Committee on
Climate Change

The infrastructure needs of a low-carbon economy prepared for climate change

Briefing note

Committee on Climate Change
March 2017

The Committee

The Committee on Climate Change (the Committee) is an independent statutory body that was established under the Climate Change Act (2008) to advise UK and devolved administration governments on setting and meeting carbon budgets, and preparing for climate change.

The members of the Committee are: the Rt. Hon John Gummer, Lord Deben (Chairman), Professor Nick Chater, Professor Sir Brian Hoskins, Paul Johnson, Baroness Brown of Cambridge, Professor Corinne Le Quéré and Professor Jim Skea.

The members of the Adaptation Sub-Committee are: Baroness Brown of Cambridge (Chair), Professor Jim Hall, Professor Dame Anne Johnson, Ece Ozdemiroglu, Rosalyn Schofield LLB and Sir Graham Wynne CBE.

The Chief Executive is Matthew Bell.

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Introduction and summary

For the National Infrastructure Assessment (NIA) to be a success it must reflect the twin challenges of deeply reducing the UK's greenhouse gas emissions and of preparing the UK for a changing climate.

These are challenges that require long-term decisions over the period to 2050, and beyond, consistent with the time horizon of the NIA. Given the long lifetime of many infrastructure investments, decisions made now must avoid locking-in high carbon infrastructure or behaviours, and keep open options for reducing emissions close to zero.

The Climate Change Act requires that UK greenhouse gas emissions are cut by at least 80% from 1990 to 2050, and that the Government produce a UK Climate Change Risk Assessment (CCRA) and a National Adaptation Programme (NAP):

- **Meeting the 2050 target** will require that emissions from electricity generation, heating and surface transport are reduced close to zero by 2050 to reach an overall reduction of at least 80%, given the challenges to reduce emissions in other areas (e.g. aviation, agriculture). Infrastructure strategies and decisions taken now will determine the costs and benefits of emission reduction. The right pathway will not only minimise costs but also create opportunities for businesses.
- **The CCRA and NAP** identify risks from climate change and the actions that aim to improve the future resilience of infrastructure. The Adaptation Sub-Committee has identified a number of measures that need to be taken forward in light of these (e.g. to develop consistent severe weather incident reporting, together with indicators of network performance and resilience, to allow improvements to be measured over time).

Infrastructure plays an important role in enabling economic activity in a modern, well-connected society. There are various definitions of infrastructure, but we focus specifically on electricity generation, heat, CO_2 and transport networks and their associated components.

Infrastructure decisions need to take into account interactions between sectors and across the economy as a whole system (including supply chains) - which could significantly reduce the need for new large-scale investment - and should avoid locking-in high-carbon infrastructure or behaviours:

- **Demand-side measures** (e.g. energy efficiency, product standards, water meters, leakage reduction) may allow for significant savings by reducing the need for large-scale infrastructure investment.
- **Developing networks** (e.g. for electricity supply, telecommunications, water) resilient to a changing climate will need to take account of their inter-dependencies, as well as the need to ensure they are more responsive ('smart') to help reduce emissions.
- **Avoiding locking-in high-carbon infrastructure or behaviours** (e.g. fossil fuel based electricity generation, buildings not prepared for low-carbon heating, transport systems that cannot accommodate new approaches to mobility) is important given the long lifetime of many investments. Decisions made now should lock-in low-carbon infrastructure and keep open options for reducing emissions close to zero. All infrastructure investments should be screened to ensure they avoid lock-in and are adequately prepared for a changing climate.

The NIA should consider these systemic issues and their implications for individual infrastructure investment needs.

As part of moving to a low-carbon economy future infrastructure projects should also consider the emissions embodied in their construction. These should be taken into account when assessing the costs and benefits of infrastructure investments, and there is a role for public procurement to encourage use of low-carbon materials in construction.

Combining the requirement to reduce emissions and ensure a resilient infrastructure, we have identified six areas where investment in infrastructure is critical to meeting the objectives set under the Climate Change Act:

1. Smart low-carbon power. The share of power generated by low-carbon sources should increase from about 50% today to 75% by 2030. That will require new low-carbon capacity capable of generating around 150 TWh to be added in the 2020s. Some of this power will be more remotely located and more intermittent than the capacity it is replacing. It will therefore require additional transmission and distribution infrastructure, interconnection to other markets, and an increase in the flexibility of the system (e.g. more storage, more responsive demand and networks, as identified in the Commission's 2016 report on Smart Power). Smart systems will have important co-benefits by allowing households to reduce energy bills and better integrate their energy demands.

2. Electric vehicle (EV) charging networks. Transport is the UK's highest emitting sector and electric vehicles are a leading option to achieve a zero-carbon transport system. Widespread uptake of EVs will require roll-out of supporting infrastructure, including the deployment of a national network of rapid charge points along major roads. Our analysis suggests an infrastructure strategy should include investment in 16,000 rapid chargers over 2,000 sites by 2030. Electricity distribution networks will also need strengthening to accommodate these chargers. The roll-out of electric vehicles will have important co-benefits by helping to improve air quality and provide industrial opportunities. Hydrogen refuelling infrastructure may also be needed for HGVs in the longer-term.

3. Heating. Decarbonising heating in buildings has significant infrastructure implications. The most efficient pathway to the 2050 target is likely to involve an increase in heat sourced from district heating ('heat network') schemes and from heat pumps. These require the roll-out of heat networks and strengthening of local electricity distribution networks in the right locations. Beyond 2030, there could be a continuing major role for the gas distribution grid and a new hydrogen transmission system if low-carbon hydrogen develops as an option. An effective infrastructure strategy should set out how heating infrastructure should develop recognising that the best combination of technologies to decarbonise heat should be identified over the course of the next ten to fifteen years.

4. Carbon capture and storage (CCS). Deployment of CCS is crucial to meeting the 2050 target at least cost by enabling emission reductions across electricity generation, industry, heating and transport and by offering a route to remove greenhouse gases from the atmosphere when used in combination with bioenergy. Post-2050 CCS will also be needed to reduce emissions to net zero, as set out in the Paris Agreement. There is currently no strategy to develop CCS. A new strategy must include an effective approach to the transport and storage infrastructure (e.g. CO_2pipelines). A number of specific approaches have been suggested (e.g. by the CCC, the Oxburgh Review) all of which have in common the need to start developing the required infrastructure now. There are initial risks that cannot be borne by the private sector. Strong public involvement will be required in the early years.

The creation of a CCS infrastructure will have important co-benefits by providing new industrial opportunities.

5. Flood risk management and drainage. The combination of urbanisation, climate change and ageing flood defence structures means sustained and increasing investment will be needed over the course of decades to prevent growing flood damages. The Environment Agency's long-term investment scenarios suggest spending will need to rise from £750–800 million per year currently to £850–900 million within a decade or so (in 2014 prices). The Committee's assessment suggests higher levels of investment may be required. In addition, local authorities and water companies will need to invest significant sums upgrading and improving drainage infrastructure, partly through retrofitting sustainable drainage systems (SuDs), to counter the likely increase in incidence of very heavy rainfall. This is potentially a large and so far unfunded pressure within council budgets and water company business plans. Current policies are also failing to ensure that SuDS are included in new development, which adds further pressure to existing drainage networks.

6. Water resource management and supply. It is expected that population growth will drive increases in water demand to 2080 and beyond. At the same time most climate scenarios project that the amount of water in the environment that can be sustainably withdrawn will reduce. There is therefore the potential for significant shortfalls in water supplies to emerge by mid-century, even in areas of the country previously unaffected by shortages. Drier areas of the country (the south and east of England) face a higher risk of more severe droughts than those experienced in the past, while English regions further to the north and west are also more exposed to the prospect of future shortages. There is a need to improve resilience, but also to keep options open as knowledge of and confidence in climate projections grow. New water supply infrastructure will be required, and there is also significant scope to make progress through water efficiency, demand management, and further reductions in leakage. The NIA should reflect this balance of supply-side and demand-side measures, and reflect on what the new 'resilience duty' on Ofwat might mean for future investment requirements.

Overall public investment in infrastructure required specifically to move to a low-carbon economy and to prepare for climate change are likely to fall well within the NIC's remit for gross public investment to be between 1.0 and 1.2% of GDP per year. We estimate the required public investment to be around 0.1% of GDP annually. That must occur alongside a larger private investment programme, much of which will be driven by Government policies. While many of these costs will be borne upfront, they are likely to be cost saving in the long-run (e.g. investing in CCS infrastructure now could help halve the cost of meeting the 2050 target, compared to if CCS is not available).

Future scenarios in the NIA will be based, in part, on climate change projections. These contain considerable uncertainty, particularly regarding extreme events and changes in rainfall. The NIA should therefore acknowledge any limitations in its assessment of climate change, such as the emissions scenarios and probability levels used. New UK Climate Projections will be published in 2018 and the NIC should consider how to build that into its work-plans and ongoing advice. Investment decisions included in this NIA will need to ensure infrastructure is resilient to climate change beyond 2050, and achieve the continuing greenhouse gas emission reductions that will be required beyond 2050.

We set out the analysis underpinning these key messages in seven sections:

1. Meeting the 2050 target and preparing for climate change
2. Electricity generation
3. Heat
4. Transport
5. Flood risk management and drainage
6. Water supply and waste water
7. Digital communications

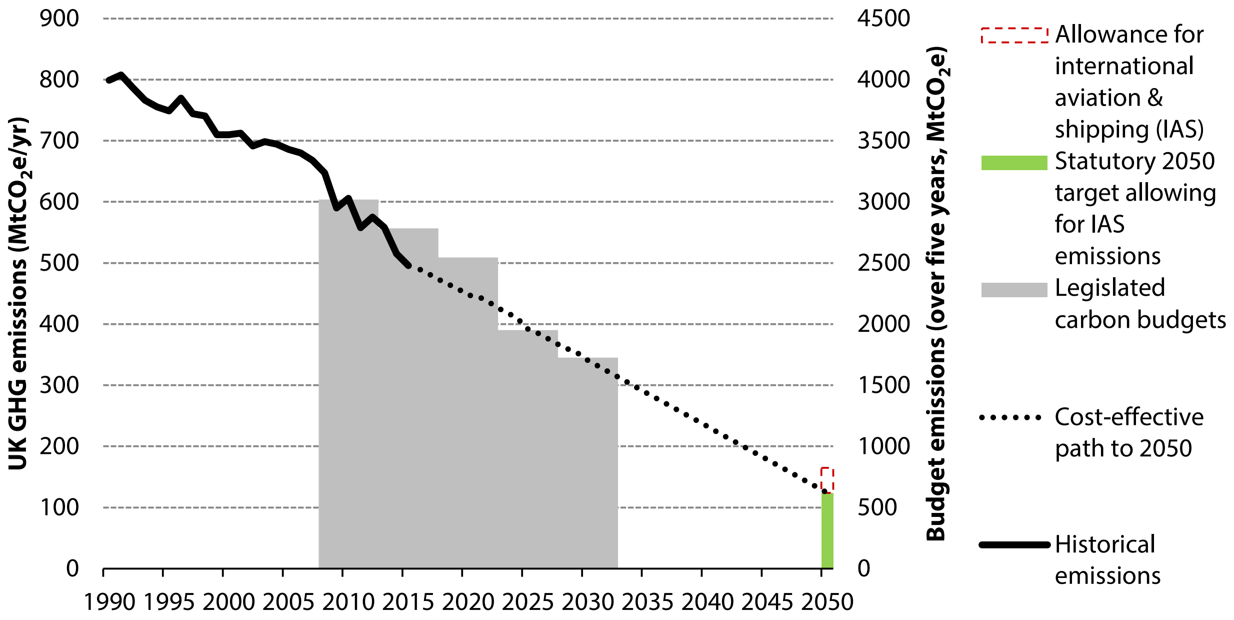
1. Meeting the 2050 target and preparing for climate change

Meeting the 2050 target

The Climate Change Act sets a legally-binding target of at least an 80% reduction in emissions by 2050, compared to 1990 levels. Carbon budgets have been legislated to 2032 on the pathway to this long-term target (Figure 1). They require a 57% reduction in emissions by 2030.

Emissions in 2015 were already 38% below 1990 levels, while GDP has grown by about 65% over the same period. Infrastructure investment decisions will play a crucial role in allowing continued economic growth while reducing emissions.

Figure 1. Carbon budgets and the cost-effective path to the 2050 target



Source: CCC calculations, BEIS (2017) *Final UK greenhouse gas emission statistics*
Notes: Historical emissions are on a 'gross' basis (i.e. actual emissions). Carbon budgets are on the current budget accounting basis, excluding international aviation and shipping (IAS) but allowing for IAS in the 2050 target.

Meeting the carbon budgets and 2050 target will require emissions to reduce across the economy. Our scenarios for the cost-effective path to meeting the 2050 target show the greatest contributions are likely to come from those sectors that rely on infrastructure, including electricity generation, heat, and surface transport. Specifically, these sectors need to keep open the option of near-full decarbonisation which may be required to meet the 2050 target cost-effectively (Figure 2).

The Paris Agreement set out a global ambition to reach net-zero global emissions in the second half of the century. It also included an ambition to limit global temperature increase to well below 2°C and to pursue efforts to limit it to 1.5°C. For infrastructure intensive sectors both these aims reinforce the need to plan for near-full decarbonisation by 2050.[1]

The need to prepare for near-full decarbonisation of electricity generation, heat and transport by 2050 implies that long-lived infrastructure for these sectors should support low-carbon options (Figure 2) and avoid locking-in high-carbon infrastructure and behaviours:

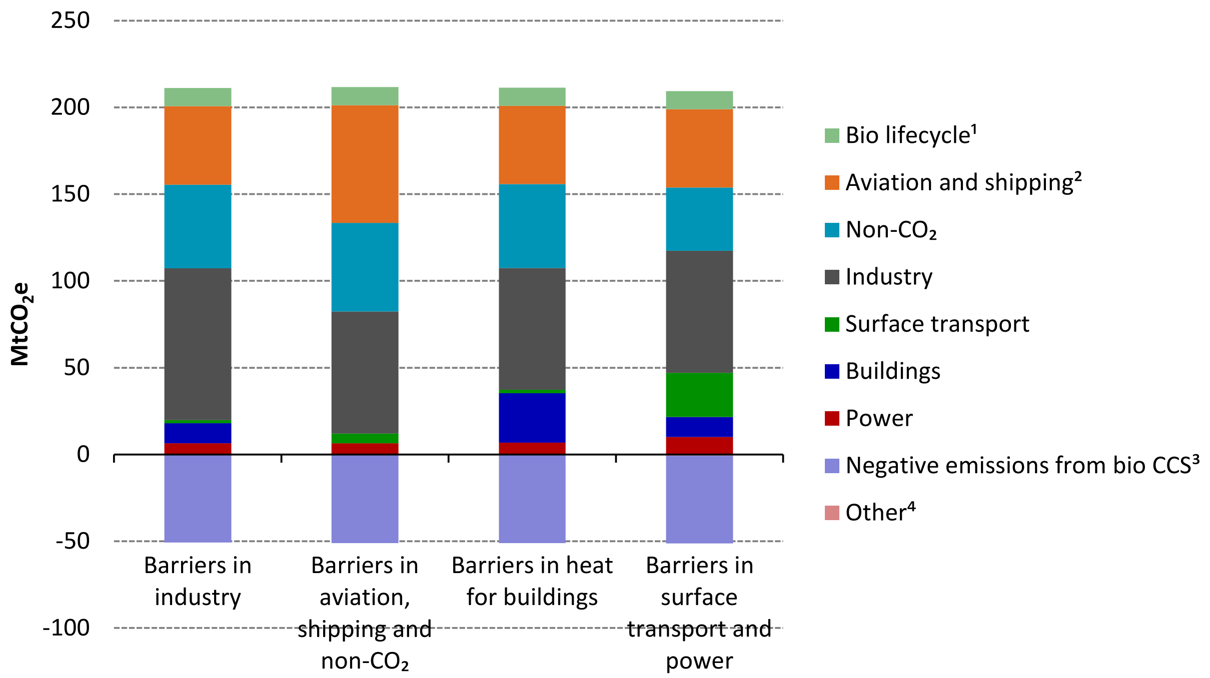
- **Electricity generation.** Decarbonisation of electricity generation is a core requirement both to reduce emissions directly and to enable other sectors to switch from fossil fuels to low-carbon electricity. Key infrastructure investments required to support this include low-carbon generating capacity (i.e. renewables, nuclear and carbon capture and storage), transmission and distribution networks, and low-carbon flexibility (e.g. smart networks and meters, storage).
- **Heat.** Delivery of heat to buildings and industry relies on network infrastructure.[2] Low-carbon heat could be provided by electric heat pumps, district heating networks or possibly hydrogen-fuelled boilers, all of which will require infrastructure investment alongside energy efficiency measures. Key strategic decisions, including on the role of hydrogen, will be required in the early-2020s. To minimise the costs of providing low-carbon heating, buildings should be highly energy efficient.
- **Transport.** Full decarbonisation of surface transport will require extensive use of electric vehicles, either powered using batteries or hydrogen fuel cells, or a combination of the two for different vehicles and trips. These will require new infrastructure for recharging and refuelling. In addition, investment in the road network should be combined with recharging infrastructure and where new investment can increase the use of private cars it should be balanced against investment in walking, cycling, bus and rail infrastructure that can enable the use of lower-carbon modes. Investment in new airport infrastructure should only proceed if it makes sense when UK aviation emissions are kept to around 2005 levels in 2050 (implying around 60% allowed growth in demand).[3]
- **Carbon capture and storage (CCS).** An effective UK CCS infrastructure will be required to support the changes across the power, transport and heating sectors and to reduce emissions from industry. Longer term (e.g. from the mid-2030s) CCS may also be needed as a route to greenhouse gas removals – removing CO_2 from the atmosphere and storing it permanently. Transport and storage infrastructure (e.g. a network of CO_2 pipelines) is likely to require strong public sector involvement at least initially (e.g. grant funding or development as a regulated asset base).

[1] See CCC (2016) *UK climate action following the Paris Agreement* available at: https://www.theccc.org.uk/publication/uk-action-following-paris

[2] For further information see CCC (2016) *Next steps for UK heat policy*. Available at: https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy

[3] For further information see https://www.theccc.org.uk/wp-content/uploads/2013/07/CCC_letter_aviation_commission.pdf

Figure 2. Scenarios for meeting the 2050 target



Source: CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*
Notes: [1]Bioenergy lifecycle emissions include overseas lifecycle emissions for imported bioenergy, as well as those occurring in the UK. [2]International and domestic. [3]Negative emissions credits are from use of bioenergy in combination with CCS or from use of wood in construction.[4]Other emissions include military aviation and shipping, emissions from hydrogen production via CCS, emissions removals from LULUCF, and abatement from injection of anaerobic digestion into the gas grid.

Preparing for climate change

Climate change poses multiple threats to existing and future UK infrastructure. Investment in assets and networks will need to address existing vulnerabilities, whilst preparing for the more extreme conditions expected with climate change.

The most up-to-date and comprehensive analysis of the risks and opportunities posed by climate change to the UK is set out in the second UK Climate Change Risk Assessment Evidence Report.[4] Table 1 presents these in terms of the specific infrastructure risks grouped by the ASC's assessment of the urgency of further action.

The UK's physical infrastructure, composed of the facilities and systems necessary for the country to function, is a priority for adaptation to a changing climate:

- Resilient infrastructure networks and services are a key foundation of economic competitiveness.

[4] ASC (2016) *UK Climate Change Risk Assessment 2017*. ASC (2015) *Progress in preparing for climate change,* https://www.theccc.org.uk/wp-content/uploads/2015/06/6.736_CCC_ASC_Adaptation-Progress-Report_2015_FINAL_WEB_070715_RFS.pdf

- Infrastructure systems are usually long-lived, often sensitive to severe weather, and their failure can have knock-on impacts on other networks and assets.
- Natural hazards such as storms, flooding, heavy snow, and droughts, already account for 10% to 35% of all delays or service interruptions to electricity, road and rail customers per year.[5]
- In the future, infrastructure in the UK will be placed under additional pressures caused by increased demand for services from population growth, urbanisation and climate change.

The Adaptation Sub-Committee's 2015 Progress Report to Parliament[6] concluded that there is limited data at a national scale to determine how much progress is being made within infrastructure sectors to prepare for climate change.

Table 1. Risks to infrastructure from climate change

More action needed	Research priority	Sustain current action	Watching brief
• Risks of cascading infrastructure failures across interdependent networks • Risks to infrastructure from river, surface/groundwater flooding • Risks to infrastructure from coastal flooding and erosion • Risks of sewer flooding due to heavy rainfall • Risks to transport networks from embankment failure • Risks to public water supplies from drought and low river flows	• Risks to bridges and pipelines from high river flows/erosion • Risks to energy, transport & ICT from high winds and lightning • Risks to offshore infrastructure from storms and high waves	• Extreme heat risks to rail, road, ICT and energy infrastructure • Benefits for infrastructure from reduced extreme cold events	• Low/high river flow risks to hydroelectric generation • Subsidence risks to buried/surface infrastructure • Risks to electricity generation from drought and low flows

Source: ASC (2016) *UK Climate Change Risk Assessment 2017: Synthesis Report.*
Notes: Definitions: More Action Needed – New stronger or different government policies or implementation activities, over and above those already planned, are needed in the next five years to reduce long-term vulnerability to climate change. Research priority- Research is needed to fill significant evidence gaps or reduce the uncertainty in the current level of understanding in order to assess the need for additional action. Sustain current action – Current or planned levels of activity are appropriate, but continued implementation of these policies or plans is needed to ensure that the risk continues to be managed in the future. This includes any existing plans to increase or change. Watching brief – The evidence in these areas should be kept under review, with long-term monitoring of risk levels and adaptation activity so that further action can be taken if necessary.

[5] ASC (2015) *Progress in preparing for climate change,* https://www.theccc.org.uk/wp-content/uploads/2015/06/6.736_CCC_ASC_Adaptation-Progress-Report_2015_FINAL_WEB_070715_RFS.pdf

[6] ASC (2015) *Progress in preparing for climate change.*

2. Electricity generation

Emission scenarios for meeting carbon budgets

Our scenarios for electricity generation, which underpinned our advice on the fifth carbon budget, imply an emission intensity at the upper end of the range of 50-100 gCO_2/kWh in 2030. This represents a reduction of 73-87% on the 2015 level of about 370 gCO_2/kWh. Achieving these reductions will require investment in around 150 TWh of new low-carbon generation in the 2020s.

Infrastructure requirements for meeting carbon budgets

Infrastructure needed to achieve a CO_2 intensity of 50-100 gCO_2/kWh in electricity generation, alongside the low-carbon generation investment, includes:

- Transmission, interconnection and distribution infrastructure (i.e. wires connecting supply to demand).
- Smart grid infrastructure and storage infrastructure.
- Carbon Capture and Storage infrastructure.

Our scenarios also involve an increase in system flexibility alongside the expansion of low-carbon capacity.

Low-carbon generation

The combination of expected plant closures and new demand from electrification of transport and heat means that new low-carbon generating capacity (able to produce around 150 TWh per year) will be needed in the 2020s:

- The UK's remaining coal plants are expected to either close or convert to biomass during the 2020s, in line with the Government's commitment to end unabated coal generation by 2025. No policy has yet been proposed to deliver that commitment, though it is not yet clear whether additional actions are needed.
- Alongside coal closures, most existing nuclear capacity is expected to close by 2030, even if plants are granted further life extensions by the regulator.
- Our scenarios for decarbonising the rest of the economy imply an increased demand for electricity via electric vehicles and electric heat pumps in buildings in the 2020s, alongside increasing demand with income growth, partially offset by a continuing improvement in energy efficiency in the 2020s (e.g. greater uptake of LED lighting and efficient appliances).

Our electricity generation scenarios for 2030 include a continuing role for unabated gas generation at around its 2014 level (i.e. around 100 TWh), with new nuclear, CCS and renewables replacing retiring nuclear and coal generation and meeting increases in demand. Overall, in these scenarios low-carbon sources provide around 75% of generation, including around 45-55% from renewable sources.

The Government has offered low-carbon contracts that will increase the share of renewable generation to 30-35% in 2020 and support one new nuclear plant in the 2020s (7% of generation). In April it will begin a new round of auctions to allocate contracts to emerging technologies (largely offshore wind) for the early 2020s. These auctions will support around 6%

of generation. Further contracts should be allocated (using competitive mechanisms) for 100 TWh of low-carbon generation to come online in the 2020s, which would bring the total low-carbon share to about 75% in 2030.

Transmission, interconnectors and distribution infrastructure

The Committee has undertaken considerable research to understand and cost the additional electricity transmission and distribution infrastructure required to support the above scenarios for low-carbon generation to 2030, including the increase in intermittent sources of generation.[7] Box 1 provides an indication of the types of investment required in electricity infrastructure.

Box 1. Electricity network investments in CCC scenarios

Additional costs of electricity transmission and interconnection infrastructure could involve:

- A near-trebling of interconnection capacity from today's levels to around 17.5 GW, at a cumulative cost to 2030 of £11.6 billion.
- Around 2,000 km of transmission capacity reinforcements. These investments would raise total costs of installing and upgrading transmission infrastructure to 2030 by nearly six times to around £6.3 billion.

Additional electricity distribution infrastructure required to support a scenario with several million heat pumps and electric vehicles could involve:

- a 20% increase in the length of the low voltage network to around 135,000 km
- an 80% increase in the number of distribution transformers to around 280,000
- a 77% increase in the length of the high voltage network to around 110,000 km
- a 77% increase in the number of substations to 2,500

These investments would raise total costs of installing and upgrading distribution infrastructure to 2030 by around 22% to around £31.4 billion.

Smart grid infrastructure and storage

Our scenarios for power sector decarbonisation involve increasing amounts of variable and intermittent renewable generation being integrated into the UK electricity system. As recognised in the National Infrastructure Commission's report on Smart Power[8], in order to manage variations in supply, the flexibility of the electricity system will need to increase over time. Both 'demand-side' response and electricity storage can provide system reserve (e.g. back-up) and response (i.e. maintaining grid frequency) services, which reduce the cost of integrating renewable electricity into the UK electricity system:

[7] Element Energy (2013) *Infrastructure in a low-carbon energy system to 2030: Transmission and distribution* available at https://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-Infrastructure_TD-Report_22-04-2014.pdf
[8] National Infrastructure Commission (2016) *Smart Power.*

- The Government has committed to deployment of 53 million ‘smart meters’ in households and small businesses (larger businesses already have more advanced metering). The total cost for this programme (excluding benefits) is estimated to be around £14 billion to 2030 but the net cost is expected to be small after savings from reduced meter reading and related costs. The communications infrastructure alongside this is also significant, with communications using the 2G network, and being managed by the Data and Communications Company (which is regulated by Ofgem).
- Smart meters are key to enabling ‘demand-side response’ (the ability for electricity demand to respond to changes in system needs). Our scenarios for 2030 involve up to 75 TWh per year of demand-side response capability. However, the business case for the smart meter programme is not predicated on any particular decarbonisation pathway but rather on the value of flexibility and cost savings that would accrue regardless of action to reduce emissions.
- Our scenarios for the fifth carbon budget involved up to 5 GW of additional electricity storage being added to the electricity system, providing ancillary services.

Carbon Capture and Storage (CCS)

CCS is a crucially important technology in electricity generation and industry, would enable negative emissions through bioenergy with CCS, and is expected to be the lowest-cost route to large-scale low-carbon production of hydrogen from natural gas for heating and transportation. Taken together, use of CCS in power and industry, with bioenergy and for hydrogen could provide around 100-250 $MtCO_2$ of abatement by 2050 (which compares to current emissions of under 500 $MtCO_2e$ and the 2050 target of around 160 $MtCO_2e$). If CCS is not available this abatement will need to come from elsewhere. Alternative options to reducing emissions in the absence of CCS include full decarbonisation of heat in buildings and full decarbonisation of the transport freight sector without use of hydrogen, as well as more dramatic social change such as dietary change.

Given these important potential roles for CCS and the lack of low-cost, or in some cases any, alternatives, the costs of meeting the UK’s 2050 target would approximately double without CCS. To realise the full potential for CCS in 2050, work needs to start now on a new strategic approach, with significant progress, including some deployment, by 2030.

A strategic approach to develop CCS in the UK could involve development of up to three strategic clusters, consisting of a number of power and industry capture facilities with CO_2 transport networks, connected to storage sites. Capture facilities connected to these hubs could include 4-7 GW of power CCS (2-3 GW in 2030), and industrial plants capturing 3-5 $MtCO_2$ (out of 16-27 Mt total including power capture) per year in 2035.[9]

[9] See CCC (2016) *Letter to Rt Hon Amber Rudd: A strategic approach to Carbon Capture and Storage* available at https://www.theccc.org.uk/publication/letter-to-rt-hon-amber-rudd-a-strategic-approach-to-carbon-capture-and-storage and Oxburgh (2016) *Lowest cost decarbonisation for the UK: The critical role of CCS. Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage (CCS).* Available at: www.ccsassociation.org

Estimated capital costs are:

- Capture: Rising to £0.5 billion in 2030 (£1.1 billion in high scenario).
- Transport and Storage: Rising to £0.1 billion in 2030 (£0.2 billion in high scenario).

Under current market arrangements, capture costs could be privately paid (e.g. under a low-carbon electricity contract funded through consumers' energy bills). Transport and storage costs may initially require public grant funding or investment through a public company that could later be privatised.

Ensuring electricity generation infrastructure is resilient to a changing climate

Towards 2050, the UK energy system is likely to increase its reliance on the power system as transport and heat are gradually electrified, moving from liquid fuels for transportation, and natural gas for heating in households. The resilience of the UK electricity system to extreme weather is therefore increasingly important, and may face more risks as the climate changes. The second UK Climate Change Risk Assessment[10] identified several key risks to power infrastructure:

- An increasing frequency and severity of flooding will see infrastructure networks near rivers, such as electricity cabling and power stations, become more vulnerable to higher flows of water.
- Increased disruption to overhead power lines and offshore infrastructure, due to higher wind speeds.
- Higher temperatures could lead to overheating of electricity network infrastructure, potentially reducing capacity.
- Projected extended periods of rainfall could increase risk of subsidence for buried infrastructure, such as high voltage electricity cables.

Actions taking place

The relative exposure of the electricity network is recognised and investment is taking place, for example, to improve levels of flood protection for major substations. Spending on substation flood protection and resilience measures of £172 million was agreed by the regulator between 2011 and 2020. Electricity distributors had, by 2012, implemented flood resilience measures to 19 major substations located in areas of highest risk (in areas at a 1 in 30 annual chance or greater), reducing the number of customers potentially at risk of disruption by nearly 290,000. The delivery of planned flood resilience measures between 2012 and 2020 will help to reduce the number of customers at risk by around a further 730,000.

Building resilient energy infrastructure

Moving to a low-carbon energy system presents an opportunity to enhance the overall resilience of the energy infrastructure network to climate change, as well as potential trade-offs:

[10] ASC (2016) *UK Climate Change Risk Assessment 2017* available at https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017

- There is a chance to build new or extend existing energy infrastructure to be more resilient to changes in climate, especially major projects where climate change must be taken into account under the National Policy Statements for energy infrastructure.
- In certain circumstances increased electrification of the energy system can reduce the resilience of individual households. For example, a power cut would affect heating and transport to a far greater extent than at present.

Despite flood resilience measures being implemented, the 2015 ASC Progress Report highlighted that there may still be around 150,000 customers in the 2020s reliant on substations in areas of high flood risk without flood resilience measures.

3. Heat

Emission scenarios for meeting carbon budgets

At present, heat in residential, commercial and industrial buildings is predominantly delivered by burning natural gas in boilers (e.g. 85% of residential buildings are connected to the gas grid). Under our scenarios for meeting carbon budgets, direct (non-electricity) emissions from buildings fall by around 22% between 2015 and 2030, through a combination of energy efficiency measures and low-carbon heat solutions (e.g. heat pumps and heat networks).

In our scenarios just over 1 million heat pumps are installed in existing buildings off the gas grid by 2030. This, together with a similar level of deployment in new-build properties, can help to create the scale needed for supply chains to develop, including developing skills and experience.

Near-full decarbonisation of heat by 2050 will require widespread adoption of low-carbon solutions - heat pumps, heat networks, hydrogen boilers - to replace gas boilers. The best option might vary across the UK, resulting in a patchwork of low-carbon supply solutions.

Infrastructure requirements for meeting carbon budgets

Low-carbon infrastructure needed to reduce heat emissions by 2030 includes potential deployment of:

- Electric heat pumps supported by strengthened electricity networks
- Heat networks
- Hydrogen boilers and networks

These solutions will require additional investment in electricity, heat or gas network infrastructure, alongside energy efficiency measures. Different solutions are better suited to different building types and locations, so a heat decarbonisation strategy must incorporate multiple approaches and engage with local authorities and local infrastructure providers.

To minimise the additional infrastructure investment required in future, and avoid costly future retrofit solutions, new buildings should be built to high standards of energy efficiency and increasingly with low-carbon heat solutions from the outset. Substantial improvements to the energy efficiency of existing buildings can be made (e.g. our scenarios include insulation of about 7 million walls and lofts in homes).

Infrastructure required to support uptake of electric heat pumps

Widespread deployment of heat pumps will require investment in the electricity distribution network, in order to provide sufficient capacity even on the coldest days, when all heat pumps are operating close to maximum output. Improved building efficiency is an essential part of effective heat pump roll-out, and it is likely that significant deployment of heat storage at the building scale will help to mitigate the rise in peak electricity demand and limit the costs of expanding local networks.

Heat networks

Heat network schemes require a certain density of heat demand in order to be economic, which means that they are suited to urban areas, new-build developments and some rural areas. In the period to 2030 low-carbon heat networks should therefore be deployed in areas of high heat density.

Low-carbon heat sources can include waste heat, large-scale (e.g. water-source) heat pumps, geothermal heat and potentially hydrogen. Development of heat network infrastructure is therefore a low-regrets option that allows for aggregation of heat from different sources, provides heat storage and could be integrated with low-carbon heat solutions based either on electrification or hydrogen, thereby leaving options open for the long-term. Our scenarios include 34 TWh of low-carbon heat supplied through heat networks by 2030, rising to around 80 TWh in 2050.

Hydrogen boilers

The existing gas network could, technically, be used to support a large-scale shift to a hydrogen gas supply. Hydrogen for heating would, in some ways, require less change in behaviour from consumers since hydrogen shares many characteristics with natural gas (e.g. the ability to increase heat supply very responsively). Roll-out would need to be done in a way that ensures a coherent hydrogen infrastructure that exploits economies of scale, but this could be at a regional rather than national scale:

- A move to hydrogen would require a switchover programme with some similarities to that for the switch from town gas to natural gas, including replacing gas appliances (e.g. boilers) with hydrogen-compatible ones, but with the need to also put in place hydrogen production facilities. The mechanics of roll-out across large parts of the UK are not yet fully understood and costs are uncertain.
- To produce hydrogen in a low-carbon way at the necessary scale within the UK would require carbon capture and storage (CCS), due to the considerably higher costs and practical limits on other solutions such as electrolysis. The need for production facilities based on CCS and for large-scale storage of hydrogen in salt caverns may also constrain the areas of the country for which hydrogen is the best option.
- It is conceivable that large-scale production of low-carbon hydrogen could become viable elsewhere in the world (e.g. areas with large potential for solar PV), with the potential for the export of significant volumes of liquid hydrogen. However, in addition to costs of low-carbon hydrogen production there would be sizeable costs of liquefying and transporting the hydrogen, likely to be greater than those for liquefied natural gas today (due to hydrogen's

lower boiling point). Given the uncertainties surrounding the economic potential for this in the future, it is not appropriate to plan at this stage for large-scale hydrogen imports.

Large-scale production of low-carbon hydrogen, with accompanying storage facilities, could also provide wider opportunities for decarbonisation including decarbonising peaking plant in the power system and supplying hydrogen for heat in industry. Wide-scale repurposing of gas networks to 100% hydrogen would also provide a basis on which to build a network of hydrogen refuelling stations for transport applications, largely solving the otherwise considerable challenge of hydrogen distribution to supply fuel cell vehicles.

Future decision points for development of low-carbon heat

Large-scale deployment of heat pumps in on-gas properties or repurposing of gas distribution networks to hydrogen will need to occur over the period 2030 to 2050. Key strategic decisions will therefore be required in the early 2020s, particularly over the role of hydrogen. The costs, feasibility and public acceptability of these options are currently not well enough understood. It will be vital to undertake pilots and demonstrations in the next decade. Before a decision to proceed with hydrogen, it would be essential that CCS is under active development in the UK, in order to provide a low-carbon route to producing hydrogen at scale. This should be part of the Government's new strategy on CCS.

The Committee have therefore advised that the Government should publish a decarbonisation strategy for heat in order to improve understanding of these post-2030 options so that they are well positioned to take the required decisions in the next Parliament.

In the immediate future, it is also important that Ofgem ensures that the next price control review for the gas transmission and distribution networks (for the period from 2021) reflects the wide range of possible pathways for heat supply, including a move rapidly away from fossil fuel use (e.g. under a 'no CCS' pathway) and a shift to hydrogen in the 2030s and 2040s.

Ensuring heat infrastructure is resilient to a changing climate

Climate risks to heat pump deployment are primarily around the electricity network required to support these. The risks and resilience measures required will therefore be similar to those identified for electricity generation, including:

- Increased frequency and severity of flooding which could see infrastructure networks near rivers, such as electricity cabling and power stations, become more vulnerable to higher flows of water.
- Increased disruption to overhead power lines and offshore infrastructure, due to higher wind speeds.
- Higher temperatures which could lead to overheating of electricity network infrastructure, potentially reducing capacity.
- Projected extended periods of rainfall which could increase risk of subsidence for buried infrastructure, such as high voltage electricity cables.

Further work is required in order to better understand if there are any additional specific risks to heat networks or hydrogen infrastructure from a changing climate.

4. Transport

Emission scenarios for meeting carbon budgets

Transport is currently the largest emitting sector of the economy, accounting for 24% of total UK emissions in 2015. Our scenario for the fifth carbon budget sets out a cost-effective path to reduce transport emissions by around 43% between 2015 and 2030. That path includes significant improvements to vehicle efficiency, large-scale roll-out of electric vehicles, moderately increasing use of sustainable biofuels and some demand-side measures.

By 2050 there is scope for near-full decarbonisation of surface transport, making use of electric and hydrogen fuel cell vehicles powered by low-carbon electricity and hydrogen. Use of these vehicles will require significant infrastructure investment, mainly to allow vehicles to refuel in different locations.

Infrastructure requirements for meeting carbon budgets

The key infrastructure elements of our scenarios include:

- **Electric vehicle (EV) charging.** The majority of charging is expected to take place at home, but a network of public rapid charge points is also required. Electricity infrastructure upgrades are necessary to facilitate this.
- **HGVs.** To 2030, a proportion of small HGVs are electrified, requiring rapid charging. To 2050, hydrogen fuel cell HGVs require a hydrogen refuelling infrastructure, or electric HGVs use pantographs connecting to overhead lines or dynamic wireless road charging.
- **Modal shift.** Further investment and electrification of the rail network, and spending on public and active transport infrastructure and behavioural change for sustainable travel.

In addition, alternative scenarios could feature:

- **More widespread use of hydrogen,** leading to fuel cells being used across all vehicle types, requiring hydrogen refuelling infrastructure to be widely available.
- **Electrification of HGVs** as significant battery density technology improvement enables sufficient range with heavy loads, making investment in a hydrogen network unnecessary.
- **Slow electric vehicle uptake**, requiring action to reduce the demand for car travel, which will likely include investment in active travel infrastructure, public transport and rail.

These alternative scenarios do not affect the key infrastructure needs required over the short-to-medium term, but could have implications in the period to 2050 depending on how technologies and costs develop. Therefore the appropriate approach is to keep these factors under review and ensure that infrastructure strategies and decisions taken now keep open these options out to 2050.

Electric vehicle charging infrastructure

In our scenario underpinning the fifth carbon budget, 60% of new vehicle sales are Ultra-Low Emission Vehicles (ULEVs, e.g. electric vehicles) in 2030, while most cars and vans are electric by 2050. It is likely that most recharging will take place overnight when cars are likely to be parked and when electricity prices are lower. With smart charging electric vehicles could provide demand-response and with vehicle-to-grid technology, they could also act as a form of distributed energy storage.

Our analysis shows that the majority of electric mileage could be powered through home charging. A strategy for recharging infrastructure in urban areas is also needed. However, consumers will also need the flexibility to recharge their vehicles away from home, using an expanded network of rapid public charging infrastructure. The scale of funding required for home and rapid charging could be up to £13 billion by 2030 and could be financed through public and private investment.

- **Home charging points.** Current 7 kW home charging points have an installation cost of under £1,000. Infrastructure required for smart home charging is likely to be private-sector incentive driven. Improvements to low voltage networks and grid capacity will be made through the Distribution Network Operators and Transmission System Operators initially, but may require public spending depending on the scale of costs and how costs are recouped through this regulated asset.
- **Other charging points in urban areas.** A strategy for recharging infrastructure in urban areas is also needed for vehicle owners without off-street parking and for urban fleet depots, which is unlikely to be commercially viable until greater levels of take-up. ETI estimate that public on-street chargers in residential areas are likely to cost £4,000 per recharge point and be able to support two cars. However, other models are also possible, such as charging hubs at existing petrol stations and supermarkets.
- **A long-distance network of public charging points.** Our analysis suggests that a network of around 16,000 public rapid chargers across the Strategic Road Network will be needed by 2030. There is a range of estimates for the costs and some are already installed:
  - Element Energy[11] estimate charger and installation costs of £30,000 to £50,000 per rapid charger.
  - ETI estimate[12] that a rapid charge network will incur a capital outlay per site of £0.5 million and £16,000 per recharge point. With a 25% mark-up on electricity prices ETI calculates that this would be commercially viable and not require public funding.
  - Ecotricity have already installed rapid charging points at every motorway service station in the UK.

These factors, and their implications for infrastructure deployment, should be kept under review given technological progress, including in battery range. For example, new 350 kW ultra-fast chargers (around 7 times more powerful than current rapid chargers) are currently being developed to charge new car models from 2018, some of which are expected to roughly double range compared to existing mass-market models. A consortium of car manufacturers have already committed to rolling-out ultra-fast chargers every 90 miles over the next two years.[13]

Emissions reduction for large HGVs remains challenging. Alternative fuels such as biofuel and natural gas will not provide the scale of emissions reduction needed to meet longer term targets, but battery electrification is currently impractical. One option for the deeper emissions

11 Element Energy (2013) *Pathways to high penetration of electric vehicles.*

12 ETI (2013) *An affordable transition to sustainable and secure energy from light vehicles in the UK.*

13 https://www.press.bmwgroup.com/global/article/detail/T0266311EN/bmw-group-daimler-ag-ford-motor-company-and-volkswagen-group-with-audi-porsche-plan-a-joint-venture-for-ultra-fast-high-power-charging-along-major-highways-in-europe

reduction required in our scenario post-2030 is the electrification of motorways and dual carriageways to provide electricity to vehicles dynamically whilst on the move (another is hydrogen; see below). Motorways and dual carriageways make up only 3% of the UK road network but carry over 70% of HGV traffic.[14] While the technology is still in early development, Sweden is trialling a 2 mile stretch of highway with overhead cables and Highways England is planning a trial of a contactless inductive recharging system for trucks in the UK. The Highways England feasibility study estimated infrastructure costs of £3-5 million per km[15], resulting in total costs of around £20-35 billion if installed on all motorways.

Hydrogen infrastructure

For most light-duty vehicle applications it is likely that battery powered electric vehicles will be suitable and cost-effective. For HGVs, hydrogen fuel cells may be a cost-effective option by 2030, but their use will depend on roll-out of infrastructure for the production and distribution of hydrogen (including availability of CCS).

The cost of a hydrogen car refuelling station is currently £1 million. E4tech estimate this could fall by two-thirds given mass adoption.[16]

Many of the issues associated with hydrogen use in transport are similar to those in heat:

- Hydrogen production with low carbon emissions will be much cheaper with CCS available.
- Hydrogen use in buildings would facilitate the use of hydrogen in transport.
- If there is no CCS and hydrogen has to be produced using electrolysis, then hydrogen consumption is likely only to be cost-effective in those vehicles that cannot easily be electrified. In this scenario, the gas grid would not be available to transport hydrogen so this would either be done by tanker or by distributed production via electrolysis.

In all of these situations, new types of vehicle refuelling infrastructure will be required if hydrogen proves to be the cost-effective option for large trucks.

Public and active transport infrastructure

Investment in infrastructure for lower carbon modes of travel such as walking, cycling, bus and rail is an important way to encourage modal shift.

- Our analysis based on the current mix of car trips in Great Britain suggests that through switching to other modes, car-km could be reduced by 5% below the baseline scenario by 2030.
- We do not prescribe the exact mechanisms by which the demand reduction is achieved which could be a mix of information provision and infrastructure improvements.

[14] DfT (2015) *Road Lengths Statistics*; DfT (2015) *National Road Traffic Survey*

[15] TRL for Highways England (2015*) Feasibility study: Powering electric vehicles on England's major roads*. Estimate is for capital costs only and range reflects an adjustment for optimism bias.

[16] E4tech, UCL Energy Institute and Kiwa Gastec (2015) *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target*

The provision of public and active transport infrastructure is often undertaken for reasons other than emissions reduction, such as reduced congestion, improved health and air quality. Therefore, it is not possible to attribute the cost of modal shift infrastructure provision to a single objective.

Avoiding high-carbon infrastructure lock-in: risks from new transport capacity

Certain types of infrastructure investment can increase capacity, such as building new roads. This could result in higher levels of demand and emissions than would have otherwise occurred:[17]

- **Roads.** DfT has set out the Road Investment Strategy to invest £15 billion to 2020 in the road network and are currently consulting on post-2020 planning. This investment is likely to slightly increase overall travel demand.
  - DfT estimates, based on the National Transport Model (NTM), suggest that the investment will result in a less than 1% increase in additional lane miles on the network, with a 0.2% increase in vehicle-km and a 0.1-0.2% increase in CO_2 emissions by 2040.
  - The NTM is not designed to model these types of investments and is likely to underestimate the impact on emissions. However, even taking account of this potential bias, the impact appears small.
  - If future road investment results in higher than anticipated traffic and emissions, the Government will have to offset this increase with additional abatement measures.
- **Airports.** Our assessment of appropriate long-term assumptions for Government planning is for aviation emissions to be around 2005 levels in 2050 (with anticipated efficiency improvements implying around a possible 60% increase in demand over the same period, or around a 45% increase from 2015). Government should plan future policy and infrastructure investment decisions that affect aviation emissions on this basis.

Ensuring transport infrastructure is resilient to a changing climate

In the 2017 UK Climate Change Risk Assessment, we highlighted the risks of flooding, coastal erosion and extreme weather to transportation. Approximately 8% of the UK's transport and road network is at a material risk of landslide disruption, and with 2°C of warming, 20-50% more roads and railways are projected to become at significant flood risk. More action is needed to improve the resilience of the transport network.

Risks to transport

All modes of transport are susceptible to damage or disruption from climate-related hazards. Increased use of transport services combined with extreme weather is already a key cause of serious disruption to transport services. Weather-related disruption is rarely limited to a single mode and although having multiple modes as options helps towards the resilience of the system, the substitution of an alternative mode cannot be taken for granted.

[17] See CCC (2016) *Meeting Carbon Budgets - 2016 Progress Report to Parliament* available at:
https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament

- **Railway network.** Much of Britain's railway network was built more than a century ago to varying engineering standards. Assets and services are exposed to flooding, coastal erosion, or debris blown on to the tracks and damage from high winds. Changes in temperature will also pose a challenge, with tracks needing to be tensioned to suit the wider range of temperatures likely to be experienced in future years.
- **Strategic Road Network.** The Strategic Road Network has been built since the 1950s, using modern materials and design standards, and has been maintained consistently over recent decades. Disruptions to the network from severe weather can be managed in the same way as other causes, such as road works and major accidents, as lasting physical damage to roads and assets is unlikely.
- **Ports and airports.** Ports handle 95% of the UK's imports and exports by volume. Half of the UK's port capacity is located on the east coast, where the risk of damage from tidal surge is greatest. Port operations are also impacted by high winds and fog. Airports are affected by flooding, high winds, freezing conditions, fog and thunderstorms.

Actions taking place

The latest update from DfT regarding implementation of the Brown Review[18] of transport resilience suggests significant action is continuing to take place. Much of the review was dedicated to improving the resilience of the rail network.

In the rail industry there is evidence of site-specific measures being incorporated for each of Network's Rails eight routes in Great Britain. However, systemic adaptation is not strongly evident across the railway network and there is a significant legacy challenge of ageing infrastructure, with both industry and the regulator recognising that historic investment has been insufficient to deliver acceptable levels of risk in the long term. There is therefore a backlog that will require sustained investment over the next 40-50 years to address.

Airports are increasing resilience more generally following the failures due to severe weather that occurred at Gatwick in December 2013. For ports there is a general lack of data regarding overall resilience compared to regulated sectors. Equipment in ports typically has a 20–100 year design life. Modern assets will already be resilient to sea-level rise, but retrofitting ageing infrastructure (e.g. raising quays) is technically complex and expensive, although some ports are raising quays by as much as 50cm, as well as taking action to protect dockside areas and equipment and supporting road infrastructure from flooding.[19]

Building resilient transport infrastructure

Transport infrastructure will need to evolve to meet the needs of the growing population, particularly in densely-populated regions. As such there are opportunities to design and maintain new transport infrastructure for a broader range of climate conditions, thus improving resilience in the sector. Adaptation measures may take the form of engineering solutions but

[18] Department for Transport (2014) *Transport Resilience Review*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf

[19] As identified in the second round of Adaptation Reporting Power reports.

also new 'smart' technologies such as sensors and telemetry that allow resources to be better utilised and any risks and issues that arise to be more quickly addressed.

Despite current investment, the winter of 2013/14 highlighted that Network Rail in particular faces a significant challenge and sustained investment is required to improve aging rail infrastructure.

Disruption from flooding at Gatwick Airport and Immingham Port in December 2013 provided lessons within both sectors. In our 2015 Progress Report we recommended that given the similar vulnerabilities that led to the loss of services at Gatwick and Immingham, all operators should review the location of critical power and IT facilities as a matter of urgency.

5. Flood risk management and drainage

Flood risks

The UK Climate Change Risk Assessment identified flooding as an urgent risk to all infrastructure sectors. Flood and coastal risk management infrastructure plays a crucial role in mitigating these risks.

Flood protection infrastructure is itself subject to climate change impacts and is typically managed separately to the infrastructure and built environment they protect. The most significant impact is a reduction in the standard of protection provided by the flood defences over their lifetime due to projected increases in seasonal rainfall and river flows, and sea level rise.

Action taking place

The National Adaptation Programme highlights that investment in flood defences will continue through delivery of the National Flood and Coastal Risk Management Strategy for England.[20] The strategy includes actions to better understand flood risk, invest in reducing the chance of flooding, and improving flood prediction, warning and emergency response arrangements. Significant advances have been made in each of these areas. However, overall, there was a period of underinvestment in managing flood risk between 2011 and 2014.[21] Since then, investment in both capital renewals and asset maintenance has improved, but the impacts of recent spending decisions are less clear in terms of the number of Environment Agency staff now working on flood and coastal risk management.

A total of £2.3 billion[22] was allocated by central government to managing flood and coastal erosion risks in England over the spending period April 2016 – March 2019. In addition, there has been a growth in external contributions under the Flood and Coastal Resilience Partnership Funding policy introduced in May 2011. Under the policy, over the last four years, an estimated £200 million in external funding contributions has been leveraged by the EA and local

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[20] *National Adaptation Programme 2013*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf

[21] ASC (2015) *Progress in preparing for climate change 2015 Report to Parliament*, https://www.theccc.org.uk/wp-content/uploads/2015/06/6.736_CCC_ASC_Adaptation-Progress-Report_2015_FINAL_WEB_070715_RFS.pdf

[22] https://www.gov.uk/government/publications/2010-to-2015-government-policy-flooding-and-coastal-change/2010-to-2015-government-policy-flooding-and-coastal-change

authorities (Figure 3). A further £700 million in funding for flood risk management was announced in the 2016 Budget.

The Environment Agency published in December 2014 an updated set of long-term investment scenarios (LTIS2).[23] The scenarios consider the optimal investment path to the middle of this century based on assumptions about the rates of asset deterioration, new development, and climate change. By the 2060s, LTIS2 suggest the optimal levels of spending over the course of the next five decades may reduce the expected annual damages from flooding by between 4% and 24% depending on the extent of climate change. However, LTIS2 also suggests that even if investment grows in line with the optimal trajectory, more homes (and probably also infrastructure) will be in areas at a high risk of flooding in the coming decades. Some already at a high risk of flooding will remain so, and others will fall into the high risk bracket as the climate changes and as flood defence structures age. This was considered in our 2015 Progress Report to Parliament as the best case scenario due to additional pressures arising from new development, and because long-term outcomes depend on economically-rational decisions being taken at every step of the process.

Defra has secured a long-term commitment from HM Treasury to invest in new and improved flood and coastal defence structures and other capital projects over the period from 2015 to 2021. Half of the 1,400 schemes in their six-year investment plan are reliant on community and project contributions being secured and at least 200 projects will not enter construction until 2021 at the earliest. However, if schemes proceed as planned the Environment Agency estimates that by 2021 there may be a 5% net reduction in expected annual flood damage.

A National Flood Resilience Review was set up following the severe flooding of winter 2015/16. Following delays this finally reported in September 2016. The review looked at the latest evidence on the current chance of widespread flooding in England, and assessed the exposure and resilience of key local infrastructure assets sited within an extreme flood outline (such as energy, water, transport and communications assets). The review identified 530 assets vulnerable to flooding, but provided no further information on the type or importance of the assets involved. Requests from the ASC to access these data for the purposes of fulfilling our statutory duty have so far been declined.

The ASC welcomed publication of the review[24] but also pointed out that the review was limited in its scope:

- It failed to address our recommendation – in our 2015 statutory report to Parliament on the UK's National Adaptation Programme – for a new and comprehensive, long-term strategy to address the risk of flooding. This requires a 'systems' approach which considers all sources of flooding and the full range of measures that should be used in combination to reduce the probability and consequences of flooding.
- The remit of the review was to focus on short-term measures that can be taken to better protect key infrastructure sites, from river and coastal flooding, before the winter.

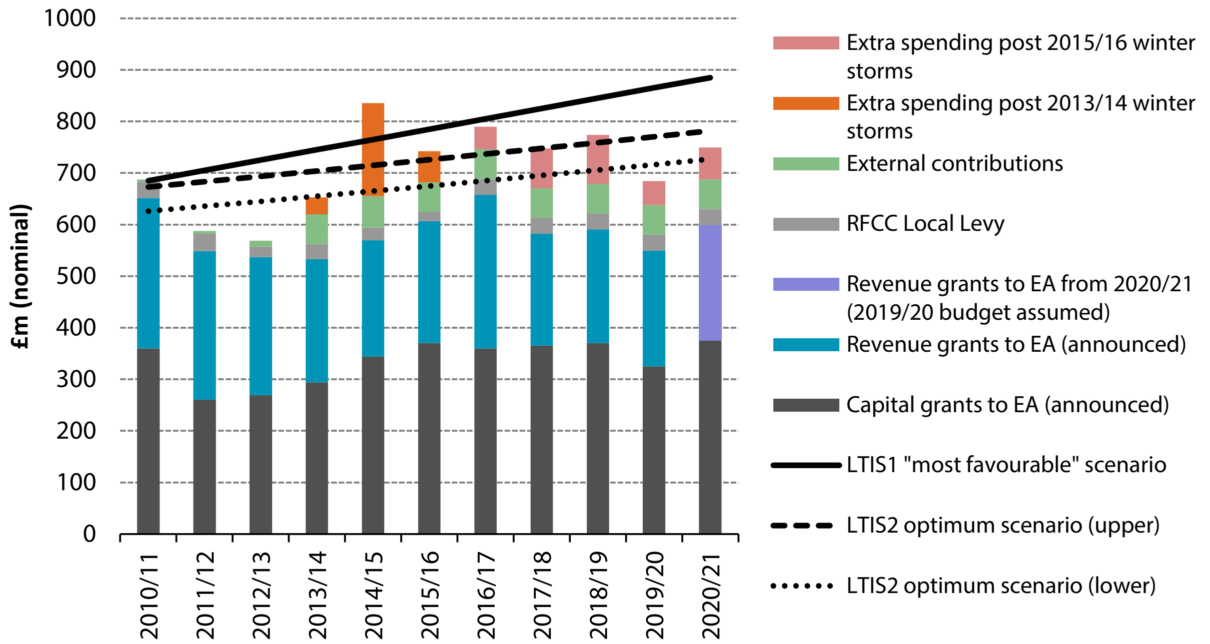
[23] Environment Agency (2014) *flood and coastal erosion risk management Long-term investment scenarios (LTIS) 2014*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381939/FCRM_Long_term_investment_scenarios.pdf

[24] https://www.theccc.org.uk/2016/09/08/ccc-welcomes-national-flood-resilience-review-but-says-further-action-needed-to-address-uk-flood-risk/

- The review ignored the risks posed by flooding from heavy rainfall overwhelming sewers – linked with the majority of flood damage in some recent events (for example, in 2007).
- The review lacked specific detail in terms of what will be done by when. This means it will be difficult to tell in the years to come whether the review has had a positive impact.

Furthermore, the report does not explain how the £700 million extra for flood risk management announced in the 2016 Budget will be spent. Of the £700 million, £350 million was held back to take forward the review's findings. The review details how only a small proportion of this will be spent - £15 million for additional temporary defences. Following further announcements in the Autumn Statement, around a quarter of the £700 million has yet to be allocated. The NIC might usefully recommend priorities for allocating the remaining funds.

Figure 3. Spending on flood and coastal erosion risk management in England compared to the long-term need



Source: ASC based on Defra (2016) *Central Government Funding for Flood and Coastal Erosion Risk Management in England* and Environment Agency (2014) *Long-Term Investment Scenarios*
Notes: Current and future spending on flood and coastal erosion risk management against the latest assessments of need. Money retained by Defra, and spending by local authorities on local flood risk management, have been removed from the figures. All figures are presented in cash/nominal terms with inflation at 1.5% per annum. The "most favourable" long-term investment scenario identified in the Environment Agency's 2009 Long-Term Investment Strategy (LTIS1) required an average of £20 million more plus inflation to be spent each and every year to 2035 in order to avoid an increase in the number of properties in areas of significant flood risk (1-in-75 annual chance of flooding or greater). The optimal investment path identified in the Environment Agency's 2014 Long-Term Investment Scenarios (LTIS2) suggested a slower rate of increase may be possible, starting at between £750 million and £800 million in 2014/15 (between £665 million and £715 million in 2014/15 once funding for local authority flood risk management is removed).

Determination of funding to protect national infrastructure

Under reforms to the allocation of Flood and Coastal Erosion Risk Management Grant-in-Aid introduced in 2011 (known as the 'partnership funding' system), taxpayer funding for flood defence projects is deliberately skewed towards protecting people and property, particularly in deprived areas. Whilst the benefits of protecting infrastructure is taken into account in the appraisal of flood defence options - in line with the HMT Green Book, the 2009 Defra Policy Statement on Appraisal, and the Multi-Coloured Manual - the protection of infrastructure is not weighted as highly as residential properties when it comes to the allocation of Grant-in-Aid.

Fully-funding flood protection for infrastructure at the taxpayer's expense would be inefficient and create perverse incentives. For example, doing so would undermine the incentive for operators to invest in resilience themselves, including in terms of network resilience, and when siting and designing new assets. In many cases it may be more cost-effective to install site-level measures, or re-locate assets especially if they are near the end of their useful life, than it would be to provide new defences at the taxpayer's expense.

Since 'partnership funding' was introduced there have been many good examples where infrastructure operators and others have worked in partnership with the Environment Agency to fund and deliver flood protection projects. But as a general trend, infrastructure operators may need to increase their own investment, and work in partnership, to ensure the resilience of their sites and networks rather than rely on flood defence measures being funded nationally, as might have been the case in the past.

6. Water supply and waste water

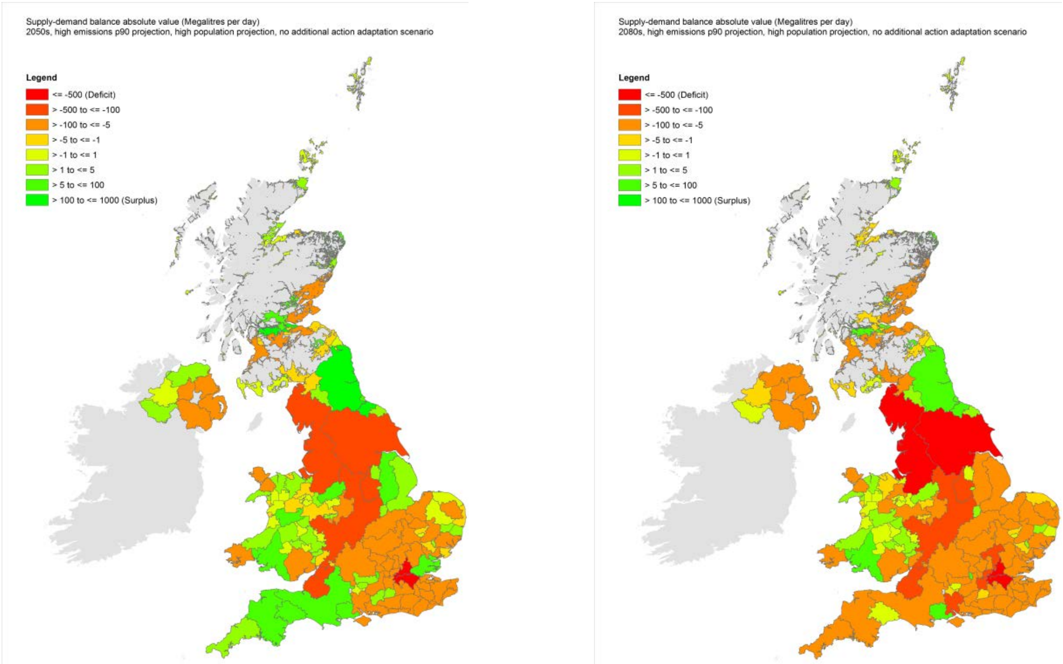
Risks to water supply and waste water

Climate change impacts to water supply and waste water can be categorised as those that affect the physical infrastructure and those that alter the availability of water resources. The combined effects of climate change and growth in population mean that the likelihood of severe water shortages is expected to increase in significant areas of the country, if further steps are not taken to reduce demand and/or make new supplies available:

- Water abstraction sites, treatment works and pumping stations need to be located near to watercourses. This means a large proportion of water company assets are in areas at risk of flooding. By the 2080s the number of clean water treatment sites in the UK located in areas vulnerable to flooding would be expected to rise by 33% with a 4°C rise in global mean temperature.[25]
- By the 2080s, Great Britain is projected (under a high population growth and a high climate change scenario) to have an overall projected supply/demand balance deficit of approximately 5-16% of total demand at that time. Figure 4 summarises the results, and shows that the projections vary greatly by region.

[25] ASC (2016) *Climate change risk assessment evidence report Infrastructure chapter*, https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-4-Infrastructure.pdf

Figure 4. Water availability projections (Ml/day) for public water supplies in Great Britain in the 2050s (left) and 2080s (right) under a high emissions scenario



Source: HR Wallingford (2015) for the ASC.
Notes: Based on UKCP09 high emissions scenario (p90) and ONS high population projection. The supply-demand balance is in absolute terms for each zone, not a per person balance. Note that both scenarios assume no additional adaptation beyond that already planned by water companies.

Actions taking place

The 2007 floods prompted water companies to invest further in resilience improvements. Further investments have been approved by Ofwat for the new Asset Management Plan period in 2015–2020 (AMP6). Water company business plans for AMP6 included £660 million for network resilience, including £60 million for wastewater services. The new system of rewards and incentives introduced by Ofwat should also encourage water and waste water companies to achieve reliable services at least cost. A new 'resilience duty' under the 2014 Water Act should further strengthen performance in time for the next AMP period, when it comes into effect, provided it is well defined and performance is measured in a consistent and robust way.

Measures to reduce water demand are being rolled out. Water companies' business plans in recent AMPs have in general increased the emphasis on water efficiency and reducing leakage. Installation of water meters is progressing and overall water consumption per person is declining, albeit at a relatively slow pace and against a backdrop of population growth in many water-stressed areas.

Building resilient water infrastructure

Water industry resilience depends on being able to meet demand for water even at times of scarcity and drought. In past reports the Adaptation Sub-Committee has concluded that there remains significant scope to reduce the demand for water. This could form a potential win-win. It would postpone some need for major capital investment in new sources of supply, whilst reducing customer bills for the increasing number of households whose use of water is metered. However, the need for water companies to invest in new water resources will remain even with ambitious reductions in water demand.

The evidence report for the UK Climate Change Risk Assessment identified that more action is needed to reduce risks to public water supply from drought and low river flows. New policies and stronger, co-ordinated, cross-sector effort is needed to deliver more ambitious reductions in water consumption and establish strategic planning of new water-supply infrastructure. However, projections of climate change and its impact on water availability are uncertain, particularly at the regional level. There is a need to improve resilience, but also to keep options open as the knowledge of and confidence in climate projection grows.

7. Digital communications

Risks to the digital communications sector

Climate-related risks have the potential to disrupt the availability and reliability of the ICT sector and consequently push up operational costs for users. ICT networks typically exhibit considerable resilience due to diversity of systems and their network topology and redundancy. The exception is at the edges of networks where diversity is at its least – typically near low population regions, or remote locations such as islands where loss of ICT for communications or control of other systems can cause the greatest problems.

In the evidence report for the UK Climate Change Risk Assessment we identified that the frequency of coastal, fluvial (river) or pluvial (surface water) flooding will damage key ICT assets such as cables, masts, pylons, data centres, telephone exchanges, base stations and switching centres. The short life-span of end-user equipment allows for gradual adaptation; however support infrastructure such as buildings, masts and cabling have longer life-expectancies making them more vulnerable to changes over longer periods.

Actions taking place

It is difficult to assess the vulnerability of ICT services to extreme weather events, as for security reasons there is limited information on the location and connectivity of ICT infrastructure in the UK. In our 2015 Progress Report we were unable to gather evidence on resilience measures and noted that this was a concern. The National Adaptation Programme contains no specific actions relating to ICT despite the sector being recognised as pivotal to other key infrastructure sectors, as well as the economy in general. Tech UK has produced a first adaptation report having been invited by Defra to do so under the second round of the Adaptation Reporting Power.[26] The report is helpful but rather than provide evidence of vulnerabilities and risk management actions it outlines where further scrutiny should be focussed, as a first step in an iterative

[26] The Adaptation Reporting Power (ARP) is an important aspect of the Climate Change Act 2008 whereby the Secretary of State can request organisations with functions of a public nature and statutory duties to produce reports detailing: the current and future predicted effects of climate change on their organisation; their proposals for adapting to climate change; and an assessment of progress towards implementing the policies and proposals set out in previous reports.

process. The report does highlight the sector's vulnerabilities resulting from dependencies on other infrastructure services – including electricity and to a lesser extent transport. It also points to potential failures from physical 'pinch points', like bridges that carry multiple utilities.

Building resilient digital infrastructure

The risks to digital infrastructure remain relatively unknown and this is hindered by the limited knowledge on the location and importance of individual assets. ICT can be subject to major disruption and cascading impacts from other sectors. Given ICT's pervasive and 'unseen' interdependence with all other infrastructure systems, and its role in underpinning business and social wellbeing, it is crucial to assess the vulnerability of the UK's ICT networks and systems, and its interdependence particularly with the energy sector, in a changing climate. Looking ahead, Tech UK[27] reported that there needs to be:

- more information on interdependencies, in particular the need to consider whether the system is building enough redundancy with its reliance on power;
- more data on how often operators re-examine flood risks;
- a review of regulatory provisions of the Universal Service Obligation (USO) for fixed line telephony, especially for new properties located in flood zones; and
- scrutiny of the current regulatory focus on customer prices for mobile services in terms of its potential impact on resilience.

[27] Tech UK (2016) *The UK's core digital infrastructure: data centres* http://www.techuk.org/images/ICT_ARP_response_to_DEFRA_2016.pdf

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