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"I hope they shouldn't happen": Social vulnerability and resilience to urban energy disruptions in a digital society in Scotland

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ABSTRACT

Energy systems are changing rapidly, bringing new types of risks, and new forms of potential disruption to energy supplies. Our growing dependence on energy, particularly electricity, means that more than ever we need to plan for disruptions and be prepared for them. What happens *during* the disruption is important: we need to understand how individuals, communities and organisations experience the event, and what measures can be taken to reduce the overall impacts. This study investigates how people and communities in the city of Glasgow (Scotland) might respond to a lengthy, widespread disruption to energy supplies. A novel three-stage diary-interview methodology was developed to explore energy practices and expectations, and to understand how people's experience of disruptions may change in the coming decade. The results show that the most consistent determinant of participants' perceived resilience, over and above socio-demographic factors, is their expectations and their degree of dependency on routine. Our assumptions regarding people's vulnerability need to reflect the importance of digital dependency: in particular, age and income should not be seen as straightforward proxies, and the paper identifies a new set of 'indicators of vulnerability'. Interdependent infrastructures are also crucial, yet underappreciated, and mean that people's ability to cope during a disruption will likely decrease over time in a non-linear 'step-change' fashion, as other sectors and services are affected. Community-level actions can improve resilience, and local scales may be more appropriate for identifying vulnerabilities than socio-demographic proxies, but this is only feasible if organisations and institutions are adequately resourced.

1. Introduction

Modern society is entirely dependent on energy, particularly electricity, and ensuring a secure and reliable supply is crucial. However, it is not possible to guarantee a completely reliable electricity supply. As a highly complex system, accidents will still occur, usually due to unexpected combinations of factors which are challenging to predict or to completely avoid [1,2]. New risks are also emerging, which challenge even the most secure energy system [3,4]. Firstly, electricity systems are becoming more complex, due to the transition from large centralised fossil power sources to more distributed and renewable generation [5]. Secondly, the pace of digitalisation and of innovation in Information and Communications Technology (ICT) brings exciting new opportunities for managing supply and demand, but is also giving rise to new uncertainties and complexities, as well as risks from cyber-attacks [4]. Thirdly, climate change is already causing an increase in extreme weather events, creating risks to physical infrastructure from storms, floods, heatwaves, and drought [6,7]. In this context, it becomes crucial to ensure that the system is *resilient* – able to prevent, contain, and recover from interruptions arising from a disturbance to the system [8].

Despite the widespread understanding that new risks to energy systems are emerging, there is relatively little research on the social resilience of end-users and communities, in the context of a serious disruption to energy supplies. Spatial and temporal dynamics are important [9], and in this respect there is a particularly low understanding of either social resilience in locations which are accustomed to reliable energy supplies, or of the implications of rapid changes in modern energy practices. The goal of this paper is to understand how households in a major city in Great Britain (GB) might perceive and respond to a lengthy disruption (loss of supply) to electricity and/or gas, and to deepen our understanding of the contextual factors influencing people's resilience and vulnerability to disruptions.

A 'lengthy' disruption could mean different things to different people, therefore a range of different timescales are considered, although the focus is on less-common disruptions of >60 min, and on large-area outages, i.e. those affecting more than just a few streets. Such disruption is also likely to impact interlinked infrastructures such as water, ICT, food, transport, and health services; yet people's reliance on such

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services and societal expectations of their availability are currently underexplored in work on social resilience [10]. A serious disruption to energy supplies could happen for many reasons, including: extreme weather damaging physical infrastructure; malicious attack or cyber-attack; a cascading failure caused by a technical fault or human error; or a serious failure of multiple supply nodes, as happened in the Texas winter storm of 2021 [6,11,12]. The main focus is not on determining the cause of the problem, but to ask "How might households or communities react and respond in the event of a serious outage?" and "How might we improve the resilience of communities to energy disruptions over the next decade?"

The paper is organised as follows. The following two sections introduce the literature on energy disruptions, social and household resilience, and vulnerability to hazards in the context of individual end-users, communities, and societies. The methods section then sets out the novel three-stage diary-interview methodology used in this study, which enables us to understand how vulnerability works in context. Next, the results from the data analysis are presented in two parts – the first part presents how study participants perceived the likely impacts of an energy disruption on their household and their community, and the second part explores changing energy practices and implications for future resilience. Finally, the discussion section explores the results in more depth alongside the existing literature, and identifies areas for future research.

1.1. Energy disruption and resilience

Notions of energy resilience can be traced back to work on systems resilience in the field of ecology in the 1970s [13], although its recent popularity in energy systems research may partly stem from its acknowledgement of the need to be able to withstand the unexpected [14]. Although resilience is not inherently positive or negative (for example, undesirable structures such as poverty traps can be extremely resilient to change [15,16]), energy research generally views resilience as a desirable attribute, particularly in situations of high uncertainty [17].

Energy system resilience is often thought about in terms of 'system' resilience – for example, backup generation, line hardening, and islanding to limit the cascading of disturbances [10]. However, such engineering perspectives on reliability and resilience are only partial, because we also need to be concerned about the impacts on end users, households, and society [18,19]. Yet relatively little research which examines resilience to potential energy risks from a societal perspective exists. Social resilience is defined by Adger as "the ability of communities to withstand external shocks to their social infrastructure" ([20]: 361). Resilience is thus not the absence of risk, but rather the existence of protective factors that 'buffer' against adversity, including diversity of options, social orientation, environmental factors, and emotional support [21]. Understanding resilience to an energy disruption means understanding what might happen *during* the disruption, in societal as well as engineering terms. Amongst other things, this includes considering the vulnerability of different end-users and communities, people's dependency on different energy services, their expectations, their responses both during and after the event, and the various mechanisms by which social resilience might be improved.

A body of existing literature examines energy disruptions in the context of households and communities (reviewed in [10,22]). Much of it stems from the United States, where Grids continue to experience frequent and sometimes severe outages, and from northern latitudes such as Canada and Scandinavia which experience severe winter storms [10]. A number of Scandinavian papers examine household resilience to disruptions, finding that preparedness is a key factor and that communities often have tacit or 'embodied' competencies which increase their resilience, despite a lack of formal preparedness measures such as emergency kits [23,24]. Preparing the public could improve their ability to respond and recover from disruptions [22]; however, communicating the need for preparedness might not have the desired effect, because people are accustomed to a reliable energy supply [25]. Community resources – both physical and emotional – can provide valuable resilience potential, but this tends to be underestimated [26,27]. For example, an expert stakeholder case study of a several-day outage in Lancaster in 2015 demonstrated that lack of community spaces quickly became an issue, with people gathering in the overcrowded hospital [28].

Several of these papers view energy disruptions through the lens of Social Practice Theory, which proposes that Social Practices comprise three elements of materials, competencies, and meanings, plus the connections between them [29]. Ghanem et al. [30], in a study on rural Welsh communities, found that social practices are modified during an outage, with old linkages between the three elements broken and new ones made. Their participants expressed resilience in terms of 'making do' and 'getting by'; however, the experience also brought some households face-to-face with vulnerability in their homes. Meanwhile, Heidenstrøm and Throne-Holst [25] and Wethal [31] find that rural inhabitants tend to emphasise their ability to cope, connected to perceptions of self-sufficiency and autonomy, as well as having a diversity of fuel options such as solid fuel and open fires (cf. [32]). Importantly, most of the existing empirical work was conducted in rural and Scandinavian locations with low reliance on gas for heating and cooking and a prevalence of solid fuel alternatives and can thus be expected to differ from experiences in locations on the gas grid.

1.2. Vulnerability to disruptions

Understanding people's resilience means also understanding vulnerability. Vulnerability of communities exposed to hazards is broadly defined as "the propensity to be adversely affected", and encompasses a variety of elements including sensitivity and susceptibility (for instance, social characteristics which mean that certain groups may be more affected), and 'adaptive capacity' (the ability to respond and recover from an event) [15,33–35]. Vulnerability is not straightforwardly the flipside of resilience, although there is still some debate over this [36]; yet the two concepts can be highly complementary, both emphasising the importance of identifying opportunities for risk reduction, coping, and adaptation [37]. Cutter et al [38] define a 'Social Vulnerability Index', wherein vulnerability is a multidimensional concept comprising multiple indicators, helping us to identify characteristics of individuals and communities that enable them to respond to and recover from disruptive events. Vulnerability should not be seen as a set of static characteristics inherent to particular individuals; rather, it is dynamic and rooted in social structures, and may be best understood from a *relational* perspective, considering local interdependencies and networks [9,39–41]. Considering this, the current paper uses a qualitative methodology to understand in more depth the complex, dynamic and contextual nature of vulnerability.

Vulnerability to disruptions will likely differ depending on particular socio-demographic characteristics, including income, age, location (urban/rural), race, ethnicity, and potentially gender [38,42–44]. However, for some of these the existing literature gives mixed results. For example, age is commonly seen as an indicator of vulnerability to outages, for instance in inclusion criteria for Priority Service Registers [45]. Yet empirical studies find that younger, single urban households may be least able to cope with outages, due to lower prior experience, preparedness, and sense of community [23,34]. We know that disruptions tend to exacerbate existing insecurities, particularly those stemming from fundamental societal inequalities [46] – for example, during the Covid-19 pandemic, low-income, Black and Hispanic households were all more likely to face energy insecurity [42]. However, Rubin and Rogers [22] note that literature on the impacts of energy disruptions on fuel-poor households is scarce, and needs to consider the potential mitigating influence of lower energy consumption. A well-established literature on 'energy vulnerability' explores the propensity of an

individual to become incapable of securing a needed level of energy service in the home [47], with vulnerability describing a "set of conditions that characterise the emergence and persistence of deprivation" ([48]: 3). In practice however, this work tends not to focus on disruptions to the physical supply of energy [39,49].

In advance of this study (2019–20), a systematic review of the literature on the social impacts of energy disruptions was conducted using the databases Web of Knowledge, Scopus, Google Scholar, and Google.co.uk. The full methodology and search terms are available in [10]. The review identified several key gaps in knowledge which informed this study, including: a) a lack of empirical work on large disruptions in urban areas, particularly areas on the gas grid; b) people's emotional responses (cf. [22]); c) the effect of socio-demographic factors such as age and income; and d) the impact of changes to the system over the next decade. In addition, the review noted that the experience of an energy disruption by households will often include the loss of other interdependent infrastructures such as gas, mobile phones and water (cf. [28]). There is a body of work on critical infrastructure interdependencies, but this work tends not to consider impacts on end-users; conversely, work on social resilience tends not to consider the potential for loss of other critical infrastructure sectors (except [25], which examines disruption to energy and ICT services in Norway). Thus, two important perspectives on energy outages in the literature sit almost entirely separately from one another, which has the effect of obscuring a major contextual factor which could influence social resilience. To address this, a key aim of this paper is to frame the methodology in terms of interlinked infrastructures, by asking participants not only about the potential loss of electricity and gas, but also about other key sectors and services.

2. Methods

This study used a set of in-depth, three-stage diary interviews (n = 24) to understand how citizens living in Glasgow might experience a lengthy disruption to their electricity and/or gas supply, with an emphasis on understanding their resilience, their adaptive capacity, and the factors which may influence vulnerability. Qualitative methods are useful for understanding people's lived experiences, particularly when considering complex and nuanced societal dynamics such as 'resilience'. Yet most literature on the impacts of outages relies on opportunistic samples, which may be skewed - for example, if some people felt they had a more interesting story to tell [22]. Therefore this study used topic-blind random sampling, conducted by a professional recruitment company using a combination of database and face-to-face recruitment. Although due to its size the sample was not intended to be representative of the population, the aim was to ensure a balance of age, ethnicity, gender, income, and location (inner city, suburbs, outskirts) (see Supplemental Tables 1 and 2). Participants were offered a £70 honorarium for their time. Twenty-five participants were recruited, with one no-show; everyone else completed all three stages. All participants gave written informed consent and GDPR compliance before the interview (Supplemental Methods 4), and the study was approved by the Cardiff University Psychology Ethics Committee, in accordance with the BPS Code of Human Research Ethics. A small sample size was chosen to prioritise depth of understanding of a complex topic, and to focus resources on collecting a large and rich amount of data from each participant; however, this constrains the generalisability of the findings, and the results should be viewed with this in mind.

The scoping review identified a lack of literature regarding electricity disruptions in urban areas. Glasgow is the largest city in Scotland, and the fifth largest in the UK, with a population of nearly one million. Scotland makes for an interesting case study, because of its high and fast-growing penetration of non-synchronous generation (mostly wind), and a hugely ambitious target for economy-wide 'net zero' emissions by 2045 [50]. Furthermore, Scottish households are dependent on gas for heating and cooking, with 83.4 % of Glasgow houses using mains gas as their primary heating source [51], and a general lack of solid fuel alternatives. Gas-fired power is also prevalent, comprising 40.6 % of UK electricity generation [52]. Gas and electricity are highly interdependent, creating specific risks, as well as a challenging situation for full decarbonisation [53]. Scotland is part of the centralised GB Grid, comprising Scotland, England and Wales, for both electricity and gas.

One of the challenges of this research question is its hypothetical nature, because many urban households will not have experienced an outage in the recent past. To address this issue, a three-stage diary interview method was used, adapted from Kenten [54], who argues that greater depth of understanding can be gained by combining solicited diary methods with a semi-structured interview. The diary component was used to make energy practices more visible to the participants, to enable them to think through the implications of an energy disruption in more depth and to contextualise it in their own experience, routine, and practices. The semi-structured interviews allowed for in-depth discussion and provided rich qualitative data, whilst also allowing participants to clarify or expand upon their diary entries, reducing the risk of analytical misinterpretation.

First, a one-hour interview was conducted on Zoom, asking general questions about the person and their daily life, followed by questions about previous experience with electricity and gas disruptions, and finally questions about what they would do in the event of a hypothetical disruption, exploring different temporal and spatial scales of disruption. During the following week, participants chose two days on which to complete a short diary task; these time intervals were designed to strike a balance between collecting enough data, whilst not being too intrusive or onerous for participants [55,56]. On each day, participants wrote down five activities that they did that day. The purpose of the diary was to use the items as objects of discussion, rather than as units of analysis in their own right, therefore it matters less whether they provide a fully representative picture of everyday life or energy use [57]. In addition, on day one of the diary task, participants were asked to write down their specific practices relating to six critical infrastructure sectors: water, mobile phone, gas, food retail, transport (public and private), and medical services. These six sectors were identified as part of a separate empirical study involving twenty-five GB experts and stakeholders – see Supplemental Methods 3 for full details.

One week later, a second one-hour Zoom interview was conducted, where we discussed the diary task and considered the impacts of an energy disruption on these activities. Finally, participants were asked to consider their 'future selves' (five to ten years) and how their practices and routines might change. Full interview protocols and blank diary sheets are available in Supplemental Methods 1 and 2. Interviews were recorded using embedded Zoom software, transcribed by a professional third party, checked for accuracy and anonymised by the researcher; names in this paper are aliases. Data were analysed using thematic coding analysis in NVivo 12. The anonymised data are available from the UK Data Service (pending embargo) [77].

The timing of this study is important to note: interviews were conducted in May–June 2021, during COVID-19 social distancing restrictions. In Glasgow, high case numbers in May meant that strict restrictions were still in place, including a ban on indoor socialising and non-essential travel, restrictions/curfews on hospitality, and non-essential businesses closed. On 5 June, limited indoor socialising was allowed, but travel restrictions and work-from-home orders continued. This study originally intended to explore energy practices face-to-face in participants' homes (e.g. [30]), but the pandemic necessitated a shift to an online design, and a scaling back of the diary task to reflect a lack of activities outside the home. Ethical considerations came to the fore, to reduce the risk that participants would feel judged, under pressure, or triggered, particularly when thinking about the future [57]. The decision was taken not to deliberately recruit fuel-poor residents, despite the fact that Rubin & Rogers [22] identify a gap in the literature on this topic, because of the financial and mental health impacts of the pandemic on individuals and on intermediary organisations such as charities which are often used as gatekeepers for recruitment [58].

Participants were recruited randomly, with no selection question relating to fuel poverty, although a small number of participants did state during the interview that they had difficulty paying their bills or heating their homes.

The nature of this study led to several methodological challenges and potential limitations. Firstly, the hypothetical nature of the question meant that participants often relied on their recollections of the past, shown to be potentially unreliable [59]. This in turn may have impacted how they imagined the future. The pandemic may have further impacted people's recollections, because of the dramatic break with past routines and the impact of Covid-19 itself on memory. Despite trying to control for these issues using the diary method, some participants drew heavily on past experiences, including from a long time ago, which may have impacted the results due to incomplete or mistaken recollections. Secondly, participants were not selected based on their prior experience with outages, because the goal was to explore long and widespread outages which have not occurred in Glasgow since the 1970s, and because of the risk of future outages for those who have not experienced one. However, in practice, this meant that interviewees had very different degrees of experience, with some streets having experienced small outages recently. Future studies could address this by sampling according to outage experience rather than just demographics.

3. Results

3.1. Perceptions of vulnerability and resilience

This results section aims to ask, "How did participants perceive the likely impact of a serious outage on themselves and others, and how might they respond in such a situation?". The section is organised according to key factors identified during the thematic coding of the transcripts, which appeared to play an important role in how participants perceived their vulnerability and resilience to a serious energy disruption. Understanding such factors may in turn enable us to develop recommendations for improving resilience in an urban area, where a lack of prior experience might mean fewer preparedness measures in place. In fact, all the interviewees owned some preparedness items, although these tended to be repurposed items such as scented candles and torches used for storage spaces (cf. [30]). Most interviewees were entirely dependent on gas and/or electricity for heating and cooking. Meanwhile, communication sources are shifting; only two of our interviewees (both >65 years of age) owned analogue radios, which had been vital to residents during the Lancaster outage in 2015, and only three owned a landline phone.

Using the qualitative research design, participants were enabled and encouraged to define 'impact' themselves, thus allowing us to view through a lens which makes sense to end users. In this respect, by far the most common theme (mentioned by twenty-two out of twenty-four respondents) was impacts on mental health, particularly stress and anxiety. Some participants spoke about being "frightened" (Ivy, Frances) or becoming "a wee bit scared… If your house is your nice safe space and then, you're not able to function in it" (Sarah). Mental health impacts of outages are sometimes measured using hospital visits [60], yet our interviews suggested a need to think more broadly about impacts on people's mental well-being [61]. Physical health and safety impacts, such as loss of heating, trip hazards, electrical hazards, and vulnerability to crime, were a concern for four participants. Only two participants spoke in terms of income loss.

3.1.1. Age

The link between age and perceived vulnerability was complex, although a general pattern did emerge in which participants considered 'younger people' as having reduced adaptive capacity (i.e. the ability to respond and recover from an event) due to digital dependency. Participants commented on their own experiences but also drew on the knowledge of their social networks, particularly close family members. For example, participants with children felt that, in their experience, their kids would find it very stressful and problematic: "Well, the people my age would probably just deal with it and adapt, whereas, I think people in the younger generations live in such a social media world, it would be the end, wouldn't it? I think younger people would be more anxious than what older people would be, definitely." (Daniel, aged 47). Ivy (aged 62) said:

> "Oh, I see it in my daughter's house with her children, they've got their TVs and their PCs, their X-boxes, they ask Google to put the lights on. So they wouldn't cope, definitely not. It's a different way of life. I think [if there was a power cut] they would think that they were back in the dark ages, because they don't know any better."

That said, some participants did not fit this model; for example, stating that their children would react completely differently from one another, based on their personalities rather than their age. Douglas (aged 57) said that "the older I got, the more worried I'd be", due to declining health, and that he would worry about his mum (aged 80), whereas his son would "fine, 'cos he's sorta more laid back about things". Of course, this does rely on participants having a reasonable level of understanding of how their close family members might react to unexpected situations, and we cannot rule out the potential that people could surprise themselves and others, although it could be argued that people may be just as knowledgeable about others as they are about themselves as individuals [62].

Several younger participants (four participants, all aged under 25) had a low level of knowledge about what to do in an outage situation. Sanaya (aged 38) talked about an incident which had occurred when she was younger, saying, "We were panicked a bit at first, because [me and my housemate] didn't really have a clue about houses, like, how to run a house". She went on to talk about how their elderly neighbours stepped in to help them, illustrating that perceptions of older people as inherently more 'vulnerable' may often be misplaced. Roy (aged 73) spoke about a recent power outage, in which the Housing Association offered help because he lives alone, but his high adaptive capacity (discussed in the next section) meant he did not need their assistance and "I said, no, I'm okay, get somebody else that needs it." All seven of the older participants (aged >60) emphasised their adaptive capacity and their ability to respond well to disruptions, although two were also concerned about safety and crime. Ivy (aged 62) also pointed out vulnerabilities which could be related to declining eyesight, loss of independence, and increased reliance on heating. Thus rather than vulnerability increasing with age, the more important factor may be poor health.

3.1.2. Income

The interviews identified a complex relationship between income and perceived resilience. Certainly, several of our higher-income participants (representing 37.5 % of the sample) possessed useful material items such as camping equipment and chimeneas, but they also had larger houses which lost heat quickly, particularly compared to those living in smaller apartments with few external walls. Most importantly though, most participants did not view material possessions as the most important aspect of their resilience; rather, the focus was on social ties. In this respect, several of the low-income participants saw themselves as having very high adaptive capacity, related to the strong social networks in their immediate neighbourhood. Roy talked about a recent day-long outage in his neighbourhood: "Most people just out asking, you know, are you okay? I've got some candles if you need 'em, or I've got, you know, torch or whatever…. And we started every hour meeting up, seeing how everybody was. So that's how we sort of got through it." Meanwhile, Eilidh, living in a large house in the suburbs, was less positive about her neighbours: "They're quite, like, insular, they don't really want to engage very much with other people... I think they would probably be quite selfish and just try and sort it out for themselves or something." Urban residents have sometimes been found to have weaker social networks than rural ones [23,31]; however, many of our

participants felt that they had extremely strong social networks, consisting of friends, family and neighbours. “Aye, we all do it here, it's just your local community, so it's quite tight in that sense. When a disaster happens everybody mucks in” (Frances).

3.1.3. Routine, responsibility, and expectations

Participants' perceived resilience was dependent, not on their age or income per se, but on the degree to which they perceive structure and routine in their daily life. Douglas said that doing the diary task and the interview made him more aware of the importance of routine to him: “And I think what it showed me is, I like my routine, so if that gets upset in any way - I don't like change [laughs].” In particular, responsibilities for work and children (38 % of the sample) drove tight schedules which would be inflexible to any kind of disruption: “It would be probably quite difficult because my hours are kind of scheduled… and to make up my hours another day would be a more challenging because I don't have childcare after school for then…” (Marie). Archie said that their routine exists mainly for their two teenage children: “We're probably too routined up, if you know what I mean. We make a structure for the wee'un, and we're actually structured to that structure, and we don't go off it.” Meanwhile, Hassan said that since being retired he has a lot more flexibility in his routine, and as such would find a disruption easier to cope with and recover from than those who are dependent on electrical devices to work: “I mean it makes no difference to me, but it makes difference to other people, you know, because they are working and they can't do the job.” Furthermore, 9 participants said that a larger area outage would be less stressful, because they would perceive lower responsibility for the problem: “And then when you look out and you see that, obviously, your neighbours have got the same problem, you think there's, it sounds silly to say, but there's almost a wee bit of reassurance that it's not just you” (Sophie). Two participants who had recently experienced outages over a large area of the city said that their sense of ‘being in the same boat’ increased. Therefore, the interviews suggested that there is not a direct linear relationship between the area of the outage and the societal impacts, as sometimes assumed, because a disruption over a small area (e.g. just a few houses) might actually be more stressful and problematic in the initial stages.

One of the most common themes in the transcripts was about disruption to expectations. For example, showering on a daily or twice-daily basis was seen as a fundamental expectation as part of people's daily routines, and many said that they would be unable to cope without hot water for 24 h. Marie and Blake spoke about their colleagues' expectations that they wash their clothes and hair every day. Indeed, many interviewees appeared genuinely surprised about the degree to which they depend on hot water, a dependency only revealed during the diary task. This was also evident during discussions about mobile phone availability (cf. [63]). Living in an urban environment, participants' expectations were of good (or fairly good) internet access at home: “When you go up to the north of Scotland and there's no Wi-Fi and you can't get a signal, the first wee while you're panicking. And it, obviously Wi-Fi is different now ‘cos you're getting Wi-Fi nearly everywhere” (Sarah). Daniel argued that societal expectations had changed in the past decades:

> “We didn't have anything growing up. It was a different era, a different way… People are so materialistic compared to what it used to be like. Incredible. And that's where I think if we had a big power cut, they wouldn't have a clue how to deal with it.”

Some of our younger participants (aged <25) spoke of societal expectations on them to be constantly digitally available: “People get really offended these days if you leave their message for more than like two minutes. So then they might get offended that you've not replied back” (Eilidh, 20).

Fifteen participants (63 % of the sample) expected the problem to be fixed within an hour or two, and 100 % thought it would be fixed within 24 h. Therefore people's responses to a longer outage would be influenced by the expectation that it ‘shouldn't’ happen. Frances said that if the issue was not fixed within a day, she would get worried that things weren't “under control” and that something more dangerous was happening “at the top”. Participants with lower expectations expressed less concern; for example, Hassan had spent much of his life in Pakistan, where power cuts are a regular occurrence: “If I was in Kashmir maybe I would have waited for months before it goes back on… but here, they don't stop until it's fixed, you know. […] If it takes an hour, it takes a day, or maybe more than a day, we have to accept that.”

3.1.4. Outage duration

Clearly, there is a relationship between the duration of the outage and the impacts people will experience, with longer outages causing greater strain on people's ability to cope. The interviews revealed that all participants expected the disruption to become more problematic over time. Importantly though, this does not proceed linearly, but rather appears to follow a pattern of distinct ‘step-changes’ at which the impacts become distinctly more severe. The most commonly mentioned of these was the point at which the freezer defrosts – around 24 h for a half-full freezer [64], although some interviewees said they would start unpacking it after ~8 h. Another major step-change was the point at which mobile phone batteries would run out, or at which mobile coverage was lost due to loss of power at the phone towers [28]. The third major step-change would occur the following morning, with most interviewees expecting the power to be fixed by the following morning at the very latest. The morning routines appeared to be the least shiftable, particularly in terms of showering and getting ready for work: “It depends on the time of the day; if it's first thing in the morning, then [the impact] it's instant, you know, because you can't get ready to go to your work and that affects everything in your day” (Natalie). Cooking was not seen as a major step-change; most interviewees said that they could ‘get by’.

One interesting finding from the interviews was that the vast majority of participants (83 %) said that they would move to a different location, particularly if one of these step-changes occurred. All but two of the interviewees owned or had regular access to a car, reflecting the Scottish population wherein 86.8 % of households have a car available to them [65]. Of course, if the outage occurred over a very wide area such as the whole country, this would not be practical. The distance people were willing to travel was mainly dependent on where people's family members lived, particularly as many didn't know anyone outside Glasgow, although a couple of interviewees said they would rather drive for several hours than deal with a step-change such as having to get up in the morning without a hot shower.

3.2. How are societal expectations changing?

Participants argued that societal expectations of electricity availability are changing. Most said they are becoming progressively evermore dependent on electricity, and saw this dependency as likely to increase more in future: “As time goes on, you get more and more, consumed by, I suppose, technology and how much your daily lives get taken over, using all of the devices” (Sophie). This was also seen as a generational shift: “Kids these days… Like, when I was younger, I would play with my dolls and stuff, whereas kids these days rely a lot on technology” (Zoe). When asked whether power cuts would impact them more or less in the future, one participant (Natalie) responded simply, “I hope they wouldn't happen”, echoing several other respondents who felt that power cuts should be a thing of the past.

3.2.1. Mobile phones and internet

Unsurprisingly, the most prevalent theme in the data (100 % of participants) was around reliance on digital technologies such as mobile phones, saying how they “use the phone for everything… Honestly, I'm never off my phone” (Zoe). Nathan said, “It's like if you forget your phone, and for two or three hours, you feel like you've not got your left

arm." Mobile coverage could be lost during a large power outage due to loss of power at the phone towers [28], and participants said they would find this "isolating" (Catalina, Douglas, Ivy), "scary" (Catalina) and "daunting" (Nathan). Importantly, digital dependence was prevalent across the age groups, and many older participants commented on their increasing use of online communication tools since the COVID-19 pandemic. Many participants said they would be completely unable to do their jobs without their devices. Sophie was reliant on a mobile app to measure her blood sugar: "If I had no power in my phone, I would be guessing the amount of insulin that I had to take, because I wouldn't know. So, that could cause either my sugars to go really high or really low". The majority of people assumed that their mobiles and data coverage would continue to work until the battery died, and that this would be the main way in which they would find information. Therefore people's resilience may be severely impacted by unexpected loss of mobile coverage during a serious outage.

Interestingly though, across the sample, concerns about loss of mobile signal sat alongside negative perceptions of digital dependency. For example, Douglas commented on the mental health implications: "You're constantly tied to it, and people are contacting you through it, and… it's not good for your health, but it's like, you can't - it's difficult not to reply." Some of our younger participants were at pains to argue that they are not dependent on their phones. Asif (aged 24) talked about how technology could be "detrimental" to society, and said, "I've been through periods in my life where I've tried to detox from using phones and computers and stuff like that". Several people said that being without a phone would become *less* problematic over time and might even become a pleasant experience, drawing on their experiences in rural areas or on holiday, although Nathan also pointed out that this shift might take longer at home because of expectations of constant mobile availability.

3.2.2. *Low-carbon technologies*

The evolution and integration of low-carbon technologies is already changing the resilience of the electricity system, and low-carbon technologies such as solar panels, heat pumps, and electric vehicles are increasingly being adopted in the home. However, of our twenty-four interviewees, only three owned or envisaged owning these technologies in the near future. The reasons given mainly involved capital costs, trust issues in companies and installers, and living in rental or social housing. One of our participants (Nathan) had solar panels but did not feel that they had made much difference to their energy practices or the potential impact of an outage. This reflects a possible limitation of the study methodology because participants were not recruited on the basis of technology ownership; future studies could deliberately explore this and perhaps compare different levels of low-carbon technology adoption. Demand-side interventions such as energy efficiency improvements were seen as more relevant than supply-side technologies, particularly in terms of retaining heat during an outage.

More broadly though, electrification was having a major impact on many of our participants, and they saw this as the key way in which their resilience might change in the future. Hannah said, "My daughter's just put lights up… you can work it with your voice … everything in your house will be worked that way eventually. So I don't really buy into that so much myself, but I think it will become more and more, you know, in the years to come". Similarly, Latika saw the potential for electricity disruption to be more problematic in the future: "If I was rich I would have, like, those blinds that come up and down automatically, so they would stop working, like, if a door was alarmed that would stop working… and even, like, if our cooker was electrical, like, induction, that will stop working." Only three participants did not have gas in their home, although an additional seven only had electric cooking, and some had recently invested in induction cookers: "Up until August last year, this wouldn't have affected me at all, because we had a gas cooker, we could still cook. […] If push came to shove, in [my son's] estate, there's nearly a hundred [all-electric] houses in that. How do they survive?" (Bryce). For some, this would mean relying on those with a gas connection, a resilience measure which will decline as more houses shift to electricity: "If your neighbour had gas, he would boil a kettle for you, things like that" (Alfred).

A small number of participants saw home solar panels as a potential resilience measure in the case of an outage because the panels would make them "a wee bit more self-sufficient" (Daniel). Conversely, electric cars were seen as increasing people's exposure to electricity disruptions: "And if we had an electric car, it'll miss its charge, and then, yeah, I mean it would just impact us a lot more…" (Latika). Participants often viewed their petrol/diesel cars as a key resilience measure, to have an 'exit strategy' of moving temporarily to another area, and felt that this would not be an option if the power went out. Participants were not generally aware of vehicle-to-grid proposals which could be an option for resilience during outages [66]; in fact, it is interesting that solar panels were perceived as positive for resilience (even though they would trip off during an outage), whereas electric vehicles were perceived as negative. It is worth emphasising, however, that more participants were considering an electric vehicle than any other type of low-carbon technology, and that perceptions of resilience to energy disruptions did not appear to be a contributing factor.

4. Discussion

This study explores how citizens might perceive and respond to a lengthy, widespread disruption to their energy supply. The goal is to understand what might make end-users more vulnerable to disruptions, in terms of their sensitivity and their adaptive capacity, and how such vulnerability is influenced by the societal context. These insights can be used to understand how social and community resilience might be improved.

When designing measures to understand and mitigate vulnerability, there can be a tendency to systematically underplay the role of adaptive capacity, for which there may be fewer demographic proxies. For example, vulnerability measures such as Priority Service Registers rely on demographic indicators such as age and disability [45]; yet the qualitative data presented here suggests a highly complex relationship between demographic factors and impacts, particularly regarding age, income, and urban/rural location. In particular, this study does not support the assumption that old age equals greater vulnerability; in fact, there was a broad consensus amongst participants that younger people are more vulnerable due to their digital dependency and higher expectations of energy availability. Interestingly, Cutter's Social Vulnerability Index [38] includes age as a measure of vulnerability via the 'median age' indicator, which contrasts with the findings here. This could be due to changing energy practices, as well as the fact that digital dependence may play a larger role when it comes to energy disruptions as opposed to general hazards. For income, again a complex relationship was identified, with low-income neighbourhoods often emphasising their social and community resilience; however, the study did not specifically target those in fuel poverty (see Methods), and the sample size is too small to draw a comparison between those participants who were struggling with their bills and those who were not. Future work could aim to understand in more detail the relationship between fuel poverty and (perceived) resilience to energy disruptions.

A more disaggregated understanding of people's vulnerability could also be used in energy system models, for instance when deciding which parts of the system to prioritise for investment, or for managing disruption during a controlled outage or a rolling blackout scenario [67]. For example, Esmalian et al. [68] use data from household surveys in agent-based modeling of power system failure during extreme events, to examine the societal impacts and to identify equity-maximising resilience strategies. Rudolph-Cleff et al. [69] use GIS mapping along with a selection of indicators of vulnerability to identify priorities for crisis communication in a hypothetical 3-day outage in the city of Darmstadt. This current study, meanwhile, argues that our

understanding of what constitutes 'vulnerability' needs to evolve, to catch up with society's rapidly changing preferences and expectations. Therefore, if age is no longer a good proxy for vulnerability, what is?

This study identified several factors. Firstly, and most crucially, is digital dependence. Therefore, resilience services and models could perhaps benefit from the inclusion of data on people's use of digital technologies. The second major factor is having young children in the home (cf. [27]); this is already included in Priority Service criteria, but could be considered more in energy models. From the interviews, it appears that having young children reduces the flexibility available to parents, particularly in the case of single parents (cf. [70]), as well as increasing their sense of responsibility and thus stress. The results also suggest that age only becomes a relevant factor when combined with poor health and isolation. Young adults should not be seen as invulnerable per se, particularly when mental health is considered; in this respect, social isolation (for instance due to a short residence duration) and digital dependence may be more accurate present-day indicators of vulnerability. Finally, modeling of energy demand during a disruption needs to consider the high prevalence of those who would attempt to leave the area, particularly as this might impact the restoration of the system if fewer loads than expected are coming back online.

Overall, however, the results highlight that people's expectations make a considerable difference to their perceived resilience to disruptions, independent of the indicators above. Understanding vulnerability requires paying attention to contextual factors such as expectations around energy practices and routines, and expectations of the future availability of energy. Furthermore, some people will feel much more impacted by a disruption to their routine than others, which means that identifying those who are likely to be more or less resilient is a highly complex task, requiring considerable resources and sensitivity to the dynamic nature of practices and expectations. Therefore, it is also important to identify measures for improving resilience at an aggregate level. To our participants, the most relevant measure was improving the thermal efficiency of homes. Investment in ambitious energy efficiency programmes would support improved resilience to energy disruptions and adaption to climate change risks, even in the context of a society which is becoming rapidly more dependent on electricity.

One of the goals of this study was to consider how energy practices are changing, and how this might impact people's resilience to energy disruptions in the future. Our participants made it clear that they expect the 'home of the future' to be fundamentally reliant on electricity and the internet to function, with many interviewees envisaging a home within the next five to ten years where every appliance is electrical and controlled with an app. There was a general sense from interviewees that this shift will be largely inevitable, driven by external forces. Households in urban areas have fewer non-electrical options available to them during a disruption. In particular, the transition away from natural gas for cooking creates a vulnerability, with people reliant on gas hobs for heating water and food, and households which have made the switch to electric cooking may still rely on their neighbours with gas during an outage.

Often, the proposed response to such growing risks is to call for better communication mechanisms during and before outages, so that households can adequately prepare [71,72]. This is necessary but not sufficient – the rarity of outages means that households may not perceive the need to prepare no matter what communication tools are used, and many may be unable to put preparedness measures in place, for instance due to a lack of space or disposable income [34,73]. More broadly, there is a risk that focusing on individual preparedness depoliticises the issue and places the responsibility for addressing systemic vulnerabilities onto individuals [74]. For example, participants emphasised the importance of social ties over material possessions for maximising their resilience. The participants also reported that feeling a sense of personal responsibility for an outage actually *increases* stress and anxiety. Therefore resilience could benefit from shifting the burden off the individual, by prioritising collective resources which support resilience to disruptions – particularly considering that collective resources tend to be cheaper than individual ones [75]. Connon and Hall [41] argue that we need a multi-level approach which enables communities to organise and develop suitable plans for their local context, whilst maintaining institutional resources for those who may be more marginalised from their communities. This requires proper resourcing and should not be left to voluntary organisations or underfunded local authorities. Local resilience organisations already exist in many countries, including as 'Local Resilience Partnerships' in Scotland; however, little is currently known about their effectiveness at addressing specific vulnerabilities or aiding citizens during major disruptions, or where their funding needs might lie, which represents an important area for future research.

A key issue for resilience is our growing dependency on electricity, driven in part by decarbonisation objectives. Decarbonisation clearly brings risks and trade-offs, yet identifying and highlighting these must be done in a way which avoids playing into discourses of delay around climate change mitigation [76]. It is always worth emphasising that failure to decarbonise will create far greater risks, not least due to the already-apparent impacts of extreme weather on energy infrastructure [6]. Climate mitigation and adaptation must go hand-in-hand – decarbonising to mitigate the future impacts of extreme weather, whilst adapting to an increasingly complex system and risk of disruption. This paper argues that this adaptation challenge requires a renewed focus on social and community resilience, in particular on people's lived experiences of energy disruptions, and a more nuanced understanding of what it means to be 'resilient' and on how resilience can be supported.

5. Conclusion

Energy systems which have historically experienced extremely high reliability are facing new challenges and risks. Improving resilience to disruptions is not simply a question of system infrastructure: it also requires an understanding of end-users, communities, and society. This study examines the expectations and responses of urban households to the idea of a serious energy disruption, using an interview study of citizens of Glasgow, the largest city in Scotland. Novel methods were used to study a hypothetical scenario, combining semi-structured interviews with a home-based diary task in a three-stage qualitative design, intended to make people's energy practices and dependencies more 'visible' to them. Such an approach could be used for future research on disruptive experiences in a broad range of sectors. In addition, the study explores the impacts of non-energy disruptions of mobile phone/internet, water, transport, food retail, and medical services, finding that people's ability to cope would likely decrease with duration in a non-linear 'step-change' fashion, in response to disruption to key practices, devices and interdependent infrastructures.

Assumptions regarding people's vulnerability are sometimes misplaced; in particular, commonly used proxies such as age and income are complex, and shifting rapidly as digital dependency grows. A set of 'indicators of vulnerability' have been identified which could be used to develop community-based responses to outages or for including socio-economic factors in energy system models: digital dependence, young children in the home, single parents, poor health, and social isolation. However, the principal factor influencing people's responses to disruptions is found to be their expectations regarding their routines, practices, and availability of energy and services.

It is also important to consider how societal expectations are changing, and how this might impact resilience in the near future. Electrification is driving major changes in energy practices and energy dependence, and vulnerabilities caused by the low-carbon transition need to be addressed, particularly around the shift away from gas cooking. Such rapid changes mean that socio-demographic proxies for identifying vulnerability can only go so far, and need to be supplemented with localized systems of provision at city or even neighbourhood scale. For example, Glasgow City has twenty-three neighbourhood wards, each of which could benefit from resourcing to help them

maximise their knowledge of their local community; in addition, local grassroots organisations could be well-placed to understand the needs of the community and identify the most vulnerable within it. A community focus can also shift responsibility off individuals, which in turn reduces impacts of stress and anxiety; yet in cities like Glasgow, this cannot be done without vastly improved resourcing.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Data availability

The data from this study is available via the UK Data Service at https://doi.org/10.5255/UKDA-SN-856107

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Appendix A. Supplementary data

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