# Infrastructure Resilience under a Changing Climate

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# Infrastructure Resilience under a Changing Climate; the urgent need for engineers to act

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## ABSTRACT

Extreme weather events are increasing in frequency and intensity, as are associated hazards such as floods, wildfires and overheating. Long-term sea level rise could have devastating impacts on coastal communities. In the last 20 years there has been steady progress in embedding climate adaptation within engineering practice, but the climate is changing more rapidly than the engineering sector is responding. This short piece outlines the challenges and progress in adapting to climate change, and the tools available for engineers to act, now, to enable infrastructure resilience within our rapidly changing climate. Engineers can use sector guidance and international (ISO) and British Standards to plan, design, refurbish, maintain and operate infrastructure under a changing climate. There are tools to build organisational capacity, so that key decision makers are aware of the need to address climate change and have the leadership to access expertise and implement change. The ICE and our fellow engineering institutions must promote climate awareness and capacity building both for students in higher education and at a strategic level within their membership.

## Introduction

Our climate is changing, and extreme weather events such as heatwaves and heavy rainfall are becoming more frequent. Sea levels are also rising (IPCC, 2023). These changes are leading to more flooding, wildfires, and greater overheating, with greater damage and cost burden (Kron et al., 2019), and with new extremes being experienced within the UK, and globally (Kendon et al., 2023; Kahraman et al., 2021). Indeed, the climate crisis is the biggest challenge that modern society faces, and our changing climate represents an existential threat for many communities, globally.

For engineers, there has never been a more exciting or meaningful time to use our ingenuity to develop solutions to tackle the climate crisis. This includes developing new materials, methods and technologies to reduce carbon emissions and align with Net Zero ambitions (Stark et al., 2019), incorporating the natural environment in engineering design and development to address biodiversity decline (Engineers Ireland, 2021), and ensuring that our infrastructure systems our resilient to a changing climate, as per this Special Edition. Society depends upon engineered infrastructure to function – think of public services, administration and government, education; also supply chains, food, manufacturing, goods. All depend upon infrastructure services – transport, energy, water, waste, and information communications technology (ICT), and the engineering profession is key to making infrastructure and thereby society resilient to the future climate through a process of adaptation.

Engineers have the knowledge and tools to plan, design, build, and maintain the infrastructure that supports modern society. It is essential that we, as engineers, incorporate weather resilience and climate adaptation into our daily work, be it the planning, design, refurbishment, maintenance or operation of infrastructure systems. This short piece outlines the challenges and progress in adapting to climate change, and the tools available for engineers to act, now, to enable infrastructure resilience within our rapidly changing climate.

## Rapidly changing climate

Our climate is changing more rapidly that climate scientists dared fear. Globally, 2023 is provisionally the warmest year since records began, with record sea surface temperatures, sea level rise, and the lowest recorded Antarctic Sea ice extent (Met Office, 2024; WMO, 2023). This is partly driven by the El Niño warming event, but warmer global temperatures are part of a long-term trend and 2023 will be the tenth consecutive year where global temperature has been at least 1°C warmer than pre-industrial times (Met Office, 2024). All regions of the world have experienced extreme weather in 2023; in Southern Europe and North Africa, the rainfall associated with “Medicane” Daniel (Mediterranean Hurricane) led to flash floods, particularly in Libya where over 4,000 people were killed in the port city of Derna when two dams collapsed following extreme rainfall. In Mozambique, Malawi and Madagascar, Tropical Cyclone Freddy was an exceptionally long-lasting (5 weeks) storm that repeatedly brought heavy rainfall and floods. There have been heatwaves in the USA and Southern Europe, notable wildfires in Canada and Hawaii, and heavy rainfall, floods and landslides in many countries including Brazil, South Korea, Malaysia, Myanmar, and more.

There is also increasing concern around the possibility of exceeding “tipping points”. These are thresholds that once passed will lead to dangerous or runaway climate effects. Tipping points that may be passed when the world exceeds 1.5°C warming include: the collapse of the Greenland ice sheet, collapse of the West Antarctic ice sheet, thawing of permafrost and coral reef die-off (Armstrong et al., 2022). Ice sheet collapse will cause sea level rises with consequences for coastal communities and infrastructure. Thawing of permafrost will release methane into the atmosphere; the global warming potential of methane is approximately 80 times that of carbon dioxide during the 20 years after it is released into the atmosphere. These tipping points, and others that occur at higher global temperature thresholds such as; Amazon rainforest dieback, collapse of the Atlantic Meridional Overturning Circulation or Artic Winter Sea ice collapse, can be avoided if we reduce carbon emissions and limit global warming to 1.5°C above pre-industrial times (IPCC, 2018). However, projections by Climate Action Tracker indicate a likely warming of 2.7°C by 2100 based on current policies and actions (Figure 1; Climate Action Tracker, 2023). Accordingly, it is imperative that we reduce carbon emissions to reduce the impact of dangerous climate change. Equally, current extreme weather events and our global warming trajectory shows that we must embed climate adaptation within ‘business as usual’ if we are to have climate resilient infrastructure, now and in the future.

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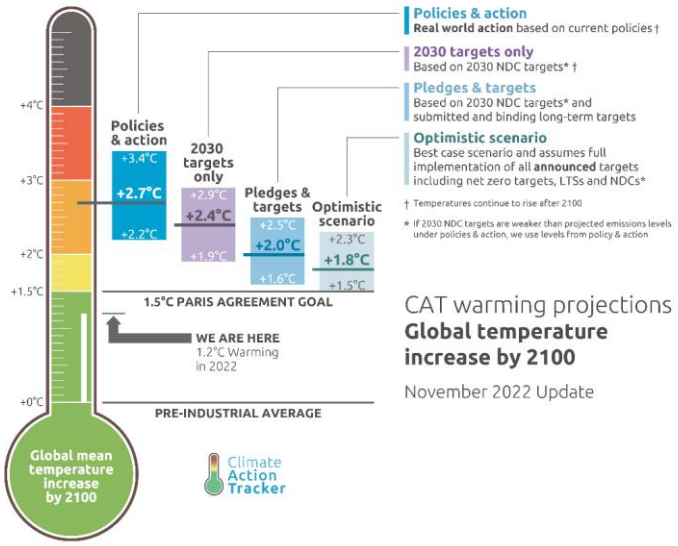


**Figure 1: Climate Action Tracker (2022). The CAT Thermometer. November 2022. Available at: https://climateactiontracker.org/global/cat-thermometer/ Copyright © 2022 by Climate Analytics and NewClimate Institute. All rights reserved**

## Progress steady but too slow

Having worked in rail and flood risk management for over forty years, including climate risk since the early 2000s (Dora), and in climate and infrastructure resilience research since the late 2000s (Ferranti), we have lived through the developing climate science and policy response with regards to climate adaptation. This includes the series of IPCC reports detailing the *Physical Science Basis of Climate Change*, and *Climate Change Impacts, Adaptation and Vulnerability,* and special reports such as that on the *Impacts of global warming of 1.5°C above pre-industrial levels* (IPCC, 2018). This also covered the period from the first UK wide projections of our changing climate issued by UK Climate Impact Programme 2002 (UKCP02) and updated to UK Climate Projections in 2009 (UKCP09), and in 2018 (UKCP18).

There has been the 2008 Climate Change Act, that mandates a Climate Change Risk Assessment every five years, the most recent in 2022. The Act additionally allows Defra to ask certain organisations - including infrastructure owners and operators - via the Adaptation Reporting Power (ARP) to explain the current and future impacts of climate change on their organisation, and how they plan to adapt.

There has also been operator led research and adaptation actions such as the *Tomorrow's Railway and Climate Change Adaptation* (TRaCCA) research project (Available via Climate Adapt (2023)) that influenced Weather Resilience and Climate Change Adaptation plans produced at route level by Network Rail in 2014 and 2019 (Network Rail, 2023). The water sector was an early leader in climate adaptation, undertaking essential research, switching to partnership working to manage water resources and incorporating climate projections in business planning (Crossfield &

Ferranti, <submitted>). However, the speed of adaptation has not kept up with the speed of our rapidly changing climate, and there is a large adaptation gap. The 2023 *Progress in adapting to climate change* report produced by the Climate Change Committee notes that there is insufficient adaptation to prepare for the climate risks within UK cities, communities, infrastructure, economy, and ecosystems (CCC, 2023). Historically, climate action and funding resource has focused on mitigation and it took until COP26, held in Glasgow in 2021, for resilience to be given a permanent home at The Resilience Hub. Both authors contributed to a range of events at the Hub helping to shape the international narrative on adaptation and resilience (Resilience Rising, 2023). The Resilience Hub continued at COP27 and COP28, driving conversations on co-created and locally informed, equitable options for climate resilience.

## Tools to support adaptation and build resilience

There are abundant resources for engineers to adapt to climate change, including ISO standards, British standards and guidance documents produced by professional institutions. Organisations like PIANC – the international trade body for ports and waterborne transport, PIARC – the World Road Association, and UIC – the International Union on Railways have all drafted guidelines on climate resilience and adaptation, that consider the impact of extreme weather events and longer-term slow onset phenomena such as rising sea levels (PIANC, 2023; PIARC, 2023; UIC, 2017). Within the UK, the electricity sector has guidelines on flood proofing substations (ENA, 2018).

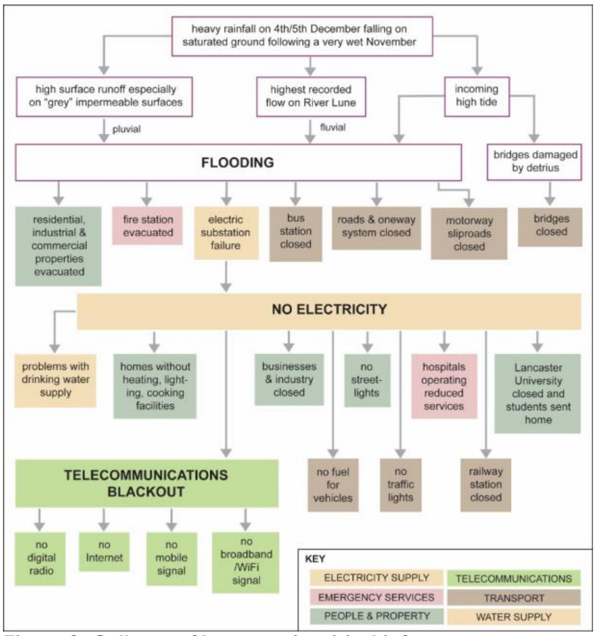


**Figure 2: Collapse of Lancaster's critical infrastructure systems following a loss of energy supply due to substation flooding in 2015. Image authors own – full article in Weather Magazine (Ferranti et al., 2017).**

In addition to these sector-specific documents, there is also ISO 14090:2019, the first international standard on adaptation to climate change. This standard supports a systems-thinking approach to adaptation, that considers not just the individual sector, but sector interdependencies and other interacting risks. Our infrastructure is interconnected, and most infrastructure networks require energy supply and ICT to operate efficiently. Figure 2 shows how the loss of energy supply following substation flooding in Lancaster in 2015 impacted all critical infrastructure networks within the city (Ferranti et al., 2017). Other wider resilience considerations include the infrastructure supply chain, for example understanding the climate risks at different stages of freight transfer for the port sector or when an infrastructure asset has failed, can the engineers access the infrastructure by road to undertake repairs? ISO14090:2019 provides a framework that allows a systems-of-systems approach to infrastructure resilience. It also considers leadership, governance, resources, impacts and risk, adaptation planning, implementation, monitoring and evaluation as well as reporting. Sections on adaptation approaches and economics offer useful guidance to experienced practitioners and those new to the topic.

Many decision-makers put off decisions because of uncertainty in climate projections or through a lack of understanding of the impacts and consequences of changes in climate on assets or asset components. British Standard BS 8631:2021 (BSI, 2021) allows for uncertainty by adopting an adaptation pathways approach. This approach considers adaptation not at a fixed point in time, but rather along the lifetime of the asset. It allows multiple adaptation options to be considered for different socio-economic and climate factors, and stages and prioritises adaptation decisions at different points along the pathway. By doing this, an engineer can design and build with relative certainty for, say, a thirty-year period. In thirty years, alternative future solutions – pathways – can be devised and analysed now, with final decisions left until nearer the decision point. This approach has the advantages of a) minimising long-term investment risk; b) ensuring current or future works do not compromise longer-term needs; and c) avoiding maladaptation. The adaptation pathways approach ostensibly puts the 'design life' approach to one side, at least when designing for climate impacts. The traditional 'alternative' is to design and construct infrastructure assets for the full design life (120 years for bridges, for example) with the associated uncertainty in climate projections over that time period, driving costs up at the initial construction stage. This is because designers account for the climate conditions prevailing at the *end* of the design life period, with all the uncertainty that that entails.

Lastly, it is important to note that design codes are only as good as their users. For example, the Structural Eurocodes EN199x series is the primary set of design specifications engineers are accustomed to using. These are key tools in the resilient design of infrastructure and are being modified to address futureproof climate design for wind, thermal and snow loadings. However, many – if not most – current infrastructure-related standards like the original Structural Eurocodes are anchored in past climate/ weather parameters. A 2023 exercise for the European Commission identified some 4000 EN critical infrastructure energy and transport standards that might need modifying to take account of the future climate. Engineers must consider whether design parameters are relevant for current and future extreme weather events, and challenge outdated design parameters. One way of upskilling in this area of design is to review standards using either ISO Guide 84:2020 *Guide to addressing climate change in standards* (BSI, 2020) or the CEN/ CENELEC *Tailored Guidance on how to include Adaptation to Climate Change in European infrastructure standards* documents (CENELEC, 2022); these offer processes to include adaptation in standards.

## Capacity building

The Paris Agreement (UN, 2015) came into force in 2016 and it established goals in its Article 7 on *"enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal".* What does this mean for engineers? Looking again at ISO14090:2019, adaptive capacity is referred to and is defined as the "*ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences".* The standard has a whole section on assessing adaptive capacity. This assessment needs to be performed across financial, human and technical resources as well as on organisational capabilities. Importantly, the focus on organisational capabilities is on *decision-making* and key decision makers have to be aware of the need to address climate change.  Leadership has to ensure the organisation is able to access expertise on climate change adaptation. Organisations are required to list and address gaps in existing adaptive capacity and how it needs to perform effective adaptation.

Fortunately, there are tools available that permit adaptive capacity diagnosis and development such as CaDD (CaDD, 2023). Capacity assessment 'snapshots' across an organisation can identify gaps in leadership, resourcing, governance and maturity using the CaDD automated survey tool.  The reports generated offer steps on how to improve adaptive capacity at an organisational or project level. The CaDD tool is one of the few tools that bring metrics into the adaptation equation, scoring maturity across nine themes in a reproduceable and repeatable way.

For engineers, we are well placed to help society build adaptive capacity both in the organisational sense and in the engineering sense. We can help make the case for long-term adaptation that leads to a resilient future state. We can promote resilience-building schemes that reduce risks through physical means – nature-based flood resilience solutions, for example, building designs that are thermally efficient or tall structures that have passive provision for potential future modifications to address uncertainties in, say, wind speeds. All these, however, need the ability of decision-makers to understand and react positively. This means, in turn, that decision-makers need to have the business case presented to them in a compelling way. This can be challenging – complex problems need robust, comprehensive analyses. Traditional economics can get in the way of sensible decisions and ISO14090:2019 advocates, among others, techniques such as multi-criteria analyses – techniques that look more holistically at the issue at hand, not simply using 'rate of return' or 'payback period'.

## Role of ICE and other professional institutions

Our climate is changing more rapidly than engineers are responding. There are sufficient tools to adapt our infrastructure and enable climate resilience. However, we need to mobilise this knowledge through the sector, rapidly, to ensure that all engineers understand the challenges of our changing climate, and their role in planning, designing, building and maintaining climate resilient infrastructure (Axelithioti et al., 2023). This knowledge mobilisation starts with schools and includes higher education and Continuing Professional Development.

The ICE and our fellow engineering institutions must promote climate awareness and capacity building both for students and at a strategic level within their membership. This means we need to support universities and colleges actively to review the taught material they use, along with action to support the profession more generally. Although the Joint Board of Moderators (who accredit civil engineering degrees) state that, "*A positioning of the Climate Emergency, with all the associated issues, [is] central to the educational culture present throughout a civil engineering degree programme"* (JBM, 2021), this does not explicitly mention climate adaptation and resilience, and is open to broad interpretation. Future engineers must understand the impact of a changing climate on infrastructure assets, and concepts such as adaptation pathways. Drainage engineers must be able to design with Sustainable Urban Drainage Systems (SuDS) that will soon be mandated on new developments. The ICE must also equip our members to influence other key decision-makers; those that are involved in planning, designing, building, and maintaining infrastructure. Decision-makers have to be aware of the long-term consequences of their decisions, and to build sustainability and resilience into infrastructure systems so that society and its needs can be served reliably.

These actions would result in three things: firstly an increased capacity to understand the rapidity of climate change and the urgency of adapting to a new, changing state; secondly, the rapid rollout of knowledge, ideas and tools to address vulnerabilities; and thirdly, a common view across engineers from those early in their careers, to the senior decision-makers and 'influencers' who can support this drive in a coordinated, integrated way. There has never been a more exciting or meaningful time to be an engineer, and the ICE and other professional institutions have a role to ensure that the sector is cognisant of all aspects of climate change so that engineers can use their ingenuity to develop solutions to tackle the climate crisis.

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