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EDITED BY
Wentao Yang,
University of Leeds, United Kingdom

REVIEWED BY
Fabio Matano,
National Research Council (CNR), Italy
Maxim A. Dulebenets,
Florida Agricultural and Mechanical University, United States

*CORRESPONDENCE
Priscila Carvalho,
priscila.carvalho@ucl.ac.uk

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Gaps in the governance of floods, droughts, and heatwaves in the United Kingdom

Priscila Carvalho* and Catalina Spataru

Island and Coastal Research Lab, UCL Energy Institute, Bartlett School of Energy, Environment and Resources, University College London, London, United Kingdom

Disaster risk reduction (DRR) and equitable resilience have cross-cutting challenges relevant to the Sustainable Development Goals (SDGs), Sendai Framework (SF) and Climate Change Adaptation (CCA). The capacity of governments to assess, prevent, prepare, respond, and recover from disasters depends on effective laws, planning, policies, governance instruments, equity indicators, harmonized standards, and a holistic approach to cross-sectoral issues and multi-scalar challenges. The principle of subsidiarity guides the United Kingdom (UK) approach to disaster governance, with decisions taken at lowest level and coordinated at different scales (national, sub-national, local). Cross-scale work needed to address large-scale issues and enable the pooling of resources, happens at a sub-national tier created especially for this purpose. At national level, there is a government lead department for each risk identified in the National Risk Assessment, with Department for Environment, Food and Rural Affairs (DEFRA) serving as the lead for floods and droughts, while the Department of Health and Social Care is the lead for heatwaves. In this paper we present the current state of the art of the governance of floods, droughts, and heatwaves in the UK, with a focus on pre-emergency phases and the shortage of indicators for assessment of the effectiveness of adaptation for all three disasters, which also compromise the realization and monitoring of targets across all three agendas. The governance of floods counts with the most developed legal framework of the three. Droughts are mainly dealt by the water sector, while heatwaves are treated exclusively as a health issue, leaving gaps with regards to the multiple risks these disasters pose to livelihoods and other sectors. Gaps and challenges that remain are related to siloed institutional approaches, lack of adaptation indicators, lack of cross-sectoral resilience standards, and lack of policy instruments and metrics to promote equitable resilience. Commonly, actions have mainly focused on the response and recovery strategies instead of risk reduction and adaptation to address rising vulnerabilities and exposure.

KEYWORDS

climate adaptation, equitable resilience, governance, risk reduction, sdgs, sendai framework

Introduction

Despite current global and national policy commitments to mitigate and adapt to climate change, Earth's mean temperature is projected to rise by approximately 2.7°C above pre-industrial levels by the end of the century (Climate Action Tracker, 2022). This increase is expected to result in more extreme weather events and recurring hazards. Six major storms took place in the UK in 2022, which saw some of the highest wind speeds in over 30 years

(Met Office, 2022c). These northerly winds led to widespread damage in Northeast England and Scotland, including power line damages and trees uprooted, with almost a million customers losing power (Met Office, 2021; OFGEM, 2022). The last decade was the warmest on record (WMO, 2022). The UK's average land temperature increased by about 1.2°C from pre-industrial levels (Climate Change Committee, 2021). Sea levels have risen by 16 cm since 1900 and could reach up to 30 cm by 2050, increasing flood risks along a third of England's coast (Climate Change Committee, 2021). The year of 2020 was the third warmest and fifth wettest in history, which led to extensive flooding, particularly in the Northern England and Wales (Kendon et al., 2020). The economic damages of the 2019/20 floods reached £333 million, but flood defences reduced costs that would have been at least fourteen times greater without such protection (ibid.). There are £200 billion worth of assets at risk of flooding (Environment Agency, 2021a). The latest UK Climate Change Risk Assessment (2022) identified that around 3.2 million properties are at risk of surface water flooding in England (DEFRA, 2022). Increased flooding poses significant challenges to various aspects of infrastructure, including energy systems, transportation networks, water management, waste disposal, and digital communication systems. Storm Arwen in 2022 caused significant disruptions for a water company, leading to power outages at 140 wastewater sites and water treatment assets serving 17,500 properties, leaving them without water (Joint Committee on the National Security Strategy, 2022). In 2018, the 'Beast from the East' created substantial travel disruptions, complicating the efforts of an energy company's engineers to visit gas sites and address technical faults (ibid.).

Annual average rainfall is increasing since 1980s in the UK and in the last decade, the summers were 20% wetter than in the decade before (1990–2000) (Climate Change Committee, 2021). There are about 6.4 million people living under flood prone areas in the UK (Sayers et al., 2017). From this total, around 1.8 million people are exposed to significant risks of floods and estimates show this number could reach 2.6 million people by 2050 in a two-degree scenario (Climate Change Committee, 2016). The socially vulnerable neighbourhoods are over-represented in areas prone to costal and tidal flood (33% of all people exposed to this risk −590,000–are within the 20% most vulnerable neighbourhoods in the UK) (Sayers et al., 2017). Saline intrusion, coastal squeeze, coastal building damage are high risks associated with coastal flooding and erosion damage. By 2080, 10.8 million people could be exposed to significant risks of floods in the UK, with the most vulnerable neighbourhoods seeing the highest rise to 1.4 million people (ibid.).

Higher maximum temperature and longer warm spells have also been the reality in the United Kingdom. England recorded 2,556 excess deaths across three heatwave periods in summer 2020. Notable heatwaves were registered in 1976, 1990, 1995, 2003, 2006 (Met Office, 2018), 2019, 2020 and 2022 (Met Office, 2022a). In 2003, the United Kingdom hit a record high of 38.5° (Public Health England, 2020). In 2019, the United Kingdom broke the 2003 record at 38.7° (Met Office, 2019). In 2022 a new record was set at 40.3° (Met Office, 2022a). Close to 12 million people are in danger of the risks of heatwaves, with most vulnerable more at risk than others (e.g., elderly people and pre-existing health conditions) (The Climate Coalition, 2021). Heat related mortality of elderly people increased by 21% between 2004 and 2018 (ibid.). It could rise by 250% without climate action and affect an additional 7.5 million people aged 65 years and above by 2070 (ibid.). Heatwaves cause the loss of life, but also the loss of productivity and overheating in buildings, which has implication for health (Arbuthnott and Hajat, 2017). There are no specific policies addressing the overheating of buildings and the lack of prevention and preparedness measures will continue to expose to the most vulnerable, locking in major risks to wellbeing (Climate Change Committee, 2021). Today, the best practice is to follow the thermal comfort guidance of the Chartered Institution of Building Services Engineers but estimates show that more than 20% of buildings exceed maximum temperature for a normal United Kingdom summer, which will certainly aggravate with additional extreme heat (Brimicombe et al., 2021).

Higher temperatures increase evaporation, causing soils to become dryer which can potentially worsen drought impacts. Even though droughts are the least frequent of the three disasters in the United Kingdom, there are recent and notable events registered in England between 1972 and 74, 1975-76, 1988-89, 1990-92, 1995-97, 2004-06, 2010-12 (Met Office, 2013) and 2022 (Environment Agency, DEFRA and Double, 2022). Droughts represent risks to food security, land, insects, trade, economic growth, carbon uptake, fish deaths, reduced breeding of birds and poisonous algae. They are characterized for being a slow on-set type of disaster, which vary in timeframe, impacts and nature (environmental drought, agricultural drought, and water supply drought) (Environment Agency, 2017). Areas most at risk of droughts are in the southern parts of the United Kingdom (Environment Agency, DEFRA and Double, 2022). In 2022 large areas were moved into drought status (Devon and Cornwall/Isles of Silly; Solent and South Downs; Thames; Hertfordshire and North London; Kent and South London; East Anglia; Lincolnshire and Northamptonshire; East Midlands; and Yorkshire) (ibid.). Many areas of England are predicted to have water shortage by 2050 due to prolonged hot and dry weather, impacting river flows and soil dryness (Environment Agency and Bevan, 2019). Without further investment in water storage and transfer infrastructure, coupled with efforts to reduce water demand, the probability of facing a severe drought before 2050 is of around 25% (Joint Committee on the National Security Strategy, 2022).

Floods, heatwaves, and droughts are critically linked and have compounding impacts. Heatwaves can exacerbate droughts and wildfires, which can lead to dryer soils that are not able to retain the heavy rainfall that usually come at the end of dry periods, aggravating impacts of floods. The negative consequences for people, environment, critically interlinked resources, and systems of provision are unquestionable. However, the increasing risks of droughts, floods and heatwaves are managed in fragmented and siloed ways and count with different stages of governance maturity, lacking indicators for adaptation and equitable resilience. There are asymmetries in the capacity to assess, prevent, prepare, respond, and recover from each of these disasters, which will continue to expose the most vulnerable to their impacts. The governance of floods counts with the most developed framework when compared to heatwaves and droughts, including in terms of laws, plans, policies, regulations, knowledge and information and prevention mechanisms. DEFRA is the lead government department for floods and droughts (DEFRA, 2015), while the Department of Health and

Social Care is the lead department for heatwaves (Public Health England, 2020). Heatwaves are treated as a health issue and together with droughts their main governance instrument is a national plan, leaving gaps and challenges with regards to the risks these disasters pose to livelihoods, resources, and sectors in other domains (e.g., land, water, energy, transport, food and building sector). Siloed institutional approaches, lack of adaptation and equity indicators, and better integrated resilience strategies, sustainability and risk reduction policies represent gaps and challenges for managing multi-hazard risks. Compared to the Sendai Framework and Climate Change Adaptation for which the United Kingdom is still developing data approaches to measure many domestic objectives (PHE, 2017; Climate Change Committee, 2021), the SDGs count with a high number of indicators to measure progress on the ground (180 of the total of 244) (DFID, 2019). In general adaptation is not following the increasing risks the United Kingdom is facing, which means it is less prepared now than it was 5 years ago (Climate Change Committee, 2021), raising environmental justice concerns. Loss of assets, income and livelihood suffered by disadvantaged groups in context of climate hazard aggravate inequalities and consequently the exposure and vulnerability of these same groups to the risks of floods, droughts, and heatwaves.

Disaster risk reduction under the Sendai Framework refers to a wide range of opportunities for risk abatement and disaster management, including prevention, preparedness, and part of the recovery process, giving particular emphasis to the reduction of vulnerability. Targets A-D of the Sendai Framework form the basis of monitoring and reporting on disaster loss data, including on reduction of disaster mortality, number of affected people, disaster economic loss and damage to critical infrastructure (UNISDR, 2015b). About 60% of the Sendai reporting countries (from a total of 87 in the last review) have a national database for monitoring disaster losses, but the United Kingdom did not report to have one (UNISDR, 2017). Under the Paris Agreement, climate change adaptation (CCA) strategies and outcomes also aim to reduce vulnerability to expected impacts of climate change. The United Kingdom actions and indicators for CCA are developed through its National Adaptation Strategy and National Adaptation Plan, completed impacts, vulnerability, and adaptation assessments, established meteorological observations, climate projects and services, monitoring and reporting. At national level, the adaptation indicator framework has been reviewed by the Climate Change Committee in 2021 covering trends of risk factors, adaptation actions and climate impacts, and many gaps in the following areas: natural environment, business, infrastructure, people, and the built environment (Climate Change Committee, 2021). The United Kingdom does not have measurable targets to assess progress towards climate change adaptation and at least 34 areas of adaptation priorities do not present strong progress (ibid.). Adaptation is yet to be mainstreamed into policy and practice, while most adaptation priorities lack account of the impacts under different warming scenarios (ibid.).

Climate change adaptation and disaster risk reduction are key to manage risks and impacts of floods, droughts and heatwaves and support equitable resilience in benefit of the Sustainable Development Goals (SDGs). On the other hand, if development follows a more sustainable path, reducing pressure on resources such as water (SDG 6), energy (SDG 7), food (SDGs 2), ocean (SDG 14), land (SDG 15), it can reduce risks and address the drivers of vulnerabilities that aggravate impacts of floods, droughts, and heatwaves. There are 25 targets and 35 indicators under the Sustainable Development Goals, which can help monitor the Sendai Framework and risk reduction and resilience (UNISDR, 2015a). The United Kingdom has data for 27 out of the 35 indicators, with actions that span across the Resilience Capabilities Programme, the 25 Year Environment Plan, Environment Bill, citizenship curriculum and abstraction plans (DFID, 2019). Gaps remain with respect to lack of disaggregated data and missing data for direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to services attributable to disasters (Climate Change Committee, 2021). Even though the global targets share common objectives on reduction of risk and vulnerability to communities, the development basis of adaptation, risk reduction and equitable resilience are not the reality. There is a need for better integrated approaches towards implementation of the global targets of the SDGs, CCA and SF that crosscut and intersect the latter objectives, addressing the drivers of vulnerability as drivers of disaster risk, and strengthening resilience across scales and sectors, with a focus on equity and justice.

We present a review on the United Kingdom's risk assessment and governance of floods, droughts, and heatwaves in the context of the three global policy frameworks (SDGs, Climate Change Adaptation and Sendai Framework). We advocate that for these frameworks to build on each other and advance fair processes and outcomes in the implementation of targets relevant for risk reduction and resilience, environmental justice has a role to play. It serves well the purpose of addressing the inequitable outcomes for people and places in relation to climate impacts and risks associated with increasing frequency and magnitude of floods, droughts, and heatwaves. Section 2 contains a review of the risk assessment approach; Section 3 contains the governance review of the three disasters in the United Kingdom. Conclusions are driven about which one counts with the most or least developed framework to safeguard that collectively and individually, everyone can prepare, respond, and recover, while having their essential needs met (e.g., housing, energy, water, transport, telecommunication). Section 4 covers the criteria and approach for risk management across national critical sectors in the United Kingdom with a focus on the three disasters. We identify the lack of data on the vulnerability of infrastructure to extreme weather and the gaps towards improved resilience. The discussion and conclusions on Section 5 focuses on the environmental justice implications of disparate governance approaches towards these disasters, including main conclusions and prospects to advance research and practice in the field of risk reduction and resilience to floods, droughts, and heatwaves.

Shortcomings in risk assessment of floods, droughts, and heatwaves

The United Kingdom produces every 2 years a classified assessment of the risks of civil emergencies that have the potential to cause significant disruption due to threats to human welfare, environment, or security (Cabinet Office, 2017). This

TABLE 1 Comparison of risk assessment criteria under the national risk registry.

Fatalities	Number of fatalities directly attributable to the emergency	2017
Casualties	illness or injury over the period following the onset of the emergency	2017
Social disruption	Levels of disruption to people's lives, from an inability to gain access to healthcare or schools to interruptions in supplies of essential services such as food, water, transport, healthcare*etc.*	2017
Economic damage	Such as lost tourism or working hours, with effects measured for the economy overall and not just the cost of repairs	2017
Psychological impact	Widespread anxiety, loss of confidence in the Government, outrage that communities may experience	2017
Human welfare	Fatalities directly attributable to the incident, causalities resulting from the incident (illness, injury and psychological impacts), evacuation and shelter requirements	2020
Behavioral	Changes to people's behavior or public outrage	2020
Essential services	Levels of disruption to people's lives, from an inability to gain access to healthcare or schools to interruptions in supplies of essential services such as food, water, transport, healthcare*etc.*	2020
Economic damage	Such as lost tourism or working hours, with effects measured for the economy overall and not just the cost of repairs	2020
Environmental impact	Widespread anxiety, loss of confidence in the Government, outrage that communities may experience	2020
Security	Law enforcement and the criminal justice system	2020
International	Damages to international relations	2020

Source (Cabinet Office, 2017; Cabinet Office, 2020).

"National Risk Assessment" (NRA) analyses the key risks over a five-year period, as a way of providing the government and local responders with the means to plan, prioritise and proportionately prepare for eventualities. The risk assessment considers environmental hazard risks and others (e.g., pandemics) in terms of likelihood, scale and extent of consequences, prioritizing the eminent emergencies and the ways of responding to them (Cabinet Office, 2020). The public has access to this assessment through the National Risk Register (NRR), which serves as a resource for individuals and organizations to prepare. The NRA helps the local level to identify potential risks and prepare plans for either preventing or mitigating the impact of incidents locally. This work is coordinated through in England and Wales, Regional Resilience Partnerships in Scotland, and Emergency Preparedness Groups in Northern Ireland (Cabinet Office, 2013c). These multi-agency partnerships are made up of representatives from local public services, including the emergency services, local authorities, NHS, and the environmental agencies. They also draw on the support by other organizations such as Highways England and public utility companies. Local Resilience Forums (LRF) are the building block for emergency planning and response activities, while the Civil Contingencies Secretariat in the Cabinet Office is responsible for providing guidance on the preparation and work coordinated by local partners. At the local level, Community Risk Registers (CCR) are published by the Local Resilience Forums to provide an overview of the risks based on local conditions, infrastructure, and geography (Cabinet Office, 2020). Local Resilience Forums should follow a uniform process of risk assessment developing Community Risk Register (CRR), but discrepancies and errors have been identified, which compromises a nationally consistent picture of local risks (Deeming, 2017).

The NRR published in 2020 includes floods, droughts, and heatwaves under the 'reasonably worst-case scenario' due their likelihood assessment and impact (Cabinet Office, 2020). For risks to be included in the NRA they need to have at least 20,000 chances of occurring in the United Kingdom in the next 5 years; and have an expected impact that reaches a minimum threshold that typically translates into significant damage to human welfare (ibid.). Likelihood scores between one and five are developed for each risk, and under each step on the scale, the probability of an event happening in the next 5 years increases approximately tenfold (ibid.). For some risks, data such as historical analysis and numeric modelling are used to inform estimates of likelihood. Scientific expertise also informs the development and review of risks (ibid.). Where possible, a combination of this analysis and expert judgement is used to estimate the approximate likelihood of an event occurring. The NRR of 2020 has 38 civil emergency risks compared to the 21 risks highlighted in the previous NRR of 2017 (Cabinet Office, 2017). The impacts of risks under the NRR of 2017 were assessed according to the five criteria (fatalities, causalities, social disruption, economic damage, psychological impact), while in the NRR 2020 spans across seven criteria (human welfare, behavioral, essential services, economic damage, environmental impact, security and international) (Table 1). The expansion of the assessment framework reflects the growing complexities of risks and is a step forward towards a more comprehensive understanding of their likelihood and impacts, which can inform more effective risk management and mitigation strategies. There are new challenges in terms of data collection, analysis, and interpretation, including with regards to cross-sectoral collaboration and coordination. Overall, there is a growing need for more integrated and holistic approaches to risk management across critical sectors and resilience building.

Under the 2020 NRR, heatwaves are the most likely to happen (25–125 in 500) and has an impact score of three (Cabinet Office, 2020). Droughts are the least likely to happen (1–5 in 500) and has the same impact score as heatwaves (ibid.). Coastal flooding and river flooding are in between the two in terms of likelihood (5–25 in 500) but are considered to have the highest impact of all three. The United Kingdom faces an adaptation deficit (Joint Committee on the

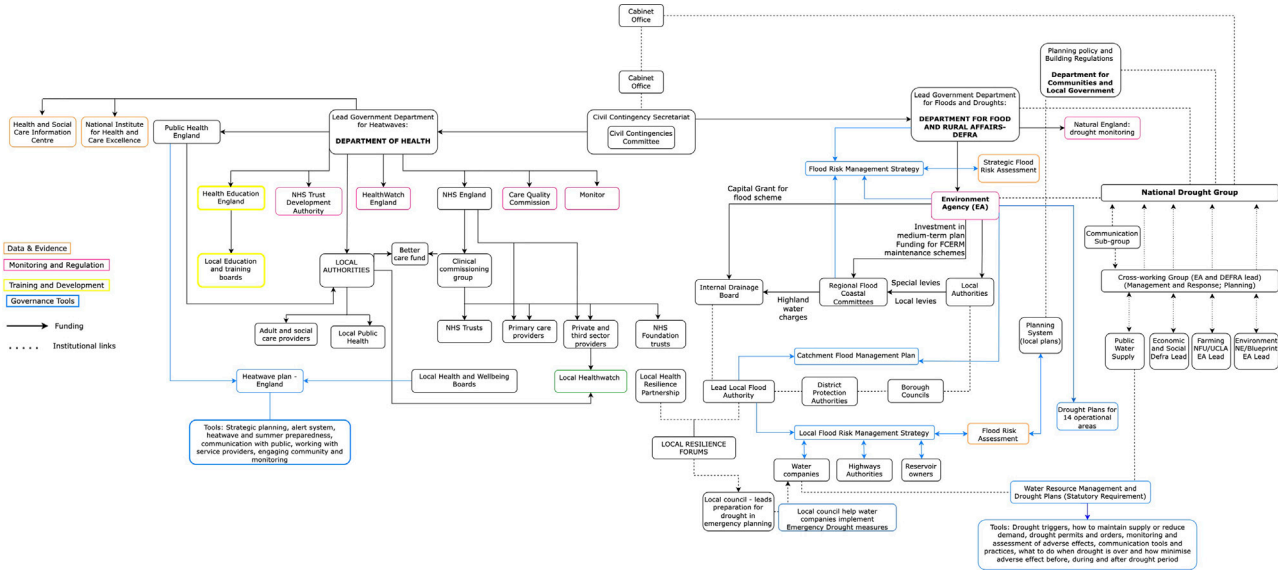

FIGURE 1
Cross-scale governance of floods, droughts and heatwaves.

National Security Strategy, 2022) so questions remain about the degree of preparedness to the compounding impacts of these latter disasters, including the United Kingdom's progress towards the SDGs, SF and CCA targets. The United Kingdom's Adaptation Committee found in its 2021 Independent Assessment that the country is unprepared for even the best-case climate change scenario, with the gap between risk levels and adaptation efforts widening since 2017 (CCC, 2021). Major adaptation deficit impacts all the United Kingdom's Critical National Infrastructure (CNI), including energy, transport, water, waste and digital communication (Joint Committee on National Security Strategy, 2022). The growing potential for incidents like the August 2020 train derailment in Stonehaven, Scotland, where heavy rainfall washed debris onto the track, causing a collision that resulted in fatalities, raises concerns (RAIB, 2022). Shortcomings were identified in the Network Rail's risk management processes, including weather forecasting accuracy, risk assessment dependability, resource deployment, and real-time monitoring of rainfall events (ibid.). The latter poses risk to effective emergency evacuation planning, which is crucial for maintaining safety and efficiency in transportation networks during impending natural hazards (Dulebenets et al., 2019a).

Every 5 years, the United Kingdom Government presents a Climate Change Risk Assessment (CCRA) to Parliament, based on an independent analysis by the Adaptation Committee, a sub-committee of the Climate Change Committee. In June 2021, the committee identified eight urgent action areas, including climate-related risks to the power system. The CCRA highlighted that, by 2050, the financial cost of infrastructure risks in a 2°C global warming scenario would be "very high," with economic costs exceeding £1 billion per annum (UK Climate Change Risk Assessment, 2022). There are still gaps in defining methodologies for risk assessment that National Critical Infrastructure (CNI) stakeholders from both government and operators can apply in practice (Climate Change Committee, 2021). Clarifying these methodologies and their related data requirements is crucial for prioritizing investments in resilience and addressing climate-related risks more effectively (United Kingdom Readiness for Storms, 2022). Unawareness of cascading risks may lead to delayed or absent mitigation actions and increased casualties during disasters, highlighting the need for cross-regulator collaboration due to the interconnectedness of various sectors and their shared risks (House of Lords Risk Assessment and Risk Planning Committee, 2021).

Asymmetries and gaps in the governance of floods, droughts, and heatwaves in the United Kingdom

Every risk of civil emergency has a government lead department at national level that is responsible for the day-to-day coordination, support and oversight of risks and management of response by central government (Civil Contingencies Secretariat, 2004; DEFRA, 2015). Figure 1 has an overview of the governance structure for floods, droughts, and heatwaves. The Department of Health and Social Care (DHSC) is the lead government department for heatwaves (Figure 1). The Department for Food and Rural Affairs (DEFRA) is the lead for floods and droughts, providing funding for risk management through grants to the Environment Agency, local authorities, and drainage boards. New or revised flood policies are prepared with other parts of government such as the Treasury, the Cabinet Office (for emergency response planning) and the Department for Communities and Local Government (e.g., for land-use and planning policy). These national policies are delivered by Risk Management Authorities (RMAs). RMAs have their own mandates with respect to risk management but should co-operate and share information in compliance with the national and local Flood and Coastal Erosion Risk Management Strategies.

TABLE 2 Phases of the integrated emergency management in the UK[a].

Phases	Description
Anticipation	Horizon-scanning for identification of risks and potential emergencies
Assessment	Analysis of likelihood of occurrence and impact of emergencies. Risk knowledge (National Risk Registry)
Prevention	Measures to stop a disaster event and/or prevent its harmful effects on communities and infrastructure (e.g., safety standards, flood defense, land use regulations, building codes, preventive healthcare, education and provisions of basic needs and services)
Preparedness	Measures to limit the impact of a disaster, including through quick and orderly reaction and structured response (e.g., warning systems, evacuation, rescue and relief, counter-disaster plans, stockpiling of supplies, resource trade-off and/or conflict plans, community drills, education and awareness)
Response	Measures and decisions to deal with a disaster as soon as it happens, split in two objectives: (i) crisis management that includes measures to avert a disaster, with protective actions that can mitigate its effects, prevent damage or disruption and secure livelihoods (e.g., fighting fires, search and rescue, health advice; and (ii) impact management that includes steps to stop incident from escalating (restoring utility services, providing shelter)
Recovery	Measure to rebuild, restore and rehabilitate the communities impacted by a disaster, which can take months or years (e.g., reconstruction of infrastructure and restoration of people's wellbeing - physical, mental, emotional, social and economic)

[a]Information source retrieved from (Deeming, 2017).

According to the principle of subsidiarity that guides the United Kingdom's governance of civil emergencies, decisions should be taken at the lowest appropriate level with co-ordination at the highest level (HM Government, 2004). Most incidents are best managed by local authorities, affected industries and emergency responders. Category 1 responders at local level (emergency services, local authorities, NHS bodies) have the duty to maintain plans for preventing emergencies, reducing, controlling, and mitigating its effects, while acting when emergencies happen by observing the formal arrangements to warn, inform and advise the public accordingly (Cabinet Office, 2012). The latter should involve Category 2 responders, which include electricity distributers and transmitters, gas distributers, water and sewerage undertakers, telecommunication providers, transport organizations, health bodies and government agencies) and other relevant voluntary organizations when developing plans. The local tier also provides the building block of the response to disasters (Cabinet Office, 2013a). The United Kingdom has developed a concept of operations specifically to guide how different levels should respond and recover from emergencies by working together (UK Cabinet Office, 2013). The Strategic and Recovery Co-ordinating Groups act as the local mechanism during the response and recovery phases of disasters (ibid.). To improve the overall co-ordination and communication between the central government and local responders, and other organizations, a sub-national tier was created as a key element of the civil protection framework (Cabinet Office, 2012). Under this tier, local responders, and central government work in partnership to ensure a coordinated planning and response, either through multi-agency setting or directly between two or more responders (ibid.). This cross-boundary work to address large-scale issues aims to enable the pooling of resources, avoidance of duplication of work by LRF and support for emergencies crossing local resilience areas (Cabinet Office, 2013a). The Department for Communities and Local Government has a Resilience and Emergencies Division, which provides the platform for multi-LRF cooperation (ibid.). The governance model in which United Kingdom civil protection is delivered to protect people, businesses and infrastructure from floods, droughts and heatwaves is the Integrated Emergency Management in Table 2, which entails six key phases–anticipation, assessment, prevention, preparation, response, and recovery (Cabinet Office, 2013b).

Legislation plays a crucial role in the governance of disaster risk reduction and equitable resilience. Table 3 has a snapshot of key laws and plans that apply directly or indirectly to the reduction of risks to floods, droughts, and heatwaves, with consideration of which global policy agendas they relate to. They set out the norms and frameworks for disaster risk governance, implementing strategies and creating specific accountabilities and liabilities for public officials, private sectors, and society. By regulating risk-related decisions, actions and responsibilities, the law sets out how the integration and coordination of local and national disaster risk management and practices should happen, including the distribution of resources and powers among different sectors and institutions (Mehryar and Surminski, 2020). In the United Kingdom, the Civil Contingencies Act provides an overarching framework for reducing risks to civil emergencies, including floods, droughts, and heatwaves, putting a duty on emergency planners and responders to identify and assess the risks affecting the area in which they operate (HM Government, 2004). Whereas the Act is responsible for setting the duties for civil protection, the details of what the duties entail, how they should be conducted and delivered is set under Regulations. Neither the Act or Regulations impose a statutory duty for authorities to take a more proactive approach towards reducing the likelihood of threats, so responders can decide how to treat risks beyond the emergency plans that are required by the Act, leaving prevention and pre-emption out (Deeming, 2017).

Actions to manage the risks of floods and coastal erosion are set under the Flood and Water Management Act (2010), which is the principal legislation guiding preparedness and response to floods in the United Kingdom. It includes the building sector, natural processes, water levels, river or watercourse, shoreline, regulatory instruments, financial support, forecast and warning, information dissemination and education. The potential and/or confirmed harmful consequences of floods for health, social and economic welfare of individuals and communities, infrastructure, and the environment (including cultural heritage) form the basis of risk

TABLE 3 Mapping key documents for managing floods, droughts, and heatwaves with global frameworks.

Key Legal Documents	Floods Droughts Heatwaves	Sendai Framework Priorities	SDGs	Climate Change Adaptation
Water Act 2003	Droughts	1, 2, 3, 4	SDG 2, 3, 6, 11	Article 7
Drought Plans 2003 onwards	Droughts	2	SDG 6, 13	Article 7
Civil Contingencies Act 2004	All	1, 2, 4	SDG 11, 13, 15,	Article 7
Heatwave Plan for England 2004 onwards	Heatwave	2	SDG 11, 13	Article 7
Climate Change Act 2008	All	1, 2, 3, 4	SDG 13	Articles 2, 7
Flood Risk Regulation 2009	Flood	3, 4	SDG 11, 13, 15	Article 7
Flood and Water Management Act 2010	Flood	1, 2, 3, 4	SDG 11	Article 7
Equality Act 2010	All		SDG 5	Article 8, 11, 12,
Water Act 2010	Drought	2	SDG 6	Article 7
Health and Social Care Act 2012	Heatwave	1, 2	SDG 3	Article 11
First National Adaptation Programme 2013-18	Flood and droughts	4	SDG 13	Article 7 and 15
Resilience and Capabilities Programme (2013)	All	4	SDG 11	Article 11
National Guidance on Risk Assessment (2013)	All	1	SDG 13	Article 11
Flood RE Insurance Scheme 2016 - 2039	Flood	3, 4	SDG 13	Article 7
Drought Response Plan 2017	Drought	2	SDG 11, 13	Article 7
Second National Adaptation Plan (2018-23)	All	2	SDG 11, 13	Article 7
Community Resilience Development Framework 2019	All	1, 2, 3	SDG 13	Article 7
National Risk Register 2020	All	1, 2, 3	SDG 13	Article 4, 7
Environment Bill 2021	All	4	SDG 6, 11, 12, 13, 14, 15	Article 4, 7, 8
Flood risks and management plans 2021-27	Flood	1, 2, 3	SDG 13	Article 7, 11
Adverse Weather and Health Plan 2023-24	All	1, 2, 3	SDG 13	Article 7

Source: Paris Agreement, Sendai Framework, SDGs, UK Government.

assessments and risk management strategies. England and Wales need to prepare national and local (FCERMS) (Environment Agency, 2020). At national level, the Environment Agency is responsible for developing, applying, and monitoring these strategies, while 'Lead Local Authorities' are responsible for local flood risk management strategies. The FCERMS sets out who are the flood and coastal erosion risk management authorities at national and local scales (Environment Agency, Lead Local Flood Authorities, District and Borough Councils, Coast protection authorities, water and sewerage companies, Internal Drainage Boards, and Highways Authorities), including their functions, objectives, and measures proposed to achieve those objectives. For example, how and when the latter should be implemented, their costs and benefits, as well as how they will be paid. The FCERMS strategy for England was first published in 2011 and the latest revision was made available in 2020. Between 2015 and 2021 more than £2.6 billion of government funding has been allocated to FCERMS (Environment Agency, 2021b). Between 2021 and 2027, the government has committed to double its expenditure on FCERM to £5.2 billion, reaching the highest amount ever allocated for protection against flood risks (ibid.). Another £200 million have also been allocated to advance resilience programme (ibid.). It is predicted that an additional 336,000 properties will be safeguarded, and twenty-five local areas will be able to advance their actions and plans to protect themselves against flood and coastal erosion risks (ibid.). However, the lack of clear standards for flood protection across the United Kingdom means that measures such as flood defences are usually put in place only after severe disasters have occurred (Cabinet Office, 2016). A reactive approach is also true in relation to key legislation and policy instruments that have been developed through time to manage the risks not only of floods, but also of droughts, and heatwaves. Tables 4 shows that key measures from the last 2 decades have been put in place after major disasters happened (e.g., series of floods in 2007 that triggered the United Kingdom Flood and Management Act 2010; Head Office

TABLE 4 Review of hazards and the legal framework (2000–2020).

Year	Hazards	United Kingdom general acts, statutory instruments, plans and programmes
2000	Most widespread and severe flood events in October/November led to 10,000 properties flooded across 700 locations, with widespread disruption of road and rail services (cost of £1bn) (Environment Agency, 2001)	
2001	Highest sunshine value ever recorded since 1909 in England and Wales (2.60 h per day)	Civil Contingencies Secretariat established; Emergency Planning Review (Hodgkin and Sasse, 2022)
2002	Flooding in the end of December 2002 saw areas get 125%–150% of December's average rainfall	
2003	Heatwave that led to 2,000 excess deaths over a 10-day period in August	Water Act
2004	Flooding in North Cornwall	Civil Contingency Act; Southern, Wessex and Anglian Flood Defense Committee Order (The Wessex Regional Flood Defence Committee Order, 2004); Heatwave Plan for England (Public Health England, 2020)
2004–06	Drought with severe impacts in east England. Fish deaths, reduced breeding and green algae identified (Met Office, 2022b)	Southern Regional Flood Defense Committee Order
2005	Flooding in North Yorkshire and Carlie and Stormy spells	First national Risk Assessment. Drought Plan Regulations 2005; Civil Contingencies Act 2004 (Amendment of List of Responders) Order 2005; Civil Contingencies Act 2004 (Contingency Planning) Regulations 2005; Wessex Regional Flood Defence Committee Order; Anglian Regional Flood Defence Committee (Abolition) Order; Social Fund Cold Weather Payments (General) Amendment Regulations
2006	Heatwave with about 680 excess deaths (Met Office, 2018)	Northwest Regional Flood Defence Committee Order; Severn-Trent Regional Flood Defence Committee Order; Mid Kent Water (Non-Essential Use) Drought Order; Southern Water Services (Kent Medway, Kent Thanet and Sussex Hastings) (Non-Essential Use) Drought Order; Southern Water Services (Sussex North and Sussex Coast) (Non-Essential Use) Drought Order; Sutton and East Surrey Water plc (Non-Essential Use) Drought Order
2007	Flooding in Lake District, Cumbria. Floods had an economic cost of £3.9bn (Environment Agency, 2021a)	The Flood Defence (Mimmshall Brook Works) Order 2007
2008	Heavy Rainfall and flooding	First National Risk Register. Planning Act; Climate Change Act; National Risk Register; Civil Contingencies Act 2004 (Amendment of List of Responders) Order
2009	Heatwave with around 300 excess summer deaths	The Flood Risk Regulations; Flood Defence (Robertsbridge Works) Order
2010	2,500+ heat related deaths. Severe flooding in Cornwall. winter of 2010/11 had coldest December in the United Kingdom series dating back to 1910 (Christidis and Stott, 2021)	Flood and Water Management Act; Water Act (provides statutory definition of flooding); Flood Risk Management Functions Order; Flood Risk (Cross Border Areas) Regulations
2010–12	England and Wales drought. Driest 18 months for over 100 years. Two dry winters led to low groundwater level and reservoir stocks hit lowest records, requiring 7 water companies to impose temporary use bans in England. Ended in 2012 with wettest April to September for over 100 years	
2011	Exceptionally warm and dry spring	National Flood and Coastal Erosion Risk Management Strategy for England; The Incidental Flooding and Coastal Erosion (England) Order; The Thames Regional Flood Defence Committee (Amendment) Order
2012	Overall, 2012 was the wettest on record since 1910 (CEH 2012), except for 2000 (Met Office, 2013)	Health and Social Care Act; Public Health England was created and is main body managing heatwaves; National Drought Group; Head Office Drought Plan
2013	March 2013 was the coldest after 1962 in the national record dating back to 1910 and colder than the preceding winter months (according to the Met Office, National Climate Information Centre)	The Flood and Water Management Act (Commencement No. 2, Transitional and Savings Provisions) (England) Order; National Guidance on Risk Assessment; Resilience Capabilities Programme
2013/14	Wettest winter in the region since the beginning of the record in 1948. The period from December 2013 to February 2014 was the stormiest for at least 20 years according to the Met Office (Met Office 2014)	Flood risk maps for each river basin district
2014	The annual Central England temperature (CET) value for 2014 the highest in the 356-year series. At approximately 0.06 °C above the previous 2006 record, it cannot be entirely certain that 2014 was the warmest on record	Water Act; Heatwave Plan for England
2014/15	winter 2014/15 was the sunniest in the United Kingdom since 1930	

(Continued on following page)

TABLE 4 (*Continued*) Review of hazards and the legal framework (2000–2020).

Year	Hazards	United Kingdom general acts, statutory instruments, plans and programmes
2015	Dry early autumn, The United Kingdom provisionally set a record for the greatest 24 h rainfall recorded	National Security and Strategic Defence Review; The Flood Reinsurance (Scheme and Scheme Administrator Designation) Regulations 2015
2016	Strong winds and floodings from storm Angus; and exceptional warmth in September	Flood RE-Re-insurance Scheme (2039)
2017	In Britain the United Kingdom Met Office reported that Wednesday, June 21 was the hottest June day in more than 40 years when temperatures reached 34.5°C at Heathrow	Drought Response Framework for England; National Drought Group
2018	Cold spell in the country in early March 2018. Extremely cold conditions steered a massive Arctic airmass toward the British Isles at the end of February 2018, where it collided with winter storm Emma in the first days of March	The Environment Agency (Teggsnose Reservoir and Langley Bottoms Reservoir) Drought Order 2018
2019	A new highest ever maximum temperature of 38.7 °C was measured in Cambridge. (Met Office, 2019)	The Floods and Water (Amendment, *etc.*) (EU Exit) Regulations
2020	Storm Ciara, Dennis, and Jorge led to flood problems	Agriculture Act; Fisheries Act; Environment Bill

Drought Plan after droughts of 2010–12; and first Heatwave Plan for England in 2004 after the excess deaths of heat in 2003).

The most important legislation and governance mechanisms implemented to manage droughts include: "Water Act 2003", "Flood and Water Management Act 2010", "Water Use (Temporary Bans) Order 2010", "Head Office Drought Plan 2012", "Drought Response Framework for England 2017", drought plans for each of the six regions of the Environment Agency in England, and drought plans for all water companies (Environment Agency, 2012). Accordingly, water companies hold statutory obligation to develop such plans and manage water supply to customers to guarantee supply. DEFRA is responsible for policy and oversight by central government, while the Environment Agency has the duty to safeguard water sources and guarantee there is enough for everyone at reasonable costs and protecting the environment. Drought permits, rota cuts, standpipes and early actions by farmers are some of the key instruments to manage the risks related to severe drought periods. These only come into play when droughts become an emergency, with threats of restrictions to public water supply.

For heatwaves the main governance instruments are a Heatwave Plan and the system for heatwave alert. The plan has been in place since 2004 and is updated every year (Public Health England, 2020). In 2012, the heatwave plan changed significantly to reflect the changes in the healthcare system and align it with Cold Weather Plan and the Public Health Outcomes Framework (ibid.). The plan is primarily for health and social care services and other public agencies and professionals who interact with those most at risk from excessive heat, such as the elderly and people with different disabilities. Responsibilities are set for the DHSC, NHS, Met Office, and community health services. The key measures to manage the heatwave risks include mortality monitoring, defining critical infrastructure, awareness, preparedness, and the resilience capability programme. However, the social processes and structures which influence vulnerability in high temperatures is yet reflected in strategies and there is no longer-term preventive approach.

The United Kingdom legal framework informing multi-hazard risk assessment and governance of floods, droughts and heatwaves counts with many laws, plans, policies, regulations, and programme which were enacted after catastrophic events took place, as shown in Table 4. Consequently, the existing measures often emphasize response and recovery strategies, which are crucial for addressing the immediate impacts of disasters. However, they lack focus on addressing the root causes of vulnerability and promoting long-term resilience to climate hazards. For example, the plans that serve as main policy instrument to manage droughts and heatwaves are essentially response plans. The heatwave plan is criticized for falling short of social, environmental, and technical risk considerations (Abeling, 2017) and insufficient efforts beyond health sector (Brimicombe et al., 2021). The drought plans set the actions that should be carried out by the Environment Agency, water companies, DEFRA, and local councils when a drought occurs. However, it falls short of considerations of disruptions due to network failures, water quality incidents and dependencies across sectors (NIC, 2020). Estimated impacts of climate change calls for more preventative and proactive approaches to manage the cascading risks of hazards and promote equitable resilience (e.g., water transfer networks to prepare for future droughts; sustainable resource management; addressing drivers of vulnerability). Better understanding of the physical, economic, and environmental factors that increase the susceptibility of an individual, assets, and resources to the compounding impacts of hazard will be key to prevent and prepare the most vulnerable to climate change. Laws, plans, policies, and regulations that address risk reduction and adaptation proactively are also key, so that community preparedness, cross-sector collaboration, public awareness and integrated approaches to multi-disaster risk assessment and governance can be advanced.

The asymmetries and gaps in the governance of hazard and disaster risks, and lack of adaptation indicators challenge the understanding about sufficient funding, policies and planning being allocated towards the right actions to protect the most vulnerable. Consequently, environmental justice concerns are raised (e.g., distribution, recognition, participation, and capability). Low-income and vulnerable communities live in areas with higher exposure to climate hazards, such as flood-prone zones or urban heat islands and have fewer resources to adapt to or recover from extreme weather events. Areas that are prone to coastal and

TABLE 5 A combined framework for equitable resilience.

Elements of Equitable Resilience Ensor et al. (2019)	Indicator categories of resilience in social ecological and socio-ecological systems Bahadur et al. (2013)	Environmental justice dimensions Menton et al. (2020)
Recognise subjectivities, inclusion, and representation	Community involvement and inclusion of local knowledge	Procedural justice
	High diversity	All justice dimensions
	High degree of equity	All justice dimensions
	Social capital, values, and structures	Distributional justice
Working across scales	Effective governance institutions	Procedural and distributional justice
	Learning	Recognitional and capabilities justice
Transformative change	Non-equilibrium system dynamics	Distributional justice
	Preparedness and planning	All justice dimensions
	Acceptance of uncertainty and change	Capabilities

tidal flooding in the United Kingdom are over-represented by socially vulnerable neighbourhoods (Sayers et al., 2017). The authors also highlighted that socially deprived communities are at a higher risk of flooding due to a range of factors, including inadequate infrastructure, substandard housing, and limited access to resources and support. Similarly, in the case of floods, these communities may be more likely to live in lower-quality housing that is less resilient to water damage and may not have the financial means to recover from the impacts of flooding. During heatwaves, low-income households may lack access to adequate cooling systems or green spaces that can help mitigate heat stress. Droughts adversely affect agriculture and food production, resulting in higher food prices and potential food shortages. These factors can place an additional burden on already vulnerable communities, exacerbating existing inequalities and health disparities.

The SDGs (Menton et al., 2020), Sendai and CCA do not explicitly mainstream environmental justice within their targets and neither does the United Kingdom have targeted interventions to address the issues of environmental justice. However, distributive justice concerns are on the rise regarding the ways in which the burdens of disasters, the benefits of adaptation and responsibilities are allocated between different individuals and groups. Recognitional justice concerns are also growing due to risks to personal dignity of individuals and collective identities (ibid.) across different phases of risk management. Recognitional justice across all phases of risk management has the potential to ensure that perspectives, needs, and priorities of all communities, are adequately considered in the development and implementation of DR3 policies, strategies, and actions. The capabilities approach to justice concerns the distribution of goods and resources (ibid.) in ways that will support people to flourish based on the multi-dimensions of wellbeing. The latter is particularly relevant in the context of disaster risk management, where the distribution of resources and opportunities is crucial to helping communities build resilience and recover from disasters. Procedural justice concerns the institutional processes in which the unfair distribution of goods and burdens, lack of recognition and lack of capabilities are perpetuated through exclusion and inequitable participation in decision-making processes (Schlosberg and Collins, 2014). In the context of disasters, this can manifest in several ways, such as inadequate representation of vulnerable groups in emergency planning and response efforts, limited access to resources and support, and disparities in disaster recovery outcomes.

The four key elements to build equitable resilience are based on recognizing subjectivities, inclusion, and representation, working across scales, and promoting transformative change (Ensor et al., 2019). These four elements are closely connected to the categories of resilience in socio-ecological systems applied to climate, disaster, and development contexts developed by Bahadur et al. (2013). The latter indicators include absorptive capacity, adaptive capacity, transformative capacity, equity, and ecosystem services (ibid.). We recommend that equitable resilience metrics be developed for the United Kingdom, combining the four key elements identified by Ensor et al. (2019), with the 10 categories of resilience in socio-ecological systems, and the dimensions of environmental justice (Table 5). Risk reduction, risk management and resilience happen in the context of unequal power dynamics, complex resource trade-offs and shifting vulnerabilities stemming for diverse sources and with distinct impacts. Developing equitable resilience metrics will be key to promote resilience-building efforts that can engage with drivers of vulnerability.

Sectoral resilience to floods, droughts, and heatwaves

The United Kingdom's infrastructure faces risks from high temperatures, flooding, drought, coastal erosion (Climate Change Committee, 2021). Flood is considered the most impactful to energy, transport, water, waste, and digital communication, with the number of assets exposed to risks likely to double by 2080 (ibid.). Drought is the most impactful to water, food, and land, with major impacts on biodiversity, agriculture, and forestry. Heatwaves are the most impactful on crops, livestock, productivity loss (2010 heatwave reached a total of £770 million), building sector, transport infrastructure and disruption (ibid.). Some flood protection measures have been implemented by electricity supply, transmission, and distribution companies, reducing risks of interruption of supply, but for other disasters and non-primary

TABLE 6 Lead Government Department (LGD) with Responsibilities on Resilience per Sector.

LDGs	Sector
Department for Business, Energy and Industrial Strategy	Chemicals
Department for Business, Energy and Industrial Strategy	Civil Nuclear
Department for Digital, Culture, Media and Sport Department for Business, Energy and Industrial Strategy	Communications
Ministry of Defence	Defence
Department of Health and Social Care	Emergency Services
Department for Transport	
Home Office	
Department for Business, Energy and Industrial Strategy	Energy
HM Treasury	Finance
Department for Environment, Food and Rural Affairs	Food
Cabinet Office	Government
Department of Health and Social Care	Health
UK Space Agency	Space
Department for Transport	Transport
Department for Environment, Food and Rural Affairs	Water

Source: (Cabinet Office, 2020).

substations, gaps remain (DEFRA, 2020). For the Critical National Infrastructure (CNI), the Cabinet Office commissions Lead Government Departments (LDGs) (Table 6) to produce Sector Security Resilience Plans (SSRP) (Cabinet Office, 2019). These latter plans are prepared through consultations with infrastructure owners and operators, regulators, and government agencies (ibid.). They assess security and resilience considering the risks to each sector, including some activities necessary to mitigate and respond to these risks. However, the lack of understanding of infrastructure interdependencies and the potential for cascading climate risks underscores the need for greater clarity regarding the roles and responsibilities of both state and non-state actors (Environment Agency, 2022). DEFRA leads the Government department for climate adaptation in the United Kingdom, while the Cabinet Office is responsible for overseeing the resilience of Critical National Infrastructure (CNI) and LGDs for each of the 13 CNI sectors (Joint Committee on the National Security Strategy, 2022) (Table 6). Under the support of the Cabinet Office, the LDGs are tasked with resourcing and overseeing the preparedness levels to the potential consequences of each risk in the National Security Risk Assessment (ibid.). Relevant departments also produce National Policy Statements for England and relevant reserved matters, to guide significant infrastructure project decisions (e.g., on ports and waste water), including adaptation requirements (ibid.). Consequently, there are issues involving the allocation of responsibilities for CNI resilience and climate adaptation across Government (ibid.).

The elements of infrastructure considered critical across the sectors are assets, facilities, systems, networks or processes and the essential workers, so any losses involving them have major detrimental impact on accessibility, security, and affordability of essential services (PHE, 2017). Higher storm wind may greatly impact power lines, data cables, offshore structures and wind turbines. The National Infrastructure Commission (NIC) has identified six key aspects of resilience: anticipate, resist, absorb, recover, adapt, and transform (NIC, 2020). The latter is in line with concept of resilience as an ability to "bounce back" after adversity. However, more broadly, the "bounce back" approach adopted within the United Kingdom's civil emergency framework entails risks of perpetuating inequalities and vulnerabilities that feed future disasters (Deeming, 2017). The focus on rapid recovery and restoration of normalcy after a disaster can result in the neglect of vulnerable groups and their needs. This can lead to further marginalization and social exclusion, exacerbating existing inequalities and increasing the risk of future disasters. An example of this can be seen in the United Kingdom's response to the 2015 floods, where the focus was primarily on repairing damaged infrastructure and restoring, without sufficient consideration for the needs of vulnerable groups (ibid.). As a result, some communities were left without access to necessities like food, water, and shelter for extended periods of time, and were more likely to experience long-term negative impacts from the disaster.

The NIC provides expert advice on infrastructure challenges involving energy, transport, water and wastewater, waste, flood and risk management and digital communications, including on framework under development for resilience standards. Land, agriculture, schools, and hospitals are out of the scope of the NIC's expert work, which does not support the critical links between these and those that are part of NIC's work (e.g., energy and water). The NIC recommends the implementation of a

framework for resilience, protecting everywhere equally, but providing a higher standard in urban areas due to services being overwhelmed when compared to rural areas (ibid.). Regulators should be responsible for setting out the initial plans for stress test, as well as the costs and benefits of different resilience standards, dependencies with standards and other sectors, and the range of shocks and stresses that infrastructure services should be resilient to (NIC, 2020). Government should partner with critical infrastructure operators from the public and the private sectors to agree on a common resilience vision for critical infrastructure nationwide and on shared and achievable resilience objectives (ibid.). Questions remain about how the measures and standards will help deliver on cross-sectoral resilience and equity aspects. The latter are hard to answer without data on vulnerability of infrastructure to extreme weather, limited engagement with suppliers on climate change, little assurance for key supply chains and business opportunities from climate change adaptation that are not well reflected in national plans or strategies (Foulkes et al., 2017).

The United Kingdom's National Adaptation Plan sets out the perspectives on resilience of core sectors. One of the main requirements is for all infrastructure projects to leave the environment in a measurable better state than found (UK NAP). For business, there is a lack of indicators that support understanding of effectiveness of adaptation over time and today most of them are self-reported, which may not be representative for different sizes or sectors (ibid.). The lack of data on interdependent risks and resilience actions by infrastructure providers makes it hard to assess whether actions by operators are really reducing risk towards the cascading failures caused by climate-related disruptions. The latter is aggravated by lack of data on how climate risks are being considered in the design and selection of places for new infrastructure as early as early as possible and through the whole life cycle of the asset. When it comes to ports and airports, resilience standards are left to individual operations, with very limited data to assess the frequency of interruptions due to extreme weather events and actions taken to lower those risks. There remains a lack of data to assess the vulnerability of local roads to specific climate risks and to assess progress in managing the impact of climate risks on local roads. In May 2020, the Government announced a £1.7 billion Transport Infrastructure Investment Fund for local roads and motorways (and railways). It is not yet clear what proportion of this additional funding will go towards reactive repair and what resources will be allocated to adaptation and increasing climate resilience. The rail sector remains at increasing risk of river and surface waterflooding under a continuation of planned adaptation action, and increased heat risk causing rails to buckle, overhead cables to sag and signals to fail.

Discussion and conclusion

Risk assessment is a developed area in the United Kingdom. However, at national level, long term adaptation plans and risk assessment (Climate Change Risk Assessments) and shorter term ones like the National Risk Assessment (NRA) are not aligned. Across scales, national and local assessments face discrepancies and a full picture of local risks is not clear. LRFs play a crucial role in developing local risk assessment but are currently underfunded and facing issues to oversee local climate risks. The overall lack of participation of local communities in risk assessment procedures is problematic and raises issues of trust. People's trust affects their response to instructions during emergencies (Dhellemmes et al., 2021). These shortcomings will increasingly impact the United Kingdom's adaptation to climate change and capacity to develop robust evacuation and shelter planning. These plans need to account for the specific risks faced by local communities and the complexities involved in assessing people's reactions to evacuation orders (ibid.). Considering that evacuation and shelter planning in the United Kingdom is based on local risk assessments, the National Resilience Planning Assumptions, and the National Risk Assessment, the identified discrepancies and likely impacts this bring to evacuation plans represent a gap within the broader emergency planning and preparedness in the United Kingdom, which can aggravate climate injustices. Effective evacuation at local level is crucial for vulnerable populations, who due to factors such as age, reduced cognitive functions, mobility, and declining vision, are disproportionately affected by disasters (Abioye et al., 2020). Unfortunately, these groups have also been identified as the most difficult to evacuate (ibid.) and effective allocation of evacuees among emergency shelters is a challenge, compounded by limited capacity and the specific needs of certain groups (e.g., individuals with disabilities, who require placement in special-needs shelters) (Dulebenets et al., 2019b). There are growing concerns in the United Kingdom about the capacity and accessibility of emergency shelters, particularly for vulnerable populations such as individuals with disabilities or the elderly.

Legislation, planning, policies, regulations, tools, governance instruments, collaborations and partnerships exist to support the United Kingdom to prepare and respond to multi-disaster risks and develop its evolving frameworks to implement and monitor the targets of the three global frameworks–SDGs, CCA and SF. However, the United Kingdom faces an adaptation deficit, which compromise targets of risk reduction and resilience across all three agendas and environmental justice. Comparing to heatwaves and droughts, floods count with most developed legal framework and highest allocation of resources. The latter has a dedicated legislation (Flood and Water Management Act, 2010), specific policy (Flood and Coastal Erosion Risk Management Policy, 2020), and strategies developed by local resilience forums, as well as a plethora of actors with distinct responsibilities to help mitigate flood risks. Flooding is the only disaster of the three that is explicitly reflected in the adaptation plans and counts with a growing budget for prevention and preparedness. Between 2021 and 2027, the government has allocated the highest amount to manage floods risks (£5.2bn), with an additional 336,000 properties being safeguarded, and twenty-five local areas able to advance their actions and plans against flood and coastal erosion risks (ibid.). Flood insurance schemes, flood defense and regional flood defense committees serve well the purpose of prevention and preparedness to risks. By 2024, a new national assessment of flood risk will compose the reforms to the United Kingdom's planning system, aimed at safeguarding that future flood risks are considered in decision-making, including through policies and mechanisms that can ensure that effectively (DEFRA, 2022). For the protection against coastal flooding and coastal erosion, an additional £1 million is allocated for the work conducted between Environment Agency and coastal authorities updating the Shoreline Management Plans that will set the priority areas of action and funds for

adaptation. A roadmap to accelerate the uptake of property flood resilience is also being developed together with several changes to the Flood RE Scheme, so that additional funds (above the cost of a claim) are available to flooded properties above the cost of a claim (CCRA, 2022). There is also a strong commitment to develop national set of indicators to monitor trends and understand impacts of flood and coastal erosion risk management policies, with aim to safeguard that communities can build resilience (ibid.).

Heatwaves count with a heatwave plan as the main national policy instrument for managing the risks of extreme heat. A drought Plan is one of the key national policy instruments for managing drought risks. Both plans are essentially an emergency response plan. More preventative approaches that can improve community resilience to risks of droughts and heatwaves will need to consider the factors that can influence an individual's vulnerability to the risks of each type of disaster. For heatwaves, quality of housing and built environment, local urban geography, lifestyle, income, employment, tenure, social networks, and self-perception of risk can influence the level of exposure and sensitivity to extreme heat and capacity to anticipate, prevent, prepare, respond, and recover. For droughts, actions to help lessen impacts includes building a water transfer network, plans to deliver additional supply and reduce demand in case of serious or prolonged droughts, reduce network failures, water quality incidents, and assess dependencies across sectors. Many risks are ignored for warmer scenarios, which are aggravated in the context of missing indicators and lack of specific laws, regulations, policies, instruments, and institutions relevant to heatwave and its impacts beyond health. Altogether, it compromises equitable risk reduction and resilience to all three disasters in the United Kingdom. There are important governance mechanisms, lessons and best practices developed to manage flood risks, which are replicable to enhance the management of the other two types of disasters beyond plans. For example, advanced flood maps that inform planning and land-use, strategy for local flood authorities to manage local risks, asset recovery and business continuity through affordable national insurance, public-private flood reinsurance schemes and analysis of impacts of disasters that translate into lessons learned replicable.

In terms of its Critical National Infrastructure better indicators, analytical tools and cross-sectoral approaches are needed that enable the assessment of vulnerability of infrastructure and impacts from disruption due to extreme weather.

The United Kingdom can expect to face warmer and wetter winters, hotter and drier summers, and rising sea levels, according to the independent Climate Change Committee looking forward to 2050. Allocating resources to adaptation and increasing climate resilience instead of following a reactive repair is necessary. Despite progress made with key sectors conducting individual risk assessments, adaptation gaps are identified across all of them. The current regulatory model for Critical National Infrastructure in the United Kingdom is based on a vertical structure, where each sector is regulated and operated separately, which mirrors the departmental oversight system, contributing to fragmented approaches to climate adaptation (Climate Change Committee, 2021; Joint Committee on the National Security Strategy, 2022). As a result, formal connections between sectors are lacking, creating gaps in preparedness and response to climate risks. This will further increase inequalities and result in long-term consequences for social and economic wellbeing. To enhance collaboration on interdependencies and improve oversight of adaptation and resilience, various mechanisms have been proposed, such as creating a statutory forum for CNI regulators, setting clear resilience standards for CNI operators, and implementing a stress testing program against extreme weather and climate change effects. Infrastructure needs urgent adapted to cope with the potential rapid effects of climate change, presenting a significant challenge for the government, operators, and regulators when it comes to all three disasters we focused on: floods, droughts and heatwaves.

Limitations of study and future research

The National Risk Register has many listed risks, but we focus on floods, droughts and heatwaves and leave many other climate related hazard risks out of the in-depth review and analysis. Consequently, limiting the insights and understanding of gaps in relation other types of hazards (e.g., extreme cold temperatures). Considering that approximately 75 local authorities (one-fifth of the country) have 50% of their population living in flood-prone areas (Sayers *et* al, 2017), further analysis of preparedness and climate adaptation with focus on local level represents another limitation of this study. We recommend that future research focuses on the preparedness of local authorities, considering the barriers they face to manage the risk of hazards and disasters at local level (e.g., underfunded LRFs). Other areas for future research, with a focus on the United Kingdom include.

- Climate change adaptation of national infrastructure.
- Cross-sectoral resilience and preparedness considering cascading impacts of climate related hazards on critically interlinked sectors (e.g., energy and water).
- Development of equitable resilience metrics for the United Kingdom.
- Improving analytical tools and methods for risk assessment across scales and distinct timeframes.
- Public education campaigns on disaster risk reduction and climate change adaptation.
- Public engagement and acceptance of adaptation measures and resilience standards for critical national infrastructure, given consumers will bear costs of high levels of investment to advance these.
- Assessment of existing emergency evacuation plans and their limitations in protecting areas with vulnerable population when multiple infrastructure assets and sectors are affected by hazards.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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