	kiloVolt-Amps
kW	killowatt
kWh	killowatt-hour
LGA	Local government area
LPG	Liquid petroleum gas
NBN	National Broadband Network
PV	Photovoltaic
RSF	Rural Fire Service
SAPS	Stand-alone power system
SOC	State of charge
UPS	Uninterruptable power supply
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
V2L	Vehicle-to-load
W	Watt
Wh	Watt-hour
VPP	Virtual power plant

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EXECUTIVE SUMMARY

In recent years devastating bushfires and other extreme weather events have seen communities across New South Wales (NSW) lose access to power from the electricity grid and, with it, a range of critical energy-dependent services. With new technologies being developed in the transition to renewable energy that enable households and communities to generate, store and use energy locally, there is an opportunity to ensure that people have alternative means of accessing power for essential activities when the grid is affected.

The ESKIES project was funded by NSW Reconstruction Authority's Bushfire Community Resilience and Recovery Fund (BCRRF) in the wake of the Black Summer bushfires of 2019-2020. The project's primary aim is to explore the options for enhancing the resilience of households and communities during weather-related power outages and to share the learnings with communities affected (or likely to be affected in the future) by these disruptions, as well as with policy-makers and other stakeholders.

We have sought to develop an understanding of:

- how households and communities have been impacted by power outages
- how they have used Distributed Energy Resources (DER) and other resources available to them to manage during these outages, and
- how DER and other resources could be used to achieve greater energy resilience in future.

As a team of social science and engineering researchers in the Collaboration on Energy and Environmental Markets (CEEM) at the University of New South Wales (UNSW), we have taken an interdisciplinary approach to investigate the potential and limitations of DER and other technologies within their social contexts of the home, the community and broader society.

(Image courtesy of Renate Egan, APVI)

Research approach

Learnings and insights from this research project were developed through:

55 household interviews	conducted with participants across 21 local government areas (LGAs) in NSW to gain an understanding of participants' experiences with electricity supply disruptions during bushfires and other extreme weather events.
13 expert interviews	including Community Recovery Support and other council officers, solar and battery system designers and installers, engineers from distribution network service providers (DNSPs), officers from the Rural Fire Service (RFS) and consultants with knowledge of microgrids and stand-alone power systems (SAPS) and community leaders.
3 online workshops	to develop a deeper understanding of the potential roles of DER in increasing resilience to grid disruptions due to extreme weather events from a household and community perspective.
3 case studies	which involved interviews with, and ethnographic observations of, key actors across three community projects focused on increasing future energy resilience.
64 solar systems	analysis of solar generation data from households in bushfire-affected areas to develop understanding of the impacts of bushfire smoke on generation and the implications for energy resilience.

Key findings

Participants employed a range of DER and strategies to cope with the impacts of power outages – each with its own advantages and limitations. Choosing DER technologies that enhance energy resilience is not solely a technical concern, it requires careful consideration of the socio-economic context as well as situational factors.

There were many instances of community members supporting one another to access energy services during weather-related outages e.g., sharing generators and communal cooking. However, it cannot be assumed that all communities have shared interests and/or the capacity to respond in these ways.

Helping households and communities to learn from past experiences, anticipate and prepare for power outages can enhance resilience at a local scale – but participants feel that governments and energy providers should also be taking action to improve energy resilience at the system level.

Different DER configurations, at individual household and community levels, can have different meanings and implications for energy resilience. Relatedly, more decentralised configurations do not necessarily entail a clear shift away from incumbent models or reliance on actors such as governments and DNSPs.

While decarbonisation of the energy supply is urgent, there is a need to consider its potential resilience implications or risk creating additional forms of vulnerability in homes and communities.

Implications for policy and engagement

There is a need for greater efforts to educate households and communities on, and for greater industry understanding, of the specific resilience capabilities and implications of different types of DER.
There is a need to take a wider view of the different types of value that DER can offer, such as bill savings, emissions reduction, and resilience to power disruptions.
Considerations of resilience should be factored into the design of policies that support the adoption of DER, such as subsidies, both to evaluate potential unintended effects and to leverage opportunities to support technologies that increase resilience.
There is potential for the electrification of household appliances to yield negative resilience outcomes if carried out without consideration of back-up electricity supply in areas vulnerable to grid outages – a dynamic that will need to be navigated in the development of policy and research.
Engagement with communities is necessary to understand their needs and the DER configurations that might best meet them, while also considering that perspectives and needs within communities differ, and to build partnerships among stakeholders to achieve energy resilience.

INTRODUCTION

Project background and aims

In recent years devastating bushfires and other extreme weather events have seen communities across New South Wales (NSW) lose access to power from the electricity grid and, with it, a range of critical energy-dependent services. Many have drawn on a variety of back-up resources and approaches to cope during these outages, but others have not been equipped to manage the extent of the outages and their far-reaching implications for access to telecommunications, water, transport, and other services.

With new technologies being developed in the transition to renewable energy that enable households and communities to generate, store and use energy locally, there is an opportunity to ensure that people have alternative means of accessing power for essential activities when the grid is affected. And with such extreme weather events projected to occur with greater frequency and intensity due to climate change, there is a need to do more to achieve this. The heatwaves that may accompany the El Niño that is likely to develop in 2023 are among such extreme weather events, which in this case could result in supply disruptions and volatile energy prices.

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Understanding energy resilience

This study is centred on the idea of resilience. A broad term employed in a variety of ways and settings, resilience is generally understood to refer to 'persisting in the face of disturbances', and this can involve a range of associated processes such as preparation, adaptation, learning and transformation [1].

The concept of resilience emerged in the 1970s in the field of ecology, where it was used to theorise the experience of instability in ecosystems, as well as in the discipline of psychology, where it was used to study the capacity of individuals to cope with adversity [2]. More recently it has been taken up across a diverse range of sectors and fields of social and natural scientific research, including disaster management, sustainable development and climate change adaptation [3], accompanied by different interpretations, emphases and aims [1].

There are ongoing debates about the value of the concept in both theory and practice, with some considering it a 'buzzword', a vague concept that can serve a wide range of political and potentially unjust ends [3–5].

In this study, we do not adopt a particular definition of resilience, nor indeed advocate for its use. Rather we attempt to understand the different ideas about what it means to be resilient to weather-related power outages that the project participants shared with us, with the aim of shedding some light on what is at stake in these visions for a more resilient energy system.

In exploring experiences of, and responses to, electricity grid disturbances, we use the broad term 'energy resilience' to describe diverse approaches to ensuring that needs for energy services are met during disruptions to the main electricity grid. This includes but extends beyond electricity supply measures, typically distributed or localised, that are robust to fires and extreme weather events (which might be more precisely referred to as increasing 'electricity resilience'), also encompassing broader measures to use other, non-electrical energy sources or reduce the need for electricity.

The resilience of energy systems is a matter of growing concern in the face of risks posed by climate change impacts as well as geopolitical and cybersecurity threats [6–9]. It is increasingly important given the dependence on energy of a number of critical infrastructural systems that are central to human well-being – and the dependence on electricity in particular is only deepening with efforts to decarbonise economies through the electrification of communications, transport, cooking and heating. The issue of energy resilience therefore relates to several major policy issues such as vulnerability, security, poverty and justice [10]. For example, marginalised groups such as First Nations peoples may experience an 'unequal resilience' if they reside in areas with poorer network reliability, as has been observed in the USA [11].

Much of the research on this topic has been concerned with improving the resilience of energy infrastructure and associated services in the aftermath of disasters [9,12,13]. Less attention has been given to the experiences and responses of households and communities when they are affected by disruption to these systems.

The emerging research on household energy resilience explores how households perceive, respond to and learn from power outages, which raises issues of social vulnerability, preparedness and energy-related household practices and habits [12,14–17]. For example, a study of remote households in Norway found that experiences of power supply disruption reshape expectations of a 'normal life' and lead people to develop alternative energy practices to cope, including the use of batteries, firewood, and non-electric equipment – although this does not translate into an acceptance of poor grid reliability [17].

Household strategies tend to rely on a diversity of technologies as well as of knowledge and skills, which among households in Sweden have been observed to include 'old ways of doing things' such as storing food outside during winter, using 'low-tech products', and socialising and working collectively whenever possible [15]. The findings from bushfire-affected communities in NSW that we share in this report are consistent with this research from elsewhere in the world.

Studies of the ways that communities respond to power supply disruption have emphasised that communities tend not to be 'passive victims that wait for energy companies', but rather, active agents that are resourceful in responding to precarity [9]. Community responses include sharing resources, labour and knowledge [9,15]. During a power outage following the 2010 Chile earthquake and tsunami, for example, these strategies included sharing freezers and establishing communal kitchens [9].

Energy Consumers Australia's *Connections That Matter* report, prepared in the aftermath of the 2019-2020 bushfires, observed that resilience in affected communities was as much about the strength of communal bonds and local service providers as it was about 'hard infrastructure' or official responses [18]. Communal efforts are, however, inevitably constrained by the resources and capacity available, and can have negative effects to the extent that they may exclude some individuals or groups within the community [9].

In their post-Black Summer study, Energy Consumers Australia found strong interest within communities in becoming more energy independent through the adoption of community-scale and household-scale DER [18]. It is clear that close engagement with communities is needed to explore these options – including to consider the range of more individual to more community-oriented approaches, examine tensions between decarbonisation and energy diversity, and navigate a tension between the imperative to rush to 'build back' and restore power promptly following weather-related power outages, and the opportunity to build a more flexible and resilient energy system for the future [18,19].

This report presents the experiences and perspectives of people from across NSW and will, it is hoped, support these efforts and inform communities, governments and other stakeholders in developing practical approaches and policies to increase energy resilience.

Report structure

The following chapter describes the methods used in this project.

The subsequent chapter, Impacts and Responses, outlines some of the impacts of grid outages felt by households and communities across the state, and some of the ways that they have responded.

Technologies and Infrastructure provides an overview of the DER and other technologies that can contribute to energy resilience.

Visions for a Resilient Energy System discusses different possible configurations of these DER at household and community scales, the different ideas of resilience that are associated with them, and some of their implications for governance and justice.

The Conclusion briefly summarises the key findings of the ESKIES project and their implications for policy makers.

METHODS

Introduction

The *ESKIES* project engaged communities in developing a better understanding of the relationship between energy and community resilience, including their existing capacity to maintain power supply during disaster events such as bushfires and floods, as well as how this capacity can be enhanced. To this end, the project team set out to identify, collect, analyse and share information and knowledge relating to energy resilience, particularly the role of solar, batteries and other DER, as well as energy management approaches.

This information has come from a range of sources, including, most importantly, the experiences and responses of residents of bushfire-affected local government areas (LGAs), examined through interviews and scenario exploration workshops, and through observation of community meetings. This has been augmented with information collected through interviews with a range of 'experts' and a desktop review of industry and community reports, and academic articles. Additionally, solar generation data during the Black Summer bushfires was collected and analysed.

These methods are described in more detail below.

Project design

With input from key community stakeholders, the project was designed and adapted to meet the needs and capabilities of the communities engaged. In particular, we were cognisant of the ongoing impacts, trauma and, in many cases, 'research fatigue' that communities across NSW are experiencing following the Black Summer bushfires and more recent severe flooding events. The commencement of the project in 2021, during the continued disruption and uncertainty caused by the COVID-19 pandemic, necessitated a plan that could withstand the existing and potential ongoing or future lockdowns and other constraints.

We therefore adopted methods that were accessible and flexible, enabling broad participation without placing onerous demands on individuals, communities or organisations and, importantly, that could generate outputs of use to those communities. To this end, we conducted interviews and workshops online to achieve this accessibility and flexibility, and to enable participation from across all the bushfire-affected LGAs, rather than focusing on specific communities.

Figure 1 ESKIES printable flyer

Outreach materials

A set of outreach materials was generated to attract participants to the project.

This included:
- ✓ A project webpage, hosted on the CEEM website, outlining the project aims and inviting participation
- ✓ A short video describing the project and inviting participation
- ✓ Digital and printable flyers (see Figure 1)

These were widely shared through the social media (Facebook, LinkedIn and Twitter) networks of CEEM and Australian PV Institute (APVI), and a range of online forums including My Efficient Electric Home (facebook.com/groups/MyEfficientElectricHome), and offered to stakeholders to distribute through their own social media, newsletters, offices and other communications.

Stakeholder engagement

To inform the research design and facilitate the recruitment of participants, we engaged with a wide range of organisations, including state and national government agencies and not-for-profits (see Table 1).

Table 1 Stakeholder organisations

Organisation	Website
Ausgrid	ausgrid.com.au
ANU - SuRF Microgrid project	https://bsgip.com/research/projects/southcoast-%C2%B5-grid-reliability-feasibility-s%C2%B5rf-project/
Australian PV Institute	Apvi.org.au
BizRebuild	bizrebuild.com.au
Business NSW	businessnsw.com
Endeavour Energy	endeavourenergy.com.au
Energy and Water Ombudsman NSW	ewon.com.au
Essential Energy	essentialenergy.com.au
Foundation for Rural and Regional Renewal	frrr.org.au
National Recovery and Resilience Agency	
NSW Office of Energy and Climate Change	treasury.nsw.gov.au
NSW Rural Fire Service	rfs.nsw.gov.au
Resilience NSW	resilience.nsw.gov.au
Service NSW	service.nsw.gov.au
Service NSW for Business	service.nsw.gov.au/business
Shoalhaven Council Resilience Project	shoalhaven.nsw.gov.au/Projects-Engagement/Major-Projects-Works/Recovery-Into-Resilience-Project-RRP
Treasury NSW	treasury.nsw.gov.au

23 local councils in the bushfire-affected areas were also approached, leveraging APVI's existing engagement with some of them through the Office of Energy and Climate Change's Sustainable Councils and Community Program and the network of Community Recovery Support Officers embedded in councils and funded by the NSW and Australian governments through Disaster Recovery Funding Arrangements (DRFA).

These included: Armidale, Bega Valley Shire, Blue Mountains, Cessnock, Clarence Valley, Eurobodalla Shire, Glenn Innes Severn, Hawkesbury, Kempsey, Lake Macquarie, Lithgow, Mid-Western, Mid Coast, Nambucca, Port Macquarie – Hastings, Queenbeyan-Palerang, Shoalhaven, Snowy Monaro, Snowy Valleys, Tenterfield, Walcha, Wingecarribee Shire and Wollondilly.

Most of these organisations were supportive of the project and passed on our outreach and recruitment materials through their networks, newsletters, social media and other communications. This facilitated the recruitment of some individuals who were encouraged to pass the outreach materials to other potential participants, with recruitment continuing through a snowballing process.

The initial engagement with stakeholder organisations and the first wave of participants also revealed several challenges:

Two years after the Black Summer bushfires, many of the bushfire-affected communities were still struggling to recover and rebuild, with many individuals suffering from trauma. This – as well as COVID-19 – informed a decision to broaden the project to include online participation with individuals from all bushfire-affected LGAs instead of in-person workshops and meetings in particular communities. Incentives for interviewees and workshop participants were also introduced to encourage sign-up.

Although electricity grid outages had caused massive disruption to many of these communities, their impacts were closely intertwined with the broader – and in many cases devastating – impacts of the fires themselves. Our participant interview script and approach were refined to draw out specific reflections on the impacts of and responses to electricity outages, while allowing participants space to discuss their whole experience.

Small business in these communities were particularly hard to engage, with multiple competing priorities to deal with, not least the difficulty of restoring their livelihoods. We therefore focused more on household experiences and responses.

Some of these bushfire-affected LGAs – and their electricity supplies – had also been affected by flooding in 2021, with some communities impacted more severely than they had been by the fires. The scope of the project was broadened to include these other disruptions, while remaining focused on the set of bushfire-affected LGAs.

Participants

ESKIES participants signed up to the project through an online form, linked to a detailed *Participant Information and Consent Form* giving details of the project, describing what participation would involve and what would happen to the information collected. Participants were assured that their personal identifying information would be stored securely and not be shared. The recruitment methods, survey and interview and workshop techniques and scripts were pre-approved by UNSW's Human Research Advisory Panel (reference number HC210522).

The online form was linked to the *ESKIES* webpage and other outreach materials. As well as the sign-up form, it included a survey that was used to screen potential participants for eligibility and collect some demographic data and household characteristics. The criteria for eligibility include residence (or business ownership) in one of the NSW bushfire-affected LGAs and having experienced electricity grid disruptions due to bushfires, floods or other extreme weather events.

Table 2 Household interviewees by LGA

LGA	Household interviewees
Bega	H32, H39
Blue Mountains	H23, H69
Central Coast	H10, H11, H17, H19, H21
Cessnock	H61
Coffs harbour	H67
Eurobodalla	H01, H20, H45, H46, H51
Glen Innes Severn	H91
Hawkesbury	H04, H33, H70
Lake Macquarie	H13, H27
Lismore	H57, H58, H59
MidCoast	H08, H43, H76, H78, H102
Oberon	H12
Shoalhaven	H15, H25, H37, H42, H54
Snowy Monaro	H18
Snowy Valleys	H02, H03, H05, H07, H09, H24, H29, H30, H31
Wingecarribee	H34, H35, H36, H38, H40, H52, H53
Wollondilly	H47, H48

Figure 2 ESKIES Household Participants by LGA

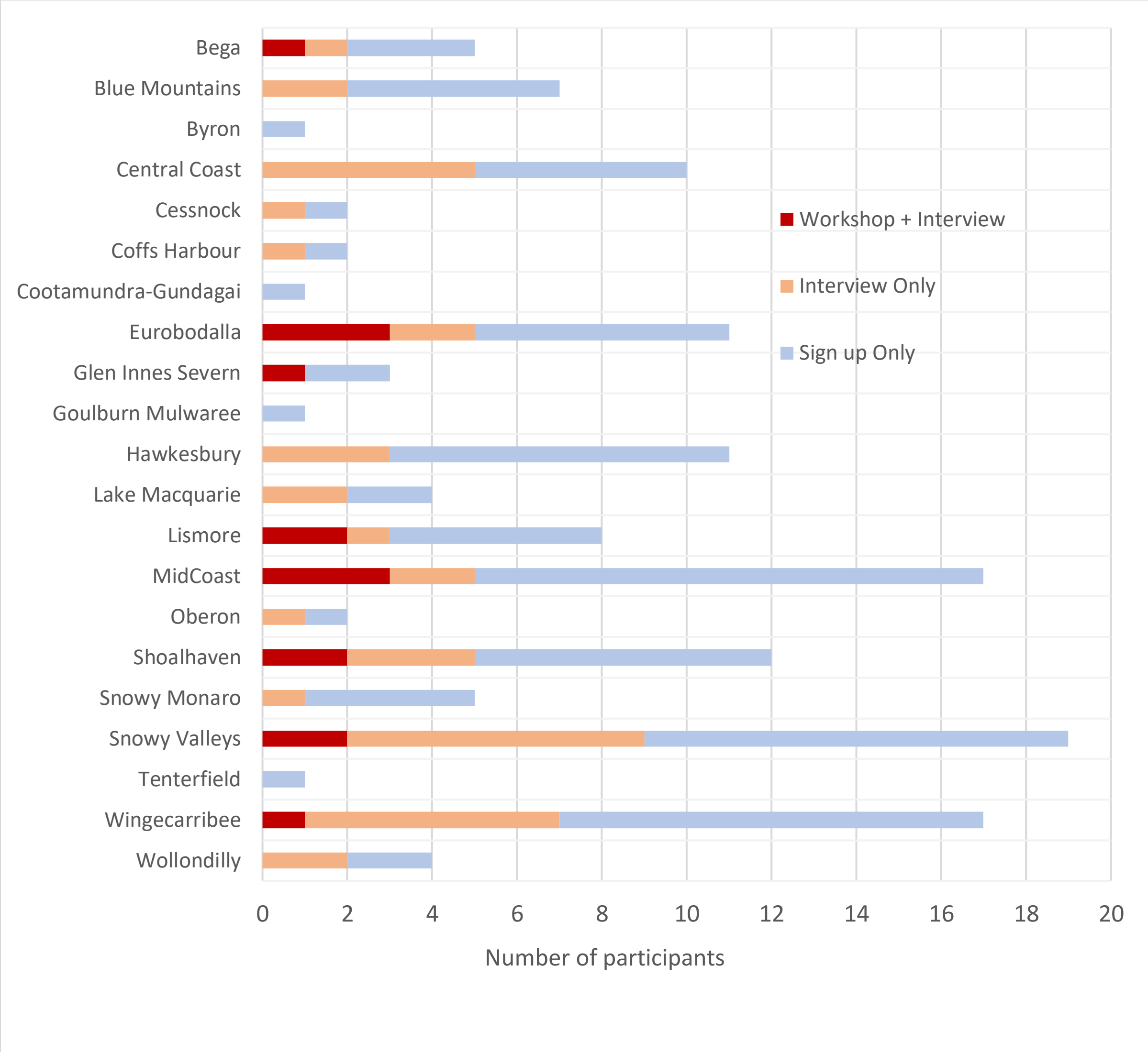
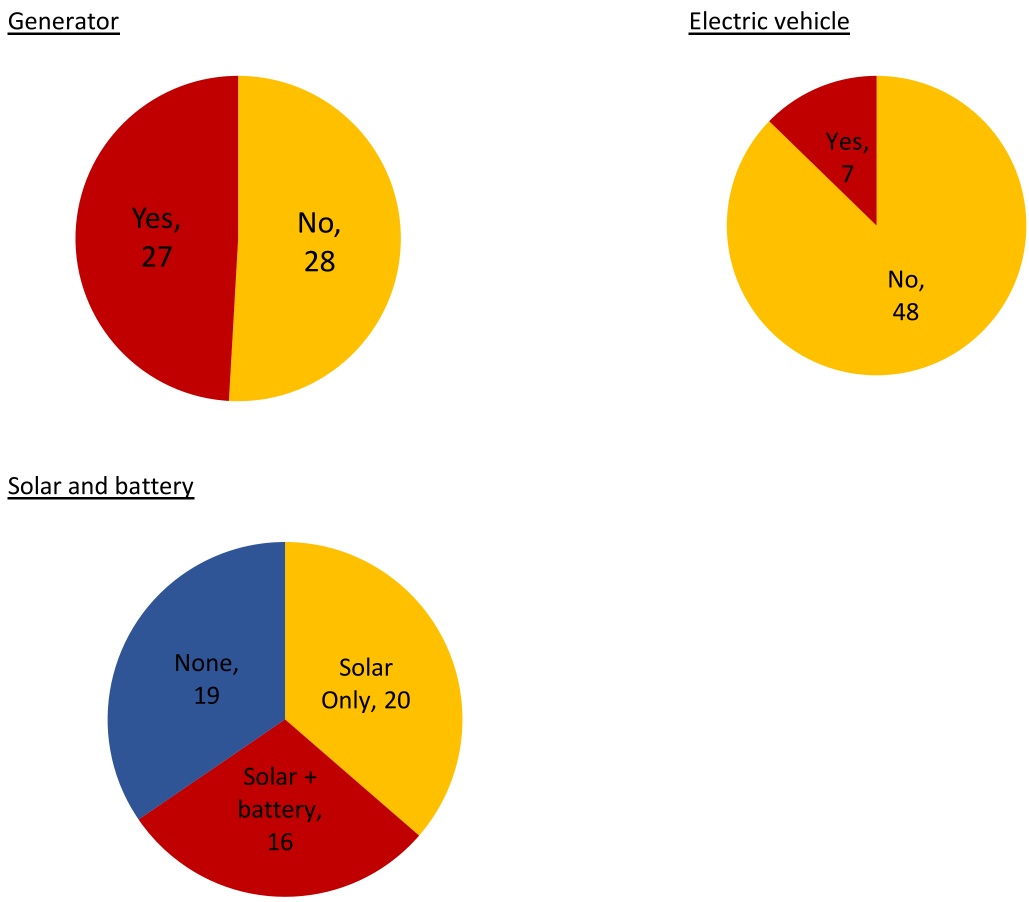


Figure 2 shows the number of sign-ups by LGA, along with the subset of those who participated in interviews (n = 55: 30 male, 25 female, 0 other) and those that were also involved in scenario exploration workshops (n = 15). Signed-up participants who were not interviewed were either ineligible, did not respond to requests for an interview or (later in the project) lived in LGAs already well represented in the project.

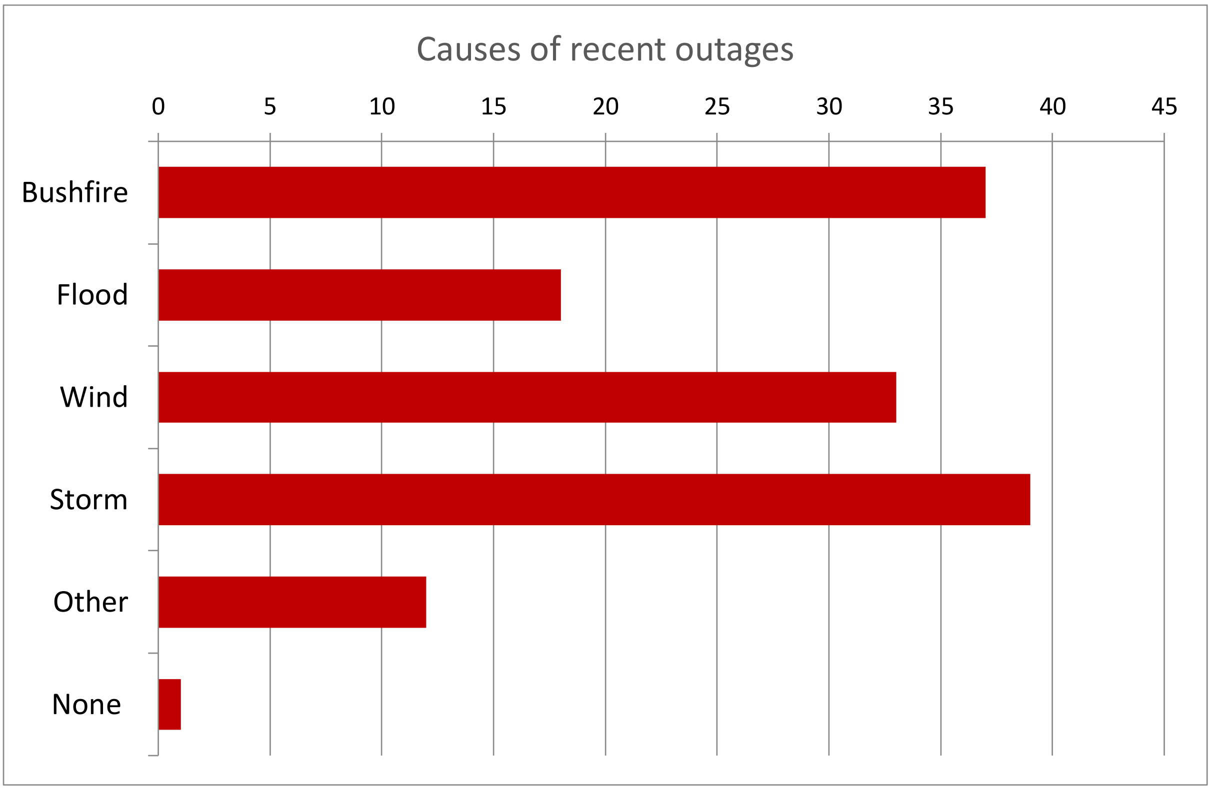
Figure 3 Bushfire-affected LGAs with ESKIES participants

Figure 4 DER ownership amongst ESKIES participants



As well as residents of the bushfire-affected LGAs, 13 ‘experts’ were interviewed during the course of the project. This included Community Recovery Support and other council officers, solar and battery system designers and installers, engineers from distribution network service providers, officers from the Rural Fire Service (RFS), consultants with knowledge of microgrids and SAPs, and community leaders.

Figure 5 Causes of grid outages experienced by ESKIES participants



Not all these 'experts' lived in bushfire-affected communities, and a few were from outside New South Wales, but their expertise is highly pertinent to increasing energy resilience in these areas. They were mainly recommended for participation by stakeholder organisations or other participants, with recruitment ongoing through a 'snowballing' process. These participants were emailed a *Participant Information and Consent Form* and either returned a signed copy or gave their verbal consent at the start of the interview.

Interviews

Interviews were used to understand participants' experiences of electricity supply disruptions during bushfires and other extreme weather events. The interviews were carried out online, using Zoom or Teams video conferencing platforms or, where this was easier for participants, on the phone. The interviews lasted around one hour and, in most cases, household participants were compensated for their time with a digital voucher.

The interviews were semi-structured, meaning that researchers used an interview guide (see below) with a set of questions to be addressed, but allowed the discussion to move beyond these questions, either driven by the participants or through additional follow-up questions in response to what the participants were saying. This approach ensured the key topics were covered but allowed exploration of the diverse experiences of participants.

It also became apparent that some participants had a strong desire to share their broader experiences of the bushfires or floods, beyond aspects relating to energy and/or resilience. Our approach was to enable this, to provide context and in consideration of the trauma experienced by many of the participants. Participants were also given every opportunity to avoid difficult topics or to pause or end the interview at any point, although none took up these options.

For the 'expert' interviews, bespoke interview guides were developed for each of the participants. These included some general questions relating to the participants' personal experiences of the bushfires and their role in community response, as well as more directed questions about their specific expertise and its relevance to improving energy resilience. As with the household interviews, the semi-structured interview enabled interviewers to dig more deeply into the particular expertise of this diverse cohort.

The transcripts of all the interviews were analysed to identify themes in the participants experiences of and responses to electricity supply disruption, their attitudes to different DERs and approaches to energy resilience. Throughout this report, excerpts from interviews are indicated with the household (H) or expert (E) participant number in parentheses.

<table>
<tr><th colspan="2">ESKIES Household Interview Guide</th></tr>
<tr><td colspan="2">Introduction</td></tr>
<tr><td colspan="2">Can you please tell me a little about yourself, your home and its location?
… and about your community</td></tr>
<tr><td colspan="2">How would you describe the role that energy plays in your home?</td></tr>
<tr><td colspan="2">Do you have any distributed energy resources [DER]: a solar system, battery, diesel generator…?</td></tr>
<tr><td>If yes</td><td>If no</td></tr>
<tr><td>Why did you purchase them?</td><td>Have you thought about purchasing any?</td></tr>
<tr><td>How do you use them in the normal course of things?</td><td>Why / why not?</td></tr>
<tr><td>Are you satisfied with what they can do for you in the normal course of things?</td><td></td></tr>
<tr><td colspan="2">If diesel genset</td></tr>
<tr><td colspan="2">when / how often do you use it and for what loads?</td></tr>
<tr><td colspan="2">Do you do any load shifting in the normal course of things (e.g. you have solar PV and use electricity during the day for tasks such as dishwashing and laundry; you are on a Time of Use (or wholesale price) tariff and try to avoid using electricity in peak periods)?</td></tr>
<tr><td colspan="2">Have you experienced any disruptions to your supply of power due to bushfires, flooding, storms or other extreme weather events?</td></tr>
<tr><td colspan="2">How often do these events occur? Have you noticed or do you expect any change in how often these are occurring?</td></tr>
<tr><td colspan="2">Household experiences</td></tr>
<tr><td colspan="2">Did you prepare for [the events described by the respondent] beforehand, if there were any warnings or alerts in advance? When you were preparing, did you think at all about the possibility of a power outage? Did you make any plans or provisions for that possibility?</td></tr>
<tr><td colspan="2">How did the power supply disruption affect you during and after [the events]?</td></tr>
<tr><td colspan="2">How did you deal with the power supply disruption? Did you use your [the DER described by the respondent]?</td></tr>
</table>

Did you adjust your energy use? Which loads / appliances / services did you prioritise? Which were unnecessary?
How long did it take for the power supply to be restored? What did that involve?
Are you doing, or thinking about doing, anything to be better prepared in future?
What do you think it would look like for your household to be more resilient to power outages related to extreme weather events?
Community experiences
Before the [the events described by the respondent], had your community done any preparation together? Had there been any conversations about the possibility of a power outage and how it might impact the community?
How did the power supply disruption affect your community during and after [the events]?
Did the community do anything to deal with the power supply disruption?
Is your community doing, or thinking about doing, anything to be better prepared in future? Have you been talking to your neighbours, friends, local organisations and government?
Who do you think has a role to play in making the community more resilient to power supply disruptions during these events?
What do you think it would look like for your community to be more resilient to power outages related to extreme weather events?
Conclusion
What does resilience mean to you? And [depending on what has been covered in the interview so far] is your family and your home as resilient as you would like? If money and time were no issue, what would you change in order to be more resilient?
Is there anything that we haven't asked you about that you think we should or that you want to talk about?

Case studies

The initial community engagement revealed great diversity in community approaches to increasing future energy resilience. Whilst some bushfire-affected communities have no plans to reduce the impacts of future grid outages, others are exploring options for SAPS at key community sites or microgrids to maintain energy supply to all or part of the town. These plans have been initiated by a range of stakeholders, including local councils, DNSPs and community groups, with different drivers, and are at different stages of development.

To help understand how energy resilience plans emerge and develop, and how and to what extent they address diverse community needs and viewpoints, we engaged with three of these projects, using them as case studies to explore the issues raised by communities and how they are addressed through different approaches to community consultation. This involved interviews with key actors and ethnographic observation of community meetings, both online and in person, and analysis of the contributions of community members and other stakeholders.

Of the three case studies, two were initiated by DNSPs and one by a community group. One of the DNSP projects was postponed early in the process, and the community-driven project has struggled to gain traction. Findings from these are limited but have contributed to shaping the analysis below. The second DNSP-driven project is described below in Bawley Point and Kioloa community microgrid.

Scenario exploration workshops

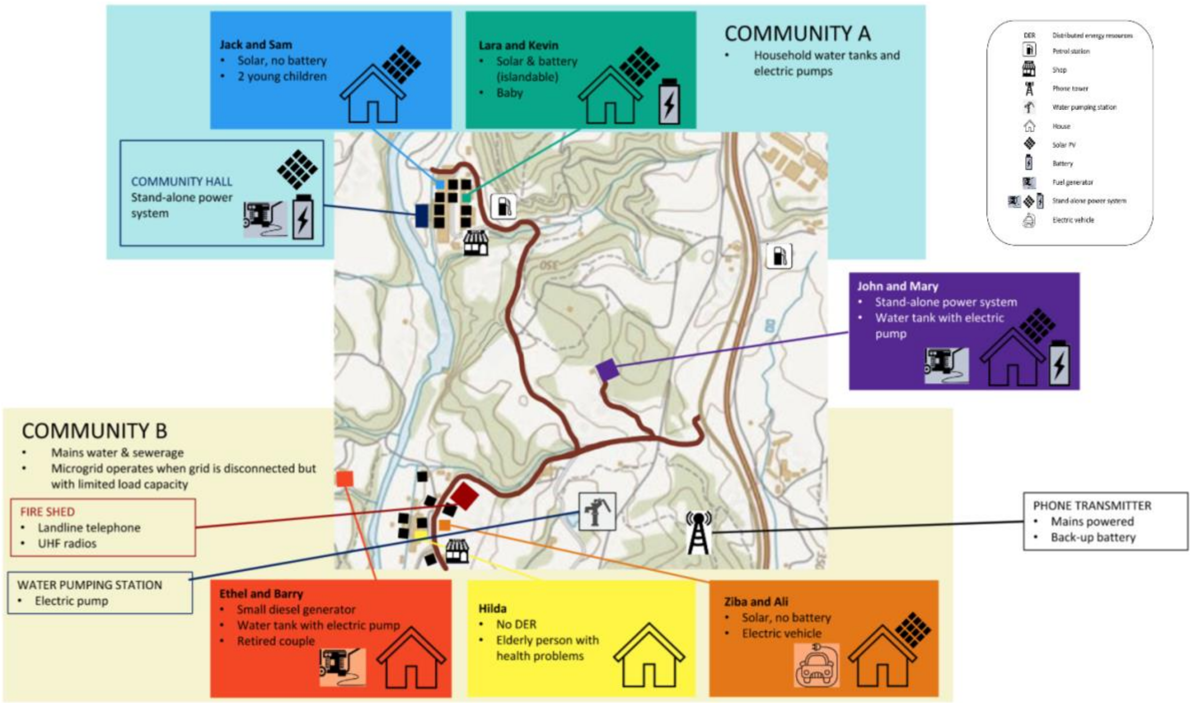
Building on the shared findings from the household and expert interviews, a series of online workshops were held to develop a deeper understanding of the potential roles of distributed energy resources in increasing resilience to grid disruptions due to extreme weather events. The aim of the workshops was to explore, together with the participants, how different DER technologies and approaches to resilience compare in different situations, including at different times in the same unfolding extreme weather event.

By facilitating the participants’ imaginative exploration of different scenarios, the format enabled them to consider and clarify their own views on the advantages, disadvantages and potential trade-offs associated with different DER technologies and modes of use, and the conditions in which they may or may not be effective.

The workshops were held online, bringing together participants from different bushfire-affected LGAs with diverse experiences, to enable them to apply their existing views and preferences about DER to a range of situations and different communities, encouraging them to reflect on e.g. their views about individual versus community solutions.

Participants who had been involved in interviews were invited to participate in the workshops, with the aim of achieving diversity across LGAs, experiences and attitudes across the 5-7 participants in each workshop. The workshops were held online, using the Zoom video conferencing platform and lasted two hours. Participants were compensated for their time with a digital gift voucher. A pilot workshop was carried out – with participants known to the researchers (most with expertise in DER technologies) – to test and refine the method and content, followed by three workshops with household participants.

Figure 6 Miro board for scenario exploration workshops



The workshops used an online collaboration platform, Miro, to present hypothetical scenarios and explore possible individual and community responses. After introductions from researchers and participants, the group was presented with a map showing some fictional residents and communities in a bushfire-affected area (see Figure 6). Included on the map were two communities, one with electricity supplied by the main grid, and the other supplied via a microgrid able to operate in 'island' mode during a major grid disturbance.

The map also identified individual households with different types of occupants, both within and outside the communities, with different types of DER, including generators, grid-connected and off-grid solar and battery systems, electric vehicles (EVs), etc. In the first community, a community hall, with an islandable SAPS was also identified.

The scene was described, and participants were given the opportunity to ask questions. They were then moved through five stages of a hypothetical scenario in which a bushfire impacted the area, causing disruption to the main grid connection and to roads, communications, water supply and fuel supply. The scenario was developed to include a range of impacts described by participants in earlier interviews.

Participants were asked to imagine what the different households and communities could – and should – be doing at each stage to maximise their energy resilience. At each stage, additional prompts and questions were given to encourage participants to explore the scenario from the perspective of different fictional households and communities.

Table 3 The 5 stages of the workshop scenario

No.	Stage	Narrative description	Questions
1	**Preparation**	1a. There are bushfire warnings in this part of the state. 1b. A few days pass and the alert level is raised to "Watch & Act".	What could the people in these communities be doing to prepare for a potential power outage?
2	**Power Outage**	2a. A bushfire is encroaching from the south and affecting the north-south transmission line parallel to the highway. Grid power is lost to communities A and B and the pumping station. 2b. Phone tower battery is now flat. No phone signal.	What does this mean for the people in these communities? What changes could they be making to the way they're using power? What are the impacts of losing phone communications and what are the alternatives?
3	**Road Closed**	Bushfire is now affecting the roads, blocking access between the communities and the highway. Road linking the 2 communities remains accessible.	Are there any differences between the 2 communities?
4	**Prolonged Outage**	Time has passed. The fire risk has receded, roads have reopened, but mains power is still out.	Are there any differences between the 2 communities?
5	**Recovery and Planning**	Power is restored. Communities are starting to recover and make future plans.	What might you prioritise in each community?

A final discussion period encouraged participants to consider the relative benefits and disadvantages of the different DER options (microgrid, community refuge, SAPS, different home solar systems) and their applicability to different situations. Participants were encouraged to discuss their ideas at each stage, and to add 'post-it' notes to the Miro board.

The workshops were recorded and the transcripts, along with the annotated Miro boards, were analysed, supplementing and extending the interview transcripts analysis described above. Insights shared by participants in these workshops are referenced in this report with the workshop number and participant number in parentheses.

Energy data analysis

The ESKIES project set out to enable participants to share data describing their energy use (as well as generation and storage) during grid outages. Although a significant proportion of the participants consented to allow access to their energy data, a number of barriers prevented its collection and sharing in the way we had envisaged. Many grid-connected solar systems, including many with batteries, do not operate during grid outages.

Few of the participants with solar and batteries have energy monitoring in place or, if they do, the monitoring is cloud-based and relies on communications which often fail during grid outages. We had envisaged there would be a specific subset of technology-orientated participants with solar and batteries, who would be interested in sharing and understanding their energy data (perhaps more than sharing their experiences). However, attempts to recruit this cohort, through methods used in previous projects, including online technology forums, have been unsuccessful.

However, participants also expressed very divergent views of the utility of DER during bushfires; while smoke has an obvious effect on solar generation, the extent of this is variable and contested. Researchers, therefore, analysed an existing dataset of solar generation data from bushfire-affected LGAs before, during and after the Black Summer bushfires to better understand the diversity of smoke impacts and the implications for solar and battery system design, in order to help communities understand energy resilience options.

IMPACTS AND RESPONSES

Introduction

The impacts of electricity supply disruptions during extreme weather events can be far-reaching, and a range of strategies may be used to achieve continued access to the services – from cooking to transport – that energy typically facilitates in homes.

This chapter outlines some of the impacts experienced and the responses employed by the participants and discusses several ideas about how energy resilience can be achieved that can be seen in the approaches taken by participants.

Impacts and strategies in accessing energy services

Participants' experiences of the duration and restoration of grid outages during extreme weather events vary significantly, from brief – but potentially frequent – outages of hours, typically associated with high wind or storms, to outages of weeks or months in some cases during the bushfires of Black Summer or flooding across NSW.

Their perceptions of the importance of access to power during an extreme weather event also vary, from highly significant ('*The power being out brings all sorts of problems*' (H30)) to relatively unimportant *('only a marginal issue'* (H24)).

The dependence of other services and infrastructural systems on electricity is considered to have potentially significant consequences, because *'with that failure [of the grid] came a cascade of failures that went from communications [to] water'* (E3).

Among the impacts considered most disruptive or damaging by participants are those on access to telecommunications, water, sewerage, fuel, and refrigeration, but impacts also include loss of access to more discretionary services associated with comfort, such as hot showers and being able to have a cup of tea.

The impact of the loss of electricity supply also includes affective dimensions, particularly during dangerous extreme weather events. An outage can leave people literally and figuratively *'in the dark'* or in *'complete darkness'* (E6), without access to information and access to services such as water and transport that they can use to protect themselves and their homes. It was described as *'scary'* and *'stressful' 'once the power went out because there's just nothing'* (H07). In these ways, the loss of electricity supply is considered to have the potential to compound other challenges.

Outlined below are some of the ways that the loss of electricity supply impacted crucial energy-dependent services during recent weather-related outages, and some of the ways that participants responded to these impacts.

Telecommunications

Grid outages can impact use of mobile phones, landline phones, television, radio, internet and social media, depending on the circumstances in the area, and for many this loss during the bushfires of Black Summer was devastating. Grid outages can impact communications both at the very local or household level – such as loss of power to Wi-Fi routers, radios or phone chargers – and through disruption to community communications infrastructure such as mobile phone transmitters or local telephone exchanges.

Limited access to communications was described as *'very isolating'* (H23) and was one of *'our biggest worries during the fires'* (H38); it made it a *'very confusing time and a very alarming time because there was just no way of trying to find out what was going on'* (E3). It left people without the information essential to be able to respond to the situation: *'people didn't get the evacuation orders and it meant that they couldn't get updates on the progress of the fire'* (E8).

And it left them without support, including the means to coordinate with friends and family to provide or get help where it was needed, to organise fire-fighting response, or to obtain medical help.

In the absence of normal telecommunications services, face-to-face communications, including in-person information sessions held within communities, became crucial: *'The only way you could get in touch with people was either go and see them or wait until they came to see you'* (H46). Participants used alternative or back-up options where other services were not available, including satellite internet; satellite mobile phones; walkie-talkies; battery-operated radios; and landlines:

'There was one man who had a landline, and his landline was still working, so he put his phone out the front of his house and people who needed to urgently make a call could go to his house and make a call from his landline' (H30).

Some communities are now working to acquire UHF / CB radios with external grants for use in future contingencies. Generators or batteries were used to power household telecommunications systems or infrastructure in the community (*'they had a generator there at the tower the whole time'* (H37)), but they last for a limited time, and it may not be possible to refuel or recharge them. One participant recounted *'an instance in July 2020 where we had a bad snowstorm, which disrupted the power, but the mobile phone didn't return for ten days because the telecom operator couldn't get up the hill to replace the petrol in the generator that was keeping the mobile phone alive'* (H18).

The dependence of telecommunications infrastructure on electricity (as well as the need for security from direct damage from extreme weather events) at multiple points makes it highly vulnerable, and for this reason, some participants are pessimistic about the possibility for DER and other back-up options to support telecommunications during grid outages: *'there's no point having power at our end if there's no power at the other end for the NBN [National Broadband Network] services to be up'* (H38). Another participant agreed:

'If there is nothing to connect to get information, I'm not quite sure why I would want to have either a generator or a battery because it's not going to give me anything' (H53).

Water

Water supply to many rural properties depends on an electric pump, either for individual supply on the property or in a communal pumping station. Loss of access to water during electricity supply disruptions can have serious and wide-reaching implications – *'if you haven't got water, you can't do anything much'* (H29) – particularly in the event that water is required for fire-fighting. Stocks of drinking water were kept on hand by some participants.

Electric water pumps powered by home solar and battery systems or generators; fuel water pumps; and gravity feed systems were also described by some participants as options that served them. Some participants have or are considering installing sprinkler systems to be powered by their home solar and battery systems and controlled remotely if needed.

Money

Grid outages can affect access to money by preventing the withdrawal of cash at ATMs and payment by card, and by prompting the closure of banks. People who already had cash were able to buy supplies that others were not able to buy. One participant described going *'to the shops to see what I could get and of course there's long queues of very grim-faced nervous people, so I managed it – I had cash on me so I could buy things. They couldn't because there was no power'* (H23).

Goods and services were provided on credit in some cases: *'money was not a problem because they [the supermarket staff] knew who everybody was, and so they just ran up a tab'* (H24). Some people lent cash to others in their communities: *'Because I had the cash, I became the bank so they took money from my joint to go buy their prescriptions and stuff'* (H37). In some cases, pubs used generators to power their on-site ATMs.

Refrigeration

For some participants, the loss of refrigeration was the most significant impact of electricity supply disruption, particularly where large and valuable stocks of food were spoiled. This was an impact that some had not fully anticipated (*'I hadn't realised, I think, things like food spoilage, how quickly that happens'* (H47)) or prepared for (*'I didn't really have a plan, other than to realise that I was probably going to watch all my food perish'* (E13)).
It can lead to food safety concerns: *'I suspect I might have given us all food poisoning with the meat we ate after our power outage […] it was after that that I read how quickly it can spoil and I kind of went, "Oh, okay <laugh>! Maybe that wasn't a good idea"'* (H47).

Generators, individual or shared, were widely used to keep fridges running – although there were limitations in this strategy, for example, when generators could not be refuelled. Participants kept fridges shut; consolidated all their food into one rather than multiple fridges; or shared fridge between households. Eskies were also used where ice was available.

Food supply

Access to food supplies may be affected during electricity supply disruptions where shops are without power and therefore unable to operate. Where there is some advance warning of an expected disruption to food supplies, those with DER in particular tend to have the possibility to prepare by stocking up on food. Those without DER may be less able to stock up due to concerns about the reliability of the electricity supply for refrigeration:

> *'We have talked about getting one of those big chest freezers and stocking up on meats and stuff. But we've decided not to because of the power […] We could stock that up and lose power, and then that's it. That's a whole whatever wastage of all that food' (H102).*

Cooking

The possibility to prepare cooked meals may be limited by electricity supply disruptions. Participants with DER recounted being able to use electrical appliances to prepare meals:

> *'we could have food, not in the oven, but we did have an electric frying pan I could use, the slow cooker, the microwave, toaster, electric jug. We changed things a bit because of the lack of the oven' (H01).*

Those with gas appliances were generally able to use them for cooking as well as boiling water for safety. Gas barbecues and camping stoves were options also employed by many participants where they were available.

Fuel

Access to fuel can be affected as petrol stations may not be able to pump fuel due to lack of electricity (or resupply due to blocked roads), or as people may be unable to reach petrol stations due to blocked or flooded roads. A lack of fuel can impede mobility, including evacuation out of an area. It can mean that people are not able to use their generators, restricting their access to other services. Many participants described stocking up on fuel in anticipation of an expected electricity supply disruption:

> *'after the fires, fuel was an issue, and people have told me that when they hear of fire in the locality, their first thought is to top up their fuel' (H51).*

People lined up for fuel at petrol stations, which in some areas was rationed, or travelling to more distant petrol stations: *'we had to drive to Wagga to get petrol, which takes half a tank of fuel to get there and back'* (H07). In some cases, fuel was transferred between vehicles or siphoned from vehicles to be used in generators.

Air-conditioning and ventilation

The loss of access to air conditioning and ventilation is considered a potentially serious impact, especially for more vulnerable people and during prolonged periods of smoke cover. One participant described it as *'a scary thing not having that [an air purifier, as well as a fridge]'* (H23). Some people used battery-powered fans as an alternative option: *'We had rechargeable fans, like little camping ones, which were absolutely essential because the smoke was just so bad'* (H09). In one instance, an electric vehicle was used to power a home ventilation system.

Lighting

Lighting is considered important for comfort in the home, as well as for security and attracting attention during extreme weather events such as flooding. Lighting was often considered an essential load when people were powering their homes using a generator, solar and battery system, or EV, but its use was typically minimised to conserve power.

Non-electricity-dependent alternatives that were widely used include battery-operated torches, candles, camp lights, and solar lights. Some participants also recounted adjusting their sleeping patterns during extended outages as a *'simple'* solution (H04) to avoid the need for lighting:

'we just would go to sleep with the sun and we just coped with that' (H40)

Sewerage

Where households depend on an electric pump to be able to flush toilets, some participants stocked up on water in buckets ahead of expected grid outages to be able to manually flush toilets. Some septic tank systems on unsewered properties can overflow without access to power.

Participants described using their generators to power septic pumps and prevent overflow, which was the main concern of one household: *'So, that was the main reason why [we bought a generator], just because that would be a massive headache if that was to happen'* (H102). In another community, a *'little petrol-operated pump'* was shared from house to house and used to pump out each system in turn (H43).

Medical, disability and veterinary services

A wide range of health services are reliant on electricity and were thus significantly impacted by electricity supply disruptions. For example, pharmacies were not able to operate, and participants described how some pharmacies and veterinary clinics also lost supplies of medicines as they required refrigeration. Pacemakers and other equipment necessary for health and disability care, such as recliners, oxygen concentrators and food blenders, are dependent on power.

The impact of loss of communications on access to medical assistance can be especially serious in the event of illness or injury. Participants described how generators was essential to maintain care for a disabled person (*'And the reason I applied for a generator [is] because once you have a generator, it takes all his vital things'* (H69)), an elderly person (*'we have an elderly neighbour who is on a heart monitor, so my partner would actually make sure that they have dragged their generator and it's connected because he has to be monitored'* (H70)), or in veterinary clinics.

Other businesses

Outages impacted, among other business activities, working from home, home businesses, and the operations of shops, pubs, and restaurants: *'The local shop owner lost everything [when food spoiled and they didn't qualify for assistance]'* (H37). Generators were purchased to support businesses in some cases:

'[our neighbour] got so frustrated in the end he bought one of the big, enormous generators. I do not know how much it cost him, but he's losing a lot of money, but in the end, he said – because he runs his business, he runs a big plumbing business and he said, "I can't do without communications, I can't do without electricity, so I've got no choice," so he bought it' (H33).

The staff of a restaurant described using candles for lighting, gas for cooking, and a mobile battery-powered payment system when a grid outage occurred during the evening trade.

Resilient responses

The responses employed by people to deal with a grid outage were described by the participants as a range of workarounds:

> *'All sorts of different fixes had to be reached to accommodate the fact that we had no power' (E3).*

Responses to grid outages include alternative sources of electricity to ensure undisrupted access to a service (e.g. using a generator or solar and battery system to run a refrigerator), alternative ways of accessing the same service (e.g. using an esky for refrigeration), or adapting to not having access to the service (e.g. doing without refrigeration).

This range of possibilities reflects the distinction referred to in the Introduction between resilience of electricity supply and a broader sense of resilience with respect to energy that can encompass using non-electrical sources or making do without it. The participants held different perspectives on the extent to which resilience consists in ensuring access to energy such that life can continue more or less as normal through grid outages (*'So we can continue to live normally, but we're just drawing power from another source instead of the grid basically'* (H27)), or in being able to live without access to energy altogether (*'we were able to deal with living without power fairly simply, with the possible exception of hot water'* (H24)).

As is apparent from the outline of responses above, DER in particular may limit the impacts of a grid outage and enable households to continue life as normal. One participant said of an outage in his area: *'we didn't notice anything. So we were limping along on our 10 or 15-year-old off-grid system but it didn't miss a beat'* (H12).

However, many instances of the latter sense of resilience as 'making do' by accepting new meanings of comfort, convenience and hygiene during electricity supply disruption were also evident in the experiences of participants, as has been observed in international research [14].

The accounts offered by participants point to the value of diversifying the energy technologies available to achieve an outcome. This is what Hasselqvist et al refer to as 'response diversity, i.e. diversity in ways of carrying out normally electricity-dependent practices' [15]. Dependence on one way of doing something, such as making a telephone call, can leave people more vulnerable when that option is not possible: *'And still people are just with one option or another, but most people do not have reliable mobile phone coverage, and when the landline goes down, they're left high and dry'* (H78). Some participants reflected that *'it was a real wakeup call about the fact that we lost [the landline option]' now that 'everybody's gone to mobile'* (H57).

Vulnerability is similarly seen to arise from a lack of redundancy in the energy system, so that households are dependent on particular powerlines: *'Apparently, we've only got one power lead into the community as opposed – in some places, it can come from the east or the west or the north or the south, but we've only got one, and the powerlines got basically burnt'* (H31).

There is a suggestion in the views of some participants that dependence on electricity – such as cashless electronic payment – itself constitutes a vulnerability: *'But this cashless economy that we live in where everyone pays with EFTPOS, tap and go […] When you lose the electricity network and the communications networks, we're back into the Stone Age'* (E6).

Some participants describe how they ensure that multiple alternative options are ready at hand: *'it's very concerning for us that we might lose telecommunications in a fire. We have triple back-ups, we've got the satellite, we've got a Telstra mobile card, and we've got an Optus mobile card'* (H18). Some have specifically invested in additional back-up options following the experience of grid outages during Black Summer: *'we actually installed a landline – we hadn't had a landline, so now, we have a landline'* (H102).

When asked what resilience means to them, some participants referred to this response diversity:

> *'when the bushfires came through, we had different ways of preparing, we have different resources that we can draw on. We weren't just relying on one response to it […] having alternatives to your usual obviously power source. […] So we can continue to live normally, but we're just drawing power from another source instead of the grid basically' (H27).*

Other examples of this diversification include *'hav[ing] a combination of petrol fire-fighting pumps and electric pumps'* (H78) or having access to a gas barbeque as well as an induction stovetop for cooking.

This diversification can also be achieved when households share resources between them, 'contribut[ing] with different energy sources or competences needed for performing practices in alternative ways' [15], as is discussed further in Visions for a Resilient Energy System.

Impacts and strategies can vary considerably according to the duration of the outage and may change over its course. As has been observed in international research, longer-duration outages can place a greater strain on households and communities, but not necessarily linearly [12]. There can be thresholds or 'step changes', such as a freezer defrosting or a phone battery running out, beyond which the inconvenience or break from the norm brought by an electricity supply disruption becomes intolerable [12,16]. One participant described this threshold in the following statement: *'that was fine for 24 hours, even 48 hours occasionally […] but over eight days, just struck us as being a really bad thing'* (H39). For example, communications may become more difficult to be without over time.

Participants describe being able to do without or defer some energy services, such as laundry, for a time, but in an extended outage a way must be found to do them later: *'So when it was ongoing for such a long time, we just needed to run a few more things in the house'* (H29). The duration of an outage determines what is considered an appropriate response, and yet decisions must be made without knowing how long it will last:

> *'we tried to not use too much, we didn't have lots of cups of coffee and we didn't have lots of lights. But in retrospect, that saved little electricity anyway, but the battery was pretty low and not knowing what to expect, so we dragged it out as long as possible' (H01).*

Some of the responses described by participants were planned, prepared and in place ahead of the extreme weather event, while others were developed as needed**. However, being prepared in advance is seen to enable households to cope better with outages.** Participants describe the importance of planning and mental preparation as well as a number of actions that may be taken in advance of an outage, including maintaining supplies of water, food and fuel on hand or stocking up in advance of an expected outage; maintaining generators and pumps ready for use; keeping battery-run equipment charged; charging a home battery ahead of an expected outage where possible.

Resilience was referred to by some participants as the anticipation and preparation that can occur ahead of events: *'It's about planning to be resilient, not just being reactively resilient'* (H76). They describe this as *'the planning ahead, thinking of what might happen and making some preparations […] But I think a lot of it is just knowing what to expect. If you know what to expect, you do not get so much of a surprise and you think ahead of what needs doing, and stock up'* (H01).

Experience from the past is considered valuable in responding to grid outages, including to guide preparations. Being used to not having grid supply is seen to enable people to manage better without it: *'we were quite used to not having grid power […] So, it doesn't impact us much if we lose power'* (H46). This may particularly be the case for people living in areas with unreliable grid supply where black-outs are already a part of everyday life [17,20], or for people who live in off-grid homes who already manage and adapt their practices to limited grid supply [15,21].

As has been observed elsewhere [12], older people were similarly seen to have 'coped better' in some cases, due to the accumulated experience of age (*'having been through it multiple times in their life, [they] know that you do not open the freezer every 10 seconds'* (H38)) as well as less dependence on electricity (*'because they were not tech-dependent'* (H38)).

People accustomed to the reliability typically enjoyed in urban centres are seen to be more vulnerable precisely because they lack experience of managing during outages and have a heightened dependence on electricity:

> *'They'd been almost cocooned in the sense of being within the CBD [Central Business District] and generally a reliance on having that power, and also not typically being affected by some of these events. So the capacity for those businesses and residents to respond and react was quite different to what we see in our outlying areas' (E7).*

Accordingly, many participants see a need to attempt to learn from electricity supply disruptions such as those experienced during Black Summer, in order to be more resilient to them in future. Some participants report that this learning is underway. One expert participant recounted that the experience of Black Summer *'really got me thinking about back-up power in a way that I haven't before'* (E13), while another participant, a member of the RFS, stated that *'most of our stations hadn't been designed to be a community hub or to operate for extended periods without electricity […] I can tell you all the brigades have got generators now'* (E6).

On the other hand, others describe frustration that, for example, vulnerable telecommunications infrastructure was rebuilt in exactly the same way *'because there was no thought of resilience, because they did it because it was cheaper, and we were not able to influence that outcome'* (H24). This may reflect the need to rapidly reestablish supply following a disruption, which can compete with the considerations and planning required to redesign infrastructure for future resilience [18,19]. Other participants shared a concern that *'If this fire that we had here didn't wake them up nothing will'* (H03) and that they *'have a feeling that we'll just end up in the same situation again, and I do not think anything will have changed'* (H08).

Conclusion

In this chapter we have outlined some of the impacts of electricity supply disruption experienced by participants during the Black Summer bushfires or recent flooding events across New South Wales, as well as their responses to these outages – highlighting the role of DER in these circumstances.

The different responses outlined in this chapter may be employed by participants at either or both the individual or more collective levels, and the scales at which energy resilience may be achieved are explored in the Visions for a Resilient Energy System. Meanwhile the technologies used, and some considerations and implications related to their use, are detailed in the following chapter, Technologies and Infrastructure.

TECHNOLOGIES AND INFRASTRUCTURE

Introduction

This chapter describes the technologies available to households, businesses and communities to increase their energy resilience to grid disruptions caused by fires and other extreme weather events. These technologies, being located in households, businesses or communities, are broadly described as 'Distributed Energy Resources' (DER). Most of them involve generation, storage or more efficient use of electricity (so might be better termed 'Distributed Electricity Resources'), but other types of energy source are also included, in as much as they reduce reliance on electricity and, therefore, on the grid.

Electrical technologies include fossil-fuel generators, solar photovoltaics, wind turbines and micro-hydro generators, home and community batteries, EVs, microgrids, modified electrical switchboards, battery-operated and energy efficient appliances. Non-electrical technologies include gas cookers, barbecues, fridges, lamps, space and water heaters, wood fires, oil lamps, candles, fossil-fuelled water pumps, solar hot water and iced eskies.

This section describes some of the characteristics of these technologies, how they are and can be used during grid outages, and the implications for energy resilience. Each has its advantages and limitations; there is no 'one size fits all' solution. Different technologies suit different situations or kinds of resilience, as well as individual preferences:

'[PV / batteries and generators] serve entirely different functions [...] so, whilst I'm a passionate advocate of PV and storage, it's not the 100% answer to 100% of situations' (H35).

The information presented here is drawn from multiple sources. It includes learnings from the experiences of ESKIES participants during the Black Summer bushfires and other events, as expressed through interviews and workshops, supplemented with insights from 'expert' interviews and technical information from academic and industry literature and other sources.

Generators

Fossil-fuelled generators are the most common DER used to provide a back-up electricity supply during power outages. As a mature, widespread and commonly understood technology, they have several characteristics which favour their use. Also known as 'gensets', generators are relatively cheap, mobile and easy to access; they are quick to start, enabling a fast response to unexpected outages; and operate in all weathers. If well maintained, they are highly reliable. ESKIES participants' experiences of generators during outages were generally positive:

'It was like a miracle in the middle of all of this chaos with bushfires' (H09).

Generators have a number of characteristics, including **accessibility, low cost, portability and reliability**, that make them suitable for emergency supply. They are likely to play an ongoing role in providing energy resilience to households, businesses and communities, either as short-term emergency supply, or back-up of solar and battery systems. They can be effective at a range of scales, including to supply individual households or businesses, shared facilities or essential services, or a whole community through a local microgrid.

Many households, particularly in regional and remote areas, keep a generator on hand, either specifically to address potential grid disruptions or for other purposes, including farming tasks, operating electrical tools and equipment on large properties, camping, use in a mobile business or to run electrical water pumps for fire-fighting.

For others, major grid disruptions or imminence of severe weather events prompt purchase of a generator – *'Everyone went and bought generators or got generators from mates or friends'* (H08) – which can lead to supply shortages. For some households, the potential for dual uses drives a purchase: *'So if we go to camping for whatever reason, we need a generator for something. It's handy to have it'* (H46).

There is a need to ensure essential services and facilities such as water pumping, petrol, food refrigeration, fire sheds, community facilities and telecommunications are equipped with the necessary connection and switch gear to facilitate plugging in a generator.

Types of generators

The most common domestic generators are fuelled by petrol or diesel, but gas generators are also available. Each has advantages and disadvantages, as summarised in the table below. Petrol presents a higher fire risk during storage and filling but petrol gensets may be easier to start. Diesel gensets need more regular use and/or maintenance and diesel fuel may degrade if stored for a long time, but they have high reliability for prolonged use.

Liquid petroleum gas (LPG) is more commonly used for larger gensets. They have lower refuelling risks, but gas storage is an explosion risk: *'If you run out of gas, you just change to the next bottle and go get that other bottle filled up, and they run for longer generally, for a gas bottle than most of the diesel generators as well'* (E11).

Manual start generators require physical effort, so may be unsuitable for elderly or vulnerable people. Battery start is easy to operate but requires additional maintenance and regular testing of the battery.

Table 4 Pros and cons of different generator fuels

Petrol	Diesel	LPG Gas
+ Available in smaller sizes, more portable + Run quieter, with fewer fumes + Run better if rarely used	+ More fuel-efficient + More reliable with prolonged constant use	+ No need to refill a fuel tank, so reduced fire risk + Quiet operation + Fuel doesn't degrade
- Run hotter than diesel - More prone to breakdown with prolonged use - Greater fire risk while filling or storing fuel	- Need to be run regularly - Diesel fuel can denature ("go stale") over time	- Lower efficiency - Explosion risk of gas cylinders in a fire
✓ Good for low-load, occasional or intermittent use	✓ Good for high-load, frequent or long duration use	✓ Good for larger applications

Generator connection

Generators are connected and used in a variety of ways during grid disruptions to support different levels of energy resilience.

The simplest technical arrangement is a **portable generator supplying one or more specific household appliances, connected via an extension lead**. Often, this is used to meet loads considered to be 'essential', most commonly food refrigeration, general water pumps for households not connected to mains water supply, phone chargers or Wi-Fi to enable emergency communications, heating or critical medical infrastructure such as a heart monitor.

During prolonged traumatic events, use of a generator to provide 'luxury' services, such as TV can also be valuable:

'We were watching Netflix in the middle of a bushfire in a town with no power, no water and no phone service and it was just so surreal, but it was such a nice thing to be able to do and be able to charge the phones and all of the radios and all of that sort of stuff that's just a hilarious thing to do in the middle of all of this chaos' (H09).

Portable generators can also be used to supply electrical fire pumps, as an alternative to pumps powered directly by petrol or diesel. In this arrangement, a generator may be thought of as completely separate from the household energy supply: 'I've just bought a 2.2 KVA petrol generator, but that's going to be for powering power tools in the bush, but thinking about that, then if I had to pump some more energy to run the hot water or the stable or whatever, I do not know if I could do that, so there would be that, but I do not think about it as part of our power system' (H23).

Generators can also be connected directly to the switchboard of a house or business, to supply the whole property or a single circuit. This requires an electrician to install a connection to the switchboard with a change-over switch, which can be a challenge in areas with skills shortages or when fires or other events make imminent supply disruptions likely: 'We did a lot of manual changeovers with 15 Amp appliance inlets for a lot of people straight after the bushfires and there were power outages from floods and the like. We started by going around to the country fire stations' (E11).

If sized and installed appropriately, a generator can provide a fully comprehensive back-up supply, meeting all household loads:

'a tree came down on my property and took out my main feed and my private pole, but it took four days without power, but we have a petrol generator here, so we just switched over the generator, and it was like nothing happened, like I even use a coffee machine' (WS2-H38).

More commonly, however, use of high-power loads such as air-conditioning (H43), or simultaneous use of multiple appliances, may be restricted when connected to a generator (see Understanding and managing demand).

Generators can also be connected to complement other DER. This can include augmenting a solar-battery system to provide greater energy resilience. Depending on the system design, this might involve use of the generator on a regular basis to maintain supply overnight, or on days of low sunshine, or as occasional back-up for grid disruptions or prolonged periods of low solar generation: *'So our batteries never dip down past 70%. […] In the eight years, we've probably used the generators maybe twice to actually top up the batteries but normally we do not have to do that'*

(H08). To further increase energy security, multiple generators can be used: *'Pete's got three generators next door. He's got a backup for the backup'* (H04).

'Portable' petrol and diesel generators, sized from 1kVA to 8kVA, are commonly wheel-mounted and easily moved by one person, but generators up to 500kVA or larger can be quickly and easily transported by road and craned into position. Connection (by an electrician) of these larger gensets to the switchboards of community facilities, to supply emergency power to community refuges, fire sheds, community halls, petrol stations, food stores, or surgeries, increased community resilience and enabled many businesses to reopen quickly after the Black Summer fires.

Generator operation

Short periods of energy supply are sufficient to maintain some energy services at an acceptable level. For these applications, a generator can be run for a few hours per day, conserving fuel and minimising noise. Examples include providing light in the evening, keeping a fridge cool (provided it is not opened frequently) or charging batteries, phones or other appliances:

> *'[We had a] little routine of powering up once a day, everybody would charge their phones, watch their TV, get their news updates. I put the dishwasher on. We do the washing, just got organised to do – cook the food, all of this, just do it all at once. Put the fridges – we put them on really high to keep things cold for the day' (H51).*

Other applications may require a generator to run continuously. Examples include freezers or fridges under high temperature conditions, water-pumping for fire-fighting or sprinkler systems, or air-conditioning for vulnerable individuals or large groups of people in a community refuge.

Some people see a generator as suitable for occasional, short black-outs but not for prolonged disruptions – *'I'm a generator guy when I need it but that's only because our mains is pretty good here'* (H03) – while others see it as the *only* reliable option – *'if it's critically important for medical equipment or if you really, really have to have it'* (H35) – particularly for emergency needs such as firefighting.

Generator requirements and limitations

Importantly, generators need to be kept in an operational state, which may involve regular servicing and/or running, depending on the specific technology, and a fuel supply maintained:

> *'I think people forget that generators aren't maintenance free. They do fail, they do need to be topped up, you can't just run a generator for a week, you're going to run out of diesel, so they can be more convenient, but they also create their own set of challenges. They have a lot of moving parts, they do not like heat either, so I'd probably contend that there are a few downsides to a generator that sometimes people do not think about as a long-term solution. I do not think you want a whole lot of fuel sitting around your house when there are fires' (E10).*

Generators need maintenance and regular use. Maintenance needs depend on whether the generator is used regularly or kept for stand-by applications, but includes checking for leaks, cleaning and replacing filters and seals, and maintaining coolant. Regular operation circulates lubricant, preventing seizing or corrosion. If the generator has a battery-start, the battery must also be maintained and kept at a suitable state of charge and maintained:

> *'[If] you're going to deploy things like diesel generators and things like that you need to make sure that you have a very rigid maintenance and run program on them. I once inherited a site that had a fantastic diesel generator, automatic switch kit, everything. The first time we run the diesel test, it wouldn't start because the battery was flat, so we sorted a flat battery, and then the diesel just would not start because it had never been run since the day it was commissioned and we ended up throwing out a shipping-container-size diesel generator and replacing it' (WS2-H38).*

Some generator owners are aware of this need, but the practice may be haphazard:

> *'We should get it out once a month and run it, but it gets run every now and again if we're doing work outside of extension lead range, so we know it works. [Fortunately,] it works every time' (H38).*

Generators need a fuel supply. Some ESKIES participants reported running out of fuel with no notice, while others failed to stock up or left it very late. As well as petrol, diesel or gas, a stock of oil is also needed. Keeping a large fuel stock poses safety risks, requires significant space, is subject to regulatory restrictions and can result in waste of degraded fuel (particularly diesel).

Accessing supplies during grid disturbances, fires or extreme weather events can present challenges, including lack of supply, transport constraints, and shortage of labour to fetch and refuel. These risks need to be balanced when deciding on an appropriate quantity to store, depending on the expected frequency and duration of outages – which may increase over time – and the degree of reliance on the generator.

Appropriate sizing is important. Whatever the technical configuration or use case, it is important to size and operate a generator to meet the required loads. For inductive loads, such as motors, pumps, fridges and freezers, this includes transient or surge currents caused by motors or compressors starting. Understanding and managing loads (see Understanding and managing demand) can avoid purchase of inappropriate resources: *'Then we had to go and buy a bigger [generator] because the one we had was a bit small'* (H29).

The noise of generators is seen by many as a disadvantage or a constraint on potential locations. Noise considerations may also restrict operating hours, particularly in higher density neighbourhoods – although one participant saw this as a way of bringing community together, because *'the generator was very loud, but as a consequence, everyone in the street knew that we had a generator'*, which resulted in it becoming a shared resource (H57).

Being fossil-fuelled, generators create greenhouse gas (GHG) emissions. The level of these emissions depends on the fuel type, the size of the generator and, importantly, whether it is used regularly or for emergencies only, and whether operation is continuous or for short periods. For some ESKIES participants, concerns about emissions inform whether and how they use generators or drives other 'offsetting' activities: *'I consider [my generator use] as carbon footprint to be fully offset'* (H23).

Generators can be affected by intense and prolonged heat or prolonged use. Care should be taken when specifying a generator to make sure it is suitable for the load to be met, the likely ambient temperatures and the intended mode of operation. Generators should be located away from direct heat and with sufficient ventilation to allow cooling.

Generator risks and limitations

There are fire and explosion risks associated with storage of fuel (especially petrol) and potential for fuel spillage and release of fuel vapour while refuelling. This poses a particular danger during bushfires: '*You've got fuel generators outside and you're moving fuel around and there's embers falling all around you'* (H70). Petrol and diesel generators should not be fuelled while running. Gas generators are directly connected to a gas cylinder, often with a changeover valve to allow swapping of bottles without interrupting operation.

Exhaust emissions from generators include carbon monoxide and are highly toxic. Generators should never be located indoors, close to windows doorways or air vents, or where prevailing winds will blow exhaust towards inhabited areas.

Overloading a generator or associated cables can create a fire risk. If an extension lead is used with a generator to supply specific loads, care must be taken not to overload the extension. Correct cable sizing depends on the power of the appliances (including the surge power) and consequent current in the cable as well as the length of cable run.

The carbon emissions created by burning fossil fuels mean generators are not ideal for long term continuous operation. In the longer term, potential Australian development of second and third generation carbon-neutral biofuels [22,23] may enable continued use of generators in a decarbonised energy system.

Rooftop solar and home batteries

Perceptions of solar

The study found very diverse perceptions of the value of solar for energy resilience.

Some negative perceptions of solar are due to first- or second-hand bad experiences with solar sellers or installers, or of inappropriately specified or sub-standard equipment. Not all solar systems, or even batteries, provide back-up supply during grid disruptions. Installing inappropriate equipment, through misunderstanding or mis-selling of different types of systems, may not meet specific household back-up requirements and, in some cases, will not improve energy resilience at all. Examples include solar inverters that shut down during an outage ('anti-islanding'), batteries that cannot be charged from PV, or batteries that only supply certain circuits or a single phase of a 3-phase-connected house. Other participants had concerns about reduced solar generation during bushfires or about costs, particularly of batteries. Although these concerns have some validity (see Impact of bushfire smoke on solar generation), they do not exclude solar and batteries from contributing to energy resilience.

However, **many participants described positive experiences of solar and battery systems in general and, more specifically, of their use during bushfires and other outages** where the systems had been appropriately designed to provide energy resilience. In particular, some gave third-hand reports of solar-battery systems providing energy for water-pumping that saved properties; similar stories appeared in the media after the Black Summer bushfires [24].

Some positive perceptions of solar's ability to reduce vulnerability to grid disruptions may be based on limited understanding of the different types of system (see sections on different types of systems below). One participant described '*the importance for getting a big solar system, I feel, because we're very vulnerable to fire up here'* (H23), without recognising the limitations of solar-only systems (see Grid-connected systems).

However, others have a clearer understanding of the need for a battery to provide energy resilience: 's*o, as I said, you wouldn't be able to actually use the solar […] unless there was some way to be self-sufficient and that you could afford to get the solar batteries with the solar power and have some sort of gas backup or something, I do not know. But if you* *had batteries, obviously that would be your backup. That would be the only way you could really get away with it, I think'* (H91).

For some of our participants, experiences of grid disruptions due to fires or other extreme weather events drive decisions to install or upgrade systems, including adding a battery to existing solar systems. However, other people are waiting for costs to decrease or battery technologies to improve before investing: *'That's right, we'll wait'* (H08).

Grid-connected systems

'I'd say is that it's one of the big misunderstandings of most consumers that you get a battery, and you have power when the grid goes down […] not all systems do it' (E10).

98% of Australia's 3.1 million residential solar systems [25] are grid-connected and are installed without a battery. **Almost all of these have *anti-islanding* inverters, which are configured to shut down when there is a grid disruption, for stability and safety reasons (to avoid solar exporting to the grid while grid repairs are being carried out).** While they have other benefits, including reduced energy costs, these *non-islandable* solar systems do not generate during grid outages and so do not provide any energy resilience. This is perhaps not widely enough understood: *'people do not understand […] that for on-grid, if the grid power goes down, you have no solar'* (H70).

There is now **a small number of solar inverters in the Australian market which can island and continue generating in the event of a grid disruption**. These *islandabl*e solar systems provide a degree of energy resilience, enabling use of appliances only during hours of sunlight, but they are not yet in widespread use.

Battery installations are increasing, with a third of Australia's household batteries installed in 2022 [26]. Battery costs are such that the bill reductions enabled by increased self-consumption of solar generation are not sufficient to pay back the unsubsidised investment cost within the lifetime of the battery. Installations are therefore being driven by state subsidies [26], perceived benefits of virtual power plant (VPP) participation, or by the need for back-up power.

However, not all solar and battery systems provide back-up power, and those that do may have limitations. Some systems are connected such that anti-islanding prevents use of the battery when disconnected from the grid. Other batteries may provide back-up during power outages (either to selected circuits or to all the circuits connected to a single phase) but the solar inverter shuts down so that the battery cannot be recharged during the outage; these systems only provide short-term back-up supply, often for a few hours, depending on which loads are connected and in use.

For longer term back-up, a fully islandable solar and battery system is needed. In this configuration, the solar continues generating to charge the battery and supply selected loads, all circuits on a single phase, or the whole house for longer periods. Unless the solar generation is significantly impacted by prolonged bad weather or smoke (see Impact of bushfire smoke on solar generation), these systems can provide resilience for outages lasting days or weeks. The addition of a fossil-fuel generator for occasional use can provide a fully resilient supply.

These resilient, grid-connected systems were confused, by some of our participants, with off-grid (permanently islanded) systems.

Table 5 Types of solar and battery system

Type of System	Operation in grid outage	Resilience	Other benefits/options
Solar Only (non-islandable)	Solar shuts down due to anti-islanding	No resilience benefits	Reduce bills, payback in 3-5 years, reduce emissions
Solar only (islandable)	Solar and special inverter deliver electricity to the house or essential circuits during the day only (uncommon)	Resilience during the day when the solar panels are generating	Reduce bills, payback in around 5 years, reduce emissions.
Solar + Battery (no back-up)	Solar & battery shut down due to anti-islanding	No resilience benefits	Reduce bills, increase solar self-consumption, help the grid, may participate in a VPP[1]
Solar (non-islandable) + Battery with limited back-up	Battery supplies individual circuits or single socket but does not recharge from solar	Resilience against short outages	Reduce bills, increase solar self-consumption, help the grid, may participate in a VPP[2]
Solar + Battery (fully islandable system) with back-up	Solar and battery supply house or individual circuits	Resilience against longer outages (but not extended periods of low generation)	Reduce bills, increase solar self-consumption, help the grid, may participate in a VPP[2]. Add a generator for reliable supply in long periods of cloud or smoke
Solar + Battery (off grid)	No change! Solar and battery supply house (likely uneconomic except in remote locations)	Resilience for long periods	No electricity bills but high upfront cost. Often include a generator for maximum security

[1] Participating in a VPP enables a 3rd party to use your battery to benefit the electricity system, in return for payment or reduced costs. There may be a trade-off between VPP income and the available back-up capacity of your battery.

Off-grid systems

Off-grid systems typically include solar and battery, with a petrol or diesel generator for back-up, and may include other renewable generators, such as wind or micro-hydro. With no grid connection, these systems are unaffected by network disruptions, and are usually designed to provide a high level of resilience.

Some people who invest in solar and batteries for resilience and independence reasons see moving off-grid as the ultimate aim: *'[I would move] completely off grid if I could because that would be the ideal for me. I think, a) you're not paying for the charge to just have it connected to your house and b) I just think everybody should be aiming to be as off grid as they can'* (H57).

'Traditional' small off-grid systems connected to minimal electric loads (sometimes low voltage 12 or 24V dc appliances) are relatively low cost but require lifestyle accommodations and management of demand to meet constrained supply and are often used in conjunction with other energy sources such as gas or wood fires.

An off-grid system designed to supply a high-consumption household with modern electrical appliances, allowing for multiple days of low solar generation, is expensive: *'So, if you want an off-grid system to supply a residential house and keep your air conditioners, your pools, your beer fridges and everything running, you're looking at over $50,000' (E11)*.

The inclusion of a generator is significant in ensuring supply during prolonged periods of low generation due to bushfire smoke or bad weather, but systems may be designed to minimise generator use during 'normal' times: *'With this last 12 months, there's been a lot of grey days or wet. And so, they have had to run the generator from time to time, but generally, they are self-sufficient' (H78)*.

Although an **off-grid supply** (or a stand-alone power system, or SAPS) is relatively expensive where a grid connection is easily available, it may be **increasingly cost-effective in remote fringe-of-grid locations**, where building new grid connections or maintaining existing ones can be expensive. Moreover, while off-grid systems are often thought of as being owned and installed by the households or businesses to meet their own energy needs, some DNSPs are installing SAPS, combining solar, battery and a generator, as an alternative to repairing, replacing or maintaining distribution lines to remote customers. In this arrangement, the customer still purchases electricity at a regulated tariff through a retailer and the DNSP is responsible for installation, operation and maintenance of the SAPS.

Limitations of solar and batteries

As described above, **the ability of a solar and battery system to provide back-up electricity supply during a grid disruption is dependent on the system design and configuration**. While household solar typically pays for itself through reduced bills within a few years, batteries are relatively expensive and, in general, the greater the level of resilience provided, the greater the cost.

Solar and batteries can be affected by extreme heat. The output of solar panels is reduced (but not eliminated) and both solar and battery inverters can shut down or reduce their output at high temperatures to avoid damage. Lead-acid and newer lithium iron phosphate batteries are less sensitive to high temperatures than lithium-ion batteries. In general, inverters should be located away from direct sunlight or extreme heat, and passive or active cooling may be needed if exposure to extreme temperatures is likely.

Participant experiences of batteries providing back-up power were mostly positive but, like any technology, solar, batteries, inverters and control systems can fail. Solar panels typically last 20 years or more, but with gradual degradation of output; solar and battery inverters typically need replacement or significant repair within 10-15 years and battery capacities decrease over time. However, good quality systems have substantial warranties: product warranties for panels are typically 10-15 years; for inverters and batteries 10 years.

Solar generation is reduced by bad weather, smoke, ash and dirt. A larger array can help offset reduced output: *'I think the headline message is that, on a cloudy day, solar performs between 30% and 50% of its capacity. When there's heavy bushfire smoke around, it's potentially as low as ten percent, so there is some generation, but it's majorly impacted. So, you need to think about that when you're sizing your system'* (E10). (See Impact of bushfire smoke on solar generation below.)

Costs and benefits

The cost of resilient, islandable solar and battery systems can result in variable levels of resilience across a community:

> *'The wealthy graziers have all got lots of solar and half of them got batteries and so on, and the rest do not have anything, so it's very patchy' (H24).*

For many users, the cost of an islandable solar-battery system is not repaid through bill savings over the system lifetime and may be more expensive than a generator for emergency backup. However, **multiple benefits should be considered**, including bill savings in normal operation, hedging against future electricity price increases, resilience to minor outages, resilience to long-term outages without need for large fuel stocks, as well as environmental benefits. But 'normal use' and emergency benefits are not always compatible, e.g. solar-battery systems designed to cycle daily do not always have a high state of charge to provide backup when an outage occurs without warning.

Solar and battery systems need to be designed to suit the resilience requirements of users, including duration of back-up supply, loads to be backed up, etc. Not all solar dealers and installers have this expertise, or inclination. Given the complexity, there is a need for clear and impartial information on the types of system available and their suitability for a local context.

Vehicle batteries

The large storage capacity of battery electric vehicle (BEV or EV) batteries, relative to typical home batteries, make them attractive as a potential back-up energy supply, while their mobility provides an opportunity to transport energy into areas of grid outage or to remote properties. However, there are (real and perceived) barriers.

Some ESKIES participants described the benefits of powering their homes from their EV battery, using vehicle-to-home (V2H) technology: *'So we can switch the switchboard from mains power to off grid power, plug the car into the inlet in the garage, and we have lights and power running off the car. So, it's really budget off-gridding'* (E13). However, V2H and vehicle-to-grid (V2G) two-way charger-inverters are currently expensive in Australia, with only one model widely available.

The most commonly-described application of V2H technology for resilience involves **operating the EV battery like a large home battery**, charging it from solar – or from the grid prior to a disruption – and then running household appliances from it when grid electricity and solar are unavailable. Less common is the **use of an EV to transport energy** from a grid-connected location to a disconnected household:

> *'The expectation is that having left fully charged, you'll arrive with at least half a battery, which if that's been available for vehicle-to-premises, absolutely that can then be used to top off the house batteries and run the house, in the event of really prolonged bad weather or a snowstorm or just provide extra backup' (H12).*

Vehicle-to-load (V2L) technology is more widely available than V2H or V2G. This involves small inverters that either plug into a 12V socket in the EV, or are built into the vehicle, with an integral 240V socket: *'They went and bought an inverter and were running loads in their house off the inverter just by plugging stuff straight into the car, basically'* (E13). These outlets typically have a maximum power rating in the range 1.5kW to 3.6kW, and a fixed or user-defined depth of discharge (DOD) limit to maintain a minimum charge level in the battery for vehicle operation.

Experience of prolonged outages during the Black Summer fires gave some people an understanding of the potential benefits of EVs for resilience: *'This one event actually has completely flipped my attitude to backup power, and now in a way that I was dismissive of EV people previously talking about the extra value of having a battery in your garage. I'll actually get it now'* (E13).

Conversely, because they need an electricity supply for charging, some people see EVs as less resilient than internal combustion engine (ICE) vehicles:

> *'They need to get out because [they] have got electric cars. So if they can't charge their car, they are absolutely stuck. They're relying on solar to charge their car – they've got no battery so they're relying on daytime powerage. So, if it was evacuation had to be at night-time and it had been smoky and they weren't fully charged, well they might struggle to actually get away from where they were living because the car wouldn't be charged' (WS3 – H91).*

ICE vehicle batteries can also provide a backup power supply via a plug-in inverter that can be used to supply a 12V mini-fridge or charge a phone, but they have much smaller capacity, typically less than 1kWh.

However, the relative benefits of ICE and EV vehicles are dependent on specific circumstances. For example, ICE vehicles require petrol delivered via electric pumps which may not be available during a grid outage (see Fuel), while an EV can be charged from an islanded solar-battery system.

As with solar and batteries, understanding aligned benefits may be important to increasing the opportunities for using EVs to increase resilience. Buying an EV solely to provide back-up energy supply is unlikely to be cost-effective or affordable; however, if an EV is purchased to provide cost-effective, low emissions transport, adding V2H functionality to use it for emergency back-up could be very effective.

As more EVs – and associated charging inverter technologies – enter the Australian market and prices drop, their role in providing energy resilience is likely to be in conjunction with other DER, rather than as a single technology. However, there is a need for policy and education focused on the potential role of EVs in increasing resilience to help drive investment in V2H.

Understanding and managing demand

Managing how electricity is used (known as demand management or load management) is a key component of energy resilience. Back-up electricity supplies of all types are commonly constrained in both power (kW) and energy (kWh). Prioritisation of loads is likely to be a consideration in the design and installation of systems, and in their operation.

Priorities will depend on individual household circumstances and may vary over time. The most commonly prioritised loads include fridges and freezers, water pumps (for fire-fighting and/or general household use) and communications (phone chargers, internet routers, computers). Other potentially important loads include lighting, cooking, hot water, sewerage pumping, air-conditioning, air filtration, or medical/care needs. For example, air-conditioning can be considered a critical load in a household with elderly or vulnerable occupants but a 'nice to have' in another property. These energy service needs are described in more detail in Impacts and Responses.

Priorities depend on the particular situation being faced and may vary over time. For example, in the presence or imminent risk of fire, water-pumping for fire-fighting is pre-eminent (WSP-E17), while food storage and cooking become more important for longer-duration outages. Similarly, loss of energy services like water heating may be acceptable to some for short periods but are difficult to manage for longer outages; 'essential' energy needs may therefore increase over time.

Back-up electricity supply, whether from a generator hard-wired to the switchboard or from a battery charged from rooftop solar, may be installed to supply the whole house load, selected circuits or circuits connected to a single phase (for 2- or 3-phase grid connections). Ensuring essential loads are available during a grid outage may require circuits to be reconfigured at the switchboard when the back-up system is installed.

The power rating of an inverter or generator constrains the total power rating of the appliances that can operate at the same time. For example*, 'many back-up supplies have a maximum power rating of 5kW'* (E11). Consideration should be given to both the continuous and instantaneous power of appliances connected to a back-up supply.
For example, inductive loads – such as water pumps, fridges, air-conditioning or any appliance that includes a motor or transformer – draw an increased 'surge' current for a short period when they are switched on or off, or during their duty cycle. **When connecting to a back-up power supply (whether solar, battery, EV or generator) there is a need to select circuits appropriate to the power and energy capacities of the supply:**

> *'We've got one power circuit on this arrangement. That includes the circuits that my fridge and freezer are on. And the car can easily deal with running those […] the light circuit, and then power points for doing things like maybe running a radio or a TV, or that sort of thing […] I think even if that particular event I described that lasted six days at our house, we could've been quite happy for six days with just those limited services, I think' (E13).*

However, **demand also needs to be managed *during* an outage to ensure that power capacity of the supply is not exceeded**: '*you make sure that you turn on the water when the fridge is not cycling'* (H13) and that energy stored is used judiciously.

Trial and error may be needed to understand the system constraints:

> *'We tried to not use too much, we didn't have lots of cups of coffee and we didn't have lots of lights. But in retrospect, that saved little electricity anyway, but the battery was pretty low and not knowing what to expect, so we dragged it out as long as possible. But now I know that as long as the sun is up, you generate enough power to run the house without too much trouble at all in the summer when you do not a heater at night and you do not need a booster hot water system.' (H01).*

Impact of fire and extreme weather on DER

Siting and installation of solar, batteries and cabling should take account of risks from fire, flood and extreme weather. **Solar inverters and batteries are affected by heat** (to an extent depending on the specific technology):

> *'One of the […] biggest concerns, is that someone puts a solar battery system into work in that exact environment where it's absolutely critical and as soon as it hits 60 degrees operating temperature, the inverter just shuts down and you do not have exactly what you wanted, so it's a big problem because the time you need it the most, it won't actually be there for you' (E10).*

Energy technologies should be appropriate to the environmental conditions they will be subject to. Some battery types are particularly sensitive to heat and susceptible to *thermal runaway*, while others are more robust. As well as siting inverters and batteries out of direct sunlight and the likely path of a bushfire, air-conditioning or other protection measures can be incorporated into installations to ensure continued operation in extreme heat:

> *'We actually developed like a fire-proof mesh screen that went around it. So the material that was made out of it can withstand ember attack but the perforations in the mesh were enough to allow airflow through to regulate the temperature of the system' (E10).*

For many participants, **experience of the Black Summer fires highlighted the vulnerability of distribution network cables**. In some locations, wooden power poles burnt during the fires were replaced by fire-resistant composite poles, while in others identical wooden poles were used, despite community requests for undergrounding. Several participants described the benefits of running power cables underground, whether locally to a property or as part of the distribution network. However, others suggested that undergrounding could increase vulnerability to flooding or may be unfeasible for long distances or told cautionary anecdotes of underground communications cables that had melted or were 'protected' by plastic covers which failed during the fires. Apart from its high cost, a possible disadvantage of undergrounding is the prolonged repair times required if cabling is damaged.

Impact of bushfire smoke on solar generation

Predicting – or even assessing – the impacts of bushfire smoke on solar generation is challenging as the environmental conditions (temperature, wind speed and direction) and circumstances (location relative to fire, altitude, terrain, etc.) are highly variable. Other researchers have examined the relationship between solar generation and concentrations of airborne particulates, including during Australia's Black Summer [27]. Hourly reductions in solar generation of between 20% and 65% were recorded in metropolitan Sydney and up to 95% in Mayfield, while in Katoomba, close to some of the fires, average reductions of 20% were recorded during high particulate conditions.

Some ESKIES participants had perceptions that solar generation during bushfires was negligible:

'…the smoke haze which will last a lot longer than the fire lasts, they will all get very, very little out of their photovoltaics and even those with battery' (WS2-H39); 'And when there's a large bushfire hanging around for days and days, and days, and days, there's that much smoke in the air, after a while, the solar panels won't work anymore and the batteries go flat' (H06).

One solar installer told us that:

'The headline message is that, on a cloudy day, solar performs between 30% and 50% of its capacity. When there's heavy bushfire smoke around, it's potentially as low as 10%, so there is some generation, but it's majorly impacted. So, you need to think about that when you're sizing your system' (E10).

However, others described the impacts as being short-lived:

'when the fires were close and the smoke was really thick, it was very little power, but I didn't really think about it until the next day but the next day even though it was still moderately smoky, the sun came up and the power came on from the PV panels' (H01).

We analysed solar generation data (sourced from Solar Analytics[2] solar monitoring company) from 64 households across six bushfire-affected postcode areas[3] from July 2019 to June 2020, to assess for variability due to smoke, by comparing days of low generation[4] during the 2019-2020 summer with the winter months.

Figure 7 shows the (surprising) result that the daily minimum generation as a proportion of the monthly maximum was lower in winter than in summer for most sites, so cloud cover in winter reduced daily generation more than bushfire smoke in summer.

Figure 8 shows the same data as a % of *annual* maximum, showing that in most (but not all) cases, minimum winter generation is significantly lower than minimum summer generation.

[2] https://www.solaranalytics.com.au/

[3] The sites were from Bateman's Bay (2536), Broulee (2537), Bermagui (2546), Kangaroo Valley (2577), Jervis Bay / Bombaderry (2540) and Colo Heights (2756). An initial set of 277 sites was filtered to exclude those with more than 60 days of missing data.

[4] Days of zero generation or less than 1% of daily average generation were excluded from the analysis. These occurred more in winter than summer and are likely to be caused by system or monitoring faults rather than reduced solar exposure.

Figure 7 Minimum daily generation (as a % of monthly maximum): summer vs winter

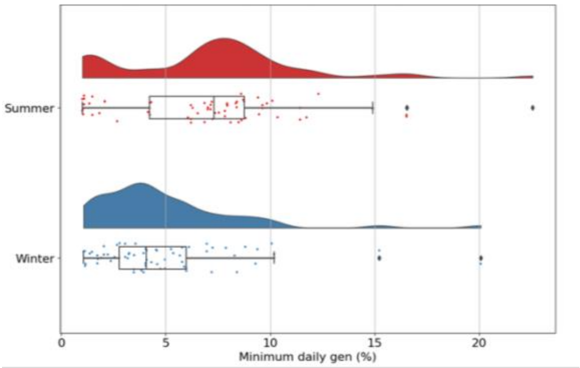


Figure 8 Minimum daily generation (as % of annual maximum): summer vs winter

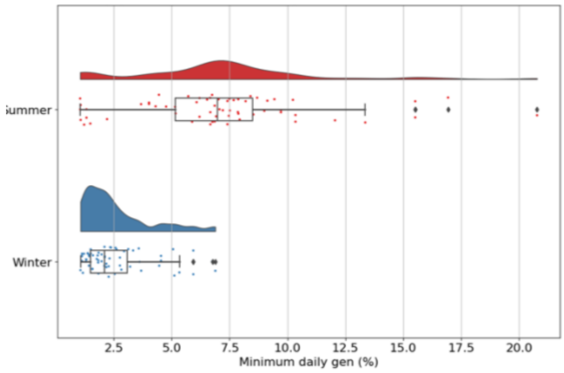


Figure 9, showing the same data, suggests that around a quarter of the sites had summer days with lower generation for the season than in the worst winter day, while

Figure 10 shows that the lowest absolute generation was lowest in summer for only 6 (around 10%) of the sites.

Figure 9 Minimum daily generation (as % of monthly maximum): summer vs winter

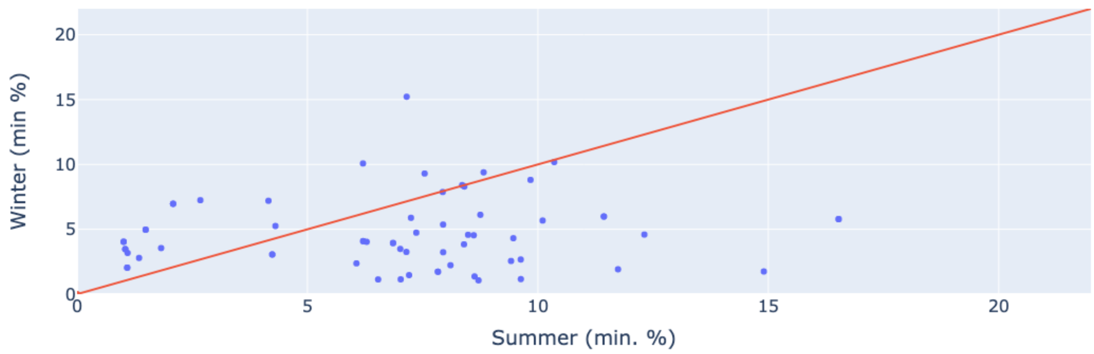
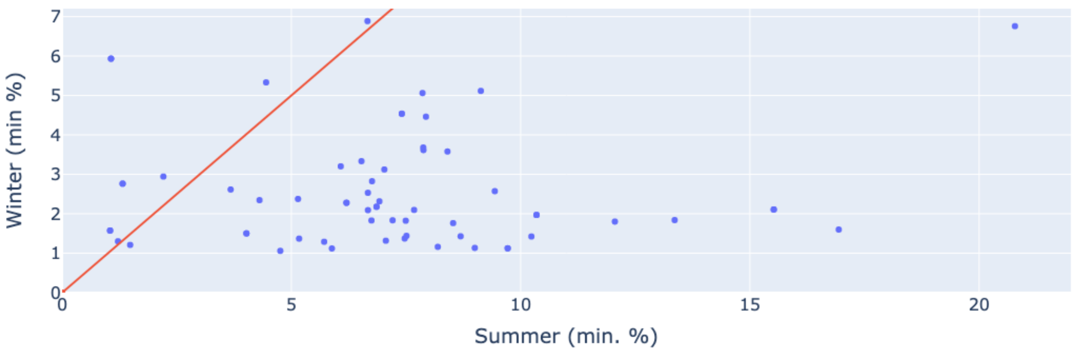


Figure 10 Minimum daily generation (as % of annual maximum): summer vs winter



The information above suggests that, while daily generation is sometimes significantly reduced during bushfires, a solar system with adequate generation on the cloudiest winter's day is likely to generate as much or more during the most intense bushfire smoke.

Many sites experienced multiple days of low generation during the bushfires. Figure 11 shows that the average number of days with less than X% of maximum monthly generation was similar in winter and summer for all levels of significantly reduced generation, but there was more variability across sites in winter.

Figure 12 shows the same data as % of annual maximum generation and shows that winter seasonal effects resulted in more days of reduced generation than the summer bushfires.

Figure 11 Total days with generation less than [x]% of monthly maximum in summer and winter

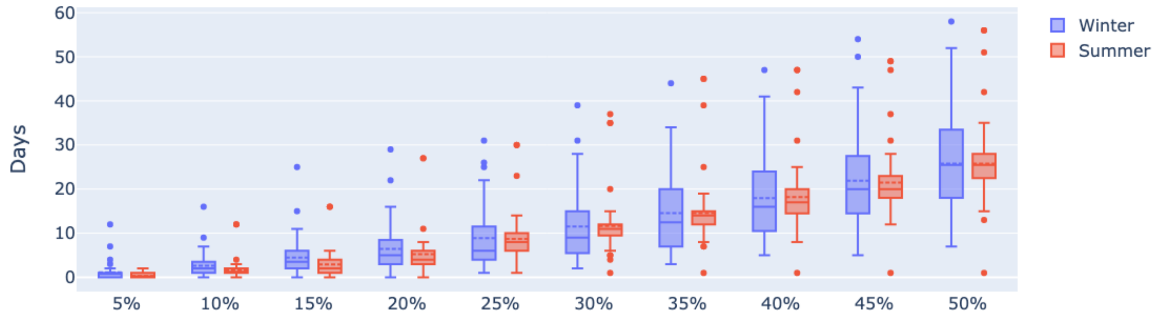
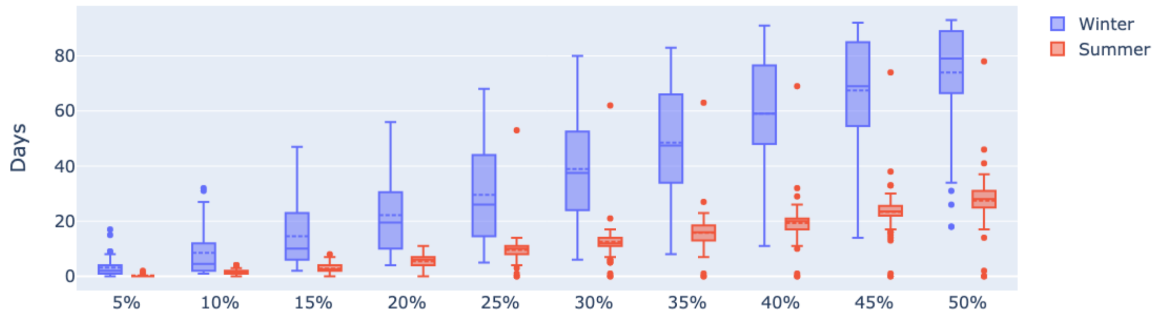


Figure 12 Total days with generation less than [x]% of annual maximum in summer and winter



Importantly for solar-battery systems, Figure 13 shows that the number of *consecutive* days of significantly reduced generation was also much higher in winter than in the Black Summer.

Figure 13 Maximum consecutive days with generation less than [x]% of annual maximum in summer and winter

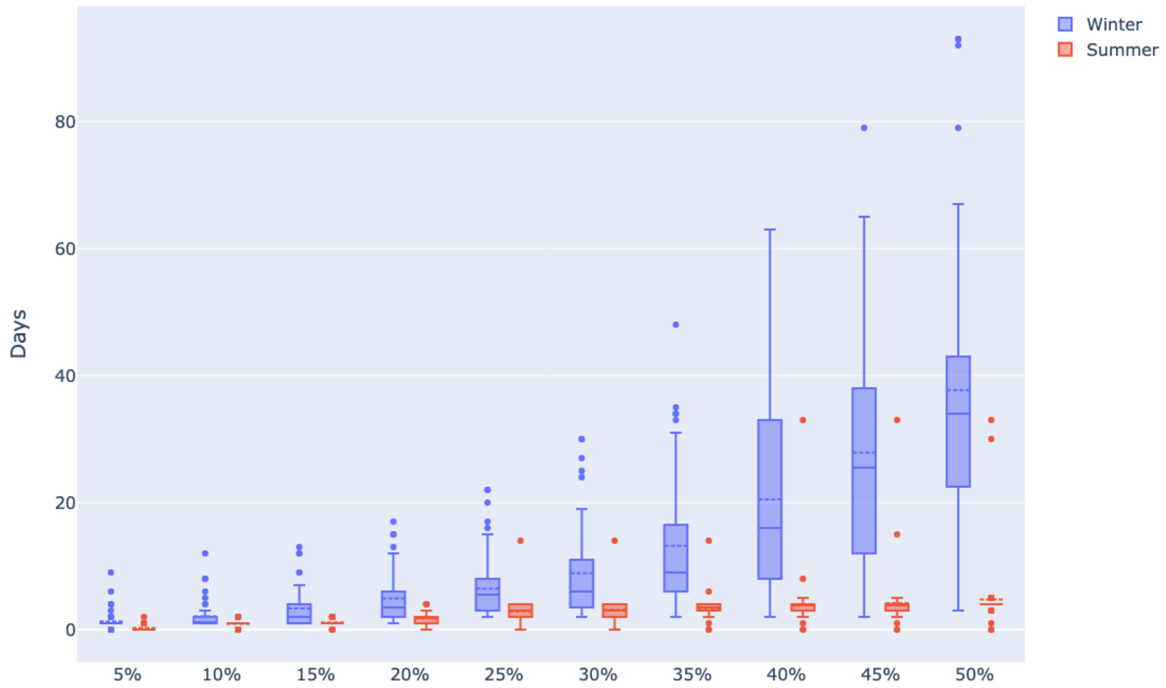
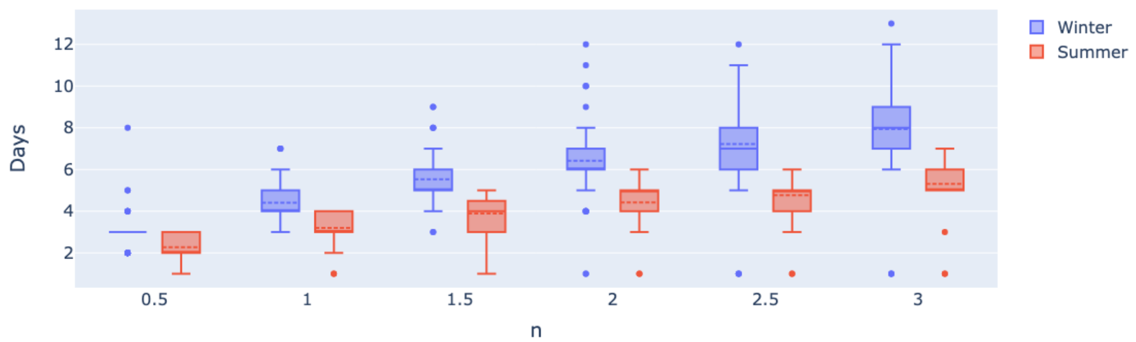


Figure 14 shows the impact of these consecutive days of cloud or smoke cover on cumulative generation. It suggests, for example, that although the worst affected site took up to 4 days to generate 1 day of average generation during the bushfires, this was less than the average time for all the sites during winter.

*Figure 14 Maximum consecutive days needed to generate n * annual average generation in summer and winter*



While this analysis shows that smoke from the Black Summer bushfires had a major impact on solar generation in the vicinity of the fires and that smoke impacts can be severe and unpredictable, the daily and cumulative impacts evident in this limited dataset were comparable to, and in many cases less severe than, the impacts of weather, shorter days and lower solar altitude in winter.

The analysis supports the anecdotal advice of one solar installer that, in many cases, *designing a solar-battery system for winter* can help address concerns about reduced generation during bushfires.

Other distributed energy resources

Although solar and fossil-fuelled generators are by far the most common forms of distributed generation, other generation sources can be used at both the individual and community level. In particular, wind resource is commonly complementary to solar, but turbines need to be elevated and away from buildings to benefit from more consistent airflow and less turbulence. The feasibility of micro-hydro generation is highly location-specific but it can provide consistent generation where there is a suitable resource, contributing to on- or off-grid systems for individual properties or community supply.

There are other types of distributed energy resource that provide energy resilience beyond those that ensure a resilient supply of electricity during grid disruptions. These include electrical appliances that do not require a 'mains' electricity supply, and those that use other forms of energy.

For powering small loads, smaller batteries can provide significant periods of resilience: '*Being a bit more prepared with battery-powered devices would be good'* (H47). Examples include power packs for charging phones; uninterruptible power supplies (UPS) for laptop or internet routers; and battery-powered torches, radios and fans. These devices variously use disposable batteries or can be recharged by plugging in to a mains supply or have an integral micro-solar array or dynamo mechanism.

For many participants, experience of grid disturbances increased their appreciation of the value of diverse energy sources. Although the fossil gas network in NSW has limited extent, bottled propane (LPG) gas is common. Gas is commonly used for cooking during extended outages, either where mains or bottled gas is the usual means of cooking or where a gas barbecue or pizza oven provides a back-up service when electric cooking is unavailable. Similarly, gas hot water has some resilience to grid outages, although some systems require electricity to run a pump or provide ignition. Alternatively, a gas cooker can be used to heat water if electric hot water is unavailable during an outage.

For some households, the resilience provided by energy diversity is the reason for retaining gas: '*We like having the gas because, when the power is out, I can still make a cup of tea on the stove, and I still have hot water because we have a gas hot water system at the moment'* (H38). There is a tension between a desire to electrify for environmental reasons and the resilience benefits of retaining gas appliances: *'So – I mean it's been good to have the gas to still cook on when that's happened, but we were planning, once we got solar, to switch to induction and get a new hot water system'* (H47).

Other households have reduced their reliance on electricity by retaining or installing fireplaces or wood-burning stoves to provide space- and water- heating. Some participants articulated the benefit of diversity in dealing with emergency situations: *'We have a combination of petrol fire-fighting pumps and electric pumps'* (H78).

Like barbecues, **some back-up appliances are purchased for other purposes**. Camping equipment used during grid outages include candles and oil lamps for lighting or iced eskies for refrigeration, gas camping stoves, camping lanterns, gas fridges and gas showers. For some, caravans and camper vans with solar, battery and/or bottled gas supplied appliances are be used to provide specific energy services, or serve as an alternate, self-contained home during an outage: *'And this was half of the justification to myself way back when, when I got the truck, was that it's not just for weekends and fun, it's for a practical purpose when we need it'* (H21).

Community infrastructure

Some of the technologies described above – particularly solar, batteries and generators – can be scaled beyond the individual household or business to provide resilience at a community level.

Resilient community buildings

Collective use of a single building is a common feature of community responses to extreme weather events and to grid outages. With a resilient energy supply, buildings such as community halls or pubs can provide a space for people to gather and share information and resources. These 'resilient energy centres' are not the same as official emergency relief centres or 'places of refuge' [28]. However, they can increase community resilience by providing multiple energy services to the community during grid outages, including:

- ✓ Communications, including internet, phone and radio connection and phone charging
- ✓ Air-conditioning and/or filtration
- ✓ Refrigeration for storage food and medicine
- ✓ Cooking facilities
- ✓ Water supply for drinking, washing, laundry

The need for these resources can vary with time after an extreme weather event (*'The community hall is really only there to give people an emergency refuge for a day or two or three when the fire comes through. After that they go home'* (WS3-H01), but some participants described the *ongoing* need for a central community facility to meet social needs and support recovery, as well as to address a prolonged grid outage.

Properties with a resilient energy supply – including individual houses – may become community resources by default, with sharing of energy leading to sharing of other resources. **An off-grid or islandable house can therefore play a role in providing wider community resilience**:

> *'…it was very useful during the fires that we did have power [because they were able to open up their home to others and share air-conditioning / showering / refrigeration etc.]' (H30).*

The Black Summer bushfires highlighted that the facility to plug in a generator is the absolute minimum energy requirement for an essential community resource. As well as shared spaces, this includes fire sheds or SES centres, relief centres, petrol stations, supermarkets, doctors or veterinary surgeries:

> *'Most of our [fire] stations hadn't been designed to be a community hub or to operate for extended periods without electricity. We'd just become like everybody else, complacent and reliant on the power network. I can tell you all the brigades have got generators now' (E6).*

Adding an islandable solar and battery system, as well as a generator, to these buildings increases costs but provides additional benefits.

Microgrids

Opportunities for developing microgrids to increase energy resilience are being explored by communities and DNSPs across NSW. Understandings of what is meant by, or included in, a microgrid vary but, in general, they involve increasing the resilience of parts of the electricity network that are vulnerable to outages by enabling it to operate independently when disconnected from the main grid. Typically, this is achieved through use of DER, including solar and batteries at the household scale and larger batteries and generation (typically diesel generators and solar) at the community scale.

The ideal design of a microgrid depends on local geography, distribution and demographics of households and businesses, topology of the existing distribution network, historic and potential causes of network disruption, economic factors and, crucially, the desired resilience outcomes. Obtaining consensus, particularly regarding the last point, can be challenging. Perspectives on the desired outcomes, as well as on the route to get there, vary according to which party is driving the development of a microgrid.

One approach is to start by increasing resilience of individual properties, installing solar and batteries particularly on community buildings as 'energy nodes' to provide a basis for future development of a microgrid: *'We've got 25 other sites that we're installing these solar generation and storage infrastructure'* (H4). This incremental approach may not result in an 'optimal' microgrid design but may develop initial energy resilience and facilitate community engagement: '*The next step for us is really trying to figure out how to bring all of these different systems into play for microgrid, how do you actually capture the power that they generate and how do you distribute it around'* (H4).

Another approach is to add community-scale generation and energy storage to the existing grid until it is able to support a small microgrid, perhaps focused on the town centre or high street to maintain essential services to the community:

> *'The idea of the microgrid was to put in a grid with a solar array and a community battery so we could actually keep the essential services going […] What we've got in mind now is a solar farm, I think three megawatts, the community battery, and then that will service the sort of main street, and possibly the pub, the RFS, the [community] hall and possibly the showground so that we can run for three days in the event of an outage' (E3).*

VISIONS FOR A RESILIENT ENERGY SYSTEM

A 5B and Resilient Energy Collective project in Cobargo NSW deployed in 2020. Image courtesy of 5B, an Australian solar pioneer developing prefabricated, pre-wired ground mount technology.

Introduction

Participants in this study see a role for a diversity of DER options to improve energy resilience – ranging in scale from individual household solutions (e.g. generators, rooftop solar and batteries) to the sharing of household DER and community-scale solutions (e.g. microgrids).

In this section, we discuss the ways in which these DER options are expected to confer resilience, which reflect broader perspectives on the extent to which resilience is best achieved at the individual or the collective level. These options also raise questions about how energy resilience initiatives – and, indeed, the energy system – should be organised and governed.

Household DER

The household DER options that are seen to hold the greatest potential for energy resilience are generators and rooftop solar and battery systems.

As discussed in the previous chapter, generators are widely considered an affordable, flexible, and reliable form of short-term backup power, particularly in remote farming communities that are prone to frequent power outages.

Rooftop solar and battery systems are generally considered a more comprehensive and seamless option than the 'back-up' offered by a generator. Some participants without these systems desired them; one commented that *'To be more energy resilient […] the obvious answer is more solar panels and an energy storage system'* (H54). These are used beyond outages to maximise self-consumption in daily life, which aligns with the interests of many participants in not only maintaining reliable access to power but also in reducing energy costs and using renewable energy.

Some people who have these systems retain a network connection that enables them to draw power from the grid as they wish but with the potential to disconnect from the network and operate in 'islanded' mode. Retaining a network connection is seen by many as valuable *'just for the option'* of drawing power from the grid (H76); *'I've made sure that the solar that we got could work with a battery off-grid if we had to, as opposed to getting purely off-grid'* (H11).

Others employ off-grid systems, including solar and battery systems as well as a back-up generator, to permanently disconnect from the network, and this is seen by some as preferable in areas where the network is particularly unreliable:

> *'We also factored that into the consideration of deciding not to invest in getting a grid connection because what's the point of connecting to a grid that's highly unreliable in adverse weather, and given the nature of the place, it's like alpine climate, and it's cold and stormy in winter all the time' (H12).*

Preferences for household-scale DER are widely expressed with reference to a desire for energy independence and self-sufficiency. This is one of the ways in which resilience is understood by the participants: *'I would be resilient if I was self-sufficient from the grid'* (H19).

Energy independence is typically valued as a way to avoid dependence on the grid – *'we very much preferred the ability to fend for ourselves and not be dependent on the grid'* (E1) – including, for some, to be *'independent of the fossil fuel industry'* (H17). This may be driven by perceptions or experiences that others cannot be relied on to prevent or respond to power supply disruptions during extreme weather events: '*I need to do more myself and look after myself […] if I rely on others, I'm going to be in trouble*' (H04).

The desire for energy independence is often associated with ideas about individual autonomy (expressed as a desire to be *'master around your destiny'* (H43) and not be *'at the whim'* of network operators (H10)) and responsibility ('*I wouldn't expect anyone else to sort my house out for me, except for me*' (H48)). Freedom of choice with respect to access and use of energy in the home is key to this outlook:

> *'it's silly that I have to be connected to the grid. I can only use the power lines out the front of my house which are owned by a single company, who then accepts no responsibility for delivering power. If there's an outage, well, it's just too bad. […] That's how the current system is, and I do not agree with it. […] Ultimately, I should have a choice and I should be responsible for my own energy independence' (H38).*

Islandable and particularly off-grid DER, along with the perspective that energy resilience consists in individual self-sufficiency, feature in one vision of what a future more decentralised energy system might look like. This is a system in which *'almost every house will have solar panels on it and almost every house will have batteries as well. And houses will become almost autonomous […] there will be a reduced need for the grid'* (H17). Some people perceive that this approach to energy provision would be 'easier' than that of the current network-based system: *'I just can't see why we spend millions and millions of dollars on infrastructure, when it would probably be so much easier for everybody to have a house with solar panels and batteries to be self-sufficient'* (H43).

However, this vision of a decentralised energy system neglects inequity in access to DER, as solar and battery systems remain practically or financially unviable for many households, as well as the potential inequity in the distribution of the costs of maintaining the electricity grid, if those costs are to be borne by ever-fewer households as others move off the grid. Some participants expressed the view that *'the grid needs everyone to maintain it'* (H52) and a sense of responsibility in *'contributing, not just being islands'* (H15):

> *'I would stay on-grid. And I think part of that is a philosophical reason too […] at the moment, not everybody could afford solar and battery. So, the less people that were on the network, there's less people to carry the cost to get the network to them. […] Unless there was a way that we all agreed everybody's getting off, we're not* going to *have poles and wires anymore, and we did some kind of other system, but I think if we're keeping with this system, then I think we all have to be part of it in some way to keep it going to those that need it in the network' (H76).*

In other words, some people are opposed to the atomisation implied in the vision of decentralisation described above.

While energy independence may be beyond reach for many households, from the point of view of the DNSPs it may be more cost-effective in some locations to provide and maintain SAPS for households rather than to provide a comparably reliable supply via the network – and, indeed, some DNSPs are now installing SAPS for the use of households in these locations. This is considered to address equity issues where some, particularly more remote, parts of the network require more resources to maintain than others. As is noted by one participant from a DNSP, *'for the average person, it's not achievable to go completely off-grid. […] For us, we're [dealing with] such a heavy cross subsidy* *in supplying the poles and wires that it would make sense for many of them [these households to move off the network]'* (E5).

Some households have been found to be unwilling to accept this option for various reasons, including concerns about its impact on the value of their properties, especially where establishing a network connection was a considerable investment made by their families in the past. Distrust of energy companies and suspicion about the interests of DNSPs in offering this option may also feed into their reluctance or hesitation: *'They said, "Why would a utility ever go and put this much money into an off-grid solution for me and you're telling me it doesn't cost us anything? […] Isn't this a scam? It seems too good to be true"'* (E2). Households' willingness to engage with these initiatives has been explored in research conducted by Essential Energy [29] Current regulations require that such households continue to purchase their electricity via a retailer, paying retail and network charges, which *'makes it really confusing'* (E5) and may further impede uptake by households.

While this model of access to SAPS is seen to *'ha[ve] a lot of merit'* (H78) by some participants, the ongoing role of DNSPs and electricity retailers means that it is far removed from a vision of decentralisation in which households need no longer engage with energy companies.

Community DER

The experiences and views of many participants show how energy resilience may be realised at a collective, rather than individual household, level. Participants commented that *'within a community or at least street by street, we are more resilient […] knowing that there is some other local help if needed'* (H13) and that *'the community does tend to offer up support to other people who might be in a situation where they do not have power'* (E8). DER may be used to support communities during power outages in various ways, ranging from informal sharing of resources to microgrids that aggregate DER to enable household access to energy, or initiatives to ensure access to energy at community facilities using resources such as SAPS.

Energy resources are shared within communities through sharing access to power sources such as generators, household or vehicle batteries, and gas-powered, battery-powered or non-electrical equipment [9,15]. More portable forms of DER, including generators and EVs, may enable this sharing more than fixed forms of DER, including home solar and battery systems, that require grid infrastructure to make sharing between sites possible.

For example, generators may be moved from household to household, or set up with extension cables to support multiple households at a time:

> *'Generally, they're sharing with people around them who do not have generators or maybe they put two or three together and bunch up all the stuff they need to keep powered, or they power their own stuff for a few hours and then run over to old Mrs Johnson and power hers up for a few hours and then run back with it […] There's a lot of looking after one another' (H37)*

Access to specific energy services may also be shared as households or businesses with DER offer access to phone-charging, the internet, refrigeration, cooked food, showers, air-conditioning and so on. Participants with DER recounted that, for example, *'we could see this was a solution for our friends and people around who'd needed power, needed to be able to have a shower, and that sort of thing, they could come and do it'* (H30) and *'the generator was very loud, but as a consequence, everyone in the street knew that we had a generator […] so we had this ongoing parade of people coming in charging their phones for over the two days that we had no electricity here'* (H57).

Sharing household DER can support community resilience by enhancing both the quantity and diversity of DER options that a community can draw on for essential energy services. One participant recounted how, *'in our town when the flood happened, there was one house in our street that had access to a generator, there was another house that had a gas stove, there was another house that had a solar hot water, so we all shared those resources in our little street'* (WS2-H51). This diversity may be particularly valuable where there are limitations in access to any of these options in an extreme weather event, as discussed in Impacts and Responses.

A sense of community in responding to power outages and other challenges in these ways is highly valued by many of the participants: *'we're very, very lucky that we've got a tight community that looks after each other'* (H42).

However, we observed that communities defined by place may contain divisions between people that affect how the idea of 'community' is understood by the residents of that place [30]. These divisions may exist between 'old' and 'new' residents; permanent residents and holiday homeowners; those living within a township and those living in surrounding areas; and other dimensions of social identity and association. One participant referred to his community as *'stratified'* (H24); another described *'city people moving in […] a lot […] just do not want to have anything to do with the country people, which is sad. And they miss out because they miss out on the community obviously'* (H10).

Divisions of these and other kinds can determine which residents are considered members of the community and might receive help when it is needed. One participant insisted that it is necessary to *'pick who you want to support, select'* according to a distinction between those who deserve help and those who do not: *'there are some people saying, "Yeah, why were the fire brigade at your place and didn't come to my place?" It's because I was bloody prepared, mate, that's why […] they're risking their lives. Why would I risk my life and go to someone's place where they've done bugger at all?'* (H04). These accounts complicate the view of communities of place as inherently cohesive groups of people who naturally support one another through challenges such as power supply disruptions.

Beyond the informal sharing of resources are initiatives to ensure that a whole community has access to power in the event of a wider grid outage. These are seen as decentralised solutions that strike a balance between a scenario in which all households disconnect from the grid – which is not considered realistic, as discussed above – and the status quo of dependence on the conventional grid – which is perceived to be too vulnerable in extreme weather events due to its size. In the words of one participant:

> *'Obviously everyone can't go off the grid and we need to also support our communities in our towns in a way that we can have an efficient way of delivering energy. But […] we need to go to micro rather than macro with our energy supplies even for our towns because of natural disasters, because […] you get cut off and the power supply is disrupted for everybody rather than if that small community could run its own power supply' (H08).*

A participant from a DNSP similarly commented that *'big is not better because the bigger you make some of these electrical systems, the more susceptible they will be to the natural disaster. So, it's a really hard balancing act'* (E2).

These solutions include microgrids that enable a local portion of the distribution network to operate disconnected from the rest of the network. These are currently being trialled in NSW (and other states) and are of interest to some participants, who ask, for example, *'why can't we have something local that would keep the power grid up?'* (H11).

Microgrids typically feature a community-scale battery and often depend at least partly on energy generated by local rooftop solar systems, which appeals to those who state that *'it seems like there should be some way that the solar that* *people do have that should be going back into the grid can somehow keep things working'* (H47) and *'I would like us to see the community supplies their own energy'* (H40).

The spatial and temporal scales at which energy is generated, stored and used in a microgrid were considered to make sense by some participants:

> *'to be able to share and contribute, then you've got the battery being maintained and larger capacity allowing you to even out ebbs and flows of your power, and ins and outs, that's what I think should happen […] whereas single [battery systems], you've suddenly got something happening and you've got a problem, you're in trouble, whereas groups of people can even out' (H42).*

The management of a microgrid may pose challenges, however, particularly with respect to the distribution of access to energy among households within the community. There was recognition of the need to foster a strong understanding within the community of the intended purpose of the microgrid – whether as emergency back-up only, or to support the community's everyday energy use – and agreement on how its limited capacity would be effectively managed – in particular, which loads would be permitted, particularly while the microgrid is isolated from the main grid.

The need for coordination through a formal agreement or protocol was a theme across the views shared by participants, which one characterised as a 'social contract': '*I presume there would be some sort of social contract already in place amongst all the participants. Maybe we would have to send out a notification to remind people of their obligations under that contract'* (WS2-H38). Establishing this agreement would involve navigating questions of how access to energy is allocated among households within the community, where some households, such as those with unwell, elderly or very young residents, may have particular needs: '*plans are required to support more vulnerable people, including those who depend on reliable energy supply for medical reasons' (H76).*

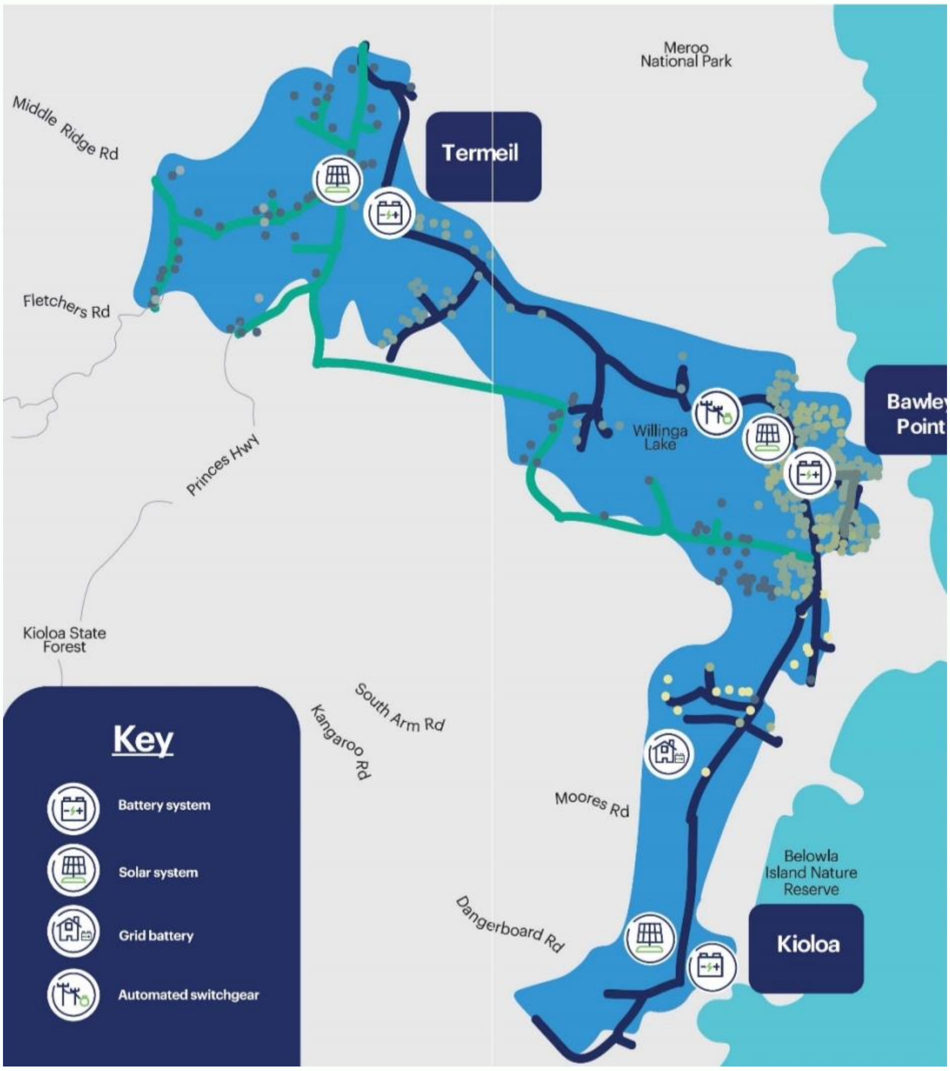
Such a 'social contract' would also need to address questions of how contributions to the microgrid through household DER installation are divided among households, particularly where they may have differing capacities to participate: *'The problem with that is I guess people come and go and it's how do you manage that […] she can't afford it, he's got plenty of money'* (H43). Some participants believe that such questions could be addressed equitably through means-testing, for example:

> *'there'd be certain people in the community that would be struggling with their power bills at the moment. So if we did have some sort of a collaborative approach to energy, then obviously those people, they do not have to pay for it, but the people that have jobs and that can pay for it, well then they should be paying for more energy use' (H08).*

Others maintain that differences within the community preclude a community approach to energy resilience: *'when you've got a mixed community, there's no way of doing a whole of community thing at the moment'* (H51).

Bawley Point and Kioloa community microgrid

Figure 15 Bawley Point and Kioloa microgrid (Endeavour Energy)



The microgrid at Bawley Point and Kioloa is being established to address network constraints in an area that is seeing growing electricity demand, particularly during holiday periods; poor reliability, due in part to its location at the edge of the network; and vulnerability to extreme weather events such as the bushfires of Black Summer which completely isolated the community for a number of days.

The project includes the installation of a community battery alongside an existing generator, as well as subsidies to support households to install home batteries. When in operation, it will draw on both network-owned assets and behind-the-meter solar and battery systems.

Endeavour Energy, the DNSP developing the microgrid, considers the approach of leveraging the DER already in the community, and supporting the installation of more DER, as a way of *'optimising what was already there, as well as potentially maybe helping customers transition [to DER] faster'* (Interview with Endeavour Energy). The subsidised installation of home batteries that will participate in the microgrid was presented to the community as preferable to seeking reliability by going off-grid: it is the *'best of both worlds as you remain connected to the grid'* [31].

The microgrid project has featured a substantial community engagement process that has included four public meetings in the local community hall, each attracting approximately 60 people, and a community reference group (CRG) of approximately 15 community members that met online five times. This process is described as having taken Endeavour Energy *'out of our traditional engagement roles'* and been essential to achieving the best possible outcomes for the community:

> *'Traditionally, for the last almost 100 years, we have been serving up solutions to customers without actually asking them whether they wanted it or not. […] It is possible to engage a community and really get far better outcomes than we would've got had we just fronted up and said, "Here is it. This is what we're doing," and so that, to me, has been the greatest benefit' (Interview with Endeavour Energy).*

This shift in role by an electricity network generated some scepticism similar to that encountered by DNSP-led SAPS programs, as discussed above. One resident commented that '*everyone I've spoken to wants to know what's in it for Endeavour… why are they doing this?*' (CRG meeting 3, 11 July 2022).

Nevertheless, for the most part, the Bawley Point and Kioloa community has been highly engaged and supportive, which may be influenced by a sense that *it is a community.* One resident described how, *'It happened for the first time in the bushfires – we felt like a community who could help each other. It feels good to think that we could help each other when the grid is down'* (CRG meeting 3, 11 July 2022). Many members of the community, particularly those in the community reference group, see themselves as working '*in partnership with Endeavour*' (CRG meeting 3, 11 July 2022).

Figure 16 Community meeting - Photo Endeavour Energy

The community engagement process has confronted the question of how the costs and benefits of participating DER installation are distributed across the community. The criteria for the size and allocation of subsidies for installing new batteries, given a finite budget, was discussed in community meetings.

Residents commented that *'the criteria for battery allocation are important. Issues may emerge if there are more people who fit the criteria than batteries. It's not a good feeling for a small community if people get left out'*, but there was also candid acknowledgement that *'fundamentally you cannot please all of us'* [32].

The community has ultimately agreed on a model which combines fully subsidised batteries for three community facilities, 60% subsidised solar systems for pensioners and NDIS recipients, and 55% subsidised batteries for interested households satisfying a set of eligibility criteria that ensured the DER would be beneficial to the network and the whole community.

The engagement process to establish the Bawley Point microgrid is considered by Endeavour Energy to have been successful, and this is supported by feedback from the community, but this model of engagement would not necessarily succeed in other communities. Of the diversity of perspectives that can exist within one community, one Endeavour Energy staff member commented *'we had some differing views at the start but, generally, the community has converged on a lot of the same decisions. I don't think that will always work in many cases'* (Interview with Endeavour Energy).

Another means to ensure that communities have access to power during grid outages is through the use of DER at community facilities. Places where people can take shelter and seek out services dependent on power, such as community halls or emergency services stations, were described by participants as valuable: *'key places that people went to meet to get information, and those places would have their own solar power, their own battery, so they'd have water'* (H30); *'the benefits and wellbeing of having this community hub, maybe it's got power, it's got Wi-Fi, there's heaps of people you're seeing there […] So I'd say the centralised aspect of a community hall with a standalone power system is very important'* (WSP-E17).

Such facilities may not be accessible to all members of a community, however. This may be the case where roads may be blocked due to floodwater or threat of fire: *'we live three kilometres away from the village, so there's other aspects as well'* (H70).

The alternative options of providing access to power at community facilities, or of maintaining power supply to individual homes through a microgrid based on individual DER, offer different advantages. Some participants consider that resources are more efficiently and effectively directed to establishing and maintaining power supply to community sites rather than individual households: *'if that meant that some homes were without but there's somewhere for those people to go, that makes sense as well'* (H27). Another commented:

> *'given the fact that most outages are less than a week even in extreme events, having a centralised system in the middle of a town, that people can come to a place of last resort, I think it solves a lot of the core issues' (E10).*

It was suggested that, even with a microgrid supporting individual homes, it would be more efficient to access energy services collectively, for example:

> *'You would write into your microgrid contract that in effect [if] we do get a microgrid for a prolonged period of time, i.e. the bushfire, is that everyone will go and congregate at Frank's house*

> *because Frank's got air conditioning, and that's where we're going to sit. Instead of running nine air conditioners, we'll just run the one and everyone will just be there' (WS2-H38).*

Others question whether these community facilities could meet all the community's energy needs and point to a need for individual DER: *'might be council sets up some of our existing facilities into places that we can go. But that doesn't help us with things like the food storage, etc. So, I guess we've all got to have some batteries that back up services'* (H27).

The suitability of different options may vary according to the duration and extent of the grid outage. One participant commented that community SAPS may be most effective in the short-term while a microgrid may better support a community in the longer term:

> *'The community hall is an emergency response and the microgrid is something that you would expect to recover afterwards. […] The community hall is really only there to give people an emergency refuge for a day or two or three when the fire comes through. After that they go home and they need the community grid' (WS3-H01).*

A microgrid is expected to have the potential to support people over a wider area, including those not immediately evacuating: *'a lot of places, further south, didn't get much of a fire threat but lost power for the same time, even though the fire was nowhere near them. So they want a microgrid so they can survive'* (WS3-H20).

These solutions, particularly microgrids, tend to depend on support from electricity distribution networks and other actors and, to the extent that they do, decisions to invest in these resource-intensive solutions in specific communities face considerations of equity of investment and costs across the network. This is in a context in which available resources may not extend to establishing microgrids in all the communities that would like them, and these solutions are made possible by cross-subsidisation across the network. A representative of a DNSP conducting a microgrid trial in a community on the edge of the network shared that the business is reflecting on *'how do we do this for more customers and how do we fairly attribute our time, effort and energy across all of [the] network rather than just, say, a couple of communities'* (E12).

The energy resilience priorities of DNSPs and communities may or may not align, depending on specific circumstances. In some locations, a community microgrid or a SAPS on a remote property may provide households with a more reliable electricity supply and increase resilience to extreme weather events *as well as* reduce costs to the network operator. Alternatively, a localised microgrid designed to provide a reliable supply to the centre of a dispersed community might address the network operator's objectives regarding 'grid resilience' in the area without benefiting people living in outlying areas. Resilience of the network is not necessarily the same as resilience of the community, in other words, and clarity about the objectives of an initiative may help to ensure that it can meet them.

The promise of decentralisation

The household and community options discussed above both belong to a vision of a decentralised energy system that is expected to be more resilient because energy is generated and stored close to where it is needed for use. This vision aligns with an ideal of *the local* as a scale of social organisation and, in the case of energy, the provision of essential services.

Participants widely articulated a need for a *'hyper-local'* approach (E10) to achieving energy resilience, informed by inclusive and ongoing community engagement to better align community DER initiatives with the particular needs of each community. In this regard, 'ownership' is connected not just to the legal ownership of DER assets, but to the sense that a project is driven by a community and shaped by its preferences:

> *'This is where the concept of having community-led recovery is so important because the community then has the ownership and they know, in their own hearts, what is going to work and what isn't going to work for them' (WS2-H09).*

Community initiatives are described as representing a shift away from dependence on the incumbent energy system actors and structures, as is expressed in the suggestion that *'we really need not-for-profit community retailing. That's the only way we're going to get this independence that we need to support the networks locally and have the resilience that's needed'* (E11).

Aspirations for local energy are often accompanied by calls for support from actors beyond the community, however, which may complicate the ideal of local independence. Governments at all levels are seen to have an important role in enabling the decentralisation of the energy system:

> *'So, I think that local, state, and federal government really need to be changing this' (H08); 'I think they need to provide more support to localised energy production and energy storage facilities' (H40); 'you can't do that [build a microgrid] just with the local community input. The local community would probably contribute to it but I think it's a much bigger job than that' (WS3-H01).*

Self-sufficiency of energy generation and use is expected to be made possible by such support (*'to be given the resources and to be self-contained, I think a whole lot of people would be happier with that provided they got the right information, the right equipment, and some support from government to make sure that they'll get it right'* (H43)), which elsewhere has been described as a *'shared responsibility'* [9]. Individual responsibility is even articulated in the same breath as a role for external support: *'I also think individual homeowners need to take responsibility and get bloody solar panels and batteries. I mean, we need to have some sort of incentive or information for people that we can trust'* (H57). DNSPs are enabling local energy through the household SAPS and community microgrids initiatives discussed above; these are models of decentralisation that do not actually involve moving off the network *as a structure of energy governance,* even if they involve no longer using the physical poles and wires infrastructure.

The interest in community-based solutions is also qualified by an acknowledgement that these may encounter limitations or challenges, such as those arising in the coordination of microgrids and *'who decides what loads can be turned on and can use that limited capacity?'* (WSP-E17).

One participant observed that *'the idea that the community is relatively coherent and actually wanting to come up with a whole-of-community option'* is at odds with the recognition that some communities are *'a bit more disjointed and having a series of vested interests'*. She went on to state that, *'while it might seem like a great idea to have a whole-of-community answer, that might not work if people's heads are in different places'* (WS2-H09).

Such limitations or challenges may necessitate external governance: *'we all contribute and buy back power but someone who's got the ability and the skills and obviously the knowledge and the economies of scale can then maintain that big battery for the local community'* (H42). The potential for a proliferation of resource-intensive community-scale solutions to result in the *'opposite of economies of scale'* was noted by one expert interviewee (E12).

What these views indicate is that decentralisation of energy supply does not imply a straightforward decentralisation of initiative or ownership. The household and community-scale options to build energy resilience outlined here depend on a number of supporting factors in the broader context, and which of these options is most appropriate will depend in part on the extent to which the capacity and resources are available to support them.

Conclusion

This chapter has outlined some of the possible configurations of DER at the individual household and community levels and how they reflect different visions of what a resilient energy system looks like. Some people perceive resilience to lie in energy independence, while others associate it with the sense of community that the ECA has previously observed can be as important as physical infrastructure in coping with grid outages [18].

Whatever the scale, the social, geographic, technological, and economic circumstances in which the DER options being considered here shape whether and how they can offer energy resilience [20]. As one participant noted, although there is a need to '*learn off what other communities have done […] it can never be a one-size-fits-all because all of our communities are just so different' (WS2-H09).*

CONCLUSION

Household rooftop solar system. Image courtesy of Renate Egan, APVI

Key findings

Our findings across this research project underscore how households and communities that have experienced bushfires and other extreme weather events in New South Wales were impacted by power outages in a variety of ways. The loss of power had significant and wide-reaching consequences for a range of energy services including access to telecommunications, water, money, fuel and refrigeration. These impacts, which varied significantly depending on the duration and extent of outages, were a source of great distress and a sense of vulnerability, leaving people literally and figuratively 'in the dark' and unable to meet basic needs.

In response, **households and communities employed a range of DER and strategies to cope with the impacts of these outages**. DER such as generators, bottled gas, rooftop solar and home batteries, EVs, microgrids, and community-scale batteries have the potential to enhance energy resilience at various scales. However, as detailed in Technologies and Infrastructure, each of these DER technologies has advantages and limitations and, while there is broad awareness of their potential resilience benefits, these are complex technologies requiring a high level of expertise for appropriate design and deployment.

Moreover, the capacity for these DER to confer energy resilience is far from just a technical concern; it is mediated by a host of social, economic, and situational factors, including the duration of outages. There is therefore a need for careful consideration of the DER options that might best enhance energy resilience given the different capacities and circumstances of specific households and communities.

In the accounts we heard, **there were many instances of community members supporting one another during weather-related outages.** People helped others or received help to access energy services by sharing generators, relying on neighbours or small businesses for phone charging or refrigeration, or communal cooking events such as BBQs. However, while these forms of community response should be acknowledged and supported, the feasibility of these kinds of communal responses depends on the circumstances. Communities can contain differing priorities and uneven capacities that challenge the ideal of a single coherent community response.

Helping households and communities to learn from past experiences, anticipate and prepare for power outages can enhance resilience at a local scale. This can inform household practices, the adoption of appropriate DER, and the improvement of community infrastructure to enhance energy resilience. However, some participants expressed a sense of fatigue and frustration around widespread calls for communities or individuals to be 'resilient' and pointed instead to the roles and responsibilities of governments and energy providers in improving resilience at the system level, e.g. through investments in resilient energy infrastructure and action on climate change.

Different DER configurations, at individual household and community levels, can have different meanings and implications for energy resilience. As we illustrated in Visions for a Resilient Energy System, while more individual-scale approaches – including the ideal of going 'off-grid' –– might help households achieve energy independence and self-sufficiency, such an approach can neglect inequities in access to DER in society, as well as the equity implications of maintaining a grid with fewer connected households.

Similarly, while collective DER configurations such as microgrids have the potential to be more inclusive, they tend to have their own context-specific political challenges with respect to ownership, leadership and decision-making. In practice, there is no binary choice between individual and community approaches; rather, they are part of a continuum of DER configurations that may be drawn upon in different ways to meet the needs of different households and communities. Likewise, in practice, more decentralised models do not necessarily entail a clear shift away from incumbent models or reliance on actors such as governments and DNSPs.

Our findings also surface **a tension between the imperative to decarbonise through electrification and efforts to build energy resilience**. Energy resilience can be strengthened by diversity in energy sources, with each serving different functions and conferring different forms of resilience, e.g., rooftop solar, bottled gas and generators can be used in conjunction. While decarbonisation of the energy supply is urgent, there is a need to consider its potential resilience implications, or risk creating additional forms of vulnerability in homes and communities.

A related insight from our research is that **there is a need for a richer appreciation of the multiple benefits that DER can offer** – looking beyond economic approaches such as payback periods on these technologies to consider benefits such as bill savings, emissions reduction, and resilience to outages.

Implications for policy and engagement

Our research findings point to several considerations for stakeholders:

1	There is a need for greater efforts to educate households and communities, as well as other actors such as installers, on the different types of DER available and their specific implications for resilience. For example, as detailed in this report, a correctly configured solar and battery system can provide a significant level of resilience, but rooftop solar alone is not *necessarily* beneficial during a grid outage. There is a need for more widespread industry understanding of the potential resilience impacts of DER as this has direct implications for how suppliers market specific products and engage consumers.
2	We contend that the tendency to frame the value of DER in purely economic terms such as payback periods is too narrow. There is a need for a wider view of the different types of value that DER can offer, such as *bill savings*, *emissions reduction*, and *resilience to power disruptions*.
3	The role that some forms of DER can play in energy resilience means that policies that support the adoption of DER, such as subsidies, can shape the resilience of households and communities into the future. Resilience should be considered in the design of such policies, both to evaluate potential unintended effects and to leverage opportunities to support technologies that increase resilience.
4	There is potential for the electrification of household appliances to yield negative resilience outcomes, if carried out without consideration of back-up electricity supply in areas vulnerable to grid outages. This tension between electrification and the diversification of energy sources is a dynamic that will need to be navigated in the development of policy and research.

5	Engagement with communities is necessary to understand their needs and the DER configurations that might best meet them, while also taking into account that perspectives and needs within communities differ. Partnerships between industry stakeholders and communities in microgrid and other community-scale initiatives, which tend to be asymmetrical in the interests and power that the partners bring to the engagement, will vary according to the specific context and the needs of communities. Extensive community engagement, with awareness of these existing asymmetries, is therefore essential to building partnerships to achieve resilience in forms that reflect the values of communities.

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GLOSSARY

Concept or Term	Meaning
Battery electric vehicle (BEV / EV)	In contrast with conventional petrol and diesel-engine cars with internal combustion engines, electric cars have one or more electric motors which are powered by large lithium-ion battery packs.
Battery or BESS	A BESS is a type of energy storage system that uses batteries to store and energy and distribute in the form of electricity at a later time.
Community-scale battery	A shared electricity storage solution for a local neighbourhood that helps balance electricity supply and demand and supports management of the electricity network. Also called a neighbourhood or community battery, but it can be owned and managed by a range of different parties. It can provide multiple technical benefits, including increasing grid stability and reliability, integration of more rooftop solar and EV chargers, reduced limits on solar exports, as well as bill savings for local customers and the wider community, depending on the business model and distribution of costs and benefits.
Distributed Energy Resources (DER)	Systems that are commonly located at houses or businesses to provide them with electricity. Common examples of DER include rooftop solar, battery storage, generators and electric vehicles. Also called "Consumer Energy Resources" or CER
Distribution network service provider	Distribution network service providers build, maintain and operate the distribution networks for electricity.
Islandable and Non-Islandable	"Islandable" refers to when a rooftop solar or solar and battery system has the capability to disconnect from the grid during an outage and continue to power your home independently. Not all solar systems have this functionality. Systems without this functionality are referred to as being "non-Islandable".
Microgrid	A microgrid is a community-scale electricity network connecting consumers to an electricity supply. A microgrid might connect several generators such as solar systems, wind turbines or fuel-burning generator, as well as smaller household and business DER. Microgrids can use community or household batteries to store this electricity.

Standalone power system (SAPS)	Standalone power systems operate independently of the grid and supply continuous power, usually using a mix of solar, battery storage and backup fossil fuel generation.
State of charge (SoC)	State of charge (SoC) is the level of charge of a battery expressed as a percentage of its capacity (0% = empty; 100% = full). It is used to describe the current state of a battery.
Uninterruptible power supply (UPS)	An uninterruptible power supply (UPS) or uninterruptible power source is a small unit containing a battery and inverter-charger to provide automated backup electric power to an appliance when the mains power fails.
Vehicle to Grid (V2G)	Vehicle to Grid (V2G) uses a bidirectional inverter-charger to enable energy stored in an EV battery to be discharged to the grid to help meet high demand or provide network stability.
Vehicle to Home (V2H)	Vehicle to Home technology works in a similar way to V2G, but uses electricity stored in an EV battery to supply household appliances or charge a home battery. This can be especially useful during power disruptions.
Vehicle to Load (V2L)	Similar to V2H in principle, Vehicle to Load allows for the battery in an EV to directly power individual appliances.
Virtual Power Plant (VPP)	Virtual Power Plants are networks of small-scale DER, often rooftop solar systems and batteries, that are coordinated to help meet high electricity demand, or provide stability to the grid. Households are compensated in return for allowing external control of their devices.