Conceptualizing Resilience: An Energy Services Approach

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC's) synthesis report reaffirms that we live in the Anthropocene, with the intensity, impacts, and frequency of human-induced climate disasters inevitably rising further in the coming decades [1]. Disasters, including but not limited to wildfires, hurricanes, and polar vortexes, are projected to get more frequent and more severe [1]. The increasing intensity and frequency of disasters can significantly increase the probability of massive failures of critical infrastructures, which in turn will affect the ability of people to meet their basic needs [2, 3]. The traditional methods of understanding the risk and vulnerabilities of societies are arguably incomplete in providing a comprehensive policy framework to support infrastructures designed to meet people's needs during and after disasters [4-6].

Risk and vulnerability are looked at through myriad of ways with current focus on public perception of risk of transitioning to different energy sources [7]. Measuring risk and vulnerability has predominantly been used to understand the probability of an event that could impact and hamper the status quo of a community [8, 9]. Risk assessment helps identify a potential threat, its consequence, and losses associated with that risk, with an aim to anticipate the crisis and measure its potential impact when it hits a system [10]. Arguably, risk measurement provides limited guidance on emerging and unforeseen threats [10].

Vulnerability, on the other hand, is the reaction to the risk, focusing on disaster response planning to include the role of human agency in the form of class, caste, gender, race, and ethnicity [11, 12]. However, even when these two elements complement each other, they are incomplete, particularly in disaster policymaking, because they do not provide a framework to understand and address the aggravating temporal impacts of disasters [4, 13, 14]. This is because the frameworks developed based on risk and vulnerability focus on the current state as a static element in the system .

Resilience as a concept is increasingly used to study and understand a system or individual elements of a system and how they can withstand a disaster and recover from the same [15, 16]. However, there is significant debate on defining resilience, as it is being used in multiple fields, particularly to develop diverse conceptual and analytical frameworks, from studying material property to understanding social and ecological resilience [17, 18, 19]. One overarching agreement regarding resilience in multiple fields, unlike risk and vulnerability, is its temporal nature, which looks at the process instead of a particular state [20, 15, 17] In this work, we utilize the National Academy of Sciences (NAS) definition of resilience as the ability of the system to prepare and plan for, absorb, recover from, and then adapt to adverse events, which is currently guiding the work on developing resilience frameworks in the U.S. [16].

Resilience frameworks are largely based on measuring technical parameters of critical infrastructure and resource availability: Performance of water supply, electricity supply, roads, and railroad systems [21, 22, 23]. The underlying assumption of measuring resource availability is that it helps measure the overall resilience of a community [2, 24]. We refer to community as a collective that can be defined geographically based on vulnerabilities to external disturbance or management of disturbance response. For example, community resilience may involve specific electric utilities working in specific service territories, as the management of their grid infrastructure and response to grid failure is organized by utility service territory. Community resilience may also involve particular geographies that are vulnerable to particular kinds of disturbance, like those from weather events; vulnerabilities may also be organized at the building scale for multi-unit residential buildings, operating as a community through shared vulnerabilities [3, 6, 11]. Nevertheless, community resilience may also be conceptualized in terms of the geographical or political units tasked with managing responses to disturbances, which may or may not effectively align with current political units [5, 6].

Barring studies like Amin et al. [3] and Delina et al. [25] that have focused on resilience in the context of natural disaster at community level, resiliency studies have largely ignored the idea of measuring energy resiliency particularly at a finer resolution of an individual or household level and are mainly done looking at the infrastructure [26, 27]. Resilience research largely considers electricity infrastructure as critical infrastructure that is central to developing community resilience to disaster [25, 28, 29]. Delina et. al [25] further makes the case that, given the central nature of the energy system, measuring and understanding energy system resiliency is as important as other systems such as food, water, and transport. As electricity is increasingly becoming central form of end use energy, studying electricity system resiliency can help us understand and develop resilient communities. However, electricity is desired not for electricity as a product, but rather for various services that can be derived by an individual or a household from the electricity, such as cooking, heating, cooling, internet in a household, or e-learning in schools [30, 19]. Hence, measuring only the means (electricity/electricity infrastructure) of this critical infrastructure does not provide adequate understanding of the resilience of services that are required.

In this paper, we make the case that the provisioning of energy services should be centered in understanding and measuring resilience, particularly considering the role of electrical energy infrastructure as critical infrastructure. We use the increasingly emphasized point of energy practitioners that electricity is a means to achieve desired services and not the end goal [31, 32]. We propose researching resilience through the lens of energy services, to include how energy is used within households and communities and are central to the development of human functioning as derived from the capabilities approach (CA). We also make the case that resilience is not just a concept with a single end goal of getting through a disaster and preparing for the next one. Resilience as a concept is becoming integral in examining the relationship between energy systems and society, as continuous adaptation and response are likely to become the norm rather than the exception due to the exacerbating impacts of climatic change. Here, we advocate for integrating the concept of energy services within frameworks and measurements of resilience to support strengthening critical infrastructures and advancing energy service security.

2. Capabilities Approach (CA)

The capabilities approach (CA) was initially used as an alternative way to look at economic development in society. As a normative theory, capabilities approach is used to evaluate human wellbeing and has gained traction as a way of explaining and rectifying manifested injustices that were not captured by theories focused on measuring material wealth and access to resources. Capabilities approach attempts to capture what people are able to achieve with their resources [33 - 35]. For instance, two households with the same quality and duration of electricity (a resource) can use that electricity very differently, based on the appliances that they might have and their need for different services. One household that have access to washing machine would be able to realize the comfort of washing clothes at home unlike other household that would need access to a laundromat. Thus, electricity for these two households realizes a different set of capabilities. Scholars working on the application of capabilities approach outline that we see incomplete pictures, when measuring only the resources or commodities that an individual or a community might possess, as they might use or have to use the same resources differently [33, 36]. This is particularly important when we understand that communities or individuals at the macro-level look similar but have diversely manifested inequities. Such inequalities become apparent during the time of crisis, such as a natural or man-made climate disaster.

The capabilities approach proposes an alternative by using the interlinked concepts of functioning and capabilities, relating to measuring individual well-being rather than access to commodities [37]. Functioning is defined as an achievement of a person, what they manage to be and do, and are different from the commodities used to achieve that functioning. Capabilities are the actual set of opportunities that are used to realize functioning, with the freedom to choose whether to realize those functionings or not [33, 34]. capabilities approach scholars make the case that measuring capabilities provides a set of opportunities with the freedom to choose from those opportunities, and the evaluation of services should be done in terms of capabilities. There is intense debate on what capabilities justice scholars should prioritize, as not all capabilities may be equally important. Nussbaum [38] proposes a list of ten central capabilities essential for humans, a debatable and customizable list required to attain secondary capabilities. We use these central capabilities to draw connections among electricity services to show their relevance for the development of human functioning (see next section).

Scholars have used capabilities approach to understand, inform, and evaluate the impact of energy on people's life [37, 39]. Nussbaumer et al. [37] use capabilities approach to develop a multidimensional energy poverty index (MEPI) focusing on deprivation of access to modern energy services. The use of capabilities approach to focus on energy, as means and not as an end, forms the basis of measuring energy services, going beyond measuring electricity as a commodity. The application of the capabilities approach by energy justice scholars supports understanding of electricity as one of the means to attain basic human rights, hence centering electricity as a means to developing human capabilities [40, 41]. Unavailability of choice among different electricity services is also seen as hampering the development of human beings with an incomplete set of opportunities that can be realized through electricity services.

In the subsequent section, we describe how capabilities approach informs the growing literature on energy services and its relevance to understanding resiliency. Furthermore, climate justice scholars use the capabilities approach to study how to restore individual capabilities after an extreme climate event, either through mitigation or adaptation efforts [42, 43]. This can be considered a partial overlap with the concept of resilience, primarily because mitigation and adaptation, which is the focus of climate justice studies, are two observable underlying points that are also part of resilience frameworks [15].

3. Resilience: The Underemphasized Aspect of Energy Services

Resilience can be traced back to having a social etymology in natural history. Since then, the term has been used in multiple fields, predominantly in ecology and engineering [18, 44]. The term's modern usage is credited to Holling, an ecologist who defined it "as a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" [45, p14]. The use of the term in multiple fields and through different lenses has led to diverse articulations and applications. The term's foundational meaning that remains common through different definitions is its association with "bouncing back" [46-48]. Resilience is associated with the inherent property of a system or substance to bounce back to its original or an enhanced stage after an external impact affecting the system. Several studies have also associated resilience with other concepts, predominantly risk, vulnerability, and robustness[5, 12, 13, 18]. Linkov et al. [4] present a schematic representation of the dynamic nature of resilience by showing how critical functionality is associated with time, and temporality is a common feature across diverse uses of resilience as a concept, with the ability to bounce back after external disturbance measured temporally (how long) as well as substantively (return to what state, with what features, and how, which varies considerably across definitions and uses) [4, 13].

Today, the predominantly used definition of resilience when looking from a disaster resilience policy making perspective in literature is from the National Academy of Sciences (NAS), which defines resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" [49, p.4]. This definition forms the basis of several studies that adopt and apply this definition to develop resilience frameworks [50]. Eisneberg et al. [13] adopt the NAS definition and combine it with the network-centric operation approach to build resilience frameworks. These frameworks are centered around measuring the physical, cognitive, information, and social indicators across prepare, absorb, recover, and adapt dimensions of resilience. Curt & Tacnet [5] assert that Linkov et al. [4] provide the most comprehensive framework for resilience analysis. However, there has been limited effort to include indicators of energy services into this framework so far.

Recent studies using different resilience tools largely look at the attributes and assets to measure resilience. Cutter [8] examined twenty-seven different resilience tools, assessments, and scorecards. The most persistent variables found include resource-based indicators such as income, education levels, infrastructure, buildings, number of doctors, etc. Curt & Tacnet [5] in their extensive literature study did a distributional analysis of studies done on resiliency of critical infrastructure. Energy infrastructure was placed as the fifth most commonly discussed critical infrastructure, studied in 13 articles[1]. Transport (road, railways, maritime, and air transport) followed by communication and water distribution networks are the predominant infrastructure studied for their resiliency [5]. However, electricity services as a means to develop a resilient system did not feature in the review. This is also reflective in a way that the authors present that there is not a single social sciences journal source in their top 12 list of articles on resilience.

Other studies present a community resilience framework that includes critical infrastructure, economics, and governance, among other parameters, outlining that resilience measurement is done at a resource level [47, 51, 52]. Cutter & Derakhshan [52] use the NAS definition to update their baseline resilience index for communities (BRIC) for the period of 2010 to 2015. The extensive study provides the resilience index values for the continental United States. The study uses a BRIC score based on social, economic, housing/infrastructure, community capital, institutional, and environmental variables. The U.S. federal government uses the BRIC as part of the federal emergency management agency national risk index (FEMA) for state and local governments, with the aim of providing a holistic picture of risk communities. However, the

[1] Network, Supply chain, industrial, flood risk, health, data acquisition, heat networks, and logistic networks were other critical infrastructure.

study lacks a detailed analysis at the local level, particularly for marginalized communities or people with special needs. Hamborg et al. [19] presents a cross-epistemic resilience framework to measure socio-ecological-technical resilience of critical power infrastructure; however, their focus is on the infrastructure and not on the services derived from it.

In the resiliency literature, there is limited to no consensus on the parameters that should be measured and the variables used. There is an explicit focus on measuring the capacities: economic, infrastructure, and social for disaster resilience [8, 13, 53]. Saja et al.[54] conducted a review of social resilience frameworks for disaster management and concluded that many social resilience frameworks use proxy indicators.

Resilience research in sustainability and social sciences is increasing [55] and this work largely focuses on a holistic approach centered around sustainable development. However, we argue that the energy service aspect is largely missing from the current social resilience framework for disaster resilience policy making. Wang et al. [56] looked at the electricity supply resilience in the case of Nepal, which has a history of disaster affecting its electricity supply. The study identifies well-being in the causal loop, but it is at the end of the loop shown as an outcome with no cross linkages with other parts of the system. Hasselqvist et al. [57] takes a step further and look at households as a starting point to investigate resilience, with an implicit use of a services approach to understand household resiliency. Hasselqvist et al. [57] provides a starting point for the conversation moving towards energy service resiliency, however the study does not make a direct connection of its implication for policy making for disaster resiliency of energy services for the households. Burton [58] comes closest to measuring the service aspect of resilience by providing a metrics that focus on social, economic, institutional, infrastructural, and community-based indicators that include the service aspect to measure resilience. For instance, measuring institutional resiliency through "% population participating in Community Rating System (CRS) for flood" [58, p.80]. However, even though the study includes detailed indicators for resilience assessment, the study does not include energy services as an indicator for resilience. To the best of our knowledge, there are no studies that conceptualize the definition of resilience and develop a resilience framework by explicitly considering human capabilities and functioning. This is surprising because CA is used in understanding and explaining the disproportionate impact of climate change on people that directs the mitigation and adaptation policy-making [42, 43].

Resilience is largely looked at from the perspective of critical infrastructures essential in maintaining the social well-being of a community [5, 19, 24]. However, instead of measuring well-being, as argued by the CA scholars, the focus is on measuring the commodity or resources. We outline that even when a study considers developing economic, technical, or social system resilience, the larger goal is to support the ability of the people to withstand and bounce back, measured through their functioning. Resilience is arguably best understood by looking at the actual beings and doings of the people, measuring the services that they derive rather than only focusing on the infrastructure. Electrical energy services are critical to resilience because they are central for accessing other basic services [37].

4. Energy Service Aspect of Resilience

Even though electricity usage has always been significant, the locus of electricity policies has mostly focused on the supply side: generation, transmission, and distribution [30]. With the advent and increased interest in renewable, community level, distributed energy generation, there is an increased focus on the importance of the demand side of electricity. The focus on the demand side is technically supported as a means to operate power systems more efficiently, by focusing on end use energy service provisions, which have historically relied on supply-side efficiency interventions. However, scholars like Day et al. [39] and Sovacool et al. [59], amongst others, argue that looking at the demand side is even more important. Doing so allows for a new focus on electricity services instead of electricity infrastructure, which is only a means to derive the electrical energy services that people require. Delina et al.[25] further makes the case that looking at energy system resiliency as a whole is equally important to include ethics in studying community resiliency of socially vulnerable communities. This brings to the forefront the case of energy service choice of the household.

The concept of energy services has helped in the development of different frameworks and models. The basic rights model used in climate and energy justice studies focuses on imperative responsibilities to guarantee basic rights to food, health care, shelter, and subsistence, which requires recognizing the prerequisite need for energy services as one of the most critical means to attain the basic rights [59, 60]. Nussbaumer et al. [37] present this definition by expressing that energy is a material prerequisite to achieving capabilities. Table 1 shows the central capabilities outlined by Nussbaum [38] and their direct or indirect relation with the example of electricity services. The list of examples is not exhaustive, and the idea here is to show the link between energy services and basic human capabilities. These basic capabilities are particularly challenged during and after a disaster that impacts access to energy services.

Table 1 Relating Nussbaum's central capabilities with examples of services drawn from electricity

S.no	**Nussbaum's Capabilities** [38]	**Example of Relationship with electricity as the means**
1	Life: normal length life, not dying prematurely	Electricity is essential as used today for household comforts, including basic needs such as clean cooking, access to clean potable water
2	Bodily Health: nourished, reproductive health	Electricity is essential for hospitals, medical transport of people (women, children and people with special needs during and after disaster), supplies, and all allied services
3	Bodily Integrity: prevent from assault, violence	Safety provided through habitable and comfortable homes; street lights, house alarms, tasers, and communication technologies supporting safety
4	Sense, Imagination, Thought: Education, literacy, scientific training	In a house with electricity, students can read and learn at night, use electronic learning tools, and access online classes
5	Emotions: Love, Gratitude, anger	Electricity is a means to provide comfort and produce goods and services
6	Practical reasons: conception of good and planning one's life	Energy access provides means of free learning and communication

7	Affiliation: social interaction, participation in political speeches	Modern communication platforms of speech is dependent on electricity for their reach
8	Other species: concern for planet, flora, and fauna	Energy provides means of learning about human impacts; Renewable electricity is a means to address those impacts and maintain energy services access
9	Play: recreational activities	Online games, transportation to the venue, lightning, refrigeration of food and beverages
10	Control: political and material of one's surrounding	Elections happening through machinery that requires electricity

The CA was initially used to study poverty as a nexus of manifested injustices, particularly in low-income countries. However, recent scholars have used the approach to understand deprivation of energy access as harmful to building capabilities. Tarekegne & Sidortsov [61] used the CA to study the means and end of electrification policy planning in sub-Saharan Africa, using the CA to assess energy justice. The authors demonstrate the utility of the energy service approach to study energy justice, paving the way to study resilience centering around energy services for electrification infrastructure resiliency.

Proponents of the CA assert that focusing on electricity services does not take away from focusing on commodities, which in this case are electricity and electricity infrastructure; in fact, it shows us how reliant we have become on one particular form of energy[2] and the disaggregation can be best observed at the service level [37]. The disaggregation at the service level is observed when electricity serves as a means to equitable access to basic goods such as food, water, and shelter. As reliance further grows on electricity as a single means to access these basic services, it becomes imperative to look at the inequities at the service level that are solely dependent on electricity infrastructure.

[2] Electricity is considered as a form of end use energy that is relied on for all the major energy services.

Resilience research should focus on electricity systems as one of the most critical systems, and this focus should involve moving beyond looking at critical electricity supply and infrastructure. This is because looking at only the physical energy infrastructure cannot address the divergence and inequities created in terms of access to energy services that people receive based on electricity as a resource. Focusing on energy services helps us distinguish between the different services that electricity offers. It shifts the unit of analysis away from measuring electricity supply access or security to instead measuring the energy services provided and their association with capabilities and functioning. From this perspective, the capabilities of a household member will depend on the type of people living in that household and hence their specific needs. For example, the size (area) of the household, different members of the household in terms of their needs (infants, people with disabilities, old age), and the services that a household requires and can afford. Furthermore, households with people with disabilities, infants, or the elderly likely need different forms and levels of energy services for functioning, and the resilience of a system cannot be accurately measured or understood if we only look at electricity supply security. Hence, just energy services access (i.e., ensuring that the critical electrical energy infrastructure can provide what households need in ways that are secure and resilient) could potentially vary substantially within and across communities, requiring different forms of data and different methods to assess resilience of critical energy infrastructures as providing access to energy services.

5. Resiliency Through Energy Services

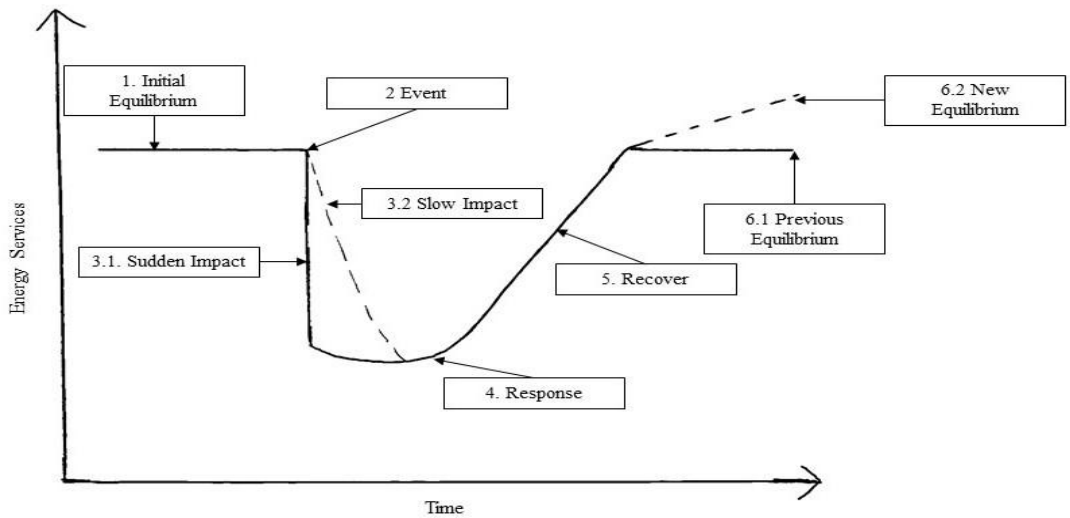
Capabilities and energy services can potentially redefine resilience and resilience research. We suggest resilience, particularly resilience of critical energy systems of a community, can be defined as:

"The ability to sustain and bounce back after an adverse event, in realizing essential functioning through the means of affordable, reliable, and safe energy services access, while accounting for alternative means to further strengthen those functionings in ways that improve equity through energy services access."

When compared with other definitions of resilience that are used to understand energy infrastructure resiliency, this conceptualization is centered around the recognition that electricity services are critical to support a range of capabilities and hence becomes central to resilience. It is multidimensional, taking into account functioning and capabilities, and centers the differential vulnerability of individuals and communities, whose needs for services are different even when everyone has access to electricity as a common commodity.

We apply this definition to the current temporal case of resilience used by Linkov et al. [62] , Carlson et al. [47], and Curt and Tacnet [5], amongst others, and to build on Hasselqvist et al. [57] to show where energy services fit in the current explanation of the term to work towards a framework. In Figure 1, we outline the six-stages to show the temporal nature of resiliency [4, 63, 64]. The first stage is when we measure the energy services that are currently being used, creating a sense of equilibrium. Even though this is referenced as an equilibrium, there might still be changes occurring within the system due to other factors. For example, a policy change might occur, leading to people switching from natural gas cooking to electric cooking. Hence, from a disaster response perspective, even though the system seems to be in equilibrium, internal

Figure 1: Energy service resilience curve, adopted from Carlson et al [47])



changes still occur within the system.

The second stage is when an adverse event occurs, affecting the services. The event's impact can take two pathways, depending on the event and the system's robustness. In path 3.1, there is a sudden impact, disrupting energy service access instantly. In path 3.2, there is a slow impact, with services access decreasing at a much slower rate. Stage 4 shows the response as the system tries to restore the services or provide alternative services to the community to minimize the impact. The depth and slant of the curve from the second point to the fourth point represent the effect on services due to the event. A steeper slope and larger depth represent a harsher impact and less resilient system. Stage 5 represents the recovery phase to improve the energy service access and security first to bring it to the same equilibrium level as the previous one represented in 6.1. However, as argued in the literature, the previous status quo may not be adequate for maintaining energy services during the next disruptive event, decreasing system resiliency [4]. The pathway of 6.2 would be the work towards a new standard of system resiliency that involves including the potential to withhold future disaster impacts on current development decisions.

Figure 1 above displays resiliency in a linear form; however, it can be more accurately understood as a circular process with a new equilibrium of 6.2 guiding the development of resilience for just energy services access to support human functioning. A framework for resilience should incorporate energy service indicators, because the goal of a resilient system is to protect functioning and capabilities [61]. Energy services are increasingly derived from electricity and are based on what functioning an individual would like to develop; hence, correlating with the dynamic nature of resiliency with the framework having the flexibility to work in a multitude of contexts.

An energy service resilience framework based on the CA can help address a range of concerns brought by the frequent nature of disasters, from distribution of risk and vulnerability and recognition of people, places, and relationships, to a number of threatened basic rights and services. This could be done using a survey instrument that focuses on measuring the energy services functioning identified in the table 1. The approach offers flexibility for addressing the local variability in the effect of experience and response to the effects of disasters. The focus of resilience is on the range of capabilities required for people to live free and productive lives they want to design for themselves.

Furthermore, it is not only the ability of individuals to function that matters, but also the ability of communities to function and preserve their group identity that is a central concern that should be included in any resilience framework [60]. This is particularly urgent for Indigenous communities and island states that stand to lose everything in the face of climatic change[25]. Maldonado et al. [65] assert that sovereign Tribal communities in the U.S. are forced to relocate and change their lifestyle pattern due to the impact of climate change, which urgently warrants addressing from a human rights approach. A current approach to resilience may be able to inform the maintenance or restoration of the technical aspects of infrastructures for these communities.

However, it could not contend with the reality that no infrastructure replacement can fully replace a way of life and freedom to choose in terms of energy services practices that they might have within the community.

6. Conclusion

In this perspective piece, we argue that current approaches to resilience, specifically focused on the critical infrastructure of the electric power grid, can be improved by incorporating an energy services perspective that highlights energy services access as requisite for just pursuit of human functioning through capabilities. We argue that the CA can inform a new approach to studying the role of energy system resilience through a focus on energy services, which is crucial and yet largely missing in the current debates around understanding and building community resilience.

Energy services are an accurate way to look at human capabilities and functioning, because ultimately, we, humans, design systems that we hope are resilient in order to protect and enhance functioning. By focusing on resources, such as electricity supply systems, manifested inequities of energy services go unnoticed and hence are missed from resilience frameworks. The degree of damage goes well beyond commodities-based parameters, devastating communities because technical parameters often overlook interdependencies and their effect on hampering the functioning of people. The increased risk of system failure should lead to understanding resilience in the context of a complex system built for people that get affected and yet secludes them from being involved as active partners in designing resilient systems.

Conceptualizing resilience through energy services and a capabilities approach to justice raises new directions for empirical research. For example, we are particularly interested in finding ways to measure energy services access to consider the true impacts of disasters in terms of just access to the energy services necessary to support capabilities. This would be potentially done through measuring for a community how many of Nussbaum's capabilities is electricity services are currently realized in the community. These results can help identify hotspots and cold spots for energy service provisions enabling these capabilities. This approach also opens new avenues for empirical research involving how communities at various scales can be assessed in terms of organization of infrastructure, disaster management, and resilience planning, suggesting that empirical examinations of a community can be organized based on infrastructural service vulnerabilities.

Furthermore, connecting the dynamic state of developing functioning and capabilities to the resilience of the electrical grid as a critical infrastructure provides an improved understanding of resilience (which, as argued above, is temporal) for individuals, households, or communities. Preparing for adverse events requires planning to respond by considering how it impacts human functioning and flourishing. This would lead to policymaking that measures the resilience of a system by considering how it can secure, adapt, and reassure human flourishing.

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