Consumer Behind The Meter (BTM) resilience as a socio-technical service

Report to the SIF Discovery Project: NPG/Resilient Customer Response/SIFIESRR/Rd2_Discovery

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1 Introduction

Historically distribution networks have always had a responsibility for ensuring customers have a reliable and resilient connection, with a particular need for the protection of vulnerable customers from loss of supply. In this context, resilience has traditionally been provided by the network operators through, for example, investment in network capacity to avoid constraint issues and the deployment of generators in the event of local outages.

However, recent extreme weather events such as storm Arwen have demonstrated that network outages can be significant and restoration of services can be challenging. Not only are such events increasingly likely, and likely to be more severe under current climate change scenarios but they pose a wider and more systemic risk due to the ongoing 'electrification of everything' under the UK's net-zero transition plans. As a result, it is not only traditional 'vulnerable' customers who are at risk in the event of local outages but so increasingly are those who rely on electricity for comfort (heating/cooling), cooking and mobility (Rubin and Rogers 2019). Where historically a power outage could be ameliorated by the use of alternative fossil fuels, especially for heat or mobility, this is decreasingly the case. Resilience to local outages, whether they are caused by extreme events or the overloading of constrained supply networks, is therefore likely to be increasingly crucial to a wider proportion of the customer base (Mahdavian et al. 2020).

At the same time there is a trend towards an increasing decentralisation of energy assets, including the widespread deployment of behind the meter (BTM) assets such as micro-generation and storage. This effectively means that customers are part of the energy system, not just a 'consumption' connection – a state often referred to as '*prosumption'* (Ellsworth-Krebs and Reid 2016; Parag and Sovacool 2016; Kotilainen 2019) or, with storage, '*prosumage'*. This can be extended to local provision of distributed energy services via collections of prosumagers (Green and Staffell 2017), potentially supported by locally-owned neighbourhood 'behind the feeder' assets via 'energy communities' (Koirala et al. 2016).

There is therefore the potential for some customers to provide localised *resilience services* (Tiwari et al. 2022; Hasselqvist, Renström, Strömberg, et al. 2022) to themselves, and potentially the local network, through the 'self-deployment' of their behind the meter assets such as solar PV and electric vehicles or fixed batteries (Sioshansi 2020; Rodrigues, Anjos, and Provost 2021) which, collectively, could form 'virtual power plants' (VPP). This is a natural extension of the accepted idea that such assets can provide demand response (DR) services to support grid flexibility through reducing or shifting power import as required.

Although the capacity available is likely to be relatively low, this could support the maintenance of essential services (e.g. communications, gas-fired heating controls, lighting, cooling appliances) at a local scale until network supply can be restored. If so, this would result in greater reliability of supply in the face of network outages, reduce the need for direct investment in resilience services by network companies and therefore provide an indirect cost benefit to all network customers[1]. However, given the value of such services to

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[1] See, for example, https://smarter.energynetworks.org/projects/nia_npg_018 which is assessing the potential for microgrids to provide resilience for customers in locations that are vulnerable to supply outages. One key focus of the project is to explore communications systems that can continue to function despite a power supply disruption.

the network provider, and of the stored/generated electricity to the asset owner, it is likely that some form of indirect investment or payment for these 'BTM resilience services' would be required.

Whilst many innovation projects are focussing directly on how vulnerable customers can be supported, this project examines how potentially some of the "least vulnerable" customers can help support network resilience. This is based on the assumption that BTM assets are most likely to be currently adopted by the 'least vulnerable' customers. If this is the case then this approach will help indirectly support vulnerable customers by allowing the network companies to prioritise restoration work on the most vulnerable customers while local BTM resilience services support some level of supply service for single or groups of less vulnerable customers. However, it is possible that publicly funded social housing retrofit programmes which provide BTM assets[2] in addition to improving energy efficiency through insulation and heat pump installation could also provide a similar asset base.

The Resilient Customer Response project aims to explore a number of elements of this concept to develop an evidence-based proposal for a longer-term trial. To do this the project will consider:

- The types and uptake of relevant behind the meter assets and the technical capability for them to provide resilience services.
- The methods and likelihood of incentivising customers to provide resilience though research into customer responses.
- The cost benefit of different approaches, considering the value of lost load, incentive structures, and network cost benefits.

This will lead to recommendations on business models / propositions to deliver consumer resilience, and the role that network companies need to play to benefit, both operationally and financially.

The purpose of this report is to review current peer-reviewed empirical evidence and available case studies of the use of BTM assets to provide local resilience services to understand how domestic customers might be incentivised to provide local BTM resilience services in the UK context. This focus on reviewing evidence of how such a service might work in practice reflects the importance of the socio-technical context to the provision, adoption and use of a new and potentially disruptive technical and social configuration. Understanding this socio-technical context will be crucial to the success of such a service because it will be enacted in moments of social and economic stress when 'normal' practices and understandings might need to be suspended. In this respect the report responds to previous work pointing out that a focus purely on technology, electrons, markets, carbon and techno-economic system simulations will be insufficient as guides to future service implementation and may well risk future failure (Strengers 2014; Miller, Richter, and O'Leary 2015).

Unfortunately, given the emerging nature and the technical immaturity of the concept this evidence base has proven extremely thin. Even a more generic focus on local energy markets suggests that the vast majority of studies focus on technical aspects, the implications for power network stability and on modelled consumer behaviour under a range of 'rational

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[2] See for example provision for the installation of battery storage under HUG2 'when it complements Solar PV' https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1153302/home-upgrade-grant-2-delivery-guidance.pdf p36

actor' models (Dudjak et al. 2021). As Dudjak et al (2021) note "*Further research is therefore needed in the area of prosumers' behaviour strategies to study their impact realistically*".

The report therefore starts by reviewing what is known about how residential consumers respond to and cope with power outages before reviewing the very few studies of stated preferences for sharing BTM assets. It then gleans insights from a range of empirical studies of 'prosumption in action'– including peer-to-peer trading, self-consumption and transactive energy trading as well as prospective preference studies of future energy trading systems. Insights are also drawn from studies of direct load control, vehicle to grid, and energy sufficiency before moving on to a number of case studies. These include solar household systems which have long been considered crucial to energy resilience in the global south (Scott et al. 2017); (islanded) mini/micro-grids (Soshinskaya et al. 2014; Hirsch, Parag, and Guerrero 2018) since although "electricity islands are forced to operate in a fully autarkic way, energy communities can adopt features of electricity islands by choice" (Kubli and Puranik 2023); experiences of power outages during Hurricane Isaac and recent experiences of preserving (and sharing) household level electricity use via solar and storage systems in New Zealand during Cyclone Gabrielle in early 2023.

The report concludes with a summary of the themes and insights generated through these sections from the perspective of potential future local BTM asset-based resilience services.

2 Power outages – what do people do?

Power outages, in common with telecommunication system disruption and failure of water supply are nothing new and have been studied for some time both in terms of specific response strategies but also as they reveal 'tacit' and largely overlooked interdependencies in everyday life (Wurtzel and Turner 1977; Trentmann 2009). These studies have tended to focus on experiences of outages in rural communities, partly because they tend to be more prone to disruption. These studies are inevitably retrospective in nature relying on respondent recall of events in the past although future-looking prospective scenario-based studies also exist (Mahdavian et al. 2020). These tend to produce largely the same results.

Customer experiences of power cuts due to the February 2014 UK winter storms were collected by Ghanem et al (2016) who noted that previous experience of power cuts was important in enabling resilience and the continuity of everyday practices (see also the recent Ofgem study of customer experiences of Storm Arwen (Rotik and Bhaskar 2022)). This included the retention of 'old' gas or camping equipment, supplies of coal and wood, and ensuring spare mobile phones were charged. In some cases, the experiences had prompted householders to acquire such equipment for the future 'just in case'.

Respondents reported adapting by only trying to warm one or two rooms, using candles as both light and heat sources and heating small amounts of hot water on gas stoves/cookers for hot drinks and hot water bottles. Meals were often adapted to fit available cooking equipment and in longer duration outages perishable food was moved to friends or relatives who still had power. Many also chose to go to bed earlier in the absence of lighting and to keep warm.

Respondents reported checking on elderly neighbours, inviting them in for warm drinks or just company. While respondents were aware of the existence of Priority Services Registers to ensure the vulnerable have basic needs met, there was also a strong feeling that action could and should also be taken at the neighbourhood and community level by drawing on experience of community planning such as that in place for flooding. This reflects a consensus that local social ties and the ability to communicate were crucial for coping with high degrees of trust in small communities and detailed local knowledge of the specific vulnerability risks of specific people.

This was also reflected in the experiences of local hospitality businesses who could not fully function, and so had no customers, but who could provide support for electricity-dependent households through bottled-gas cooking facilities. In other cases village shops stayed open but could not use cash registers so were prepared only to serve people they knew via informal credit arrangements reflecting the strong informal networks and high social capital within these communities. As the authors note, this illustrates the importance of looking beyond individual households when considering how resilience can be strengthened by local 'community'/meso-level organisations or processes in the face of technical infrastructure failure. As the study shows, informal social resilience is intrinsic to different degrees in most communities, and is provided by knowledgeable neighbours and others who could provide or share resources. This enabled households to retain some form of normality even when they needed to find ways to prioritise certain aspects of their everyday energy-using practices and especially when modifying them was not possible.

That said, respondents also noted the difficulty in communicating outside their immediate neighbourhood in the absence of electricity meaning they were unable to check on or report wellbeing to more distant kin or friend networks. The lack of access to media, and especially information on the extent and probable duration of the cuts also meant that customers found it difficult to take appropriate adaption steps.

A similar study of household preparedness in 14 Norwegian & Swedish households (Heidenstrøm and Kvarnlöf 2018), who tend to be more reliant on electricity for heating and cooking under normal circumstances, highlighted that outages provided the opportunity to see what a household requires to function and what it can do without.

As in the UK, past experiences were crucial to preparedness with respondents keeping woodburners, gas/oil lamps and gas stoves; knowing not to open fridge/freezer unless critical, storing candles, torches, wood and ensuring suitable non-perishable food stocks.

However, they also point to the localised practices of some of these adaptions such as access to wood for wood-burners and the widespread experience of basic camping/cabins without water/electricity for holidays.

The study also highlighted the importance of social connections to adaption with examples including the use of informal credit to acquire groceries from the local store and a more general sense that neighbours would help each other due to mutual social relationships. Some reported contrasting the rural situation where there was detailed local geographical and infrastructural knowledge underpinned by strong social relationships (knowing neighbours, where people live, who is at home and what resources they may have/need) with the perceived, perhaps mythical, lack of these in an urban context.

As with the UK findings, 'acceptance' of blackouts was very much linked to knowledge of the probable duration and so assembly of coping strategies. Being able to communicate with neighbours and friends outside the immediate locale was also key as was not being (or caring for) vulnerable others – such those with ill health, having young children, or caring for farm stock.

Overall, the study concluded that

"*There is a need to incorporate households as competent actors in managing blackouts through their everyday practices, and not merely address them as recipients of information and support*." (Heidenstrøm and Kvarnlöf 2018, 280)

A more recent study of Norwegian households (Wethal 2020) highlighted many of the same responses and concerns:

- Wood-burning stoves (and pre-stoked woodstores) become the main heat source with respondents wearing additional thermal underclothes or outside clothes inside to keep warm, alternative cooking methods included bottled gas grills and gas/charcoal BBQs;
- Loss of mobile communications due to battery discharge was crucial;
- Loss of access to water for those on private pumped supplies, including farmers was a significant issue, much more so than the UK although this was also reported during Storm Arwen (Rotik and Bhaskar 2022). Responses included pre-storing water due to the weather forecast, carrying water from streams or melting snow where there was access to a wood-burner;
- Lack of knowledge of the probable duration of the outage (linked to loss of communications) prevented sensible decision making since it "might come back on in 1 hour!";
- Previous experiences with blackouts became a tacit form of knowledge embodied in peoples' daily lives that became activated before or during disruptions. There were a range of learnt practices (e.g. pre-stocking with water on weather forecast; not opening freezer etc); keeping 'old' materials which would still work (e.g. pans for wood stove), deliberately not installing an induction hob and opting to retain generators;
- Social ties and neighbourhood support were widely reported with neighbours coming to use the toilets of those with working water supplies, letting neighbours charge phones from generator-fed supplies and giving a particular focus to those they knew to be vulnerable, whether elderly or otherwise;

However, respondents also noted that neighbours were expected to be responsible and to have taken necessary precautions so that they did not become an 'unnecessary burden'. In some cases, as in the previous study, this appeared to elicit contrasts between long-time rural dwellers and relative newcomers from more urban areas who lacked the experience of previous outages.

A summary of the literature focusing on behavioural and psychological responses of the public during a major power outage (Rubin and Rogers 2019) draws together many similar points:

1) Preparing the public should reduce the impact of an outage. Households with children and those who have experienced previous outages may tend to be better prepared;
2) Specific vulnerable groups including older adults and those with psychiatric or medical conditions will require targeted help to prepare – these groups could form a possible focus for resilience services due to their medical and other needs; provision of resilience services could involve specific places people can walk to – c.f. 'warm spaces' made available during the winter of 2022/23 in the UK[3];

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[3] https://www.warmwelcome.uk/

3) Clear public health communications will be needed to reduce risks of (especially):
    a. carbon monoxide poisoning due to increased use of fuel-burning appliances for heat & hot water/cooking in the home (where the built form was not intended for this);
    b. food poisoning (due to poor food hygiene);
4) The loss of communication infrastructure is likely to be an important stressor among the public so providing basic support for charging mobile phones and ensuring local cell towers continued operation were key. There was evidence that some people charge devices or small battery packs at work and 'bring power home'. EVs and V2G could play the same role but at a larger scale;
5) Panic is unlikely and so too is self-evacuation but the latter depends on whether the probable duration of the outage is known and does not reach critical thresholds – such as loss of frozen foods or persistent low temperatures;
6) Acts of altruism will, probably, outweigh acts of criminality. Reports of altruism (helping friends & neighbours) are common with far fewer reports of looting or theft. It has been widely reported that neighbours feel responsible for each other, checking on older or vulnerable neighbours and relatives, sharing resources, helping them to evacuate or, as above, trusting community members to take supplies from local shops on credit;
7) The public's information needs will focus on 'what has happened' and 'when will power be restored'. The latter is especially crucial in order for people to make adaption plans. These can include fixing a generator, or moving frozen food or self-evacuation to a friend or relative who has power – assuming mobility is possible. Other information needs include the safety of drinking water in the event of treatment plant failure and where local shelters/hubs are located;

The review also noted that emotional responses are common (see also (Mahdavian et al. 2020)) with people describing feelings of 'cosiness' and 'social connectedness' due to the kinds of responses described above. However, these were likely to decline with duration and especially with uncertainty over duration but tend to be maintained if basic needs can be met such as basic comfort, hot meals and drinks. These emotional responses also tended to be maintained if 'outage competence' was high through previous experiences.

Interestingly, parallel research on those who have experienced long term trauma (e.g. chronic natural hazards) and recent trauma (Frazier et al. 2013) suggests a greater sense of wellbeing for those who engage in pro-social behaviour. This implies that neighbourhoods who have experienced supply disruption will a) value a resilience intervention/service b) be more likely to engage and contribute if outage re-occurs and c) increase their own sense of well-being by doing so.

Finally, a recent study of 21 Swedish household's recollections of power outages (Hasselqvist, Renström, Håkansson, et al. 2022) confirmed many of these themes suggesting three emerging strategies of resilience:

- Increasing *response diversity* – such as different energy sources or variations in practices mirroring the range of strategies developed by off-grid households;
- Developing *Individual* resilience – through the development and sharing of experiences of low-energy or disrupted supply living. This was thought especially beneficial for affluent groups or urban dwellers who do not usually experience disturbances to energy supplies;

- Developing *Community* resilience – through the proposed use of local, networked modular energy assets, mirroring the value of socially connected resources for 'getting by' and 'coping' especially in responding to disasters and hazards (Carmen et al. 2022; Wood, Boruff, and Smith 2013). It was especially noted that getting help from neighbours depended on strong social relationships which may be missing in some contexts. In this case meso-level organisations such as Housing Associations or workplaces were suggested to play a strong role.

Overall, this section suggests that those with BTM assets would be very likely to share energy resources in an outage situation and that the provision of a basic level of service which can support lighting, communication and critical health requirements could be an initial focus. If sufficient capacity were available this could be extended to 'comfort' services such as enabling hot water heating, cooking and finally some limited form of space heating for those who have no other source. However, it may be that providing higher levels of service could only be supported in a designated hub or shelter so that resources (and assets) can be concentrated.

3 Sharing or propensity to share power in grid outages

Evidence from more general research on resource sharing in extreme resource scarcity (Ember et al. 2018; Brewis et al. 2019) suggests that 1) sharing of food, water and labour beyond the household are both cultural universals and quite customary when resources are scarce; 2) societies who experience more resource stress (including unpredictable food-destroying natural hazards) share more frequently but 3) sharing beyond relatives may be attenuated when resource stress is high. These findings resonate with some of the findings of grid outage studies, especially where they may be more frequently experienced, even if unpredictable in timing.

In the food sharing literature in particular, scholars note that:

1) sharing is a way for groups lacking the means to buffer resource variability to "store" food with others – a food '**battery'**;
2) unpredictable items of food, such as game, are more often shared than predictable items – potentially because they cause temporary gluts that cannot be preserved (i.e. **surplus generation**);
3) individuals who share more food with others receive more when they are injured or sick – highlighting the value of **reciprocal** or 'tit for 'tat' returns;
4) an average individual gets more food per capita when food is shared – exactly as noted in the **social dilemma** discussion below.

While electricity supply disruption is perhaps not quite of the same scale as climate-related hazards and other food resource stressors, it might follow that extensive sharing should be particularly advantageous in higher risk environments – such as local networks prone to supply outages. More specifically, the work suggests that sharing in situations of energy scarcity might be confined to relatives in areas which have high levels of local kinship. In areas of lower local kinship (e.g. housing situations with higher in/out of area flows) sharing may be reduced still further due to increased 'anonymity' and weaker social bonds. However, it is unclear if local non-kinship social bonds can replace kinship bonds in the kinds of industrialised, non-subsistence cultures (see (Georgarakis et al. 2021)) discussed above and also in the case studies below.

Given what we know about how customers respond to power cuts and how globally universal resource sharing has been found, how likely is it that customers would share (or trade) energy from BTM assets?

Unfortunately, there has been very little research to date on whether individuals or households do or are likely to share access to BTM assets under outage conditions. Most studies focus on modelling technical components under ideal conditions or at best provide simplified 'rational actor' models of consumer response. As noted above 'power outages' are difficult to research as the study would have to be in place and ongoing to provide observational data and avoid retrospective views. One example reported in (Kurz et al. 2022) cites an example of a Dutch village which was cut off by snowfall in 1979. One resident connected a generator to the village electricity network but the system failed as households did not self-regulate consumption sufficiently for the generator to cope. However there have been at least two recent and contrasting studies of customers' prospective views on their propensity to share access to BTM assets.

Snow et al's 2022 (2022) study interviewed 39 Australian PV owners who were not co-located or part of an 'energy community'. The interviews used a number of 'visualisations' of a neighbourhood energy monitoring system to "*gather perspectives on voluntary curtailment (understand users' motivation and ability to curtail during peak demand based on awareness of local network capacity) and identify factors affecting users' willingness to share their energy use data and allow shared control over their energy assets*". Note that the interviews did not explicitly use 'sharing resources in an outage situation' to frame the interviews and this may not have been considered as a context by the respondents.

The study found that most participants were reluctant to allow the 'network' to control BTM assets due to a lack of trust, particularly distrusting the network operators' motives, concerns over their priorities and a consensus that these priorities would not be in their own interests. Further, most participants were reluctant to act in the common good as they weren't confident others would also do so. In consequence the majority were not interested in understanding the capacity constraints of the local network and how near capacity current usage was with many offering the opinion that this was a network problem not theirs. This potential tension between consumer and presumed commercial network operator 'value' is recognised in the wider literature as a potential problem for most distributed energy systems (Adams, Brown, et al. 2021).

Very few battery owners in the sample were prepared to curtail their use to benefit the network, many stating that they had bought the battery purposefully to enhance their own independence so were not inclined to relinquish this (c.f. autarky – see Section 4.1.1).

The study also noted that many respondents confused the retailer and network operator's actions, roles and responsibilities with only a few respondents, who tended to have strong community attachment or experience of working for energy collectives, motivated to engage in VPP or curtailment.

Overall, the study concludes that "*individuals who are concerned about their data, value privacy and/or are unwilling to share energy use data and/or do not trust the energy sector, are less likely to be motivated to share energy use data, engage in forms of consumer-network participation such as VPPs, micro-grids or voluntary curtailment trials*."

In contrast a small (n = 80) survey study of self-produced energy sharing preferences in Germany reached very different conclusions (Kurz et al. 2022). 65% of the sample had PV or solar thermal installed and 73% had experienced major power outage. Respondents were told they possessed "*a PV system which they could decouple from the usual grid to either consume the produced energy themselves or to share it with certain stakeholders*" and were then asked if: "*1 = I would not share any electricity, 2 = I would share excess electricity (my own consumption is not restricted), 3 = I would share parts of my electricity (my own consumption is restricted), 4 = I would share all of my electricity*." With four different stakeholder groups:

- Neighbours
- Friends and family,
- Public non-critical infrastructure
- Critical infrastructure

The study sought to identify the mediating role of empathy and norms and expectations of reciprocity, such as 'tit' for 'tat' sharing as identified by Hahnel and Fell (2022), in the propensity to share electricity with others.

As Kurz et al note, this situation provides a classical social dilemma – where an individual receives a higher pay-off for not co-operating (they get to use all their own electricity) but all individuals will receive a lower payoff if none co-operate. The literature on social dilemmas suggests that introducing structural rewards (payment) can crowd-out altruistic intentions/rewards by converting social decisions to commercial/economic/business ones. As we have seen in previous sections, this is not always beneficial or preferred with altruistic rewards often playing a dominant role in resource sharing in outage situations and providing a route to improved self-perceptions of well-being.

Overall, the study found that most respondents were willing to share but, in common with the discussion of load control of batteries and V2G below, none were prepared to share 'all'. More detailed responses depended on who to share with:

- Friends/family and critical infrastructure: sharing was increased by the degree of empathy-elicited altruism (degree to which they proactively engaged in helping behaviour during the COVID-19 pandemic) and altruistic norms; interestingly structural rewards (payment) only had an effect on 'self-oriented' individuals, and little effect on 'other oriented' individuals (who had installed PV for climate rather than economic reasons) and may even lead to decrease due to inability to 'provide free help'
- Neighbours & public non-critical infrastructure (schools, sports facilities, universities, or community centres) – no statistically significant effects were found but there was generally a lower willingness to share with these recipients; the paper suggests generally decreasing community 'identity' as a cause but general willingness to share includes neighbours in potential recipients;

Further, the stronger the perceived threat (i.e. greater negative consequences), the more likely sharing with critical infrastructure (strongly) and towards friends and family (moderately). This was taken as evidence of altruistic norms and can be linked to the higher likelihood of resource sharing under conditions of increased scarcity noted above.

No effects were found for historical reciprocity (whether they had received help during the COVID-19 pandemic) possibly due to the perceived anonymity of context. However the study cites other research showing that reciprocity is reduced with increased anonymity and the global ubiquity of reciprocal norms suggest this needs further research.

Overall, the paper concludes that "*the social dilemma of electricity sharing appears to rather be a game of individual intrinsic motives than incentive-based structures*" and so "*policymakers should place more emphasis on fostering strong community ties than on higher (feed-in) tariffs*". Doing so would leverage the voluntary sharing behaviour reported by PV system owners in this study. This implies that design principles for co-operation during power outages should:

- Avoid focus on increasing remuneration only – this may demotivate some as it converts a moral/social decision to an economic one. This is a double-edged sword depending on the donor's social value orientation;
- Try to expand feelings of felt responsibility and social closeness with neighbours to promote the tendency to 'share' beyond friends and family or critical infrastructure;
- Try to establish and foster a 'community energy resilience' identity – potentially via a local resilience network or some other meso-level actor

Unfortunately, the paper offers no analysis of thresholds for sharing apart from noting that no PV owners would share all of their energy. In addition, although not discussed in the paper the results show a large and statistically significant negative effect on the propensity to share with neighbours for those who have previously experienced an outage. Given the studies of network outages above this seems a contradictory result although it may reflect concerns that PV owners have regarding over-sharing their resources given their previous experiences of power outages. Finally the paper suggests an overall "*lower level of prosocial acting towards neighbours*" which also contradicts the studies of network outages and general resource sharing discussed above and is further contradicted by the Hurricane Gabrielle and other case studies below.

4 Learning from other energy contexts

Given the relative lack of direct evidence for BTM asset sharing attitudes, preferences and practices this section reviews a number of other socio-technical energy contexts to derive relevant insights. It starts by reviewing dimensions of and motivations for becoming a prosumer before reviewing studies of direct load control and user preferences for vehicle-to-grid. Each section provides a summary of insights and implications many of which resonate with previous sections and are also illustrated further in a number of the case studies described in Section 8.

4.1 Understanding prosumption and prosumage

While the term 'prosumer' first appeared in the 1980s as a way to characterise the (re)emergence of consumers who took an active role in shaping and adapting the products they 'consumed' (Toffler 2022; Nye 2006), its application in the energy sector is more recent (Ford, Whitaker, and Stephenson 2016; Kotilainen 2019). This reflects the relatively recent growth in micro-generation assets which enable consumers to play a substantially more active role in the energy system by storing, trading or otherwise contributing surplus energy.

This conception has been further expanded to include the notion of local energy communities or co-operatives whose aim is to be substantially self-sufficient in energy resources (Georgarakis et al. 2021) and further still to incorporate non-generation 'services' such as demand reduction (*negawatts*) or demand shifting (Parag and Sovacool 2016) to support local and, by aggregation, grid-level flexibility (Kubli, Loock, and Wüstenhagen 2018).

As we might expect, motivations to become prosumers in either the narrow (energy generators/consumers) and wider (providers of flexibility and resilience services) senses vary between households, communities, cultures and contexts (Hackbarth and Löbbe 2022). At least two recent reviews organise these motivations along technological , economic, environmental and social dimensions (Georgarakis et al. 2021; Adams, Brown, et al. 2021) and in doing so offer potential insights for motivations to offer local resilience services.

4.1.1 Technological independence

A number of studies emphasise the technological aspects as key motivators for the acquisition of BTM assets, including straight forward technological exploration by early adopters (Ableitner et al. 2020; Cárdenas-Álvarez, España, and Ortega 2022) but also the more complex desire to use novel technologies to gain a degree of self-sufficiency, autonomy and independence (*autarky*) (Adams, Brown, et al. 2021; Ritzel, Mann, and van Zyl-Bulitta 2022; Adewole et al. 2023).

This is especially the case with storage systems (Ecker, Spada, and Hahnel 2018; Snow et al. 2022) which enable households to increase their self-consumption and consequentially to decrease their peer-to-peer energy trading. Ecker et al's survey-based study of prospective preferences suggested that respondents were willing to pay a higher installation price to maximise autarky compared to maximising autonomy. In addition, when key benefits of an energy storage system were framed in terms of autarky, respondents also set higher sale prices on their surplus electricity. As noted elsewhere, this means that prosumagers who aim to maximize their individual autarky paradoxically reduce autarky at the aggregated level by increasing the cost to non-prosumers/non-prosumagers of purchasing electricity from within the peer-to-peer trading network (Adams, Brown, et al. 2021; Pena-Bello et al. 2022).

A similar stated preference study of an urban convenience sample in Nigeria also highlighted the critical desire to use peer-to-peer energy trading to support autarky, to secure additional income and to reduce household energy costs. Although the key driver for autarky was 'reduced reliance on the grid', the desire to trade energy did not appear to be driven by a consideration of the experienced unreliability of current electricity supply (Adewole et al. 2023).

As Georgarakis et al (2021) note, further distinctions need to be made between self-sufficiency at the community and households levels. As described above, a peer-to-peer trading system of households who maximised self-sufficiency and independence may have little to trade. On the other hand, increasing peer-to-peer trading means that participants may become **more** dependent on the community even though they are **less** dependent on grid-supplied electricity (Pena-Bello et al. 2022). As Hahnel et al (2020) point out, for those prioritising autarky "*it may be beneficial to emphasize the added value of autarky on the community level as compared to individual independence*". This in turn might encourage this group to support community or neighbourhood level energy storage systems that support community level autarky and resilience (Adams, Brown, et al. 2021).

Although there is a general lack of evidence on the interaction between autarky and other preferences, it seems likely that those who are mainly motivated by autarky (independence/self-sufficiency) may be *less* likely to offer BTM assets as a local resilience service since they will be more likely to value their ability to maintain their own levels of service. However, the preceding discussions suggest that this may be mediated by social or political standpoints which encourage the extension of autarky to include other local actors – to maintain some level of 'local autarky' in the event of a grid outage. Indeed, as Georgarakis et al point out, there is need to re-assess preferences when "prosumers are confronted with potential future insecurities of electricity supply" (2021, 9).

4.1.2 Economic dimension

This dimension highlights the financial motivation to engage in prosumption and generally focuses on the household level financial benefit of using self-produced electricity. This can take the form of payments for production (Feed-in Tariffs) or the savings to be gained by avoiding importing energy from the grid at retail prices. In the latter case this relies on the difference between the price a household would receive for exporting their surplus to the grid and the import retail price.

While economic considerations were found to be important motivator for engaging in prosumption in studies of German and Australian households (Mengelkamp et al. 2019; Wilkinson et al. 2020), the opposite was found in a study of Dutch prosumers (Georgarakis et al. 2021). Studies have also noted that engagement in active trading requires both additional time (Georgarakis et al. 2021) and a relatively high level of 'energy literacy' (Hackbarth and Löbbe 2020) while an ethnographic study of two off-grid villages in India highlighted that "*configuring a return is not merely an economic act but an intricate sociocultural process*" (Singh et al. 2018, 19). This followed from the observation that valued returns could be anywhere on a continuum from in-cash to in-kind and even intangible and individuals' preferences for the type of return expected varied with the nature of their social relationships (Adams, Brown, et al. 2021).

A stated preference study using a representative sample of the German population to understand trade-offs between offered price, and state of battery charge when trading self-generated electricity found 3 emergent trading clusters (Hahnel et al. 2020):

- *Price-sensitive prosumers* (39% of the sample) responded to the offered price once battery charge > 50%;
- *Autarky-focused prosumers* (31.6%) – only traded when battery > 95% charged reflecting the discussion of autarky above;
- *Heuristic prosumers* (7.0%) – traded when the battery > 50% charged and more aggressively when > 80%.

In each case we see that the propensity to trade 'floats' above some self-assessment of battery charge sufficiency. How this sufficiency level is determined by respondents is unclear – the experiment varied the state of charge between 5-95% in 15% 'blocks' and so participants must have been applying some form of rule of thumb regarding their own needs.

Further, other work has shown that economic considerations are prioritised when there is either an anonymous or distant relationship to the other trading party but, perhaps paradoxically, there is also evidence that in some contexts peer-to-peer traders wish to trade with specific households who are either known to them or perceived to be in need, especially where that trade might offer a cost saving to the recipient over their 'usual' retail price (Hackbarth and Löbbe 2020; Hahnel and Fell 2022). This is taken to imply that some form of semi-automated trading via a simple flat rate for automatic surplus export to the 'anonymous' grid and also a more nuanced and targeted set of local or relationship-based pricing defaults may be required to sufficiently enable local energy trading.

This aspect was explored in more detail by a stated preferences experiment which sought to establish how prosumers with surplus energy would set peer-to-peer prices for different stakeholders in representative population samples from the UK and Germany (Hahnel and Fell 2022). The study revealed three different pricing strategies that appeared to be consistent across the two samples:

- '*tit-for-tat'* pricing with general neighbours and local small businesses. In this case small price discounts were generally offered and expected;
- '*altruistic'* pricing with friends and family, local schools and hospitals, and low-income households. In this case, and especially where the other parties were 'trusted', much higher price discounts were offered and especially to low-income households with greater perceived need. However, the degree of discount offered to low-income households varied according to stated political orientation with those holding 'left leaning' views tending to offer larger discounts;
- '*noncooperative'* pricing for large companies, including energy retailers. In this case little discount (and often a premium) was offered on sale of surplus energy with the size of the premium again varying according to the stated political orientation of the respondent. In this case, as would be expected, those with left leaning views tended to demand a higher price premium from larger corporate entities.

The study also reported a tendency to offer higher discounts to local actors if the respondent also expressed a higher degree of local attachment highlighting the extent to which local relationships play a role (see also (Kacperski et al. 2023)). Overall, the study also found that a majority (> 60%) wished to set prices manually rather than automatically and of these 84% wanted to set prices differentially.

However, it is important to note that results from stated preferences experiments can suffer from social acceptability bias – where respondents respond in ways they feel will enhance the experimenter's view of them. In addition there is also the possibility of the 'intention-behaviour' (or 'value-action') gap (Babutsidze and Chai 2018). Taken together these phenomena mean that stated preferences may not play out in actual socio-economic activities.

This is potentially demonstrated in a study of 37 Swiss households who were actively engaged in trading their solar PV surplus. The study found that only 30% wanted to actively set prices and this group appeared to value the gamification nature of the task, free market concepts, and that there was no need to trust a third party in setting a price for their surplus. Of the remainder, 35% preferred automated pricing for reasons of convenience and simplicity potentially reflecting actual experience of the time required to engage in price setting (Ableitner et al. 2020).

An additional concern with differential pricing was noted in a recent study of 'platform capitalism' as enacted via Airbnb which sought to understand how 'social context based' pricing worked in practice and draw parallels and thus insights for future peer-to-peer energy trading (Fell 2021). Besides suggesting that peer-peer trading would be more likely in more highly educated areas, although mediated by availability of suitable assets which may not always follow education/wealth dimensions, the study also noted that discriminatory pricing via revealed and presumed characteristics such race, gender and nationality is a substantial risk where there are high levels of choice over who to trade with. This suggests that differential pricing mechanisms such as those discussed above may need to ensure sufficient protection against discriminatory pricing that might reflect conscious or unconscious biases. Fell suggest strategies that include monitoring impacts; putting reasonable limits on trading choices; diversifying trading potential (e.g. offering flexibility or other demand response services as well as energy trading) as well as informed targeting and/or increased incentives for less engaged and energy-literate groups who live in areas of significant network constraint or risk.

Overall, it seems likely that households with BTM assets would see economic value in making energy services available to the local network in a grid outage situation. Householders may wish to charge for such services, either directly to the recipient, or indirectly via a mediator such as a local council, an ‘energy community’ or a trusted emergency response organisation. It is also likely that if payment is requested, householders would wish to offer default and differential prices to different stakeholders. For example, they may wish to offer services for free to close relatives and neighbours and at some discount to key local services.

The problem of how to address ‘over-consumption’, which may be critically relevant to a local resilience situation where ‘fair shares’ need to be observed, has been addressed in a number of simulation studies. In particular Javadi et al (2020) model the effect of combining time-of-use tariffs in a peer-to-peer trading system with inclining or rising block tariffs (for grid import) and shiftable loads. Their simulation suggest that this combination incentivises self-investment in behind the meter generation assets by seeking to maximise self-consumption or within-peer-to-peer trading to avoid the effects of the rising block tariff. However, empirical evidence on customer response to rising block tariffs is mixed (Prasanna et al. 2018) with some reporting a small reduction effect (Li et al. 2014) while others noting that the tariffs simply enable those with more resources (income) to continue consuming due to the relative inelasticity of electricity demand to both price and income and the relatively low proportion of household income spent on energy (Quan and Kim 2023). There is further mixed evidence on demand response to inclining block tariffs by different social groups (Quan and Kim 2023) suggesting that a purely ‘economically rational’ response cannot be assumed as is often the case in simulation and optimisation studies.

An alternative approach, described by (Prevedello and Werth 2021) in a study of islanded PV + battery storage minigrids in the Philippines, could be to enforce subscription to a daily energy ‘import’ cap (see also the Eigg microgrid case study in Section 8.1 below). Under normal conditions this is intended to incentivise self-consumption but under local grid outage conditions when limited service is being provided by BTM assets, the cap could be lowered to ensure basic service can be equitably maintained. While offering some of the same demand reduction potential as direct load control, this approach offers subscribers discretion over which loads to drop. Interestingly the study also observes the use of SMS to give warning of imminent poor or extreme weather events with the expectation that minigrid subscribers would seek to save energy in readiness for lower generation. Unfortunately, the paper does not describe how subscribers responded to these warnings although they note that cooling appliances used to store fish, the main source food, tended not to be switched off.

More importantly, it is significant that all of the studies reviewed are in the context of tradeable (or shareable) surplus over and above the household’s own self-consumption but where grid supply is available if required. In a grid outage situation, where households may be looking to conserve energy stored and/or generated (and replenished) behind the meter for their own use, the above insights may no longer hold. In particular, we would expect 'normal' price response to vary substantially depending on the household's inclination to 'share' and, perhaps more crucially, on its view of its own resources, and their prospects of replenishment. This is discussed in further detail below in the context of direct load control and vehicle-to-grid.

4.1.3 Environmental dimensions

As might be expected, pro-environmental attitudes and climate-change awareness have been found to be associated with interest in self-consumption, peer-to-peer trading and other forms of energy presumption (Adams, Brown, et al. 2021). Indeed in the Georgarakis et al (2021) study of Dutch prosumers and energy co-operative members, over 85% stated that 'Tackling Climate Change' was a motivator to install a renewable energy system with 75% stating 'reduce energy costs'. In contrast, reducing energy costs was not a motivator to join an energy co-operative or community (stated by 10%). In this case tackling climate change (80%) 'Decentralise energy production' (~ 60%) and 'Create a sense of community' appeared to be significant. Similarly, concerns about environmental and climate issues have been shown to be major motivators for participation in 'energy communities' (Soeiro and Ferreira Dias 2020) and these tend to align with more communitarian motivations such as enhancing local community interaction and engagement.

More subtly, a recent Austrian study of prospective energy community participants suggested that climate concerns, when framed in an individualistic manner, were less persuasive than when framed in a local or regional context (Kacperski et al. 2023). Attitudes to climate change have also been found to mediate stated energy trading preferences. Not unexpectedly, those with stronger pro-environmental views were more likely to offer discounts to schools and hospitals and also requested lower buying prices when attempting to purchase energy from large corporations (Hahnel and Fell 2022).

It seems likely therefore that households with BTM assets who are also more motivated by environmental and climate aspects would be more inclined to provide access to those assets for neighbours and local public services in a grid outage situation and at a relatively discounted price.

4.1.4 Social dimensions

The discussion of economic motivations also drew attention to the value respondents and participants place on non-monetary and social returns. Indeed many have characterised the motivation of 'energy communities' as integrative social action foremost and action on energy self-sufficiency and fossil fuel dependence reduction second (Parag and Sovacool 2016; Adams, Brown, et al. 2021; Wahlund and Palm 2022), although others have cautioned that the knowledge and capital resources required to engage in energy communities may continue to exclude the already marginalised (Tarhan 2022).

In this context pure economic gain has to be set alongside other 'social' returns that the prosumer/sager or prosager collective value. A number of the studies introduced above have noted the complexity of these values with survey-based work suggesting that 'creating a sense of community' and 'improving revenues of the community' were key motivators for engaging in energy co-operatives (Georgarakis et al. 2021). The same study, aligning with (Hahnel and Fell 2022), suggested that respondents were most likely to share (for indirect gain) surplus energy with local households who could not afford energy, public facilities in the community and familiar persons in the community. They were least likely to do this for a member of the community they did not know, highlighting the role of social networks and prospective indirect reciprocity in decisions to share scarce resources beyond the immediate household/family in the face of natural hazards (Ember et al. 2018; Brewis et al. 2019).

Interestingly, in contrast to expectations that relatives would be preferred for 'zero return' sharing (c.f. (Ember et al. 2018)), Georgarakis et al also found that 'local households who could not afford energy' were the most likely group to receive 'free energy' with 'family members' ranking third after 'nobody'. Whilst this result could be seen as confirming other work showing strong interest in social equity amongst prosumers (Wilkinson et al. 2020), these results should be viewed with caution given the potential effects of social acceptability bias.

Moving beyond survey-based work to more in-depth ethnographic studies, Singh et al (2018) conceptualise energy exchange as 'energy transfer' and 'return transfer' to highlight the often non-monetary returns that are directly or indirectly exchanged for energy. Their work notes a continuum of return types ranging from in-cash, to in-kind and intangible all of which co-exist and overlap with the social system in which the energy system is set. The preference for a type of return is shaped by social relationships between specific actors such that 'configuring a return' is a socio-cultural, not just an economic process. This becomes clear when considering their classification of returns:

- *in-cash* generally being preferred for 'socially distant' others, often with a desire for profit; not used at all for the 'socially intimate';
- *in-kind* being used for both 'socially distant' and 'socially close' others but with careful estimation of the monetary value of the in-kind service provided (such as labour, food items etc). For the 'socially close' profit was foregone;
- *intangible* being used only for 'socially intimate' others with much lower regard for value estimation. Intangible returns included offers of labour or expectations of goodwill, friendship or unspecified future social support

Based on these results Singh et al "*advocate for an off-grid setup where all the three types of returns are facilitated, and people are provided with the control to structure and choose from these returns depending on the varying contexts of energy exchanges*." P210. In doing so they echo a number of other studies (e.g. (Skjølsvold, Ryghaug, and Throndsen 2020; Pires Klein et al. 2021)) which encourage energy system practitioners to move beyond purely monetary economic exchange as the basis for local energy systems due to four key benefits:

- it would enable the energy trading system to become significantly more focused on people-centric exchange and local cultural processes enhancing both usefulness and 'acceptability';
- it would enable those with limited ability to pay in-cash to access energy services;
- it provides a way to link the energy system to local in-kind and intangible exchange systems;
- it supports dynamic and contextual re-configuration of value and returns.

The latter is especially important given the continuous malleability of social relationships. While these conclusions are generally framed in the context of rural communities in the global south, the insights are relevant to a local grid outage or extreme event situations in the global north when households may place a higher value on in-kind or intangible returns. However, there will be a need to guard against 'free-riders' who intentionally or unintentionally ‘over-demand’ leading to a degradation in service for all – a classic case of a tragedy of the commons (Hardin 1968). It may be that a sustainable system needs to use in-cash returns with socially distant others to mitigate this risk and to support the use of in-kind/intangible with socially intimate others reflecting trust and expected ‘fairness’. It is likely that some form of enforcement, such as direct load control or household level ‘brown-outs’ will also be necessary. As Kurz et al note, we cannot expect co-operative behaviour to manifest sustainably without the organisation and maintenance of some design principles in all but the most micro-community contexts. Rather, there may need to be “…*clearly defined thresholds of acceptable use per individual, participation in decision-making, effective monitoring, or graduated sanctions*” (Kurz et al. 2022).

4.1.5 Summary

Overall these different dimensions offer a number of insights for potential BTM asset-based resilience services:

- Those who have installed their assets for reasons of independence (autarky) may well resist attempts by ‘the network’ to control or share access to the energy provided by those assets. However, it is possible that emphasising the meso (neighbourhood) level independence that this would provide may act as a mediator;
- Those who are focused on economic returns may wish to use default or automatic tariff-setting for sharing their energy, once a certain own-charge threshold is reached and they may wish to set prices differentially for different ‘stakeholders’. We should expect the exact value of these differential prices to vary according to socio-political and environmental leanings but also the degree of local attachment, anonymity of the trades and the perceived need of the recipient;
- For maximum flexibility and utility, a service should enable in-kind and intangible social returns to be part of the system. Energy ‘gifting’, especially in times of disruption and for those perceived to be in greater need builds on current practices of local neighbourhood support and enables those who cannot ‘pay’ in monetary terms to contribute a future return in other ways. However, a system built purely on social returns would be at risk of exploitation by free riders. In a local BTM resilience service context where many of the stakeholders are known to each other this may be less risky than in a generalised ‘anonymous’ market system. Nevertheless it may still be necessary to provide some ‘restraints’ on levels of energy usage and potentially an enforceable cap.

More generally the studies of prosumers/prosumagers suggest that neighbourhoods with pre-existing energy co-operatives or ‘energy communities’ may provide ‘early adopters’ for such services. This would be especially the case for those who may have experienced supply outages in the past and particularly for those whose motivations include supporting local actors, improving equitable access to low cost energy and developing a more engaged and socially connected community.

4.2 Direct load control

In the absence of a body of evidence of how residential consumers/prosumers/prosumagers respond to grid outage situations, this section reviews consumer response when resource use is directly and deliberately curtailed to preserve system viability.

(Fell et al. 2015)’s survey-based study showed that for many people direct load control (DLC) is acceptable in principle but within tight bounds and with an override facility. However, the

DLC tariff presented to participants in this study was intentionally non-punitive, projecting a small ('less than 1°C') impact on internal temperature. Overall, only 30% of the respondents were strongly or somewhat against switching to the DLC tariff and Fell et al suggest that inclusion of unlimited overrides meant that people perceived themselves to retain sufficient control. This benign DLC tariff was reported as more acceptable than a time-of-use tariff which raised concerns over limitations on the timing of everyday activities in contrast to an occasional and small reduction in comfort. In the BTM resilience context, it may be that both consumers and prosumagers would be willing to accept direct load control provided an over-ride was available. However, the risk of enabling over-ride is that a household would then demand 'too much' from the limited service. In this situation some form of cap may need to be enforced (see for example: (Martin 2020; Prevedello and Werth 2021)).

A Swiss survey-based study (Yilmaz et al. 2020) found distinctions in the acceptance level of DLC for 'devices' (assets) such as heat pumps, electric boilers, PV systems, home batteries (more likely to accept) compared to 'appliances' (e.g. tumble dryers, washing machines, dishwashers, Evs – less likely to accept). This appeared to be driven by the different 'place' of assets vs appliances in the flow of everyday life – for example, families with children were less likely to accept DLC of appliances and confirms similar studies which showed "*that households' sensitivity to restrictions in electricity usage is much stronger than their sensitivity to restrictions in heating*" (Ruokamo et al. 2019). In the latter, such restrictions were least acceptable in the evening reflecting the importance of time-critical energy-using practices.

The Inclusion of EVs in the list of 'appliances' that respondents were less keen to see directly controlled may reflect the extent of dependency on mobility and concerns over having sufficient charge to complete household activities (see Section 4.3 on Vehicle-To-Grid). As interestingly, apartment dwellers appeared to be more accepting of DLC for devices than single home-owners possibly because apartment dwellers have more experience of incomplete control over energy infrastructures. However the authors also highlight the heterogeneity of responses across the sample, emphasising that acceptance of DLC was highly varied even though some common themes could be identified.

A discrete choice experiment intended to elicit load priority preferences in the context of DLC found that there was greater DLC acceptance for those who already owned BTM assets (Yilmaz, Cuony, and Chanez 2021). Further, financial incentives made a greater difference to accepting DLC over heat pumps whereas having an over-ride function had the strongest effect on increasing acceptance of DLC over EV charging followed by a monthly incentive of CHF 60 (~£55). As the authors note "*respondents want full control over the charging of the EV*" and they also indicated a preference for day ahead notification and no more than 20 DLC events per year. The study suggests that purely economic reward will not necessarily work for all 'appliances' due to other considerations such as the need for mobility and this is likely to be exacerbated for those who have high dependency concerns. In addition, the study found that trust was crucial with those who had least trust in the DNO/DSO's ability to provide transparent information also more sensitive to the presence of an over-ride facility.

Observational studies of living with DLC in the context of retrofit using heat pumps to replace gas boilers and a form of DLC to reduce heat pump energy use at specific times indicate that, for most respondents, DLC took place with no perceptible loss of comfort (Calver, Mander, and Abi Ghanem 2022). The results also suggested that those at home during the day had a higher degree of flexible energy consumption to offer DSR schemes and that the automated nature of the intervention enabled participation in flexible electricity consumption for households who were not strongly energy or digitally literate and who lacked infrastructure investment capital. However, the authors also point out that this relies on system installation as a public investment or as a commercial service paid for out of demand reduction benefits to avoid an up-front cost barrier. The study also raised the issue of private renters who may be at risk of energy vulnerability but who are unable to alter their energy infrastructure to benefit. Finally, the study's review of the retrofit and installation process highlighted improvements in the way householders could have been engaged in the process rather than having the intervention 'done to them'. This is an important lesson for prospective local BTM resilience services which are likely to depend on the more active and pro-active engagement of a range of neighbours with varying degrees of energy and other literacies.

In the context of EV smart charging, Libbertson (2022) found that willingness to relinquish control depended on factors beyond their respondents' control such as work patterns and access to charging stations. They conclude that attitudes or stated preferences which may indicate positive inclinations to relinquish control of charging and offer flexibility services to the grid may fade in the light of practical and perceived everyday life constraints. These constraints will need to be addressed if effective and equitable flexibility markets are to emerge.

Finally, a recent survey-based study of motivators for joining a hypothetical direct load control service (Sridhar et al. 2023) found that respondents formed 3 clusters:

- Adopters: 17.1% - motivated mainly by interest in technology and home automation (classic early adopters c.f. (Rogers 2010)); local generation as a higher motivator than financial and environmental factors, slightly prefer environmental over financial motivators; less likely to be female, less likely to be highly educated
- Followers: 31.4% - low interest in technology in new programs; low preference towards local generation; encouragement by contacts as a high motivator; lower income & semi-detached homes (?)
- Neutral: 51.5% (the rest)

When analysing respondent attributes the study suggested that

- Age group 60+ - had a higher preference towards smart home automation over local generation than age group 40–49;
- Age group 60+ - had a higher preference towards smart home automation over financial benefits than age groups 40–49 and 30–39;
- Respondents with basic education prefer other motivators than smart home automation when compared with people with 'higher' education.

The paper concludes that DLC service providers should focus on the Adopter group because they had a stronger inclination to participate and a stronger interest in automation. According to their results the authors conclude that these were typically male with lower education levels. However, taking into account the clusters and the varying factors that indicated cluster membership, the study concluded no single dimension was likely to increase residential DLC participation and different groups would need to be targeted individually.

In summary, experiences with and preferences for direct load control suggest that BTM asset owners may be amenable to direct and automatic control over their assets in a grid outage situation. However, as discussed above with respect to peer-to-peer trading and in the next section with respect to vehicle-to-grid, this is likely to be mediated by their perceptions of dependency on their own resources. This in turn may depend on being able to 'over-ride' to preserve their own energy resources (but at risk of at least inconveniencing neighbours) when time-critical energy-uses are needed. This seems especially likely in the evenings for some types of households (e.g. those with children) provided 'normal' patterns of work and schooling are maintained through the outage. More importantly, financial incentives may not overcome some of these constraints.

4.3 Vehicle-To-Grid

In contrast to direct load control, vehicle-to-grid provides a case study of how users respond to a context where they may be attempting to preserve a scarce resource (electric mobility) at the same time as being incentivised to use power for self-consumption in the home or even to sell or trade.

Studies focused on V2G confirm the findings discussed above in the context of direct load control. For example, in contrast to the results reported in Section 4.2, a discrete choice experiment study suggested that existing and potential electric car and solar PV users were more likely to state a higher willingness to engage in flexibility (allow higher degrees of DLC) than heat pump users (Kubli, Loock, and Wüstenhagen 2018). However, the study also showed that EV respondents had differential response depending on the state of remaining charge with flexibility far less acceptable if guaranteed charging levels decline below 60% of a full charge (see above discussion of studies of propensity to trade energy under different states of battery charge (Hahnel et al. 2020)). Although this is indicative of a threshold effect, the 60% value was most likely an artefact of the choice scenario. More detailed analysis suggested that an incentive of ~ £40/month (CHF 45) would be required to shift respondents from a 'no flex' (0% EV discharge to grid) to a 'fully flex' (up to 60% discharge) DLC situation. This value was much lower for shifting to PV 'fully flex' and much higher (exceeding mean bill size) for heat pump fully flex and contrasts with the relative acceptance of HP load deferral discussed in Section 4.2 with respect to DLC. This may reflect the difference between having experienced thermal load deferral with seemingly little loss of comfort compared to the presentation of an apparently 'uncomfortable' flexibility option in a choice experiment.

The concerns over battery state of charge/range anxiety as a key factor in V2G preferences are also highlighted in qualitative interview studies of Dutch EV drivers (van Heuveln et al. 2021) with additional requirements for financial incentives and reliable user system control. This is supported by a further study which noted increased anxiety about range, the need to plan more carefully and, interestingly, the potential restriction on freedoms that users tended to associate with personal vehicles (Ghotge et al. 2022).

Adding more nuance, a choice experiment suggested that although Dutch EV drivers preferred not to engage in V2G contracts this was reversed when fast-charging was available (Huang et al. 2021). This is explained with reference to concerns over 'discharging cycles' and 'the guaranteed minimum battery level' both of which decline in importance when users had access to fast charging.

Overall, these studies reinforce the evidence discussed above that there may be limits/constraints to propensity for V2G in a BTM resilience situation and that this is likely to depend on the state of charge in the context of the household's perceived need for both mobility and self-use. This is especially the case where the householder has concerns about dependency on storage and the ability to replenish. However, given that 'normal preferences' may shift in a grid outage situation where resources are suddenly scarce for local social networks such as family & neighbours the 'sharing threshold' may shift and the apparent need for financial compensation may reduce (see Section 4.2). Further, if EV battery replenishment via PV or by driving to a charging point (e.g. work etc) is feasible then predicting availability 'tomorrow' (c.f. the Eigg energy system (Martin 2020)) may shift these thresholds further.

5 "We're all vulnerable now"

Following on from the previous discussions of vulnerability during power outages and the existence of Priority Service Registers or similar, a number of authors have noted that key indicators of 'vulnerability' may need to be adjusted given ongoing socio-technical trends.

For example, as a recent conceptual paper notes "*It is unclear how affluent households who are used to constant access to electricity would be affected by and deal with an increased variability in availability of electricity…. However, it is clear that a future with more disruptions is in conflict with the increasing reliance on electricity that we see across many parts of society today*." (Hasselqvist, Renström, Strömberg, et al. 2022).

The paper goes on to consider 4 dimensions of future energy resilience:

- *Backup (electrical) energy sources* – which allow continuing use in outages albeit with the risk of reinforcing inequalities (need for investment capital, space to house, knowledge to acquire and run). To most customers these are likely to represent novel storage technologies but can address the 'problem' of relying on alternative fossil fuels which are seen as poor options due to emissions, pollution, difficulty of access to resource (e.g. firewood) and the difficulty of implementing in urban areas once households have moved off gas.
- *Energy efficiency* – widespread transition to energy efficient appliances but also the improvement of thermal performance in buildings (to reduce heat loss) in order to reduce energy use in shortages. This may not be that helpful in outages unless 1 is also implemented. Energy efficiency is a widely understood and accepted principle but like 1) it requires capital and knowledge and may be inaccessible to tenants in the sizeable rented sector unless landlords are prepared to invest;
- *Flexibility* – shifting use during shortages. This is considered less useful during outages unless 1) is implemented and is needed to allow for battery re-charge from self-generation to 'spread the load' in a BTM resilience service context. There are risks of inequality/injustice as not everyone is equally flexible (Powells and Fell 2019; Fell 2019) and flexibility entails adjustment to the timing of everyday practices. Enacting flexibility through changing location (evacuating self or goods & appliances) requires relatively local social ties (or community sites) that can be enacted. Flexibility would also require a means for households to prioritise energy usages in time of outage/low supply and these priorities are likely to differ between different households.
- *Energy sufficiency* – (see Section 6) reducing the levels of energy used to allow 'life to go on' in shortages and outages. In the latter case this implies electricity independent activities but this could be avoided in the BTM resilience service context although

> this would still require ‘sufficiency’ to prevent ‘over demand’. Sufficiency is therefore seen as contributing to 1) if own or ‘shared’ energy resources are scarce. Sufficiency can partly be enacted through 2) but it also implicitly requires high energy-use households, who are generally more affluent, to actively reflect on their energy-intensive practices and reconfigure what they do. Outages can lead to such reflections and adaptations if there is the perceived potential to repeat (see Section 4.2 on experiences and adaption to outages). However, changing energy-intensive practices can be daunting and difficult especially where they are seen as integral to living ‘a good life’. In addition, it is very challenging to agree on levels of sufficiency if this is needed to define resilience services or policies. While the concept goes against prevailing notions of growth and prosperity, there is evidence that taking a sufficiency approach to consumption leads to positive effects such as freeing up time for other activities, increased wellbeing, and improved finances.

The paper concludes that this framework allows ‘resilience service stakeholders’ to develop localised solutions that incorporate different aspects of these four dimensions. It also enables households to move beyond reactive consumers to be more engaged and pro-active in their own resilient energy futures. In particular, the paper suggests that increasing energy resilience using any or a mix of the above will give customers confidence in their and the network’s ability to lead ‘good life’ in a slightly more uncertain future where partial disruptions are more frequent. This in turn will allow a more rapid transformation to a renewable and climate-resilient energy system since:

“*the use of back-up sources decouples a good life from constant* grid-based *electricity supply, efficiency lowers the demand during shortages while sufficiency and flexibility have the potential to decouple a good life from constant electricity supply, independent of source, but flexibility for shorter periods and sufficiency longer and more permanently*” (Hasselqvist, Renström, Strömberg, et al. 2022, 8)

In particular the authors envisage utilising a combination of these dimensions to “live a good life” suggesting that, although a back-up system may not deliver enough power to run a washing machine, the household can be flexible (wash later) or sufficient (air out clothes, or spot clean by hand). The key however is to recognise that there will be a mix of responses by different households based on context, habits and their understanding of the likely duration and level of the shortage/outage (c.f. Section 4.2).

Following on from the suggestion that the digital interconnectedness and digital dependence of societies the global north is an emerging vulnerability, Cox describes a diary-interview based study of potentially novel energy vulnerabilities in the case of power outages in an urban setting (Cox 2023).

The paper notes that assumptions about direct linkages between vulnerability and age and income may be misplaced. For example, the results suggest that poor health is more relevant than age per se, although acknowledging that older people would be expected to have a higher prevalence of ill health. However older people also considered themselves more confident of their ability to adapt based on lifetime experiences of electricity outages and a relative lack of digital dependence.

Social ties (social capital) were considered more significant than income resources (economic capital) with low-income participants seeing themselves as part of strong local social networks in the immediate neighbourhood which provided a high adaptive capacity. This was contrasted with a respondent living in a large house in the suburbs who commented on the ‘relative anonymity’ of her neighbourhood. As with the studies of actual outages described above, respondents were particularly sensitive to the role mobile and other forms of communication media played in their ability to cope giving a strongly expressed need to ensure charging of mobile phone batteries and maintenance of mobile network coverage.

Respondents’ own perceptions of the fixed or flexible nature of their structures and routines also affected their perception of their ability to cope in an outage situation and may also affect their propensity to share energy in a BTM resilience service context. In contrast to the findings from the direct load control section, this was especially noted with respect to morning ready-for-work/school routines which were seen as the hardest to shift.

In terms of material responses, participants noted that they would be increasingly reliant on ‘on-gas’ neighbours for access to cooking or heated water with norms of ‘required’ cleanliness coming to the fore in terms of personal washing and access to clean clothes.

Some mentioned solar PV as a partial solution but saw eVs as an additional dependency rather than a solution, potentially due to lack of knowledge of V2G concepts. This concern is also reflected in the quite general view that a vehicle represents a final exit strategy in extremis and can also provide access to heat/cool (c.f. Section 8.5–- Louisiana: Hurricane Isaac).

Finally, and in common with observations of response to outages, respondents noted that concerns over duration would not necessarily be linear but would have ‘cliff-edges’ when, for example, freezer contents defrosted, medical equipment no longer worked, mobile phones ran out of charge or other sources of support such as local shops suffered similar cascading loss of service.

The paper concludes that community level actions could improve resilience and that local scales may be more appropriate for identifying vulnerabilities than customer-level or aggregated demographics. This follows from their observation of the complex relationship between ‘standard’ demographics and vulnerability, particularly illustrated by the consensus amongst interviewees that “younger people are more vulnerable due to their digital dependency and higher expectations of energy availability”. Social isolation (e.g. recent residency with solo living with few local ties) and digital dependence may therefore need to be considered as part of the evolution of vulnerability indices as should thermal efficiency of the home to reduce heat loss and the presence of working parents with children who are known to find outages additionally stressful due to the disruption to tightly integrated habits.

However, the paper also notes that local-scaled identification of vulnerabilities is resource intensive and needs to be ‘properly’ resourced suggesting that ‘meso’ level organisations such as the Regional Resilience Partnerships in Scotland[4] or Local Resilience Forums in England[5] may be best placed to do this rather than network operators. These organisations might also be able to provide the kind of close engagement with stakeholders that is known to enhance the chances of success (Adams, Brown, et al. 2021). This could also enable the development of more locally suitable knowledge bases and plans (similar to or as part of

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[4] New Zealand has similar regional Civil Defence emergency management groups https://www.civildefence.govt.nz/find-your-civil-defence-group/

[5] https://www.gov.uk/guidance/local-resilience-forums-contact-details - although these are based on relatively large Police Force operating areas.

community emergency plans[6]) which can reserve institutional resources for those who are most marginalised or vulnerable. They would also help to shift the 'burden' of coping from the individual by emphasising collective preparedness and resources which may also benefit from economies of scale.

6 Energy sufficiency – how much is enough?

With respect to different 'levels' of service, recent academic research, building on work on planetary limits and equality of access to resources, has started to ask whether energy sufficiency could be usefully defined in order to propose how much of a service is 'enough' and for whom (Tina Fawcett and Sarah Darby 2019; Sorrell, Gatersleben, and Druckman 2020). In this case sufficiency is taken to mean "*a state in which people's basic needs for energy services are met equitably and ecological limits are respected*." (Tina Fawcett and Sarah Darby 2019, 2) and in the case of BTM asset-based resilience services, we can apply the 'ecological limits' phrase to the limits of the islanded system.

Sufficiency is conceived as being a 'social foundation' where basic needs are met thus 'sufficient' energy services must meet needs for shelter, health, work, mobility and communication. This framing intentionally contrasts 'needs' with 'wants' and continues a long-standing debate on the nature and basis for distinctions between the two. Inevitably "*a sufficiency framing will involve challenging social and political debates, and technological advances will not allow us to side-step these*." (Tina Fawcett and Sarah Darby 2019, 1).

However, given that other policy areas, such as income and benefit support, implicitly or explicitly make judgements about what is 'sufficient', Fawcett and Darby argue that such judgements should also be possible in the energy sphere. As they point out what is considered a 'basic need' has the tendency to be renegotiated over time in all spheres as recent work on the upwards ratcheting of 'socially desirable' levels of heating, cooling and other 'basic needs' has identified (Shove 2003; Kuijer and Watson 2017).

Nevertheless Fawcett and Darby point out that 'sufficiency' is implicitly embedded in:

- decisions about rising block tariffs that increase energy prices as usage passes certain thresholds (Prasanna et al. 2018), or decisions about lower tariff rates for specific (e.g. low income) groups;
- demand capacity charges which apply higher cost bandings to increase capacity available to specific users or conversely capped rates which apply to all users (as discussed below in the Eigg microgrid context);
- concepts of under and over-crowding and thus of permitted housing size, floor area and density which, although not specifically energy policy nevertheless have consequences for energy use since larger spaces generally require more energy to attain comfort.

In discussion Fawcett and Darby note that "*judgements on what is sufficient are place- and time-sensitive and also influenced by history, by infrastructures and cultural norms*"(Tina Fawcett and Sarah Darby 2019, 9) making it very difficult to reach consensus. However they see the distributional problem of how to allocate resources according to need between people as an even more fundamental challenge and point to the UK work on a Minimum

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[6] https://www.gov.uk/government/publications/preparing-for-emergencies/preparing-for-emergencies#community-resilience

Income Standard (Davis et al. 2020) as offering potential methods to develop conceptions of energy sufficiency.

These concepts are conceptually linked to a capabilities approach to energy services (Tiwari et al. 2022) which focuses on well-being and achieving the level of service required rather than binary access to x or y kW. According to the authors this enables the distinction between the different services that electricity offers, moving the analysis away from measured access or supply to a focus on the quality of service provided and the capabilities and function this provides.

As has been alluded to in a number of previous sections Tiwari et al note that "*the capabilities of a household member will depend on the type of people living in that household and hence their specific needs*." This might include the number of different household members (infants, those with disabilities, those with ill-health, those with caring responsibilities for dependents) with different needs and will vary according to a range of social and health-related dimensions. This means that "*they will need different forms and levels of energy services for functioning, and the resilience of a system cannot be accurately measured or understood if we only look at electricity supply security*".

This implies that equitable or 'just' resilience services which ensure that the infrastructure can provide what households need may vary substantially within and across communities. As noted above establishing these needs is likely to be a difficult and highly context-specific task even where some forms of basic levels of service (e.g. lighting and refrigeration) are presumed. Who, for example, may need a higher level of service to enable health or care-related functioning?

Establishing a hierarchy of services in different contexts is therefore seen as highly contingent and is one reason that defining 'sufficiency' in any given context is challenging, especially for those unused to imposed system limits on behaviour. One tool for eliciting such hierarchies, SMARTER instruments/surveys have recently been trialed in a study designed to understand the relative 'importance' of a number of household appliance uses. (Aloise-Young et al. 2021). This approach presented visualisations of 'comfort shapes' for home temperature, shower duration and temperature, dish-washing and laundry and asked respondents to order them according to a range of dimensions. The results suggested that a comfortable air temperature ranked higher than any other 'load' and that shower temperature was more important than duration. The point here is not necessarily the 'average' result but exploring the heterogeneity of results to indicate the extent to which most respondents, or specific groups of respondents, report similar rankings.

It may therefore be possible to use a form of this method to elicit 'sufficiency' preferences from groups of customers in particular locations to inform the design of BTM asset-based resilience services. This might help to highlight not just 'commonly held preferences' as core 'sufficiency' levels but also 'outliers' who for particular reasons of health or other 'need', have distinctly different preferences and thus potentially require a different level of 'sufficiency'. Further, as (Aloise-Young et al. 2021) point out, utilising these methods in the user interface to a BTM asset-based resilience service might allow users to set 'default sufficiency preferences' for load curtailment (or service usage levels) which can support the efficient management of the service. However, in the absence of mechanisms to limit 'over-use', whether social or financial, we might expect 'rational actors' to set these as high as possible to maximise personal benefit rather than to minimise energy use to a basic 'sufficiency' level. Given recent critiques of this model for human action in the energy sector

(Strengers 2014; Andor and Fels 2018; Buckley 2020) and the evidence of socially but not economically 'rational' behaviour in times of supply outages described above, whether such 'selfish settings' will actually play out in practice is unclear.

7 A social license to automate

A crucial aspect of potential BTM asset-based resilience services will be the degree of automation that is required to make the service work effectively and immediately and which is accommodated by the actors (stakeholders) who constitute the service. As preceding sections have discussed, some of those with BTM assets are likely to be content with an automatic 'sharing' of resources up to some sort of default thresholds, perhaps to ensure their own basic level of service can be maintained, while others may prefer to more malleable system which enables them to set sharing thresholds according to the recipient of the energy.

These considerations have recently become the focus of research on the 'social license to automate' (Adams, Kuch, et al. 2021; Michellod et al. 2022). These studies draw on concepts developed to characterise the 'social license to operate' between communities and resource extractors (e.g. mining) which suggest three critical dimensions:

1. <u>Economic legitimacy</u> – providing financial benefits to the community and other stakeholders;
2. <u>Socio-political legitimacy</u> – respecting local ways of life and contributing to the well-being of the locality in financial and non-financial ways;
3. <u>Interactional trust</u> – the company involved is seen to listen, respond and keep to agreements.

The highest level of community support (identification) is considered to be reached when all three of these precursor dimensions are met and trust in the company becomes institutionalised rather than purely interactional (Michellod et al. 2022).

Initially focusing on flexibility and demand response, Adams et al (2021) use this lens to suggest that although intended to 'hide' system activity, automation nevertheless depends on the engagement and consent of the user. From an instrumentalist perspective, this will depend in turn on the balance of benefits and disadvantages (legitimacy). This is particularly the case where the automation encroaches on the users' perceptions of their own control over energy use in the home. Perfectly illustrated by a number of the studies of PV and EV owners discussed above, this can manifest through stated distrust of the motivations of the automation; concerns that resources will not be available 'when needed' and potential loss of comfort or disruption to household practices. Users have been shown to prefer ownership of automation systems by independent organisations or governments rather than commercial utilities and have also indicated a preference for locally managed semi-automation which keeps usage and other forms of data either local or completely private. Overall, it is suggested that users may be more open to schemes which preserve a sense of control perhaps through the setting of defaults or the ability to adjust automation schedules.

These findings can also be extended to 'energy communities' where organisational form (public vs private) and forms of governance are strong determinants of user willingness to ceded control and allow access to data for system management purposes. A second critical factor is then the rationale for who benefits from the system's automation. In the case of BTM asset-based resilience this means that the 'resilience' benefit to the consumers involved will need to be clearly articulated with as little room for mistrust or perceptions of 'other agendas' as possible. As noted elsewhere, communities which have long experience (or recent severe experience) of supply disruptions may weigh the benefits and disadvantages differently to those with other experiences (Skjølsvold, Ryghaug, and Throndsen 2020). Nevertheless, it is likely that transparency of benefits will be key, as will decisions about which organisational form will take the lead in offering the service and the extent to which communities can be involved in co-owning, co-managing and co-benefiting from the service. This may require network operators to move beyond conceptions of 'public acceptance' and enable users to play very active roles in co-creating and shaping their energy infrastructures (Strengers 2012; Ryghaug, Skjølsvold, and Heidenreich 2018). In all cases, identifying and ensuring "*economic legitimacy, socio-political legitimacy, and interactional trust*" dimensions are sufficiently met will be crucial to building community support (Adams, Brown, et al. 2021; Michellod et al. 2022).

8 Case studies

This section provides a number of case studies that illustrate the themes and insights that have emerged from the academic studies reviewed above. They range from studies of island microgrids in Scotland, Thailand and the Philippines to the use of Solar Home Systems in Bangladesh and experiences of grid outages during recent severe weather events.

8.1 Eigg Electric: the Eigg microgrid

Eigg is a small island off the south west coast of Scotland which, at the time of a study by Martin (2020), had a population of 105. Eigg has a long-standing electricity microgrid building on earlier household-level energy self-sufficiency. The microgrid comprises a mix of intermittent renewables (micro-hydro, solar, wind) and back-up diesel generation. The system, Eigg Electric, is owned and managed by the community with paid residents conducting monitoring and some basic maintenance. Domestic power consumption is capped at 5kW per household, irrespective of household size or 'need' and should this cap be exceeded, the household's power is temporarily shut off in an extreme version of punitive direct load control but seemingly with a social license to automate (see Section 7). This encourages householders to generally reduce energy consumption and 'spread' use out over time (energy use shifting) to ensure their own continuity of service. Perceptions of 'sufficiency' (see Section 6) are therefore set in the 5 kW household cap rather than by any agreement on what sufficient power constitutes for a specific or group of households (see also (Prevedello and Werth 2021) for a similar example in the Philippines). Islanders are encouraged to heat and cook using other energy sources (wood, kerosene, bottled gas). There is an explicit understanding amongst islanders that appliances or uses that require/produce heat will break the threshold, and this understanding often appears to emerge through experimentation and trial and error, rather than the use of energy monitors to make estimates of appliance usage.

Martin (2020) describes how the Eigg micro-grid users attend to environmental and sensory information (not an energy monitor) to self-regulate demand in order to 'fit' with intermittent renewable generation. On Eigg, "*an intermittent energy supply, and the need for energy shedding and shifting, are not novel, but instead part of the everyday*". This may offer insights for the design of user interfaces for BTM local resilience platforms since the ongoing availability of (re)charged storage assets or of solar PV-based energy will depend to a great extent on future weather conditions. Making visible the ‘state’ of the system is one approach but the study of Eigg users also suggests a very strong orientation to local weather conditions and the effect these will have on the availability of intermittent generation. This in turn leads to active self-regulation of usage.

Interestingly Martin also discusses the everyday visibility of ‘frequency’ to users of Eigg electric. Islanders are aware that other people’s usage (and their own) can have deleterious effects on system frequency so that appliances or components stop working even though ‘there is power’. Martin recorded various levels of understanding of the reasons for this which usually focused on experiences with specific services that have been interrupted – such as doing the laundry.

In the case of Eigg, actors in Eigg Electric are well known to each other such that there is a strong level of trust that fair use will be enacted– although still controlled by the cap. The community was also familiar with microgeneration and so may already have been more ‘energy literate’ than other neighbourhoods. Nevertheless, experiences with Eigg Electric suggest that BTM asset-based resilience services could:

- encourage members to internalise simple rules of thumb to ensure system continuity rather than emphasise ‘kW counting’ or appliance monitoring. These could include, for example: “anything that significantly heats up or cools down uses more energy and should be avoided”;
- promote self-regulation by encouraging members to pay attention to environmental cues which can inform them of the potential availability of intermittent generation (and subsequent storage);
- implement an enforceable cap to preserve system viability even if a trading system designed to prevent ‘over-demand’ is in play;
- provide additional information (and feedback) on potential frequency issues and their manifestation.

8.2 Islanded microgrids in Thailand and the Philippines

The Philippines rank 4th in terms of climate related risks while Thailand ranks 9th (Eckstein, Künzel, and Schäfer 2021) making resilience of critical systems such as food, water, health and energy a critical concern for both countries.

A recent review paper presents a useful discussion of what makes resilient island microgrids resilient – these are intentionally islanded microgrids intended to work ‘standalone’ as an integrated energy market rather than provide critical services in the event of a grid disconnection (Delina, Ocon, and Esparcia 2020). Nevertheless, the paper offers more generic implications for implementing BTM-based local resiliency:

(1) Such microgrids require a shift in the relationships between consumers and service providers with a shift towards user-ownership of significant parts of the energy system. This requires buy-in from users which is essential to encouraging end-user care of the energy system – in contrast to the ‘not my problem’ views report by Snow et al (2022) for Australian PV owners;
(2) Systems and their processes should be embedded in and emphasise the well-being of the socially and environmentally vulnerable among the communities they serve and must recognise the complex political economies of their locales – one size will not fit all;

(3) There will need to be substantial investment in or provision of technical, managerial, and entrepreneurial capacity to ensure user-operators can maintain their energy systems before, during and after extreme events. If possible, this should enable scalable self-help through local skills which can be rapidly drawn on in times of need[7]. The paper emphasises the case for small scale modular micro-systems for use in households and small communities because they can easily self-organise, ideally requiring little external support to function.

The paper then proposes a process of developing a thorough understanding of context-specific and local vulnerabilities although it is unclear how this can scale to multiple communities unless each 'community' carries out the assessment (see Section 6). Finally, they argue it is crucial that the stakeholders in these socio-technical systems, from end-users to community organisations to governments and businesses must be willing to embrace the changes required to successfully implement and maintain such a system (see Section 7).

Based on their case studies, which exhibited a mix of solar, biogas, wind and biomass energy sources, they note that:

- locally available, demand-responsive, sustainable, and renewable fuels were preferred in order to end reliance on (imported) fossil fuels;
- the availability, reliability, and adequacy of energy services was achieved through independence, modularity, and flexibility of the assets – in one case these assets were held at the household level, in the other at the community level;
- putting resilient energy systems in place had decreased vulnerabilities, while increasing peoples' motivation to cope with emergent challenges, including extreme ones.

The authors note that most of the technologies required are already commercially available and, with costs also declining "*more community-based awareness-raising and capacity strengthening remain imperative for scaling up energy resiliency in many climate-vulnerable off-grid islands*." This conclusion can readily be extended to BTM asset-based resilience services because some level of local skilled capacity will be necessary to ensure system sustainability – a potential role for local disaster management partnerships or local energy groups/co-operatives.

Finally, the study also points out that "*not all climate-vulnerable islands have the same strong and empowered social infrastructures*" implying that some communities will be more receptive to BTM resilience services, and more able to grasp their opportunities than others. As the authors conclude "*Closing capacity, policy, and funding gaps helps in countering the romanticised notion that all community-oriented projects, or, in this case, island projects, are or will always be successful*." Similarly, we should not expect all 'communities' to be receptive to the BTM resilience service ideas, especially if they have no experience of grid outages and little in the way of energy literacy or local social infrastructures.

8.3 Post-disaster Bangladesh

Bangladesh suffers from both extreme weather events (cyclones), coastal flooding and river flooding due to rainfall in upstream catchment areas (Amin et al. 2021) making it the ^{7t}h worst-hit nation for climate related risks (Eckstein, Künzel, and Schäfer 2021). As a result, the

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[7] e.g. Community First Responder networks: https://www.sja.org.uk/get-involved/volunteer-opportunities/community-first-responders/

Bangladesh energy infrastructure regularly faces severe risk and damage. While 97% of Bangladeshi's can now access electricity this supply is fragile and regularly impacted by natural disasters.

The potential for local or even household level minigrids to alleviate this problem has been noted, as has the potential to ensure more reliable and affordable electricity for those in energy poverty (Khan 2019). Partly in response to these issues a Solar Home System (SHS) installation programme, managed by a Government financial institution, has supported the installation of combined solar PV and battery storage. The programme has been seen as a regional exemplar for the installation of sustainable and distributed generation (Amin et al. 2021) with a number of studies highlighting the social and economic benefits that accrue (Kabir, Kim, and Szulejko 2017; Khan 2020; Hossain, Shapna, and Li 2023). Khan's analysis in particular highlights the role of reliability as a key driver and outcome, while affordability of the investment required was a key barrier. Key benefits included the use of light to allow increased study time for children, lengthened working or trading hours and additional entrepreneurship or home-based commercial activities. This provided greater income generation, cost savings from reduced kerosene use for lighting and other purposes and improved internal and external air quality due to the avoidance of kerosene burning and diesel generators. Other benefits included improved access to information (via TV/radio) or communication resources such as market information and farming practice advice which was highly valued by rural agricultural communities (Kabir, Kim, and Szulejko 2017; Khan 2020).

Focusing on the role of SHS in disaster response, Amin et al's (2021) survey-based study showed that those who had adopted SHS had a significantly reduced chance of experiencing disaster damage and disruption. In particular, their econometric modelling suggests that experiencing frequent damage, previously having used SHS and having young children were key predictors of using SHS as the main source of energy in a post-disaster situation. Experiencing damage alone was not a predictor, suggesting that adopting SHS was not a coping mechanism for Bangladeshi households and the study points to the increased risk of damage to lower income households who in turn still face financial barriers to the adoption of SHS, despite government support. Interestingly the results also suggest that those in less susceptible areas and housing types were also less likely to use SHS as a main energy source after a disaster since their grid connection may be more resilient.

Unfortunately neither Amin et al's (2021) study nor the more generic assessments of the impact of SHS in Bangladesh (such as (Hossain, Shapna, and Li 2023)) discussed above provide insights into what SHS owners actually do in a disaster situation in terms of self-use and sharing energy with non-SHS owning neighbours.

8.4 Puerto Rico: Hurricane Maria (2007)

Casa Pueblo, a grassroots citizen's organisation originally formed to combat large scale open-cast mining plans in Puerto Rico installed a solar array on its large renovated house/building in 1999 (Massol-González, Johnnidis, and Massol-Deyá 2008). Following Hurricane Maria in 2007, which left some parts of the island without power for up to 18 months (Krantz 2020), Casa Pueblo "*was able to share the electricity it generated with residents relying on home* *medical equipment such as respirators*"[8]. This transformed the building in to a 'pop-up hospital' (Krantz 2020) and inspired community leaders to pursue an externally funded microgrid programme. This programme installed solar panels on the roofs of 13 local businesses in the Adjuntas region in return for an agreement to provide critical services such as medicines, refrigeration and cell-phone charging during a future major power outage. In return the business received cheaper electricity (via self-consumption) and avoided the need to use expensive diesel generators. An important part of this work was the design and implementation of micro-grid controllers that could co-ordinate with each other to ensure that damaged parts of the microgrid could still receive energy resources from other parts. This has included understanding the spatial and temporal distribution of different loads on the microgrids such as a bakery businesses vs a small shop.

More recently a larger programme of mini-grid and micro-grid design has been implemented by the U.S. Department of Energy specifically aimed at providing behind the meter distributed energy resources to improve resilience to future storms (Mahmud, Narang, and Ingram 2022). Further community-based initiatives in other parts of the island have included a "*16-kilowatt PV system to power a community centre housing an art-therapy space, a kitchen, a laundry room and a library*" and a "*four-kilowatt PV system to power a community centre's refrigerators*". Other projects have installed mini-grids for schools, health clinics and hospitals. In all cases the role of local communities in 'co-producing' these solutions is considered crucial to their ongoing success (in contrast to an unsuccessful Tesla-funded 'parachuted' project which failed to engage local communities) while "*Puerto Ricans also have seen solar as key to energy independence and energy sovereignty*" (Krantz 2020) in direct reference to the autarky motivations discussed in Section 4.1.1.

While the engagement with and co-production of resilience solutions with the communities has been discussed elsewhere in this report, the Puerto Rico experience highlights the need to consider local business premises in BTM asset-based resilience. Businesses would have an economic incentive to take part and may also be able to provide continuity of their own service during an outage. As the next case study shows, this may be particularly relevant for (fossil) fuel stations and local food/grocery shops.

8.5 Louisiana: Hurricane Isaac (2012)

In 2012 Hurricane Isaac affected large parts of the US state of Louisiana with over 1 million people losing power, some for up to 10 days. Citizens had little previous experience of extended power cuts as they tended to evacuate during hurricanes but did not do so in this case as forecast storm severity was relatively low. The hurricane brought relatively little damage or flooding except for the interruption to power supply which was therefore experienced by a very large number of customers.

A retrospective study showed that access to communications (mobile phone charging) and energy-using healthcare services became a key issue (Rubin and Rogers 2019). Hospitals, most of whom had back-up generators following previous hurricanes, saw increased demand not specifically for health services but for 'health appliance use' services. As Rubin and Rogers note "*Reliance on electrical equipment may itself be partly a product of socio-economic status, with those who are more affluent being more likely to use (and suffer from*

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[8] https://www.ornl.gov/news/researchers-bring-more-reliable-electricity-puerto-rican-microgrids

the loss of) electric home aides and air conditioners to manage their health conditions". As the outage continued, local libraries and Red Cross shelters began to act as 'electricity shelters' to reduce the burden on hospitals.

These findings were confirmed by an interview-based study of emergency managers, politicians and business owners which highlighted a number of consequences of the outage (Miles, Jagielo, and Gallagher 2016):

- Traffic congestion – since there was little evacuation, members of the public drove their cars to stay cool using air conditioning, to look for working fuel stations, purchase food and supplies, or even to view damage from the storm. Further, traffic light outages contributed significantly to traffic congestion which caused delays in "*deliveries of food and other supplies to nursing homes and assisted living facilities*";
- Lack of fuel – almost all fuel station pumps were inoperable due to the lack of back-up generators;
- Sewage system failure – almost 75% of sewage lifting pumps were inoperable although there was some evidence of preparedness following previous hurricanes so that generators were in place at some;
- Cell (mobile) towers were mostly not affected due to use of diesel generators and batteries but communication services could not be used to the public's inability to charge their phone;
- School closures – caused significant disruption for working families where their work place still functioned;
- Healthcare services were generally prepared (own generators) due to previous hurricane experiences and it was noted that some private dialysis centres ran 'pre-dialysis' in preparation. However, many assisted living centres did not have generators and needed help to evacuate or were otherwise ill prepared;
- From a commercial point of view, small businesses, especially local grocery and food businesses were hit the hardest as they tended not to have back-up generators.

In common with the outage studies reviewed in Section 4.2, key issues were uncertainty and poor communication over the potential duration of the outage meaning that customers could not make appropriate adaption plans.

Finally, echoing Rubin and Rogers, Miles et al conclude "*The practice of temporary electricity shelters or collective charging stations is worthwhile for emergency managers and hospitals to develop further. Offering such shelters for the public to recharge devices could reduce unnecessary burdens on health care facilities*."

Apart from adding to the list of 'key disruptions', the main insight for BTM asset-based resilience services is that it may be most efficient to use the aggregated feeder-based capacity available to provide services in a particular place that is easily reachable by residents. This could be a public 'hub' a specific business premises or even a designated home. It may even be cost effective to provide additional generation and storage assets at those sites.

8.6 New Zealand: Cyclone Gabrielle (February 2023)

Cyclone Gabrielle hit the east coast of the North Island of New Zealand in late February 2023 bringing high winds and torrential rain. The latter caused widespread flash-flooding and consequent destruction of local distribution network assets as well as destroying a large number of houses, farms and commercial properties. The cyclone was the deadliest weather event in New Zealand since 1968. Some 10,000 residents were either temporarily (evacuated) or permanently displaced, over 225,000 homes lost power as did water treatment plants and other critical infrastructure with some homes in the Gisborne area without power for over 3 weeks. Repair estimates for the electricity distribution network alone have been estimated to exceed £50m[9].

Media reports of neighbours sharing critical resources, including on-farm generators were commonplace but from the perspective of this report the most intriguing analysis has been provided by SolarCity, a provider of BTM PV and energy storage systems which has recently acquired by Blackrock. Solarcity's business model is to contract a consumer to purchase electricity at a reduced price for a long term period and install, at zero cost, a PV and battery system that is intended to feed power to the home at morning and evening peak, recharging either from the installed PV or from the grid when wholesale process are low (Solarcity 2018). Solarcity have previously demonstrated considerable success in shaving peak loads for their customers, reducing peak load impact on the local distribution network, and have also recently contracted to provide aggregated flexible demand response services to the NZ reserves market[10].

In the context of Cyclone Gabrielle however, Solarcity engineered the system to ensure that customer batteries charged to their highest level (90% full) over the 24 hours prior to the cyclone's arrival (c.f. SMS weather warnings in (Prevedello and Werth 2021)). Their subsequent analysis has suggested that ~80% of their customers experienced a grid power outage during the Cyclone period with a mean duration of 25 hours (Solarcity 2023) and 5% experienced an outage of between 5 and 10 days . However, they suggest that the installed PV/battery systems enabled customers to maintain "the power needs most important in peopl''s homes for more than 95% of the time, operating for up to 5-6 days off grid".

> Solarcity Chief Product Officer Gareth Williams stated:“"*We work closely with our customers when they install a solarZero system to identify the circuits they want to keep on in case of a weather event, like lights in living areas, TVs, fridges, internet, some handy plugs. Then we have a team monitoring their system 24/7, and we can dial into it remotely to make changes and optimise it for energy efficiency–- w''re right there with you, i''s all part of the service that we offer*”"[11]

To some degree, Solarcity are therefore enabling customers to set their own 'sufficiency service levels' (see Section 6) and seemingly with an established license to automate (Section 7).

Although independent research has yet to be conducted, Solarcity analysis suggests that "*each day the solarZero platform provided a daily average of almost 10 kWh of electricity to support key functions like internet connectivity, lighting, refrigeration, television and occasional bigger loads like a microwave, toaster and kettle*." This equated to ~40% of customers' usual energy use at this time of year (Gareth Williams and Eric Pyle 2023).

In addition the company has collected a number of news stories of how their customers made use of the system no only to support their own needs “"*The back-up energy powered*

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[9] https://www.rnz.co.nz/news/national/484319/cyclone-gabrielle-power-will-likely-stay-out-in-napier-for-some-days

[10] https://www.solarcity.co.nz/blog/solarzero-enables-world-first-trade-in-the-nz-electricity-reserves-market

[11] https://www.solarcity.co.nz/blog/how-solarzero-kept-the-lights-on-during-cyclone-gabrielle

my two fridges…and my wine fridge”"[12]) but also those of their neighbours. Documented examples include:

- Charging mobile phones, providing connectivity and supporting a family with a new baby – in this case the respondent remarks that they were not aware of the power cuts until dark when theirs were the only house lights visible in the neighbourhood (Gareth Williams and Eric Pyle 2023, 9);
- Enabling neighbours to charge mobile phones, have warm showers, make use of (satellite) internet access, plug in refrigerators and at the same time provide lighting (and BBQ food) as an informal ‘community hub’[13]. The home-owner noted that “*we were generating enough power to keep the battery at full capacity*” and so may not have been concerned about sharing a potentially non-replaceable resource;
- Enabling neighbours access to both clean and hot water “*One lady I know popped in so I could give her some water. Sh’'s on an electric pump to get water to her place, so had no access to it due to the power cut”*"[14]

Although not conducted using rigorous qualitative research methods and no doubt selected to enhance Solarcity’s position, these examples can be viewed through the lens of scarce resource sharing as discussed in Section 3. In the New Zealand context, the limited evidence we have suggests that energy sharing extended beyond the family to (some) geographically and/or socially close neighbours, especially those in direct need of basic life services.

Solarcity have also suggested that their system enabled a less abrupt restart to grid import once customers were reconnected with the battery system delaying significant grid-draw for up to five hours (in one example) depending on the state of battery charge.

Finally, although Cyclone Gabrielle’s arrival in New Zealand’s summer coincided with close to maximum solar irradiance, solarcity have suggested that their system, with a 10.8 kWh battery, could provide a minimum level (350W) of supply in winter for 88% of the time across a 72-hour power cut.

Unsurprisingly, Solarcity are now positioning their service as a key solution for New Zealand’s future disaster planning especially given the likelihood of both future climate related weather events and highly destructive earthquakes (Gareth Williams and Eric Pyle 2023), a position supported by other New Zealand research (Brent and Mohseni 2023). This includes advocating for:

- a ‘non-network’ resilience programme alongside, or in place of, traditional network reinforcement funded by lines companies under direction from the regulator;
- the need to ensure sufficient numbers of systems are installed on each neighbourhood feeder to potentially sustain ‘islanded’ communities;
- specific public funding to install systems in evacuation/community centres, including marae, where they can provide low-cost energy under normal conditions but then provide enhanced local resilience services without the need for fossil fuel generators under emergency or islanded conditions;
- publicly funded ‘islandable’ microgrid projects to test the practical feasibility and limits of the concept and crucially, but perhaps more prosaically…

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[12] https://www.solarcity.co.nz/blog/solarzero-saves-the-day-for-kathryn-delaney-and-the-wine-and-the-airbnb-guests

[13] https://www.solarcity.co.nz/blog/solarzero-enables-hawke-s-bay-family-to-help-their-neighbours

[14] https://www.solarcity.co.nz/blog/solarzero-saves-the-day-for-mary-and-pixie-from-whangarei

- amending building regulations to specify pre-wiring for solar and battery systems at build time to prevent the need for expensive retrofitting at a later date.

9 Implications and Insights

This report has provided a wide-ranging review of a number of energy-use contexts to shed light on the potential for BTM assets to offer a resilience service in the case of local network supply disruption.

Studies of how customers respond to power supply disruptions repeatedly demonstrate that sharing of resources with neighbours, whether electrical or otherwise, is common-place without the need for explicit financial returns. This does not seem to be confined to relatives but extends to neighbours in need. The case study of Cyclone Gabrielle in particular illustrated that BTM asset owners were quite prepared to share their stored energy resources, especially where they could be continually replenished via Solar PV. Maintaining basic communication services is crucial to enabling people to cope with ongoing disruptions, especially as communicating the likely duration is important to enabling adaption strategies.

This attention to own resources recurs in nearly all of the studies of energy trading or sharing preferences whether in the context of 'surplus' energy trading, sharing during supply disruption or vehicle-to-grid. In each case there appeared to be thresholds to sharing which were set against an assessment of what was 'needed' by the asset owner for their own service provision. This worked in different ways for differently oriented asset owners with some only prepared to 'share' given very high levels of (own) stored energy while others were more responsive to the price they were offered to share when own-storage reached a lower threshold.

While caution should be exercised in extrapolating from studies which only discuss sharing of 'surplus' in a non-disrupted supply context, there is considerable evidence that returns to sharing do not need to be purely financial. Indeed, restricting returns to purely 'in-cash' not only ignores the flexibility of 'in-kind' or 'intangible' returns highlighted by some of the resource sharing research but could actively prevent sharing. This is explained by reference to the classic 'social dilemma' – not just that non-cooperative behaviour will mean that on average all members of a group will have fewer resources, but that non-financial returns are known to enhance self-perceptions of well-being. Enabling the use of a variety of 'returns methods' (or even energy 'gifting') and enabling asset owners to set or expect differential returns for anonymous others vs local key infrastructure vs those in most need vs distant and close social relations may be key to ensuring a flexible system that fits to local social priorities. This is especially the case in a local feeder outage context where the resilience service users are more likely to know each other.

Automated sharing or trading is likely to be preferred by some asset owners but enabling differential 'return' preferences to be set either by default or actively will also be key for some. However, expecting all asset owners to actively engage in a 'sharing market' is likely to be over-optimistic given the time constraints of everyday life, especially for working families. In combination with the need to consider in-kind and intangible returns, this means that the results of simulations of 'market-based sharing' assuming universally 'economically rational actors' should be treated with caution.

Studies of direct load control, vehicle-to-grid and minigrids suggest that implementing a graduated energy demand (kW) cap may be feasible to prevent intentional or un-intentional over-demand on a BTM asset-based resilience service. Concepts of sufficiency could help in setting different levels of this cap for different customers with different vulnerabilities or it may be considered more equitable to set the same cap for all regardless of ‘need’. There is evidence that direct load control (i.e. switching off to preserve system viability) may be preferred for heating and hot water compared to ‘appliances’ which often have more immediate temporal demands. Preferences such as these could be used to set default ‘allowable’ loads or priorities over a given time period or it may be simpler (and more flexible) to allow customers to decide for themselves which loads (energy uses) to prioritise under a given cap. Given that this cap may fluctuate as the BTM asset-based service supply/storage levels fluctuate, the kinds of attention to the effects of their own usage (demand, frequency) and to ‘current energy availability’ discussed in the Eigg microgird review may need to be supported. This might involve communicating 'rules of thumb’ about what can be used (or done) at what time.

There is also evidence that if the principles of a ‘social license to automate’ are implemented, users may be willing to accommodate both an automatic cap and automated sharing and pricing. This will entail ensuring:

- Economic legitimacy – providing financial benefits to the community and other stakeholders;
- Socio-political legitimacy – respecting local ways of life and contributing to the well-being of the locality in financial and non-financial ways;
- Interactional trust – seen to listen, respond and keep to agreements.

This ‘social license’ will need to overcome issues of transparency and trust, especially from BTM asset owners who may have been originally motivated to invest in these assets in order to achieve as much independence from the network as possible. In this case emphasising the ‘community’ or ‘neighbourhood’ level of independence afforded by the service may be key.

It is clear from the evidence review that those most able to cope with network disruption, and potentially those most amenable to a BTM resilience service would be those with experience of repeated network disruption. Given the potential need to engage a variety of local stakeholders in the implementation of the service, those areas with existing ‘energy communities’ or other forms of community action, especially along dimensions of energy independence, low carbon technologies, resilience or self-help may be particularly open.

Expanding the assumptions about who could contribute to a BTM asset-based resilience service also seems fruitful. The studies of supply disruptions, and to some extent the prospective studies of sharing preferences, point to the value of instituting local ‘energy shelters’ or ‘hubs’ and ensuring that local ‘key’ service or infrastructure providers can contribute to and benefit from the service. These could be provided by existing ‘walkable public spaces’ such as libraries, pubs or other small businesses which could enable significant economies of scale as well as larger capacity assets. Where these small businesses support essential services such as food and fuel their inclusion in the system would allow the continued provision of these services, potentially to members of a local community who cannot access hot food, heat and mobility for themselves.

In this respect, many of the studies highlighted that it may not be the network operator who is best placed to offer a local BTM asset-based resilience service. Where direct control or automation is required, where reaching ‘into the home’ is a key requirement, where there are expected to be tensions between network and consumer ‘value’ or where ‘social benefit’ is prioritised, studies persistently highlight the increased levels of trust assigned to non-commercial stakeholders. This may reveal a declining social memory of directly controlled electric storage heating but nevertheless it points to a local service delivery model of the kind that was highlighted in a number of the case studies of islanded minigrids. It may be that enabling a form of local shared service ownership model with administration and co-ordination undertaken by local organisations who are trusted to be transparent on motive and intended local resilience outcome; have access to and can mobilise local skills and resources; have a good understanding of local vulnerabilities and, crucially, can achieve a local ’social license to automate’ will be key. Potentially this could include a role for local ‘meso’ level organisations modelled on the Regional Resilience Partnerships in Scotland or Local Resilience Forums in England, especially if the service is positioned as part of a wider ‘local resilience’ initiative that could include response to flooding and other relevant hazards. These organisations might also be able to provide the kind of close engagement with stakeholders that is known to enhance the chances of success.

Finally there may be a need to broaden the concept of ‘vulnerability’. While this is implicit in the overall rationale for the overall project, a number of studies pointed to ‘new dependencies’ which may not have been considered in criteria-setting for PSR services[15]. These include heightened dependency on ‘digital’ communication tools for young people and those who have predominantly switched to working from home; those who are relatively socially isolated through solo living (whether elderly or not); those whose homes have poor thermal efficiency and thus heat retention and, perhaps more contentiously, recent relocators to (especially) rural areas who have little previous experience of power supply disruption and therefore lack sufficient preparedness.

In summary, the evidence review suggests a number of ‘design principles’ for BTM asset-based resilience services:

- Increase all forms of resilience as part of the service:
    - Increasing *response diversity* – such as exploring different energy sources or sharing variations in practices mirroring the range of strategies developed by off-grid households;
    - Developing *Individual* resilience – through the development and sharing of experiences of low-energy or disrupted supply living, especially for groups who do not usually experience disturbances to energy supplies;
    - Developing *Community* resilience – proposed to be via the use of local, networked modular energy assets.
- Preserve communication services
    - Not knowing what was happening, how long it would last and not being able to communicate with family and friends were key stressors for those experiencing network disruption, significantly effecting their ability to adapt to the inconvenience.
- Inclusive, flexible and intuitive design:
    - Avoid focus on simply providing financial returns – this may demotivate some as it converts a moral/social decision to an economic one;
    - Provide support for variable price in-cash returns but also support in-kind and intangible returns to sharing – such as energy ‘gifting’ – to enable differential returns to be set or expected for specific others or categories of others;

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[15] See https://www.thepsr.co.uk/#am-i-eligible

    - Enable sharing ‘thresholds’ to be set for own-asset storage or supply levels but provide cues such as feeder level visualisations of (and rewards for) sharing ‘behaviour’ to enable social regulation of ‘selfish settings’ and to demonstrate that ‘others’ are acting as ‘you are’;
    - Promote self-regulation by encouraging members to pay attention to environmental cues which can inform them of the potential availability of intermittent generation (and subsequent storage);
    - Provide additional information (and feedback) on potential frequency issues and how they might manifest;
    - Encourage members to internalise simple rules of thumb to ensure system continuity rather than emphasising ‘kW counting’ or appliance monitoring;
- Leverage social capital:
    - Expand feelings of felt responsibility and social closeness with neighbours to promote the tendency to ‘share’ beyond friends and family or critical infrastructure;
    - Establish and foster a ‘community energy resilience’ identity – potentially via a local resilience network or some other meso-level actor;
- Don’t be afraid to get tough:
    - Implement an enforceable cap to preserve system viability even if a trading system or other incentives designed to prevent ‘over-demand’ is in play;

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