Joint Committee on the National Security Strategy

Inquiry: Critical national infrastructure and climate adaptation

UK Energy Research Centre response

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1. Risks to the electricity system from climate change

Extreme weather events caused by climate change are bringing new risks to electricity systems around the world that are difficult to predict. The third UK Climate Change Risk Assessment (CCRA3) published in June 2021 has highlighted "*Risks to people and the economy from climate-related failure of the power system*" as one of the highest priorities for further adaptation action in the next two years [1].

Extreme weather events are currently responsible for the majority of long electricity outages in the UK [2]. Currently, electricity supply interruptions are rare, normally affecting a small (often rural) area or lasting for only a short time. However, CCRA3 states that the electricity sector has an 'adaptation shortfall' regarding storms, lightning and high winds, and that storms and high waves may create risks stemming from increasing reliance on offshore wind [1].

There is strong scientific consensus that the UK will face significantly increased precipitation in winter and higher average temperatures all year round. Evidence is mixed on the impacts on some other types of extreme weather. Crucially, however, society's *dependency* on electricity will increase as a result of electrification of heat and transport and digitalisation [3]. An increasing proportion of electricity supply is also dependent on the weather. While the 'levelised cost of energy' from wind and solar is now very low, there is a need for reliable low carbon sources of electricity during extended periods of 'wind drought'. There is also a need for the right mix of 'hardening' measures, to reduce the probability of widespread electricity system interruptions and ease restoration, and increase society's resilience to losses of supply. Climate change is expected to bring ever more extreme heatwaves to the UK. This will also reduce the electricity system's basic ability to transfer power under such conditions as currents must be limited in order to avoid overheating equipment[1].

The GB electricity system has never suffered a total collapse, and the likelihood of such an event remains very low, but not zero [4]. Prompt restoration would depend upon smooth cross-organisation working, between the Electricity System Operator (ESO), generators, and transmission and distribution network owners [2]. The Department of Business, Energy and Industrial Strategy (BEIS) has set the ESO a 2026 target of being able to reconnect 60% of demand in every region within 24 hours, and restore supplies to all customers within 5 days of a system collapse [5]. Much of the generation capacity currently depended on to drive a system restoration process is based on fossil fuels and is being retired. Use of smaller, highly variable resources makes the process more challenging, at a time when increased electricity dependence means that it must also be more reliable.

[1] 'Real time thermal ratings' are a way of ensuring that enforced limits to power transfers are well-adapted to ambient conditions but they are not yet widely used by the electricity networks industry.

Case study: Storm Arwen, 26-27 November 2021

Storm Arwen brought strong winds, with gusts of over 90 mph at a few locations. Such speeds have been experienced in recent years, e.g. in December 1998 and January 2012. However, in Storm Arwen they came from an unusual direction (the North) [6] and were accompanied by freezing temperatures, causing damage to overhead power lines and trees and leaving around a million homes and businesses without electricity, with 30,000 homes still without power four days after the storm [7], [8]. The last households were reconnected after ten days [9]. SSEN, which operates the electrical distribution network in northern Scotland, described the storm as "*once in a generation*", causing "*almost two years' worth of overhead line faults in just one 12-hour period*" [10]. The gas and electricity system regulator, Office of Gas and Electricity Markets (Ofgem), has initiated a review of the role of the Distribution Network Operators (DNOs) during the incident, including of their communications with customers [11].

Case study: August 2019 electricity outage

On August 9th 2019, 1.1 million customers lost power in a major power system disturbance due to a cascade of outages triggered by a lightning strike. The incident was not directly attributable to climate change, and the system should be protected and controlled such that a lightning strike on the transmission network does not cause any interruptions to supply. However, the incident demonstrated the susceptibility of the power system to combinations of unanticipated events – including but not limited to weather-related ones – and some significant failures of regulatory processes [12], [13]. For example, the voltage dip caused by the lightning strike revealed that controls at two large generators had been incorrectly set.[2] The network fault also caused large numbers of smaller distribution-connected generation to trip, due to the operation of protection devices that had been banned by Ofgem but not yet removed. The combined loss of generation caused the system's frequency to change from 50 Hz so quickly that further small-scale generation disconnected due to operation of 'rate of change of frequency' protection set to an outdated threshold. System frequency then fell so far that automatic 'low frequency demand disconnection' was triggered, successfully arresting the frequency fall but disconnecting supplies to a number of essential services to which continuous supply should have been a priority.

Home and local generation e.g. solar panels

Increasing numbers of homes have installed rooftop solar panels. Householders might expect this local, micro-generation to provide them with electricity during a power cut, but this would not normally be possible without the installation of costly supplemental equipment such as batteries. Connection standards currently require that micro-generators are fitted with a controller which automatically disconnects

[2] Normally, compliance of large generators' controls with the Grid Code should be verified by the Electricity System Operator. One of the generators affected – a combined cycle gas turbine – was first commissioned in 1996. However, the other, a large offshore wind farm was in the process of being commissioned and had been granted an interim operational notification by the ESO. Faulty control of the power electronics on the wind turbines was implicated in the event [10].

from the local network in the event of isolation from the main grid[3]. While local generation could, in theory, provide resilience in the event of a wider system failure, it would have to be done within a section of network that has been designed to be operated safely whilst 'islanded' from the rest of the system [14] [4].

2. Infrastructure Interdependencies

Some of the main impacts from an energy system disruption would stem from failures of non-energy sectors and infrastructures [15], [16]. The CCRA3 discusses risks to systems including water, energy, transport and information and communications technology (ICT), and considers the *magnitude* of cascading risks to be *high* across the UK at present [1]. Examples of recent critical national infrastructure (CNI) failure interdependencies in the UK include:

Storm Desmond, Lancaster, 2015. Exceptionally heavy rain flooded an electricity substation. For over a day, the city was not only without electricity, but also lost mobile phone signal, internet and digital radio. Transport and water supplies were also disrupted [16], [17].

August 2019 outage. Although the outage itself lasted less than an hour, it caused a number of trains to automatically disconnect, as a rail sector standard suggested they should. Due to a recent software upgrade, some trains proved impossible to re-start without a technician and a laptop. Passengers were stuck on trains for many hours and rail disruption lasted >48 hours [15].

A modelling study for the UK found that around 40% of modelled electricity failures led to disruptions in other sectors [18]. Two-way interdependencies could also cause further knock-on disruption to the electricity system, for example if interruption of electricity supplies to communications hubs impacts monitoring and control of power system equipment. Energy, water and ICT infrastructure is often co-located, meaning that a weather-related electricity supply interruption may impact multiple sectors simultaneously [19].

Research finds that the vulnerability of CNI to extreme weather events could be significantly underestimated if such interdependencies are not considered [20]. However, major failures are rare, and there is therefore a lack of available data on impacts. New research by UKERC (currently under review) draws on expertise from nine CNI sectors in the UK and finds that all sectors would be impacted by a disruption to electricity supplies but that timescales vary significantly between sectors (more detail below).

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[3] This precaution is called "anti-islanding" (i.e. to prevent forming a "power island"). This measure is necessary to protect electricity network staff, working to fix a local fault, from risk of accidental electrocution due to current from local micro-generators.

[4] One key challenge is design of network protection needed to identify any short- circuit faults and safely and quickly isolate them. At present, distribution network protection is designed with the assumption that power comes from sections of the network operating at higher voltages rather than from generation connection at the same or lower voltage levels.

This research also highlights how staff shortages could create cascading impacts, as illustrated during the COVID-19 pandemic. A weather-related electricity disruption would occur over much shorter timeframes, but could create challenges for communication across sectors and to the general public [21]. Poor communication has been highlighted by Ofgem as a major issue in the aftermath of Storm Arwen [11]. The pandemic has also hastened the pace of digital dependence as organisations shifted to remote working, meaning that emergency plans from pre-2020 might already be out of date.

The CCC states "*there is no systematic national assessment of interdependency risk or a framework to improve resilience in the 2nd National Adaptation Programme, including addressing risks and opportunities from climate change*", and recommends greater cross-sector work to improve resilience [22].

2.1 Electricity and communications

Probably the most critical CNI interdependency is between electricity and communications [23]. In the case of a large, widespread power outage, disruption to mobile phone signals could occur within a short space of time (as illustrated during Storm Desmond in Lancaster); however, the complexities of the electricity and mobile communications networks and their interactions are such that it is very difficult to know where and when disruptions to mobile phone services will arise. Mobile phone networks are not required by law to provide any specific backup in the event of loss of power supplies, Ofcom considering such backup "*prohibitively expensive*" [24]. Moreover, reporting of power cuts often relies on mobile communication.[5]

Most organisations (including CNIs) increasingly use mobile or internet-based means to communicate with their staff [2]. Supply chain logistics are also vulnerable to a loss of internet as digitalisation and cloud data-sharing increase. Improved standards for data availability across sectors would make it easier for critical infrastructure managers to plan their emergency responses and avoid being caught out by unexpected telecoms failure.

In 2017, 70% of calls to emergency services were made from mobile phones [26]. Ofcom rules require telecoms providers to take "*all necessary measures to ensure their customers can call the emergency services during a power cut*", yet only identifies those relying on a landline as 'at risk' [26]. Such rules are written with the expectation that mobile networks will continue to function, assumptions which will likely be challenged in the event of weather-related disruption.

It is also worth noting that the analogue technology used for landline phones is due to be replaced by digital IP telephony in 2025, meaning that landlines will not work at

[5] A mobile app and cloud-based computing developed by a small or medium-sized enterprise in Scotland enabled SSEN customers to report outages and get information on service status even when phone lines were overrun. The software also enabled damage reports to be handled through a different process to outages, allowing immediate danger-to-life to be prioritised. However, access to the service depended on mobile communications [25].

all without backup power and customers will be reliant on mobiles [27]. While the vast majority of UK premises have adequate mobile signal, mobile coverage remains much weaker in rural areas; 8% of UK landmass has no mobile signal [28].

The UKERC research mentioned earlier (currently under review prior to publication) in which views were sought from experts in nine different CNIs suggests there is disagreement between different stakeholders within the communications industry itself on the impacts of loss of energy supply.

2.2 Electricity, health and emergency services

Electricity supply disruptions, particularly those related to severe weather, have been shown to impact health and emergency services [29], [30]. Hospitals in the UK are generally well-provisioned with backup generators, although these do require regular maintenance. During the first 24 hour period of Storm Arwen, Scottish Fire and Rescue received over 900 emergency calls, almost three times their normal number, with more than 500 of the calls being due to the impact of the severe weather associated with the storm [31].

The impacts of severe weather on electricity disruption and health are highly correlated with socio-economic status [32]. Systemic risks such as socio-economic inequality exacerbate the impacts of disruptions [21]. Thus, measures to improve resilience to disruptions across society should focus on addressing these types of systemic risk factors, alongside the physical infrastructure itself.

Local Resilience Forums (LRFs) in England and Wales were mandated in the Civil Contingencies Act 2004, which established 42 LRFs covering all policing areas. LRFs are expected to deliver "*a systematic, planned and co-ordinated approach to encourage Category 1 responders, according to their functions, to address all aspects of policy in relation to: risk; planning for emergencies; planning for business continuity management; publishing information about risk assessments and plans; and arrangements to warn and inform the public*" [33]. An LRF is described as performing "*a crucial role in driving arrangements to plan, validate and meet*" needs including maintaining energy supplies. A review of the effectiveness of LRFs and equivalent arrangements in Scotland (Local Resilience Partnerships) and Northern Ireland (Emergency Preparedness Groups) following events such as Storm Arwen would seem to be appropriate.

2.3 Electricity and transport

The most severe effect of the August 2019 outage was to the rail sector. Currently around 40% of the rail network is electrified, and increased electrification is expected [34]; loss of electrified traction supplies would likely occur immediately in the event of a loss of electricity. Trains also depend on electricity for signalling – rail sector experts interviewed for UKERC research suggested that 24-48h of backup power can be expected on most sites, but that in any scenario involving a long and widespread disruption to electricity supplies it would become extremely difficult to move trains around safely, with consequences for supply chains.

UK government has enacted legislation to ban the sale of new petrol and diesel cars by 2030, and projections indicate that the majority of cars and vans will be electric by the 2030s [34]. A prolonged disturbance to the electricity system would therefore cause greater disruption to road transport in the future.

2.4 Electricity and gas

One major two-way CNI interdependency is between electricity and gas. This was illustrated during the Texas outage in February 2021, where severe winter weather (partly attributable to climate change) left 4.5 million households without power for several days. Gas supply constraints and problems at power stations meant that gas-fired electricity was less available, which in turn meant less electricity to pump the gas [35]. In an energy system such as Britain's with a high penetration of gas-fired electricity, a shortage of electricity from other sources (e.g. during a 'wind drought') could mean that more gas generators are brought online, which in turn makes gas availability tighter. That said, the experts we spoke to in our research suggested that it would take several days, or possibly weeks, for an electricity outage to cause disruption on the gas system.

Home heating would be severely impacted by a power cut: approximately 23.9 million (82%) of the UK's homes have gas boilers for heating and hot water, which require electricity supply to operate [36]. During a winter weather event, loss of heating could become a serious health issue within a short space of time. Sometimes during gas outages, people are issued with temporary electric heating, which in turn can cause problems for local electricity networks that had not been designed for mass use of electric heating. Improved energy efficiency in homes should be considered a critical measure for improving resilience to climate-related energy disruptions.

2.5 Electricity and water

Climate change can disrupt the water sector directly, due to flooding which often occurs at low-lying sites, and indirectly if electricity disruption causes pumps to fail. Such weather-related disruptions can be expected to increase significantly in a high-warming climate change scenario [1]. During Storm Desmond, attempts to restore electricity supplies were hampered by flood waters. Storm Arwen left 20,000 households without water; electricity and comms disruptions hampered the water company's operations [37]. A prolonged power cut could also disrupt waste water and sewage treatment operations, bringing risks to the environment and human health [38].

Many critical sites in the water sector have backup generators; however, other sites are recognised as being vulnerable to loss of power and rely on hired mobile generators which may be in short supply during a large disruption, and mostly utilise carbon-intensive fuels. The sector generally has procedures in place for delivering water supplies to customers in the event of a loss of power, but is heavily dependent on mobile phone networks for arranging emergency staff rotas. Any loss of water supply would have a knock-on impact on healthcare and on industrial processes, particularly heavy industries such as steel which require water for various purposes (as well as electricity). Many manufacturing sites recirculate process water and some have their own supply; however, an electricity outage could interrupt water circulation and abstraction, leaving sites with no option but to shut down, with consequent impacts on the economy and supply chains.

3. What might constitute an 'acceptable' level of resilience to climate change within UK CNI

The resilience of the electricity systems in Great Britain and Northern Ireland – their ability to prevent, contain and recover from interruptions to supply arising from disturbances – is broadly a function of regulation.

Generation adequacy at times of peak demand is largely governed by a Capacity Market instituted by the UK Government [39] (though at other times it depends on the wholesale electricity market's response to 'scarcity pricing').

Both the high voltage transmission network and lower voltage distribution network are designed according to standards intended to broadly reflect expectations of reliability. The transmission system is operated in accordance with a statutory Security and Quality of Supply Standard (SQSS) [40]. Stability of the system depends on how every item of equipment connected to it responds to disturbances. Standard rules for responses are written in the Grid Code [41] and in Engineering Recommendations [42] and can be augmented by specific requirements written into connection agreements. However, as we discussed in relation to the August 2019 GB system event, these rules are not always fully enforced. One independent panel report has argued that they are currently ill-suited to the changing nature of the system [43] while Ofgem recommended a review of the standards that the ESO is required to apply when securing the electricity system against credible disruptive events [44]. The Government review of the August 2019 event called for the definition of what essential services are, better understanding of their capacity to deal effectively with power disruptions and the provision of guidance for essential services' owners or operators to support resilience planning. We are unaware of significant progress against these recommendations.

Although some commentators have suggested that provision of a reliable supply of electricity should be left to "*decentralised contracting and retail innovation*" [45], our research suggests that even providers of CNI often have a fuzzy understanding of what level of reliability is currently provided or what they would need, especially during a major, widespread disturbance. This and the rapidly changing nature of the electricity system with greater use of variable renewables and power electronics based technologies and higher dependency on electricity suggests to us that there remains a key role for a coherent, up-to-date and strongly enforced set of standards. The set of standards currently in place does not have those characteristics.

It will be impossible to completely avoid weather-related electricity disruptions, some of which will be attributable to climate change. Determination of an 'acceptable' level of electricity system resilience needs to take account of the very severe economic and societal impacts of a loss of electricity.

Determining an 'acceptable' level of resilience should take into account the differing needs of different types of end-user, *in addition* to system resilience measures such as reliability and restoration standards. Different end-users will have greatly differing levels of tolerance to climate-related electricity disruptions [46]. For example, many in rural areas may have a higher level of resilience than those in urban areas [24], [47]. Energy suppliers and DNOs are expected to maintain Priority Service Registers of vulnerable electricity users [48] but it is unclear to us whether they are always complete and up-to-date. Younger people often have less outage experience and preparedness, higher levels of mobility, and greater dependence on digital communications [47], [49]. Impacts on mental health should also not be underestimated, despite not generally being included in official loss and damage estimates, and exposure to impacts of climate change has been shown to have potentially lasting effects on mental health [50], [51].

Local, community and grassroots organisations could play an important role in understanding and managing vulnerability, and supporting communities and vulnerable individuals in the event of outages. However, they require proper resourcing to do so. Local resources, such as places where people can go to get warm food and find information, could substantially reduce pressure on the emergency services. While arrangements such as Local Resilience Forums promise to provide much needed coordinated preparation and response, their effectiveness needs to be demonstrated.

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