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Original research article

Towards a socio-technical perspective on resilient power systems: challenging techno-centrism in the Swedish electricity sector

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A B S T R A C T

Electric power systems face a multitude of threats and changes, including climate change impacts, energy transitions, security threats, and rapid technology diffusion at the household level. Resilience has emerged as a relevant concept to describe the power system's ability to adapt and transform to manage all these changes. Yet resilience does not have a fixed definition, and little is known about how it is being operationalized in the energy sector. This paper examines how Swedish electric utilities interpret what resilience means in their power system context, and how they envision households' roles within it. The study draws on seven focus groups with 26 professionals from seven electric utilities from different parts of Sweden.

The results demonstrate how techno-centric perspectives largely dominate utilities' interpretation of the resilient power system, and how households are given somewhat contradictory roles within it. However, discussions around households' potential roles also contest the view of resilience as merely a technical issue. Thus, the analysis identifies tensions that emerge when more social aspects of resilience are made visible, including what actors are recognized as important co-producers of resilience. The paper advocates for a more socio-technical interpretation of energy resilience, which can offer a broader set of strategies for managing changes in the power system, that are better aligned with a sustainable energy transition. A key contribution of the paper is thus that it demonstrates how socio-technical resilience can serve as a conceptual tool to challenge expectations and norms associated with electricity infrastructure in affluent contexts.

1. Introduction

Power systems around the world are undergoing big changes and are facing diverse threats. Climate change, electrification, aging grids, security threats, geopolitical conflicts, and resource depletion are some of the global challenges that are altering the conditions for how electric power is produced, distributed and used [1]. It is suggested that to manage all these changes, power systems need to become more resilient [2,3]. Resilience often refers to a system's ability to persist, adapt, and recover from outside changes and disturbances and transform to be better equipped to deal with future changes [4]. Power grids are often considered critical infrastructures because electricity provision is seen as crucial for economic and social life [5]. By extension, resilience of the power system affects society's resilience overall. As described above, power systems also face many different threats, disturbances and changes that impact their vulnerability and operation. However, there is not one agreed upon definition of resilience, as a result it is often used vaguely [6]. While resilience has been widely adopted and debated in fields like disaster risk reduction [7], its social dimensions within electric power systems are still emerging areas of study [5,8], leaving significant knowledge gaps. Furthermore, it has been suggested that because resilience is adopted in vastly different areas in both research, policy and practice, more knowledge is needed on how it is being interpreted and used in different contexts, to provide conceptual clarity [6]. As power systems confront increasingly complex challenges, there is a need to examine how different stakeholders of the energy system understand resilience, and how these understandings in turn shape energy services and professional practices within the sector.

In Sweden, the context of this study, the aforementioned changes and threats to the power system have received heightened attention in recent years. Climate change is affecting both power production and power distribution [9]. The electrification of heavy industries and the transport sector is projected to increase electricity demand from 140 TWh (2022) to between 190 and 310 TWh by 2050 [10]. Increase in solar power and wind power production with higher intermittency and variability, creates challenges of balancing demand and supply [11]. Increased attention is also being paid to security threats such as attacks on the infrastructure, especially because of Russia's invasion of Ukraine [12]. At the same time, the Swedish grid is constrained by limited transferring capacity between and within local grids, which in turn can hinder electrification processes and restrict industrial expansion [13]. While the grid needs to be able to support electrification to replace fossil fuels,

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expansion of the infrastructure and power production is expensive, takes time, and is resource intensive. This dilemma prompts questions of whether more efficiency and demand side flexibility in the power system can perhaps reduce the need for grid expansion and power production [11].

Conditions for users' interactions with the grid are also changing at household level. Electric vehicles, home batteries, photovoltaics, new electricity price signals, and smart grid services with opportunities for cost savings through flexible electricity use are becoming increasingly popular. These trends change the traditional supplier-customer relationship as households can now be "prosumers" and offer flexibility through their use of home electricity installations. Additionally, as part of the increased attention to security threats, households are being assigned important roles and responsibilities as "resilient subjects" in Swedish civil defense policies [14]. For example, households are encouraged by national and local authorities to be prepared to cope with different disruption scenarios including blackouts [15].

The overarching aim of this paper is to contribute to an emerging social science literature concerned with unpacking and reimagining energy resilience in the context of sustainable energy transitions [4,5,16–18]. An important purpose of this literature is to better recognize and integrate social aspects into the conceptualization of energy resilience. This paper complements previous studies by examining the perspectives of electric utilities, tasked with managing the electricity infrastructure on local and regional level. The aim is broken down into two research questions: 1) How do electric utilities understand resilience in relation to the power system? and 2) How do they view households' roles in a resilient power system?

2. Energy resilience as analytical concept

Broadly speaking, energy resilience typically refers to the ability of a system to tolerate, adapt and recover from energy-related disturbances and pressures [4,8]. Notably, resilience is used in various ways across scientific disciplines. It ranges from being used in engineering as a measurable system property, to a conceptual lens in social science [4,17]. In this paper, resilience serves as an entry point for exploring the utilities' ideas of how challenges in the power system can and should be managed. As such the resilience concept offers a way of theorizing around transitions and systems' ability to respond to outside changes [19].

There are three central components in the energy resilience concept that shape its meaning. These are labelled somewhat differently in the literature but revolve around roughly the same cornerstones, which be categorized as: the *system* and it's *function*, *disturbance*, and *resilient system behaviors* [4]. The system refers to the entity that is envisioned to be resilient, for example, a power grid or a city.

The *function* or "nucleus" refers to the process that is supposed to be maintained or protected through resilience within the system, for example, constant energy access [3] or essential energy services [18]. It represents processes that are considered essential and therefore prioritized.

Disturbances represent the anticipated pressures that the system needs to be resilient against. In previous research on resilient power systems, primarily from technical research domains, typical expected disturbances often revolve around extreme weather events of different kinds [3,8]. Due to recent rise in geopolitical tensions, increasing attention has also been paid to deliberate attacks on electricity infrastructure, with the invasion of Ukraine as an example [20]. Furthermore, as advancements in technical innovations, electrification and digitalization accelerate, potential disturbances or changes that warrant resilience can also be interwoven into the power system itself. Such examples include increased risk of high load peaks due to EV charging [21], and increased dependence on complex digital and online infrastructure which creates vulnerability [22].

Finally, the *system behaviors* represent preventive and absorptive ways in which the system can be resilient against disturbances. These resilient system behaviors are sometimes divided into different phases: adaptation, restoration, toleration, and transformation [4]. In previous research concerning power systems, measures to strengthen such resilient system behaviors include improving the physical robustness of the grid, relocating substations, ensuring emergency generators, ensuring spare parts and management of repair crews, and implementing systems for monitoring weather events [3]. In this paper, the resilience components of *function, disturbance*, and *resilient system behaviors* are used to unpack electric utilities' understanding and operationalization of resilience.

2.1. Socio-technical conceptualizations of resilience in power systems

'Socio-technical' perspectives on infrastructures rejects that the technical and the social dimensions of society and infrastructure can be distinctly separated. Socio-technical energy research is typically concerned with understanding the co-evolution of technology and social outcomes such as energy norms, energy cultures and energy practices [23]. In this view, phenomena such as patterns of residential energy use are not something that simply exists "out there" but is rather the result of socio-technical system development. Socio-technical perspectives are therefore built on an assumption that technical and social development is deeply intertwined, and must be understood in relation to one another [24]. When it comes to energy systems and electric power grids, socio-technical perspectives are common to understand energy transitions, but are still rarely applied in studies on resilience of electricity systems, with some important exceptions, mostly focused on the household perspective [16–18,25].

Interdisciplinary and socio-technical perspectives on resilience in energy systems and power systems complicate how the aforementioned concepts of *function, disturbance* and *resilient systems behaviors* are understood. For example, interdisciplinary studies show that households' prioritization of trips and vehicle types, and their use of heating systems, impact system resilience for fuel disruption, highlighting how drawing of energy system boundaries impact the conceptualization of both disturbances and how they can be managed [26]. Similarly, interdisciplinary and social science studies of energy resilience that incorporate demand side perspectives present alternative ideas of what constitute the central *function* of the system, suggesting that the point of energy resilience is not necessarily to ensure constant electricity access, but rather to be able to maintain a good life [17] or to get access to essential energy services [18].

Other socio-technical dynamics are also relevant to understanding resilience in power systems. It has long been suggested that *learning* is a central system behavior for improving resilience [27–30], closely related to adaptation and transformation. Learning also points to an important socio-technical system dynamic for resilience – that the system needs to be exposed to disruptions, pressures and changes to some degree to adapt and over time improve its resilience [31]. Such mechanisms can for example be understood in terms of double-loop learning [32] or crisis induced learning [33], phenomena where experiences of adversity lead people and organizations to rethink their assumptions, drawing insights from the experiences, and ultimately make efforts to be better prepared for future similar scenarios. Another socio-technical system dynamic central to resilience in power systems involves *collaboration* as a key arrangement that allows resilience to be improved in communities [34]. Such collaborative resilience initiatives can be between national, regional, and local governments, between public and private actors, but also between public actors and civil society. In the power system context, one such example is citizen-led energy communities which involves collaboration between utilities and residents, and which offer opportunities for increased resilience locally [35]. Although recognized as important socio-technical aspects of resilience in the larger resilience literature, these aspects are often overlooked in the technical literature on resilience of electricity systems. This paper

considers how a socio-technical perspective can inform our understanding of resilience of power systems, which includes changes such as energy transitions, but also extends to crisis preparedness and climate adaptation.

3. Methods

A qualitative approach was used to explore utilities' understanding of power system resilience and households' roles within it. The following sections describe recruitment of respondents, focus group interviews, and analysis of data.

3.1. Recruitment & participants

Data was collected through seven semi-structured focus group interviews with 26 respondents from seven electric utility companies. Sweden has about 170 electric utility companies, which vary in size, ownership structure, distribution area, number of inhabitants, and geography [36]. Utility companies here means Distribution System Operators (DSO), meaning the companies responsible for operating the regional and local power grids in Sweden. The selection of utilities invited to participate in the study was based on an ambition to capture some of this variation in terms of organizational size, geographical location, and demographics, thereby hopefully capturing different kinds of challenges faced by utilities and grids across Sweden. Suggestions for what specific utilities to invite were gathered by talking to power system experts within and without the research organization RISE Research institutes of Sweden, that are regularly in contact with utilities in their work. In total eight companies were invited; seven participated. The invitation outlined the study's purpose, themes, and focus on households. To be able to discuss both social and technical aspects of resilience, professionals with expertise in technical infrastructure, security, communication, and customer service were sought in the invitation. Based on this information, the utilities suggested suitable participants themselves. The participants represented utilities from different parts of Sweden from north to south and east to west, encompassing island communities, big rural areas, bigger and smaller cities as well as mountain areas. In terms of organizational size, they ranged from being small, municipally owned, to being one of the biggest utility companies in Sweden. It should be noted that the majority of respondents had technical or generalist professions, but there were some variation also here, including professionals in customer service and communication. Table 1 provides an overview of the companies and participants, using fictive names for both companies and participants.

Table 1
Overview of participants.

Company fictive label	Number of respondents	Roles represented in focus groups
Coastline Energy	4	*Simon*, Grid Planning engineer *Emelie*, Planning engineer *Amanda*, Customer relations Molly, Customer relations
Eastpoint Energy	3	Rikard, Security manager *Julia*, Customer service Karoline, Communications officer
Clearvolt	3	*John*, Senior specialist regional grids Peter, Senior specialist local grids *Marcus*, Customer relations
PowerSouth	6	*Kristoffer*, Grid strategist, project manager *Jacob*, Department of measuring, verification of energy meters *Milo*, Representative from department of measuring, customer contact *Henrik*, Product manager Sandro, Head of grid infrastructure *Tanja*, Grid strategist, project manager
Inlandis Energy	3	Nils, Head of strategy and business development *Matilda*, Security and quality assurance *Tommy*, Consultant within strategical areas
Northreach	3	*Albin*, Business innovation *Karin*, Local grids Joel, Local grid, measurements
GridWay Electric	4	*Andreas*, Security, preparedness, total defense officer *Helene*, External analysis Stefan, Energy market engineer *Daniel*, Grid operations manager

3.2. Focus groups

Focus groups were appropriate for this study for several reasons. The topic of resilience and its relationship to the power system and the household customer segment is intricate and nuanced. Consequently, there is an advantage in having colleagues from the same organization reflect on and analyze these issues collectively rather than individually. One of the strengths of focus groups as a method is the ability to share high-effort cognitive tasks, such as discussing complex problems or interpreting challenging concepts [37]. Focus groups enable participants to reflect on resilience based on their individual perspectives and experiences, while also providing the group's articulation of the perspectives of the organization as a whole.

Because the utility companies involved were located across different regions of Sweden, one focus group was held physically on site, while the others took place online via Microsoft Teams meetings. All discussions were recorded and transcribed with the respondents' consent. Respondents were informed of the purpose of the study through written and verbal information. The interviews were led by the first author, while one more researcher provided support and took notes. The sessions lasted between 77 and 112 min, not including the initial presentations and information about the study. The focus groups were moderated in such a way that all themes of the guide (see 4.2.1 below) were included, however, the intention of the focus group was not to cover all suggested questions, but rather to spark discussion among the participants and to invite everyone to share their view. As a rule, a discussion among the participants on a subject was considered more important and valuable to give room to rather than to ask a specific question, in order to capture the utility employees' agreements and disagreements, shared experiences and so on. The focus groups were carried out in the winter of 2024–2025.

3.2.1. Focus group interview guide

The focus group sessions started with a round of introductions where each respondent presented themselves and their role within the company. The guide for focus groups was structured according to five themes: 1) Knowledge about households 2) Experiences from the Energy Crisis, 3) Resilience, 4) Contact with households and 5) Present and future challenges. These themes guided the conversation and were put in a deliberate order to help the group warm up and to explore resilience from different angles and with the help of specific scenarios. For example, the 2022–2023 energy crisis served as an entry point for reflecting on resilience in relation to the power system and households. In Sweden, the 2022–2023 energy crisis led to volatile and accelerating electricity prices and higher risks of power cuts. In the resilience theme, the respondents were asked to reflect on what they thought a resilient grid and a resilient power system meant. When needed, a simple definition of resilience was provided to support the discussion. Follow-up questions included anticipated threats and changes to the power system, as well as measures or opportunities that could strengthen resilience. A sub-theme on resilience focused on what type of changes or disruptions might affect households, and in what ways, if any, utilities believed households would affect power system resilience. As indicated by the theme labels, households were also present in other themes. For example, they were asked to describe broadly what they knew about households in their grids, and in what ways they came in contact with

them. The purpose was to examine how respondents viewed households' roles in resilience through their professional experiences and relationships with households. The full focus group interview guide can be found in Appendix 1.

3.3. Analysis

To answer each research question, two different analytical approaches were used, both a form of reflexive thematic analysis [38]. The first departed from three distinct analytical questions, and the second was more data-driven. The first research question and analysis concerned utilities' interpretation of resilience. The coding was guided by three analytical questions suggested by Hamborg et al. [4] to examine how resilience is interpreted by a specific actor: "Resilience of what?" "Resilience to what?" and "Resilience by what means?". Each question represents one of the elements in the resilience concept described earlier: *system & function persistency*, *disturbance*, and *resilient system behaviors*. "Resilience of what?" reflects how the system is understood and what function is supposed to be protected. "Resilience to what?" is about what changes and disturbances are anticipated. "Resilient by what means?" reflects how actors envision that resilience can be improved.

The second research question, concerning households' roles in resilience, was answered using a more inductive approach. Two overarching themes were created: "cost-driven users of technology" and "social actors (un)prepared for blackouts". The themes were created based on the recurring stories told by the utility respondents, which centered around ideas of households' price sensitivity, their interaction with the grid through their technologies, and on the other hand their adaptive ability, or lack thereof, in case of a power cut. The reason for the separate analysis was that the respondents' description of households did not easily fit into the first analysis based on the components in the resilience concept. Rather, the respondents' stories about households challenged how they otherwise viewed resilience, as we shall see in the results. A separate analysis of households' roles was thus advantageous to pinpoint tensions between resilience perspectives. The results are brought together and discussed at the end of the paper. Examples of codes for each theme can be found in Appendix 2.

4. Results

The results are presented through five themes organized into two main subsections. First, the respondents' interpretation of what a resilient power system means is introduced. Secondly, the analysis that examines their views of households' roles are presented. Importantly, respondents sometimes disagreed or expressed uncertainty around the complexity of resilience. Thus, the results highlight recurring arguments and ideas rather than an exhaustive account of all discussions.

4.1. The resilient power system

The first three themes represent the first research question and are presented according to the three analytical questions "resilience of what?", "resilience to what?" and "resilience by what means?" [4].

4.1.1. Resilience of what: Reliable and constant electricity access

When the respondents together tried to make sense of what a resilient power system means, their focus was often on ensuring reliable access to electricity, here equated to constant electricity supply. In discussions on disruptions of different kinds and ways of enhancing resilience, there was most of the time an underlying assumption that utilities should protect electricity supply and avoid that power is cut as much as they possibly can. Reliable and constant electricity supply thus represents the 'function', and the answer to the question "resilience of what?"

There were numerous examples that demonstrated this intention and focus of the utilities and their work. For instance, resilience was repeatedly related to the robustness and quality of the physical infrastructure. Respondents in technical professions that worked closely with grid operation and had been doing so for many years, explained that they have systematically worked for a long time to reduce the number of disruptions and blackouts in their grids. They did so by improving robustness, monitoring and redundancy in the infrastructure. One specific measure to reduce risks of blackouts was that most utilities had been digging down cables to make them less exposed to impacts like falling trees. For utilities such as Northreach in the north of Sweden, it was more difficult to put cables in the ground due to their climate and geography. Instead, they created broader "streets" for power lines in which trees were cleared out of the way, to minimize risk of damage. These types of measures are means to increase resilience that clearly connects to the function they aim to protect – reliable and constant electricity supply. The intentional focus on ensuring reliability and minimizing disruptions was exemplified by Nils: "*The ambition is that you should be able to get electricity 24 hours a day, that you should be able to trust your electricity supply. I don't remember what words we used in our vision and our goal formulation but that's the message.*" His colleague Matilda fills in: "*Safe and secure electricity supply*". This quote demonstrates how respondents believe that users of the grid – such as households – should be able to expect constant and reliable electricity access.

Reliable and constant electricity supply as the central objective of a resilient power system was not merely an idea that the utilities believed in and initiated themselves. It was clearly communicated and enforced upon them from the local and national governmental level, and to some extent also demanded by households (which we will return to later). Indeed, respondents referenced both specific legislative demands on them to uphold electricity supply within certain timeframes, as well as financial incentives in the form of compensation to customers and fees they needed to pay, that strongly encouraged them to reduce disruptions. Furthermore, these expectations were not perceived as static: Tommy testified that the general trend was that demands on electricity supply reliability were constantly increasing from all directions. In the Clearvolt focus group for example, it was mentioned that after any larger disruptive event that affects customers, there were typically higher demands communicated towards the utilities to prevent such disruptions from occurring again from both politics and the public. Or as in Northreach, where Albin described that since the big storm Gudrun in 2005,[1] improvements to make the grid "weather secure" had been going on for twenty years, accelerated by regulations that came after the storm. In addition, utilities often tried to stay ahead of these legislative demands, as exemplified by Peter from Clearvolt: "*(..) Then of course we want to be even better, we want to find solutions to minimize it [disruptions] even more, that of course is as cost-efficient as possible*". As such, maintaining high reliability and continuously reducing the number of power cuts appears to be institutionalized in the sense that it is embedded both in regulation and in policy instruments from the government, and in the utilities' own goals and practices.

Importantly, the task of ensuring constant electricity supply at all times did not go completely unchallenged by the respondents. PowerSouth struggled with power shortages, however, they were discouraged from authorities to use for example short power cuts to households to mitigate such problems. Yet they did have a responsibility to protect the infrastructure and deal with power shortages and power peaks. Gabriel, head of infrastructure, expressed frustration at the difficult task of balancing societal benefits in connecting new users to the grid, and regulatory ambiguities and constraints that limited their options for increasing resilience such as briefly cutting power when needed.

Despite the deeply settled focus on securing electricity supply and reducing the risk for power outages, disruptions were typically not seen

[1] The storm Gudrun, which struck southern Sweden in January 2005, left around 730,000 households, businesses, and industries without electricity, some for extended periods during freezing winter conditions, and over 3000 miles of electricity grid were destroyed [39,40].

as completely avoidable. As phrased by Rikard: *"It's not about if it happens, it's about when it happens"*. Furthermore, electricity supply was not protected to the same extent everywhere. Disruptions were described as more common in the periphery of local grids, where the amount of cable per capita was bigger, making the reliability and safe operation both more expensive and more practically difficult to maintain due to voltage differences.

Relatedly, some respondents testified that as their supply reliability increased in percentage, each marginal improvement would be more costly. This, too, was something that made some respondents question how far they should go to reduce disruptions. For example, at GridWay, respondents reflected on how much it would cost to reduce disruptions that would last perhaps six minutes, and whether households would perhaps be willing to accept such very short disruptions.

To summarize, the answer to 'resilience of what?' is a reliable electric grid that can ensure uninterrupted electricity access. However, respondents also acknowledge how maintaining grid reliability at all times is challenging, and can create tensions with other objectives such as cost-efficiency and affordability.

4.1.2. Resilience to what: Complexities in everyday operations and crises

Respondents anticipated a multitude of disturbances that the power system needs to be resilient against to ensure reliable and constant electricity supply. Aging grids, climate change, higher intermittency due to renewable energy generation, and security threats were some of the pressures and changes that respondents mentioned.

Broadly speaking, the way respondents talked about possible disturbances can be divided into two types of scenarios. The first is about changes and challenges that relate strongly to processes of electrification and digitalization, leading to an increasing technical complexity in everyday operations. These disturbances emerge for example when renewable energy technologies are integrated, and when grid constraints and power peaks put pressure on the utility. The other type of scenario is more crisis adjacent, such as deliberate attacks on infrastructure or extreme weather events. This dual categorization of different types of disturbances, as well as potential contradictions in preparing for both of them, was illustrated by Kristoffer:

"I'm thinking sometimes about this duality in the resilience concept. Somehow, complexity increases, there are more interdependencies, more technology and more data that needs to run together to be optimized and work together and so on. But on the other hand, if there is a crisis or war and something really happens, it's often the basic things that are needed. That you can repair and fix what is actually there, that you have materials in reserve and wires and fuel. That is not built on the optimized and the complex that works in peacetime. So how are you supposed to make ends meet with accelerating and optimizing, working with flexibility and at the same time be able to quickly back up and deal with another scenario as well?"

The quote hints at a potential conflict between adapting to increasing technical complexity in everyday operations, and at the same time being able to ensure basic necessities in case of an emergency or larger disruption. Such a conflict was also confirmed when respondents mentioned that electrification and digitalization will lead to an increasing dependency on electricity which in turn could lead to higher vulnerability.

Many of the challenges that respondents anticipated in the "everyday operations"-scenario relate to society's energy transition, digitalization, electrification and growing popularity in technologies such as EVs, batteries, PVs and smart control systems. These technologies were expected to lead to new demand patterns and higher risks of power peaks and power shortages, in turn creating new requirements for what type of electricity services the utility should accommodate. For example, decentralized solutions for producing, storing and selling electricity has made it possible for the prosumer role to emerge, which in turn means that the grid must allow for electricity to be delivered "both ways". Innovations such as PVs, EVs, batteries and smart control systems were perceived as related to resilience in the sense that they could both cause disturbances, and constitute resilience resources, as we shall see in the next theme. While EVs and PVs, for example, can put strain on the grid, they can also help strengthen resilience. The electrification of the car fleet means that mobility is being coupled with the home's electricity use and that a growing share of cars are reliant on the power grid. This was a concern to the utilities because many parts of the grid are not sized to be able to meet the surge in electricity demand that replacement of all fossil cars would mean. PVs were attributed the opposite problem – they could rather create production peaks (so called "solar peaks") during seasons when demand is low, resulting in a mismatch between production interests and demand.

In addition to being either about increasing technical complexity in everyday operations or associated with crisis, the anticipated disturbances were shaped by geographical, seasonal and socio-economic characteristics of each local grid. For example, increasing amounts of EVs was expected to result in higher seasonal variations in electricity demand, especially by utilities Inlandis Energy and GridWay Electric that operated grids which encompassed large ski resorts with huge influx of tourists in winter. As the number of EVs increase, especially through tourism, sufficient grid capacity for charging infrastructure, as well as possible charging power peaks, were emerging challenges for these utilities. This example points to how electrification, demand patterns and geographical conditions intertwine, and shape what disturbances are anticipated and relevant for the utility to build resilience against.

More crisis- or emergency-related disturbances, such as climate-driven impacts, were also shaped by temporal, seasonal, and geographical aspects in the sense that they were expected to differ depending on grid and time of year, as well as how far climate change progresses. These variations were illustrated by, for example, Karoline from Eastpoint Energy, who was concerned about their islands' exposure to bigger storms, by Henrik from Powersouth, who was concerned about flooding due to their low altitude, and Stefan from GridWay Electric further north, who was concerned about increased precipitation and landslides.

All in all, what is the power system expected to be resilient against? Anticipated disturbances are either related to increasing technical complexity in everyday operations due to electrification and digitalization, or more crisis adjacent scenarios such as extreme weather events or attacks on the grid. In both cases, anticipated disturbances are shaped by the grids' geographical and socio-economic demand characteristics as well as seasonal variations.

4.1.3. Resilience by what means: Technological improvements

The resilient power system was frequently associated with a high-tech network that is informative, communicative, online, and automated. When the respondents identified measures to improve resilience, they therefore often focused on suggesting technical advancements that could achieve such a grid. The resilient grid was envisioned to be able to advise users on ways to prevent problems such as power peaks, and potentially even control certain electricity use when needed. The resilient grid was even described as aware, in the sense that it could self-diagnose its condition and communicate possible strains and disruption risks. In other words, as framed by Amanda, it is a grid "*that knows itself*". The connection between a resilient grid and an informative and smart grid was also described by Gabriel: *"What is a resilient grid? Well it's a grid that is as automated as possible, as modern as possible. You have access to as much data and as much insight into data as you possibly can. In part measurement data (…) and then customer use patterns (…). But it's also active systems that will give you access to how the grid is doing at each moment in time"*. This envisioned smart grid served several resilience purposes from the utilities' perspective. It could help to prevent disruptions, and by using the grid more efficiently, it could also be a less expensive and less resource-intensive alternative to constantly expanding the grid to accommodate new technologies or demand patterns while ensuring constant reliability.

As mentioned earlier, the electrification of the car fleet and

technologies for small scale production and storage of electricity was not just considered a change that the grid must be resilient to. These technologies were also attributed important resilience properties. For example, EVs can be used as batteries during power shortages, and can be strategically charged during production peaks and even feed back into the grid (so called Vehicle-to-grid). PVs are also suitable for decentralized micro production which was described as a way of increasing resilience since such production sites are more difficult to target for attacks.

This technological development, that provided both disturbances and resources for resilience, was generally seen as something inevitable and largely controlled by the market. Throughout the focus groups, there was a shared view that the utility's role was to adapt and support this development as best they could, to enable users such as households to "plug-and-play", regardless of any challenges associated with EVs, PVs, batteries or other systems. At the same time, the respondents found themselves wondering how they could support ways of using these technologies that could mitigate disruption risks such as power peaks. In this regard, respondents like Amanda emphasized the importance of legislative measures that could regulate the design of technologies in a way that would make them less of a problem for the grid, for example through lower or smarter production settings for PV systems.

Importantly, not all measures envisioned to improve resilience were high tech. Some were more oriented around increasing robustness of the infrastructure and ensuring strong crisis preparedness and energy security overall. Alternative fuels and latent power reserves in society, for example in the agricultural sector or in local communities, were mentioned as possible means to deal with power shortages to prevent blackouts. Placing grid stations strategically is a way of reducing the grid's vulnerability to climate change impacts such as flooding and landslides. Utilities also mentioned different ways in which they improve their ability to repair the grid as fast as possible.

This theme answers the question "resilience by what means?". Respondents suggest measures to strengthen resilience that are largely focused on technological and physical grid improvements. This technocentrism is further confirmed by the recurring belief that technological advancements that affect the power system are inevitable. However, respondents also recognize that the way household technologies are used will determine whether they constitute disturbances or resources. This leads us to the second overarching part of the results, which explores the respondents' views on the role of households.

4.2. Households' roles in a resilient power grid

The analysis resulted in two major themes that reflected how respondents discussed the role of households in the resilient power system: the first concerns households' contribution to resilience through their technology use. The second concerns discrepancies in households' preparedness and response to disruptions and blackouts.

4.2.1. Cost-driven users of technology

When utilities talked about households as potential co-producers of resilience, households' roles were often centered around their technology use and their response to financial incentives. Indeed, flexibility seemed to be top of mind for many respondents when asked what role households have in power system resilience. Flexibility here means shifting the timing of electricity usage in accordance with price signals such as electricity retail price and power tariffs. In the focus groups, flexibility was mainly discussed in relation to the appliances that use most electricity in homes: electric heating and EV charging. Consequently, respondents thought it was most important that households in single-family homes heated with electricity and those with EVs would become flexible. Additionally, respondents saw an opportunity in households being more aware of seasonal variations in electricity production. Such flexibility was suggested to include using more electricity in times of abundance, like in summer when PVs are producing a lot, and less during periods with limited electricity production, for example windless winter days.

Importantly, there was some disagreement in the focus groups around how much households could be expected to engage in flexibility. Some respondents recognized and emphasized the difficulty for households with unfavorable financial conditions, low interest and low technology skills to be able to upgrade their homes and follow price signals. Respondents who worked in customer relations professions like Julia, Karoline and Amanda also highlighted the important yet difficult task of communicating and educating households on complex electricity issues in a way that is comprehensible and inclusive. These discussions and disagreements show how some respondents clearly recognize households' engagement as conditioned by their energy literacy.

Throughout the focus groups respondents were aware of the diversity of households in their grid and acknowledged the need for support to increase their engagement. Some like Jacob even challenged whether households should be expected to be flexible at all. He reasoned that a modern society should adapt to the needs of the users, not the other way around, which connects to an idea of households as passive recipients of uninterrupted electricity. Other respondents emphasized the important role of automation as a way of enabling flexibility in households without demanding too much engagement from them.

Nevertheless, respondents identified technologies like heat pumps, home batteries, PVs, and EVs as ways households could help strengthen resilience in the power system. These could be used as resilience resources, either through flexible use, to prevent power cuts, or in the case of batteries and PVs, as helpful back-ups during blackouts. In this way, households could build resilience bottom-up, thereby help to ensure electricity access, as illustrated by Marcus: *"(…) It may very well be that we're entering a new era of resilience, because you're putting technology in the hands of all consumers that enable them to become resilient. I'm thinking about batteries, EVs, PVs, neighborhood batteries or whatever, that you can build resilience from below in that way. And if there's disturbances like there's sometimes in the local grids, well then the car discharges instead. So I think that's a technology trend that will come, and with the help of these cheap batteries and cars everywhere you might be able to make ends meet. Now the grid has reduced as much [disruptions] as they possibly can, and then you meet up from below with other technologies to keep the last disruptions away. So I think that will be a major trend ahead"*.

The EV was repeatedly emphasized as a very important household technology from a resilience perspective. EVs can both be used as back-up batteries on cold winter days, they can feed back into the grid during power shortages, be used for frequency regulation, and they can be strategically charged on sunny days to help make use of solar power production peaks. The way households charge and drive their EVs was also believed to have a big impact on the power system. For example, Stefan explained that he had started advocating for households to "charge calmly", meaning slower and with lower power, as a way of mitigating power peaks and enable more EVs to be charged at once.

While flexibility and technologies were identified as important strategies and tools for households to contribute to resilience, respondents often saw this type of engagement as conditioned by how well financial incentives and market developments could attract households' interest. The belief that households are mostly cost driven was apparent when respondents discussed the reduced electricity consumption during the energy crisis of 2022/2023, as exemplified by Henrik: *"I think the reduction in electricity use [during the winter of 2022/2023] was a pure financial thing for 98% of the customers. 'We have to reduce our usage because electricity is so expensive'. I don't think it had so much to do with the power shortage."* Again, this mirrors the understanding of market-driven technological development and price signals as central to households' roles in resilience, shaping both anticipated disturbances and envisioned solutions. However, not all respondents believed households were purely cost driven. Some like Stefan, Daniel, Nils and Tommy believed that if there was a serious emergency in their grids, households would certainly try to help mitigate it if the utility would ask them to. Such

reasoning points to other motives for collaborative resilience.

This theme points to how a certain category of households is viewed as potential co-producers of resilience through their investment and use of technologies. These are typically households living in detached homes with electric heating and EVs. Overall, households' role is here expected to be dependent on the success of price signals. However, there were also ambivalence and occasional disagreements on what motivates and conditions households to adapt their usage.

4.2.2. Social actors (un)prepared for blackouts

There was an overall perception across the focus groups that a large share of Swedish households takes electricity access for granted, in spite of the heightened interest in electricity use in households following the energy crisis of 2022/2023. Respondents observed how many households are becoming increasingly electricity dependent through more appliances, and at the same time less and less prepared for any type of disruption. Expectations on functioning and uninterrupted electricity supply seemed to be ever growing, not just from authorities, but also from households. Julia and Caroline for example described how some people reacted during blackouts, calling immediately, expressing stress and frustration that the power was gone, and demanding instantaneous and detailed information about when the problem would be fixed.

However, it was emphasized that not all households were badly prepared for blackouts. Respondents noticed a big disparity between urban households and rural ones concerning how accustomed they were to blackouts and consequently how prepared they were. This was evident in Northreach, where wires were still air-borne in some parts of the grid due to unfavorable ground conditions. Because the length of cable per person was much longer than in the cities, some rural parts of the grid were more vulnerable to damage, thus households living in these areas were more exposed to disruptions. Respondents from Northreach saw how households in the periphery of the grid network were well prepared in the event of a blackout, and did not appear to be surprised nor react very strongly to disruptions. Respondents from Gridway Electric, Eastpoint Energy and Inlandis Energy, grids that also encompassed large mountain areas and rural areas, had observed the same thing. Although the respondents wished that rural households would not have to be more used to disruptions than the urban households given the emphasis on ensuring grid reliability, they still recognized the disparities in expectations and adaptive ability. The respondents also believed that the level of preparedness was directly connected to how much experience households had of blackouts or other disruptions, which connects to learning as a socio-technical component of resilience. For example, Rikard shared a memory that reflected the difference between expectations and adaptability between local rural households and urban summer house residents: "*(…) I worked at the control center and operated the grid, and then lightning struck at this island, and there was a blackout. And I think within 30 seconds from when the power went, this man with a distinct Stockholm accent calls, and is yelling like a dog that the power is gone. He's really angry and demands that power should come back NOW, (…) he was supposed to watch TV or something. Really angry, called several times and things like that. And the power came back after a while, the boys had been out and fixed something. Two weeks later after this, I was working a shift again, and then this [other] older man from the island calls and says with a crackly voice 'yes, I'm wondering when the power might be back?'. (…) And then it was this type of consequential error at his house from the first breakdown. But this old man, he had been chopping wood for his stove to heat his porridge and things like that, but now he felt it was starting to get a little difficult. So there you have the extremes we meet every day.*" This anecdote demonstrates how some respondents understand households' adaptive ability as derived from experiences of disruptions, mediated by generational and geographical household characteristics.

As mentioned previously, utilities were clear about their focus on protecting electricity supply and reducing disruptions as much as possible. In this regard, they hoped that households would not have to care about disruptions, as phrased by Nils: *"The expectation is that they [households] should not notice any disturbances."* Despite this, respondents still found the decreasing preparedness for blackouts in households problematic. Convinced that disruptions can never be avoided completely, and considering the risk of attacks of different kinds, respondents from across the focus groups stated that it was important that households take crisis preparedness seriously. If people knew how to handle shorter disruptions, the utilities could focus their resources and communicative channels on making sure the most critical parts of the grid were repaired and maintained and that the most vulnerable parts of society were taken care of.

Respondents' stories illustrated that in the past, rural communities' contributions to grid resilience went beyond just being prepared for blackouts individually. In Gridway Electric, respondents recollected shared memories from some time ago, when households would help the utility by identifying where infrastructure breakdown had occurred, for example individuals noting where a tree fell on the power lines as they passed by on snowmobiles, or telling the utility where an excavator was parked that might have accidentally damaged a cable. This information would then speed up repairs since the utility would not have to identify where the problem was themselves. Such help and support from households had not just been just ad hoc, but in some cases also organized and structured through an emergency assistance network where individuals in civil society signed up to help in case of a disruption. They were educated by the utility to help with small repairs and to be observers out in the communities – a form of socio-technical resilience collaboration.

Although greatly appreciated by the utilities, that type of resilience related collaboration between households and utilities had evidently reduced since respondents spoke about it mostly in past tense. The emergency assistance network had been decommissioned as the grid improved and the number of disruptions decreased. However, as attention to security threats has increased in Sweden especially since Russia's invasion of Ukraine, such collaboration with observant households appeared relevant and valuable once more, according to security manager Andreas: *"This whole thing with prepared villages is something I've only heard in anecdotes. But from a security perspective, as I understood it, people could call in when they were walking their dogs, to say that there was a strange car outside the hydroelectric power plant, things like that. And that would have been a great help today when we see these attempts of mapping and cable breakage in the Baltic sea and so on, there's a lot of strange things going on right now. And if we would have had this preparedness with people who actually knew what they should be looking for, and they could call in, that would actually help us a great deal"*.

To summarize, this theme reflects respondents' perception that households increasingly expect uninterrupted access to electricity, and that households' preparedness for blackouts is decreasing, especially in urban areas. Meanwhile, in some rural areas, households' resilience towards disruptions such as blackouts is observed to be stronger, a tendency which is attributed to them being more exposed to disruptions. Rural communities have also historically been helpful collaborators in other ways, by informing the utility about infrastructure breakage and suspicious activity. This theme thus displays households as an important social actor that can help strengthen resilience through crisis preparedness.

5. Discussion

In the following sections, the implications of the results are discussed and related to previous research. Throughout this discussion, some potential tensions and contradictions are also identified. These tensions point to the opportunities in nuancing and challenging current representations of the resilient grid and households' roles within it.

5.1. A techno-centric view of resilience

The institutionalized norm of increasing grid reliability and ensuring uninterrupted electricity access at all times aligns with research that suggests infrastructures are built in a way to effectively protect society from cycles of nature and variations in resource availability, making electricity invisible and taken for granted [41–43]. Considering the climate crisis, the dominating logic within infrastructural management of energy to "secure supply" has thus been problematized and suggested to reduce adaptive ability and reinforce unsustainable ways of living [44].

While utilities' understanding of resilience is focused on always maintaining grid reliability, they still acknowledge that disruptions and emergencies can never be completely avoided. This fact requires them to know how to repair and ensure that the most critical parts are taken care of in case of a serious breakdown. Utilities' parallel resilience thinking therefore points to a potential conflict between prioritizing resilience measures that are preventive, and prioritizing resilience measures that are absorptive and restorative [4]. The tension lies in focusing only on technical measures for both scenarios – accelerating optimization and "smartification" to ensure grid reliability amid electrification and digitalization, and at the same time ensuring that essential parts can be repaired and recovered quickly if the infrastructure is damaged in some way. This tension had already been identified by some of the respondents themselves. The tension grows further when put in the context of a sustainable energy transition, where expansion and reinforcement of the grid ultimately is both expensive and resource intensive. Resolving the tension between prevention and restoration requires these different resilience interpretations to be integrated – for example analyzing how optimization, digitalization and smartification of the grid potentially impact system vulnerability in case of hostile attacks or extreme weather events, and how electrification and crisis preparedness may go hand in hand. Another, more radical way of relieving the tension is to explore other objectives rather than achieving 100% grid reliability, which seem to require constant infrastructure upgrades and which, according to the utilities themselves, is ultimately impossible since new risks and threats constantly appear on the horizon. Looking beyond grid reliability as the only resilience metric could involve interrogating how electricity demand is formed, and whether it is realistic to accommodate the infrastructure to ever growing electricity demand in society.

5.2. Households: Passive recipients or co-producers of resilience?

The results show how households are simultaneously excluded and included as important social actors in the resilient power system. On the one hand, households are expected to be passive recipients of uninterrupted electricity, who should not have to worry about any disruptions as these are expected to be prevented by the utility. On the other hand, households are seen as important co-producers of resilience, either by helping to prevent disruptions through their use of technologies, or through their preparedness and ability to cope with potential blackouts. Thus, a divide can be identified between households' roles in relation to different resilience objectives that are either preventive, or absorptive and restorative. In resilience ideas focused on prevention of disturbances; they either have a passive role or a role mediated through technology. This can be likened to previous studies showing how technical narratives dominate energy industry visions, in which households are seen as either "automated or absent" [45]. In absorptive and restorative resilience, households are assigned a more social role through their ability to cope with blackouts.

While resilience was often interpreted as a technical issue, there were important instances in the utility respondents' stories where more socio-technical resilience dynamics related to *learning* emerged. It was acknowledged that differences in socio-economic conditions and knowledge about the power system shape households' flexibility potential. It was also acknowledged that communication efforts to increase knowledge is a complex yet important task to support households. In addition, there was an emerging concern among the utilities for ever growing expectations from households on unlimited and uninterrupted electricity supply. There were not, however, any explicit reflections on the utilities' own role in contributing to households' experiences and expectations. These results mirror Silvast [5], who also noted utilities' concern for households' rising expectations, increasing electricity dependency and discontent with disruptions. Utilities also considered households' ability to cope with blackouts as essential for crisis preparedness in the overall system. The respondents believed that such adaptability was the direct result of experiencing blackouts and learning from them, an observation that acknowledges *learning* from adversity as a central socio-technical resilience dynamic [30,33,46].

With support of previous research, these observations could, however, be given even more consideration and recognition as important socio-technical dimensions of resilience for power systems in policy and practice. For example, previous studies suggest that households' energy literacy and their perception of meaning and responsibility sharing in the energy system are critical factors not just for flexibility, but for households' energy resilience overall [16,30,47]. Furthermore, clear and transparent communication has been shown to be crucial for emergency demand response [48]. In relation to crisis preparedness, previous research has found that experiences of disruptions indeed shape households' ability to cope [49]. Overall, it has been suggested that policymakers and utilities need to better understand the link between infrastructure governance and demand side practices [44,50].

Examples of more socio-technical ways of working with resilience could also be found in some of the utilities' past, including examples of *collaborative* resilience. Initiatives like the assistance network where households reported damages on the grid were not technology focused. These collaborations between utility and households were rather built on relationships, observation skills, local community knowledge, and a sense of shared responsibility. Albeit situated in a different time and a rural context, such examples show the opportunities in recognizing *collaboration* as an important socio-technical resilience component for the power system, where the supply and demand side can cope with challenges in the infrastructure together.

To summarize, a tension can be identified between technical views of resilience, in which households are either passive or help resilience through (smart) technology use, and more socio-technical perspectives, in which households help manage disruptions in a diverse set of ways, including by learning and collaborating around disruptions. Another related tension points to how only focusing resilience on grid reliability, where disruptions are expected to be prevented, may be in conflict with crisis preparedness, a set of practices based on the understanding that disruptions are not always avoidable. This tension presents itself when utilities on the one hand acknowledge that households' preparedness for disruptions comes from experience and learning, while they on the other hand try to reduce households' experiences of such disruptions as much as possible through their work in ensuring uninterrupted electricity supply. All in all, these tensions illustrate the limitations in having a too techno-centric view of resilience, in which social aspects linked to households' agency and adaptive ability, are excluded. In more socio-technical interpretations of resilience, households' roles can be seen as mediated by their experiences, socio-economic conditions, knowledge and relationships, as well as their technologies.

5.3. Towards a socio-technical perspective on resilient power systems

Utilities in this study saw ensured grid reliability as a central goal of resilience. However, the link between reliability and resilience is complex. In some regions in the US, a rise in climate-related blackouts have led some to warn that lowering public expectations for electricity can hinder household electrification and shift electricity from a public good to a private commodity [51]. At the same time, the current study suggests that ever increasing public expectations on uninterrupted supply

can indirectly undermine crisis preparedness and drive resource-intensive grid expansion. Thus, while reliability remains important, it should not be the sole focus of resilient power systems.

The power system faces many different types of changes and threats and at the same time, the climate crisis compels society to find a way to operate it within planetary boundaries. In this context, a too technical operationalization of resilience only focused on ensuring electricity access can be limiting and overlooks important social aspects of the power system. To resolve this, I suggest that the electricity sector should adopt a more socio-technical perspective on power system resilience. This means that in the utilities' work to enhance resilience, they should analyze in what way a measure or objective for resilience impacts opportunities for *energy literacy, learning*, and *collaboration,* which are clearly important socio-technical dynamics between electricity users and suppliers that impact resilience overall. By clearly recognizing households' agency as a potentially valuable part of power system resilience, energy system actors such as utilities can find ways of supporting resilient energy practices that are consistent with planetary boundaries and helpful for both the system and the household.

The electricity sector can also explore other answers to the question "resilience of what?". The literature offers alternative, more socio-technical ways of thinking about energy resilience. These include other types of functions, for example maintaining 'a good life' [17] or 'essential energy services' [18] in spite of different kinds of disruptions and changes in the power system. Such definitions open up for a broader set of measures to strengthen resilience, including both social and technical aspects. Through dialogues with local communities and households, actors of the power system can explore what a good life and essential energy services means in times of power limitations or disturbances, rather than limiting themselves to grid reliability as the only acceptable resilience metric. These functions may also offer opportunities for supporting socio-technical mechanisms that are beneficial for energy resilience such as greater energy literacy, learning and collaboration in households. By working with a combination of such functions, occasional disruptions like shorter power cuts are not necessarily equated to a crisis, but rather a possible consequence of managing the power system within planetary boundaries [17]. As suggested by Nye [43], the energy transition may thus involve "voluntary greenouts" in contrast to involuntary blackouts. Considering alternative resilience functions and recognizing learning and collaboration as central to resilience could possibly involve for example introducing power cut exercises as a way of practicing resilience [30].

As this study shows, maintaining uninterrupted electricity access appears to be an institutional norm beyond the utility level. Thus, while utilities constitute a central stakeholder of the power infrastructure, they are not free to operationalize resilience however they want. A more socio-technical view of resilience that targets both sustainability, efficient everyday operations and crisis preparedness may therefore require regulative changes. It may also require collaborative efforts between municipalities, utilities, electricity traders and national and regional energy authorities. In this regard, future research should examine and challenge how interpretations of resilience at municipal or national level account for 1) disruptions and changes in the power system, and 2) the roles of households and other social actors.

Hamborg et al. [4] has provided a helpful framework for unpacking 'resilience talk' through their questions "resilience of what?" "resilience to what?" and "resilience by what means?". Meanwhile, scholars from other social science domains have made an important problematization of resilience by asking "resilience for whom?" [52]. Based on the current study, situated in the context of sustainable energy transitions in affluent countries, this paper contributes by arguing that a socio-technical perspective on resilience is needed to challenge current norms, and support energy practices that are consistent with planetary boundaries. Therefore, another important question to unpack energy resilience may be "resilience *by whom"?*

5.4. Limitations and methodological reflection

Throughout the results, respondents did not appear to focus a lot on severe grid related crises like large scale and prolonged blackouts, although such scenarios were mentioned, for example the storm Gudrun in 2005. Even if continuity plans and recovery from blackouts were mentioned, the respondents generally appeared keener to discuss ways of *avoiding* or *preventing* blackouts as well as other disturbances. Blackouts were a more central theme when the respondents discussed households' roles in resilience, as those scenarios actualized the questions of households' adaptive ability. This tendency in the focus group could be for several reasons. Because the power grid is considered a critical infrastructure, it should be noted that some matters that relate to resilience of the grid, like security plans for widespread emergencies like prolonged blackouts, may be subject to secrecy and might be difficult for these respondents to share in detail. However, the purpose of the study was not to document the utilities' security routines as such, but rather to understand the principles and prioritizations which underlie the utility employees' understanding of resilience in their grid context, and how it relates to households. Furthermore, when it comes to blackouts, the Swedish power system performs relatively well in comparison to the EU and OECD [53], despite geographical challenges. Widespread and prolonged blackouts are rare in Sweden, which could explain why respondents did not emphasize such scenarios. Finally, the focus group guide (see Appendix 1) had a somewhat future-oriented outset, which may have encouraged discussions on prevention rather than adaptation and restoration.

However, while the respondents often focused on common disturbances in Sweden such as shorter power cuts or power peaks, the material still illustrates a tendency to center resilience around maintaining power supply, or recovering it as soon as possible, and less about conceptualizing necessary levels of energy services in other, more socio-technical ways. The results therefore tell a story of what assumptions and ideas around the power system underpin what resilience means in these utilities' contexts, regardless of whether it concerns resilience in a prolonged blackout or in everyday operation.

Conditions for operating power system vary greatly around the world, therefore insights from this study are not directly transferable to all contexts. For example, the actors participating in this study were concerned about digitalization, optimization and smartification of the grid as both a challenge for resilience and a way to realize resilience, which relates to Sweden's commitment to digitalizing and electrifying society overall. At the same time, the role that households are envisioned to play in the resilient power system may also differ between countries. In some contexts, households may already be used to coping with frequent blackouts or power limitations, while most Swedish households experience relatively few disruptions and limitations in electricity supply. The insights produced by this paper concerning the electricity sector's tendency to understand resilience as technical issue is relevant for countries with comparable conditions for power system operation characterized by high reliability and well-functioning power production and distribution, and particularly countries which also have high electricity use.

6. Conclusion

The participating utilities' understanding of power system resilience is dominated by a technical perspective, focused on maintaining uninterrupted electricity supply. In their interpretation, households are given dual roles, either as passive recipients or co-producers of resilience, either through technology use or their ability to cope with blackouts. The results demonstrate tensions between preventive and absorptive resilience objectives, and utilities' acknowledgement of households' social characteristics also challenges an otherwise techno-centric view of resilience. Considering the multifaceted challenges faced by the power system, the paper argues that a too techno-centric

resilience conceptualization that is only focused on grid reliability overlooks important social aspects and becomes limiting. Consequently, the paper advocates for a more socio-technical view of resilience in policy and practice, in which households are clearly recognized as important social actors whose knowledge, experiences and relationships shape energy resilience. By emphasizing the need for socio-technical resilience conceptualizations in research and practice, the paper contributes to social science literature that seeks to ensure electricity infrastructure is developed in a way that is compatible with sustainable energy transitions.

CRediT authorship contribution statement

Hanna Björner Brauer: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used Microsoft Co-Pilot to find suitable synonyms, as well as appropriate English translations of Swedish industry terms. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Declaration of competing interest

I declare that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Interview guide for focus groups with electric utilities

This interview guide shows a list of questions that guided the focus group discussions, sorted under different themes. However, it should be noted that the focus group interviews were semi-structured and explorative. As such, many of the questions we did not need to ask since participants had vivid discussions and conversations which covered many of the topics. Additionally, it was important to focus on phenomena that the participants themselves deemed important and relevant, therefore we let their interest direct what questions got most attention.

Introduction: Researchers introduce themselves. Information about the study and the purpose of the focus groups is given verbally. Any questions from participants are addressed. Researchers ask participants if they consent to the interview being recorded.

Introduction of professional roles: Each participant briefly describe their job and role within the company.

Theme 1. Households in your electricity network

- I would like to start by asking you to tell me a bit about the households in your electricity network. Who are they? What different types of households are there? Where do they live, in what types of housing, etc.?
- Are there any household customers that stand out more than others? How so?
- How do you communicate with households today?
- How do you work within the organization to understand the needs and conditions of households?

Theme 2. The energy crisis of 2022/2023

- What was your situation during the energy crisis of 2022/2023? How were you affected?
- What were the biggest challenges during the energy crisis? Was there anything that was difficult?
- Did the contact with household customers change during the energy crisis? If so, how? How did you handle it?
- Is there anything you would do differently if the same situation arose again in a few years?
- What lessons have you learned from the energy crisis? Has it affected how you organize your work today?

Theme 3. Electricity limitations and resilience

- Now I thought we would talk a bit about resilience – How would you describe a resilient electricity grid? (resistant, adaptable, prepared) [Note: Pause, let everyone have a say and think about resilience. Be ready with a short/simple description of the concept].
- What types of disturbances or limitations should the electricity grid be able to handle today and in the future?
- What types of disturbances or limitations do you see as the most difficult/critical?
- If we look at your household customers instead, what types of electricity-related disturbances or limitations do you think households might need to handle? Today vs. in the future?
- How will households be affected by challenges such as power shortages or electricity shortages in the future?
- How important is it for households to be prepared for electricity to be, for example, limited or expensive during certain periods in the future?
- [You just told us about a resilient electricity grid and what it might mean…] How would it help your mission if households were prepared or "resilient" to limitations in electricity supply? What would it mean for you and the electricity system, do you think?
- If we imagine a situation where electricity is more expensive during certain periods, there may be power limitations, etc. What role would you say you have in that situation related to households? Do you think different households might need different support, communication, or information?
- What is challenging about supporting households in this? Communicating about it?
- From your perspective: what skills are needed to support households?

- If you imagine a dream scenario where you had unlimited resources to work on this – what would it look like? What would be in place then? How would you work on this?
- What other actors are important to support and guide households to be prepared for energy crises or electricity shortages? How do you collaborate with them today?

Theme 4. Managing households' efforts during the energy crisis

- Have you in any way worked to communicate to households that their efforts during the energy crisis were valuable/important?
- How do you think such communication could look?
- How could you explain to households that their reduced electricity consumption actually helps in such situations? How could you confirm that their effort is important?
- How can you and other actors work to maintain households' engagement for the next crisis? How can you in your role help them strengthen their preparedness for such a situation? What other actors can help strengthen households' preparedness, do you think?
- What challenges might exist in such communication? Different households have different conditions, some have jacuzzis in the yard while others live in old rental apartments, etc. Can you communicate the same to everyone, or do you think there are different groups that are important to reach in different ways?
- In what way have you learned from households' responses during the energy crisis, and how have you integrated that knowledge into your work?
- What support for learning/skills development is provided within the organization to meet future challenges related to household customers and energy supply?
- Who besides utilities has an important role here?

Theme 5. Current situation and future

- What are the biggest challenges you see ahead in your role, related to household customers (or otherwise)? Are there any?
- Is there anything particularly difficult about the household segment in your industry? What and why?

Conclusion

- Now I/we have asked the questions we planned to ask, but I wonder if there is anything you would like to add before we finish? Is there anything you think we should know more about or that you want to tell us?

Thank you very much for taking the time to participate in this interview. If you have any questions afterward, you are welcome to contact us.

Appendix B. Tables with coding examples

Table 1
Coding according to analytical questions from the CER framework.

Analytical question	Criteria	Example of code	Example statement
Resilience of what?	Statements that reflect assumptions and ideas around what is supposed to be protected/maintained through resilience, as well as how the boundaries of the system is understood	Demands for grid reliability are increasing	”(…) Then you see how the reliability of the grid is developing. And the general trend is that requirements on reliability in electric power grids are just getting bigger and bigger”
		The utility's task is to provide access to electricity	”(…) We have this type of connection obligation. We are required to connect a client within our area. And the client specifies what it wants and what it wants to connect. So our role has been to fulfill the client's request”
Resilience to what?	Statements that reflect expected disturbances, changes and pressures on the power system, that it needs to be resilient against.	Overvoltage, for example caused by “solar peaks”	”I mean things can happen in the grid. And I'm thinking that our rural grid which is pretty weak, if there comes a lot of solar panels and batteries in this weak grid (…), then we will surely get problems with overvoltage. And perhaps also undervoltage, but overvoltage is the most problematic thing to handle”
		Increasing complexity, difficulty to keep up	”The biggest challenge I think, is the complexity. And the fast changes that we have to adapt to. That is the thing that… It is very general, but that it's becoming more and more complex. And it has a little to do with how Sweden works overall, that we are not very quick to change direction, in many contexts”
Resilience by what means?	Statements that reflect measures, strategies and system behaviors that can strengthen resilience	Optimization, e.g. through integration of digital systems	”Yes, the system for breakage, the map system, the relay protection system, the meters, and also that intelligence along the cables that… indicators they're called, to get all them to collaborate so you can get a better picture of, what has happened?”
		Expanding and reinforcing the grid	”And then, we need to expand our grid that we have to manage this transition too. So that will make the investments that we have to do will… it will be expensive for everyone in the end.”

Table 2
Inductive coding concerning households' roles in the resilient power system.

Theme	Example code	Example statement
Cost-driven users of technology	Households need clear financial incentives to adapt to e.g. power peaks	"So if customers are going to control their consumption or change it [become flexible], if they're going to stop being comfortable, that is a matter of price"
	Households can strengthen resilience through their technologies	"Yes the person that has batteries is of course more resilient than a person that does not have batteries. Then it is just a matter of how many kilowatt hours it can store, this battery. And what power they can extract from it"
Social actors (un)prepared for blackouts	High expectations on uninterrupted electricity from households	"People from other countries might be more used to this that the power comes and goes (…) Meanwhile, people that are born and have grown up in Sweden, it's just supposed to work when you push the button, lights should go on and everything is up and running and the dishwasher is running and the washing machine is running."
	Big discrepancies in preparedness for blackouts	"(…) It's a very big difference between customers if you're talking resistance (…). We have a very big variation. We have some customers that might not call us for a few days if they had a blackout, because they are so prepared for it, they have stoves at home and things like that. While other customers… are incredly affected as soon as the blackout happens. So there's a very big difference between customers in that sense in our grid"

Data availability

The authors do not have permission to share data.

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