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ON INFRASTRUCTURE

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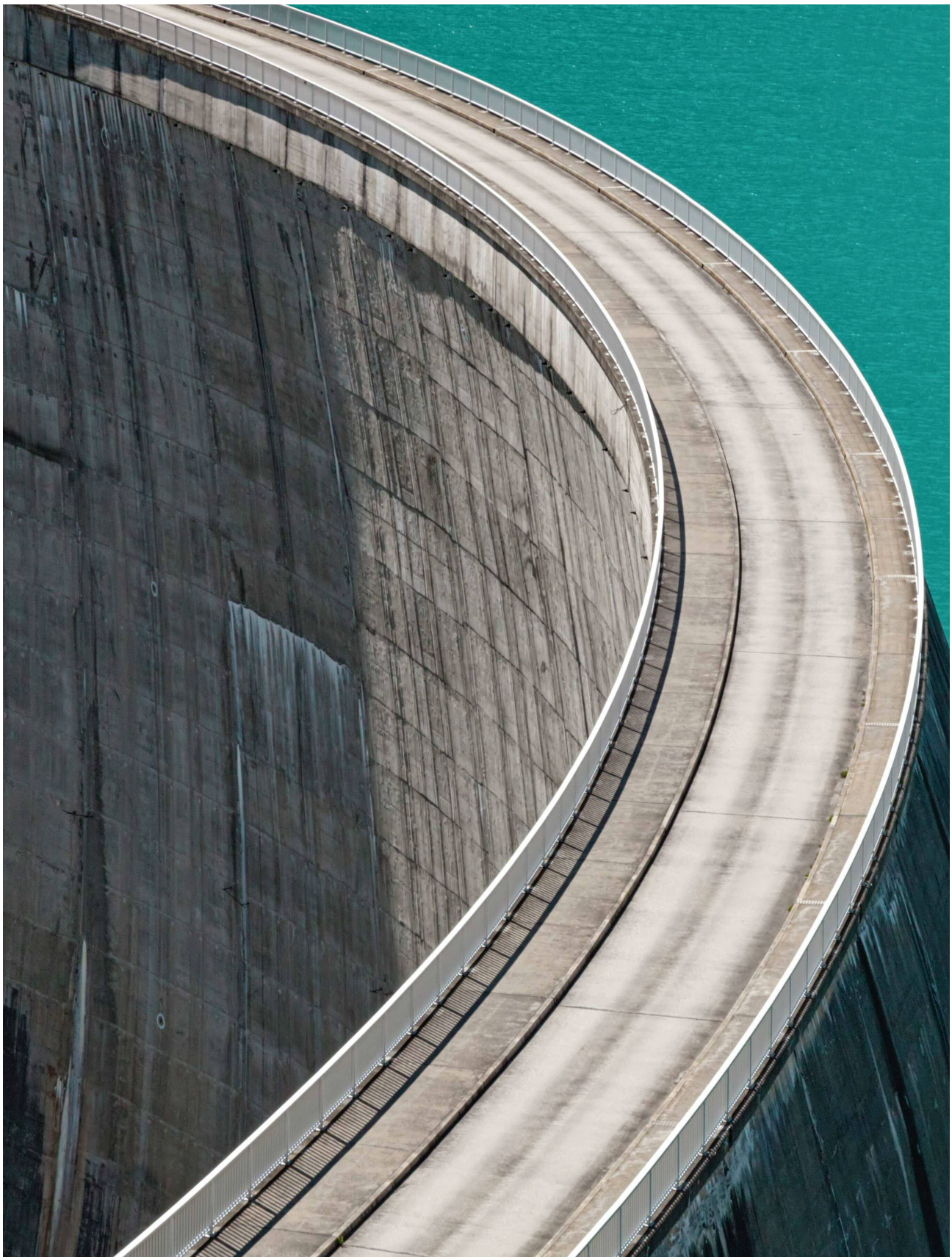
On Infrastructure



Foreword

Dr Janet Young CBE

Director General, Institution of Civil Engineers

Throughout human history, engineering has been synonymous with innovation. This hasn't changed, but the scale and complexity of engineering challenges have.

Modern infrastructure services – the energy, transportation, communication, and water networks upon which people depend – must serve growing populations, contribute to growing economies, and respond to the growing threats of climate change and biodiversity loss.

The pace and scale of change present enormous challenges. Our infrastructure is under the kind of pressure it's never faced before. To deal with competing social, economic, and environmental demands, infrastructure will need to be smarter, greener, and more resilient.

We cannot just be reactive to changing trends and new challenges. We must be proactive. The development decisions governments make today will affect generations to come. The physical structures engineers design and deliver need to last for decades – ideally centuries. And that means their footprint, the patterns they form, and the behaviours they create will last just as long.

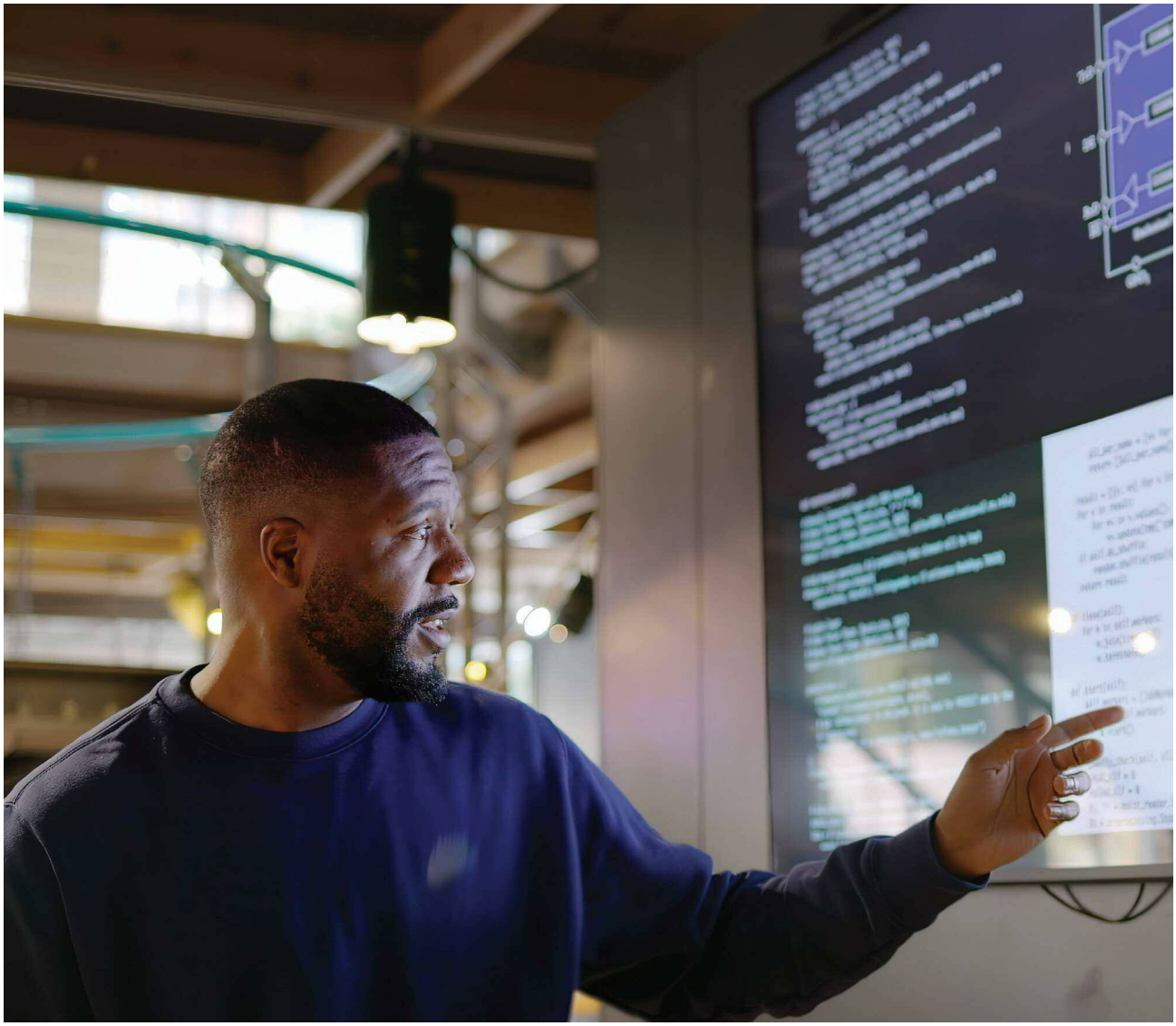
Resilience and sustainability are separate concepts, but they go hand in hand. Resilient assets thrive in the face of change. Sustainable assets continue to provide for future generations without a decline in quality. At the Institution of Civil Engineers (ICE), sustainability has been at the heart of our mission for many years.

Infrastructure has enormous power to improve people's lives. The ICE's mission is to enable that transformation by giving the world the engineering capacity and infrastructure systems it needs to thrive. Our strategy recognises that we can best achieve this by supporting the delivery of the UN Sustainable Development Goals.

Providing the infrastructure that societies need also requires strategic planning and prioritisation frameworks that deliver the right projects, on time, and on budget.

Providing the infrastructure that societies need also requires strategic planning and prioritisation frameworks that deliver the right projects, on time, and on budget. The ICE-led Enabling Better Infrastructure programme focuses on upstream strategic infrastructure planning. It helps decision-makers prioritise, fund, and strategically deliver a clear national vision with pace and certainty.

A confident delivery environment also creates the best conditions for innovation. Innovation can often be uncertain. It relies on investing in new industries, using new methodologies, adopting unproven technologies.



Societies rely on infrastructure systems that are remarkably complex.

Societies rely on infrastructure systems that are remarkably complex. People's needs are becoming more complex in turn, and building and maintaining these systems is increasingly challenging. So, embracing innovation and technological advancements is absolutely crucial to success.

The future will continue to see spectacular innovation in our field. The research led by Policy@Manchester and the articles included in 'On Infrastructure' are vital in driving that progress. They help provide policymakers and engineers with the knowledge and expertise they need to design and deliver resilient, sustainable, thriving communities.

Just as important as the technology, research, and development of new tools and approaches is how we work together to use them. Nobody – civil servants, practitioners, academics, consultants, contractors – can answer today's challenges alone. Only through collaboration can we develop the engineering solutions needed to help society prosper.

Getting around: digital platforms and public transport systems

Professor Michael Hodson, Professor Andrew McMeekin and Dr Andrew Lockhart

Over the last 15 years, digital mobility platforms for ride hailing like Uber, bike sharing like Beryl, e-scooter rental like Lime and journey planning apps like Citymapper have become common in urban societies. They are often seen as 'disrupting' the organisation of existing public transport systems and creating competition. Yet these platforms can be strategically incorporated into existing systems by public authorities aiming to address public policy priorities and improve systems. They also address sustainability challenges, especially in accelerating the shift away from personal car use.

Passenger transport authorities in metropolitan areas need to assume strategic control over platformised city-regional transport systems to deliver on public policy goals. To do so, they need properly devolved powers and the opportunity to steer the development of a platformised city-regional transport system - which entails strategy development across transport services and their supporting infrastructure.

The remaking of metropolitan public transport systems

City-regions globally face a variety of sustainability challenges. These include improving the quality of life of their residents by addressing carbon emissions and poor air quality, while also achieving long-term economic growth. In this context, how to organise the transport infrastructure supporting the movement of people and goods into, around, and out of metropolitan areas, has become a pressing concern.

Responding to this challenge, digital mobility technology has become widespread, offering a variety of ways of moving around urban areas and multiple new mobility services, including mapping and system-wide mobility-as-a-service platforms.

Established bus, tram and rail transport operators have also incorporated digital technologies into their provision. These services are usually accessed by users and passengers on their mobile phones or devices.

Platformised city-regional public transport in England – development and future

The digitalisation of existing metropolitan transport systems is shaped by social interests as well as by technology. As part of our research into how digital platforms are reshaping urban mobility systems, sociotechnical analysis has demonstrated three ways of platformising existing metropolitan public transport systems.

Firstly, in the years following the Global Financial Crisis of 2008 and fuelled by venture capital, privately owned ride-hailing and micro-mobility platforms sought to 'land' their services in urban areas.

These services sought to expand their area of operation by building networks of users. The operation of digital mobility platforms, as conventionally understood, saw asset-light private companies offer 'new' mobility services, which relied on the repurposing of existing assets in tandem with the use of platform technologies.

The variety and volatility of platforms poses problems for how they are coordinated and integrated with existing public transport systems.

Cities and urban contexts became primary sites in which dozens of such platforms operated. Yet, many of these have been fleeting in their presence, as was demonstrated by Mobike's bike-sharing service in Greater Manchester. The variety and volatility of platforms poses problems for how they are coordinated and integrated with existing public transport systems.

Secondly, partly as a response to the problem of coordination and integration, private companies, such as MaaS Global, Citymapper, Moovit, Uber and Google have experimented with attempts to use technology to build new mobility service systems. Controlled by private, profit-seeking platform companies, these systems seek to integrate existing public and private transport services. This means that control of the system shifts towards the company and away from public transport authorities.

Thirdly, in recent years, public transport authorities have recognised that they need to take a more strategic approach to controlling public transport. They must explore how digital technology can re-make metropolitan transport systems. In order to meet sustainability challenges and other public priorities, metropolitan transport authorities are experimenting with how platformisation can support public transport provision at city-regional scale and allow them to gain greater control over the operation of public transport systems. This development is most advanced in the West Midlands, with a publicly funded, publicly controlled Mobility as a Service (MaaS) initiative, due to launch in 2024.

Towards strategic city-regional platformisation

Digital systems and existing transport systems can be organised in different ways but policymakers and public bodies must navigate the tension between contributing to public policy goals and creating new markets and commercial opportunities for private platform providers.

Given this dilemma, there is a need for bodies such as the UK Department for Transport (DfT) to develop a clear position in response. This is particularly important given the multi-billion-pound allocations, through City Region Sustainable Transport Settlements (CRSTS) and other public funding streams, that DfT has devolved to the public transformation of transport systems at city-regional scale.


BUS
AND
LANE

Strategy at this scale needs to decide how platforms and the existing transport system should be organised and which transport services, infrastructures and sources of data should be under public control.

Control, organisation and infrastructure

In a highly complex system of operators and infrastructures, the key strategic issue from a public authority perspective is how to integrate these in line with public policy goals.

Establishing who controls platforms has profound implications at city-regional scale, where transport authorities must consider how the public good is best served by the opportunities they provide. Strategy at this scale needs to decide how platforms and the existing transport system should be organised and which transport services, infrastructures and sources of data should be under public control. This clearly requires a framework to support challenging and ongoing conversations on this issue within combined authorities and transport authorities, and with national government.

Our framework - the Urban Digital Stack

We have drawn on our research in this area to develop a framework and resources to support officials with this. This framework can help urban policymakers and decision makers in considering key challenges and developing strategies. The concept of the Urban Digital Stack is to provide a multi-layer framework for urban policymakers to think about how multiple platforms should be organised in relation to existing urban public transport systems.

Looking at how multiple platforms can be shaped and organised by existing urban decision makers and public transport systems, we focus on how platforms can add to the existing landscape of urban public transport systems. The tool explores what social and political challenges this raises for the control of existing and digital forms of infrastructure, and implications for the organisation and ownership of data.

The Stack does not provide simple prescriptions. Its purpose is to help urban policymakers and decision makers to think about and to debate key challenges and questions with colleagues and other stakeholders and to support them in developing strategies and plans for responding to the challenge of digital mobility platforms. It can be used to communicate strategy in policy documents or presentations.

Building capability - no simple answers

There is no simple prescription or route map for how the platformisation of transport systems at the scale of city-regions should unfold - and what role public authorities will have in this.

Building capability at city-regional scale is an ongoing challenge. National government should support the long-term funding of transport bodies. They must also create properly devolved powers and allow them the power to develop a platformised city-regional transport system.

Application of the Urban Stack is one tool that could be used to apply lessons more widely as part of Department for Transport best practice.

Michael Hodson is a Professor and Research Director of the Sustainable Consumption Institute at The University of Manchester.

Andrew Mcmeekin is a Professor of Innovation at The University of Manchester.

Andrew Lockhart was a Research Associate at The University of Manchester Sustainable Consumption Institute.

Rattling the supply chains: creating a more sustainable way to do business

Dr Arijit De

As global supply chains account for approximately 80% of global greenhouse gas emissions, sustainable supply chain management is not merely an ethical aspiration; it is a strategic imperative with far-reaching implications for economic, environmental, and social wellbeing.

Policymakers and regulatory bodies play a pivotal role in shaping the trajectory of supply chain sustainability – and have to navigate a complex interplay of market dynamics, technological advancements, and regulatory frameworks. Failure to address sustainability issues can lead to adverse consequences such as resource depletion, environmental degradation, and compromised resilience in the face of disruptions.

Sustainability, risk mitigation and the importance of AI

Supply chains are made up of interlinking networks – and the ever-increasing interdependencies among organisations have made these supply chain networks susceptible to both human-made and natural disruptions.

Global disruption events such as the Japanese tsunami in 2011, Typhoon Haiyan in the Philippines in 2013 and earthquakes in Chile in 2015 have significantly compromised the performance of goods supply chains in recent decades. On the national scale, disruptive events can also impact supply chains and businesses – such as KFC's logistics blunder and road accidents at the vicinity of a distribution depot in 2018, leading to two-thirds of their outlets in the UK having to close due to a chicken shortage. The COVID-19 pandemic is also a significant recent example of a disruptive event on both a global and national scale.

Other disruptive events include labour strikes, adverse weather, factory fires, political upheavals, and epidemic outbreaks. Furthermore, supply chain organisations face increasing challenges in meeting the environmental regulations enacted by governmental bodies (for example, international maritime organisations implementing sulphur footprint regulations to reduce global sulphur emissions, due to their harmful effects on human health).

By integrating sustainability metrics into decision-making processes, organisations can meet the dual challenges of

As supply chain operations are interrelated, AI models for mapping these relationships (such as advanced machine learning and mathematical optimisation techniques) become increasingly important.

mitigating fuel costs and reducing carbon emissions while enhancing operational resilience during disruptions. As supply chain operations are interrelated, AI models for mapping these relationships (such as advanced machine learning and mathematical optimisation techniques) become increasingly important.

Algorithms and frameworks that capture the perspectives of stakeholders (such as raw material suppliers, manufacturing or production facility businesses, distributors, transport organisations and logistics service providers) can facilitate more informed and effective decision-making processes, particularly in route selection, transportation choice, and product shipment decisions.

Models developed using AI can facilitate early-stage risk mitigation in product manufacturing, enhance time-to-market efficiency and resource allocation and finally, enhance supply chain resilience. For example, grocery and general merchandise retailers in the UK have used AI-driven algorithms to optimise supply chains by dynamically adjusting delivery routes based on real-time data, predicting the best transportation methods, and accurately forecasting demand to manage inventory. This approach enhances efficiency, reduces costs, and mitigates risks, ensuring faster delivery times and a stronger, more flexible supply chain. It is important that the Department for Business and Trade incorporate these models and approaches into UK supply chain strategy.

Carbon emissions containment

Containing carbon emissions is also an important consideration for sustainable freight transportation. University of Manchester research suggests that a move away from road transport to moving goods by sea wherever possible will significantly reduce both total costs and overall carbon footprint.

Moreover, complex challenges arise when reducing carbon emissions for moving products longer distances by road, as decisions need to be made on reducing vehicle trips while considering bigger vehicles and improving the vehicle capacity utilisation by focussing on economies of scale.

Supply chain infrastructure and resilience

From a supply-chain infrastructure perspective, The University of Manchester research findings emphasise the importance of fortification investment (allocation of resources and capital to strengthen and secure this infrastructure). This helps in making the supply-chain logistics networks more resilient to disruptions, optimising product flow from distribution centres and enhancing better connectivity during disruptive scenarios by adopting goods sharing strategies between facilities.

Infrastructure policy development should prioritise sustainability criteria, incorporate renewable energy sources, and ensure efficient utilisation of resources.

It is important to adopt strategies to manage disruption within a supply-chain network (such as labour strikes or weather events). Infrastructure policy development should prioritise sustainability criteria, incorporate renewable energy sources, and ensure efficient utilisation of resources. A good example of this is the fact that the adoption of electric vehicles within the supply-chain logistics industry leads to significant reductions in carbon emissions and costs, particularly in urban areas where there are dense networks of customers who live close together.

Research and evidence point towards a move away from traditional road transportation and switching to electric vehicles. Along with electrifying the transport mode, the use of greener fuels like ammonia and hydrogen and adopting greener technologies within maritime transportation is also recommended.

Policy steps for sustainable supply chains

Research at The University of Manchester suggests several policy recommendations imperative for advancing sustainability in supply chains:

- Policymakers and national government departments should prioritise the integration of sustainability criteria into procurement practices and supply chain regulations. This entails incentivising sustainable behaviours among stakeholders and fostering collaboration across industry sectors (such as freight, food and manufacturing). Government could incentivise sustainable supply chain practices by offering tax credits, subsidies for green technologies, and grants and low-interest loans for sustainability projects, as well as by promoting suppliers with strong sustainability credentials and setting regulatory standards for emissions reductions, efficient resource use and waste minimisation.

- Investment in technology and infrastructure is essential for enabling the transition towards sustainable supply chains. Embracing digitalisation, automation, artificial intelligence and renewable energy sources, such as employing electric vehicles, can facilitate resource optimisation and emissions reductions. Here, a step forward for infrastructure investment would be for government to invest in and expand electric vehicle infrastructure/charging points.

- Regulatory frameworks such as the UK's Climate Change Act should adopt a comprehensive approach that addresses not only environmental concerns but also the social and economic dimensions of sustainability. This necessitates the alignment of policies with international sustainability goals such as the United Nations Sustainable Development Goals (SDGs).

Applying the recommendations – findings from research

University of Manchester research findings underscore the importance of a holistic approach to sustainable supply chain management. By leveraging AI models, behavioural insights, integrated sustainability assessment, and early-stage risk mitigation strategies, organisations can navigate complexities, enhance resilience, and drive transformative change towards sustainable supply chain practices.

Our study *'Optimization model for sustainable food supply chains: An application to Norwegian salmon'* investigates transportation scenarios and captures the impact of adopting maritime transportation methods in place of road transportation for lowering the overall cost, the fuel costs and for reducing carbon emissions. Our research report *'Improving the operational efficiency and reducing transport-related carbon emissions of food distribution hubs'* provides empirical evidence on the benefits of collaboration between local food producers. This can contribute to: more sustainable food systems; improved producers' economic fortunes; and, with small-scale food producers suffering from low margins and weak bargaining power, improved local economic development.

The convergence of research insights and policy imperatives presents a compelling opportunity to drive transformative change in supply chain management.

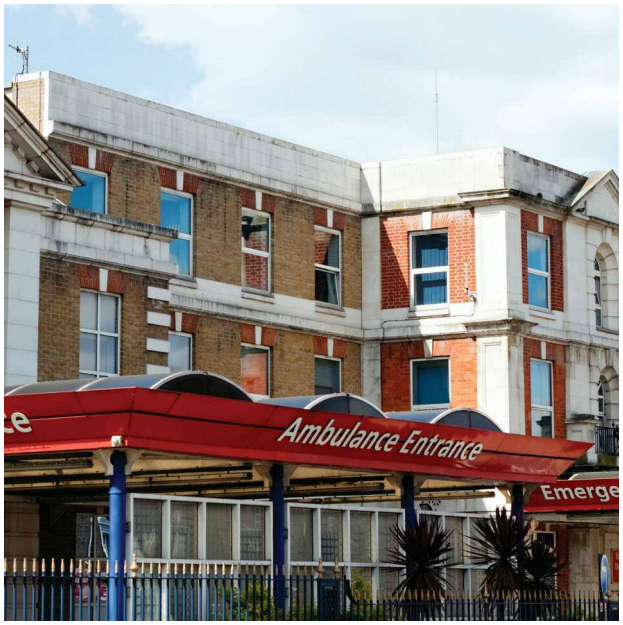
By embracing evidence-based policymaking and collaborative governance, policymakers can steer towards resilient, equitable, and sustainable supply chains that benefit present and future generations, while ensuring the robustness and efficiency of the supply-chain infrastructure.

Arijit De is an Associate Professor in Management Science at the Alliance Manchester Business School, The University of Manchester.

The growing infrastructure crisis in English NHS hospitals

Professor Anne Stafford

Since the COVID-19 pandemic, NHS England remains in crisis. We are now accustomed to ambulances queuing outside accident and emergency departments, bed shortages, growing waiting lists for elective care, and old, crumbling hospital buildings. Examining the consequences of using private finance to deliver healthcare infrastructure and services, through exploring the expense of privately financed but publicly funded hospital schemes (known as the Private Finance Initiative, or PFI), reveals a lack of visible and joined-up public accountability.



Policymakers should be aware of a shift to a two-tier NHS capital estate as up-to-date PFI hospitals increasingly outshine shabby and dilapidated older hospitals, with a related impact on service delivery. A rise in health inequalities is a likely consequence. Another implication is a lack of transparency around the significance of private financing and its impact on the public purse.

What are the financial consequences of using PFI for hospital buildings?

Expenditure to keep NHS hospitals up to date has been an issue since NHS formation in 1948. Many old buildings are still in use and in a poor state of repair due to structural failure and lack of routine maintenance. Governments in power from 1979 put little investment into hospital infrastructure. From 1997 to 2010, the government addressed the problem by using PFI to deliver 109 hospital projects (around 20% of English NHS hospitals).

PFI hospitals are built using private finance, with government paying the private provider an annual rental charge to cover the cost of building the hospital, and a service charge, which covers operating and maintenance costs. Charges include the finance costs of the debt borrowed to build the hospitals and a profit element for the private partners. Charges increase according to criteria laid down in the contract, which can mean steep increases when inflation is high. Contracts last for between 30 and 60 years.

PFI hospitals are more expensive to operate than non-PFI hospitals, but as there is an enforceable contract in place, the private partners must ensure that PFI hospitals are properly maintained. In contrast, austerity policies since 2010 mean backlog maintenance on non-PFI hospitals, which is not *planned* maintenance work, but rather the work which should have already taken place, has increased from £4bn in 2012 to £11.6bn in 2023, an

increase of 290% and greater than the £8bn allocated by the government in 2022 for capital investment to 2030. Of particular concern is an estimate of £6.3m for 'high' and 'significant' risk backlog.

Research findings – affordability and infrastructure

My University of Manchester research examines affordability issues relating to hospital infrastructure in detail. Whilst PFI charges, in total, only represent around 1.4% of total NHS spend, at local trust level they can create affordability issues.

Some trusts have reduced costs by taking actions on their PFI contracts. Two trusts terminated PFI contracts, reducing their annual operational expenditure, although it is an expensive process, with significant financial penalties being paid to break the contract. Another trust went bankrupt over the high cost of its two PFI hospitals, in part because the finance costs were much higher than the average, thereby pushing up the deficit. Affected hospitals had to be transferred into other nearby trusts.

A further hospital managed to exercise a break in its soft Facilities Management element, reducing its service payment by around £9m per year. Barts Health NHS Trust, which has the UK's largest NHS PFI scheme, decided at the time of construction not to fit out two whole floors of the Royal London Hospital in a bid to reduce operational costs from the start. Even with this decision, actual PFI charges remained higher than originally projected.

NHS trusts usually consist of more than one hospital. Frequent mergers take place between trusts, often with the aim of meeting financial challenges. At trust level, financial decision making is therefore likely to prioritise PFI over non-PFI hospitals because the former's costs must be paid due to the binding legal contract with the private provider.

My University of Manchester research examined the financial position of the trusts with the five largest PFI schemes, all of which also contain non-PFI hospitals, and their related private partners over the period 2017-2022. Four trusts experienced mergers during the past decade, with one trust undergoing three mergers. All trusts recorded at least one deficit, and four recorded at least three, despite receiving additional COVID-19 income.

Overall, the five trusts show a continuing pattern of recorded deficits and/or rising backlog maintenance, whilst in contrast their PFI private partners were delivering good, low-risk returns for their financiers. Moreover, the outflow of high finance costs plus any profits means less money remains within the NHS for tackling healthcare problems.

What's the likely future for NHS infrastructure?

We remain in a crisis position, with continued underfunding and a growing pool of poorly maintained infrastructure, yet increasing numbers of patients.

One likely outcome is that a two-tier hospital system may develop in England, as patients who can, will choose to attend modern, well-maintained buildings for elective care, over older, more inefficient structures. Patient choice could ultimately lead to destabilisation and intra and inter-trust tension across the system, dependent on how combinations of PFI and non-PFI hospitals, bed numbers and PFI charges play out in a complex scenario.

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Outpatient Departments
Cafe & Shops
6

Exactly what will happen is difficult to predict. A systematic decline and fragmentation of monitoring and transparency of accountability and evaluation of financial performance over time makes it difficult to properly scrutinise the financial impact of using private finance for hospital infrastructure. However, we do know there are insufficient resources available to permit fair allocation across trusts, meaning that in reality the main choice patients have for prompt treatment is whether they are willing and able to pay for private healthcare. This increases health inequalities.

Recommendations for a robust and reliable NHS infrastructure

The government should seek out examples of best practice in hospital buildings construction and utilisation and share them centrally, so that new fit-for-purpose buildings can be delivered efficiently and at affordable cost. There needs to be greater oversight of the interface between the NHS, the Department of Health and Social Care and the Treasury in relation to the joined-up provision of care.

Many non-PFI hospital buildings are in a poor state of repair and unfit for purpose. Government should set out a policy commitment on a rolling programme of capital investment using public finance, prioritising the replacement of worn-out buildings and addressing the shortage of hospital beds in under-resourced trusts.

Government should ensure total health spending is at least the pre-Covid long term average of 3.8% growth per year, or even better to the level of growth experienced under the last Labour government of 6.7%. This would ensure that NHS trusts containing PFI hospitals can afford to pay the high charges levied by the private sector, whilst maintenance work on non-PFI hospitals can be carried out in a timely manner.

There needs to be greater oversight of the interface between the NHS, the Department of Health and Social Care and the Treasury in relation to the joined-up provision of care.

A policy decision to slow down or abolish change and merger across NHS trusts would lead to more stability for financial decision making across regions.

Public accountability and oversight of capital investment in the NHS needs to be strengthened going forward, potentially going beyond the remit of the National Audit Office.

There is great scope for the Parliamentary Public Accounts Committee to make recommendations and take actions. These could include evaluation of the use of private finance and a fair return in healthcare, a challenge to private sector legitimacy and a more transparent allocation of taxpayers' money to healthcare services.

Anne Stafford is a Professor of Accounting and Finance at the Alliance Manchester Business School, The University of Manchester.

Positioning green infrastructure as essential infrastructure in the UK

Professor Ian Mell

As the impacts of the climate and biodiversity emergencies become clearer, there is a growing need to rethink how infrastructure is developed and managed in the UK. The planned redundancy of concrete and steel as building materials makes sustainable urban development problematic. However, the EU, via their Nature-Based Solutions (NBS) research programme, and the UK government, through the Environment Act (2021), and its Biodiversity Net Gain (BNG) legislation, have attempted to transition towards a more resilient approach to development. The promotion of green infrastructure (GI) as an essential form of urban infrastructure is a key component of this debate.

The role of green infrastructure

GI has been identified as a go-to form of sustainable investment since the late-1990s, due to its promotion of increased quality, quantity, functionality, and accessibility of nature within urban areas. Working to promote socio-ecological multi-functionality and encourage spatial connectivity, GI can offer alternative pathways to future-proof cities via more adaptive forms of infrastructure investment.

However, an ongoing reluctance is visible within built environment discussions among planners, developers and engineers who contest the long-term functionality of 'nature-based' interventions, compared to those associated with the delivery of property or transport infrastructure.

Unfortunately, the functional lifespan of much man-made urban infrastructure is now leading to failures, and politicians and urban planners are searching for new ways to regenerate the existing urban fabric.

Working to promote socio-ecological multi-functionality and encourage spatial connectivity, GI can offer alternative pathways to future-proof cities via more adaptive forms of infrastructure investment.

The ICE, and others, argue that continuing to develop cities without an explicit focus on nature may be a fool's errand that undermines the sustainability of urban areas.

Returns on investment

Increased extreme heat, rainfall and drought events, and the subsequent impact on urban liveability and environmental functionality have led environmental advocates to call for GI to be considered as essential infrastructure. The introductory chapter of the Institute of Chartered Engineers (ICE) *Manual of Blue-Green Infrastructure*, for example, calls for GI to be reclassified as an essential form of infrastructure. The ICE, and others, argue that continuing to develop cities without an explicit focus on nature may be a fool's errand that undermines the sustainability of urban areas. By emphasising an ecological focus in master planning, increasing the proportion, diversity, and functionality of urban ecosystems, and working with water and climate specialists, cities can rethink how to align socio-cultural and politico-economic systems with ecological ones.

Numerous examples exist illustrating the return on investment that GI provides for cities including:

- £2.1 billion per annum could be saved in health costs if everyone in England had good access to greenspace, due to increased physical activity in those spaces.
- Research by CE Delft and the European Public Health Alliance found air pollution costs London £10.32 billion per annum in total, or £1,173 per year per person.
- Urban GI can lower ambient air temperatures by between 1.8°C - 8°C.
- GI is effective at reducing peak discharge in 80% of frequent storm events.
- Up to 84% of energy costs could be saved by the cooling effect of green roofs, and 64% for green walls (climatic and building content dependent).
- i-Tree analysis for London states that the city's street trees support energy saving in buildings, increase property prices by 15%, remove 561 and 1680 tonnes of pollution from inner and outer London per annum respectively, and provide 499,000 and 1,868,000 tonnes of carbon storage per annum for inner and outer London, respectively.

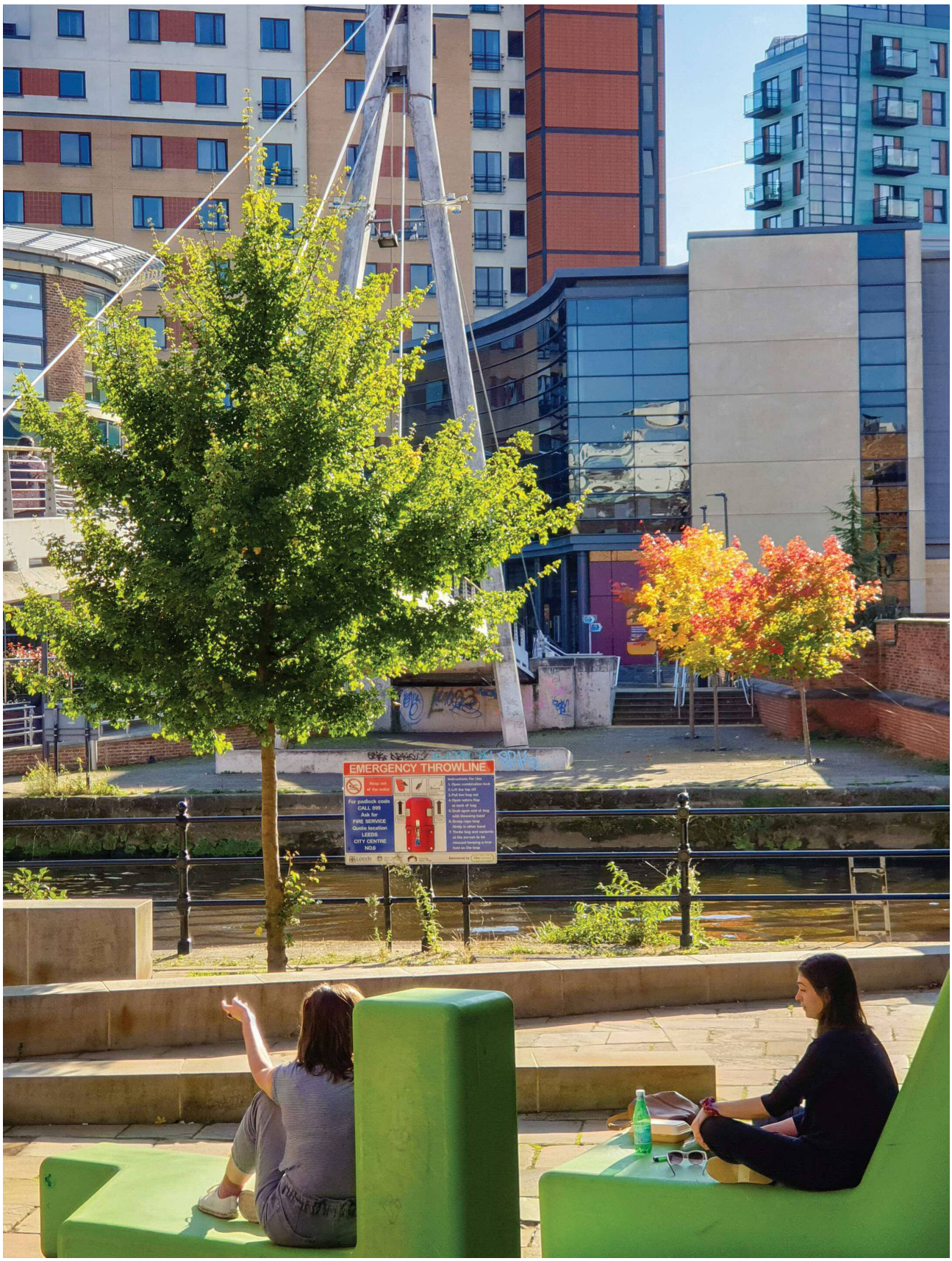
Current approaches and strategies

The grouping of such evidence has shaped the UK's promotion of Biodiversity Net Gain (BNG) (and the Biodiversity Metric 4.0 to deliver it), Local Nature Recovery Strategies (LNRS), and the National GI Standard Framework, establishing them into positions of prominence.

Each of these approaches places an explicit value on nature as an essential infrastructure, requiring a more strategic approach to ecological provision. This is established via a minimum 10% increase in biodiversity delivered via BNG, and adherence to the Urban Green Factor (UGF) metric and design principles in the GI standard framework.

BNG, for example, states that it *"…makes sure that habitats for wildlife are left in a measurably better state than they were before the development"*. The application of BNG aims to deliver biodiversity enhancement either on-site, off-site or as a combination of both, depending on circumstances.

Likewise, the National GI Standard guidance calls for local government, developers, and land managers to support the delivery of green and blue spaces that are accessible, of high quality, and multi-functional. Moreover, the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It is also critical that the new UK government engages effectively with research if they are to develop policies that support ecological functionality.

ongoing use of the UGF in the City of London, as well as in Swansea and Southampton, has shifted the emphasis of planning considerations to GI being a 'must-have', not a 'nice to have' form of infrastructure. Without the inclusion of GI, planning permissions are less likely to be granted.

The increased emphasis on nature as an essential form of infrastructure has emerged due to ongoing advocacy work from Natural England, England's Community Forest Partnerships, the environment sector more broadly, local government, and academics. Each of these have provided compelling evidence of the added ecological and socio-economic value that investment in GI can deliver.

Recommendations for essential GI

To successfully transition towards a more resilient form of urban development requires more than evidence. It is also critical that the new UK government engages effectively with research if they are to develop policies that support ecological functionality.

The government should implement the following changes to achieve resilient urban development:

- The Government should legislate GI within law as 'essential infrastructure' thus giving it an equal prominence as other forms of investment in development debates.
- Labelling GI as essential infrastructure would complement the current legal protection afforded to the environment by the Environment Act (2021) and Biodiversity Net Gain (BNG) requirements by ensuring that greening (it's in widest sense) is embedded within all future policy and legislation.
- Providing a legal guarantee that GI is considered as essential infrastructure would require the Treasury, the Ministry of Housing, Communities and Local Government (MHCLG), and the Department of the Environment, Food and Rural Affairs (Defra) to allocate the appropriate funding to support investment.

These pathways require government at all scales to continue to evolve their thinking regarding the inclusion of environmental quality, quantity, and functionality within future strategic planning and delivery plans.

Ian Mell is a Professor of Environmental & Landscape Planning at The University of Manchester.

Towards a just energy future for UK households

Dr Isabelle Bi-Swinglehurst

Since 2021, the rapid rise of energy prices has sparked public awareness of energy poverty, with 13% of households in England classed as fuel poor, meaning they are finding it difficult to pay for the energy needed to have a warm home. Additionally, 44% of households in Great Britain are using less fuel (ONS, 2024). Those living in the poorest households were spending three times (7%) the relative proportion of disposable income on gas and electricity than the richest decile (2%) households. Infrastructure challenges in maintaining a warm home include limited availability and choice of housing stock, older homes, and poorer quality materials.

This crisis has shown that governments, at local and national levels, have implemented policies to address energy poverty, including price regulation and tax breaks, limits on disconnections, discretionary financial assistance to vulnerable households and social tariffs for energy efficiency improvements and energy savings. The energy crisis brings to the forefront a wider discussion, providing an opportunity to consider how to develop support mechanisms that appropriately capture the complex and diverse social nature of energy usage going forward.

Infrastructure, energy policy and data

The UK government in 2023 pledged to design infrastructure that future-proofs access to safe, clean and affordable energy for the long term, and to develop policies that address energy efficiency of the housing stock, household income and energy prices. To accomplish this, energy access planning requires recognition of social inequalities, especially for household income patterns. Data underpins decision-making in infrastructure projects, but the data itself can also underpin ongoing social injustices and inequalities in access.

Many policies rely on indexes that combine various sources of data. The Index of Multiple Deprivation is the official measure for relative deprivation in England, including factors such as income, employment, housing, crime, education, health, and living environment to produce a relative scale of highest deprivation. However, the sources of data are not published and therefore not replicable. Complex usage of energy – driven by gender, age, disability, employment, and geographical considerations – leads to different vulnerabilities that are not well captured within a relative scale of general deprivation

Energy poverty – a nuanced picture of the most affected

It is important that decision makers recognise that energy poverty is distinct from general deprivation, which has

Data underpins decision-making in infrastructure projects, but the data itself can also underpin ongoing social injustices and inequalities in access.

traditionally been used as a proxy. Extensive research into energy poverty shows that certain demographics are disproportionately affected by hikes in energy costs. These nuances do not fit broadly into the general deprivation data models, which inform policy. People can and have altered their energy consumption during this recent energy price crisis to accommodate the financial strain, at the expense of health and wellbeing, thereby underrepresenting the extent of energy poverty if mitigation measures were not put in place.

The gender pay gap, whereby the average woman earns less than the average man and a higher percentage of part-time workers are women, combined with parenthood, with full-time mothers earning less than full-time fathers, means that one-parent mothers' households face combined challenges to meet energy needs.

Likewise, households with disabled people and older individuals have lower incomes but differ in varied and acute energy needs, such as requiring energy-intensive equipment. To reduce energy bills in the short run, older people who reduce energy usage may experience worsened health outcomes in the long run, as 'thermal discomfort' takes longer to recover from. The UK Government estimated in 2014 that ten percent of winter deaths are attributable to energy poverty – and this is before the energy crisis and price hikes a few years later.

Shifting working patterns, shifting energy use patterns

While energy prices are now declining, the need for energy and its geographical distribution is expected to change to reflect changes in employment patterns. The rise in remote working, where homeworking doubled from 2019 to 2022, means that more workers are using energy at home to work.

Remote workers are reported to pay more for their energy bills compared to their office worker counterparts.

Remote workers are reported to pay more for their energy bills compared to their office worker counterparts. While the average remote workers tend to have higher occupational classifications and earn more than on-site workers, inequalities can exist, as low-wage remote workers spend a higher proportion of their disposable income than their higher paid counterparts.

Policymakers will need to address this growing cost to remote workers as working from home patterns continue and the new government should consider how employers can ensure employees pay for fuel and energy bills equitably.

Geographical inequalities

Lastly, geographically, regions outside of London have as high or even higher average standing charges. As wages in London surpass the national average, households living in other regions face similar or even higher heating bills (in the case of West Midlands and Yorkshire and the Humber) but on lower wages. Intersecting with gender, disability and the changing nature of working patterns, this leads to certain poorer regions with lower wages who face a disproportionately higher relative financial strain to maintaining a warm home.

These social and geographical inequalities are researched thoroughly, but how infrastructure planning takes these into consideration is less clear and, of course, the changing nature of energy usage means that there needs to be more timely information.

Policy pathways – targeted measures versus blunt tools

Key to policies that empower fair and just access to affordable energy is recognition of people's distinct needs - which may be missed within the reliance on large statistics. Statistics remain a useful guide to highlight more vulnerable areas, but a proposed complement is to design interventions at the local level, based on extensive consultation with residents who are best placed to explain their personal circumstances and the realities of the existing housing stock in the area.

There are a myriad of government and regulatory bodies entrusted to ensure fair energy access. A consultation, led by a national body such as the Ministry of Housing, Communities, and Local Government supported by local authorities, could investigate the extent of modern household energy needs.

Local authorities currently carry out energy projects in diverse ways, and these efforts can only continue with secured funding from central government to acknowledge these diverse social needs. This feeds into cross-working between government departments and the sharing of information to devise strategies, policies, and interventions. This collaboration is crucial if the goal is to design infrastructure that recognises these social drivers, which intersect with the traditional three pillars of housing stock, household income, and energy prices.

To build on this, one way to operationalise this understanding of changing needs would be to establish working groups and co-produce with third-sector partnerships, to raise awareness and design responses to acute energy needs driven by social factors. A potential outcome could be the creation of a national energy usage index - a hybrid index using quantitative findings supplemented with local consultations and interventions, recognising different energy pattern usages of the population. This index could inform local authorities, the housebuilding industry, and planning committees to address acute energy needs driven by social infrastructure needs.

Consultation measures and targeted initiatives can be a costly investment in both resources and time, compared to employing a blunt quantitative tool in developing infrastructure. However, statistics cannot adequately capture the intricate social usages in different circumstances.

With the increasing unsustainability of energy costs, the changing and heightened need for energy, and the implications for designing infrastructure that promotes equitable access, now may be the time for nuanced discussions in infrastructure planning to ensure just and equitable access.

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The digital infrastructure divide: the spatial landscape of broadband coverage across the UK

Professor Cecilia Wong and Dr Helen Zheng

Changing social norms and the COVID-19 lockdowns have drastically shifted how we utilise the internet to conduct our daily lives, creating a rapid increase in home/hybrid working and online shopping. High quality, reliable and good coverage of telecommunication infrastructure has resulted in differential locational advantages and socio-economic outcomes.

University of Manchester research and data has uncovered a spatial divide in broadband coverage, accessibility and speed across the UK and between rural and urban areas.

Post-COVID digital landscape

There has been major improvement in the provision of ultrafast broadband (>300 Mbps) in the UK in recent years. According to Ofcom's 2023 Connected Nations report, gigabit-capable broadband has already reached 78% of residential premises (77% of all premises), which means users can buy different speeds depending on the service offered by the internet service provider.

This rapidly transformed landscape is mainly achieved through the provision of full-fibre broadband. Full fibre is one of the broadband technologies - in a full-fibre connection, the connection between the exchange and the premises is directly provided over fibre. It can support speeds over 1 Gbps (1000 Mbps). Full fibre broadband was at 57% of residential premises (56% of all premises) in 2023, representing a rapid increase from 42% in 2022 and 4.8% in 2018.

The importance of speed

Speed matters greatly in broadband accessibility as it affects the internet search and high frequency trading, uploading and downloading speeds, as well as ensuring stable online access with simultaneous users – an important consideration when several members of a household may be studying or working at home and taking online meetings.

An Ofcom commissioned study in 2018 found that broadband investment on speed improvements had resulted in an increase in the UK GDP at 0.47% per annum (a 6.7% total GDP increase) between 2002 and 2016. Our own University of Manchester spatial analysis found that there are some weak relationships (tested to

This rapidly transformed landscape is mainly achieved through the provision of full-fibre broadband.

be statistically significant) between access to ultra-fast, full fibre and gigabit broadband provisions and the size of local economy and labour productivity.

A spatial divide

Across the UK, 97% of all residential premises have access to superfast broadband of at least 30 Mbit/s. However, a closer look shows that England, Scotland and Wales (55% or less) are lagging behind Northern Ireland (90% and over) in a major way in terms of gaining access to full fibre broadband, and the spatial divide is also witnessed in gigabit capable broadband.

Our data also highlights major urban/rural differentials in England, Scotland and Wales: while 82% of residential premises in Northern Ireland's rural areas have access to full fibre/gigabit capable provision, the comparable figures for England, Wales and Scotland are at least halved.

The uneven spatial distribution of ultra-fast broadband access is mapped in Figure 1. In addition to highlighting the differentials across the four nations and the urban-bias of provision, it also shows that combined authorities which have larger peri-urban catchment areas (such as the North East, South Yorkshire and Cambridgeshire & Peterborough Combined Authority areas) display more varied density and coverage of ultra-fast broadband.

Funding and spatial bias

As pointed out in the *Ofcom Connected Nations 2023* report, there is a vicious cycle of development as operators are mainly focusing full-fibre deployment in areas that already have superfast broadband. There is a reliance on government schemes to provide funding to improve broadband coverage for hard-to reach areas. The 'transformational' broadband connectivity in Northern Ireland has been the outcome of Project Stratum (a move to improve broadband connectivity by extending Next

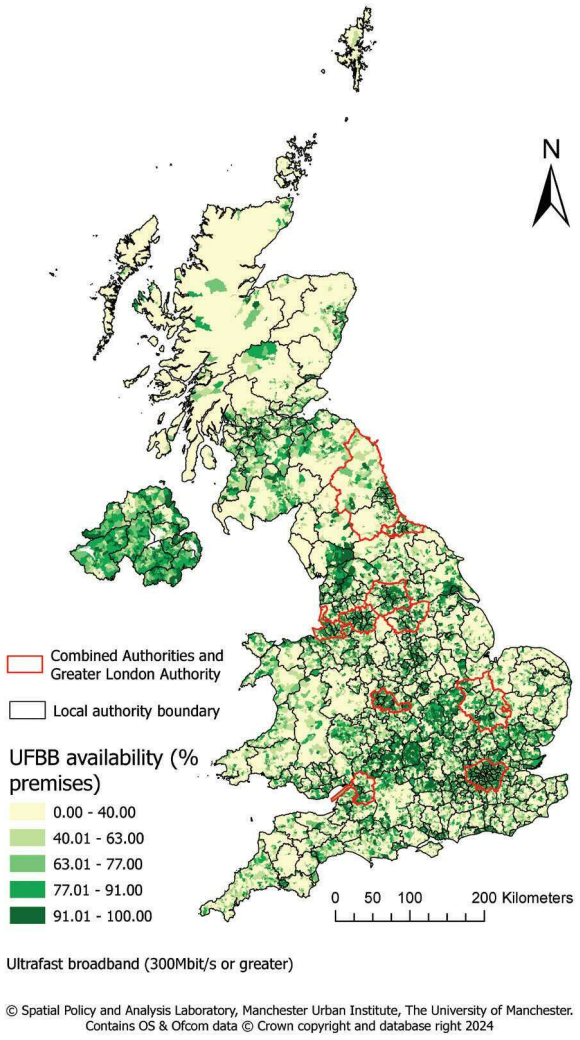

Figure 1: Ultrafast broadband availability by output area in the UK

Generation Access (NGA) broadband infrastructure to approximately 81,000 premises across Northern Ireland), with a £150m (out of £165m) funding boost from the UK Government. This was, however, achieved under the special deal of the confidence and supply agreement between the Democratic Unionist Party and the Conservatives after the 2017 general election.

It is important to note that telecommunications is a reserved power of the UK government which has primary responsibility for broadband policy and coverage targets, though the delivery of broadband infrastructure projects often involves local authorities and the devolved administrations. When examining the funding distribution of Building Digital UK (a UK government executive agency, responsible for bringing fast and reliable

broadband and mobile coverage to hard-to-reach places across the UK) for superfast broadband development in 2020, it is clear that has been a strong spatial bias of government spending as 73% was for England but less than 10% for Wales.

The latest development highlighted in the *Connected Nations* report is that the government has started *Project Gigabit* (over £5bn) in September 2023, aiming to cover 1.1 million premises across the UK. There are also plans for the three devolved nations, with Scotland's *Reaching 100%* (£600m) the most ambitious and Wales's £57m *Superfast Cymru* the most modest. This means that there are likely to be shifts in the spatial pattern, although the pattern would be one continued with spatial variations given the path dependent nature of broadband investment with a continued focus of full-fibre deployment in those areas that already have superfast broadband.

A place-based approach will be crucial to reducing the unequal distribution of ultrafast broadband.

Policy commitments and pathways

As our own findings show links between access to ultra-fast broadband provisions and the size of local economy and labour productivity, it is clear that broadband access should be firmly embedded into national and local agendas (or government strategies with ambitions for greater social equality). A place-based approach will be crucial to reducing the unequal distribution of ultrafast broadband. The National Infrastructure Commission has also recognised the importance of a place-based approach for infrastructure development, stating *"The role that infrastructure can play in levelling up economic opportunities across towns and cities in English regions is one of three strategic themes shaping the Commission's work programme leading up to the second National Infrastructure Assessment."*

Despite the former government's policy commitment to improve broadband connections to the very hard- to-reach premises in rural and coastal areas, the target was seen as overambitious due to the lack of commitment of sufficient funding.

With a new government, a placed-based approach could award more powers to combined authority mayors, such as North Yorkshire and East Midlands, to make long-term strategies and prioritise investment. Empowering local planners, working in tandem with communities to remove red tape and designate where improved broadband infrastructure projects are prioritised, may be a key to unlocking crucial access for some rural and coastal areas.

The lack of clarity on 'how and where taxpayers' money will be spent' has also provided less impetus for investors in the industry. A place-based approach, which tangibly shows the outcomes of investment in communities, could address this gap and encourage more local investment.

The dramatic turnaround of broadband provisions across urban and rural areas in Northern Ireland, however, serves as an exemplar (which government, civil service working with industry and Ofcom could use as a blueprint), demonstrating that things can be done if there is a political will and the backing of funding resources.

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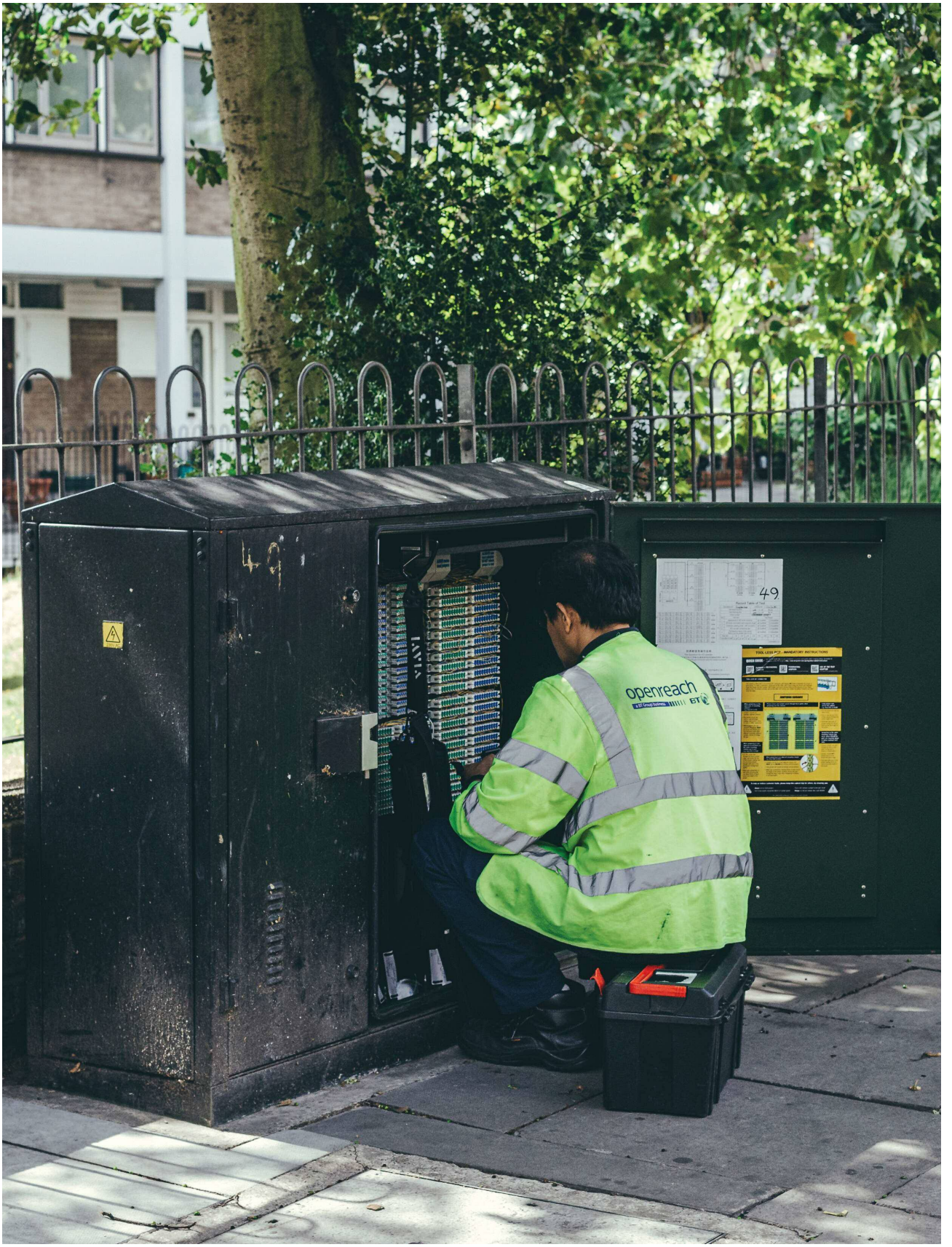
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Urban green infrastructure: understanding and assessing risks from climate change

Dr Jeremy Carter

Extreme weather events are increasing in frequency and intensity, whilst climate change projections point towards further, largely negative, impacts on humans and nature. In response, climate change adaptation has become a stronger component of policy agendas globally. As part of this response, climate risk assessments are routinely undertaken across a wide variety of sectors and spatial scales. There is a strong case for such assessments to embed into green infrastructure (GI) decision making, to support the planning, design and maintenance of GI in a future characterised by a changing climate.

Green infrastructure is at risk from climate change

There is growing evidence of the environmental, economic and social benefits offered by GI to urban areas. As a result, policy frameworks at national and local levels commonly advocate GI measures, and there is increasing recognition that GI should be considered a form of critical infrastructure alongside the likes of transport, water supply and electricity generation infrastructure.

These forms of critical infrastructure are impacted by extreme weather and climate change hazards. Because of this, related risks are commonly assessed, and adaptation responses are subsequently implemented in an effort to maintain the services that they provide to society. For example, identification of risk to rail lines from flooding and sea level rise helps to target measures needed to protect the network from such hazards.

GI is critical to urban areas - and is also at risk from the changing climate. Researchers are only just beginning to consider this topic, often focusing on current weather extremes rather than future climate change projections. Examples include studies exploring how high temperatures and drought conditions impact urban trees and woodlands, which have identified negative impacts including reductions in leaf cover and increased exposure to pest species. Soil moisture deficits can also stress urban grassed areas, leading to dieback of grasses.

These impacts can, in turn, compromise the ability of urban GI to provide the benefits and services it is valued for, notably those linked to adaptation to climate change such as cooling air and surface temperatures and enabling rainwater capture and absorption.

GI is critical to urban areas - and is also at risk from the changing climate

Green infrastructure risk assessment – our research study

Despite the threat that climate change poses to urban GI, approaches to assess related risks spatially, at a scale

that can inform local decision making, are not available. A recent study involving researchers based at The University of Manchester represents the first example of such a risk assessment.

The study assessed risk to Greater Manchester's (GM) grassed areas from an extended period of low water availability. Grassed areas are an important element of GM's urban GI and are more susceptible to harm from water deficits than trees.

The year 2018 was selected to base the risk assessment around. A high-pressure system over the UK during the summer of 2018 brought exceptionally high temperatures and low rainfall - conditions projected to become more common in GM with the intensification of global heating. This offered the ideal case study to explore climate change related risks to grassed areas across the city-region.

Greater Manchester grasslands – spatial risk assessment

This study identified specific areas of GM's grasslands where there is a high risk of grasses dying back under conditions of low water availability.

Soil characteristics linked to their capacity to hold water stand out as a key factor in determining levels of risk. Also, being surrounded by highly built-up urban landscapes makes grassed areas more sensitive to low water availability as this reduces the water recharge capacity of soils, thereby intensifying levels of risk.

However, to help maintain their functionality under such conditions, grassed areas can be irrigated with ground water. The presence of ground water close to the surface indicates higher capacity to adapt to low water availability conditions, and therefore presents the opportunity to moderate the severity of associated risks posed to grassed areas. These factors were evaluated at a fine scale to generate a spatial assessment of risk to GM's grassed areas from low water availability (see Figure 1).

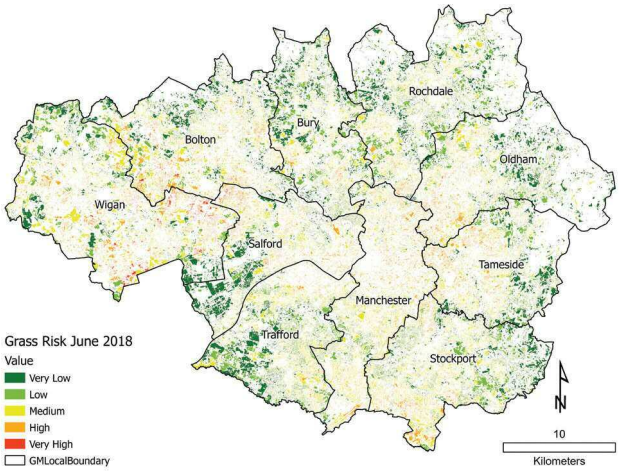

Figure 1: Risk to Greater Manchester's grassed areas from low water availability conditions in June 2018. (Source: Carter, J.G., Labib, S.M., Mell, I. 2024. Understanding and Assessing Climate Change Risk to Green Infrastructure: Experiences from Greater Manchester (UK). Land, 13 (5), 697.)

Implications, interventions and inequalities

A key role of GM's GI is reducing fluvial (from rivers and streams) and pluvial (excess surface water runoff that exceeds the capacity of natural and manmade drainage systems) flood risk. This is because it can capture and absorb rainwater, thereby reducing the volume of water reaching rivers and streams, delaying flood peaks, moderating the extent of surface water runoff and ultimately reducing flood risk.

These GI functions are negatively impacted by conditions of low water availability as grasses die back, exposing underlying soils which dry out and harden. This is concerning for GM, where flooding is a key hazard facing the city region. Intense rainfall events during the summer

Intense rainfall events during the summer months, which has the potential to cause flash flooding, is a specific threat.

months, which has the potential to cause flash flooding, is a specific threat. The risk assessment output (Figure 1) enables targeted interventions to reduce this risk in areas of greatest need, for example where GI at high risk from low water availability is located in built up areas threatened by pluvial flooding.

This study also identified that grassed areas within the most highly deprived areas of GM were more likely to be at high risk from low water availability conditions compared to grassed areas within GM's least deprived areas. This is indicative of broader socioeconomic inequalities concerning access to urban GI. Given the role that GI can play in enhancing health and wellbeing, there is a requirement for planners and decision makers to ensure that GI in areas suffering from deprivation is adapted to climate change.

Ways forward for green infrastructure

Enhancing the resilience of GI to climate change should be considered consistently and systematically, not just in GM but in cities and urban areas across the world. University of Manchester research highlights that analysing and spatially visualising patterns of extreme weather, and climate change risk to urban GI, can support related planning and decision making.

This is particularly important at present in the UK, with local authority GI budgets stretched. New GI investments and interventions need to be climate resilient, especially as the likes of public gardens and street trees are long lasting features of urban environments. Specific approaches that should be considered include providing capacity to irrigate GI and developing planting schemes that are more resistant to low water availability.

Concerning existing GI resources, our mapping exercise described above can help to prioritise where local interventions should take place, and this approach could usefully be developed and rolled out to other local authorities. Irrigation approaches are an important part of the response, as are schemes to modify surface cover, e.g. planting trees within grassed areas. Such interventions should be prioritised in areas of social and economic deprivation, where additional benefits can be captured from enhancing GI resources.

Policy direction is needed at the national level, particularly from the Ministry of Housing, Communities and Local Government, to stimulate local planning authorities to recognise and act to reduce the risk of climate change to urban GI. Organisations such as Natural England must also help to build knowledge and awareness of climate change risk amongst GI stakeholders.

This is crucial, given the threat of climate change to GI, and the need to maintain and enhance the benefits and services that this form of critical infrastructure can offer to urban areas over the coming decades.

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Water reuse for sustainable practises in new housing infrastructure

Dr Ella Foggitt, Dr Claire Hoolohan, Professor Alison Browne

Demand for water will outstrip supply within the next 25 years in England. Changing patterns of water use – for example, as a result of increasing hygiene standards - are intersecting with long-standing infrastructural challenges of ageing water and sewerage networks. England could face a water supply gap of over 4.8 billion litres per day by 2050, with infrastructural issues exacerbated by climate change resulting in immediate and substantial challenges to public water supplies.

New options are needed to supplement the 14 billion litres per day currently delivered by water companies. The Environment Agency anticipates that demand management will contribute 65% of activity needed to resolve the forecast deficit, particularly in the next 10-15 years. This involves improving the efficiency of water supply and changing the way that water is used.

The role of housing developments in water supply

New housing developments present multiple opportunities to foster more sustainable ways of living and help reduce water demand. The Enabling Water Smart Communities project (a collaborative project bringing together UK water utilities, innovators in the built environment, leading academics and industry bodies) explores opportunities for integrated water management to contribute to solving problems in water systems.

To realise these opportunities, focus needs to shift away from individual residents to instead recognising the various ways that water use is embedded in the design of homes and communities. The importance of retrofitting existing housing stock notwithstanding, new build homes present an opportunity to set more ambitious water use targets to improve water efficiency and reduce demand.

The UK government is already exploring how to reduce water scarcity. However, today's building standards are insufficient to mitigate climate change or manage water scarcity. While proposals to revise building regulations are being considered, more can be done by exploring the potential for water reuse.

While proposals to revise building regulations are being considered, more can be done by exploring the potential for water reuse.

Current emphasis is placed on fixtures and fittings - the materials that supply and affect the flow of water in homes and gardens. Important conversations about how a fixtures and fittings approach can radically reduce water use, particularly in new build homes, are ongoing. However,

issues around how to ensure water-efficient appliances are installed in new homes, how they are used over time, whether assumptions made about their use hold up, and how water reductions will be maintained as appliances break down or reach the end of their design-life, need to be considered.

Fit-for-purpose water supply systems

Looking beyond fixtures and fittings, water reuse options that offer potential for fit-for-purpose supply at the development scale, present further opportunities. Water reuse could enable wider changes by altering how people interact with water in their homes, communities and the natural environment. Development-scale water reuse is where rainwater and greywater (e.g. wastewater from showers and sinks) are captured and reused in housing developments for practices such as toilet flushing.

The relationship between residential water reuse and overall water demand is understudied, but there is evidence that suggests it could help to reduce potable water demand. Research also shows that the degree of support for water reuse depends on its end-use (whether for gardening, toilet flushing, washing clothes/bodies, or drinking/cooking).

With this evidence, water reuse offers a potential fit-for-purpose water supply via a dual-pipe system, allowing some needs such as drinking, to be met through a potable system, and other practices such as irrigating gardens, clothes washing and toilet flushing, using a reuse system. Thus, water reuse could reduce potable water demand associated with specific practices while continuing to deliver on public health objectives. Research in Australia showed the importance of understanding community definitions of risk – with trust in the management of these infrastructures and technologies more important for risk perception than the 'yuck factor' of water reuse.

Greater attention and investment in social science research is needed to expand this knowledge base, including on the effect of water reuse and reconfigured water supply systems, such as dual pipe systems, on overall water demand.

Current challenges to water reuse systems

There is also a need for critical attention on how policy developments in other areas affect everyday life, and therefore change patterns of water use in new developments. New homes and communities must deliver on a range of environmental objectives – from biodiversity to climate change mitigation.

New homes and communities must deliver on a range of environmental objectives – from biodiversity to climate change mitigation.

Shifts towards active travel and remote working practices have uncertain implications for water demand. Careful consideration of how the design of infrastructures within new developments shape future ways of living with water, and balancing changes in consumption through fit-for-purpose supplies - both have roles to play here. Meanwhile, wastewater policy issues could impact public perceptions of water companies' ability to safely govern water reuse, with evidence showing that public support of water reuse is closely linked to trust in the water authorities. Overall, there is limited evidence on community perspectives of water reuse systems, particularly in the UK. The Enabling Water Smart Communities project is working to address this gap, exploring the potential for mains-limited developments in England with professionals and publics.

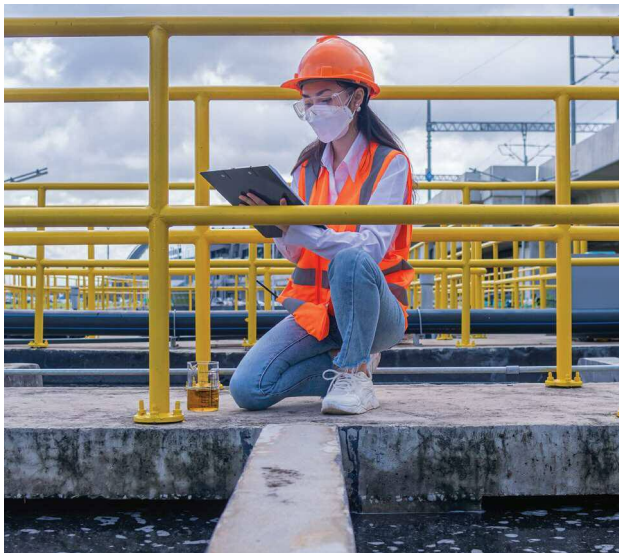
Perceived health risks can also challenge the feasibility of new water reuse schemes as they can lead to highly cautious risk reduction measures - which come with high operating costs. Another substantial issue is the Drinking Water Inspectorate regulations, which state that water supplied to residential properties needs to be 'wholesome.' Current interpretations of this regulation mean that only potable water can be supplied to residential properties, irrespective of the use. Thus, current understandings of Regulation 4 (Wholesomeness) of the Water Supply (Water Quality) Regulations 2016 (England) and 2018 (Wales) limit ambition of water reuse. A review of this legislation could help ensure that these regulations protect public health while creating a space for innovations to reduce water demand.

Monitoring, reviewing and collaborating for sustainable water infrastructure

To ensure ongoing resilience and sustainability of water infrastructure systems, there is a need to review water regulations to ensure the protection of public health while also creating space to trial new models of water provision, such as water reuse, that lessen environmental impacts.

There is a need for robust, long-term and transparent monitoring by regulatory agencies to ensure that building standards are adhered to, and that the anticipated savings are realised once homes are lived in. Collating and sharing information on the target water consumption per capita versus the actual per capita consumption once homes are built, as well as measures taken to achieve the target, would all be useful, along with building regulations to guide this.

Better understanding is needed to identify effective models for the ownership, governance, use and maintenance of such infrastructures. Here, evidence from dual water delivery systems in other global contexts could be useful.



Rethinking roles within and between communities with collaboration between local authorities and government bodies could be one route to fostering long-term resilience and sustainability. Ensuring that homes, amenities and infrastructures in new developments contribute to tackling societal and other problems we will face in the future, requires us to critically reflect on whether current designs of homes and communities enable or restrict more resilient ways of using water.

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