

NATIONAL NEEDS ASSESSMENT

A Vision for UK Infrastructure

Sir John Armitt, Chair, President Institution of Civil Engineers

Martin Baggs, former CEO Thames Water

Nick Baveystock, Institution of Civil Engineers

Graham Dalton, Independent

John Dickie, London First

Jim Hall, Oxford University & Infrastructure Transitions Research Consortium

Steve Holliday, former CEO National Grid

Rhian Kelly, CBI

Jon Lamonte, Transport for Greater Manchester

Professor Lord Robert Mair, Cambridge University

Robbie Owen, Pinsent Masons

Richard Threlfall, KPMG

Gareth Williams, Scottish Council for Development and Industry

AUTHORS

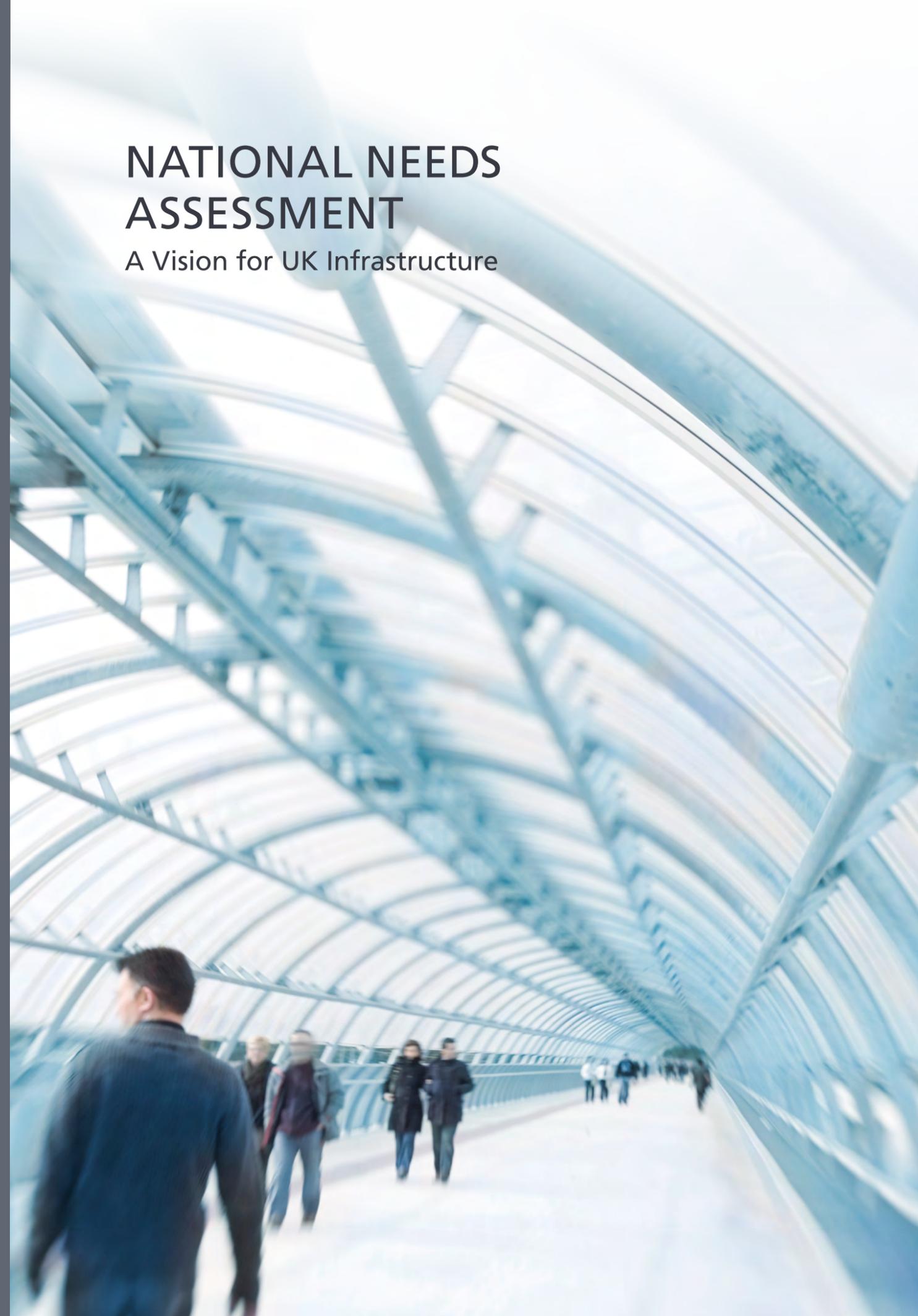
Atkins
ICE
ITRC

PROJECT TEAM

Atkins
ICE
ITRC
KPMG
Pinsent Masons

The team would like to thank all those who provided written evidence and attended the workshops through the UK.

For further information about the **National Needs Assessment** please contact **Andrew Wescott** andrew.wescott@ice.org.uk



CONTENTS

EXECUTIVE SUMMARY	5
What is the National Needs Assessment?	
Why do we need world class infrastructure	
What should be done - recommendations	
What we mean by infrastructure	
DRIVERS OF INFRASTRUCTURE DEMAND	25
Introduction	
Drivers of demand for infrastructure services	
Demand outlook by infrastructure sector	
Energy Transport	
Digital communications	
Water	
Flood management	
Solid waste	
Housing	
SECTORAL ANALYSIS: interventions, challenges, opportunities and options	53
Energy	
Transport	
Digital communications	
Water	
Flood management	
Solid waste	
Housing	
CROSS-SECTOR INTERDEPENDENCIES	82
Interdependencies in demand	
Delivering the vision	



Modelling from the Infrastructure Transition Research Consortium (ITRC) projects the UK population will be 75 million by 2050.



ITRC's macro-economic modelling projects UK GDP in the range £2.7–3.7Tn by 2050.



The total energy demand in Great Britain could move from its current level of around 900 TWh/year to 1200 TWh/year depending on the adoption of potentially disruptive new technologies such as energy storage and the electrification of heat and transport.



The adoption of digital communication by businesses has resulted in 20% of total ecommerce turnover in 2013 – an estimated £557bn.



Internet penetration is at around 90%, there are more than 22.6m fixed residential and SME broadband subscribers (ITRC 2016),



Broadband Delivery UK (BDUK) aims to achieve 95% superfast broadband coverage by 2017.



The UK leads the G20 nations with its digital economy, which accounted for 8.3% of total GDP in 2010 and is forecast to grow to 12.4% by 2016



The UK's housing needs are estimated to amount to at least 300,000 new homes per year for the foreseeable future.



26% of morning peak trains arriving to London were over capacity in 2014.



The combined excess capacity of morning and evening peak trains totalled 4.1% in 2014, higher than the average of 1.4% across 10 other major cities in England and Wales.



The direct cost of strategic road congestion was estimated at £2bn in 2010 and is anticipated to rise to £8.6bn in 2040 in the absence of intervention



UK airports exhibit delays above the European average. Estimates put Heathrow's runway capacity at 95%, Gatwick's at 80%, Stansted's at 59% and Manchester's at 53% (ITRC 2012). ITRC projects that Heathrow, Gatwick and Luton will reach capacity within the next decade.



Disruption from flooding costs the UK economy £1bn per year. 2.44 million properties are at *risk* of flooding from rivers and the sea, 3 million from surface water flooding, and 244,000 are at *high* risk of flooding. These numbers are set to increase in future due to population growth and climate change.

EXECUTIVE SUMMARY

National Needs Assessment Vision

The National Needs Assessment Executive Group has set out its vision for the UK's Infrastructure.

'The UK will invest efficiently, affordably and sustainably in infrastructure assets and services that will drive the economic growth necessary to enhance the UK's position in the global economy, support a high quality of life and realise a low carbon future.'

What is the National Needs Assessment?

The National Needs Assessment (NNA) has taken stock of the performance of the UK's infrastructure. In it we set out the steps that are needed for a national infrastructure system that is efficient, affordable and sustainable – an infrastructure fit for an innovative and productive global trading nation. In the NNA we identify the drivers of future change in infrastructure networks, including economic and population growth, technological change and climate change. We identify how these challenges can be addressed and future opportunities harnessed.

The NNA provides the National Infrastructure Commission (NIC) with a blueprint for its own National Infrastructure Assessment (NIA). It guides the NIC towards the immediate infrastructure interventions that are required now, the decisions needed to deliver services for the next generation and scenarios for our infrastructure needs until 2050.

Why we need world class infrastructure?

Modern societies depend on infrastructure to sustain their quality of life and business competitiveness. Our advanced economy increasingly relies on connectivity – bringing people together physically and virtually to innovate and trade. Investors need confidence

that our infrastructure systems are reliable and affordable.

The UK is a long way from having the modern infrastructure networks that are required by a world-leading economy. The perception of business people (recorded in the World Economic Forum's Global Competitiveness Report¹) is that the UK's infrastructure lags behind many of its global competitors and we are ranked 24th in the world. There is a significant and growing risk of severe drought impacts arising from the combined effects of climate change, population growth and environmental drivers. Congestion on Britain's roads and railways is already constraining economic growth.

Each industrial revolution has been based around a transformation of infrastructure: first with the construction of canal networks, then with railways, electrification of industry and the proliferation of modern communication technologies. Another infrastructure revolution is under way, which is enabling smart delivery and use of infrastructure services. We use smartphones to navigate around traffic jams and have household devices that optimise energy use. These are precursors to much more profound innovations that will transform the way we use resources like energy and water, and connect with each other. Much of that innovation will take place in surprising and spontaneous ways but co-ordination will be needed to secure the greatest benefit. Infrastructure is not a series of stand-alone assets. It delivers benefits through complex networks that need to be precisely managed. If we do not take the right steps, for example by establishing standards, we will lose out on the opportunities that the future holds.

The government has recognised these challenges. Infrastructure remains high on the political agenda. In 2010 Infrastructure UK was created and developed four national infrastructure plans, which for the first time brought together a pipeline of planned infrastructure investments. The National Infrastructure Commission has now been given a more strategic remit to recommend the long term direction for infrastructure. Government is also developing an industrial strategy with infrastructure as its central pillar.

Unfortunately delivery has fallen short of strategic ambition. Tough decisions have not been made. Incoherent energy policy has deterred large and small investors who would have been willing to back technologies from carbon capture and storage to photovoltaic panels. Households are paying more for energy and water than they need to because the right policies have not been enacted to promote efficiency and help reduce demand. Persistent delays in the decision on airport expansion threaten London's status as a global aviation hub. Many parts of the country do not benefit from ultra-fast broadband. Local planning policy is not delivering enough new houses where they are needed.

Demands on our infrastructure services are increasing and changing.

Modelling from the Infrastructure Transition Research Consortium (ITRC) projects the UK population will be 75 million by 2050. An increase in population tends to increase the total level of UK household expenditure and different regional demands for national infrastructure services. ITRC's macro-economic modelling projects UK GDP in the range £2.7–3.7Tn by 2050. The total energy demand in Great Britain could move from its current level of around 900 TWh/year to 1200 TWh/year depending on the adoption of potentially disruptive new technologies such as energy

storage and the electrification of heat and transport.

The adoption of digital communication by businesses has resulted in 20% of total ecommerce turnover in 2013 – an estimated £557bn. The UK performs well in digital communications. Internet penetration is at around 90%, there are more than 22.6m fixed residential and SME broadband subscribers (ITRC 2016), and in 2014 on average 38m adults (76%) in the UK accessed the internet every day. Broadband Delivery UK (BDUK) aims to achieve 95% superfast broadband coverage by 2017. The UK leads the G20 nations with its digital economy, which accounted for 8.3% of total GDP in 2010 and is forecast to grow to 12.4% by 2016

The UK's housing needs are estimated to amount to at least 300,000 new homes per year for the foreseeable future. 26% of morning peak trains arriving to London were over capacity in 2014. The combined excess capacity of morning and evening peak trains totalled 4.1% in 2014, higher than the average of 1.4% across 10 other major cities in England and Wales.

The direct cost of strategic road congestion was estimated at £2bn in 2010 and is anticipated to rise to £8.6bn in 2040 in the absence of intervention.

UK airports experience delays above the European average. The south east in particular faces major challenges. Estimates put Heathrow's runway capacity at 95%, Gatwick's at 80%, Stansted's at 59% and Manchester's at 53% (ITRC 2012). ITRC projects that Heathrow, Gatwick and Luton will reach capacity within the next decade.

Disruption from flooding costs the UK economy £1bn per year. 2.44 million properties are at *risk* of flooding from rivers and the sea,

3 million from surface water flooding, and 244,000 are at *high* risk of flooding. These numbers are set to increase in future due to population growth and climate change, even if investment in flood defences was to increase.

WHAT SHOULD BE DONE?

NEED FOR A NEW STRATEGIC, CONNECTED APPROACH

We cannot afford to spend our way out of infrastructure challenges simply by building new capacity. Nor would that be the smart choice. Technology, enabled by the right policies, provides the opportunity to use new and existing infrastructure capabilities much more efficiently. This will enable high quality affordable services. Infrastructure policy should involve a combination of increased capacity (where necessary), optimised by technology.

Technological innovation means that people are paying for infrastructure services in different ways – from Uber taxi car rides to bundled telecoms packages. Paying for road use with car tax and duty on fuel will become obsolete as vehicles become powered by electricity (a low tax fuel) and car ownership diminishes. Charging per trip with smart metering provides a more flexible way of paying for roads while enabling smarter management of demand.

Some of the greatest opportunities for innovation are in people's homes and workplaces – working and socialising with ultra-fast digital connectivity that removes a need to travel, smarter use of energy and storage which can be balanced with intermittent renewable energy supplies, energy generation with cheap photovoltaic cells, drastic reductions in demand for heating and cooling through intelligent design and retrofit, re-use of rainwater and sewage, resource recovery from solid waste – these are

all opportunities that should be harnessed in new and retrofitted buildings. Opportunities to reduce demand for water through recycling and reuse are currently not cost effective at a household scale but are being realised at community level.

We must reduce the cost of building and operating infrastructure. Innovation and training will be key. Use of offsite manufacturing and building information modelling (BIM) can reduce construction costs and provide data packages that are shared across multiple projects. Sensor technology will streamline new construction (with significant cost savings) and improve the whole life approach to maintenance and asset management. This technology can cut the cost of maintenance by identifying leaks in water mains and gaps in the thermal insulation of houses, for example. There are many other examples of advances in sensor technology leading to significant cost savings of new construction and of management and maintenance of infrastructure.

The UK needs a long-term strategic approach to infrastructure provision that can cope with future uncertainties (in population, technological development and climate), but commits to critical decisions when they are needed. Many aspects of infrastructure provision can be scaled up or down depending on changing needs – this particularly applies to scaleable supply systems and actions to manage demand – these are 'low-regrets' measures. On the other hand, certain critical decisions need to be made about major investment and policy commitments. Many of these decisions are now overdue.

Housing. Inadequate supply of housing is constraining Britain's economic opportunities. The current approach relying wholly on local planning processes and private housing is not delivering enough development, either via greenfield construction or through densification of existing urban areas. Uncertainty as to where new housing, population and economic activity will be located undermines our capacity to plan infrastructure services for the future.

Housing development will always require a balance between local and national objectives, as well as private homes and other types of housing such as rented accommodation. At the moment national needs are not being met by the local planning system.

The history of the last 30 years suggests that private sector provision is only able to meet around half the UK's total housing demand.

RECOMMENDATIONS

- Major housing proposals (approximately 5,000 units or more) should be considered as part of the Nationally Significant Infrastructure Projects (NSIPs) planning regime. If approved under this regime, individual housing proposals would have in-principle Government support and housing developers could then develop them in detail in partnership with local authorities and other organisations, and in combination with the required on and off-site infrastructure.
- The Government should enable the roll out of in-vehicle technologies to support the efficient use of road space and rapid development and implementation of autonomous vehicles for both freight and passenger traffic.
- The NIC should undertake a comprehensive review of public land available for housing. Once completed it should seek out opportunities to unlock this land for development through the provision of economic infrastructure.

Energy. Ensuring secure, affordable and low carbon energy supplies involves a range of actions to manage energy demand and provide new low carbon generation capacity. Uncertainty over energy policy has disincentivised investment. Population increase, economic growth and the need to decarbonise heating and transport provide upward pressure on electricity demand, but there are low-cost technologies and policies that could cut electricity bills for households and businesses. Demand response technologies and distributed storage will help to deal with intermittent renewable energy supplies. There is a lack of clarity on what the energy supply portfolio will contain. Without urgent delivery of new low carbon supplies, capacity margins will become alarmingly small and there will be a risk of missing targets in the fifth carbon budget.

RECOMMENDATIONS

- Recommendation: The Government should commit to a plan for low carbon electricity generation capacity which ensures security of supply through to at least 2035. To create a stable environment for these long term investments, Government should commit to a diverse mix of energy generation based on nuclear, renewables, gas and interconnectors and set out an expectation as to the approximate proportions of different sources of generation. For example, as set out by the Committee on Climate Change - 20-25% nuclear, 35-40% renewables, 25-30% Combined Cycle Gas Turbine and 10% interconnection². This should be combined with broad targets for the proportion of the energy mix to be derived from other technologies.
- Recommendation: As part of the National Infrastructure Assessment the NIC should set out alternative strategies for energy security post 2035. This includes use of technologies, such as Carbon Capture and Storage and electricity storage.
- Recommendation: Government and Ofgem should take a more proactive role in enabling a smarter energy system as a way to reduce the need for major new power projects and thereby reduce costs for consumers. The Government should establish a clear policy for reduction of energy demand in households and businesses and introduce consistent schemes to enable these reductions.

Transport. Transport systems are under relentless pressure from rising demand. Strategic investment in new capacity is required on the busiest parts of the highway network. This must be combined with steps to manage the use of road space more efficiently through the use of demand management and support for the uptake of driverless vehicles. Without these interventions the benefits of new capacity will be rapidly drowned out by increased demand. Electrification of the vehicle fleet will help to address the urgent challenges of local air pollution and carbon emissions.

Strategic investment is required to provide additional capacity on the most economically important rail routes. New rolling stock will also improve the passenger experience.

RECOMMENDATIONS

- The NIC should identify priority routes for capacity improvements on the strategic road, primary road and rail networks. This should include completion of the construction of HS2 Phases 1, 2A and 2B and the development of business cases for the extension of the high-speed rail network to Scotland, the South-West and across the Northern Powerhouse.
- To support the efficient use of road space and rapid development and implementation of autonomous vehicles for both freight and passenger traffic the Government should enable the roll-out of in-vehicle technologies.
- The Government should establish and implement new ways of funding road infrastructure. This should include consideration of a road pricing system. Any such system must enable users to understand their road use and make informed choices about their travel patterns

Road congestion in urban areas delays commuting and other economic activities. Local air pollution is harming people's health. There is an under-provision of public transport in several of the UK's large cities. Technologies, including smart ticketing and multi-modal travel information, will enable better use of public transport options. Active transport (cycling and walking) is disincentivised by bad urban design.

RECOMMENDATION

The Government should increase investment in the commuter rail network and other public transport to ensure the economic development of urban centres is not constrained by overcrowding and congestion. Substantive funding for transport should be devolved to local and regional authorities sufficient to allow them to invest in the growth of their economies.

A global service economy relies upon people being able to fly to emerging markets as well as long-standing trading partners. Continued delays in the decision about airport expansion are undermining London's status as a global aviation hub for the UK.

RECOMMENDATION

Following a decision on further runway capacity in the South-East, the Department for Transport should deliver a National Policy Statement which sets out a plan to achieve this capacity to serve the entire country's economic growth.

Digital. High speed connectivity is a necessary requirement for the digital economy. Innovation in fixed and mobile digital technologies will continue rapidly in a competitive global market. However, the pace of innovation can actually disincentivise investment. Government has a role in establishing standards, opening up networks and ensuring that high quality access is available even where it is less financially viable for commercial providers. The government has already set aside £530m to support the broadband delivery UK programme to provide fibre broadband to reach 95% of the UK by the end of 2017.

RECOMMENDATIONS

- Government should provide the private sector with incentives to roll out 'ultrafast' broadband coverage. Where the market fails to respond to those incentives, the Government should intervene to require that coverage is provided.
- The NIC should investigate the digital communications requirements of new and emerging infrastructure systems (such as connected cars), and ensure that the enabling digital technologies are put in place. There should be a particular focus on the capacity and capability of the digital network.

Water. The water sector in the UK has delivered good security of supply since privatisation but the risks of serious shortages in the future are now being recognised. Management of these risks should begin with more vigorous action to manage demand and continued work to reduce leakage. Where this supply is insufficient to keep up with the population pressure on demand and the impacts of climate change on water availability, timely steps should be taken to provide new supplies, while safeguarding and restoring water for the environment. Supply options include water transfers, storage, groundwater recharge, desalination and effluent re-use. Further investments will be required to renew wastewater assets to deal with an increasing population and meet improving standards of wastewater discharges.

RECOMMENDATIONS

- Government or NIC should review the need for changes in policies relating to the extension of metering, smart metering, new tariff structures and requirements for water efficiency and innovative technologies (e.g. rainwater and greywater recycling) in new building and refurbishment.
- Given the national impacts of a severe drought, the Government should review the case for establishing minimum standards of resilience for water supplies.
- NIC should work with the water sector to reduce the risks associated with the planning and promotion of new strategic water infrastructure schemes including water transfers and new storage.

Flooding. Flooding is estimated to cost the UK approximately £1bn per year in economic damage. Recent floods have illustrated the vulnerability of UK infrastructure to flooding. Climate change threatens to increase this risk in the future – indeed flooding was the largest risk in the Climate Change Risk Assessment³.

The Environment Agency in England and its counterparts in the devolved administrations have promoted a ‘whole systems’ approach to managing risks from river, coastal, groundwater and surface water flooding. This includes measures to retain water upstream in catchments, avoid inappropriate development in floodplains, install sustainable drainage systems in urban areas, and invest in flood defence where it is cost-beneficial to do so. Like any infrastructure system, ongoing expenditure on monitoring and maintenance is necessary to sustain the performance of flood defence assets. There are particular challenges in managing flood risk in communities where large scale flood defences are not cost-beneficial – innovations in property-level protection systems will help to reduce residual risk.

RECOMMENDATIONS

- The Government should continue to analyse flood risk at the scale of catchments and coastal cells. Resources should be allocated so as to minimise the economic risk of flooding. Further action should be taken to promote the uptake of property-level protection where community flood defences are not cost-beneficial.
- Government should establish large scale experiments to quantify the benefits of catchment-based flood management.



Solid waste. The percentage of recycled municipal waste in the UK has now reached 44.9%⁴. There is evidence that waste is now decoupling from economic growth. However, opportunities for recovery of valuable resources from waste are still under-exploited. For most of the last government administration there was no policy on waste. In a circular economy valuable resources will be recovered from waste and the quantities of waste being incinerated or committed to landfill will be minimised.

RECOMMENDATION

The Government should develop and implement strategies to encourage greater recycling and reuse. This includes a strategy to develop a circular economy to close the loop of product lifecycles.

We support a cross-sector approach to infrastructure

Responsibility for infrastructure is vested in a range of levels of government as well as in the private sector. People have many interests in infrastructure, which influences their quality of life and economic opportunities. Building infrastructure involves difficult resource allocation decisions and building in people's backyards. It is essential that the NIC engages with a wide range of stakeholders to build consensus around the nation's infrastructure needs and how they are to be addressed.

Our recommendations represent an integrated package of interventions, which should not be cherry-picked. Questions of where people live will drive all subsequent considerations of the infrastructure services that they will need. In the analysis in this report we set out pathways of infrastructure investment in each infrastructure sector which take account of the

RECOMMENDATION

The National Infrastructure Assessment should take an integrated cross-sectoral approach to the UK's future infrastructure needs. The NIA should consider the range of possible drivers of demand for infrastructure services and quantify policies that will manage and provide for those demands.

While we have made concrete recommendations for government and the National Infrastructure Commission we recognise that government cannot on its own fulfil all of the nation's infrastructure needs.

The coalition that has come together to conduct this National Needs Assessment commits to supporting the NIC in its development of the National Infrastructure Assessment.

WHAT WE MEAN BY INFRASTRUCTURE

Infrastructure provides the services that enable society and the economy to function. We often notice when it goes wrong or if it blights our lives. We ignore it when it functions properly. It is present in our everyday lives from the moment we boil the kettle, turn on the shower, journey to work and turn the light out to go to sleep. And even then it continues to work away tirelessly to ensure we can repeat the pattern all over again.

While it is tempting to generate a wish list of infrastructure programmes and projects to resolve our current challenges we must take account of the world we are living in. We face a number of challenges and constraints which must be factored into the needs of the assessment process.

Affordability

Government is seeking to balance the books and reduce public spending. While the desire to achieve a budget surplus by 2020 has been removed, public spending remains tight and local authorities have less money to deliver services.

Both domestic and business consumers face affordability issues. The United Kingdom has some of the highest energy prices in Europe for both households and industry.⁵ While infrastructure networks and assets require a revenue stream the government has to make difficult decisions around the balance between affordability and providing infrastructure services for all users.

One of the current challenges facing infrastructure delivery and its investors is the question of who provides the revenue stream. Traditionally funding has come from either the tax base or user charging. The regulated sectors – water, energy and communications –

derive the majority of their revenue from user charging. Households and businesses have become accustomed to this method and while there are some issues around affordability, in general the system is accepted.

However, there are other sectors where the principle of 'user pays' has struggled to gain traction. Road user charging is rarely used across UK roads. Technology exists to enable user pays and demand management on UK roads but the popular acceptance has yet to match this.

Investment

Within the UK a mix of private and public investment pays for infrastructure programmes and projects. Regulated sectors enjoy a high level of private investment due to the consistent approach to regulation and stable credit ratings. While regulation may have to adapt to the changing needs of users and the economy this should not be to the detriment of investor confidence.

The Infrastructure Pipeline, managed by the Infrastructure Projects Authority, has provided investors with a forward view of upcoming infrastructure programmes and projects. The long term programme approach to infrastructure delivery is welcome as it addresses stop-start investor concerns. For example, the Roads Investment Strategy, a five year programme, has provided the supply chain with a forward look at upcoming projects.

Energy, water, flooding, transport and digital all enjoy capital infrastructure programmes of five years and beyond. All sectors should approach a total expenditure approach to address shortfalls in maintenance spending which tends to operate on annualised budgets. This will enable a whole life approach to infrastructure investment which ensures that maintenance spending does not fall behind the level necessary.

Official UK Government sources suggest that between 2010-11 and 2014-15 £49bn has been invested in infrastructure from a combination of public and private sources.⁶ While welcome, this falls short of the OECD recommended target of £80bn per year by 2020–21⁷.

Population growth and demographic changes

Office for National Statistics suggests a UK population of 75 million by 2050. This will inevitably impact across the whole range of infrastructure needs, including demand for housing, transport and energy. In general, people are likely to live longer, migrate more, and concentrate in denser urban environments. Family sizes are getting smaller, creating additional need for housing and infrastructure.

The availability and affordability of housing poses a major challenge to the UK. Demand for housing is projected to keep growing. Increasing the housing supply will correspondingly increase demand across all infrastructure sectors including transport and energy.

Ageing Infrastructure

Much of the UK's infrastructure such as sewer systems, rail network infrastructure and housing stock have been serving the UK for over a hundred years; much longer than originally designed for. Many of these assets now need replacement or investment to extend their lives. Given current economic constraints, a strategic asset management approach is required to provide clear prioritisation and better performance.

Climate Change

Average annual UK temperatures over land and the surrounding seas have increased in line with global observations, with a trend towards milder winters and hotter summers in recent decades.⁸ The Paris Agreement is a significant step forward. 195 nations including the UK will 'pursue efforts' to prevent more than a 1.5°C increase in global temperatures. Current commitments to reduce emissions however, even if fully implemented, will still lead to an estimated 2.7°C rise by 2100.

The greatest direct climate change-related threats for the UK are large increases in flood risk and exposure to heatwaves and shortages in water. Since 1990, the UK has experienced eight of the ten warmest years on record and five of the ten wettest years – 2000 and 2012 were the wettest on record. The November 2004 to July 2006 drought was the equal driest period since 1932 and the April 2010 to March 2012 drought was equal driest since 1910⁹.

Technology

Rapid technology developments have potential to dramatically impact infrastructure across all sectors and across all infrastructure lifecycle phases including design; manufacture and construction, end user experience and access and maintenance and operations. Key technology developments include autonomous vehicles, drones, storage solutions for renewable energy and sensor technologies and the internet of things within manufacturing and construction, operations and maintenance. However, many of these technologies also present new challenges for regulation and safeguards that will need to be carefully considered in order to deliver the full potential.

Technology developments are both difficult to predict and are likely to have widespread influence on behaviour and user expectations



for infrastructure. Major infrastructure investments need to consider potential technology disruptions and build in flexibility and resilience.

Skills

With the growth in infrastructure investment, the infrastructure pipeline creates a demand for over 250,000 construction and over 150,000 engineering construction workers by 2020, driving a need to recruit and train nearly 100,000 additional workers¹⁰.

The required skills blend to deliver the investment plans will change over time leading to a need to retrain and up-skill around 250,000 of the existing workforce over the next decade in addition to the need to recruit new workers.

Technology changes and automation of services will change the nature of skills required to deliver and manage infrastructure. Use of offsite manufacturing, sensor technologies, digital information and Business Information Modelling (BIM) will alter the skills required by engineers and those delivering, operating and maintaining infrastructure.

Devolution

While this report primarily addresses the mix of UK-wide reserved powers and England-only responsibilities of the National Infrastructure Commission, many of the drivers, challenges, opportunities and options are the same across the UK. Much infrastructure policy is devolved and ICE therefore intends to take forward, with national partners, consideration of these issues in Scotland, Wales and Northern Ireland as part of its ongoing work.

As part of the NNA, we have held workshops and gathered evidence across the Devolved Nations, with a number of specific priorities identified.

Scotland

Major investment in strategic transport infrastructure is improving capacity in key sections of the network, reducing journey times between Scotland's cities by road and rail and preparing networks for the future.

The waste sector is improving but meeting our ambitious landfill diversion targets is dependent on waste infrastructure projects progressing smoothly through procurement.

Scotland's geography and areas of relatively low population density are challenges to universal digital coverage. The Scottish Government continues to lead the Digital Scotland Superfast Broadband Programme. The programme met its initial target of 25 Mbit/s speeds for 85% of households across the whole of Scotland (including commercial coverage). It plans to give access to at least 95% of premises by the end of 2017 and 100% by the end of 2021. In Scotland, 92.0% of premises were in areas with outdoor 4G coverage from at least one mobile network in May 2016 (compared to 98.8% in England) and 58.4% of premises in Scotland had outdoor coverage from all four 4G networks (compared to 74.7% in England). The Scottish Government and mobile operators recently agreed a Mobile Action Plan

The water and waste water sector has continued to improve although a recent spike in water quality issues has highlighted the need for continued focus in areas that have generally performed well. Energy and carbon efficiency will become even more important in future regulatory periods, as will water conservation.

Developments in flood warning systems are being delivered. Improvements in flooding infrastructure will be contingent upon the successful enactment of local delivery plans and continued capital investment. A mixture

of adaptive and mitigating measures is required to ensure that homes, businesses and critical services – healthcare, schools, energy supplies, transport – are resilient to the impacts of flooding.

The gap between capacity to supply energy and demand in the UK is narrowing. Over the next decade more than half of Scotland's electricity generating capacity will be retired. Policy uncertainty, rapid changes to renewables subsidy regimes and a continued lack of binding decarbonisation targets at a UK level have created insecurity in our electricity market and a system of generation and distribution which lacks resilience. Clear, long-term energy policy guided by expert advice is required in Scotland and the UK to ensure sustainable and predictable energy supplies now and into the future.

Local transport has suffered from a continued lack of investment in local roads maintenance, and the risk of further network deterioration without decisive action. Under investment in local road networks undermines strategic investments. The Scottish Government has implemented strategies to promote active transport but uptake remains modest.

Northern Ireland

Northern Ireland's ability to be globally competitive and to sustain its own economy depends on reliable and resilient infrastructure networks. The establishment of the Department for Infrastructure in May 2016 provides a cohesive government authority for flooding. Strategic flood maps and Reservoirs Legislation introduced in 2015 focuses on reservoir safety and mitigates the risk of flooding. Capital should be invested in new defences and resource into maintenance of existing assets to minimise the negative effects of flooding on communities and business.

Flooding impacts on the operations of all other infrastructure sectors. The failure of transport and energy services over the winter period due to flooding bears witness to this. While it is not possible to protect against all eventualities, nationally significant infrastructure should be resilient to flooding.

While there has been some progress with water main rehabilitation programmes and drinking water standards remain high lack of funds due to cuts has constrained further progress. In addition to water main rehabilitation, improvement in recent years to trunk main interconnection is welcome.

Wastewater infrastructure is an issue across Northern Ireland, with £750 million needed between 2020-2026 to address capacity and water quality issues around Belfast. The implementation of Sustainable Drainage Systems (SuDS), which provide better management of water quantity and quality, and improved social amenity, is recommended. The planning departments in the councils should become the champions for SuDS to ensure they are considered at the early stage of any application and are embedded in the development culture.

There are several issues in energy infrastructure provision in Northern Ireland. While some progress has been made since 2014, such as the expansion of the gas network and the restoration of the Moyle Interconnector, the largest and most important project — the North-South Interconnector — has still not moved into its construction phase. Without its successful delivery by 2021, Northern Ireland will be operating at an energy deficit due to the forthcoming Kilroot Restrictions, posing a serious threat to consumers in terms of price and security of supply.

Currently, there are gas and compressed air energy storage projects underway in East Antrim that have attracted EU funding. Though the delivery timeline goes up to 2021, these projects are of strategic importance. Their delivery would contribute to the security of NI's energy supply with up to 60 days of gas storage and 324MW of compressed air storage.

Government has set a target of 40% of electricity demand provided from renewable sources by 2020. Northern Ireland has met the initial goal of 20% renewables by 2015, but meeting the 2020 target will require significant infrastructure investment.

Northern Ireland's road network is our most valuable physical asset with a net worth of £32 billion. Overall investment in structural maintenance of the roads network is too low. The impact of years of underinvestment, combined with increases in the weight and volume of traffic has taken its toll — especially on our minor rural roads. The ongoing deterioration of the network and a growing backlog of maintenance now exceeds £1 billion. The NI Executive must prioritise maintenance of the network and not leave it to be funded by the leftovers from the financial monitoring rounds.

Despite these maintenance setbacks, there have been some positive developments. The completion of the A2 Shore Road and A8 Belfast to Larne dualling in 2015 has eased traffic in those areas, and the progress being made on the A26 Frosses Road and A31 Magherafelt Bypass is also promising. The York Street Interchange and A5 and A6 developments will provide improved connectivity and an economic boost and these should be completed during the next Programme for Government to realise their benefits.

Waste infrastructure is hotly contested in the public sphere, resulting in a slow pace of progress. There needs to be demonstrable Government leadership and focussed policies based on scientific data in order to efficiently manage our waste resources. Northern Ireland requires Energy from Waste (EfW) facilities in order to meet its waste management needs. The establishment of EfW facilities would not only negate the cost of exporting our waste and paying for some of the highest energy costs in Europe, but would also contribute to the circular economy through the creation of jobs.

Wales

Clear strategic leadership is required for transport infrastructure and services. However, the Welsh transport strategy is outdated and control of most of the network by 22 local authorities challenges integration. The focus on investment to aid economic growth in city regions and enterprise zones provides some useful direction. However, further development of governance structures is required before this approach can be properly implemented. The continued evolution of the Wales Infrastructure Investment Plan should assist in updating Wales' transport strategy and plan and in developing the forward plans around skills and capacity for delivery. Future capital and revenue streams for transport, particularly road infrastructure and for buses, appear likely to be inadequate to maintain and improve the network. Maintenance issues exacerbated by severe weather will require continuing focus. Local authority and Welsh Government revenue budget cuts are affecting asset management strategies with a drive to ensure that a low maintenance approach is integral to new infrastructure while impacts on existing transport infrastructure will become more evident.

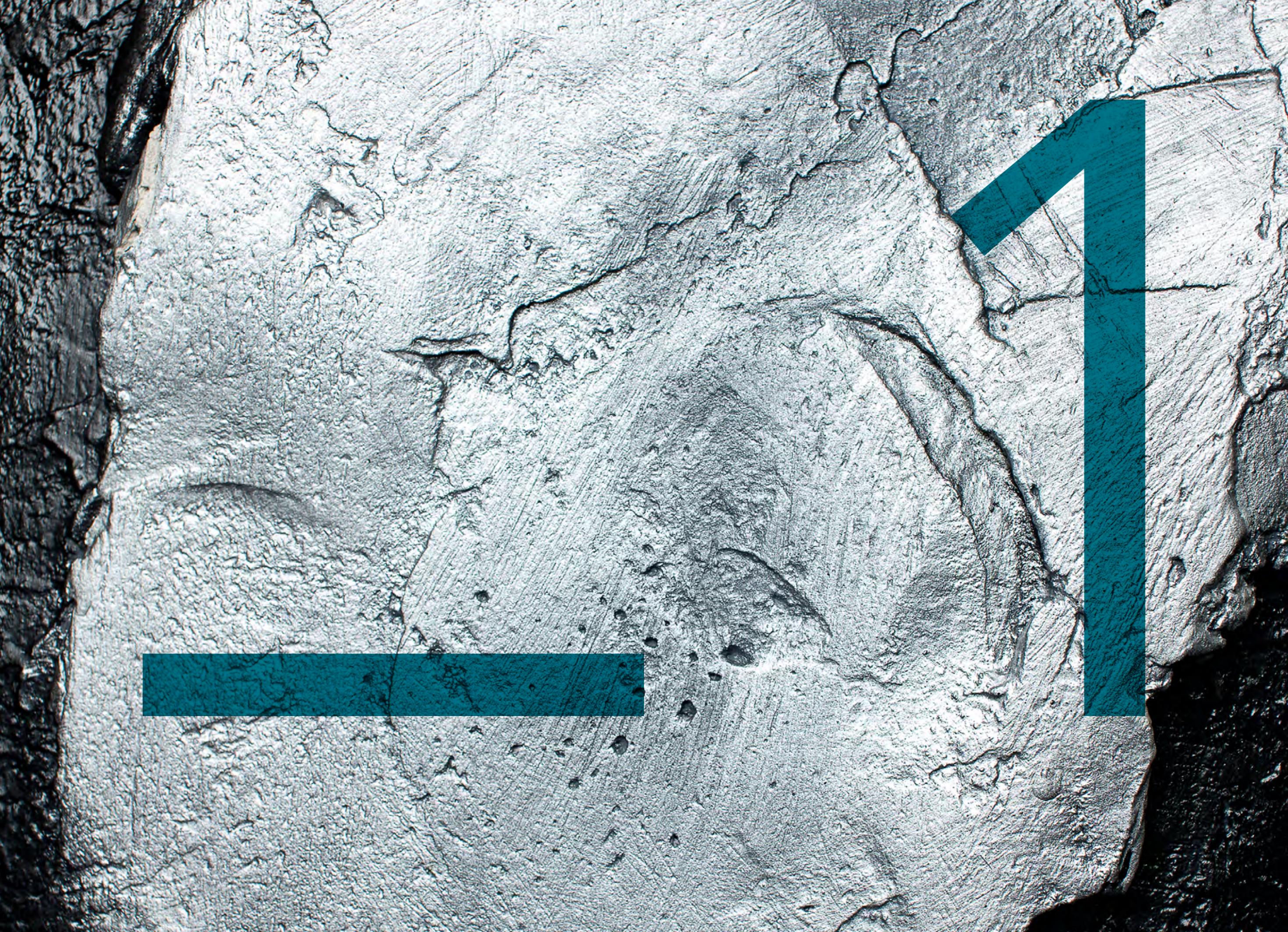
Wales' flood and coastal risk management infrastructure is in good condition overall and significant investment has been made over the past few years but there is concern about long term funding and maintenance requirements. The predicted impacts of climate change and an increasing asset base mean that continued and increased investment will be needed to minimise the impacts of flooding. Improvements to long-term asset management are required and more can be done in working with the natural environment. Catchment management could be used more effectively for flood risk management. Lead local flooding authorities and Dr Cymru Welsh Water should coordinate their efforts through their flood risk plans and the Asset Management Period to optimise flood management opportunities.

The Welsh Government is developing a water strategy. This will consider how water resources are managed to support communities and drive green growth, through the provision of ecosystem services benefits. The aim is for a water resource that is resilient, sustainable and managed in a way that optimises the benefits for Wales. In addition the Welsh Government is developing a draft Environment Bill. The main challenges to protecting the aquatic environment in Wales relates to legacy mining issues and diffuse pollution from agriculture alongside the pressures of protecting many designated and high quality water bodies. The relationship between the natural and built environments is important to the resilience and future proofing of the sector. Catchment management is an important part of the overall hydrological cycle and which can provide benefits across the built environment. It also reduces the level of pollutant treatment that water companies need to undertake and can be used to manage flood risk management. It also helps to manage diffuse pollution from rural and urban

sources. The ecological status of some water courses are failing against EU directives both in terms of quality and quantity.

The Silk Commission has recommended to the UK Government that there should be devolution of planning powers to approve energy projects of up to 350 megawatts. This would give Wales greater flexibility over its generation mix and could enable it to take greater advantage of its renewables potential, as has been the case in Scotland.

In 2010, the Welsh Government provided a strong strategic lead with Towards Zero Waste, a framework that sets out resource efficiency and waste management principles, outcomes and targets, explicitly promoting the closed loop recycling essential in moving to a circular economy. The aim - zero waste by 2050 - is to be achieved by ambitious (but statutory) targets of recycling or composting 58% of municipal solid waste (MSW) by 2015/16 and 70% by 2024/25. Good progress is being made - Wales is leading the way in the UK, recycling 52% of MSW. Despite Wales' progressive waste policies it still has a high landfill rate - 41% compared to 34% in England. It is estimated remaining landfill sites have a maximum of 10 years life as the zero waste regulations mean new landfill sites are unlikely. Wales will need to increase its Energy from Waste capacity. Hardly any Welsh waste is processed through EfW - only 5% in 2012/13 compared to 22% in England. There are no large-scale EfW facilities in Wales although two are planned.





DRIVERS OF INFRASTRUCTURE DEMAND

Introduction

The nature and scale of demand for national infrastructure services is driven by long-term changes in population, the economy, technology, society and the environment.

Investment in infrastructure will be challenged by a number of fundamental long-term trends that include:

- demographic developments (e.g. migration, ageing, household fragmentation and urbanisation)
- environmental factors (e.g. climate change)
- technological progress (especially information and communication technology)
- trends in governance (particularly decentralisation)
- an expanding role for the private sector
- an increasing need to maintain and upgrade existing infrastructures (OECD, 2007)

This section of our NNA draws on analysis undertaken by the Infrastructure Transitions Research Consortium (ITRC) and the written submissions received as part of the consultation. The magnitude of demand depends also on the nature and cost of services that are available, so demand cannot be analysed in isolation. Our projections contain a wide range of uncertainties because they are contingent on future policy interventions. Nonetheless, understanding of the drivers of change and consequent

possible scale of demand for infrastructure services helps to ground a national infrastructure strategy in quantitative terms.

Demand for infrastructure services

Demand for infrastructure services is changing. There are a number of factors that are influencing changing demand, which we refer to as 'drivers'. These include population and economic growth, climate change and technological change. Many of these factors are outside the direct control of decision-makers who are responsible for infrastructure but they need to be accounted for in their decision-making about the future. We do that by exploring possible scenarios for how these drivers might change.

Demography

The Office for National Statistics (ONS) projections gives a possible range of population growth in the UK. To understand the implications of that growth for infrastructure systems the ITRC population projection model extends the range of ONS projections and disaggregates the projections to a high enough resolution to be used for infrastructure planning.

Alongside population growth behavioural change could be driven by a range of factors including technology and digital communication. This may change work patterns (not necessarily reducing overall travel but changing travel patterns); ability to make productive use of travel time; younger people's changing attitudes to car ownership and use – all could have significant impacts on future demand for infrastructure. The ITRC population model is driven by three interdependent components: fertility (birth rate), mortality (death rate) and migration. To explore the range of potential demographic futures a consistent framework is required to determine how each component should be varied relative

Figure 1 (below): Total population change for eight scenarios (A-highest; H-lowest) compared against ONS high, low and baseline projections to 2100.

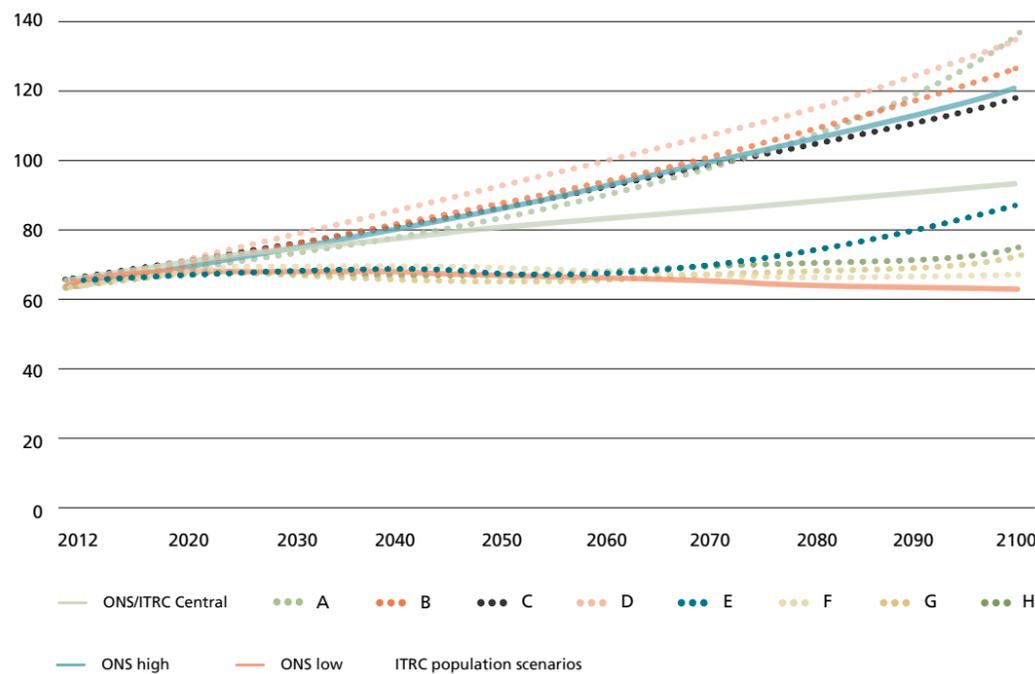
to the others. Scenarios have been specified by combining parameter settings ('high' or 'low') of the three model drivers, taking account of co-dependency between them. Cutting across these drivers is a 'prosperity' dimension which has a positive influence in population. For example, low mortality would be expected under a high prosperity scenario with the opposite occurring under low prosperity.

ITRC developed three scenarios, each with a high and a low dimension, resulting in a total of eight different scenario combinations. By assuming the specified values for each scenario it is possible to identify the behaviour of each model component under the eight scenario combinations. The following provides key results for i) population growth, ii) ageing, and iii) urbanisation and the implications for future infrastructure demand in the UK.

Population growth

Scenario results indicate that an important overall trend in the population projections is simply 'growth'. In the baseline, all regions will experience growth in the range of 20–35% before 2100 (Figure 1). The model produces a central projection of UK population in 2050 of 75 million with a range of 65 to 95 million. This has direct and significant implications in terms of demand for infrastructure services across all sectors.

At the regional level, the population of the south east grows faster than the northwest in all eight scenarios (Figure 2). There is a mismatch between population growth and infrastructure availability resulting in pressure on existing facilities. For example, growth in the southeast where transport congestion is highest in contrast to modest growth in Scotland where resources, such as water, are most abundant.



Ageing

The population structure is expected to age markedly in every region under all future scenarios. A more elderly population has important policy impacts in terms of the kind of transport services that need to be provided but also in relation to varying patterns of demand for energy, water and waste services.

The relatively slow uptake of information technology among more elderly consumers is also important. For example, by not leveraging the full potential of efficiency improvements such as integrated transport services or energy demand management in households.

The age profile varies significantly both geographically and between scenarios. Scenarios involving high migration and relatively slow growth in life expectancy will give rise to younger age structures which may trigger increased demand for infrastructure

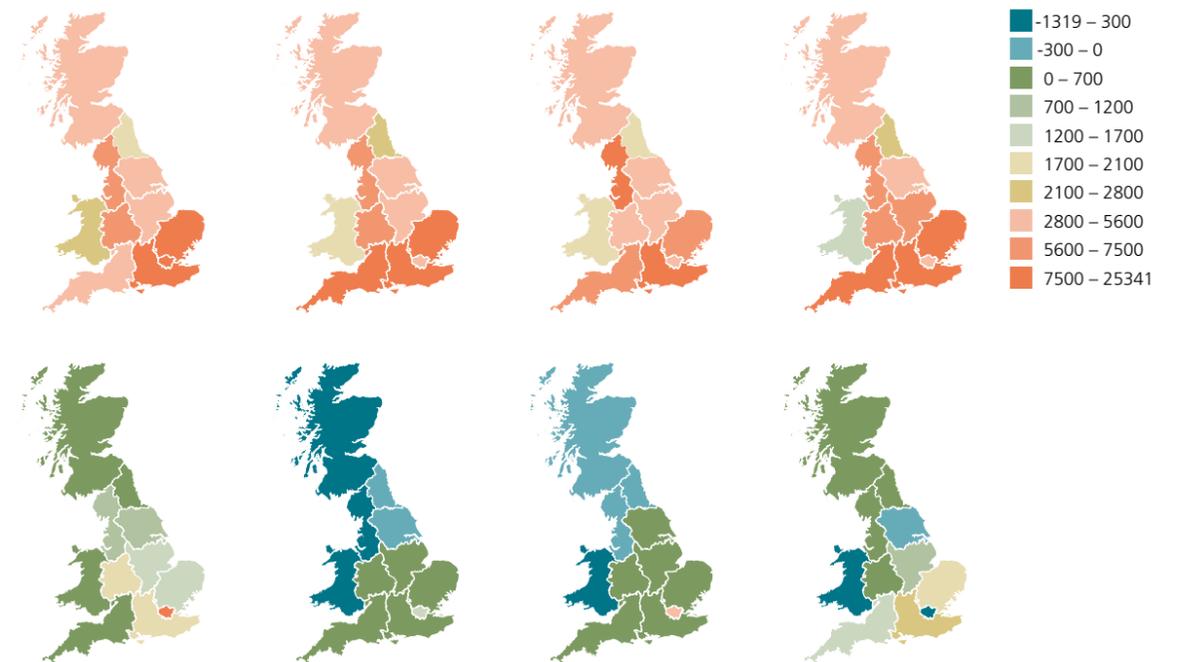
services and negatively impact the service network where it is already constrained such as in the south east.

Urbanisation

The prospects for urbanisation vary markedly across regions and between scenarios. The balance of demographic growth between rural and urban areas is a key uncertainty which has potentially profound implications for infrastructure policy.

Urbanisation also has governance implications. In the UK, local authorities have traditionally played a central role in some infrastructure sectors (e.g. waste and transport), while in others (e.g. energy) they have become increasingly active in recent years. This has opened up opportunities for greater coordination of infrastructure development at a local level, albeit in the context of notable limitations on local government finances.

Figure 2 (below) Geographical disaggregation of ITRC population scenarios



Economy

There is widespread recognition of the link between infrastructure and economic growth. Analysis by the IMF has shown that in a sample of advanced economies, a 1 percentage point of GDP increase in investment spending increases the level of output by about 0.4% in the same year and by 1.5% four years after the increase¹¹. If the national infrastructure stock is to meet the needs of a growing economy it is essential to forecast how the demand for each of the key sectors of infrastructure may change under different economic scenarios.

Scenarios were generated from Cambridge Econometrics' (CE's) MDM-E3 model of the UK economy and are based on the following sets of assumptions:

- UK population by region – the model used the eight demographic scenarios discussed above as direct inputs for generating economic scenarios
- World economic growth – scenarios were developed by CE to represent a range of world economic conditions that affect UK international trade with the rest of the world. Three variants were used:
 - Central: a baseline view with non-UK economic growth averaging 3.5% p.a. over 2010–20, and 4–5% p.a. over 2020–50
 - High: average non-UK economic growth of 4% p.a. over 2010–20, rising to 5–6% over 2020–50
 - Low: average non-UK economic growth of 2% p.a. over 2010–20 and growth of 3–3.5% p.a. from 2020–50
- Fossil fuel prices –based on the Department of Business, Energy and Industrial Strategy (DBEIS) fossil fuel-price assumptions from the most recently updated energy and emissions projections publication extended to 2050 (DECC, 2012).

Economic trends

Global economic growth affects UK economic performance through changes in prices and patterns of trade. An increase in population tends to increase the total level of UK household expenditure and different regional demands for national infrastructure services. The direct effect of an increase in population is an increase in the level of UK household expenditure, principally on services rather than manufacturing. While population scenarios may be similar in their projections of total population, differences in demographic structure (i.e. proportion of working age) introduce supply-side differences in the availability of labour, altering wages and household incomes.

Economic change will affect the population's ability to utilise infrastructure services. For example, higher GDP is likely to result in higher demand for infrastructure services as people tend to consume more energy and travel further and more often. Economic growth may also affect government's and infrastructure owners' ability to invest in infrastructure systems.

ITRC's macro-economic modelling projects UK GDP in the range £2.7–3.7Tn by 2050. In each projection, the scenarios indicate that services will continue to dominate Gross Value Added (GVA) by 2050, with activity concentrated in London and the surrounding regions, a reflection of the continued dominance of these regions in the underlying population projections.

Energy prices

Global fossil fuel costs affect operating costs and transport costs in particular. Increased fossil fuel costs will therefore reduce levels of demand for some services. National policy measures such as carbon taxes may also affect these costs but are generally assumed to be outside of the models.

Climate change and resilience

The committee on climate change reports that the greatest direct climate change-related threats for the UK are large increases in flood risk and exposure to high temperatures and heatwaves and shortages in water.¹² For example, a general increase in winter temperatures is expected to reduce energy demand used for heating during these times. Conversely, warmer summers will require more energy for cooling purposes.

Changes in temperature and rainfall will place additional pressures on infrastructure, in particular the rail, road, water and energy sectors.¹³ Climate change will also affect the availability of water resources and the potential for extreme loads on infrastructure systems. Flood management systems will therefore need to take into account for this changing risk through time.

Further to a pressing need for climate change mitigation, resilience is an important driver of demand. Resilience often requires reconfiguration and retrofitting (e.g. of buildings) as well as the provision of new infrastructure that is flexible and easily adaptable to new priorities and changing needs.

Technology

Technology advances have potential to dramatically impact all infrastructure sectors from how it is built and delivered (internet of things, 3D printing, offsite manufacturing, electric and autonomous freight), how it is powered (mainstream electrification of transport and heat, domestic energy storage and localised power generation by renewables or micro-generation), how it is operated and accessed (autonomous vehicles, internet of things and big data), and how it is maintained through sensor based condition monitoring.

While it is difficult to predict the scale and pace of the impact of technology it is clear that there are some new challenges that require national policy and legislation consideration if the maximum benefits are to be delivered. These potential benefits include reduction in carbon footprint, reduced operating costs to users and infrastructure providers, greater influence of demand for transport and energy and improved quality of life. Key challenges exist in data management, safety and security as technology enables more automation and reliance upon it and access to personal information in an unprecedented scale.

The ITRC model broadly assumes that choices about the uptake of technology lie within the strategic choices available to decision-makers, while acknowledging that technological development more broadly is a global process out of control of a national decision-maker. However, disruptors are finding new ways to circumnavigate traditional economic systems and create new ones – as UBER has done with the taxi trade and AirBnB with hotels and guest houses. That gives a greater role to users, and so decisions on the uptake of technology are likely to be shared between users and decision-makers. The largescale, nationwide application of a specific technology (e.g. smart meters, domestic energy storage, shale gas extraction, carbon capture and storage, desalination, road user charging, autonomous vehicles) is within the authority of national legislation and regulation whereas some external technology-related factors, such as global energy prices, are considered to be beyond anyone's control.

Behaviour

Similarly, there are many processes of behavioural change that are largely outside the control of infrastructure decision-makers. For example, ITRC treats demographic changes like household size or internal migration as external variables in the analysis, even though they will profoundly affect demand for future infrastructure services. On the other hand, behavioural instruments that are intended to directly influence the demand for infrastructure services, such as road-user charging and energy 'demand response', are taken as being part of the infrastructure strategy and have an assumed effectiveness. Processes and technology should be used making it easy for people to make choices that ultimately benefit them.

DEMAND OUTLOOK BY INFRASTRUCTURE SECTOR

ENERGY

Historical demand for energy in the UK

The electricity and gas sectors hold the biggest share of energy infrastructure assets in the UK. Until 2005 electricity consumption had steadily increased over the whole period of recent history largely due to the penetration of electrical equipment and increasing numbers of end uses for electricity in buildings. Gas consumption has grown at a much greater pace, reaching a maximum of over 1,100 TWh in 2004, from 171 TWh in 1970 (Figure 3). Such growth has been spurred by the oil shocks and discovery of the oil and gas resources in the North Sea in the 1960s/1970s, and has been further accelerated by market liberalisation in the 1990s which has made gas the fuel choice for power generation.

Total energy consumption in the UK has been decreasing over the past 10 years. In 2014, primary energy demand was 6.3 per cent lower than in 2013, caused mainly by record warm weather and decreased demand for heating (DECC, 2015).

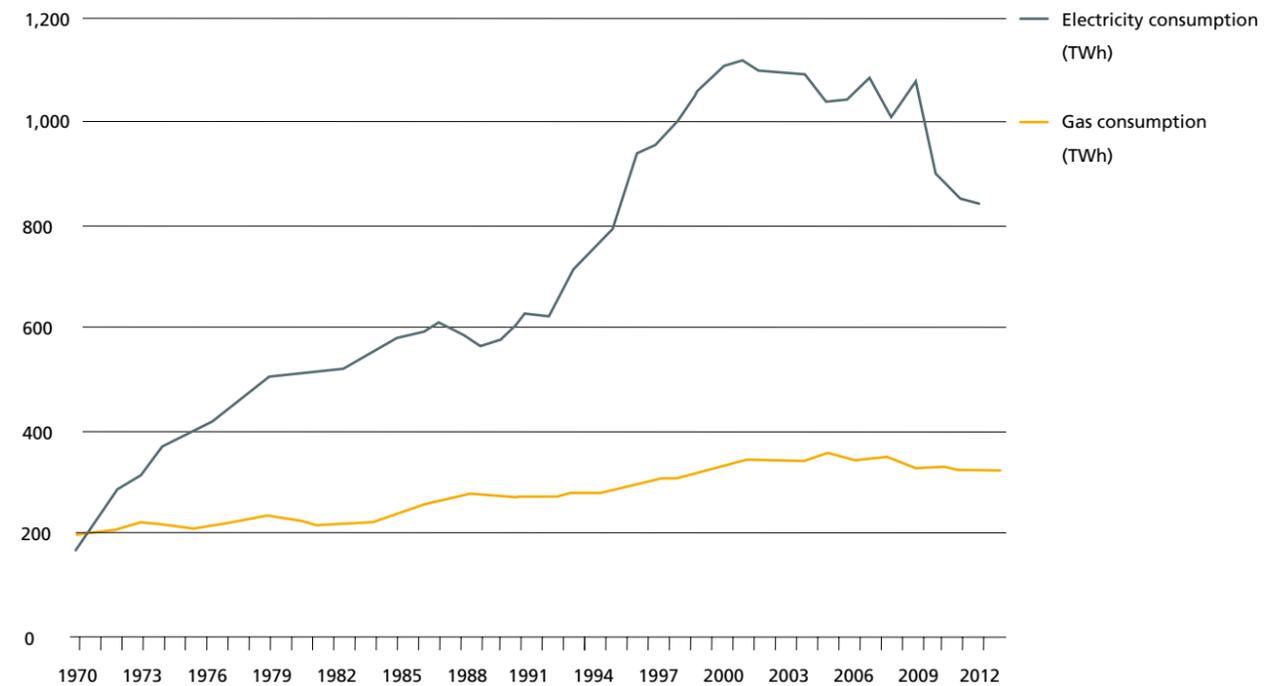
Future demand for energy

Population and economic wealth are projected to grow under every ITRC scenario, which will increase the demand for electricity and heating services. A growing population together with increasing numbers of home appliances and consumption of electronics means that electricity demand will increase over the long term. The economic structure of the UK is shifting from energy-intensive to higher value, lower energy intensity, which will drive down energy use from industry. By contrast, a larger proportion of the population holding jobs in services and professional and managerial occupations will lead to greater potential to telework and flexibility. This may change the pattern of demand away from shared offices to individual homes which are generally less efficient.

Smart grids and meters will contribute to decreasing demand by providing greater flexibility and shaping consumer behaviour. Similarly, energy efficiency, demand response and stronger interconnections will enable more effective management of peak demand. System transition strategies involving high levels of electrification of transport and heat, which are attractive for the decarbonisation agenda, will require very large increases in electricity generation capacity (especially gas-fired power generation) to meet peak demand. Conversely, distributed generation with storage will serve to decrease electricity peak loads.

Main demand drivers	Effect on demand
Population growth	↑
Climate change altering patterns of average and extreme precipitation	↑
Increasing environmental standards	↑
Sustainable drainage systems	↓
Household water demand reduction	↓

Figure 3 (below): UK electricity and gas consumption 1970-2014. Source: DECC (2015)



TRANSPORT

Historical demand for transport in the UK

Demand for transport infrastructure has grown dramatically over the past 60 years (Figure 4). This has been driven by a variety of factors, including the increasing affordability of travel due to economic growth combined with relatively low costs, population growth, and societal changes such as increasing numbers of female drivers.

In the mid-1950s road travel in Britain amounted to around 60bn vehicle kms per year. This was estimated to have increased to 488 bn vehicle kms by 2012. Seaports handled 257.9m tonnes of imports in 2012 (almost double the 1980 figure) and 135.1m tonnes of exports, while British airports were used by 220.6 million terminal passengers. In contrast, the growth in rail trips has been more moderate, with 58.4bn passenger km in 2012/13 compared to an average of 40bn passenger kms at the end of the 1990s (DfT, 2010 & 2013).

There is evidence that car trip growth levelled off in the early part of the decade but this is likely the effect of the economic slowdown during the period 2008-12. It is likely that peak demand has not occurred yet as further growth is projected.

Future demand for transport

The substantial population growth projected in coming decades means that total travel demand will almost certainly increase even if travel per person is static or declining. Moreover, despite having the potential to ease congestion at peak commute times, telework and greater flexibility may also mean that a larger proportion of the workforce will have more than one job, increasing the need to commute. In addition, as the population ages, the number of some peripatetic jobs like social care will also increase, driving the demand for transport services upwards.

Main demand drivers	Effect on demand
Population growth	↑
Aging of population	↑
Increase in economic wealth	↑
Policies promoting modal shift	↓
Policies promoting demand management techniques	↓
Pricing policies (congestion charges, parking levies)	↓

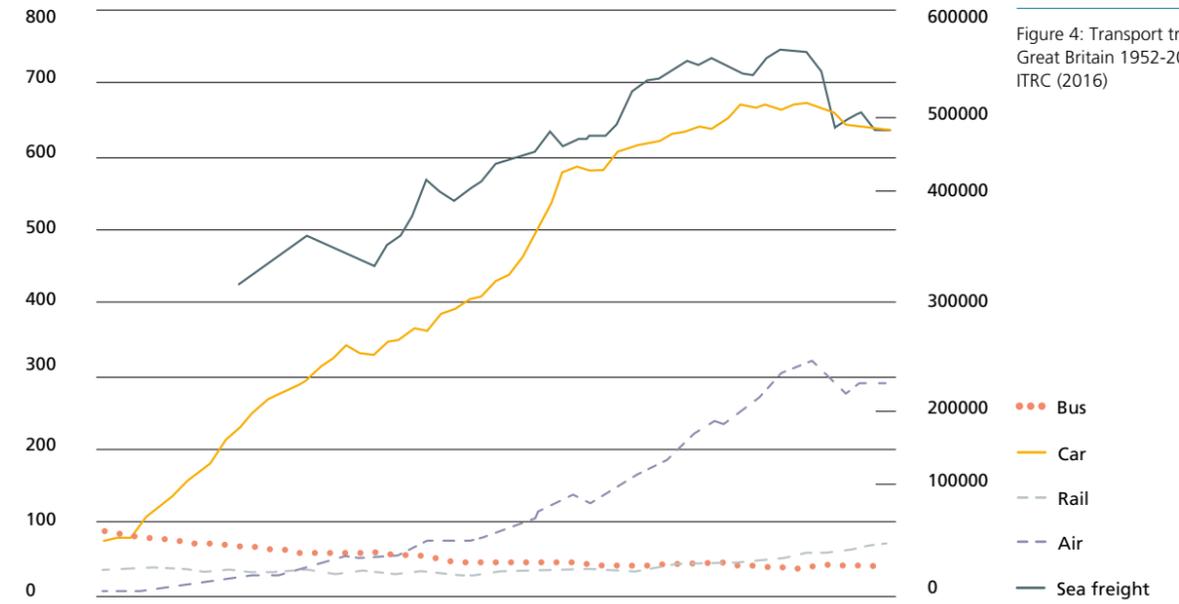


Figure 4: Transport trends in Great Britain 1952-2013. Source: ITRC (2016)

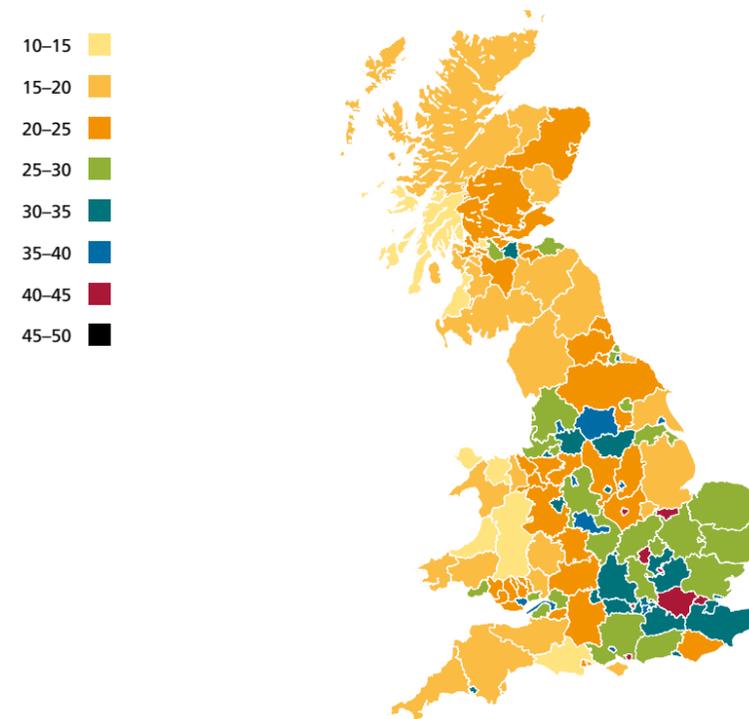


Figure 5: Possible scale of traffic growth without demand management strategies



Increase in economic wealth means that more transport services will be needed to support an increased demand for people to travel and the supply of goods. Economic growth is likely to be centred on London and the surrounding regions giving greatest pressure on its infrastructure.

Conversely, policies promoting modal shifts towards short range electric vehicles for urban use, light rail and tram systems, and walking and cycling will relieve stress across networks. The impact will be geographically uneven: modal shifts are more likely to be successful in denser urban areas compared with rural places.

Demand management techniques such as promoting car sharing or smart planning of trips - made possible by the increasing penetration of information technology - will also have a substantial impact on demand reduction. Rerouting, remodeling, retiming and reconsidering travel all contribute to make best use of existing infrastructure. Parking policy, road space reallocation and other policy interventions also play a role in managing demand.

While predictions on the impact of autonomous vehicles on transport demand are divided, autonomous vehicles could increase road travel demand. There is potential to increase road traffic density, route around congestion using autonomous decision making as well as open up road travel to new groups of society. However, this may not mean that additional roads are needed, rather the update of the existing road network to support widespread autonomous vehicle usage. The Department for Transport has launched a consultation on future vehicle technologies and set aside research budgets for technology developments as well as development of legislation and policy so that autonomous cars can be legally used and insured on UK roads.

Transport economics may also play a big role in decreasing demand. Transport costs are linked closely to energy price changes, and therefore to both energy supply policy and changes in energy demand elsewhere. This could place future supply of affordable transport at risk if, for example, no transition was made away from 'conventional' fuels for road transport and fossil fuel supplies were to dwindle in the latter part of the century, while demand increases in other industry sectors and countries. Pricing policies, such as road user charging or workplace parking levies, can increase user costs and reduce demand.

DIGITAL COMMUNICATIONS

Historical demand for digital communication in the UK

The UK currently has a very advanced digital communication infrastructure system comprising communication (fixed and mobile telephony, broadband, television and navigation systems) and computation (data and processing hubs). Much of this infrastructure has been provided in a relatively short space of time compared to more traditional forms of infrastructure. For instance, while the US maintained the largest internet penetration rate throughout the 1990s the UK rapidly caught up in the first decade of the 21st century (Figure 9). Yet because of the complexity and rapid innovation compared to other physical infrastructure sectors the future of digital communication system is highly uncertain, which makes it challenging to analyse future trends.

Future demand for digital communication

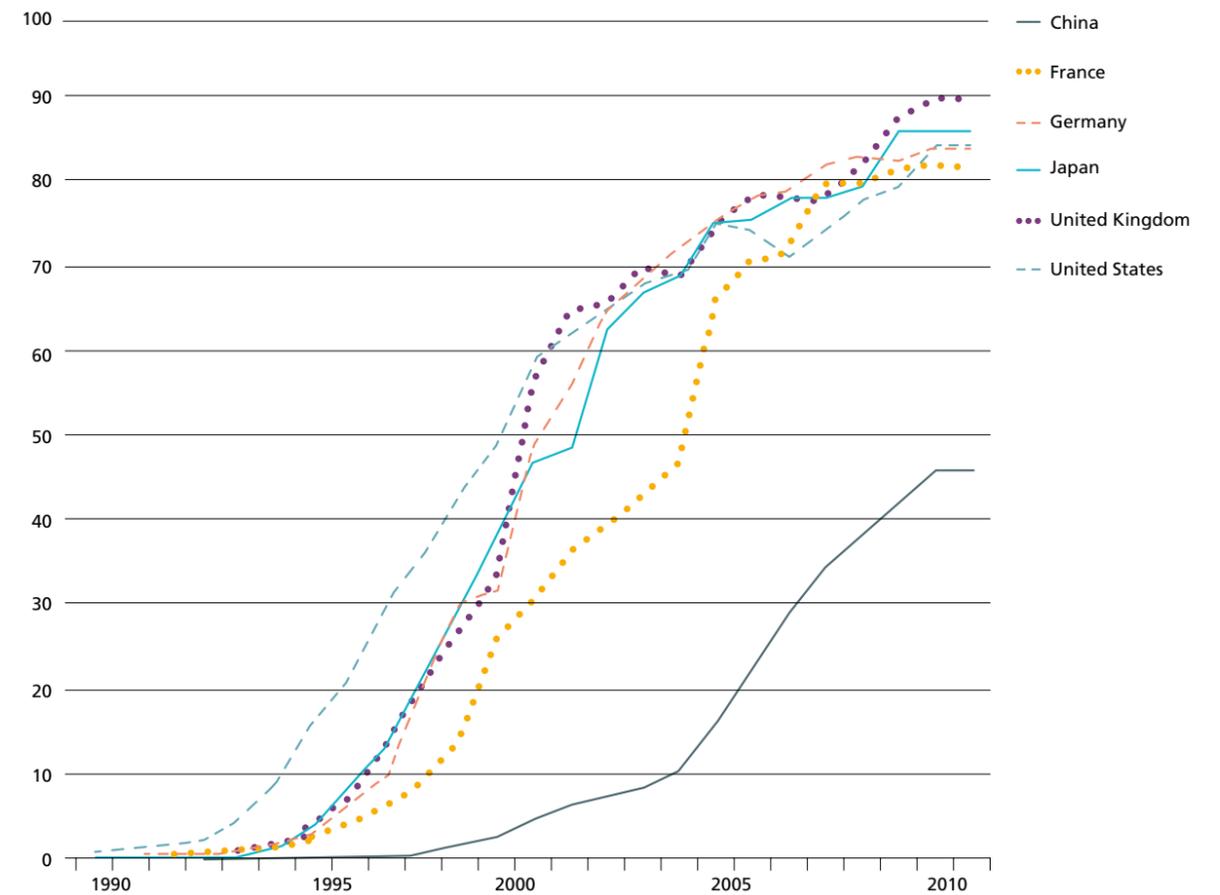
Population growth and higher purchasing power of consumers and businesses will translate to higher demand for digital communication services and digital infrastructure. A shift in focus of policy from basic access to *access quality* - represented by the European Commission's Digital Agenda for Europe to provide internet access speeds to all EU citizens of 30 megabits per second (Mbit/s) with over 50% of citizens subscribing to a connection over 100 Mbit/s by 2020 - will drive up demand.

Continued development of the digital economy will increase consumption of digital communication services - the UK is one of the top economies in Europe for the proportion of sales arising from e-commerce. The adoption of digital communication by businesses has resulted in 20% of total ecommerce turnover in 2013 – an estimated £557bn (ONS, 2014).

Shifting cultural and work habits will play an important role in further driving demand (e.g. telework). The internet of things is increasingly being integrated into business and personal life in the UK, changing digital services consumption modes and lifestyles. Digital infrastructure will support high quality connection through fixed and mobile networks right across the country enabling demand management, high quality services and greater resilience.

Main demand drivers	Effect on demand
Population growth	↑
Increase in economic wealth	↑
Regulation to provide minimum and better quality access to digital communication	↑
Development of the digital economy	↑
Cultural and work habits	↑
Increasing integration of 'the internet of things' into business and personal life	↑

Figure 6 (below): Internet penetration rate (per 100 people) for the top six economies 1990-2014. Source: ITRC (2016)



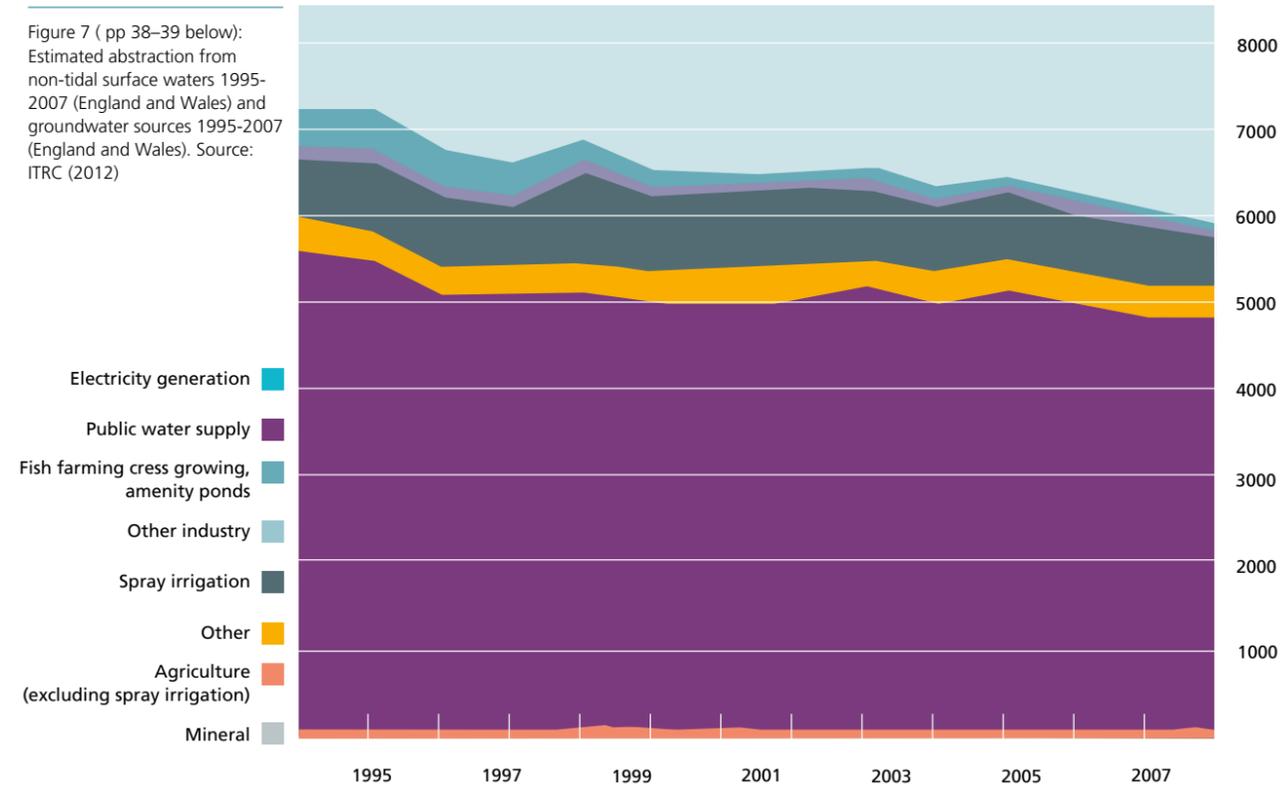
WATER

Historical demand for water in the UK

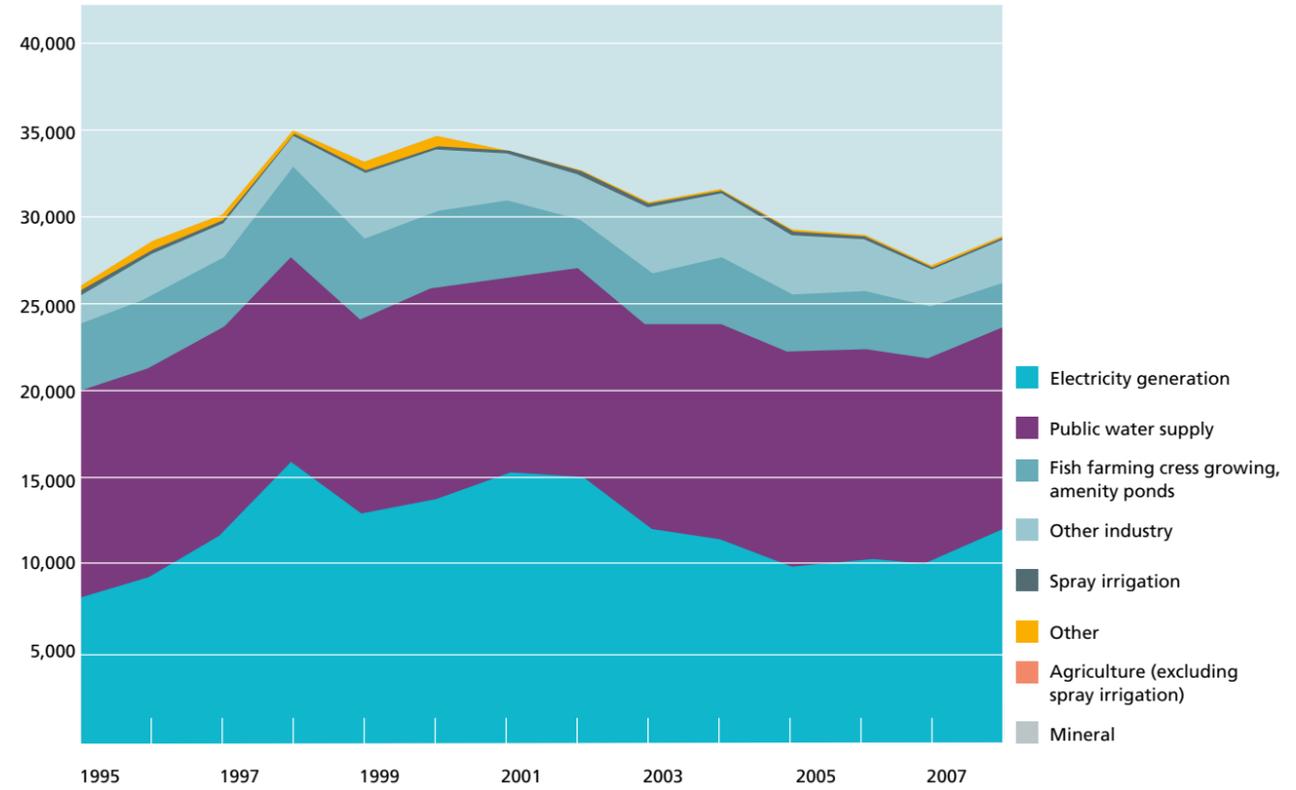
Demand for water is divided into domestic and non-domestic uses. Non-domestic demand for water comes from industry, power generation, primary production and commerce (EA, 2012). Over 1995-2007, power generation was the biggest consumer of water, whereas public water supply was the largest abstractor of non-tidal surface and groundwater sources (Figure 10). Leakage is an important contributor to total demand, constituting 20%-25% of distribution input in public water supplies (Water UK, 2010; Ofwat 2011). This percentage has however been declining since the 1990s (Tooms et al., 2011) and now all water companies are operating to meet sustainable economic levels of leakage agreed with the regulators.

Mean per capita consumption (PCC) remained at around 150 litres per person per day (l/p/d) over the 20 years to 2008 in England and Wales. The impact of domestic metering and increasing efficiency in white goods is resulting in a declining trend of increase in PCC, with metered customers typically reducing consumption by up to 10%, however the greater efficiency of white goods has been offset by the increased discretionary water usage for hygiene / leisure and increasing affluence. This is in line with the demand of other European countries, although a continued increase in water use efficiency is possible (Defra, 2008).

Figure 7 (pp 38–39 below): Estimated abstraction from non-tidal surface waters 1995-2007 (England and Wales) and groundwater sources 1995-2007 (England and Wales). Source: ITRC (2012)



Main demand drivers	Effect on demand
Population and economic wealth growth (especially regional)	↑
Metering mechanisms	↓
Charging mechanisms	↓
Leakage reduction	↓
Regulation and educational policies	↓
Management of water sector's interdependencies with other sectors (especially energy)	↓



Future demand for water

Demand for water is expected to increase with growing population, economic wealth and climate change. Demand in South East and East of England will grow most rapidly owing to high concentrations of population and economic activity. At the same time, available supplies are likely to reduce due to environmental pressures, drought and climate change. This will place the area under further water stress, as the high population density results in per capita precipitation broadly equivalent to arid regions of the world in spite of its higher yearly average rainfall.

The following water company areas were classified as areas of serious water stress by the Environment Agency and Natural Resources Wales (2013 classifications):

- Affinity Water
- Anglian Water
- Essex and Suffolk Water
- South East Water
- Southern Water
- Sutton and East Surrey Water
- Thames Water

Water metering will contribute to improvements in system efficiency as well as reducing water consumption, but is controversial because it is seen as a limit to personal freedom. As at 5 March 2014, 41% of customers in England and 34% of customers in Wales paid for water by a meter (Water Meters: the rights of customers and water companies, House of Commons Briefing Paper Number CBP 7342, 29 October 2015).

Companies' forecasts of domestic metering are show a planned increase to 61% by 2020 (in excess of 70% in the south east), Domestic metering typically reduces PCD by 15 L/p/d (Walker, 2009). Similarly, water charges may also lead to a reduction in consumption, but the pressure on low-income households caused by rising water bills (Defra, 2011) coupled with the unacceptability of disconnecting households from the water supply even if they cannot or will not pay bills (Walker, 2009) make increasing the cost of water increasingly impracticable. Nonetheless, the extension of domestic metering (in many instances with smart meters) is likely to be followed by the development of new and innovative tariffs.

Regulation (i.e. building and plumbing codes) and educational policies could also contribute to demand reduction but indication from Government is that this is unlikely to be implemented because it is neither socially nor politically acceptable. Such approaches would be encouraged by the Government's proposed abstraction reform, although the approach to permitting under reform could potentially lead to a reduction in the volume of available water to all abstractors. Water UK estimates this reduction could be up to 50% in some areas.

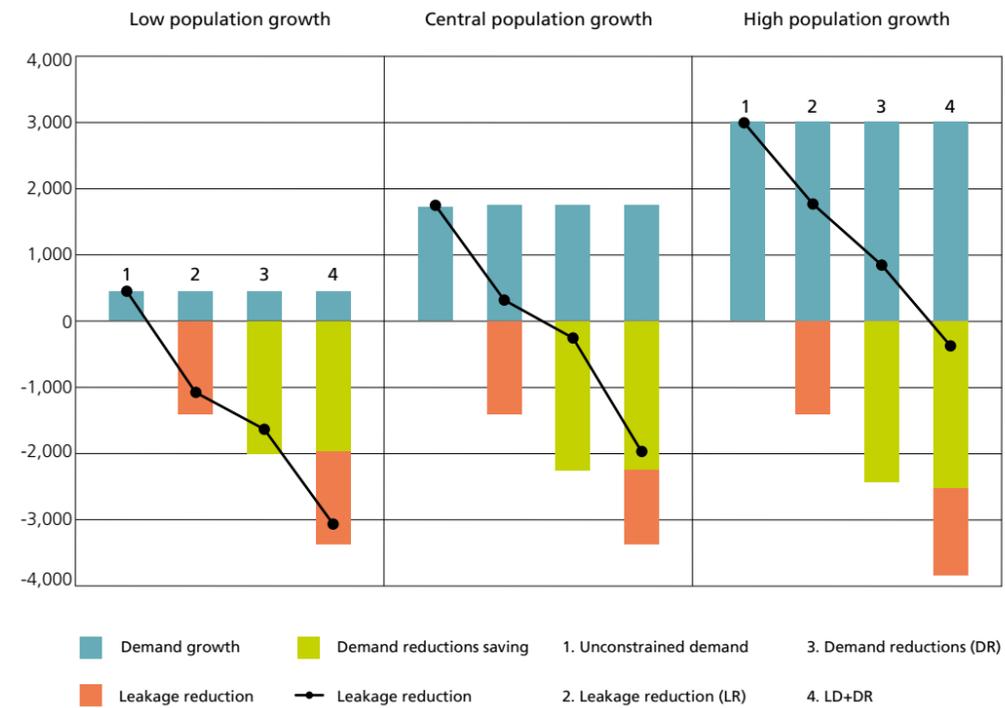


Figure 8: Demand pressures and possible demand reduction

WASTEWATER

Historical demand for wastewater in the UK

A programme to improve wastewater treatment has been in place in Europe since the early 1990s, driven by legislation to improve environmental quality in rivers and coastal waters. The result in the UK has been the minimisation of untreated and primary treated sewage discharged into the environment, as well as the increase in tertiary treatment from serving less than 15% of population in 1990 to over 40% in 2009 (Figure 9).

The volume of wastewater treated reflects per capita daily water use, currently about 150 L/day in the UK, most of which is returned to the sewerage system. However, demand is also affected by effluents of industrial users and urban surface runoff collected by the sewerage system. These additional sources introduce challenges: industrial users may discharge pollutants that are difficult to remove from wastewater, whereas urban runoff increases liquid volumes that must pass through the sewers, especially problematic at times of severe storms and flooding, for combined sewerage systems.

Future demand for wastewater

Population increase will require greater sewerage and treatment capacity with the potential need for expanded network size and trunk sewer capacity to accommodate increased wastewater volumes. Climate change, through changing patterns of average and extreme rainfalls, will also add pressure to increase volumetric requirements if sewer surcharging and flooding of foul water are to be avoided (some sewerage systems convey both domestic wastewater and surface runoff and the volume swells considerably during storms).

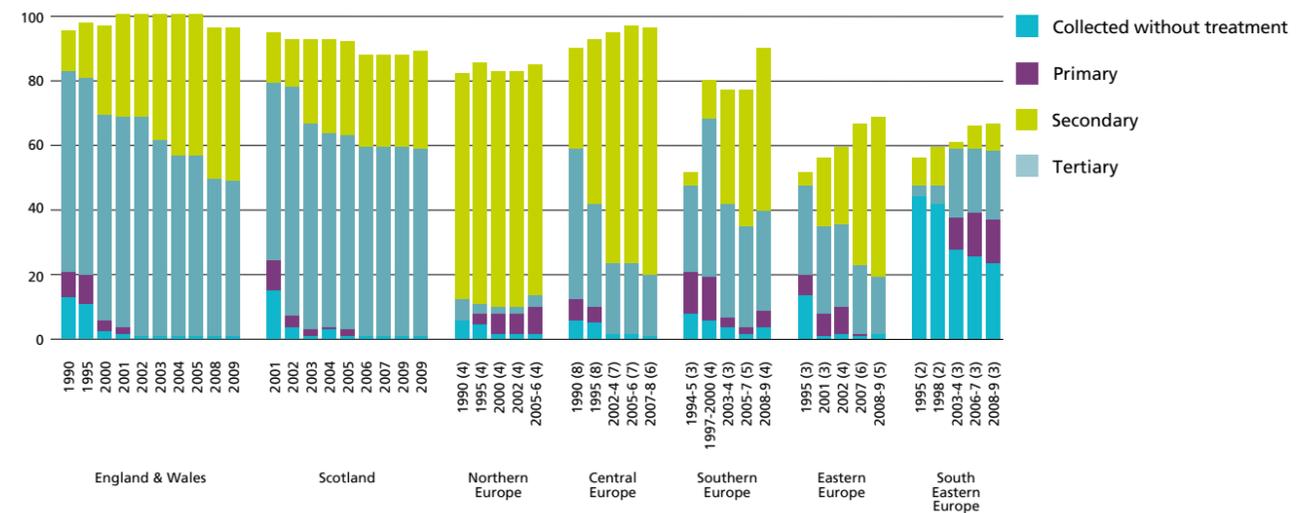
Coupled with population growth, the need to meet environmental standards will drive up wastewater treatment demand since receiving

waters in the environment are limited in their capacity to assimilate the waste for a given effluent standard. Even for effluents treated to current regulatory standards there is a limit to the population size able to be supported by available receiving waters. Although this does not appear to be an issue for England and Wales in aggregate some water catchments are already potentially threatened at low flows. Examples include the Tame at Minworth, north-east of Birmingham, the Soar at Leicester and the Avon at Coventry, which requires wastewater effluents to be pumped to other catchments. This is prior to consideration of the tightening of environmental standards in response to 'new' pollutants.

Conversely, sustainable drainage systems, such as reed beds, swales and infiltration ditches to permeable paving and allowing for discharge directly to the ground will decrease demand for wastewater treatment. These measures permit the detention of runoff and its absorption close to its source. An alternative strategy for reducing demand is reduction of household water use by harvesting rainwater and re-using grey water. However, the technology for reuse at household scale is currently not cost effective, particularly for the existing household stock – it can be more cost effective where there is significant new build and managed recycling of water can be part of planned development at the community scale. The notion of managed recycling is important, it requires local / distributed treatment of wastewater for re-use in non-potable applications such as WC flushing, requiring dual reticulation systems as well as dual treatment. It also requires clear codes of practice in place with consumers to avoid cross-contamination of supplies.

Main demand drivers	Effect on demand
Population growth	↑
Climate change altering patterns of average and extreme precipitation	↑
Increasing environmental standards	↑
Sustainable drainage systems	↓
Household water demand reduction	↓

Figure 9 (below): Improvement in the standards of wastewater treatment across Europe 1990-2009. Source: ITRC, 2016



FLOOD RISK MANAGEMENT
Historical demand for flood risk management in the UK

Provision of flood risk management infrastructure has become increasingly focused on urban areas where the benefits of investment are highest. Flood protection for low grade agricultural land has been allowed to deteriorate and many floodplains and estuaries are targeted for 'managed realignment'. The Environment Agency's Long Term Investment Scenarios (LTIS) indicate the scale of current flood risk from rivers, the sea and surface water flooding.

Future demand for flood risk management

A combination of increasingly severe storms in coastal and riverine areas in many parts of the country and continuing floodplain development is driving up the need for investment in flood protection. Although it is unlikely that development of properties in floodplains will follow population projections without any control, making such an assumption is useful to explore where investment should occur if future housing needs must be met by building in floodplains (EA, 2014). Climate change, in greatly increasing the frequency and intensity of flood events, means that the benefits of mitigating flooding risk also increase rendering worthwhile expensive flood management options that would have otherwise may not have been in some areas. This will drive up the level of future investment. Public perception of

flooding risk is also an important determinant of the level of investment.

Green infrastructure, consisting of eco system solutions such as floodplain forests and constructed wetlands will mean less need for 'hard infrastructure' investment.

SOLID WASTE
Historical demand for solid waste in the UK

Over the past two to three decades waste management in the industrialised world has gradually shifted from providing safe disposal of unwanted materials, often by entombing the waste in a sophisticated, engineered landfill, to recovering materials and value through re-use, recycling, composting and energy recovery. In the UK, this shift has resulted in a 71% reduction in the amount of biodegradable municipal waste going to landfill since 1995 (Figure 10). Recycling and composting have increased from almost nothing in 1995 to nearly 45% of municipal waste treatment today and energy from waste accounts for about a third of renewable energy generated (Defra, 2015). Despite this change in approach only about half of the annual 300m tonnes of waste has value recovered from it (mainly through material but also energy recovery). Progress has been driven primarily by government targets and taxation rather than an awareness of the value of recovered resources (ITRC, 2016).

Main demand drivers	Effect on demand
Population growth	↑
Increase in economic wealth	↑
European directives and national regulation	↓
Landfill tax	↓

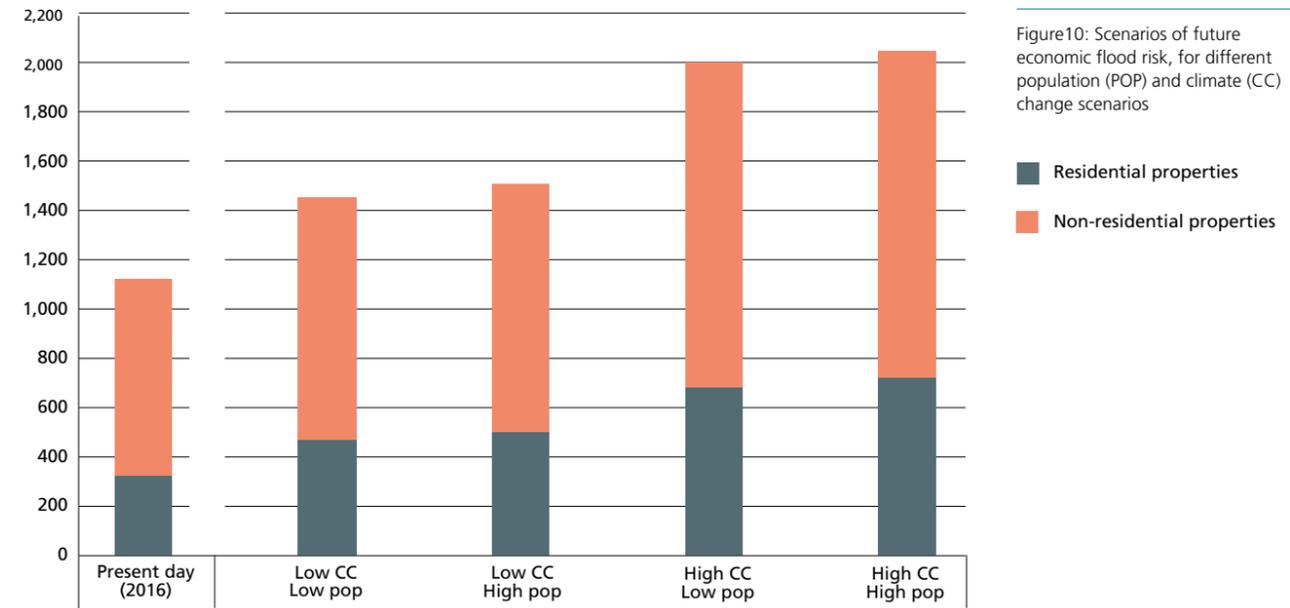


Figure 10: Scenarios of future economic flood risk, for different population (POP) and climate (CC) change scenarios

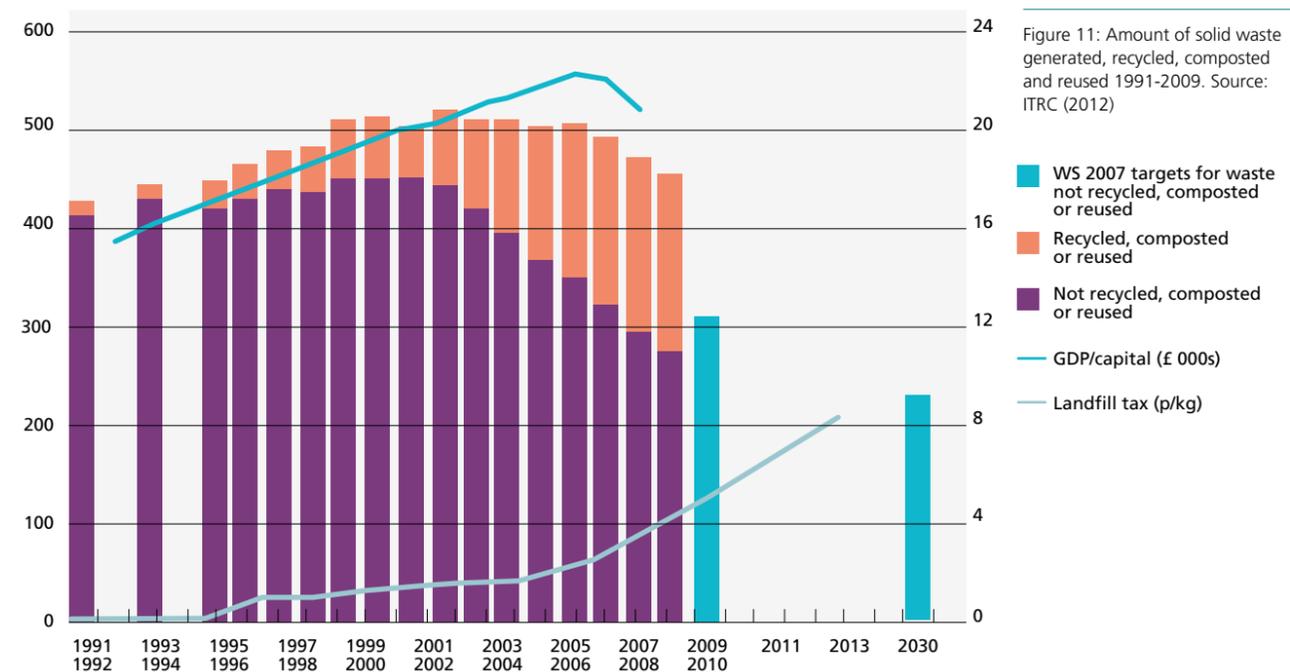


Figure 11: Amount of solid waste generated, recycled, composted and reused 1991-2009. Source: ITRC (2012)

Future demand for solid waste

A growing population and relative economic wealth contributes to generating solid waste. However, recent publications on resource security (Defra, 2012), resource efficiency (European Commission, 2011) and sustainable materials management (OECD, 2012) show a move away from the linear view of resource management towards a circular economy.

European directives and national regulations have played an important role in increasing the demand for services to recycle or re-use solid waste. The potential banning of the disposal of all biodegradable municipal waste to landfill in the next decade may require additional new infrastructure.

Waste that is disposed to landfill is currently (2014/15) taxed at £80/tonne which has had the effect of making landfill the most expensive form of waste treatment in the UK.

This makes investment in other forms of treatment and disposal financially viable. Such tax has had and will continue to play a role in reducing disposal to landfill.

HOUSING

Historical demand for housing

Population growth and demographic and social changes (such as ageing population and the growing number of one person households), as well as rising incomes, have had a profound effect on the demand for housing. There is a backlog from previous years of under supply and affordability of homes is a pressing requirement. In many places the level of wages has not kept pace with the increase in demand and prices. The number of homes available in the social sector has also declined.

Future demand for housing

There is ongoing debate about the relationship of housing and infrastructure and whether housing should in fact be classified as infrastructure. Housing differs from the other infrastructure sectors. It is not a network and investments in housing can vary considerably in scale. Housing should be fully considered as part of this assessment, not least because it shares inextricable links with other forms of infrastructure - in particular with transport, energy, water, digital, flooding and waste.

The UK's housing needs are estimated to amount to at least 300,000 new homes per year for the foreseeable future¹⁴. All regions require significant additional housing investment but, at the regional level, almost a quarter of all housing need is likely to be concentrated in London and over 60% in the four southern regions. This regional imbalance is related to population and economic growth. There is a high demand for housing in areas of high job growth such as London and the south east and increasingly urban areas including Oxford, Bristol and Manchester.

The planning system is often cited as the biggest challenge to housing growth. However, planning permission for 255,032 new homes was granted in England in 2015 – up 57 per cent from a low point of 162,204 in 2009, according to the latest housing pipeline report from the Home Builders Federation (HBF) and industry data collector Glenigan. Furthermore, figures published by the government in March 2016 show that the number of planning permissions for homes rose 6% that year. The number of major applications being processed swiftly by local authorities is also at an all-time high with a record 81% decided within the required time.

The UK has become increasingly reliant on private developers to deliver housing. This poses a challenge in attracting investment in areas where the market fails to provide adequate incentives to supply.

The key challenges in delivering the scale of housing required are:

- Local authority planning departments are chronically under-resourced which has an impact on determining planning permissions and the myriad of pre-commencement conditions needed prior to building works starting.
- The capacity of the housebuilding sector is constrained. The downturn in 2008 prompted about 250,000 people to leave the construction industry. Now that demand has returned, there is a skills shortage, with bricklayers, carpenters and joiners in short supply.
- Small and medium-sized developers experience difficulty in accessing finance – not least because of the complexity of seeking funding – and have declined in number.
- Lack of social and economic infrastructure (e.g. transport, schools, medical centres) which constrains delivery of housing in certain areas.

In July 2016 the House of Lords Select Committee on Economic Affairs published a report Building More Homes¹⁵. It recognises the inability of the private sector to build the number of homes needed and recommended that local authorities and housing associations be incentivised to make a much greater contribution to the overall supply of new housing. For example, by being able to borrow to build social housing.

Figure 12: UK Housebuilding: Permanent dwellings completed

	Private	Public	Total	Private %	Public %
1959	153.170	128.400	281.570	54%	46%
1970	174.340	187.880	362.220	48%	52%
1980	131.990	110.010	224.000	55%	45%
1990	167.470	35.910	203.380	82%	18%
2000	154.480	22.270	176.750	87%	13%
2001	152.3330	21.440	173.770	88%	12%
2007	196.700	27.930	224.630	88%	12%
2008	150.720	32.100	182.820	82%	17%
2009*	117.583	39.233	156.816	75%	25%

Source: Communities and Local Government *Based on Experian forecast for Great Britain



The report identified that the release of public land provides a good opportunity to support the building of low cost homes and help smaller builders return to the market and recommends a senior cabinet minister is given responsibility for overseeing this.

The report also recognised that local planning authorities are stretched and need better resourcing and also considered planning could be simpler to help small housebuilders.

The committee's main conclusions are:

The government's housing target

- To address the housing crisis at least 300,000 new homes are needed annually for the foreseeable future. One million homes by 2020 will not be enough.
- To achieve its target the government must recognise the inability of the private sector, as currently incentivised, to build the number of homes needed.
- The governments focus on home ownership neglects other tenures; those on the cusp of ownership are helped and those who need secure, low cost rental accommodation are not.
- Local authorities and housing associations must be incentivised and enabled to make a much greater contribution to the overall supply of new housing. Without this contribution it will not be possible to build the number of new homes required. The likely reduction in the housing benefit bill over the long-term is a further reason to increase the supply of social housing.

Local authority building

Government must ensure local authorities who wish to build social housing have access to the funds to do so. The current restrictions on the ability of local authorities to borrow to build social housing are arbitrary and anomalous. Local authorities should be able to borrow to build social housing as they can for other purposes.

Building on public land

- The number of new homes the government expects to be built on public land by 2020 amounts to nearly one third of their housebuilding target. Government should ask the National Infrastructure Commission to oversee the number of homes that are actually built on public land.
- The release of public land provides a good opportunity to support the building of low cost homes and help smaller builders return to the market. The requirement to achieve best market value when releasing public land should be relaxed.





SECTORAL ANALYSIS — INTERVENTIONS, CHALLENGES, OPPORTUNITIES AND OPTIONS

This section provides a description of the main sector-specific challenges to the realisation of the NNA vision for the UK infrastructure system, highlighting areas of uncertainty and complexity that prevent a clear extrapolation from current to 2050 needs. The recent ICE State of the Nation report (2014) indicated that the energy, transport and flood management sectors need the most attention from policy makers and industry, whereas the water and waste sectors are performing better. Nevertheless, the latter two sectors require 'future proofing' if they are to deliver the transition to a low carbon economy and meet the needs of society. The digital communications sector is currently performing well. However, increased demand and reliance on digital infrastructure services across other sectors mean that connectivity must be upgraded and universalised.

The distinct sets of challenges faced by each sector are addressed by strategic options which will enable the UK to realise the infrastructure vision and deliverables. This section recognises that opportunities co-exist with challenges and identifying these presents options for each sector which include;

- major investments in new capacity
- interventions in demand management and behavioural change
- technological, policy and regulatory change
- climate change mitigation and adaptation measures
- alternative sources of financing and funding

Strategic options are assessed against future scenarios of demand developed from ITRC projections of population, economic activity and climate change.

ENERGY

The UK currently faces what has been called the 'energy trilemma', namely balancing security of supply, environmental goals (including carbon emissions and local air quality) and the affordability of energy for domestic and industrial energy users.

SECURITY OF SUPPLY

Imports account for 0.9% of total energy supply (DECC 2015a). However, import dependency varies according to the type of energy and is likely to increase in future. Gas demand in 2015 was met by domestic supply accounting for 460 TWh, net continental imports amounting to 179 TWh, and 152 TWh of LNG imports¹⁶. Going forward, the dwindling of domestic gas resources will lead to increased dependence on imports.

Reliability of electricity supply was guaranteed by a generation capacity of 72 GW over a peak demand of 53 GW in 2014¹⁷. However, capacity margin was only 5% after derating¹⁸ (l). The planned retirement of 1/5 of electricity generation capacity within the next 10 years will put pressure on the capacity to meet future demand.

ENVIRONMENTAL GOALS

The energy sector is the single largest national source of emissions. In 2014 it emitted 163.8 Mt CO₂e (31.8% of total emissions)¹⁹. The UK's energy mix is dominated by fossil fuels, consisting of 34% natural gas, 37% oil and petroleum and 12% coal²⁰. At 71%, bioenergy (including plant biomass, landfill gas and domestic wood burning) dominates renewable sources of energy²¹.

Total demand for electricity - amounting to 311 TWh in 2015 - is met by generation from coal (22%), natural gas (30%), nuclear (21%) and renewables (25%)²².

The Climate Change Act 2008 makes it the duty of the Secretary of State to ensure that the net UK carbon account of all six Kyoto greenhouse gases for the year 2050 is at least 80% lower than the 1990 baseline, with the exclusion of emissions from aviation and shipping. The choice of energy generation technology after 2030 and the level of demand management will be critical in determining how these strict legal commitments are met.

AFFORDABILITY

Significant uncertainty exists around demand for energy to 2050, with consequences for affordability. ITRC modelling has suggested that even under baseline ONS population projections the total energy demand in the UK could move from its current level of around 900 TWh/year to between 800 and 1200 TWh/year, depending on the adoption of potentially disruptive new technologies such as energy storage and the electrification of heat and transport. The investment needs associated with these different scenarios will challenge affordability, in particular for low income ('fuel poor') households.

Volatility in wholesale prices and an unstable approach to regulation – such as with the

removal and establishment of offshore wind subsidies without clear explanation or underpinning long term policy objectives - impedes investor confidence and the ability to form a credible case for future energy investment²³.

ELECTRIFICATION

It is widely accepted that decarbonising the energy sector requires - in addition to mitigating power emissions for electricity generation (see new sources of energy) - a major contribution to decarbonising transport and heat. This involves electrifying the road vehicle fleet and using heat pumps to provide heating services. In the absence of demand management, 23m electric cars²⁴, 300km of rail track electrification per year and up to 80% replacement of alternative heating technologies with heat pumps would be required to achieve decarbonisation by 2050. This results in more than doubling of electricity consumption to 677 TWh (ITRC 2016), demand which can be lowered by implementation of electricity storage and demand response, in addition to conservation and efficiency measures (see demand and efficiency).

Heat services for new developments are already largely being electrified alongside improving thermal efficiency of buildings. This is implemented through the use of heat pumps and the standardisation of electric heat in new housing developments (ITRC 2016) and is anticipated to continue to 2050.

- Alternative technologies will replace heating fuel technology up to 86%-91% of fuel consumption in the residential sector, 71%-83% in the service sector and 21%-49% in the industrial sector;
- Electric heat pumps will replace 80% of gas, 80% of electricity, 80% of oil and 80% of solid fuel consumption in the residential

sector. They will replace 65% of gas, 75% of electricity, 60% of oil and 60% of solid fuel consumption in the service sector. In industrial low temperature processes, electric heat pumps will replace 15% of gas, 15% of electricity and 15% of oil consumption, and cover 40% of gas, 40% of electricity and 40% of oil demand for space heating; and

- Ground source and air source heat pump installations in residential and service sectors will reach 50% (ITRC 2016).

Further reductions in carbon emissions could be achieved through the enforced retrofitting of heat sources and insulation in existing residential buildings and office spaces. However, the strategy for electrification of heat and transport introduces challenges. At present there is no storage in the electricity system able to manage the equivalent seasonal variations in heating demand²⁵. Such capacity will likely be under-utilised during summer seasons but still carry significant economic costs²⁶. Furthermore, the deployment rate of heat pumps is highly dependent on customer acceptability as it requires different heating practices and supply chains which currently have very limited capacity. Thus, it is necessary to consider alternative strategies to provide heat services that may be more efficient with respect to cost and non-cost factors.

Timing is important: if electrification is rolled out too early then the full benefits of a 'decarbonised' electricity system will not be achieved. This may even result in a temporary increase in emissions as electricity continues to be generated from carbon-emitting fossil fuel sources. Electrification may result in stranded gas assets including storage units and gas pipe network sections.

DEMAND AND EFFICIENCY

Aggressive technological and behavioural measures could reduce energy demand to 40% of that in an unconstrained demand scenario (ITRC 2016). Behavioural change can be promoted through education encouraging conservation of energy or technological measures such as pricing, which acts as a deterrent, as well as monitoring technology that enables users to track and moderate their own consumption. A potential blocker to the success of consumer behaviour change is price inelasticity of demand for services. For example, Turner & Townsend noted that water metering has not been as effective as expected in reducing demand²⁸.

Technological measures include energy efficiency (in buildings and appliances, such as insulation, lighting, cooking, electronics), lower energy consuming technologies in industrial processes, distributed generation (in particular, solar PV and solar thermal), fuel switching, and electricity storage and demand response offering greater system flexibility. A 'whole house solution' or a 'smart home' can deliver self-consumption rates from 60-90% and enables the consumer to export electricity when it is economically advantageous to do so. Evidence submitted identified three specific technologies: power-to-heat system (such as hot water boilers or heat pumps), stationary battery storage, and controlled charging of electric vehicles and plug-in hybrids²⁹⁻³⁰. Another example is Dynamic Demand, the large scale deployment of which has the potential to reduce reliance on frequency-sensitive generators in the energy sector³¹. Such a system would offer significant cost and carbon savings, minimise the need for extra power generation and increased capacity in power networks³², increase security of energy supply and resilience to price fluctuations³³. The increasing sophistication of metering with digital transformation and smart technologies³⁴



enables more effective monitoring to determine pricing and can provide the basis for block tariffs³⁵ to manage temporal variation in demand. ITRC projects a 100% roll out of smart meters by 2020 (ITRC 2016).

Independent experts from E3G recommended that energy efficiency be viewed as a form of infrastructure in its own right³⁶ to encourage investment in efficiency as an infrastructure priority. This could be achieved by attitudinal change³⁷ or policy measures. For example, requiring increased energy efficiency in building design³⁸ (a behavioural change on the part of engineers, architects, housebuilders, etc.) would act to manage demand for energy irrespective of consumer behaviour. A 2015 report by Green Alliance suggests that the UK electricity market would save over £2bn by 2025 if power stations were encouraged to compete against electricity saving³⁹. ITRC (2016) anticipates that efficiency improvements across buildings, appliances and lighting can produce the following outcomes:

- 5% reduction in leakage rate in buildings (increasing thermal efficiency)
- 10% efficiency improvements in residential and service sector lighting
- 20% in industrial sector lighting
- 10% efficiency improvements in residential and service sector appliances
- 20% in industrial sector appliances.

Use of demand management technologies can be enabled by the right market incentives to allow these technologies to compete and to address inertia and the ‘smoke and mirrors’ pricing created by vertical integration, high market concentration of power and poor wholesale market liquidity. According

to Tempus Energy Supply Ltd., this requires a cost-reflective system, with clear price signals for efficiency savings and easy market access for new entrants⁴⁰. Pennon Group Plc recommended the development of ‘zones of enterprise’ where aligned thinking is applied to the planning process such that local industry is directly supplied with energy, which can ensure that generating capacities are tethered to direct end users⁴¹.

ENERGY SOURCES

An optimal strategy for energy needs to include a mixture of supply technologies to balance their strengths and weaknesses (Eyre and Baruah 2015, Maclean et al. 2016). The choice of technology will depend partly on the population density and types of properties in the area served. For example, in densely populated areas repurposing of existing gas grid for hydrogen might be preferred to heat pumps as it would avoid disruption to households and allows utilisation of existing storage assets for inter-seasonal demand. The challenge is to build enough hydrogen producing capacity which will be costly regardless of whether electrolysis technologies (using excess intermittent generation) or steam methane reformation processes (using CCS) are used.

A fair and target consistent carbon price, provided through the carbon price floor or EU ETS, would give new technologies a level playing field on which to compete against fossil fuel alternatives⁴². Investment in areas such as CCS, confronted with a challenge around liability for very long-term risk which presents a deterrent to investment, could be unblocked by the underwriting of long-term risk by government⁴³.

Whilst coal and combined cycle gas turbine (CCGT) remain two of the three major electricity generation sources, a continued shift

towards renewables is envisaged by 2050. This is anticipated to consist of a portfolio of low carbon technologies – mainly offshore wind, but also nuclear and distributed renewables (solar PV) - with gas fitted with Carbon Capture and Storage (CCS) as a transitional fuel and back up for intermittent renewables.

Written evidence asserted that nuclear energy should be pursued as a long-term solution to the UK's energy needs⁴⁴ with the prioritisation of investment in the next generation of nuclear plants.⁴⁵ The key challenge with nuclear energy is uncertainty: large projects are complex to finance and have long-lead in times, while modular mini-reactors are unproven (Ofgem 2016).

Additional renewable capacity will be needed in the 2020s to ensure that the UK can meet its fifth carbon budget⁴⁶ and as such renewable energy should be promoted, possibly via the introduction of a programme of effective incentives⁴⁷. The timely deployment of offshore wind infrastructure, which can take as long as 10 years from the award of lease to first power generation, should be ensured through clarity of support for the sector in the Levy Control Framework post 2020⁴⁸. Deployment of renewable technologies could also be enhanced by delivering electricity transmission links to Scottish islands, which would have the added benefit of contributing to their continuing economic development⁴⁹. Finally, energy from waste and energy recovery facilities, with materials recycling and anaerobic digestion technologies, offer a new means to generate and store energy⁵⁰, although this is not expected to ever represent more than a small proportion of total energy supply. This could be unlocked by larger scale investment in gasification aided by collaboration between energy companies and the waste sector to secure reliable supplies of waste material⁵¹.

Uptake of distributed renewable generation such as solar and wind has to date been more rapid than expected. Feed-in tariffs and other incentives for renewable investment have recently been removed but the uptake is expected to continue due to rapidly reducing costs of photovoltaics and the improved reliability of supplies of energy from renewable and distributed sources offered by energy storage (ITRC 2016):

- 25 GW of new distributed solar capacity
- 70 GW of new offshore wind capacity.

Electricity power generation is likely to transition from carbon intensive coal to more efficient CCGT as well as zero emission nuclear (ITRC 2016). The ITRC projects 1270 GWh of additional gas capacity as a result. UK shale gas reserves are likely to be developed to increase diminishing domestic gas supplies. If there is no major move to electrification of heat then an increase in Liquefied natural gas (LNG) capacity will be also be required in the long run. Indeed, the risk of stranded assets for the gas network provides a further argument for continued investment in gas efficiency and capacity.

Carbon capture and storage (CCS)⁵² holds powerful potential for decarbonisation of the energy sector, but requires government support, commitment and national and local infrastructure planning to provide certainty and make the most of current capacity, including integrated regional and local planning to deliver CO₂ to the storage location. In addition to existing infrastructure, the next step is to develop a network linking the capture sites to transport infrastructure and storage sites in order to demonstrate the viability of the technology and delivery chain at scale⁵³. CCS has the potential to be safely storing 15% of current UK CO₂ emissions by 2030 and

up to 40% by 2050. The Government should push forward the establishment of a system of economic regulation for CCS and a means of incentivising industrial CCS.

TRANSPORT

The UK transport system faces challenges in terms of increasing congestion and delays across transport modes. Pressure is greatest in the south east, the UK's most populated area.

Growth in road transport, which levelled off during the economic recession, is now picking up. Road travel reached 311bn vehicle miles in Britain in 2014 (DfT 2015b). The average speed on local A roads in England during weekday morning peaks was 23.6 mph in 2014, a 2.7% decrease from the previous year. The average delay on the strategic road network was estimated at 7.8 seconds per vehicle mile in 2014 (DfT 2015b). The direct cost of congestion on strategic roads was estimated at £2bn in 2010 and is anticipated to rise to £8.6bn in 2040 in the absence of intervention (ICE 2014). Another challenge in road transport raised by the Rees Jeffrey Road Fund is inconsistencies in funding and governance techniques and timeframes between the strategic road network and the majority of roads which are managed by local highway authorities.

Rail traffic continues to grow: trips amounted to 62.4bn passenger km in England and Wales in 2014 (DfT 2015b). 26% of morning peak trains arriving to London were over capacity in 2014, with a total of 139,000 standing passengers (22% of all passengers). Afternoon peak trains departing London had a total of 78,000 standing passengers. The combined excess capacity of morning and evening peak trains totalled 4.1% in 2014, higher than the average of 1.4% across 10 other major cities in England and Wales (DfT 2015a).

In 2014, 238m terminal passengers flew from the UK (DfT 2015b). UK airports exhibit delays above the European average. The south east in particular faces major challenges. Estimates put Heathrow's runway capacity at 95%, Gatwick's at 80%, Stansted's at 59% and Manchester's at 53% (ITRC 2012). ITRC projects that Heathrow, Gatwick and Luton will reach capacity within the next decade.

As the transport sector currently accounts for 20.5% of UK GHG emissions (116.8 Mt CO₂ was emitted in 2013, DECC 2015b), a future transport strategy will have a significant impact on the UK's ability to meet the requirements of the 2008 Climate Change Act. Furthermore, investment in climate adaptation and risk reduction will increasingly be required to mitigate the impacts of the higher frequency and intensity of natural hazards predicted with climate change.

DEMAND AND EFFICIENCY

The impacts of the adoption and integration of digital technologies on transport demand and network throughput and efficiency (supply) could be profound and make projection of future needs for the network particularly challenging. Technology is already having a significant impact on freight, for example through the boom in internet shopping is putting increased demand on local delivery fleets and routes. While the effects are unclear, the increased use of drones to deliver online purchases will impact on local delivery services and could reduce the demand for deliveries by road. Developments in Information and communications technology (ICT) systems are likely to result in a more 'agile' workforce, resulting in reduced transport system demands. Since investment is frequently driven by peak demand⁵⁴ for any given mode of transport, changing working patterns (such as flexible working and staggered work days) will reduce the size of peak demand and hence the level of capacity increase required⁵⁵.

Real time routing information and coordination and optimised journey planning support tools will result in increased efficiencies and resilience to disruptive events. Greater consumer information on the cost of transport choices, enabled by technological solutions, can play a role in shaping expectations and behaviours. Single ticketing across transportation operators and modes will also improve system efficiency.

There will likely be only moderate fuel efficiency improvements for conventional vehicles and air and sea transport (the latter two backed by large R&D investments), although ITRC projects a gradual move towards alternative fuels for road transportation including hybrids, electric and hydrogen powered vehicles. These should be promoted with government support and investments in charging infrastructure for electric vehicles (ITRC 2016). Air traffic management technology and procedures will enable a more dynamic use of air space, increasing access, removing 'hot spots' and reducing costs. In the rail sector, electrification is set to be implemented at a rate of 100km per year (ITRC 2016) – although this falls short of the rate of 200km per year which would enable the UK to meet the Transport targets established by the 2011 European Commission White Paper. Other technology advances such as deployment of the internet of things within the rail network with 12000 rail infrastructure assets already connected to an intelligent infrastructure system of points, track circuits and signal power supplies is already claimed to have avoided 153,000 delay minutes and provided savings of circa £4.66m. This is set to provide additional capacity to the network by more efficient use and improvements to asset management with real time condition monitoring to optimise maintenance. The disruptive impact of upgrades on transport infrastructure can

be mitigated by provision of new, parallel infrastructure and education and better communication to encourage public acceptance.

The challenges arising from pressure on certain modes of transport and climate change may be addressed by targeted demand management. Representations identified means to reduce demand either for transportation overall or for modes of transport which are constrained by lack of capacity or the sustainability agenda. For demand management aimed at the latter, measures to reduce demand for one mode of transport are best combined with capacity increases or incentives in another mode of transport, making use of 'integrated travel planning'⁶⁰.

Road pricing schemes⁶¹, congestion charging and restriction of parking (limiting the quantity of available parking, enforcing parking charges and control)⁶² can be effective at reducing private road transport. Another measure to reduce demand is changing the business rating system so that it reflects costs imposed by traffic-generating businesses⁶³.

Blockers in transportation demand management are social, political and technical. Local government TAG stated that, despite its effectiveness, integrated travel planning has not been given sufficient priority by central government⁶⁴. The growth of electric vehicles and the reduction in fuel excise duties brought about by increasing fuel efficiency act as countervailing forces to efforts to reduce demand for private road transportation, with the result that financial disincentives are increasingly necessary⁶⁵. Behaviours and choices concerning transportation tend to be ingrained and the public are often resistant to use of bus and rail as alternatives to the private vehicle⁶⁶.



According to the local government TAG, if demand management is to succeed in the long term, significant efforts at cultural change, including changing consumer expectations, are required. Issues to resolve include determining what level of demand management is publicly acceptable – for example, the highly political nature of ‘polluter pays’ schemes makes them challenging to implement on a large scale – and the extent to which modal shifts in transport should be pursued - such as freight from highways to rail and shipping, from domestic aviation to high speed rail, and towards urban mass transit.

Travel behaviour is intimately linked to land use patterns as well as transport provision and choices. Residential areas in locations with a good range of facilities and public transport services within easy walking distance tend to produce much less car-based travel than those that are remote from local facilities, for example.

TECHNOLOGICAL INNOVATIONS AND AUTONOMOUS VEHICLES

In road transport, the development of smart motorways and other digital technologies may reduce demand and congestion and improve the efficiency of existing road capacity⁶⁷ among some user groups although the impacts of new technologies are uncertain. Evidence suggests that increased uptake of autonomous vehicles would result in significantly *increased* road demand⁶⁸ as autonomous vehicles enable greater road use for those currently unable to drive conventional vehicles such as the young and the elderly. A recent KPMG report⁶⁹ concluded that AVs will lead to more than 1tn additional people miles travelled and up to 4tn additional vehicle miles travelled, in the US alone, by 2050. ITRC (2016) analysis estimates that the benefits of currently available digital technologies are able to maintain current average traffic speeds until 2030-40, while

new potential ‘game-changing’ technologies could maintain or increase average speeds up to 2050. Digital railways systems, such as Network Rail’s digital railway programme⁷⁰, can deliver efficiency improvements for the rail network by enabling an increased number of trains and therefore rail passenger journeys.

The recent Travel in Britain in 2035 report discussed⁷¹ the implications of new transport technologies. There are several areas where technologies can make a difference to provision, management and use of transport. 3D printing could create consumer products closer to their markets, reducing shipping distances. Autonomous Vehicles have multiple potential benefits, such as reducing the frequency of crashes due to human error, enabling vehicles move closely together or travel at higher speeds, improve accessibility of road travel to the elderly, under-age, disabled and change in ownership models.

The British Vehicle Rental and Leasing Association (BVRLA) Fleet Technology White Paper (2014) states that ‘intelligent mobility’ is viewed by many senior figures within government as being just as important as ‘low carbon’. The potential benefits of intelligent mobility include reduced congestion, improved fuel efficiency, reduced carbon emissions and enhanced journey predictability.

There is uncertainty about the timeframe for autonomous vehicles to become a mainstream transport choice (possibly within the next two decades). The proliferation of autonomous vehicles will need radical changes to the way we plan and finance infrastructure. Governments, infrastructure owners and road industry suppliers around the world are facing the same questions: what might a driverless future look like? And how do we make investment decisions about future

infrastructure if we do not know how it is going to be used?

There are two approaches to roll out of autonomous vehicle; incremental change as automation features are gradually introduced by automakers, or revolutionary change driven by technology players and new mobility providers. Infrastructure planners need to be highly adaptable and flexible due to the uncertainty.

Automation is in the hands of automotive manufacturers rather than governments as they introduce technology to respond to market demand. But in the longer term demand by road network operators could also shape technology in vehicles.

CAPACITY INCREASE

Investment in new capacity to reduce congestion is optimised when it is targeted geographically and by mode of transport to complement efficiency measures and achieve strategic aims.

In road and rail the National Infrastructure Plan (NIP) sets out schemes to provide new capacity to 2022, including HS2. Between 2022 and 2050 capacity improvement could be delivered by continuation of NIP level investments or by continued investment above the NIP level, with the optimal level of investment determined with regards to the diminishing marginal returns of capacity increases on congestion outcomes. We should invest to realise the maximum economic and social outcomes, subject to constraints, which may include assessment of cost to the economy of not pursuing schemes.

There are likely to be only moderate increases in road capacity which will be concentrated at ‘pinch points’ in the network⁷² while maximum capacity per hour on motorway,

dual carriageway and single carriageway lanes is expected to remain constant (ITRC 2016). Road management technology such as smart roads and vehicle technology (e.g. autonomous vehicles) is likely to provide an increase in road capacity without additional road surface. Digitally connected autonomous vehicles will enable real time route planning to avoid congestion and could travel at much greater proximity resulting in additional capacity on current roads.

While high speed rail development could promote a modal shift away from domestic aviation, new international hub capacity in the south east is a pressing need as attested to by the Airports Commission in 2015. The benefits of capacity investment can be maximised by improved surface access to airports⁷³ including connectivity to high speed rail services, which will also serve to complement cross-modal demand management.

Smart asset management approaches to both road and rail maintenance has potential to increase availability of the road and rail networks through reduction of unplanned maintenance time.

Potential investments to increase capacity in water transport include port expansion⁷⁴, wharfage improvements and increasing headroom under bridges, and development of priority freight routes⁷⁵. Water transport capacity increases can form part of a wider transport strategy and induce multi-modal shifts through the promotion of port connectivity and access, towpaths and riverside paths as healthy travel choices⁷⁶.

The representations made several recommendations for a spatial approach to transport infrastructure. Transport infrastructure should act to support economic expansion and provision of new housing, and

hence investment to increase capacity should be prioritised in these areas⁷⁷. Measures should be taken as a priority in urban areas and city regions, including those forming the 'Northern Powerhouse'⁷⁸, to promote decongestion⁷⁹.

New urban transportation systems in major cities can contribute to an overall reduction in congestion. By increasing public transport capacity these investments complement the efforts of demand management to reduce congestion and environmental impact (namely carbon emissions and air pollution) of transport. Investment should seek to achieve 'high quality, integrated public transport networks with a key role for new rail and rapid transit capacity', 'high levels of cycling and well-used bus services', and could be supported by 'effective sustainable urban mobility plans for appropriate travel to work areas'⁸⁰. Other strategic investments include in freight consolidation centres to reduce congestion in urban areas. Provision of funding for local devolved governance structures would enable these network improvements.

ITRC analysis finds that a systems efficiencies strategy incorporating investment in new capacity, demand management, systems efficiencies and fuel switching to electrified and low-carbon sources could result in an overall reduction in emissions to under 40Mt by 2050 (ITRC 2016).

DIGITAL COMMUNICATIONS

Due to rapid innovation, increasing demand and a changing economic landscape, it is challenging to forecast the future of the digital communications infrastructure system to meet our future connectivity needs, there will almost certainly be a mix of fixed, mobile, wireless and satellite connectivity.

The UK performs well in digital communications. Internet penetration is at around 90%, there

are more than 22.6m fixed residential and SME broadband subscribers (ITRC 2016), and in 2014 on average 38m adults (76%) in the UK accessed the internet every day. Broadband Delivery UK (BDUK) aims to achieve 95% superfast broadband coverage by 2017⁸¹, an increase from the current take-up rate of 21% of premises (ITRC 2016). The ITRC projects 100% provision of high speed broadband (>24 Mbit/s) coverage across the UK and 100% coverage of 4G mobile broadband by all the available mobile network operators in 2050. Targets have also been established by the European Commission's digital agenda for Europe to provide internet access speeds to all EU citizens of 30 Mbit/s, with over 50% of the citizens subscribing to a connection over 100 Mbit/s by 2020 (ITRC 2016).

The UK leads the G20 nations with its digital economy, which accounted for 8.3% of total GDP in 2010 and is forecast to grow to 12.4% by 2016. Around 270,000 companies (14.4% of all businesses) are active in the sector (ITRC 2016). Turnover from e-commerce was estimated at £557bn in 2013, around 20% of total revenues (ITRC 2016).

A lack of sufficient digital connectivity has a detrimental effect on business operations, productivity and output and hence competitiveness in the global marketplace. Securing digital connectivity is thus critical to the UK's long term prosperity. A key challenge for the digital sector is a persistent digital divide between those who have access to the latest technologies and those who do not, with resulting social and economic exclusion, particularly as dependence on e-services and digital communications increases⁸². 8% of all UK premises (2.4m) cannot access a broadband speed of 10Mbit/s (Ofcom 2016), while around 3% of premises in the UK fall below the government's current minimum target

download speed of 2 Mbit/s (ITRC 2016). While all four mobile network operators (O2, Three, Vodafone and EE) enable you to make a call in 99% of urban areas, this proportion falls to 72% in rural areas, 41% on UK roads, and 31% inside buildings in rural areas (Ofcom 2016). Universal digital connectivity would serve as an equaliser of economic opportunity in that it enables participation in a modern digital economy. To what extent should public finances be used to invest in the UK's digital economy, such as in gigabit fixed connectivity to businesses and consumers?

Demand for services in the digital communications sector behaves differently from that in other infrastructure sectors. Rather than demographic and economic changes the key drivers of demand are technological innovation and the speed at which products are brought to the market. Past trends have shown that the availability of new devices and higher bandwidths enables new content, applications and services which in turn create new demand for bandwidth⁸³. However, innovation has the potential reduce future demand. Developers of online applications and services are investing significant resources to minimise their products' use of bandwidth in order to improve user experience and free up capacity.

OPPORTUNITIES AND OPTIONS

Quantifying future demand based on potential future technological discoveries is fraught with uncertainty. A different approach can be adopted whereby the 'needs' of the sector are taken into account. Needs include those of domestic consumers and commercial and governmental organisations, each of which differs in level of connectivity facilitating access to different types of contents, applications and services. It is ultimately the decision of government as to what level of access all members of society should have.

The UK is close to providing basic connectivity (for web browsing, email, basic file transfer, video calling and other services) to all, as demand is generally met by the private sector such as via the current market rollout of superfast broadband (SFBB). According to Ofcom (2015), the government's new universal service obligation (USO) of 10Mbit/s for fixed broadband as set out in the Digital Economy Bill meets the demands of current technologies for simultaneous video calls and web browsing. However, technological innovation means these needs are likely to increase and a key challenge is ensuring services are delivered equitably throughout the UK. In rural areas high costs⁸⁴ – and reluctance on the part of consumers in remote locations to bear these higher costs – make investments in both fixed and mobile (4G, 5G) assets unfavourable for the private sector⁸⁵. Targeted (government) intervention is therefore required to provide UK-wide coverage (Ofcom 2016). (Next page, figure 13)

A more ambitious objective, requiring additional investment, is to provide equal access to all online content, applications and services – including content which requires higher bandwidths such as high definition (HD) and ultra-high definition (UHD) (4k or 8k) on-demand television services. Ofcom's vision (2016) is that over the next decade most consumers and businesses will move from 'superfast' to 'ultrafast' broadband and it intends to provide the regulatory environment to facilitate this. Estimates of projected bandwidth demand for 2023 show that peak technical demand for a single person household with standard definition television could be satisfied with 10Mbit/s (Kenny & Broughton, 2013) whereas a household with four intensive users and a 4k television would require 25Mbit/s. The top 1% of households would demand in excess of 35Mbit/s. Demand is likely to

increase further with the introduction of novel technologies.

By 2050 the main access points to data services will be through mobile devices and the internet of things grounded on widespread coverage of 5G (or other) mobile broadband⁸⁶. To date there has been strong political ambition for the UK to be a world leader in 5G technology deployment, reflected in Ofcom Strategic Review of Digital Communications 2016. However, the desire for expediency in delivery must be balanced with the need to ensure implementation of a system that can meet long-term economic, social and environmental needs. As with existing digital connectivity efforts must be made to ensure comprehensive coverage.

WATER

Although the UK climate is generally wet and mild compared to much of the world, less rainfall and high population density in the south and east means that water availability per person in these regions is low. Regional rainfall differs significantly. The southeast is the driest part of the country (London is drier than Istanbul) and already water stressed. By contrast, the north and west and much of Wales and Scotland receive the majority of UK rainfall but are more sparsely populated. The challenge for future water supply in the UK is to meet the demands of socio-economic growth and climate change –without compromising the environment and other users of water, or placing an excessive financial burden on consumers.

Recent work by water companies and particularly by Water UK (2016)⁸⁷ has assessed the resilience of supplies to key drivers (drought, environment, growth and climate change) over the next 50 years. This shows that significant and growing risk of severe drought arises from climate change, population growth and environmental drivers. Some risks (drought

and environmental demand) are immediate and will require a prompt response. The most cost-effective approach to increasing resilience is likely to drive action in the current round of water resource management plans (WRMPs).

The investment needed to increase resilience to drought is relatively modest. Building on the existing water resources planning framework Water UK concludes that a ‘twin track’ approach that includes supply enhancement, with associated transfers, as well as demand management, remains the most appropriate strategic mix to meet supply demand pressures now and into the future.

There is a case for considering more extensive measures to manage demand than are in place today to provide a greater level of resilience to more extreme future shocks. However, such levels of demand management are ambitious and will require significant behavioural change, innovation and potential regulatory change.

Inter-regional transfers, new storage capacity and re-use of water may represent key components of a more resilient system, through a combination of localised and strategic schemes. For example, using the River Severn and River Trent to transfer water to the south and east. However, connecting major supply systems has implications for river regulation, water quality, and environmental risk (both the natural environment and carbon costs of moving water over large distances). In some cases, the nature of drought risk within the supplying water resources systems may also increase as a result. The transfer and trading of water, as well as innovation across all other aspects of supply and demand of water are a key focus of ongoing regulatory reform. (Figure 14)

There is a case for a national level ‘adaptive plan’ that supports on-going WRMPs and

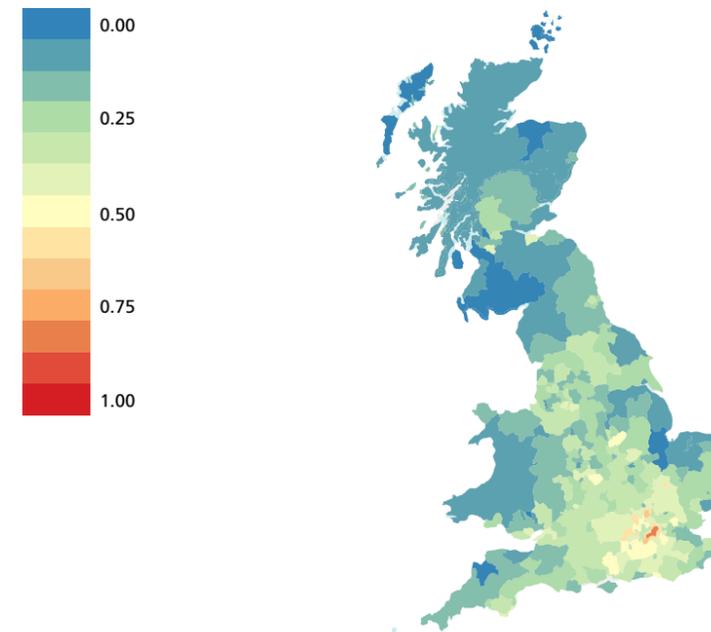


Figure 13: Attractiveness of provision of 4G mobile technologies, indicating likely locations of under-provision where it is unattractive for commercial providers to invest

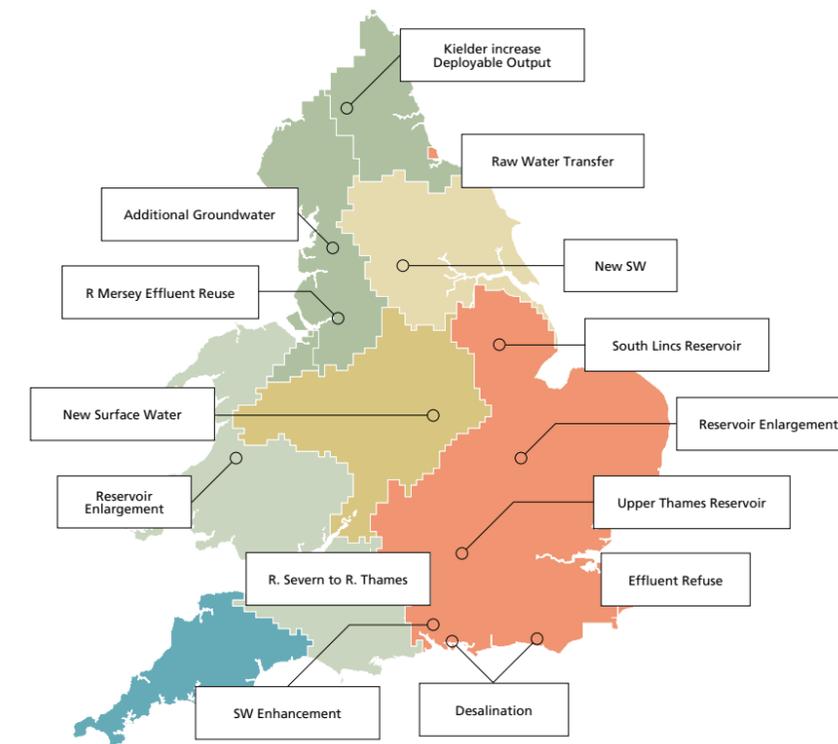


Figure 14: Possible infrastructure investments within the Water sector (after Water UK)

balances risks against opportunities to defer costs. Such a plan would identify the key 'trigger points' that will determine which set of investments and policy interventions would be needed for the 2040 and 2065 horizons, depending on how risks materialise in the future.

The UK enjoys high levels of sewage connectivity compared to the rest of Europe. However, meeting increasing environmental standards together with improved understanding of the fate of contaminants and better detection have driven more challenging wastewater treatment standards and significant investment in new infrastructure, often requiring increased energy and chemical consumption, resulting in higher tariffs for customers.

The energy intensity of wastewater treatment infrastructure also makes it a target for policies to reduce greenhouse gas emissions, such as the 2008 Climate Change Act. The wastewater industry consumes approximately 0.4% of the national energy budget (Ofwat, 2011).

OPPORTUNITIES AND OPTIONS

Action should in the first instance focus on leakage and demand reduction, as established in WRMPs. Demand management is expected to play an important role in future water security for the UK. Water companies plan to increase metering coverage from 48% in 2011 to 61% in 2020. A key advantage of metering is the ability to provide complete coverage within a short time frame and its increasing sophistication, with digital transformation and smart technologies⁸⁸, enables more effective monitoring to determine pricing and can provide the basis for block tariffs⁸⁹ to manage variation in demand.

Furthermore, technology that enables users to track their own consumption of infrastructure can induce behavioural change on its own⁹⁰.

A potential blocker to the success of consumer behaviour change is price inelasticity of demand for services. For example, Turner & Townsend noted that water metering has not been as effective as expected in reducing demand⁹¹.

Other demand reduction measures include technologies such as grey water re-use and policy measures such as tariffs, water efficiency audits, pay-as-you-save schemes and educational programmes. A less hi-tech method involves designing for reduced point of use consumption - one-cup kettles and half-flush toilets⁹².

Education has a particularly important role for technological roll-outs as it can ensure that the benefits of technologies are fully exploited. Demand management in the delivery of water services is incentivised by mechanisms such as outcome delivery incentives within the 2015-20 period, with additional mechanisms for upstream water trading and sludge management being considered as part of the price control methodology by Ofwat⁹³.

Wastewater management will also be improved by approaches to flood risk management which increase systemic resilience, including sustainable urban drainage schemes (SuDS) and other 'green infrastructure' solutions which provide buffering capacity (see flood management section).

However, total volume of wastewater is still likely to increase, requiring new treatment capacity and acting to increase emissions. In delivery of new wastewater capacity adoption of new technologies could decrease or retain net energy consumption for wastewater treatment. More energy could be recovered from waste in future (see waste section)⁹⁴. Targeted 'green infrastructure' solutions can be implemented to naturally remove pollutants from watercourses.

Increased centralisation of services could alleviate increasing costs through economies of scale. Wastewater plays an important role in maintaining river flows – smaller sewage works, which might benefit most from centralisation, can be the sole contributor to river flow during dry periods – so there is an environmental cost. This would require planning reforms and an estimated cumulative capital investment of £17.5bn (ITRC 2016). For the time being, decentralised technologies do not achieve the same economic advantages, levels of reliability or purity of effluent.

Further regulatory reform could ensure the implementation of building-level efficiency measures (including demand management). Many new housing developments are being connected through dual wastewater and storm water networks which could contribute to lower per capita costs and lower susceptibility to water quality problems during extreme rainfall events. There is potential – albeit requiring major new investment - to retrofit dual sewer systems. Depending on demographic trends, projected cumulative expenditure on new sewers to 2050 ranges between £20 - 120bn (ITRC 2016).

Nevertheless, strategic supply investments will be required to ensure security of supply if high socio-economic growth scenarios are realised and with the increased frequency and severity of droughts expected under climate change⁹⁵. The challenge will be determining what type of supply infrastructure should be built, when, and where. Scope exists for increased local capacity to mitigate these uncertainties: the ITRC (2016) projects that an increase in reservoir storage capacity of between 2,500 and 4,000 Ml/d will be required. Drier regions may be forced to move towards alternatives such as desalination, new groundwater and effluent water re-use technologies.

An alternate strategy entails focusing investment to increase capacity in locations with greater water resources (west and north) and using inter-company water transfers between these regions and water poor regions to maintain supplies to 2050⁹⁶. Overall, the ITRC estimates cumulative investment costs of £75 -132bn to meet modelled demand (ITRC 2016)⁹⁷.

FLOOD MANAGEMENT

A number of recent floods since 2005 (have raised awareness and stimulated investment in flood risk management. Total investment increased from £570m in 2005/06 to £869m in 2014/15 (nominal prices) (Defra 2015a).

Nevertheless, flood events continue to cause large-scale disruption to critical services and result in large economic losses and growing public frustration. Pennon Group Plc and AECOM recommended that attention be paid to flood defence infrastructure as a priority⁹⁸, not least because deficiencies in flood defence place the resilience of wider regulated infrastructural sectors at risk⁹⁹. 2.44 million properties are at *risk* of flooding from rivers and the sea, 3 million from surface water flooding, and 244,000 are at *high* risk of flooding. These numbers are set to increase in future due to population growth and climate change, even if investment in flood defences was to increase.

Protection is geographically uneven. Provision of flood risk management infrastructure has become increasingly focused upon urban areas where the benefits of investment are highest, while protection for low grade agricultural land has been allowed to deteriorate and in many floodplains and estuaries are targeted for 'managed realignment'.



OPPORTUNITIES AND OPTIONS

The main challenge for the sector is to devise the optimal investment strategy for flood risk infrastructure. This is likely to take the form of an enhanced whole systems (EWS) approach comprised of a portfolio of structural and non-structural measures to maximally reduce risks.

Flood defence standards will need to improve in response to increasing climate hazard risks. Evidence from the EA's long term investment strategy 2014 (LTIS) highlights the cost-beneficial nature of flood risk management solutions. It recommends a programme of investment over the next century to reduce risks where benefits are greater than costs. Modelling shows that a cost-beneficial investment programme will require between £750m and £920m per year on average to maintain a climate-adjusted current level of risk for expected annual damage reduction of 4%-24% in the next 50 years (EA 2014).

A challenge is determining the location of investments in flood defence infrastructure of varying standards. High levels of protection are adopted in urban areas, while 'partnership funding' arrangements are resulting in investments being directed to locations that can mobilise local funding contributions and that are willing to accept affordable (i.e. lower standard) flood protection.

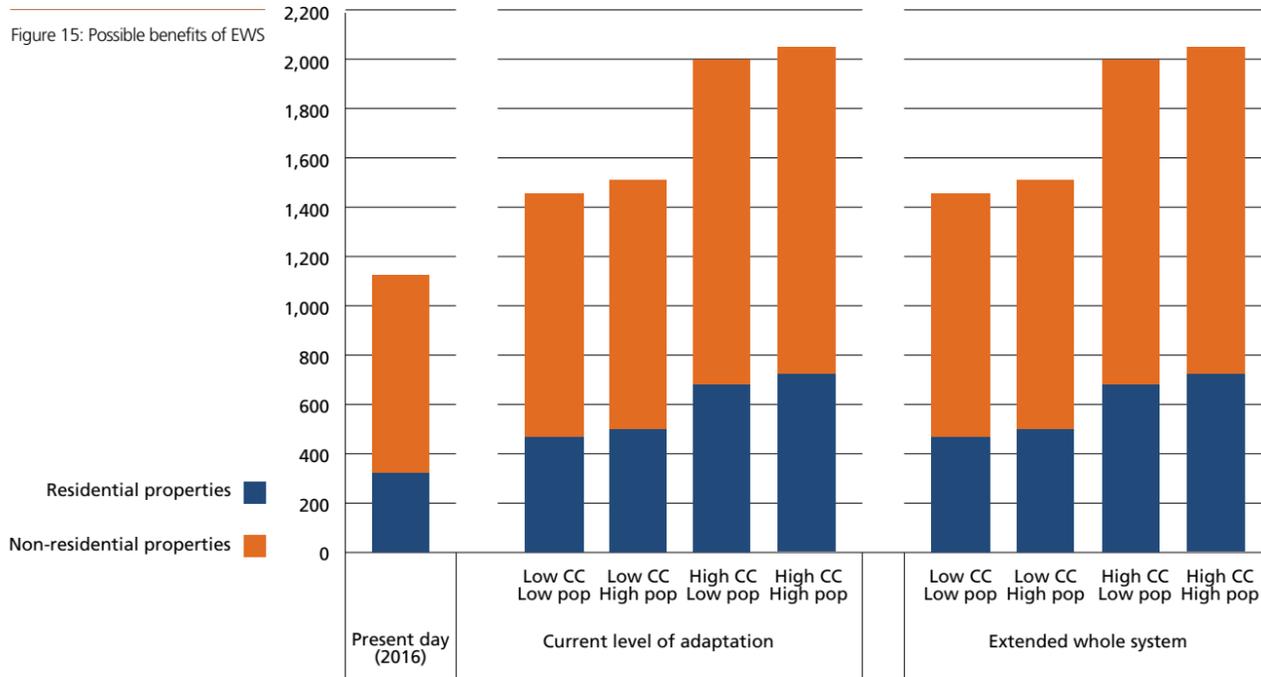
In tandem with structural defence investments for selected areas, the overall need for flood defence expenditure could be reduced through land use – such as reducing development on the floodplain - and catchment-wide measures. The need for flood defence infrastructure is strongly influenced by choices that are made about the location of residential and commercial development and the measures individuals and businesses take to protect their own property¹⁰⁰. Demand management for the development sector, likely required with

respect to national socio-economic policy, was identified as having potential for significant impact¹⁰¹.

A more rounded approach could be taken to river basin management. For example, allowing certain rivers to flood to relieve downstream pressures - and to the reconfiguration of urban areas, including the installation of green infrastructure to better manage runoff, rain water harvesting and sustainable urban drainage schemes¹⁰². Key elements of the sewer network have seen capacity increases and have been separated to reduce flood risks. Expenditure in some areas could be avoided altogether through a retreat from flood-prone coastlines and floodplains, although this is politically contentious.

Representations recommended that a strategic approach be accompanied by a review of the responsibilities for flood risk management – the large number of organisations involved is set only to increase with adoption of larger-scale adaptation measures – and a funding model that shifts the onus of paying for flood defences away from the public purse. A written representation recommended the privatisation of flood defence infrastructure with a mechanism for revenue funding to a body which is incentivised and regulated. This follows the example of the privatisation of the water industry, which has improved service and compliance through investment and resulted in efficiencies that have reduced customer bills¹⁰³. Better policy and guidance alignment and closer working between the Environmental Agency (for England) and Scottish Environment Protection Agency to harmonise planning and environmental guidance on flood scheme appraisal would enhance a strategic approach. (Figure 15)

Flood defence infrastructure is itself particularly vulnerable to climate change and increased



prevalence of extreme weather events. As a result, datasets for flood forecasting should be made more dynamic to allow rapid adaptation of forecasts and design standards and flood defence design should incorporate adaptable modular designs and design for exceedance. Resilience should be built at multiple scales (from households and businesses through to cities and regions) and can make use of increased 'real time' information available. Pennon Group Plc advised that government should consider whether the Environment Agency should have a duty to maintain assets it has constructed, in a similar way as Section 37 and 94 of the Water Industry Act places a duty on water and sewerage companies¹⁰⁴.

Even if an EWS approach is fully adopted, risks remain large and in excess of 2016 levels under a 4°C warming climate scenario (ITRC 2016). Hence there is a need for commitment to climate change mitigation in other infrastructure and policy sectors.

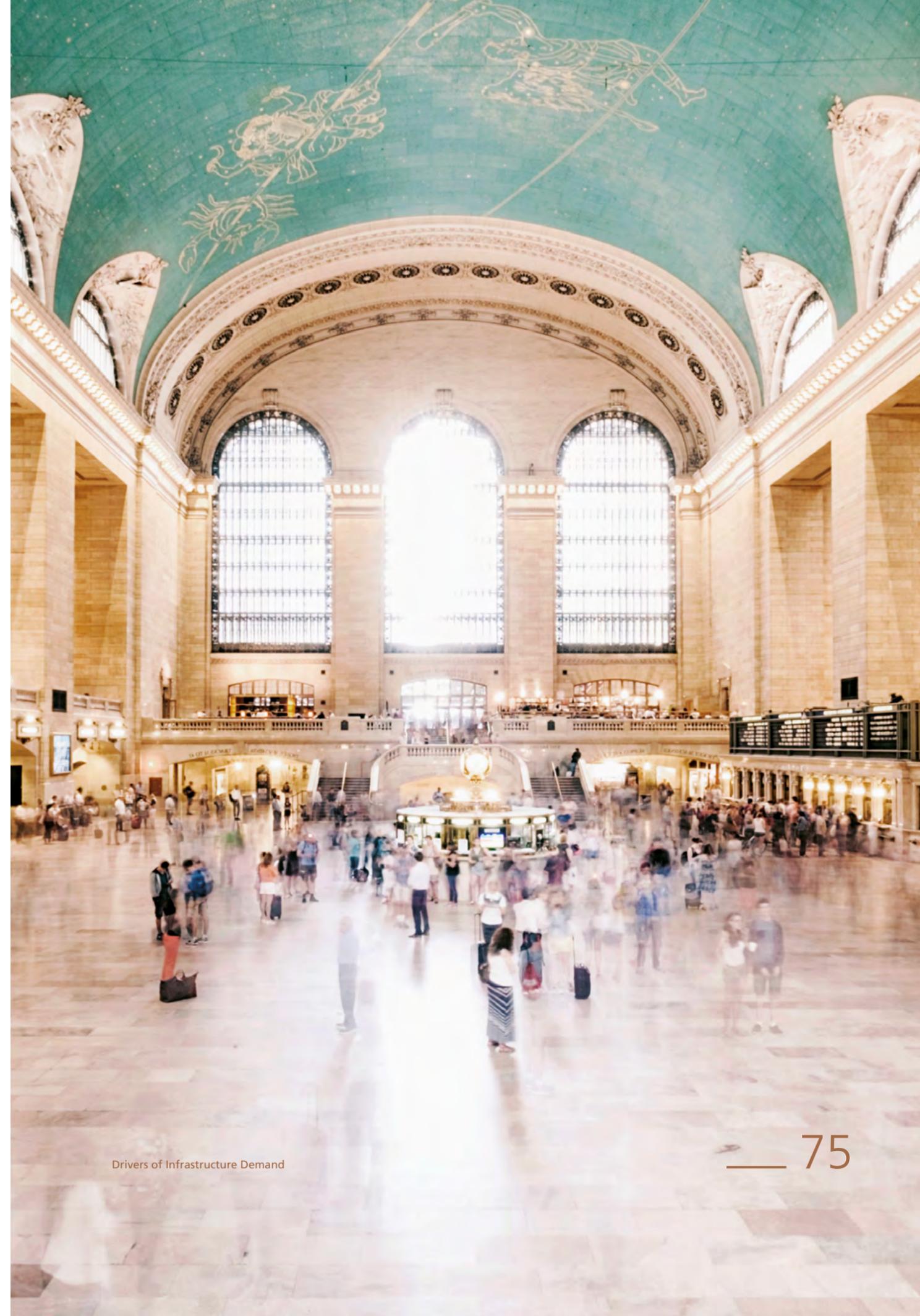
CARBON EMISSIONS AND FLOOD MANAGEMENT

Climate change is to result in temperature increase and changing patterns of average and extreme rainfalls, both of which increase the likelihood of flooding and hence the need for investment in flood defence infrastructure. Demand in this sector is particularly pressing because any deficiencies in flood defences place the resilience of other infrastructural sectors at risk¹⁰⁵.

ITRC modelling (FRM1) shows the Expected Annual Damages (EAD) from flooding at 2016 and 2080, with 2080 risks presented under a 4°C rise and under high and low population growth scenarios. Risk reduction that can be achieved under two flood adaptation scenarios¹⁰⁶. Even if an Enhanced Whole Systems (EWS) approach is fully adopted, risks remain large and in excess of 2016 levels

under a 40 warming climate scenario. Hence there is a need for commitment to climate change mitigation in the other infrastructural sectors (e.g. by decarbonisation) to reduce overall risk levels. As part of this, it must be recognised that there are significant embodied carbon emissions associated with the supply and construction of new infrastructure as well as from the operation of existing assets. A robust carbon accounting system including a measure of 'whole life carbon emissions' was recommended by representations as a key factor in the planning, design and construction of infrastructure¹⁰⁷.

Once enacted, successful climate change mitigation could offer cross-sectoral benefits, including improved security of water supply as the projected increased severity and frequency of droughts induced by climate change could be to some extent mitigated. Wastewater demand management due to possible lower intensity or frequency of storms (which result in pressure to increase volumetric requirements to avoid sewer surcharging and flooding of foul water).



SOLID WASTE

UK waste has been decreasing over the years owing mainly to EU regulations and landfill taxes. Targets achieved include:

- Biodegradable municipal waste sent to landfill was 9.2m tonnes in 2013. This represents 26 per cent of the 1995 baseline value, which comfortably met the 2013 EU target (no greater than 50 per cent of the 1995 baseline) (Defra 2015c).
- 72.7 per cent of UK packaging waste was either recycled or recovered in 2013 (2013 EU target was 60%) (Defra 2015c).
- The recovery rate from non-hazardous construction and demolition waste in the UK in 2012 was 86.5 per cent (EU target by 2020 is 70%) (Defra 2015c).
- Targets still to be met include:
 - EU target for the UK to recycle at least 50 per cent of household waste by 2020. The recycling rate of waste from households reached 44.9 per cent in 2014 (Defra 2015c).
 - 5% of waste arisings to landfill by 2030.
 - 70% of total waste to be composted and recycled by 2030.

Additional EU waste management targets were announced in 2014 (European Commission 2014): by 2025 no recyclable waste (including plastics, paper, metals, glass and biodegradable waste) to be landfilled; by 2030 recycling and preparing for re-use of municipal waste increased to 70%; and increasing the amount of packaging waste recycled or prepared for re-use to 80% by 2030.

OPPORTUNITIES AND OPTIONS

The UK possesses adequate capacity (including planned assets) to satisfy future needs for solid waste treatment. Even if no action is taken to reduce waste, policies and regulations will continue the current trend of reducing waste (from 59.2 Mt in 2015 to 56.8 Mt in 2050), in spite of population and economic growth.

Meeting future demand will therefore be more dependent on how the UK plans to harness the opportunities of a circular economy that maximises sustainable use and value of resources to the benefit of the economy and environment¹⁰⁸.

Material recovery could be enhanced by a re-use and recycling strategy to make better use of existing capacity to recovery – with a potential increase from 18.48 Mt in 2015 to 21.4 Mt by 2050 (ITRC 2016). The UK recycling system should be realigned to include manufacturers, re-processers and recyclers¹⁰⁹. A minimised waste export strategy builds capacity to process and recover resources from waste streams that were once destined for overseas. An enhanced energy from waste strategy builds new energy from waste plants, leading to a high energy balance (energy produced onsite the waste treatment plants minus amount utilised to run the plants).

Yet waste minimisation is the most straightforward strategy to reduce the cost and environmental impact of waste management and should be deployed alongside strategies for re-use and recovery. An ambitious strategy could reduce total waste produced to 22.2 Mt in 2050 and significantly reduce carbon dioxide emissions and costs associated with waste collection and treatment. Measures including designing in recyclability, designing out waste, light-weighting and eco-packaging will result in a reduction in overall volume of waste.¹¹⁰ Monitoring and pricing can reduce demand

for waste services¹¹¹. Extending responsibility through pricing, such as by 'pay as you throw' schemes, was identified as a financial disincentive for the generation of waste as well as a revenue stream for increasing capacity to deal with waste materials¹¹². Such schemes also promote increased understanding of the impact of waste generation by the public and industry¹¹³. Furthermore, technology that enables users to track their own consumption of infrastructure empowers user to manage their own demand¹¹⁴.

A circular economy where opportunities for recycling are maximised and all residual waste may be sent for energy recovery rather than landfill is estimated by the Environmental Services Association to require a further £5bn investment. An aggregated services model, such as that proposed by Viridor, can contribute to the development of progressive policies in recycling and resources and realising economic benefits (productivity, employment and business growth) of a circular economy.

Regardless of the form taken by the UK's circular economy, consideration will need to be given to the fact that export, currently the destination of a large proportion of UK waste, is due to decrease overall and may also need to be redirected away from the EU¹¹⁵ to other regions.

Another important prerequisite for waste management is the need for regulation and data standardisation to ensure greater transparency and accounting for waste streams. There is currently no duty on waste producers to report data unless waste is hazardous or subject to regulations. Producers are resistant to constraints on their use of materials¹¹⁶. The scope for data collection should be widened¹¹⁷ to support improvements to waste infrastructure. Data is particularly scarce for the commercial and industrial

(sector, responsible for almost a quarter of the total waste generated by the UK in 2012 (Defra 2015c). Add this to the construction and demolition) sector, for which data is also lacking, the two sectors produce three times the volume of municipal waste¹¹⁸. This makes it difficult to assess where and what type of new waste treatment facilities are required¹¹⁹.

Representations recommended prioritising the pursuit of a more coherent strategy and investment plan in waste¹²⁰ and recycling infrastructure¹²¹. Operation of the market and incentives to investors can be improved by enhanced financial incentives and reduction of risk. Security in equity and debt financing has particular potential for commercial and industrial (CI) waste stocks, for which debt finance is currently not secured against local authority contracts and equity financing is affected by uncertainty of supply¹²². Another suggestion was for local authorities to procure waste and recycling services in clusters to achieve economies of scale¹²³.

HOUSING

Opportunities and options

A number of recent measures and policy changes aim to reduce barriers to meeting the UK's housing needs:

Release of public land

At least 900,000 hectares (6%) of all freehold land in England and Wales is owned by public sector organisations, according to a new report commissioned by Telereal Trillium¹²⁴. This is significantly more land than previously estimated and if used, and planned, properly could go a long way towards solving our housing crisis.

The Homes and Communities Agency (HCA) is the national housing and regeneration agency for England and an executive non-departmental public body of the Department for Communities and Local Government, with a remit to manage the delivery of housing on public land. It takes ownership of public land, which it sells to house builders and others with the objective of overcoming barriers to development to help increase the speed with which house builders can build new homes.

The HCA is responsible for:

- Increasing the number of new homes that are built in England, including affordable homes and homes for market sale or rent
- Improving existing affordable homes and bringing empty homes back into use as affordable housing
- Increasing the supply of public land and speeding up the rate that it can be built on
- Regulating social housing providers to make sure that they're well managed and financially secure, so maintaining investor confidence in the affordable housing sector and protecting homes for tenants

- Helping to stimulate local economic growth by using our land and investment, and attracting private sector investment in local areas

In London, the HCA acts as a regulator for the Greater London Authority, which is responsible for housing and regeneration. The proposed Homes for Londoners (HfL) initiative brings together the Mayor's housing, planning, funding and land powers to raise investment, assemble land and commission and construct new homes which offer Londoners a 'fair deal'¹²⁵. London First's July 2016 report recommends that HfL's primary focus should be getting public land ready for development: assembling sites around core public land-holdings, setting out an acceptable level of density for development and offering the land to the market with clear requirements for mixes of tenures.

The House of Lords refers to criticism from the National Audit Office¹²⁶ which was unable to establish how many homes had been built on released land as government departments were not monitoring what happened to a site after it was sold. The report suggests that the government should make far more public land available for housing to help provide low cost housing and give a senior Cabinet minister responsibility for the delivery of the programme, and overseeing the number of homes that are actually built, with support from the National Infrastructure Commission (NIC).

Further to this, the NIC could provide a better integrated overview of the release of public land in relation to the provision of strategic infrastructure and help to identify how infrastructure could unlock further growth.

Devolution

Devolution holds potential to increase democratic accountability and levels of housing delivery, through enabling sub-national advocacy and drives to attract investment. The RTPI has argued¹²⁷ that social well-being, employment growth and economic competitiveness are put at risk by a failure to fully integrate the provision of housing and infrastructure across local authority boundaries. They argue that this integration needs to occur at a range of scales, which could be enhanced by the devolution of powers and responsibilities to combined authorities. However, there remains a need for decision-making on the national level to actively enable and shape sustainable housing growth rather than simply respond to existing demand.

New delivery models

Infrastructure providers, such as Network Rail and Transport for London, are considering new models of housing delivery involving creating communities around specific infrastructure assets. This would achieve cross-sector synergies as well as the integration of economic, social and housing infrastructure which is widely recognised as essential for sustainable, high-quality housing delivery. A new agreement between Network Rail and the HCA will see them working with local councils to deliver up to 10,000 new properties on sites around stations, hence facilitating the development of housing in areas supported by economic infrastructure.

Planning reform

There has already been significant planning reform over the past few years to try and speed up the planning process often at the expense of the quality of new development. While the planning process does inevitably delay development, careful planning is required to ensure the effective and sustainable delivery

of the right type of housing, and the creation of high-quality places that are well integrated with other economic, social and physical infrastructure.

The Housing and Planning Act 2016 contains a framework for the creation of 'Planning in Principle', a new route to obtain planning permission for housing-led developments with the aim of limiting upfront investment by developers before they have certainty on the principle. The measures are due to be fleshed out towards the end of this year. The Act also streamlines the process for getting a neighbourhood plan which, according to early figures, boosts housebuilding by more than 10%.

The Government also proposes to amend the National Planning Policy Framework (NPPF) to encourage local authorities to take a proactive approach working with developers on planning for new settlements (Garden Villages, Garden Cities). However, it hasn't put forward any new tools for supporting local authorities.

Other planning reforms include:

- Office-to-residential permitted development rights have now been made permanent;
- The Government is piloting a Brownfield Register project introducing a duty on local authorities to hold a register of Brownfield Land capable of being developed for housing;
- The Government is proposing to amend para 22 of NPPF to make clear that unviable and underused employment land should be released unless there is significant and compelling countervailing evidence.

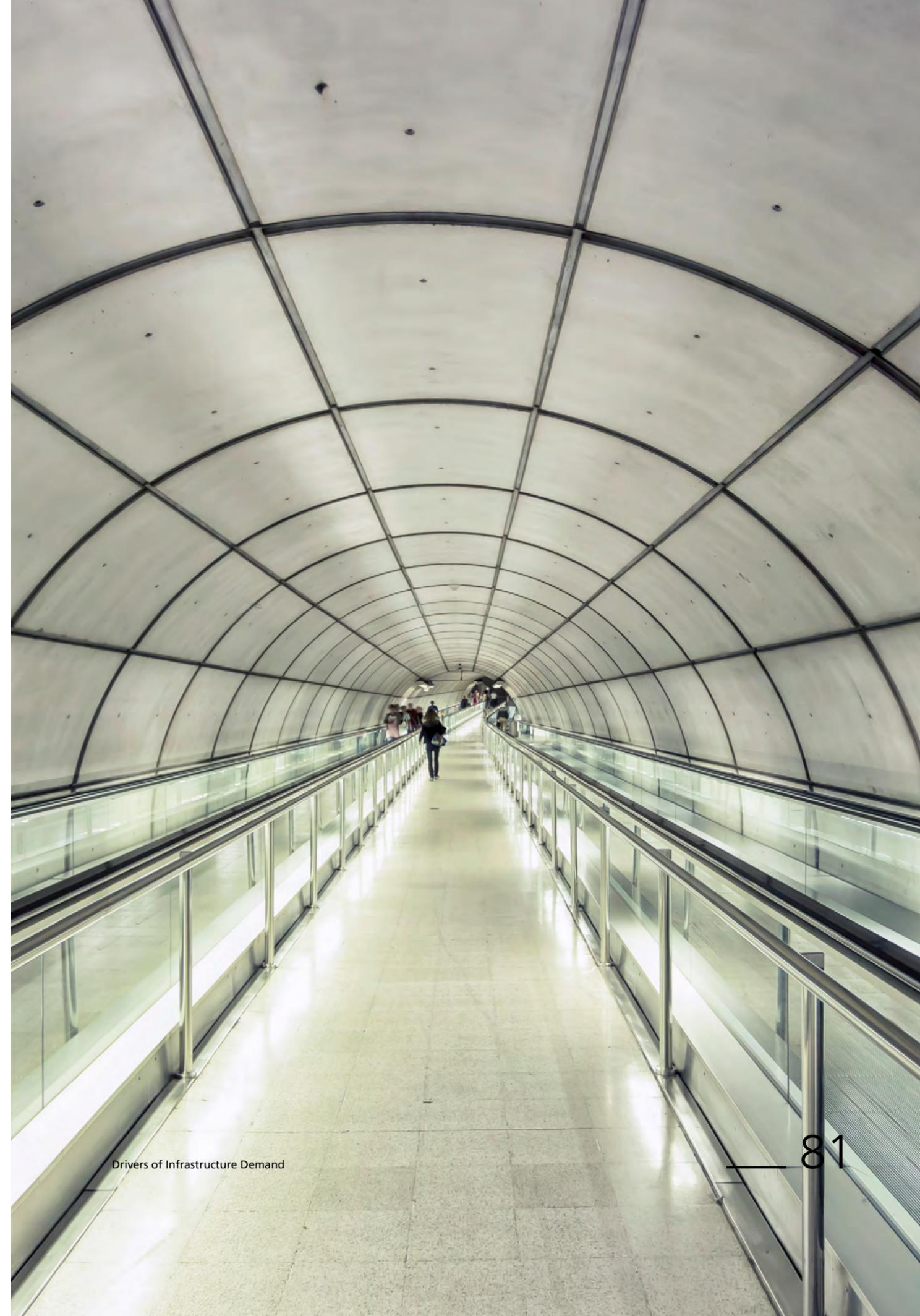
Further reform of the Planning process to expedite housing delivery is not therefore required, although adequately resourced

planning departments are crucial to the effective delivery of development. Allowing local authorities to set and vary planning fees in accordance with the needs of their local area, as recommended by the House of Lords report, and ensuring this is ring-fenced for expenditure on planning and development, would help to boost the capacity of local planning authorities to properly plan for and manage housing delivery.

Public investment

A £1bn housing delivery fund, the 'New Communities Partnership', was launched in May 2016 to help the public sector build 10,000 new homes across the UK over the next four to five years. This initiative brings together Kier Living, The Cheyne Social Property Impact Fund and The Housing Growth Partnership (a joint venture between the Homes and Communities Agency and Lloyds Banking Group). The partnership will provide local authorities and housing associations with an innovative delivery model for building new homes on their own land, giving them the option to choose between sale and/or rental developments, and offers significant scope for affordable development. The House of Lords report calls for the Government to relax limits on local authority borrowing to build social housing and provide financial support and flexibility for local authorities to enter into partnerships with housing associations and institutional investors.

The Starter Home Land Fund (March 2016) encourages local authorities to form partnerships with HCA and use the funding to support acquisition, remediation and de-risking of suitable land for starter home developments that can then be built out by developers by 2020.





CROSS-SECTOR INTERDEPENDENCIES

Economic infrastructure sectors are typically viewed in isolation. The result has been organisations operating in silos and frequently uncoordinated decision making. This means that the interdependencies between infrastructure sectors have not been properly accounted for. That is problematic, because each infrastructure makes significant demands upon other – for example requiring energy and digital communications infrastructure. The most catastrophic consequences occur when failure propagates from one infrastructure network to others. Yet the interdependent nature of infrastructure sectors also presents opportunities for cross-sectoral mutual benefit and enhancement in solutions. Analysing the national infrastructure as a system-of-systems allows these important interdependencies to be captured and quantified and measures to maximise efficiency to be identified.

The NNA seeks to overturn this in favour of a more strategic, sustainable approach which will efficiently meet the UK's infrastructure needs to 2050. The written representations, affirming the importance of cross-sectoral decision making for infrastructure, recommended that the NIC's potential to coordinate sectoral interests be realised by a cross-sectoral remit and cross-sectoral representation.

Interdependencies in demand

Many interdependencies occur because of the demands that one infrastructure network places on others. Interdependence also occurs because increasing demand from households and businesses, due to economic and population growth tends to be correlated across all sectors. There are technological changes that mean that these interdependencies are becoming more significant.

Electrification and electricity demand

Large scale electrification of heat and transport services is anticipated in order to meet the UK's carbon target of at least an 80% reduction in carbon emissions (relative to 1990 emissions) by 2050. Although critical to achieving decarbonisation the impact of electrification on energy demand is among the top two largest infrastructural interdependencies modelled by the ITRC¹²⁸ and must be considered and mitigated.

ITRC (2016) modelling shows that electrification of heat and transport could result in the almost doubling of electricity consumption by 2050 (Figure 15). In a business-as-usual situation (no electrification strategy, represented by the unconstrained demand strategy), electricity consumption is projected to increase from 380 TWh in 2015 to 467 TWh in 2050. By contrast, total electricity consumption in 2050 is projected to reach 677 TWh under the ITRC's electrification strategy scenario - consisting of 23m electric cars, 300km of track electrification per year, and up to 80% replacement of alternative heating technologies with heat pumps (represented as 'unconstrained demand + EHT strategy')¹²⁹.

Under the electrification strategy, generation capacity must increase to 191 GW to meet a peak demand of 98 GW (Figure 16) – with concomitant increased investment requirements and carbon emissions. There is a potential conflict between maximising both these objectives. Government will have to take considered policy choices to ensure that a balance is achieved. To avoid nullifying decarbonisation gains from electrification of the heat and transport sectors, aggressive technological and behavioural measures will be required in the energy and transport sectors to reduce demand ('demand management' scenario Figure 15), alongside a move to low carbon technologies to provide

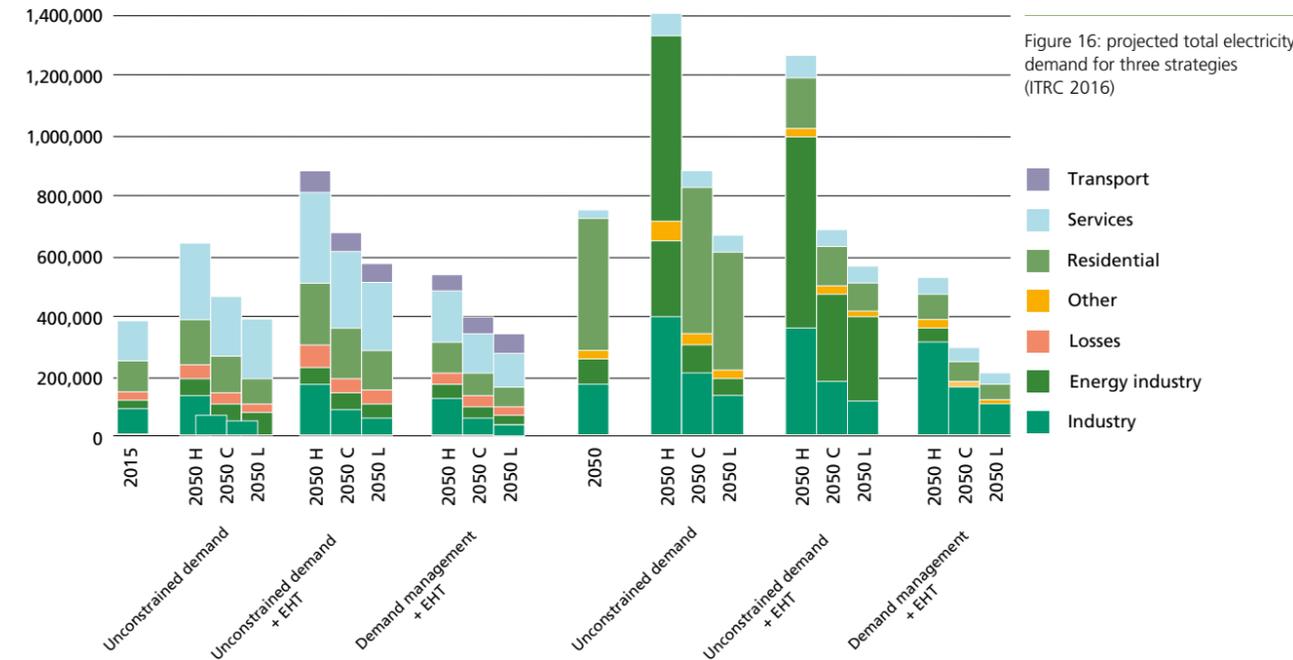


Figure 16: projected total electricity demand for three strategies (ITRC 2016)

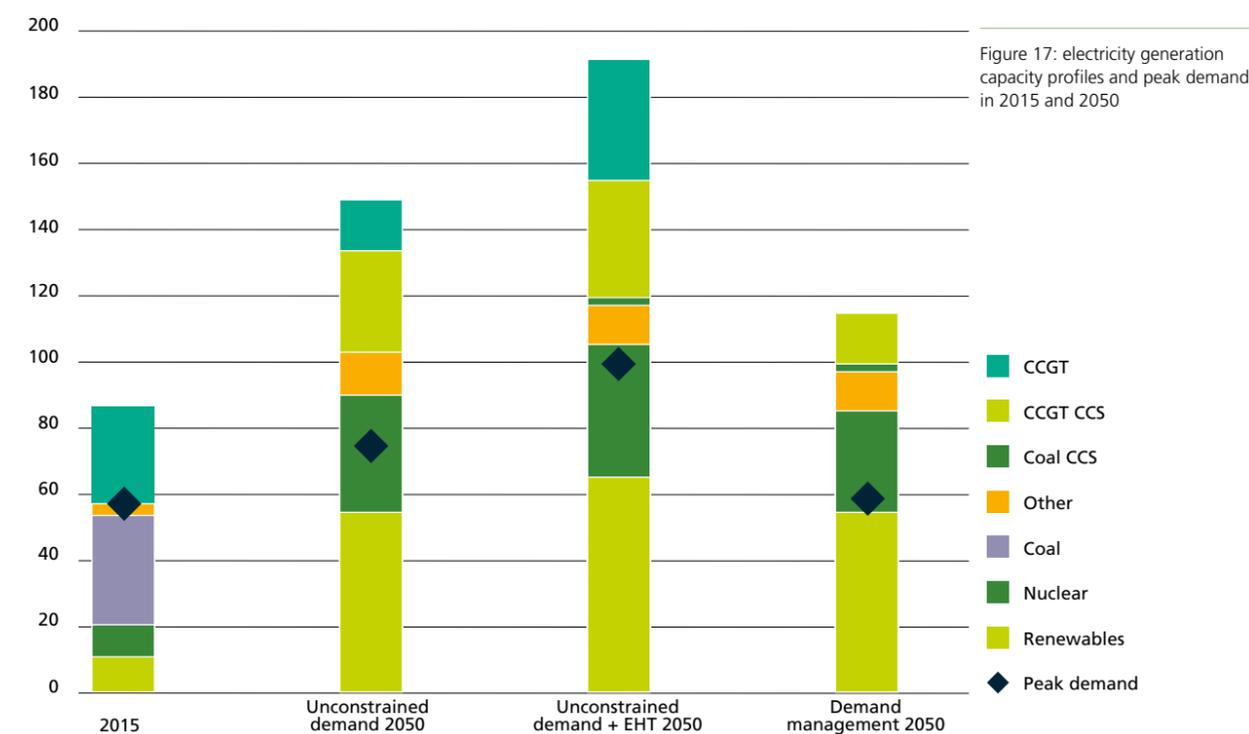


Figure 17: electricity generation capacity profiles and peak demands in 2015 and 2050

generation capacity. As shown in the ITRC's demand management 2050 scenario, the implementation of distributed electricity storage (24 GW by 2050), demand response (10% of peak demand by 2050) and efficiency and conservation measures lowers the system's peak demand to 58 GW (Figure 16 and 17).

Digital communications and electricity demand

The projected increased prevalence and enhanced services levels of the digital communications sector are driven by factors both within and outside of the digital sector itself and are likely to increase the UK's total electricity demand. Future higher demand for digital communications is difficult to quantify as it is a product of a complex array of factors comprising:

Policy/regulatory shift in focus from basic access to improved quality of access and universality.

Development of the digital economy increasing consumption of digital communication services

- Shifting work and social habits such as deeper integration of telecommunications
- Internet of things and demand management for infrastructure such as smart meters for water consumption and journey planning for transport
- Momentum within the digital communications sector as demand is driven by availability of new devices and enhanced service offer

Whilst digital communications and ICT more generally, are expected to consume a growing proportion of electricity generation, digital technology is also central to reducing energy demand and balancing intermittent supplies

with variable demand, through demand response technologies.

ENERGY AND WATER DEMAND

The future energy supply portfolio will have a significant impact on demand for water. According to ITRC (2016) modelling of future inter-sectoral demand, the potential changes in demand for cooling water from the energy sector is one of the top two interdependencies as a proportion of total sector demand¹³⁰.

Thermoelectric power stations (coal, gas and nuclear) often use water intensively, as it is needed for producing and cooling steam to generate electricity. Cooling water accounts for 28% of all licenced abstractions¹³¹ and 5% of available freshwater resources in England and Wales are directed to this purpose¹³².

Future needs for cooling water will depend on the energy supply portfolio. Closing of inland coal-fired plants and nuclear new-build on the coast is reducing cooling water demand. New inland gas plants could increase cooling water demand, in particular if they are fitted with carbon capture and storage technologies. The water intensity of energy generation almost doubles when CCS is installed to capture emissions from coal power plants, meaning cooling demands can be 26 to 140% higher¹³³.

Mitigating overall demand for energy via the demand management measures described in previous sections will have a role to play in reducing water requirements. Methods could also be employed to reduce water demands for CCS power stations, including:

- 'Closed loop' cooling systems that re-use cooling water in a second cycle rather than discharging it back to the source the first time. This reduces the amount of water for cooling but consumes more of it.

- Switching to hybrid cooling systems that use both water and air could reduce water use by 15-35%. Dry air cooling is also an option but increases costs even further
- Shift generating capacity to either estuaries or the coast thus using non-freshwater sources for cooling (Byers et al 2015).

Housing and multi-sectoral demand

Housing, including the location of development and the quality of the building stock, affects the quantity and type of demand in all other infrastructural sectors.

Whilst lack of adequate transport infrastructure can act as an obstacle to housing delivery in certain locations, where housing is delivered in spite of inadequate transport infrastructure the result is an increase in congestion, carbon emissions and air pollution. Housing delivery in locations at risk of flooding or water shortage results in a need for greater capacity and investment in these sectors.

Housing location influences the effectiveness of different energy sources, as the choice of technology will depend on the population density and types of properties in the area served, according to the ITRC (2016). In places off the gas grid or with low population density, electric heat pumps are the most suitable solution. However, in densely populated urban and suburban localities, repurposing of the existing gas grid for hydrogen might be preferred as it would avoid disruption to households in addition to utilising existing gas storage assets for inter-seasonal demand management. For areas of high density, mixed use, including core loads such as large service sector buildings and leisure centres or as part of community energy schemes as well as for multi-storey buildings, district heating may offer the most effective solution. Planning of the energy system and housing provision must

take these interdependencies into account, alongside the need to decarbonise the UK economy.

The nature of the built environment influences demand for infrastructure services, in particular energy, water and urban drainage. The opportunities for improving energy efficiency and reducing demand in houses have already been discussed, as have the opportunities for reducing water use. In fact the two are interconnected because of the amount of energy that is used for heating water – savings in the use of hot water will save both energy and water. Housing development also influences the amount of runoff that is generated by rainfall – avoiding the increase in paved areas and use of sustainable drainage systems reduces the demands placed on sewer systems.

Cross-sectoral demand for digital communications

Our consultees anticipated the development of smart networks and cities¹³⁴ where power, data and telecommunications are fundamental to the delivery and monitoring of essential services such as water, transport, electricity and gas. While offering huge potential for demand management and efficiencies in these infrastructure sectors the key role envisaged for digital communications risks placing a strain on digital infrastructure. Future need for digital communications is particularly difficult to assess due to the powerful influence exerted by emergent technologies and products, some of which will act to increase, and others to diminish, demand. As outlined in the individual sector analysis, the level of provision will depend on the extent of market incentives and government regulation.

OPPORTUNITIES FOR CROSS-SECTORAL SOLUTIONS AND ENHANCEMENT

Water and wastewater solutions

Demand in the water sector has a direct impact on the wastewater sector as most of the national per capita daily consumption of water (150p/c/d) is returned as wastewater. Accordingly, demand management in the water sector translates directly into demand management for the wastewater sector, reducing the need for investment in new capacity of wastewater treatment and reducing this infrastructure sector's contribution to carbon emissions.

ITRC has modelled the future demand for wastewater services based on the projected future population and the national per capita daily consumption of water and tested two demand reduction strategies (medium and high) with lower per capita water use, respectively 127 and 117 p/c/d, based on the demand management interventions in the water sector. Total volume of wastewater in 2050 is over 1m ML lower in a high demand reduction strategy, saving £18bn compared with a scenario in which demand is unconstrained. It also results in a reduction in cumulative emissions of almost 3 Mt by 2050¹³⁶.

Flood risk management and wastewater solutions

Measures to mitigate flood risk frequently also act as a form of demand management for wastewater. 'Green infrastructure' solutions involve naturally removing pollutants from watercourses and adding addition buffering capacity to reduce the impacts of flood events, whilst sustainable urban drainage schemes (SuDS) reduce the amount of storm water discharged into sewers and hence directed to treatment plants for processing. It is not

possible to quantify savings from SuDS at this stage since the relevant data are unavailable (ITRC 2016). Dual sewers mitigate flood risk and the need for wastewater intervention by reducing system susceptibility to extreme rainfall events.

Housing and multi-sectoral solutions

The interdependencies of housing delivery and demand for economic infrastructure, while adding complexity to decision making also present opportunities for demand management and cross-sectoral enhancement. To seize the opportunities presented by housing delivery, representations recommended integration of the decision making framework for infrastructure with planning (such as coupling land use planning with the identification associated off-site infrastructure requirements¹³⁷), regulation and demand management¹³⁸, and that a spatial approach be taken: 'it is vital that we understand the spatial implications of national infrastructure investment, and in particular how this relates to locations where major development is proposed, and where resources are located in relation to demand'.

Digital communications and multi-sectoral solutions

The increasing pervasiveness of digital and 'smart' technology, enabling collection and analysis of big data, is to have a profound impact on infrastructure needs, demands and delivery across all sectors – only likely to increase with future innovation. Projected contributions of digital communications to infrastructure sectors include:

Energy: smart grids, meters and 'smart house' solutions for demand management;

Transport: telecommunications and teleworking reduce the need to travel and act as demand management for transport, smart

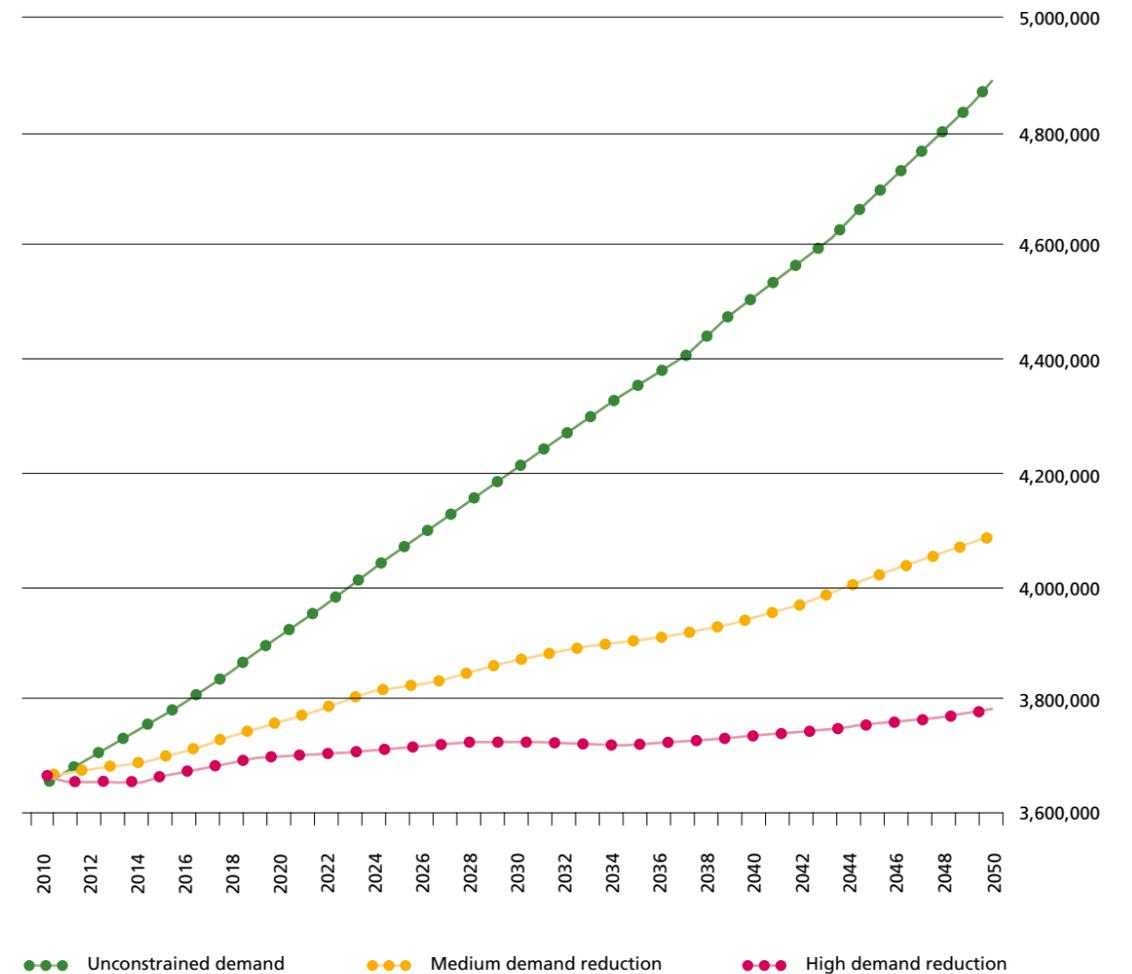


Figure 18 (opposite): Volume of wastewater treated for three alternative strategies



highway and journey planner systems and autonomous vehicles manage congestion and peak demand; improved transport network availability and increased capacity through condition and usage monitoring and condition based maintenance; and Water, wastewater and solid waste: smart metering to manage demand¹³⁹.

Big data requires significant electricity to power it. The National Resource Defense Council reports that in 2013 US data centres consumed energy equivalent to 34 500MW coal fired power stations¹⁴⁰. Managing the storage and sharing of the huge quantities of data requires policy action if data demand and ultimately energy to support are not to grow beyond sustainable levels.

Demand management via housing delivery

Demand management for UK economic infrastructure needs can be achieved through strategic decisions concerning the location of new housing delivery and technical measures in building design.

Concentrating new housing development in locations offering easy access to sustainable and public modes of transport serves as a form of demand management in the transportation sector. Increased use of urban and suburban transportation contributes to an overall reduction in transport congestion and help to decarbonise the national transportation system and reduce environmental impacts such as air pollution.

Demand for flood defence and management infrastructure can be mitigated by ensuring that new development occurs in areas at low risk from flooding and unlikely to produce downstream flooding impacts. Priorities identified by representations include better policy and guidance alignment and closer working between the Environmental Agency

(for England) and Scottish Environment Protection Agency to harmonise planning and environmental guidance on flood scheme appraisal. Flood risk – as well as demand for water and wastewater infrastructure - can be further managed with the installation of sustainable urban drainage systems (SuDS), green infrastructure, dual wastewater and storm water networks, grey water re-use (estimated by ITRC 2016 to yield 60 Ml/d), and rain water harvesting in new developments.

The design and construction of housing offers potential to contribute to energy mitigating energy demand and production of waste. Construction methods can be designed to maximise re-use and recycling of materials and minimise waste, contributing to the circular economy agenda. Use of heat pumps and the standardisation of electric heat in new housing developments contribute to the decarbonisation of the energy sector, whilst thermal efficiency measures (e.g. insulation) reduce overall demand for energy. The need for density in new developments should be balanced with provision of green infrastructure, which acts to reduce the urban heat-island effect and store carbon. Representations identified 'whole house solutions' or 'smart homes' - which could include power-to-heat systems and stationary battery storage technologies - that can deliver self-consumption rates from 60-90% and enable the consumer to export electricity when it is economically advantageous to do so¹⁴¹. The housing sector's potential contribution to energy demand is likely to increase in future as working patterns shift away from offices to (potentially less efficient) individual homes.

In the long term new housing development could contribute to mitigating the regional imbalance in UK transport congestion and water demand (Figure 19, next page), if new development is utilised to encourage

population redistribution towards the water-rich, less populated north and west. Spatially rebalancing the UK economy is a multifaceted task requiring significant and varied investment and political commitment - including in transport infrastructure - to promote a more even distribution of employment opportunities. Nevertheless, the provision of high quality housing facilitating development of places and communities is integral to the rebalancing agenda.

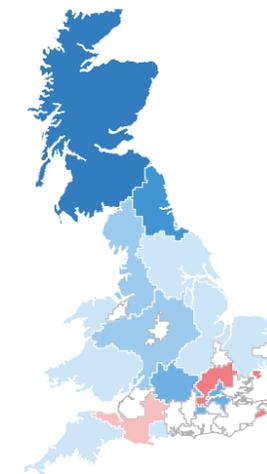
Housing delivery also presents the opportunity for providers of digital infrastructure to exploit economies of scale, facilitating the deployment of new to market and often very expensive technologies where dense population allows access by a large quantity of early adopters.

In order to fully realise cross-sectoral benefits offered by the housing sector, measures must be implemented in the existing housing stock which will form the majority of the UK's housing stock to 2050. Existing stock can be retrofitted to enhance demand management in energy (insulation, electric heat, smart systems) and flood risk, water and wastewater (SuDS, dual sewer networks, rain water harvesting, etc), albeit frequently requiring large-scale investment.

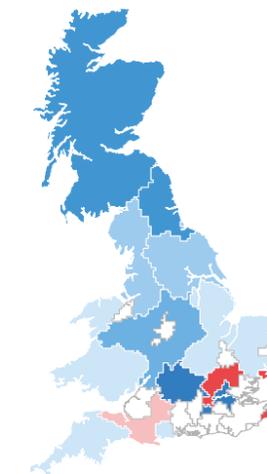
Housing delivery to increase economic infrastructure capacity

Effective housing delivery is dependent upon supporting infrastructure. As such, delivery of housing in locations lacking in sufficient infrastructural capacity can act as a stimulus to investment in capacity increase. Moreover, housing delivery can contribute towards the funding of investment in infrastructure via section 106 obligations or Community Infrastructure Levy (CIL). For example, the Northern Line extension has secured over £200m from the developers of Battersea Power Station in this way.

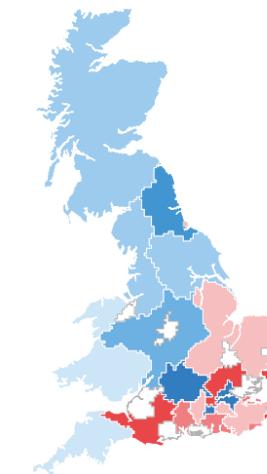
Unconstrained demand



Low population growth
High flow climate scenario



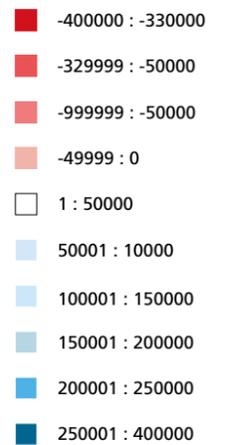
Central population growth
Central flow climate scenario



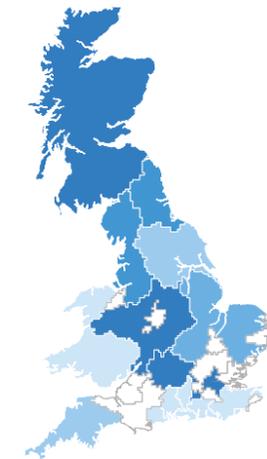
High population growth
Low flow climate scenario

Figure 19: UK water balance 2015-2050 for the unconstrained demand and leakage reduction + demand management strategies under three population/climate scenarios.

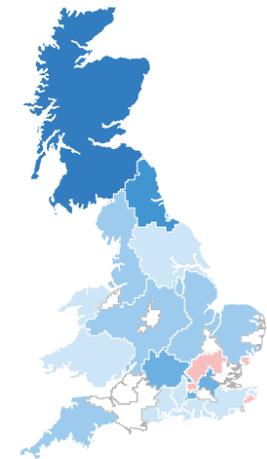
Supply-demand balance (ML/d)



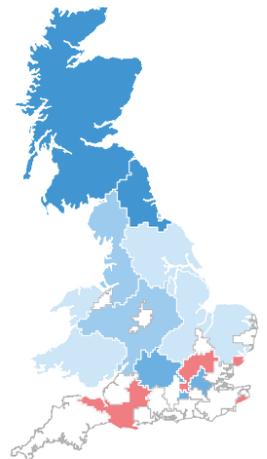
Leakage reduction & demand management



Low population growth
High flow climate scenario



Central population growth
Central flow climate scenario



High population growth
Low flow climate scenario



CONCLUSION: DELIVERING THE VISION

The government has recognised the importance of infrastructure for the UK and the need for a more strategic approach to infrastructure planning and delivery. This is reflected in the creation of the National Infrastructure Commission. Internationally, a growing number of countries have entities that are charged with looking strategically at infrastructure needs. The NNA has demonstrated how important a strategic approach is, given the changing nature of demands for infrastructure services and the ever-growing integration between different types of infrastructure.

We have seen recurring themes throughout the NNA project.

A SHARED VISION: Planning infrastructure is complex, and involves negotiating many different objectives. An over-arching vision is helps to cut through that complexity and provides the principles for weighing up different objectives. That over-arching vision needs to be widely adopted and overseen by strong leadership and management¹⁴¹.

The vision should consider how infrastructure decisions influence other policy agendas¹⁴². This should extend from consideration of economic and financial factors to a wider selection of factors¹⁴³ covering human wellbeing, health and safety and sustainability in infrastructure decision making. For example, air quality provides a link between infrastructure decision making and the health policy agenda.

We hope that the NNA has contributed to the development of a shared vision for Britain's infrastructure. The vision will continue to evolve and be refined, but a consistent direction is essential to provide confidence to investors and to demonstrate that we, as a nation, are able

to thrive in a challenging future.

A CROSS-SECTORAL FRAMEWORK: Responses to the call for evidence affirmed the importance of adopting a cross-sectoral approach to infrastructure and suggested ways in which this could be enacted. Nationally significant infrastructure projects do not exist in a vacuum. Rather, infrastructure policy should include provision of housing, electricity and social infrastructure (e.g. schools, GPs, post offices), as well as digital infrastructure¹⁴⁴, and in doing so take account of the wider needs of communities¹⁴⁵.

A GROWING EVIDENCE BASE: The NNA has assembled evidence through consultation, modelling with the ITRC's NISMOD system, and from a range of other sources, to provide evidence upon the drivers of infrastructure needs and the range of options for responding to those needs. Analysing the options is challenging, because of the complexity of infrastructure systems and the uncertainties about what the future holds. We welcome the growing expertise in industry sectors, government and academia for systems analysis, but the NNA demonstrates that more needs to be done to integrate that expertise and the relevant datasets. Moreover, this evidence base needs to be made more widely available, so that a range of stakeholders can understand the options for national infrastructure.

Techniques are required to encourage cross-sectoral decision making. A priority or ranking system for each sector, informed by an impartial assessment of the inter-relationships between projects in different sectors at all levels from national to local, would enable agreement on priorities and mitigations across sectors, avoiding a situation where problems are shifted from one sector or infrastructure network to another¹⁴⁶. Cross-sectoral collaboration will be achieved where

there is benefit to the parties involved¹⁴⁷. Hence a crucial role for formal assessment and demonstration of the benefits of partnership working in terms of improved project outcomes and reduced or shared costs¹⁴⁸.

GOVERNANCE AND REGULATION:

Governance of infrastructure takes place at a range of different scales. It should be undertaken within a framework provided by a long-term strategy or plan incorporating cross-sector synergies and indicating the responsibility of each sector¹⁴⁹. The framework should align the strategies and principles of all government departments and agencies - cross-sectorally¹⁵⁰ and at all spatial scales¹⁵¹ - and major stakeholders¹⁵². Central government departments such as BEIS, DEFRA, DFT and DCLG could enter into joint-working relationships with private sector companies¹⁵³.

Evidence provided pointed to a role for local and regional governance. Combined authorities, LEP and other 'super-structures' such as the Northern Powerhouse¹⁵⁴ have the potential to reinvigorate local and strategic planning and collaborate with central Government to identify infrastructure requirements. Greater clarity surrounding the role of these sub-national groupings is needed¹⁵⁶. This could be delivered by devolution¹⁵⁷ and resulting increased ownership and vision on the part of empowered regional authorities¹⁵⁸.

Collaboration between stakeholders is key to ensure timing and benefits of investment are maximised¹⁵⁹. This could involve collaboration of industry trade bodies such as Water UK and Environmental Services Association¹⁶⁰. Professionals can share best practice commercial delivery with the support of professional bodies. Regulators can play a key

role 'in improving dialogue and knowledge transfer between sectors'¹⁶¹. The UK Regulators Network (UKRN) could support development of a resilience framework linking individual incentives within each regulated sector price control¹⁶².

The NNA partnership and wider infrastructure industry stand ready to support the NIC and Government in its work on infrastructure delivery and policy.

FOOTNOTES

- 1 http://www3.weforum.org/docs/GCR2016-2017/05FullReportTheGlobalCompetitivenessReport2016-2017_FINAL.pdf p.354
- 2 These ranges are comparable to those in the Committee on Climate Change Sectoral scenarios for the Fifth Carbon Budget [E://documents.theccc.org.uk/wp-content/uploads/2015/11/Sectoral-scenarios-for-the-fifth-carbon-budget-Committee-on-Climate-Change.pdf](https://documents.theccc.org.uk/wp-content/uploads/2015/11/Sectoral-scenarios-for-the-fifth-carbon-budget-Committee-on-Climate-Change.pdf)
- 3 <https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/synthesis-report/>
- 4 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/547427/UK_Statistics_on_Waste_statistical_notice_25_08_16_update__2_.pdf
- 5 http://ec.europa.eu/eurostat/statistics-explained/images/2/29/Electricity_and_gas_prices%2C_second_half_of_year%2C_2013%E2%80%9315_%28EUR_per_kWh%29_YB16.png
- 6 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/520086/2904569_nidp_deliveryplan.pdf
- 7 <http://researchbriefings.files.parliament.uk/documents/SN06594/SN06594.pdf>
- 8 Committee on Climate Change 2016 <https://documents.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf>
- 9 <http://www.metoffice.gov.uk/climate/uk/interesting>
- 10 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/464354/NIP_for_skills_final_web.pdf
- 11 IMF 2015
- 12 <https://documents.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf>
- 13 <https://documents.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf>
- 14 House of Lords Select Committee on Economic Affairs: Building more homes, 15 July 2016. Available at: <http://www.publications.parliament.uk/pa/ld201617/ldselect/ldeconaf/20/20.pdf>
- 15 The full report can be found here: <http://www.publications.parliament.uk/pa/ld201617/ldselect/ldeconaf/20/2002>.
- 16 DBEIS (2016: 113) 'Digest of United Kingdom Statistics 2016'
- 17 DBEIS (2016) 'Historical electricity data: 1920 to 2015 – Capacity'
- 18 Ofgem (2015: 6) 'Electricity security of supply'
- 19 DECC (2015: 14) '2014 Greenhouse gas emissions final figures'
- 20 DBEIS (2016: 28) 'Digest of United Kingdom Statistics 2016'
- 21 DBEIS (2016: 158) 'Digest of United Kingdom Statistics 2016'
- 22 DBEIS (2016: 121) 'Digest of United Kingdom Statistics 2016'
- 23 E3G
- 24 Large portions of the road transport fleet are expected to become electrified. This includes 25% of the fleet powered solely by electricity and 30% using electric hybrid technology (ITRC 2016)
- 25 Winter gas peak demand for heat can be 12 times higher than in the summer, and is 5 times the current electricity peak demand (Maclean et al. 2016).
- 26 Eyre and Baruah (2015) have estimated the cost of additional generation capacity at £3,000 per household not including the price of the heat pump, which is currently £8,000 per household (to decrease to £5,000 by 2030)
- 27 Turner & Townsend
- 28 Turner & Townsend
- 29 Lightsource Renewable Energy

- 30 For example, Viridor is capitalising on a shift in trend towards a more decentralised energy distribution model whereby local energy suppliers and end users are more interconnected, with a £1.2 billion investment programme to establish a strategically located energy recovery facility network. Each facility is Combined Heat and Power (CHP) enabled, offering the potential to export energy in the form of electricity and heat (Pennon Group Plc).
- 31 Open Energi, National Grid, Cardiff University. Dynamic Demand is a Demand Response service that reacts instantaneously to second-by-second changes in the balance between supply and demand on the grid. Compared to the inefficient and greenhouse-gas-intensive method of quickly ramping power plants up and down, demand-side flexibility is essentially carbon-free.
- 32 Local Government TAG
- 33 Barton Willmore LLP
- 34 Mott MacDonald; Turner & Townsend; LDA Design
- 35 Mott MacDonald
- 36 E3G
- 37 E3G
- 38 RICS
- 39 DONG Energy
- 40 Tempus Energy Supply Ltd.
- 41 Pennon Group Plc
- 42 DONG Energy
- 43 The Geological Society
- 44 Mott MacDonald; University of Exeter
- 45 AECOM
- 46 DONG Energy
- 47 AECOM
- 48 DONG Energy
- 49 Crown Estate
- 50 Pennon Group Plc
- 51 Environmental Services Association
- 52 <http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/>
- 53 The Geological Society; Crown Estate
- 54 The increasing use of telecommunications technologies such as video conferencing and improvements to internet connectivity may act as a substitute for business travel. While there is little evidence to date that telecommunications have become an adequate substitute continuing technological improvements could increase their appeal.
- 55 Network Rail; Turner & Townsend
- 56 CIHT
- 57 AOA
- 58 National Rail ORBIS programme.
- 59 Network Rail
- 60 Local Government TAG
- 61 Turner & Townsend
- 62 Local Government TAG
- 63 Local Government TAG
- 64 Local Government TAG
- 65 Mott MacDonald
- 66 Reuby & Stagg
- 67 Major government intervention is likely to be required to increase take-up of electric vehicles and make unsubsidised electric vehicles as affordable as their gasoline counterparts, and infrastructure to accommodate electric and autonomous vehicles will need to be provided.
- 68 AECOM; Smithson Hill (SE Cluster)
- 69 KPMG <https://assets.kpmg.com/content/dam/kpmg/pdf/2016/04/auto-clockspeed-dilemma.pdf>
- 70 Network Rail. The programme will make use of new and emerging technologies to efficiently accommodate rapidly increasing demand: European Train Control System (ETCS) digital signalling; Traffic Management (TM); Automatic Train Operation (ATO); and use of data to provide passenger information. In the longer term, high-speed rail technologies such as magnetic levitation.
- 71 Travel in Britain in 2035: Future scenarios and their implications for technology innovation, 2016, prepared by RAND Europe for Innovate UK
- 72 The main congestion hotspots in the UK are on the strategic road network around London, Birmingham and Manchester.
- 73 AOA. Airport development and surface access should not be considered independently from one another. CAA market research found that the cost and convenience of getting to an airport was ranked second (after route availability), in a passenger's choice of airport.
- 74 Mott MacDonald
- 75 For example, use of the River Lee Navigation as a freight transport corridor to move construction materials and waste from Crossrail 2 tunnel portal out onto River Thames, and the Aire & Calder Navigation could be improved to accommodate barges of Euro Class II to navigate from the ABP ports of Hull, Grimsby, Immingham and Goole to a new inland port at Leeds for storage of goods and onward transportation to the North West of England (Canal and Rivers Trust).
- 76 Canal and Rivers Trust, Freight Advisory Group (2014) 'A Proposed Policy for Waterborne Freight', available at: <https://canalrivertrust.org.uk/media/original/6213.pdf>
- 77 Network Rail
- 78 ICES
- 79 Mott MacDonald
- 80 WMITA
- 81 Defined as providing download speeds in excess of 24 Mbit/s, in addition to delivering 100% coverage of basic broadband of 2Mbit/s
- 82 Ofcom 2016
- 83 Digital communications services are also anticipated to change cultural and workplace habits, such as increasing the demand for teleworking.
- 84 Unlike other markets, where customers are willing to pay higher prices to receive goods or services in remote locations, broadband is regarded as having a 'broken value chain' to the extent that customers are often unwilling to pay extra for services to make them viable.
- 85 Public investments will be necessary to deliver connectivity to the last 5% of premises in the most remote and hardest to reach areas.
- 86 This may result in a shift from fixed access use to mobile connectivity.
- 87 Water UK https://dl.dropboxusercontent.com/u/299993612/Publications/Reports/Water%20resources/WaterUK%20WRLTPF_Final%20Report_FINAL%20PUBLISHED.pdf
- 88 Mott MacDonald; Turner & Townsend; LDA Design
- 89 Mott MacDonald
- 90 Turner & Townsend
- 91 Turner & Townsend
- 92 Turner & Townsend
- 93 Pennon Group Plc
- 94 Sewage sludge produced 845 GWh of electricity in 2014 (Defra 2016), which is estimated to be 58% of the total electricity used for wastewater treatment
- 95 ITRC Analysis of Strategic Options report Figure WS1
- 96 The cost to transfer 1,100 (ML/d) of water from the north of England to the south-east via pipeline has been estimated at £9-12billion making such schemes more expensive than programmes for improved local supply in the south-east (Environment Agency, 2006).
- 97 Canal and Rivers Trust
- 98 Pennon Group Plc; Aecom
- 99 Pennon Group Plc
- 100 LDA Design
- 101 Oxford Brookes
- 102 Rain water harvesting and sustainable urban drainage systems should be installed on new developments as a priority. Benefits of retrofitting housing stock could be explored.

103 Pennon Group Plcs	122 Environmental Services Association	136 Figure 18 shows the total volume of wastewater treated growing from 3.7 million Ml in 2010 to 4.9m ML in 2050 in the unconstrained demand strategy. Such amount decreases to 4.1m ML in the medium demand reduction strategy and 3.8m ML in the high demand reduction strategy. The high demand reduction strategy saves £18bn compared to a situation of unconstrained demand (Table WW1). The cumulative emissions in 2050 are 38.03 Mt for the unconstrained demand strategy, 36.02 for medium demand reduction, and 35.25 for high demand reduction (Figure WW2).	159 Mott MacDonald
104 Pennon Group Plc	123 Cory Environmental		160 Pennon Group Plc
105 Pennon Group Plc	124 Telereal Trillion, New Homes on Public Sector Land, Accelerating Delivery, April 2016: http://www.telerealtrillion.com/cms/cms_files/high_res_final.pdf		
106 (i) Current Level of Adaptation (CLA) – the minimum intervention case where the level of adaptation is equivalent to those introduced today (2016) - and (ii) Enhanced Whole System (EWS) - the NNA strategy case where a broad portfolio of interventions are chosen (including structural measures, restricting development on the floodplain, catchment based measures, re-establishing natural processes and enhanced flood forecasting and warning). Numbers for the figure are derived using the Fast Flood Explorer used in the 2017 Climate Change Risk Assessment (CCRA).	125 http://londonfirst.co.uk/wp-content/uploads/2016/07/Homes-for-Londoners-WEB.pdf		
107 Scottish Water	126 National Audit Office, Disposal of public land for new homes, June 2015	137 Bill Lee	
108 Pennon Group Plc. The EU Circular Economy package offers an opportunity to re-connect policy in partnership with national governments, requiring strong and consistent policy from political leaders which encourages private sector investment.	127 Strategic Planning (January 2015): http://www.rtpi.org.uk/media/1230885/RTPI-Strategic%20Planning-Brochure%20FINAL%20web%20PDF.pdf ; Delivering Large-Scale Housing (September 2013): http://rtpi.org.uk/media/630969/RTPI%20large%20scale%20housing%20report.pdf	138 Oxford Brookes; Local Government TAG	
109 Pennon Group Plc	128 The NISMOD-LP modelling framework couples sector models for each of the infrastructure sectors. This enables the effects of inter-sectoral infrastructure demands to be modelled. Among the top two (as a proportion of total sector demand) is the potential for large increases in electricity demand through widespread uptake of electric vehicles.	139 LDA Design	
110 Pennon Group Plc; Environmental Services Association	129 For rail transportation, the rollout of electrification schemes incorporated in the NIP planned investments alone will lead to a 20% switching of current diesel use to electricity by 2030 and will increase the electricity peak demand of transportation from around 60.6 GW to 62.8 GW in 2026 (ITRC 2016). The NIP extends only to 2030; over the longer term, electrification will increase further.	140 Barton Willmore LLP	
111 Turner & Townsend	130 The NISMOD-LP modelling framework couples sector models for each of the infrastructure sectors. This enables the effects of inter-sectoral infrastructure demands to be modelled.	141 CIHT	
112 Cory Environmental	131 ITRC 2016	142 Reg Sell; 2050 Climate Group	
113 DS Smith; Cory Environmental	132 Newcastle University Institute for Sustainability 2016	143 CIHT	
114 Turner & Townsend	133 Byers E, Qadrdan M, Leathard A, Alderson D, Hall JW, Amezaga JM, Tran M, Kilsby CG, Chaudry M. (2015) Cooling water for Britain's future electricity supply. Proceedings of the ICE – Energy doi:10.1680/ener.14.00028	144 Reuby & Stagg; 2050 Climate Group; COSLA	
115 Much of the UK's waste is currently exported to the EU where there is over-capacity of waste assets. This overcapacity is likely to be decommissioned towards 2050. There is also uncertainty over terms of trade with the EU following Brexit	134 Pennon Group Plc; RICS	145 Turner & Townsend	
116 Environmental Services Association	135 Pennon Group Plc; Barton Willmore LLP	146 Pennon Group Plc	
117 DS Smith		147 LDA Design	
118		148 Barton Willmore LLP; Pinsent Masons LLP; AOA	
119 DS Smith		149 Pinsent Masons LLP	
120 Pennon Group Plc		150 CIHT	
121 Cory Environmental		151 CECA; 2050 Climate Group	
		152 Pennon Group Plc	
		153 LDA Design	
		154 England's Economic Heartland Strategic Alliance	
		155 LDA Design	
		156 ICES	
		157 Smithson Hill (SE Cluster)	
		158 Pennon Group Plc	
		159 Pennon Group Plc	