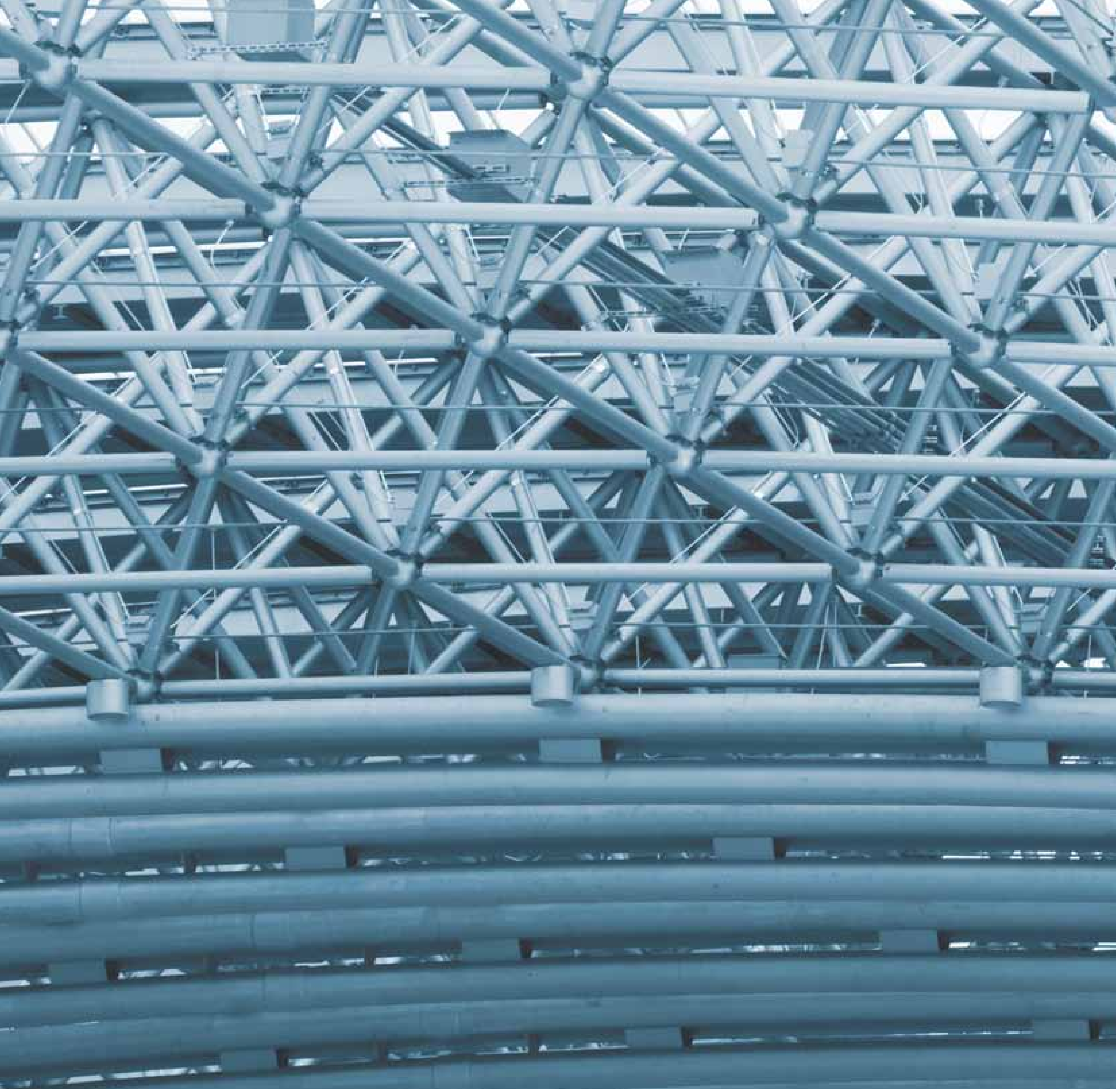

A Fast Track Analysis of strategies for infrastructure provision in Great Britain

Technical report

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Strategies for National Infrastructure provision in Great Britain

Cycle One of the Infrastructure Transitions Research Consortium's analysis of long term dynamics of interdependent infrastructure systems – the Fast Track Analysis

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Executive summary

A GLOBAL PRIORITY

National Infrastructure (NI) provides the foundation for economic productivity and human wellbeing, and is the cornerstone of modern industrialised society. It shapes many of the interactions between human civilisation and the natural environment. However, in the UK and other advanced economies, NI faces serious challenges of:

- Growing demand for infrastructure services from a modern economy and growing and ageing population;
- Significant investment requirements so that an ageing infrastructure system can meet this demand and provide reliable, cost-effective and high quality services;
- Increasing complexity and interdependence of infrastructure networks.

A growing stock of infrastructure helps to promote economic growth by increasing productivity, participation in the economy and aggregate demand. Infrastructure investment is also necessary to reduce the likelihood and consequences of system failure and to ensure a healthy environment and a stable climate.

The lead-time and long lifetime of major infrastructure means that a long term view is essential. Yet a long term strategic approach is challenged by the associated uncertainties, be they technical, environmental, political or financial. Interdependence between infrastructure sectors add to the complexity and uncertainty in the strategic planning of NI.

In the 2011 National Infrastructure Plan (NIP),[1] the UK government has identified a strategy for meeting infrastructure needs. Metrics for monitoring UK infrastructure performance and strategic priorities for the future are set out in the NIP. The NIP underlines the importance of taking a long term and cross-sectoral view of infrastructure provision.

1 HM Treasury and Infrastructure UK (2011). National Infrastructure Plan 2011. London, UK: HM Treasury.

THE UK INFRASTRUCTURE TRANSITIONS RESEARCH CONSORTIUM

The UK Infrastructure Transitions Research Consortium (ITRC) has been funded by the Engineering and Physical Sciences Research Council (EPSRC) to develop and demonstrate a new generation of system simulation models and tools to inform analysis, planning and design of NI. The research programme deals with energy, transport, water, waste and ICT systems at a national scale, developing new methods for analysing their performance, risks and interdependencies. ITRC will provide a virtual environment in which to test strategies for long term investment in NI and understand how alternative strategies perform with respect to policy constraints such as reliability and security of supply, cost, carbon emissions, and adaptability to demographic and climate change.

The 5 year ITRC research programme started in January 2011. In its first year, the ITRC has begun the development of a new generation of simulation models for national infrastructure assessment that will be ready for piloting in 2013. In parallel, the ITRC has undertaken a Fast Track Analysis (FTA) in order to:

1. Ensure that the ITRC research programme is building upon existing knowledge.
2. Review and refine the scope of the ITRC research.
3. Pilot and communicate new analysis concepts.
4. Strengthen the relationship between the research team and the consortium's partners in government and industry.

This report describes the method and results from the FTA. It includes:

1. A review of the energy, transport, water, waste and ICT sectors, including governance arrangements and future opportunities and threats.
2. Development of a scenario framework for long term analysis of NI, and associated uncertainties.
3. Development and analysis of alternative long term strategies for infrastructure provision.
4. Synthesis of insights that will be used to focus the remainder of the ITRC programme.

THE CURRENT STATE OF NATIONAL INFRASTRUCTURE AND FUTURE CHALLENGES

Review of literature and consultation with industry has identified current trends and issues in the NI sectors.

ENERGY SECTOR

Reliability of the energy sector is high. Major investments are anticipated in electricity generation and distribution in order to maintain and increase capacity, meet the UK's greenhouse gas (GHG) emissions reduction commitments and address EU directives. All other infrastructure sectors are dependent upon the energy sector, but of these only transport represents a significant proportion of energy demand (34%). Yet the energy sector is also dependent upon ICT and transport infrastructure and is responsible for 32% of fresh water abstraction, though the majority of that cooling water is eventually returned to rivers.

TRANSPORT SECTOR

Demand for transport infrastructure has grown steadily over the years for a variety of reasons, including population growth, economic growth combined with relatively low costs making travel affordable for most people, and societal changes such as increasing numbers of female drivers. Growth seems likely to continue, although demand for personal car transport may reach a saturation point. Continued growth in demand will result in increased congestion and delays, particularly on roads and rail, which will in turn tend to inhibit further growth. Building new transport infrastructure will alleviate congestion and delays in the short term but also induce further demand. Increasing transport costs will act to inhibit demand, which could have an adverse impact on the economy unless transport growth can be decoupled from economic development. Ambitious carbon reduction targets will drive development in vehicle and fuel technologies and result in increased use of electric vehicles on roads, increased rail electrification and lower use of carbon fuels. This will require substantial investment in energy infrastructure, particularly for electricity. Providing new energy infrastructure will impose further requirements on the transport system, for example, a change in the combination of imported fuels may have alternative shipping and storage requirements which will affect ports infrastructure.

WATER SUPPLY SECTOR

The water industry supports a diverse range of uses for water, all of which possess stringent levels of service with respect to both water quantity and water quality, dictated by a complex legislative and regulatory framework. As well as significant geographical and seasonal variability, pressures including increasing consumptive demand, an ageing and deteriorating infrastructure, affordability, and a potentially critical redistribution of resource under future climates, providing a potent set of challenges for the water supply sector in the 21st century. It is unlikely that even major change in the behaviour of consumers will be sufficient to alleviate such pressures without additional investment in infrastructure. Thus, a broad programme of measures combining management of consumptive demand across all users of the water environment alongside strategic provision of new supplies is necessary.

WASTEWATER SECTOR

Wastewater treatment accounts for the majority of the total asset value of the water industry, with capital expenditure on sewerage services programmed to exceed £12 billion between 2010 and 2015 in England and Wales alone. There has been extensive investment in wastewater treatment in order to improve water quality standards in rivers and coastal waters, though improved treatment standards imply escalating energy costs. Energy use in wastewater treatment now averages roughly 300 MW. Options that would reduce or eliminate energy use in wastewater treatment are needed to ensure the future affordability of service. Projected changes in rainfall patterns due to climate change and major and minor flooding pose a risk to the existing drainage infrastructure.

SOLID WASTE SECTOR

The solid waste sector deals with approximately 300 million tonnes of waste annually in the UK. In the last decade, the sector has transformed rapidly, responding to EU and national legislation. This has increased the amount of waste recycled, composted or reused and nearly halved waste going to landfill. Historically, economic growth and household waste generation were coupled, but there is some evidence that this may no longer be true. National and EU directives (e.g. possible banning of all biodegradable municipal waste to landfill in the next decade) for reducing solid waste will affect the levels of investment needed in the near term. There is the possibility of a complete paradigm shift towards solid waste becoming a resource recovery industry.

INFORMATION AND COMMUNICATIONS TECHNOLOGIES (ICT)

In comparison to the physical infrastructure sectors already discussed, ICT is a new and rapidly changing sector, but it is less clearly defined and understood. ICT infrastructure is considered to comprise of communication (including fixed and mobile telephony, broadband, television and navigation systems) and computation systems (including data and processing hubs). Significant increases in ICT capacity have been provided via a competitive industry, which has innovated to provide new technologies and respond to consumer demand (which is itself largely driven by innovations in consumer and enterprise technologies). Further rapid increases in coverage, in particular in superfast broadband, are anticipated, though there are some locations where the market alone cannot deliver. The current way that the electro-magnetic spectrum is used may also become a constraint: solutions include reallocation of the spectrum use and technological innovation. ICT has a critical role in infrastructure interdependence and failure.

INFRASTRUCTURE GOVERNANCE

Alongside these sector-specific issues, the shift towards liberalisation, private provision and competition in infrastructure sectors has led to a more complex governance landscape in which utility providers must negotiate with a range of other actors to effect change. Additionally, current governance arrangements continue to operate in isolated sector-specific silos, paying limited attention to cross-sectoral synergies and interdependencies.

THE ITRC FAST TRACK ANALYSIS METHODOLOGY

National Infrastructure systems have to cope with the implications of long term changes in population, the economy, society and the environment. The nature of these changes is hard to predict in the long term, so the ITRC is adopting an approach in which plausible ranges of these future changes are analysed. A simplified version of this methodology has been developed for the FTA, in which three primary scenario dimensions that are common to all infrastructure sectors have been analysed: demographic change, energy prices and economic growth.

Whilst the ITRC modelling tools that are now under development will enable the analysis of many combinations of these and other scenario dimensions, in the FTA the analysis has been restricted to only three combinations, representing low, medium, and high growth scenarios.

Sector-specific issues can be as influential as these cross-cutting scenario dimensions, and include for:

- **Energy**: GHG emissions targets.
- **Water supply and wastewater**: the effects from climate change on water availability and quality; the requirements of the Water Framework Directive.
- **Solid waste**: EU directives and national standards.

A multitude of possible means of providing NI are conceivable in the context of these scenarios, including supply and demand-side measures. The ITRC is seeking to explore how integrated cross-sectoral approaches may yield new insights and benefits. As a first step, in the FTA three distinct and cross-sectoral transition strategies have been identified.

- The **Capacity-Intensive** (CI) strategy represents high investment in new capacity to keep up with demand and maintain good security of supply in all sectors.
- The **Capacity-Constrained** (CC) strategy represents low investment, in which there are no increases in the current level of infrastructure investment, but an emphasis is placed upon demand management measures.
- The **Decentralised** (DC) strategy represents a reorientation of infrastructure provision from centralised grid-based networks to more distributed systems. This will involve a combination of supply and demand-side measures.

The three transition strategies are analysed against the demand for infrastructure services associated with each of the three FTA scenarios in order to provide insights into future infrastructure performance in a range of possible conditions.

RESULTS FROM THE FAST TRACK ANALYSIS

Results are reported by NI sector, followed by a cross-cutting synthesis.

ENERGY SECTOR

The analysis of transition strategies for the energy sector using the MARKAL model demonstrates that, under the FTA medium growth scenario, carbon emissions reductions of 80% across the economy can be delivered by all of the infrastructure transition strategies. All strategies can deliver continued electricity supply security, provided the required investment levels can be met.

In all FTA scenarios, the CC strategy has the lowest cost due to an emphasis upon demand reduction. The DC strategy scenario has the highest cost due to use of less cost-effective technologies. The DC strategy offers benefits in terms of increased supply diversity, although the Shannon–Wiener index does not account for the security benefit provided by over-capacity in the CI transition strategy.

Under the high growth scenario, carbon targets would inevitably be more challenging, and higher absolute levels of investment are required to ensure security, but this investment is a lower proportion of GDP. Conversely, under low growth carbon targets are less challenging but investment requirements form a higher proportion of GDP.

TRANSPORT SECTOR

Low, medium and high growth scenarios for transport demand have been developed, using an elasticity model to relate transport demand growth to growth in population, fuel prices and GDP, with any added taxes or charges also being considered (e.g. national congestion charge). Demand suppression due to congestion was modelled using feedback relationships between demand and resulting journey times. The low growth FTA scenario is more consistent with historical trends in transport demand. The transition strategies that were analysed in the FTA involve differing levels of capital investment in roads and rail, including investment in the HS2 high speed rail link. Transport infrastructure would be particularly stressed under the high growth scenario.

Vehicle emissions standards and differing rates of uptake of electric vehicles were also analysed. Future electrification of road transport sector would reduce emissions at the point of use, but could result in more congestion due to energy price effects (moving from highly taxed petrol to untaxed electricity).

The CI strategy (high investment and fast uptake of electric vehicles) would result in higher growth in demand (e.g. 23% more car/van km in 2050 compared to the reference case). Whilst contributing to congestion, this demand growth is compensated by improved fuel efficiency (approximately 70%), thus it results in the largest reduction in CO_2 emissions (19% fewer emissions from cars and vans, and 25% fewer emissions from HGVs in 2050 compared to reference case).

The CC strategy (low investment, low uptake of electric vehicle, introduction of a national congestion charging scheme) would result in the lowest growth of demand, with an estimated reduction of car/van km by 3%, and with reduced CO_2 emissions of 7.3% for car/vans and 2.4% for HGVs in 2050 compared with the reference case.

WATER SUPPLY SECTOR

Contrasting levels of water demand and supply-side measures were tested in the CI and CC strategies using data on public water supply in England, Scotland and Wales. Whilst security of supply is currently good, population growth and climate change represent a threat to the industry over the coming decades, unless per capita demand is reduced and or capacity is increased. This needs to take into account the large regional variations across Great Britain. The CI transition strategy implies high investment in supply infrastructure (including reservoirs, transfers and desalination) as well as in capital programmes of leakage reduction. These measures contribute to security of supply in terms of both capacity and flexibility of use of resources. In high climate change and population growth scenarios, the strategy sees rapidly increasing capital and energy costs. The strategy is threatened by the possibility of climate change reducing water availability, the requirements for restoring aquatic environments and the energy implications of desalination and inter-basin transfers.

The DC strategy implies more local self-sufficiency, which is vulnerable to supply and demand side uncertainties. The CC strategy emphasises vigorous price and regulatory measures to reduce demand to an average of 110 litres/person/day by 2050, which have the added benefit of reducing energy use, in the water sector and by water consumers. At the same time margins between supply and demand are eroded, with implications for security of supply.

WASTEWATER SECTOR

For wastewater treatment, demand is determined by population. However, population density and the treatment technologies implemented determine the unit cost of treatment. As with water supply, economies of scale favour centralised strategies and increasing population density further reduces costs. In the CC strategy, for which we assume incremental changes to current infrastructure, energy costs increase rapidly. The performance of the CI transition strategy is characterised by replacement of existing energy-intensive treatment capacity with new treatment capacity using new energy recovery technologies. These technologies allow wastewater treatment to become an energy-neutral or energy-generating process. However, these new treatment technologies still require research and development. The cost and long design life of the existing sewerage infrastructure means that radical transitions would be very costly. This will mean managing the existing assets actively and intelligently, perhaps accelerating the adoption of the active monitoring and control of sewerage systems and developing strategies to incrementally replace or renew the network.

SOLID WASTE SECTOR

For solid waste, in most scenarios, EU and local government imposed targets will require new capacity for some treatments (e.g. composting and recycling) but this could be achieved at the investment levels envisaged in any of the transition strategies. However, in high growth FTA scenario it will be challenging to meet recycling targets and the implied requirement for new treatment sites may also be problematic.

INFORMATION AND COMMUNICATIONS TECHNOLOGIES (ICT)

ICT capacity has continued to rapidly expand keeping well ahead of demand thanks to on-going innovation in a competitive market. It is anticipated that this arrangement will continue, so the sector has not been subject to the same quantified analysis as other sectors. In 2010, ICT consumed an estimated 13–16% of the total electricity in the UK. Projections indicate that global electricity usage in ICT will grow by approximately 9% per year, a trend that may continue up to 2020. However, since 2000 there has been a continuing decrease in growth for home computing and other electronic consumer goods in the UK, and new products have greater energy efficiencies, which may serve to depress future growth of energy use in ICT. Beyond 2020, technological changes make electricity demand from ICT very difficult to project.

CROSS-SECTORAL SYNTHESIS

Each NI sector requires a somewhat different set of metrics to evaluate its performance, which are presented in the main text of the FTA report. Performance has been reported with respect to three metrics that apply across all sectors: (1) cost, (2) CO_2 emissions and (3) security of supply. This enables the cross-sectoral evaluation of the transition strategies and evaluation of key questions of interest to stakeholders.

What are the implications of growing demand for infrastructure services?

High growth in demand for infrastructure services is associated with increasing needs and costs for infrastructure provision, in particular given the CI and DC transition strategies, but high growth in demand is associated with scenarios in which more resources would be available for infrastructure investment. However, high growth in demand is also associated with higher GHG emissions, unless the CI transition strategy is adopted, in which case innovation and investment enables a successful transition to infrastructure systems that are all effectively decarbonised. Higher transport demand is associated with increased transport congestion even given a CI approach to transport infrastructure provision, as, without demand management measures, demand continues to expand to fill the available capacity.

What are the implications of constrained investment in UK infrastructure capacity?

Evaluating the performance of the CC strategy provides insight into the implications of constraints on investment levels for NI. For example, in the water sector the CC strategy requires vigorous price and regulatory measures over many years, in order to achieve the per capita water demand target of 110 litres per day. Security of supply is eroded, especially in high growth scenarios. The CC strategy is the least cost approach, as costly supply-side measures are avoided through demand management. However, whilst demand reduction can under some circumstances result in efficiency improvements without deterioration in the quality of the infrastructure service (for example, improved building insulation reduces energy requirements for space heating), in other sectors, notably transport, stringent demand reduction will have implications for the economy and society.

What are the implications of a carbon-constrained future?

As a consequence of the Climate Change Act (2008) the UK is committed to a reduction in GHG emissions of at least 80% (relative to 1990 levels) by 2050. Increasing global demand for fossil fuels at a time of reducing global oil reserves reinforces the case for reducing dependence upon fossil carbon. The UK's GHG mitigation commitments imply a major restructuring of the UK's energy supply infrastructure and ripple through other NI sectors, which are all dependent upon energy. Changes within these sectors in turn influence the energy sector, in particular in the case of a transition to electric vehicles. For both wastewater and solid waste, there is the potential for the energy demand from these sectors to be met through conversion of the waste streams to energy.

What are the implications of a decentralised National Infrastructure system?

The FTA revealed that reorientation towards a decentralised arrangement of infrastructure (both in terms of technology and governance) could result in NI performance increases. The energy sector analysis, for example, revealed that the decentralisation transition strategy resulted in the greatest diversification of energy supply options. Decentralisation also has the potential to capitalise upon interdependencies (e.g. via local waste to energy conversion or combined heat and power plants) and provide new supply options (e.g. rainwater harvesting in the built environment). However, the evaluation of the cross-sectoral performance of the DC transition strategy indicated that there are significant front-loaded capital investment requirements to transition towards a decentralised arrangement, particularly in the high and medium growth scenarios.

What are the implications of interdependence between infrastructure sectors?

Demand for different infrastructure sectors is highly correlated, both due to the final demand associated with population and economic growth and because of intermediated demands between infrastructure sectors. The FTA has revealed the importance of cross-sectoral interdependence, in particular via energy demand from all sectors. Potential changes in demand (e.g. from electric vehicles and as a consequence of ICT) need to be accommodated in the energy sector. Changes in other sectors, for example, in transport congestion or water availability will also have cross-sectoral impacts. The FTA has not revealed new opportunities that could be accessed by taking interdependence into account, though these may exist at the scale of individual facilities or infrastructure corridors. However, understanding interdependence is essential to recognise new cross-sectoral demands that otherwise might not be accommodated and to minimise the risks of infrastructure failure.

NEXT STEPS FOR THE ITRC

The Fast Track Analysis has demonstrated the feasibility and utility of long term cross-sectoral analysis of infrastructure demand and capacity. Cross-sectoral analysis has demonstrated how different sectors are shaped by many of the same drivers, especially those that influence demand (demography, economy) and energy prices. Where new investment is required, different sectors may be competing for the same pools of public and/or private finance.

A cross-sectoral approach provides the opportunity to define a common direction of travel and to understand the contribution that separate policies or plans make to overall performance. Yet analysis of governance arrangements has underlined how current regulatory frameworks are not well adapted to this 'system of systems' perspective.

Undertaking the FTA based on currently existing datasets and models has not been straightforward as there is no tradition in the UK or internationally of taking a 'system of systems' approach to analysis of NI. The FTA analysis of each sector is therefore to some extent shaped by the assumptions and constraints of existing approaches within that sector, as set out in the FTA report and annexes.

Going forward, the ITRC is adopting three methodological perspectives in its development of tools for analysis of NI provision. The development of models and tools is taking place in the first three ITRC Work Streams and are explained below.

Work Stream 1 (WS1) is developing a system of quantified capacity/demand assessment modules (CDAM) for analysis of long term strategies for infrastructure provision. In that sense it will resemble the FTA but will be based upon more quantified and more fully integrated models including:

- A micro-simulation model for generation of high resolution demographic and demand scenarios.
- A regional economic model that will generate regional multi-sectoral projections of industrial demand for infrastructure services.
- A model of the UK electricity and gas networks and a new disaggregated energy demand module.
- A national strategic model of trunk road, rail, port and airport infrastructure.
- A national water resources system model, coupled with a model of wastewater treatment systems.
- A national solid waste assessment model.

ICT will be excluded from the WS1 analysis, as the FTA has illustrated that new capacity has being provided historically and this can be expected to continue for the foreseeable future. Further the demand is very sensitive to unforeseen technological developments which makes future analysis difficult.

These models will be coupled in an overall simulation framework in which the main scenario uncertainties are extensively sampled, expanding upon the small number of scenarios analysed in the FTA. A set of infrastructure investment options will be developed for each sector and assembled flexibly into cross-sectoral packages, representing a major extension of the three transition strategies analysed in the FTA. New tools will be developed to explore and visualise the results of the analysis.

The interaction between this overall modelling system and the NI database being developed in Work Stream 4 (WS4) is illustrated in Chapter 5. The WS4 database, which is built using an open source spatial database architecture, already contains more than 300 different layers of infrastructure and demand data and is rapidly expanding.

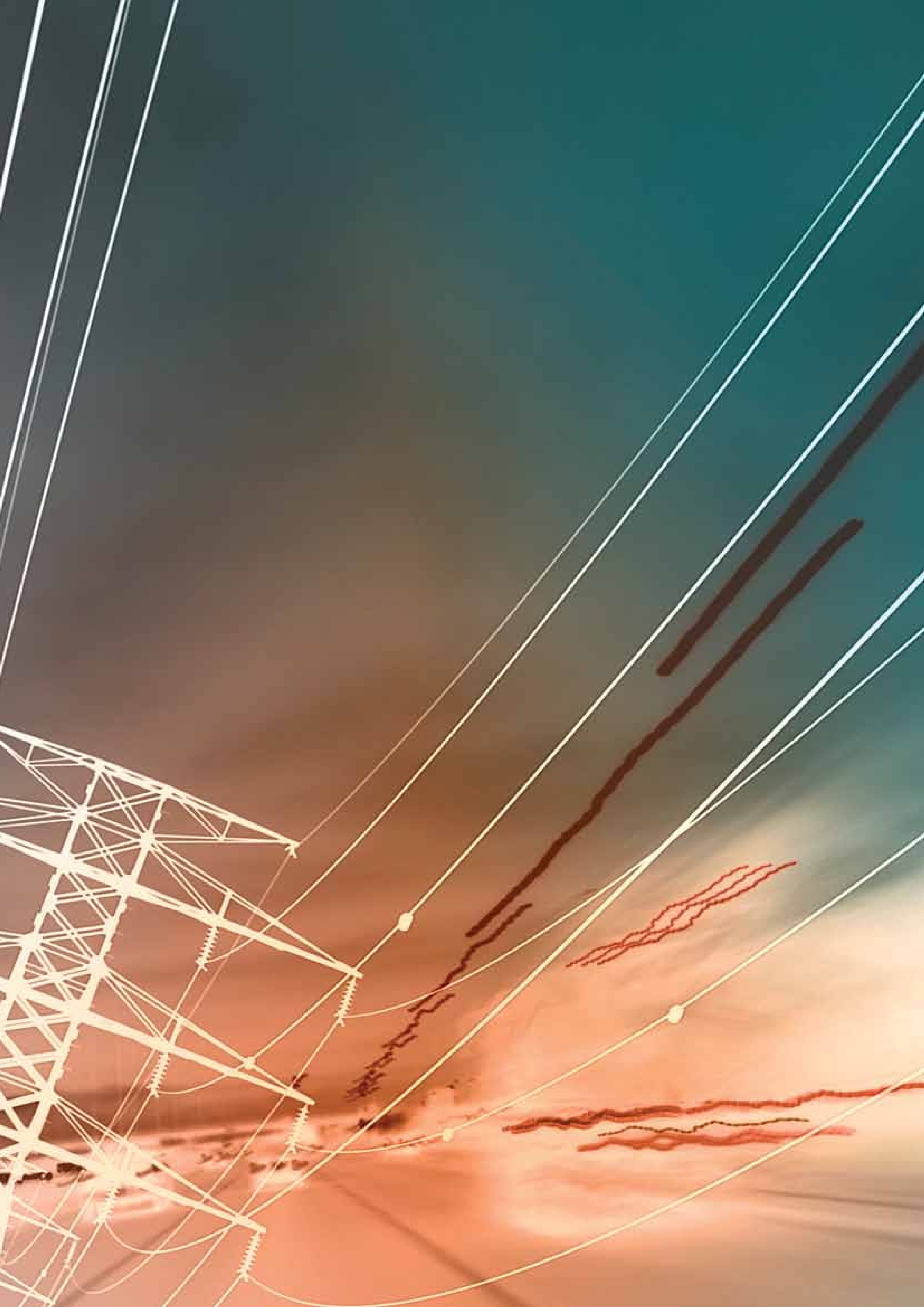
Development of this new generation of models is due to be completed in March 2013. They will be used to conduct a much more complete and quantified analysis of infrastructure transition strategies than has been feasible in the FTA. That second cycle of national infrastructure assessment is due to be delivered at the end of 2013.

The FTA has not examined in any depth the risks of infrastructure failure and the ways in which interdependence between infrastructures may exacerbate those risks. This topic is the focus of ITRC **Work Stream 2** (WS2). Given the severe long term threats posed by climate change, WS2 has begun by focussing upon climate-related hazards, though scope to extend to other natural hazards and man-made hazards will be explored later in the research programme.

Spatially coherent probabilistic scenarios of extreme climate related hazards and their associated uncertainties are being developed. Working with our industrial partners and building upon previous studies, WS2 will characterise the vulnerability and interdependence of energy, transport, water, waste and ICT systems. Central to WS2 will be the development and testing of network models for analysis of interdependent NI failure and risk. Quantification of the direct consequences of infrastructure failure will use the economic and demographic scenarios developed in WS1. The indirect economic consequences of failure and recovery will be analysed at regional and national scales using an input–output modelling approach. Results will be presented as a range of metrics of vulnerability and risk.

Scoping of **Work Stream 3** (WS3) is now under way, exploring a variety of complex systems approaches to simulate and interpret the long term interactions between infrastructure, society and the economy. The research in WS3 will start with exploratory simulations of synthetic examples and work up to more realistic models. Complex systems methodologies under examination include land use and transport spatial interaction models, dynamic network models and a variety of methods in evolutional economics. The most promising approaches will be tested in order to identify patterns of emergence and to understand how in the real world these new insights may be used to steer NI systems towards sustainable outcomes.

The Fast Track Analysis has helped the ITRC to frame its research programme for the coming 4 years. It has identified priorities for more detailed analysis and has helped to refine understanding of those factors that need to be incorporated in development of the new generation of NI models that is now under way within the ITRC.



1 Towards integrated assessment of National Infrastructure

This chapter provides an overview of the challenges facing National Infrastructure in the UK,[2] and explains the contribution that the UK Infrastructure Transition Research Consortium is making to address these challenges.

1.1 CHALLENGES FACING NATIONAL INFRASTRUCTURE PROVISION IN THE UK

National Infrastructure (NI) provides the foundation for economic productivity and human wellbeing, and is the cornerstone of modern industrialised society. It provides the energy and water resources that society needs in order to function, and enables people, information, and goods to move efficiently and safely. NI shapes many of the interactions between human civilisation and the natural environment. Whilst infrastructure is mankind's most visible impact upon the environment, modern sustainable infrastructure is also essential to minimising human impacts, for example on the water resources system and the climate.

NI includes the five economic infrastructure sectors: (1) energy, (2) transport, (3) water, (4) waste, and (5) information and communication technology (ICT). They contribute directly to economic growth, a high quality of life, and a high living standard. However, in both the UK and other advanced economies, NI is facing serious challenges. These challenges threaten its ability to continue to provide their essential services that support nearly all aspects of daily life.

1.1.1 CHANGING DEMAND FOR INFRASTRUCTURE SERVICES FROM AN AGEING NI SYSTEM

Growing demand for an infrastructure that is ever-ageing, challenges its ability to provide a sustained service.

2 The focus of ITRC work is for Great Britain, however this Fast-track analysis uses data from both GB and UK; these distinctions are made in the text.

Table 1: Summary of NI systems and governance in Great Britain

	Energy	Transport	Water	Waste		ICT
				Wastewater	Solid waste	
Example component systems	Electricity Natural gas Liquid and solid fuels	Roads Rail Aviation Shipping	Water supply	Sewerage Wastewater treatment	Household Commercial and industrial Construction and demolition	Fixed (cable, wireless) and mobile (mast, satellite) communications Mass data and computation facilities
Scale	National International	Regional National International	Regional	Regional	Regional	National International
Ownership	Private	Mixed (by mode)	Mixed (by region)	Mixed (by region)	Mixed (public responsibility with private operation)	Private
Governance & regulation	Varies, e.g. electricity has unregulated market prices but regulated network charges (Ofgem)	Varies, e.g. rail has regulated efficiency targets and prices; roads are government planned with some private provision	For England and Wales, price and investment regulated by Ofwat, drinking water quality regulation by DWI, Environmental regulation by EA. Similar structure in Scotland		Local Authority run. Environmental regulation by EA/ Defra in England and Wales, SEPA in Scotland	Competition regulation by Ofcom
Issues	Security of supply GHG emissions targets	Congestion High speed rail Airport capacity	Demand management Climate change Environmental regulation	Energy costs Environmental regulation	Waste minimisation and recycling targets Resource recovery	Technological innovation

Infrastructure in Great Britain is ageing, with a considerable amount of existing infrastructure stock built in the 19th century (HM Treasury and Infrastructure UK, 2010a): this can cause supply insecurities. Consider for example the 31,000 km of water mains in London, where nearly half (44%) are over 100 years old. Thames Water has replaced over 2000 km of these mains since 2003, at a cost thus far of £650 million, reducing leakage by 27% (Thames Water, 2011).

While infrastructure is ageing, it must also meet demand from a growing and ageing population with changing expectations and preferences, alongside the demands of a modern economy. In the case of ICT, households with access to the internet increased 16% over the last 4 years (ONS, 2011), while the absolute number of adults accessing the internet every day nearly doubled from 2006 to 2010 (ONS, 2010b). In the case of transport, the last 15 years has seen growing demand across all modes of travel for long distance trips (i.e. over 160 km). This growth is expected to continue, with the Department for Transport (DfT) forecasting that between 2008 and 2043, there will be an increase of 36% in the total number of long distance road, rail, and air trips per person (DfT, 2011b).

NI is one of the main determinants of environmental quality. As well as delivering Britain's energy supply, NI is also a major contributor to overall emissions, since it consumes well over half of that energy. Investment in water treatment infrastructure has been responsible for improvements in water quality in rivers and coastal areas, and further investment will be required in order to meet the Britain's obligations under the EU Water Framework Directive. Changes in the solid waste infrastructure sector are reducing the quantity of waste going to landfill. Higher standards for vehicle and industrial emissions are improving local air quality. It is expected that society will continue to demand environmental improvements with important implications for NI: providing Britain's capacity to meets its carbon emissions targets is a key issue.

1.1.2 INTERDEPENDENCE BETWEEN INFRASTRUCTURE SECTORS

Infrastructure interdependencies introduce layers of complexity, uncertainty, and risk to NI planning and design.

Over the last 50 years, infrastructure in the UK shifted from unconnected structures to interconnected networks (CST, 2009). This shift has important implications for the resilience of infrastructure sectors. For example, a recent power failure at a major exchange in Birmingham resulted in the temporary loss of broadband service for hundreds of thousands of customers across the UK, particularly affecting business customers (BBC, 2011a). Even small, temporary failures can have significant effects on economic productivity. In the long term, these risks intensify as systems become larger and increasingly interdependent. The combined effect of ageing infrastructure, growing demand (nearing capacity limits) from social and economic pressures, interconnectivity, and complexity leads to systematic weakening of the resilience of infrastructure systems (CST, 2009). Climate related extremes have caused major service interruptions in recent years (e.g. due to floods and snow). Climate change is increasing the risk of extreme events (IPCC, 2012).

The changing patterns of demand mentioned in Section 1.1.1 influence different infrastructure sectors in rather similar ways, providing a further source of interdependence in the long term. For example, if it is possible to reduce domestic demand for water this will have implications not only for water supply, but also for energy (as 18% of household energy is used for heating water (DECC, 2011c)) and wastewater treatment. Moreover, in some instances one infrastructure sector is a major component of demand for another sector: the transport sector represents 34% of energy demand in the UK, whilst electricity generation is responsible for 32% of all non-tidal water abstractions (Defra, 2009a).

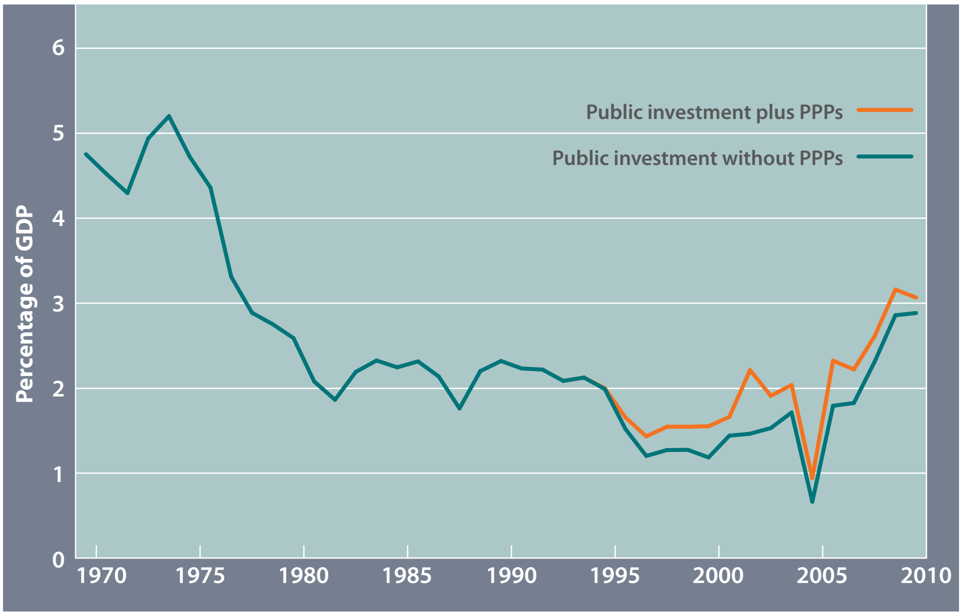
1.1.3 SIGNIFICANT INVESTMENT NEEDS

Significant investments are needed to renew infrastructure, to meet growing demand, to meet the UK's emissions reduction commitments, to ensure secure supplies and to maintain a competitive economy.

Significant levels of investment are needed to address the challenges of the ageing infrastructure, growing demand, and climate change. Over the next 5 years, there are £250 billion of planned investments in infrastructure (HM Treasury and Infrastructure UK, 2011). Whilst historically the UK has a strong record of investment in infrastructure, the past several decades have seen uncoordinated, incremental, and inefficient investments (HM Treasury and Infrastructure UK, 2010a). Indeed, in the last 30 years the investment in infrastructure as a percentage of GDP has reduced significantly (Figure 1).

Further, maintaining and strengthening NI standards designed to protect and improve environmental quality implies an on-going programme of investment. The energy sector alone for example requires an investment of approximately £200 billion between now and 2020 (BIS, 2011c). The Large Combustion Plant Directive (LCPD) puts in place further measures to reduce acidification, ground level ozone and particles throughout Europe by controlling emissions of sulphur dioxide (SO_2) and nitrogen oxides (NOx) and dust (particulate matter (PM)) from large combustion plants (LCPs) in power stations, petroleum refineries and other facilities with a thermal input of 50 MW or more.

Figure 1: Public Investment in the UK in per cent of GDP, updated by the authors (Blanc-Brude *et al.*, 2007).

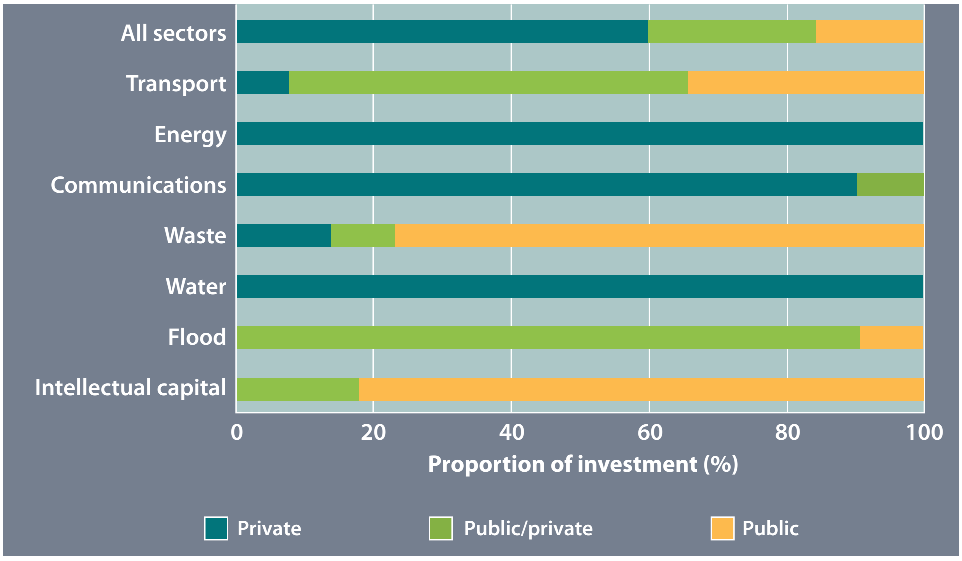


1.1.4 ATTRACTING INVESTMENT FOR INFRASTRUCTURE IN A COMPETITIVE GLOBAL MARKET

There is a significant need for private investment into infrastructure in the UK. The National Infrastructure Plan (NIP) 2011 states that nearly two thirds of expected investment between 2011 and 2015 is expected to be privately funded (Figure 2). In order to attract these investments in an increasingly competitive global environment, it is essential to have a coherent long term national plan for infrastructure and a stable policy and regulatory framework.

However, there are particular challenges with this long term approach, for example, risk-conscious investors could be discouraged from investing in infrastructure associated with a low-carbon economy (i.e. green infrastructure), since the economic viability of such investments relies heavily on long term policies. Further, investments in technologies such as offshore wind are considered higher risk as these infrastructure assets lack a credible investment performance track record in this country, and have high transaction costs as a result of expensive processes (e.g. feasibility assessments, mergers and acquisitions (M&As), and due diligences). This can further serve to discourage investors.

Figure 2. Source of funding for infrastructure investments Source: HM Treasury estimates, based on investment to 2015 and beyond. (HM Treasury and Infrastructure UK, 2011).



1.2 INVESTMENT FOR ECONOMIC GROWTH

Investments for a reliable and resilient NI facilitate economic competiveness, provide a competitive advantage, and positively impact growth. In many ways, infrastructure defines the boundaries of national economic productivity. It is an often-cited key ingredient for a nation's economic competiveness (Urban Land Institute and Ernst and Young, 2011). The World Economic Forum (WEF) for example lists infrastructure as the second 'pillar'[3] in its Global Competitiveness Index, a measure of national competitiveness (WEF, 2011a).

Investments in increasing the resilience of infrastructure against the impacts of climate variability and change can serve as a competitive international advantage. Public investments in infrastructure generally have positive impact on economic growth, and there is a strong positive relationship between the growth rates of public capital and GDP (Figure 3, overleaf).

3 WEF uses 12 'pillars of competitiveness' in the Global Competiveness Index. These include: (1) institutions, (2) infrastructure, (3) macroeconomic environment, (4) health and primary education, (5) higher education and training, (6) goods market efficiency, (7) labour market efficiency, (8) financial market development, (9) technological readiness, (10) market size, (11) business sophistication, and (12) innovation.

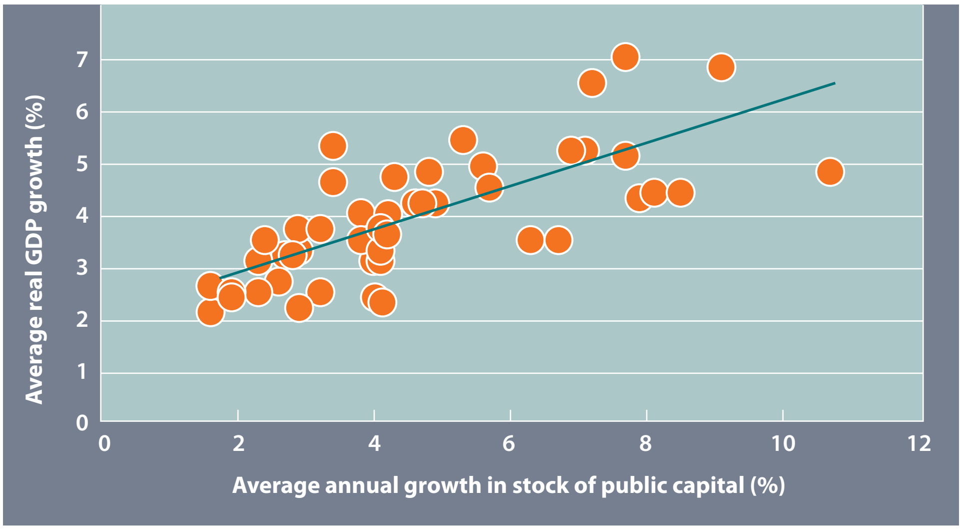


Figure 3: Relationship between growth and capital stock increase. Modified, as produced in Arslanalp *et al.* (2011). Sources: Heston, Summers, and Aten (2006); Kamps (2006); and authors' calculations. Note: The data are for 48 advanced and developing countries between 1960 and 2001 (Arslanalp *et al.*, 2011).

It has been extensively argued that the poor state of the UK's infrastructure is the main reason that could discourage foreign investment within the UK (Helm, 2009). Helm observed a link between the state of the UK's infrastructure and economy. Eddington (2006) (and Helm) asserted that public investments in rail and road transportation have major productivity impacts. Crafts (2009) further supports Eddington and Helm in showing the link between productivity benefits and investing in infrastructure. Although the WEF's recent ranking of the UK's infrastructure would suggest that it is in a comparatively good state, the WEF's measurement of infrastructure quality is subjective and seems to be subject to volatility that is out of proportion with feasible year-on-year changes in infrastructure provision: the UK's ranking changed from 20th in the 2009–2010 report to 6th (out of 142) in the 2011–2012 report on global competiveness.

Economic benefits of infrastructure provision

There has been extensive work showing the relationship between public investment in infrastructure and economic growth, particularly by US scholars such as Aschauer (1989), Munnell (1992), Gramlich (1994), and Lau and Sin (1997). Aschauer focused on the output elasticity of public spending on capital projects such as streets, public sector buildings and utility infrastructure. He concluded that that the change in private sector output for a unit of public sector investment ranges from 0.38 to 0.56 (Aschauer, 1989). Aschauer's claims of such a high elasticity of output were contested by other scholars such as Munnell and Gramlich. Munnell accepted that the impact of infrastructure investment on economic growth is statistically significant (her estimate of the elasticity of output was 0.30). However, she warned against the bias which may occur due to reverse causality when economic growth may cause or encourage investment in infrastructure. Thus, Munnell argued that cumulated results of economic growth and output cannot be used to guide government spending as these results do not account the effects of reverse causalities. She emphasised cost benefit analysis of specific projects may be undertaken in order to ensure intelligent decision making in public investments in infrastructure (Munnell, 1992). Gramlich further supports Munnell's argument by suggesting the need to invest in optimal stock of infrastructure instead of increasing the expenditure based on these aggregate economic growth results alone. Gramlich rests his argument on the bias which occurs due to the narrow definition of public investment in infrastructure (often implied as infrastructure stock). Although the relationship between 'economic growth' and 'investment in infrastructure' is statistically significant as claimed by Aschauer, there needs to be clarity when defining such investment; Gramlich argues that more evidence is needed to understand what type of investment in infrastructure is responsible for this growth, since investments in R&D, infrastructure capital, human capital, etc. may be responsible for actual growth but may be neglected in some definitions of investment (Gramlich, 1994). These biases due to narrow definitions and reverse causalities were rectified within the econometric analysis by Lau and Shin who came out with lower margins where elasticity of output of public spending in infrastructure were calculated as 0.11 (Lau and Sin, 1997). Although all works have highlighted the significant relationship between public infrastructure investment and economic growth, some scholars such as Gramlich and Munnell warn that public spending decisions should be wary of these blanket results and decisions should be made on a case by case basis.

A typical approach to identifying the contribution of various factors to economic growth, is to estimate a production function that seeks to explain economic growth in terms of the relative contributions of labour, capital etc. Égert, Kozluk and Sutherland (2009) argue this approach by including infrastructure as a separate growth factor in their analysis of OECD countries. They thus seek to identify the contribution of infrastructure investment to economic growth relative to 'conventional' investment. This framework is not only able to comment on whether infrastructure investment contributes to economic growth, but also how the contribution of infrastructure investment compares to other forms of investment (i.e. whether there might be evidence of over-or under-investment in infrastructure in some countries). In this context, over-investment suggests that a country is utilising its infrastructure inefficiently and resources may in fact be better spent on other forms of capital that yield greater returns in terms of economic growth and vice versa.

The ITRC has begun to apply the approach in Égert, Kozluk and Sutherland (2009), which used OECD data, to European data from Eurostat, using similar indicators of physical infrastructure. Early findings corroborate the OECD results for road and rail: investment in these infrastructure types yields higher economic growth than investment in other non-infrastructure assets. The magnitudes for road and rail are similar to the OECD estimates. Similarly, electricity generation capacity has a positive effect on economic growth; in this case, our early estimates suggest a contribution to economic growth comparable to that of road and higher than the OECD estimates. Like the OECD study, the ITRC team finds the contributions of motorways and telecommunications to be less conclusive. The ITRC intends to develop the empirical analysis to better understand the role of infrastructure in economic growth. As in the OECD study, the ITRC finds substantial heterogeneity across different countries and types of infrastructure in the contribution of infrastructure to economic growth. Future work will provide greater insight into these relationships.

1.3 RECENT DEVELOPMENTS IN NI PROVISION IN THE UK

The UK has established new supporting institutions to begin to address infrastructure challenges identified in recent reports, and attract private investment.

Over the past several years, there has been an increased focus on infrastructure in the UK. The Council for Science and Technology report on national infrastructure in the UK (CST, 2009) identified significant vulnerabilities, capacity limitations and a number of national infrastructure components nearing the end of their useful life. It also highlighted serious fragmentation in the arrangements for infrastructure provision in the UK. Each year the Institution of Civil Engineering (ICE) publishes a State of the Nation report (ICE, 2010a) that includes a grading of infrastructure sectors in the UK. The ICE's 2009 report on Defending Critical Infrastructure (ICE, 2009) emphasised the need for long term strategic planning. Further, Defra's 2011 report on a Climate resilient infrastructure (Defra, 2011a) makes significant steps towards identifying key risks and actions to prepare for the impacts of a changing climate in the UK.

The government has made proactive steps towards addressing many of the aforementioned challenges facing NI. The coalition government's Plan for Growth (BIS and HM Treasury, 2011) states that radical changes to the planning system will include fast-tracking major infrastructure projects. Additionally, in April 2011 the Government published binding principles of economic regulation to provide greater long term certainty for investment in UK infrastructure (BIS, 2011b). The reduction of uncertainty in policy and regulation can further assist in attracting private investments.

The UK is one of the first countries to establish a Green Investment Bank designed to work in close coordination with the government objectives and fulfil the dual tasks of transitioning to green infrastructure as well as earning returns from investments. The Green Investment Bank is intended to accelerate funding from the private sector and help address market uncertainties by providing risk mitigation products and innovative financial recipes alongside investment capital (BIS, 2011c). The government has committed around £3 billion until 2015 to support initial green investments.

Infrastructure UK and the National Infrastructure Plan

In 2009, Infrastructure UK was formed as a unit within the Treasury with three objectives (HM Treasury and Infrastructure UK, 2010b):

- enabling long term investment;
- developing effective long term plans and priorities; and
- improving delivery.

UK's **National Infrastructure Plan (NIP) 2010** (HM Treasury and Infrastructure UK, 2010a) identified priorities for infrastructure provision and set in place a number of actions needed to address those priorities. It emphasised the necessity for government to produce such a holistic plan that is able to capture dependencies between sectors, and balance requirements for maintenance, resilience, and renewal of existing infrastructure.

The **National Infrastructure Plan (NIP) 2011** (HM Treasury and Infrastructure UK, 2011) sets out a new strategy for meeting infrastructure needs in the UK comprised of three elements: (1) a medium-term cross-sectoral plan with a pipeline of infrastructure projects, (2) mobilisation of financing through the coordination of private and public investments, and (3) a new Cabinet Committee that will provide leadership in ensuring the infrastructure plan is delivered efficiently.

The plan identifies a pipeline of over 500 infrastructure projects (over three-quarters of which are for energy and transport) to 2015 and beyond. Most of these projects are major programmes (e.g. highways, rail, nuclear, offshore wind and broadband), although there are also individual projects identified due to their size, complexity, or importance to the economy.

Further, the NIP 2011 outlines new steps taken by government to open new sources of finance, including attracting new investors (e.g. signing the Memorandum of Understanding with two groups of UK pension fund, to support investment), exploring new sources of revenue for investment (e.g. tolling), and the use of guarantees to accommodate certain investment risks in major new projects.

These recent developments begin to build an important foundation for addressing the pressing challenges of NI. However, NI still faces significant challenges, particularly in the long term cross-sectoral planning.

1.4 CHALLENGES IN LONG TERM PLANNING OF NI PROVISION

Whilst a long term view is essential in the planning of NI, development of a long term strategy is challenging because of the uncertainty in the long term and because of the complexity of possible pathways for future infrastructure provision

It is essential to take a long term view in planning for the replacement infrastructure nearing the end of its life, and for the required additional capacity to meet increasing demands (HM Treasury and Infrastructure UK, 2010b). New infrastructure often has a long lifetime (50–100 years (Defra, 2011a)), thus, present and near-term investments will define the infrastructure of the future.

Whilst a long term view helps ensure new NI will meet current and future demand, anticipating future demand is challenging due to the high degree of uncertainty in the long term (HM Treasury and Infrastructure UK, 2010b). Moreover, infrastructure provision can encourage patterns of development and land use that become practically irreversible. Choices about technologies can lock in patterns of behaviour and economic activity. Complex interdependencies between infrastructure sectors intensify the uncertainty in the long term planning of infrastructure. Hence, when predicting future demand for a given infrastructure sector, the demands from other sectors must be considered (e.g. the need for transportation services to provide fuel sources to the energy sector, or the necessity of energy in the ICT sector). Thus, evaluating the demand for a given sector in the long term requires a coordinated planning effort across infrastructure sectors to balance these dependencies.

The effects of climate change complicate the planning process. The long term impacts of climate change can amplify interdependency risks over time, and thus should be considered in the adaptation of infrastructure in the UK (URS, 2010). During the floods in June 2007, for example, there were concerns that a breach of the Ulley reservoir's dam would result in the loss of high voltage power lines and the flooding of a regional power substation that supplied electricity to all of Sheffield (Defra, 2011a). While, fortunately, this breach did not occur, risks of this kind will likely increase with climate change. As there are significant uncertainties in both the scale and timing of these climate impacts (Defra, 2011a) on infrastructure, planning appropriately for a resilient infrastructure is challenging.

In the context of this range of uncertainties, the notion that a unique and comprehensive plan for infrastructure provision could be developed is obviously unrealistic. In many respects, individual utility companies and investors are best positioned to assess opportunities and risks and adapt their strategies on an on-going basis. However, given the long term nature of infrastructure provision and the complex inter-sectoral interdependencies, it is necessary to define broad directions of travel. A strategic direction is needed to ensure that long term investment is forthcoming and to guard against the possibilities of inconsistencies between sectors and systemic failures. Whilst the need for such a strategic approach is already acknowledged; for example in the CST report (CST, 2009) and the ICE's advice on the 2011 National Infrastructure Plan (ICE, 2011), such a strategy does not yet exist.

1.5 TOWARDS AN INTEGRATED ASSESSMENT OF NATIONAL INFRASTRUCTURE PROVISION

The legacy of sector-based planning combined with uncertainty in the long term, challenge the development of integrated assessments.

If the process of transforming national infrastructure is to take place efficiently, whilst also minimizing the associated risks, it will need to be underpinned by a long term, cross-sectoral approach to understanding national infrastructure performance under a range of possible futures. The 'systems of systems' analysis that must form the basis for such a strategic approach does not yet exist. (Details of alternative methods of long term futures analysis are given in Annex A.)

A 'system of systems' approach would build confidence that infrastructure capacity and demand can be efficiently matched whilst avoiding risks of failure or unforeseen side-effects. It would assist in unlocking performance gains (including sustainability) by selecting sector-specific infrastructure that are in the context of a cross-sectoral strategy. Further, by focusing on the long term, it would assist in the prioritisation of short term and long term investment requirements. Thus, it could serve to increase the efficient use of resources by appropriately targeting investments on key needs. Additionally, it could provide finance and workload continuity, and avoid 'stranded assets'. Such a coherent, integrated plan would provide the basis for consistent regulation and further serve to attract the necessary private investments amidst the competitive global market.

1.6 THE UK INFRASTRUCTURE TRANSITIONS RESEARCH CONSORTIUM

The ITRC will deliver the theoretical research, models and practical decision support tools to enable strategic analysis and planning of a national infrastructure system fit for the 21st century.

The aim of the UK Infrastructure Transitions Research Consortium is to develop and demonstrate a new generation of system simulation models and tools to inform analysis, planning and design of national infrastructure. The research programme is dealing with energy, transport, water, waste and ICT systems in an integrated way, paying particular attention to their interdependencies. The modelling and simulation techniques that the ITRC are developing will enable the future performance of these systems to be better understood and different strategies for NI provision to be tested in a virtual environment. These NI strategies will be assessed with respect to a range of metrics, such as reliability, security of supply, cost, carbon emissions and flexibility to demographic and climate change.

The ITRC research programme is structured around four major challenges dealing with (1) balancing capacity and demand over the long term, (2) planning for resiliency against risk, (3) understanding the evolution of infrastructure with the economy and society, and (4) developing integrated strategies for NI provision.

Challenge 1: How can infrastructure capacity and demand be balanced in an uncertain future?

The ITRC will develop methods for modelling capacity, demand and interdependence in national infrastructure systems in a compatible way under a wide range of technological, socio-economic and climate futures. The ITRC will thereby provide the tools needed to identify robust strategies for sustainably balancing capacity and demand.

Challenge 2: What are the risks of infrastructure failure and how can we adapt national infrastructure to make it more resilient?

The ITRC will analyse the risks of interdependent infrastructure failure by establishing network models of national infrastructure and analysing the consequences of failure for people and the economy. Information on key vulnerabilities and risks will be used to identify ways of adapting infrastructure systems to reduce risks in future.

Challenge 3: How do infrastructure systems evolve and interact with society and the economy?

Starting with idealised simulations and working up to the national scale, the ITRC will develop new models of how infrastructure, society and the economy evolve in the long term. The ITRC will use the simulation models to demonstrate alternative long term futures for infrastructure provision and how they might be reached.

Challenge 4: What should the UK's strategy be for integrated provision of national infrastructure in the long term?

Working with the consortium's partners in government and industry, the ITRC will use our new methods to develop and test alternative strategies for Britain's national infrastructure, building an evidence-based case for a transition to sustainability. The ITRC will analyse the governance arrangements necessary to ensure that this transition is realisable in practice.

The ITRC is a consortium of 7 universities, led by the University of Oxford. The ITRC research programme began in January 2011 and will continue until the end of 2015. The research programme was designed in collaboration with 43 organisations in government, industry and the engineering institutions, including Infrastructure UK, and will continue to work closely with these organisations in order to maximise the benefits to industry and government.

Three cycles of analysis of the strategies for infrastructure provision will take place during the ITRC research programme, in order to inform NI planning. This report describes the first cycle of the analysis undertaken during the first year of the research programme, based on pre-existing datasets and models, to explore the scope of future NI challenges and to demonstrate new concepts in long term analysis of infrastructure systems.

The objectives of this Fast Track Analysis (FTA) have been two-fold:

1. To develop and demonstrate key cross-sectoral concepts and approaches for analysis of NI systems.
2. To take an integrated overview of the five NI sectors in order to provide key cross-cutting insights.

The methodological perspective adopted in the FTA corresponds to ITRC Challenge 1 (i.e. the FTA explores long term capacity and demand for infrastructure services). The FTA yields a preliminary set of insights to inform Challenge 4, though it has not been possible to propose a definitive answer to this question. The FTA has served to promote early collaboration amongst the institutions in the ITRC and with our partners in industry and government.

1.7 STRUCTURE OF THIS REPORT

This report summarises the Fast Track Analysis undertaken in the first year of the ITRC.

Chapter 2 provides the basic framework developed by the ITRC to analyse change in interdependent NI systems and its application in a Fast Track Analysis (FTA). It also sets out the approach used in the FTA to determine key cross-sectoral drivers of changes, and to derive consistent scenarios for use in the assessment.

The starting point for analysis of future infrastructure provision is understanding the current system and trends that have been identified for the near term. Thus, **Chapter 3** provides a historical review of the governance of infrastructure. Next, **Chapter 4** reviews current infrastructure provision in each of the NI sectors (energy, transport, water, waste (comprising wastewater and solid waste), and ICT), along with a cross-cutting review of governance arrangements for NI in the UK.

Chapter 5 presents analysis of the future performance of NI in the context of our scenarios of change (identified in Chapter 2) and a small number of strategies for future infrastructure provision. In the FTA it was not feasible to exhaustively explore a wide range of strategies in each infrastructure sector. Three contrasting strategies are analysed them in the context of each of the five infrastructure sectors (Capacity-Intensive, Decentralisation, and Capacity-Constrained).

Chapter 6 provides a discussion on the initial analysis of the FTA. It also provides insight into how the results serve to prioritise issues for further analysis in the next four years of the ITRC. Background material is provided in on-line annexes, which are accessible with hyperlinks from the text.

2 A framework for analysis of change in interdependent infrastructure systems

This chapter provides the framework proposed by the ITRC to analyse change in interdependent National Infrastructure systems. A simplified version of this framework has been piloted in the Fast Track Analysis (FTA).

The framework is based around the analysis of demand for infrastructure services and the capacity of infrastructure systems to deliver those services now and in the future. Through this analysis, the ITRC seeks to

- develop new understanding of the performance expected from infrastructure systems in the long term, with respect to a range of metrics, and
- provide a platform to test strategic options for NI provision.

2.1 A SERVICE-BASED APPROACH TO INFRASTRUCTURE PROVISION

Analysis of National Infrastructure (NI) often begins with the hardware that constitutes infrastructure capital: power stations, highways, reservoirs, treatment works, pipes and cables. Starting with physical infrastructure is natural, as it is readily identifiable and represents the accumulated capital costs. However, such an approach distracts from the purpose of national infrastructure, which is to provide services to people and the economy. It also tends to emphasise the flux of resources through infrastructure networks (e.g. gas, water) and implies that increasing flux represents improved infrastructure provision (and perhaps also increased revenue for the utility providing that resource). Again, such a perspective is undesirable, because improved service provision (e.g. for heating or washing) need to not be accompanied by increased resource use.

A service-based perspective on infrastructure provision emphasises the *purpose* of infrastructure provision rather than the physical infrastructure and resource fluxes involved in providing infrastructure provision. The essential services that are considered are:

1. **Energy services,** enabling activities such as heating, lighting, and power for machines (e.g. transport);
2. **Transportation services** that provide mobility for people and goods between locations;

3. **Water supply services**, that provide fresh water to households and industry;
4. **Solid waste services**, for removing, treating and re-processing;
5. **Wastewater services**, providing a similar role for wastewater;
6. **Telecommunications services** that transmit information and enable digital communication.

In order to provide access to the services listed above, NI operates physical facilities and accompanying human systems to convert, store, and transmit *flow entities*. The term *flow entities* is used to encompass the broad range of physical and virtual commodities infrastructure deals with in order to deliver infrastructure services.

An Infrastructure service is the *provision* of an option for an *activity* by *operating* physical facilities and accompanying human systems to *convert*, *store* and *transmit flow* entities.

Table 2 provides examples of the processes necessary to provide infrastructure services (i.e. conversion, storage and transmission).

Table 2: Examples of the three processes necessary for infrastructure services

Process	Examples
***Conversion* takes place in:**	Electricity generation in various types of thermal, hydro, wind, solar and tidal facilities; Transport interchanges and trans-shipment facilities; Water and wastewater treatment facilities; desalination plants; Solid waste recovery and incineration; Telephone exchanges; routers and switching stations; transmitters and receivers; IT systems.
***Storage* takes place in:**	Gas, liquid and solid fuel stores; pumped storage; Depots; Reservoirs; Waste consolidation facilities; Data storage facilities.
***Transmission* takes place in:**	Electricity transmission and distribution networks; gas pipelines; Carriage of passengers and freight in road vehicles, trains, ships and aeroplanes; Water pipelines; Sewers; Wired and wireless communications.

As infrastructure services are at the centre of ITRC's approach, the definition of infrastructure follows from it. Thus, *infrastructure* is the collection of physical facilities and human systems that operate in a coordinated way to provide infrastructure services. This definition recognises that the human, communications, and mechanical systems that control the operation of fixed infrastructure facilities are essential elements of the system. It is important to note that a given service (e.g. space heating) may provide one of several alternative flow entities (e.g. gas or electricity) and that different services (e.g. freight and passenger transport) may be provided by the same physical facilities.

Infrastructure is the collection of all physical facilities and human systems that are operated in a coordinated way to provide ***infrastructure services*****.**

Consumers are entities that have demand for infrastructure services in order to go about their businesses or to enhance their wellbeing. **Providers** of infrastructure services (in the public and private sectors) commission and operate physical facilities and accompanying human systems (collectively 'infrastructure systems').[4] Finally, in the consumer–provider relationship, **externalities** are the people and the environment subject to the various positive and negative (e.g. pollution) effects of infrastructure services.

The disparities of where infrastructure facilities are located and where the services are utilised can be important to the service specification, since the availability of a service (e.g. fibre optic cable communications) does not necessarily mean that it is accessible to all consumers, some of whom may be geographically remote or disconnected from the network.

A number of benefits arise from the centrality of infrastructure services in the ITRC framework. For example, in the modelling and analysis it enables the possibility of substituting means of provision for a given infrastructure service (e.g. space heating may be provided by gas, liquid or solid fuel). Additionally, it naturally leads to the development of indicators of efficiency in terms of cost per unit of service provision, or energy input per unit of service provision, etc. Finally, it focuses the analysis on the aspects of infrastructure systems that have a direct effect on service provision (e.g. with respect to reliability) and the associated cost.

2.2 INFRASTRUCTURE CAPACITY AND DEMAND

NI systems can be described in terms of its *capacity* to supply infrastructure services and the *demand* for infrastructure services that it is expected to satisfy. Both capacity and demand vary in time and geographically. The five NI systems are interdependent in that they place demands upon one another, e.g. all of the systems require energy infrastructure to function. Another source of interdependence is that components of demand for different infrastructure services are correlated, e.g. increased temperatures imply increased demand for both water and energy (for cooling).

The capacity of infrastructure services defines the limits to and quantity of activities that it can sustain. The overall capacity for the supply of an infrastructure service is determined by necessary conversion, storage and transmission infrastructure operating as a system. Determining capacity involves analysis of these different systems elements and their interactions.

4 Providers of infrastructure services will usually also be consumers of infrastructure services, leading to interdependency between infrastructure services.

For services that are provided as discrete events (e.g. train departures or waste collections), the same aggregate capacity (e.g. in terms of passengers per hour or tonnes of waste removed per week) may be provided by services of different frequency. Thus, the time profile of capacity may be of interest.

Capacity of infrastructure services defines the extent and amount of activities that may be enabled.

Demand is determined by economic, demographic, behavioural and technological factors as well as by the existence of a specific infrastructure service. Further, demand may be modified by the capacity of the infrastructure (in particular in the transport sector, where capacity affects journey times and comfort). This is particularly true at times when demand may approach capacity limits. Pricing mechanisms and other policies may also serve to modify and reduce demand. Capacity and demand can also be inter-related via pricing mechanisms (e.g. tariffs to reduce peak demand in the energy sector). Thus, capacity and demand are not generally independent, though they may be treated as such in special cases.

Demand for infrastructure services is defined as the amount and extent of actions enabled by infrastructure services that consumers seek to conduct.

Under normal operating conditions, the supply of infrastructure services will be equal to or greater then demand. However, in the event that there is a reduction in capacity (e.g. due to planned maintenance or unplanned failure) or a spike in demand, then the supply may be less than the demand. The supply then, is the amount of activity that is actually enabled from the infrastructure service.

Supply of infrastructure services is defined as the amount and extent of actions that are actually enabled.

Insufficient capacity and supply, compared to demand, leads to inadequate service provision, e.g. in terms of traffic congestion or water shortages, on a range of different timescales. In the long term (i.e. over periods of decades) (i) the capacity of infrastructure systems will change due to deterioration, retirement and replacement of infrastructure and (ii) the demand will change due to, amongst other reasons, economic, demographic and behavioural factors. The interplay between these highly uncertain sets of processes of change will determine the balance between capacity and demand in future, alongside major policy drivers such as the need to decarbonise energy infrastructure.

2.3 THE PERFORMANCE OF INFRASTRUCTURE SERVICES

The performance of an infrastructure service is a multi-attribute construct. The first and necessary attribute is the availability of the service to satisfy given levels of customer demand at given locations, both at present and in the future. This availability derives from the existence of the necessary physical facilities and their operation. Table 3 lists the categories of performance used by the ITRC. These categories can be formed into multi-criteria sustainability metrics (e.g. economic benefit, service reliability, carbon emissions, etc.).

Table 3: Categories of performance measures with descriptions

Categories of performance	Description
Capacity utilization	Part of the available local capacity that is used for providing the actual level of supply.
Supply reliability	Probability of occurrence of a failure of supply to meet demand.
Indicators of cost and efficiency of infrastructure service provision	Measure the cost of infrastructure services from the perspective of (i) consumers and (ii) service providers. Costs for consumers will be in terms of units of service provision, as will many of the operating costs for service providers. These cost indicators are the reciprocal indicators of efficiency (service provision per unit cost input), so the same category also includes other efficiency indicators, notably service provision per unit of energy input. Service providers will also be interested in other cost elements, including annual maintenance costs and capital costs of new infrastructure provision.
Indicators of externalities of infrastructure service provision	Measure the extent of a number of 'side effects' of infrastructure service provision, such as greenhouse gas emissions and effluent water quality.

Past service performance can in principle be measured, though relevant observations may not exist in practice. Multiple metrics will be required in order to provide a perspective on the various aspects of performance listed in Table 3.

For planning purposes, the focus is upon present and future performance. Past performance is of relevance in so far as it provides evidence of present and future performance. Understanding future performance requires the employment of various versions of 'models', which may include extrapolations, projections and scenarios alongside more detailed computer models.

Future infrastructure performance is regarded to be a function of:

1. The performance of the existing infrastructure system;
2. Exogenous drivers of change in demand and capacity;
3. Future deliberate interventions in the system, e.g. investments in new capacity or policies to manage demand.

Thus, analysis of future infrastructure performance requires:

1. Knowledge of the existing infrastructure system;
2. Analysis of exogenous drivers of change and their associated uncertainties;
3. Analysis of alternative future strategies for infrastructure provision.

The following section deals with drivers of change, with Section 2.5 describing the primary drivers identified for the FTA. Section 2.6 describes our approach for analysis of uncertainties. Section 2.7 describes our approach to constructing infrastructure strategies.

2.4 DRIVERS OF CHANGE IN NI PERFORMANCE

Social, economic, environmental and technological changes in the future will have profound impacts upon the use and capacity of Great Britain's national infrastructure. While decision-makers naturally focus mainly on the short term effects of changes to policy, national infrastructure systems have a long lead-time to implement, are long-lived and can become locked-in due to associated land use change and economic development. They therefore require a long term policy analysis approach. Yet a long term perspective brings with it great uncertainties.

Table 4: Primary drivers by sector, including secondary drivers where relevant

Driver	Energy	Transport	Water	Waste water	Solid waste
Socio-economic					
Population growth	Primary	Primary	Primary	Primary	Primary
Household size			Primary	Secondary	
Economic growth	Primary	Primary	Secondary		Primary
Energy costs	Primary	Primary	Primary	Primary	Secondary
Environment/climate change					
Mean temperature change	Secondary		Primary		
Change in precipitation levels			Primary	Secondary	
Policy and technology options					
Centralised/decentralised decision making	Primary		Secondary		
Carbon emissions reduction targets	Primary	Secondary	Secondary	Secondary	Secondary
EU directives/National strategies and standards	Secondary	Secondary		Primary	Primary
Improved waste processing technologies			Secondary	Primary	Primary

The various factors influencing performance in five infrastructure sectors were reviewed. The methodology for this review is described in Annex B. Three broad driver themes have been defined: (1) Socio-economic (comprising Demographic and Economic drivers); (2) Environment/Climate Change; and (3) Policy and Technology Options (comprising Governance, Policy and Regulation, and Technology). Table 4 summarises the primary and secondary drivers identified in each sector. The fact that sectors share many of the same drivers is a key source of interdependence in infrastructure performance.

2.5 FAST TRACK ANALYSIS OF PRIMARY DRIVERS

From Table 4, it is evident that the key exogenous drivers common to most of the sectors are (1) population growth, (2) economic growth and (3) energy costs (Figure 10). Consequently, these three drivers were developed as scenarios across all sectors (where applicable) for the FTA. Each of these three primary drivers is discussed in more detail and quantified in the following sections.

Sector-specific issues can be as influential as these cross-cutting scenario dimensions, and include for:

- **Energy**: GHG emissions targets;
- **Water supply and wastewater**: the effects from climate change on water availability and quality; the requirements of the Water Framework Directive;
- **Solid waste**: EU directives and national standards.

These sector-specific drivers are considered in the context of the Transition Strategies in Section 5.1. Other key drivers which seem to be common at a secondary level include the levels of capital investment (again, positively linked to GDP), and carbon emissions reduction targets. Policies to mitigate the amount of CO_2 and other emissions are included in the FTA as part of the Decentralisation Transition Strategy (see Section 5.8.2).

2.5.1 POPULATION GROWTH SCENARIOS

The Office of National Statistics provides annual principal, low and high growth projections to 2033, and 5-year projections up to 2083 for population numbers in England, Scotland and Wales; the expected growth level in 2083 was then extended to 2100. These projections are summarised in Table 5, with a comparison for Great Britain of the three growth scenarios given in Figure 4. Further analyses of the demographic changes up to 2083 (the limit of the ONS projections) is given in Annex C.

In the Principal Scenario, the population of Great Britain increases from its current level of 60 million to 72 million by 2033, and to 84 million by 2083 (the limit of ONS projections). Extrapolating this growth trend, the population in 2100 for this scenario is forecast to be around 88 million. The analyses below are predominantly based on changes in population size, but a general overview of the likely characteristics of future populations is given here, and will become highly integrated to future analyses within the ITRC project.

Table 5: Projected population growth figures (Source to 2083: Office of National Statistics, www.ons.gov.uk)

Population (millions)		2025	2050	2075	2083	2100
England 2008 baseline: 51.46 million	Low	54.49	57.20	55.89	55.29	53.93
	Principal	57.97	65.66	72.24	74.42	79.12
	High	60.50	74.55	90.38	96.08	109.29
Scotland 2008 baseline: 5.17 million	Low	5.19	4.65	3.88	3.65	3.21
	Principal	5.47	5.57	5.52	5.52	5.51
	High	5.77	6.55	7.38	7.70	8.40
Wales 2008 baseline: 2.99 million	Low	3.09	2.96	2.68	2.58	2.37
	Principal	3.25	3.48	3.65	3.70	3.81
	High	3.41	4.04	4.75	5.01	5.60
Great Britain 2008 baseline: 59.62 million	Low	63.77	64.81	62.45	61.52	59.50
	Principal	66.68	74.71	81.41	83.64	88.45
	High	69.67	85.14	102.51	108.79	123.28

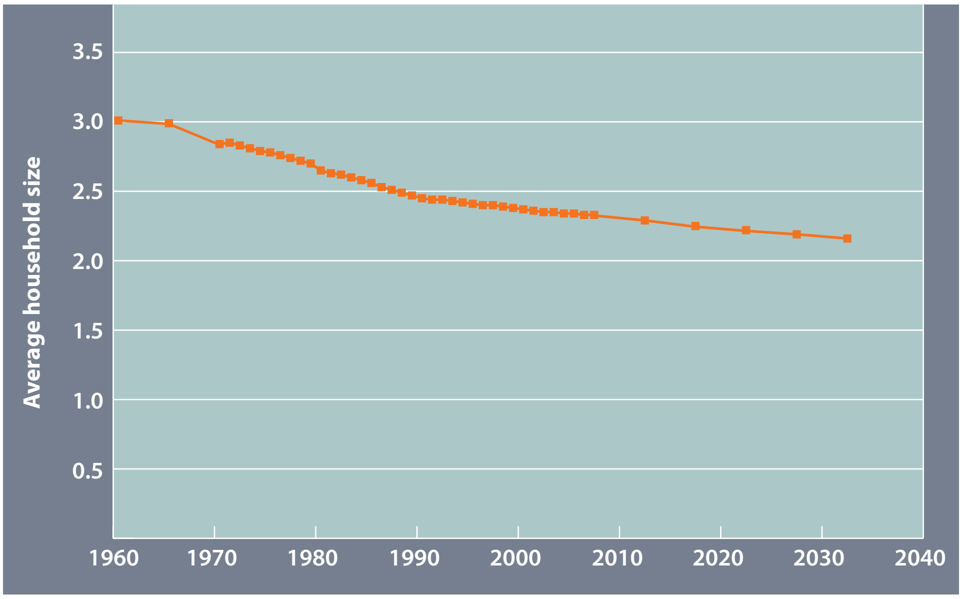
Figure 4: Great Britain population projections for the FTA scenarios. Data from the Office of National Statistics population projections (2008–2083), extended to 2100 by the authors. Population pyramids (for the principal projection) for 2008 and 2083. Data from the Office of National Statistics sub-national population projections (2008–2033), extended to 2083 by the authors.

For the principal projection, the future population will become progressively more elderly, and these increases are most significant amongst the very elderly, as can be seen in Figure 4. In 2008 there were 1.3 million people aged 85 and over; by 2033, this has more than doubled, and increases by a factor of 5 to 7.4 million by 2083. While elderly age groups are currently heavily skewed towards women (68% of people aged 85 or over are women), this ratio will approach parity with increasing life expectancy (to around 53% women over 85 in 2083). Demographic ageing will have a profound impact on health, social services and housing, but for other infrastructure services such as transport and ICT the impact may be less important.

The ethnic composition of the population will become increasingly diverse over time through a combination of on-going positive net immigration and the youthful age structure of minority groups, some of which are also maintaining fertility at levels significantly above replacement.

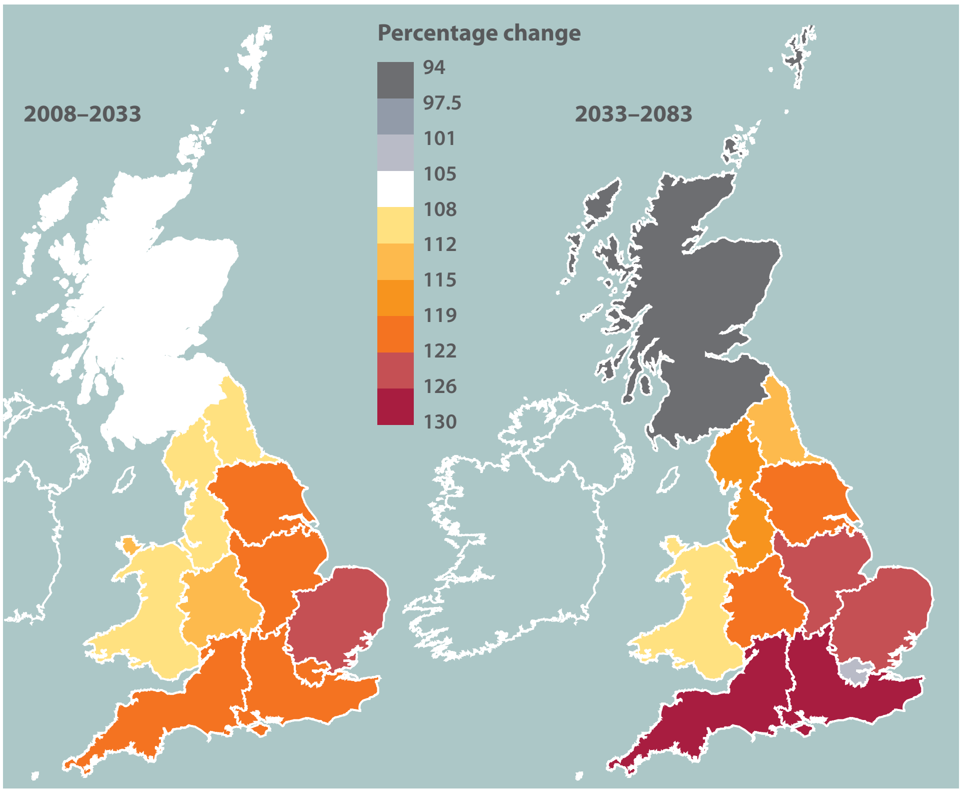
Recent trends show a significant decrease in average household size, falling from more than 3 persons per household (pph) in 1961 to its current level of 2.33 pph (see Figure 5). This is due, in part, to increasing participation rates in higher education and the formation of households at ever younger ages. At some point this process must be naturally limiting, and could go into reverse with the advent of the phenomenon of 'boomerang children' and larger household sizes amongst the ethnic minority groups. Nevertheless, ONS estimates a continued reduction in average household sizes down to 2.16 pph in the 25 year projection (to 2033). Continuation of this trend implies average household size below 2 pph by 2083.

Figure 5: Household size projections (source: ONS (2010a) Household Projections, United Kingdom, 1961–2033).



Demographic change is likely to remain region-dependent. The fastest growing regions are the south and east of England, while the north of England, Wales and Scotland, are expected to exhibit much lower growth rates. In the 25 year principal projection (2008–2033) the East, South-East, Yorkshire & Humberside, South West and East Midlands all have growth of 20% or more. The North, North-West and Scotland have growth of 10% or less. These trends are exacerbated over the 75 year projection period, with growth approaching 60% in the South West, whereas Scotland has close to zero growth (Figure 6, overleaf).

Figure 6: ITRC projected regional population changes (principal scenario 2008–2033 and 2033–2083). Source: Office of National Statistics sub-national population projections, extended to 2083 by the authors (see Annex C).



However, there are major uncertainties. Modelling demographic change depends on three primary sets of assumptions, regarding fertility, migration and life expectancy. For the high growth scenario, it is assumed that each of the individual components of change points to an acceleration of growth in the population (higher fertility, increasing life expectancy and more net migration). Conversely, in the low growth scenario each component is associated with reduced growth (lower fertility, restricted improvements in life expectancy and a marginal net migration balance). Further details on population growth composition are given in Annex C.

All of the demographic projections are subject to the influence of government policy and other external influences at local, national and global scales. For example, border controls or quotas could influence migration; while investment in medical research and health care facilities could affect life expectancy. Fertility rates are understood to be affected indirectly by the performance and outlook for the economy. Regional housing policy could strongly determine local demographics, which might ultimately be responsive to infrastructure effects such as the availability of water or congested transport networks. These feedbacks will be explored is later phases of the ITRC project.

2.5.2 GDP SCENARIOS

In their ongoing assessment of the growth of emerging countries, Pricewaterhouse Coopers (PwC) give estimates of future long term economic growth, based on (1) World Bank data for growth up until 2009, (2) PwC's short term projections for the years up until 2014 and (3) their long term growth assumptions (population growth and increases in human and physical infrastructure) for 2015–2050 (PWC, 2011). The projections of GDP growth up to 2050 is 2.3% per annum, which is consistent with historic trends (Hicks and Allen, 1999).

To provide ranges, upper and lower boundaries of +/- 0.7% per annum were selected based on historic trends. Around 0.3% of this can be accounted for by high and low growth in projected population and fossil fuel prices; the remainder reflects variations in world economic conditions. Hence, the three GDP scenarios are growth from 2008 as follows:

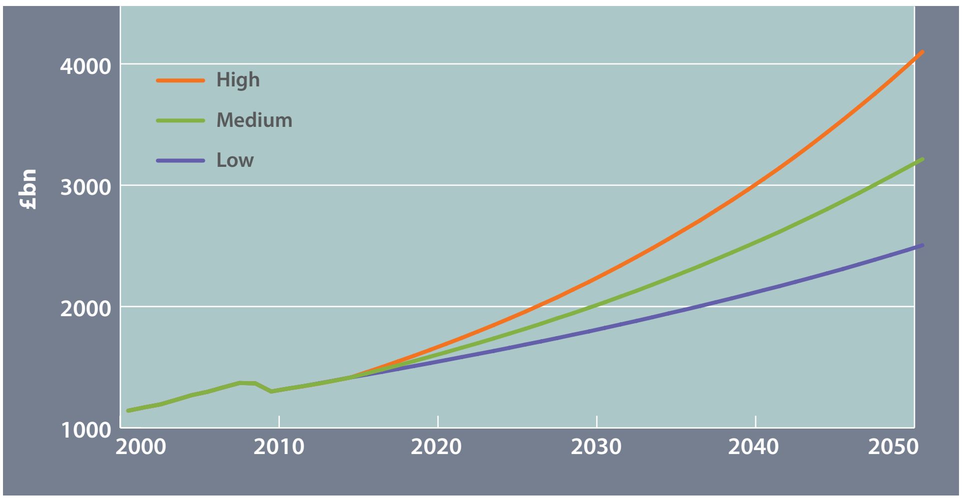
- Low economic growth: 1.6% per annum
- Medium economic growth: 2.3% per annum
- High economic growth: 3.0% per annum

Economic projections based on these growth scenarios have been made with an enhanced version of the MDM-E3 econometric model (Multisectoral Dynamic Model – Energy-Environment-Economy) are discussed in Annex D. MDM-E3 generates annual comprehensive forecasts for a number of variables that are of interest for the ITRC research programme, including UK and regional macroeconomic factors such as output, prices, exports, imports and employment at industry level (allowing identification of industry expenditure on electricity, gas and water services); household expenditure; sectoral investment. The model also forecasts UK-level energy demand and emissions, for 3 primary energy users and 22 final users, and 8 main fuel types.

The key exogenous inputs to the model are both UK-wide and global in scope. At a UK level they include regional population projections by age range; current and capital Government expenditure; tax rates and allowances; and availability of extractable resources (coal, oil, gas). The main source of data for these inputs is official UK statistics, published by the UK Office for National Statistics. At a global level the inputs are economic activity, prices and interest rates; fossil fuel prices; and commodity prices.

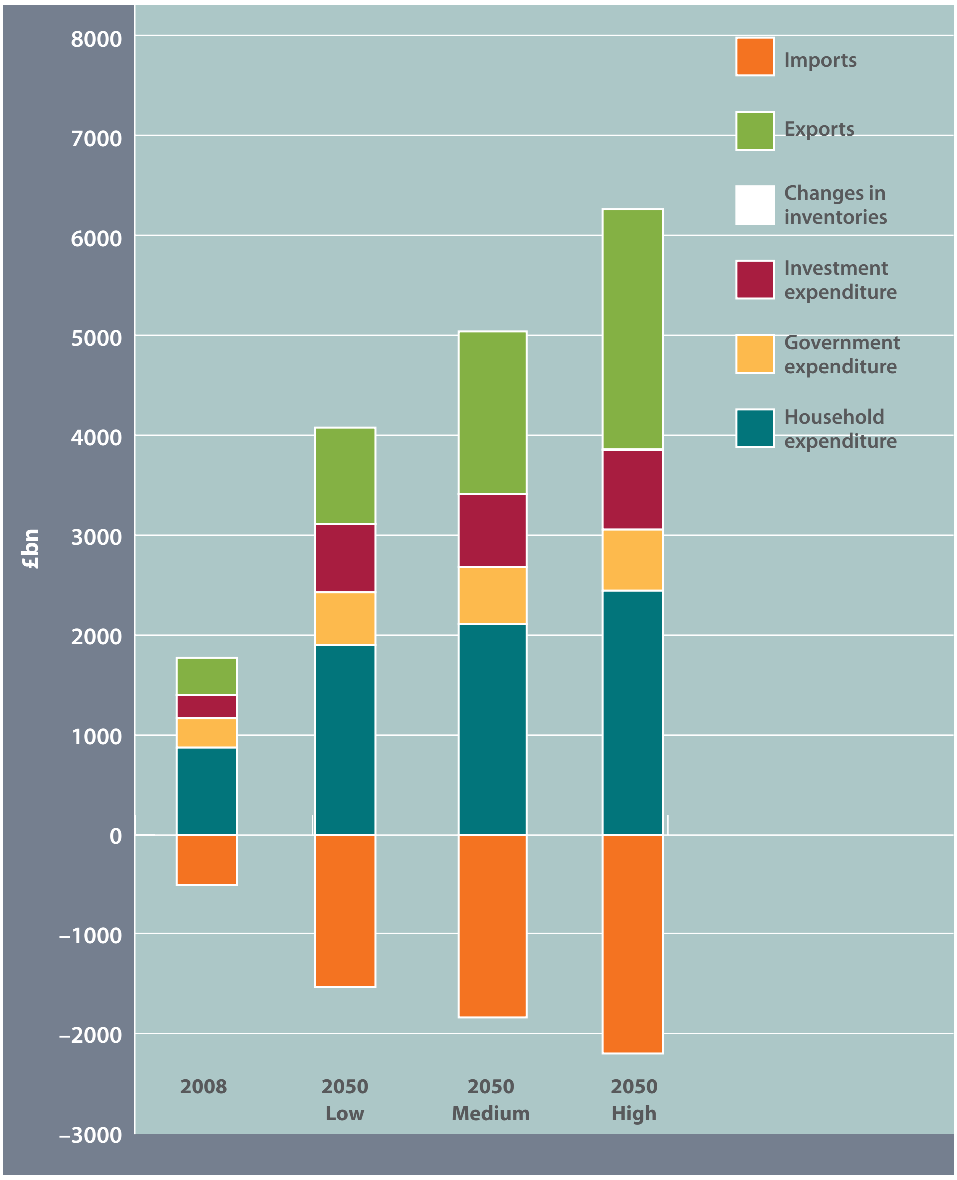
Figure 7 shows how GDP changes under each of the growth scenarios. The largest changes in GDP by component of final demand come from exports (owing to the changes in world economic activity). In the low and medium growth scenarios, the volume of imports continues to exceed the volume of exports. However, in the high growth scenario, the higher export growth leads to the UK becoming a net exporter of goods and services. Higher export demand must be met by higher UK production, and consequently the labour input must increase, leading to more wage income in the aggregate. Higher income drives higher household expenditure, including greater demand for imported goods and services. Demand for imported inputs to production also increases owing to higher production requirements in the UK.

Figure 7: FTA GDP growth scenarios for UK.



In MDM-E3, higher industry output leads to higher investment expenditure, implicitly to augment the capital stock in order to sustain higher production. Government investment expenditure also increases, to support greater provision of public services. Consequently, investment in 2050 is higher in the high growth scenario and lower in the low growth scenario, relative to the medium growth scenario, as shown in Figure 8.

Figure 8: UK GDP by component of final demand.



2.5.3 ENERGY COST SCENARIOS

Fossil fuel price assumptions are those used by the Committee for Climate Change (CCC) (2010), from figures produced by DECC (2010), based on an analysis of the international market and other forecasts. Since the ITRC baseline is 2008, these figures are for the projections published in 2009. The projections are presented in four different scenarios of future global fuel markets, but for the FTA, analyses are limited to the low (low global energy demand), central (reflecting timely investment and moderate demand) and high (reflecting high demand and producers' market power) scenarios. The resultant energy prices are:

- The range for gas prices in **2030** is 35p to 121p/therm, with a central price of 76p/therm.
- The range for coal prices in **2030** is £32 to £83/tonne, with a central price of £51/tonne.
- The range for oil prices in **2030** in these scenarios is $61 to $153/barrel, around a central price of $92/barrel.

Figure 9: Fossil fuel price assumptions to 2050 (from Committee on Climate Change (2010) 4th Carbon Budget – Reducing Emissions through the 2020s).

These DECC projections were produced up until 2030, and CCC assumes that these costs will remain largely similar up to 2050. For the FTA, it is assumed that costs are maintained up to 2100.

UK electricity wholesale prices are currently closely linked to national, and therefore global, gas prices as gas-fired power generation is the current long run marginal technology. In scenarios in which electricity is decarbonised over the period to 2050, it is expected that this linkage will increasingly be broken with electricity prices driven by the costs of low carbon technologies (renewables, fossil fuels with CCS and/or nuclear). Electricity costs therefore become an output of the infrastructure system rather than an input assumption.

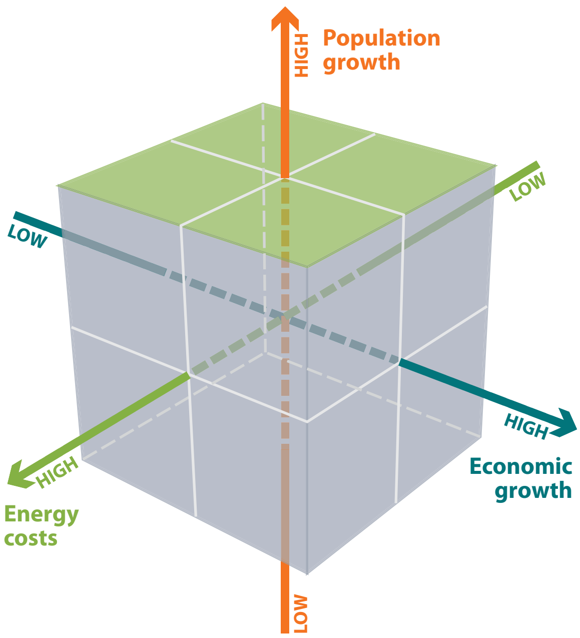
Similarly trends in transport fuel prices may diverge from oil prices as alternative fuels such as electricity and biofuels become more important.

In all cases the costs of fuels to distributed users are higher than those in wholesale markets due to the costs of distribution, i.e. of the relevant infrastructure. This is particularly important for gas and electricity, where final user prices exceed wholesale markets prices significantly.

2.6 EXPLORATION OF UNCERTAINTIES

While decision-makers naturally focus mainly on the short term effects of changes to policy, national infrastructure systems have a long lead-time to implement, are long-lived and can become locked-in due to associated land use change and economic development. They therefore require a long term policy analysis approach. Yet a long term perspective brings with it great uncertainties. It is important to understand how future plans may be vulnerable to such uncertainties and, where possible, to seek decisions that are robust to those uncertainties. One approach to long term policy analysis is described by Lempert *et al.* (2003), who develop a range of plausible scenarios and explore the performance of many alternative strategies with respect to that range of possible futures. In the work of Lempert *et al.*, the performance of a set of policy options is assessed with respect to a range of possible future conditions (Figure 10). The aim of exploring this space of possible future conditions is to identify vulnerabilities and opportunities, in order to seek strategies that are robust to uncertainty.

Figure 10: Scenario dimensions adopted in the FTA.



2.6.1 SCENARIO ANALYSIS IN THE FTA

For the FTA, a simplified approach has been adopted using just three scenarios. While this simplified approach using only three scenarios has disadvantages compared to the more comprehensive approach to be used subsequently in ITRC (Lempert *et al.*, 2003) it allows a proof of concept which also provides a broad overview of the likely impacts of the more important drivers of change. Subsequent work in the ITRC will involve more extensive exploration of the scenario space by Monte Carlo sampling and include further dimensions of uncertainty, beyond the three driver dimensions identified in this chapter.

These primary drivers are not independent – historically, energy costs and GDP have been negatively correlated, whilst GDP and population growth are positively correlated. These interdependencies have been incorporated in the three scenarios summarised in Table 6. The base year is 2008 for all the scenario parameters.

Table 6: Summary of ITRC FTA scenarios

Scenario	Population growth	Economic growth	Energy costs
Low growth	Low ONS projection	Low (1.6%)	High fossil fuel prices
Principal	Principal ONS projection	Projected (2.3%)	Central fossil fuel prices
High growth	High ONS projection	High (3.0%)	Low fossil fuel prices

2.7 STRATEGIES FOR INFRASTRUCTURE PROVISION

The aim of the ITRC is to provide methodologies and tools to test strategies for national infrastructure provision. These strategies may consist of many decisions, for example, public spending on infrastructure, arrangement to enable private investment, and tariffs or other regulatory arrangements to manage demand. A *transition* to a sustainable NI system is considered to be a process that leads, over a period of decades, to a system configuration (in terms of both capacity and demand) that performs well with respect to economic, social and environmental criteria. Our contention is that the scope for feasible transitions to sustainable infrastructure systems is much increased if the five NI systems are considered in an strategic, integrated way, rather than in isolation, thereby exploiting synergies and avoiding unintended interactions.

Of particular interest are policy decisions that result in a robust, resilient and reliable infrastructure system, which supports sustainable economic growth, helps meet environmental targets and satisfies both local and national requirements, while still offering value for money (HM Treasury and Infrastructure UK, 2010a). To assess this, a range of alternative policy and technology options or scenarios must be evaluated to make quantitative comparisons of the likely consequences of each alternative.

The process for generating the space of strategies takes into consideration varying levels of aggregation for different infrastructure subsystems. Strategies might consist of changing the physical infrastructure facilities and networks. However, they may also include regulations and taxes that provide incentives for private investors and consumers to change their behaviour or demand for infrastructure services. The ITRC approach proceeds with the generation of the strategy space in the same manner as developing the space of possible future conditions:

1. Identify all possible mechanisms for policy intervention within and across the different sectors.
2. Identify a set of (mostly) independent basic dimensions that allows a representation of all policy options. Those basic dimensions might consist of scalar choices or a finite set of distinct options.
3. Construct the overall strategy for a single sector by sampling the basic representation of the entire strategy space.

Given the uncertainties inherent in models of capacity and demand, predictions that may be made about the likelihood of any given strategy to yield a sustainable outcome will be highly uncertain. Moreover, the broad aim of sustainability is reflected in multiple, and sometimes conflicting, objectives. Under the circumstances, it would be unrealistic to suppose that an *optimal* strategy could be located – a wiser approach is to identify strategies that perform acceptably well under a wide range of possible future conditions and against a set of sustainability metrics.

For the numerical evaluation of the impact of strategies on the performance of NI systems, the space of possible future conditions is represented formally and is sampled into a manageable, representative, subset of all possible future conditions. By evaluating the national infrastructure system performance for varying strategies and future conditions, the ITRC can identify robust strategies (Lempert, 2002) (i.e. strategies that perform well in multiple possible futures).

2.7.1 APPLICATION TO THE FTA

The FTA develops three illustrative transition strategies that comprise portfolios of sequenced sector-specific governance and technology options for NI at specific investment levels. These transition strategies are constructed to represent some of the boundaries of the decision space. Each transition strategy has goals that guide the individual selection of options in the portfolio.

In the FTA the construction of an alternative set of transition strategies has involved:

1. Defining key questions of interest to decision-makers.
2. Determining the essential ambition or aim of each question(s), which provides the goal(s) for transition strategies.
3. Clustering these aims to define three distinct transition strategies.
4. Using the clustered aims as goals to guide the selection of a subset of options for each transition strategy .

The three transition strategies for the FTA are Capacity-Intensive, Decentralisation, and Capacity-Constrained. These strategies are described in more detail in Chapter 5. These strategies enable the exploration of key questions and the multiple dimensions of associated aims. Whilst they have been selected to be divergent, they all start with current infrastructure systems, limiting the potential for radical change. Thus each of these strategies contains a legacy of today's infrastructure system, which is a key characteristic of NI.

After the construction of the transition strategies, the FTA has sought to interpret the strategy in the context of each sector and calculate the corresponding system performance. The results of this interpretation are presented graphically in Chapter 5.

2.8 SUMMARY

The analytical framework described in this chapter uses a systems approach. The UK national infrastructure is represented as a complex physical and socio-economic system that contains the five infrastructure sectors as subsystems. The capacity to supply infrastructure services and the demand for infrastructure services are properties of the infrastructure system that emerge for a given future projection of external variables that influence the system. This interest in emerging properties of the infrastructure system renders the framework a 'system of systems' analysis.

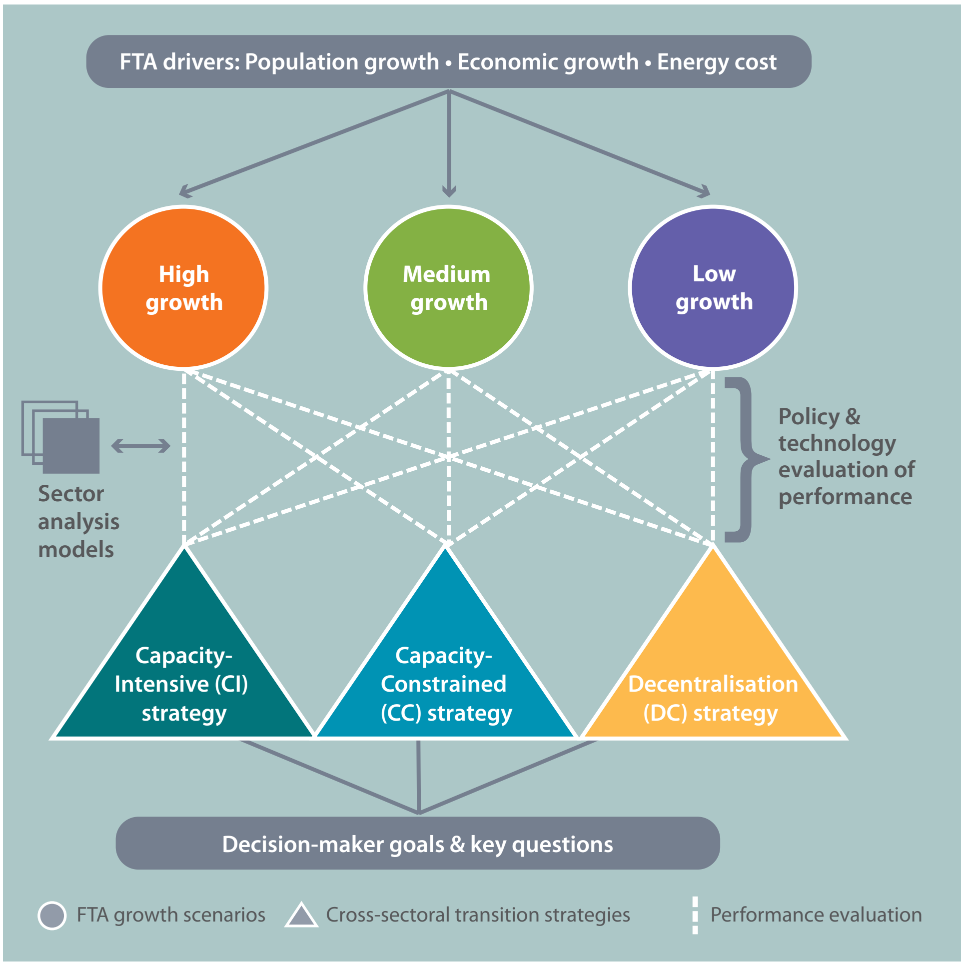


Figure 11: Overview of the FTA methods and framework.

Building from the core concepts in the ITRC approach outlined in this chapter, the FTA focuses on analysing the long term capacity and demand for infrastructure services. This requires the development of framework that links the sector models explained in Chapter 5 with appropriate scenarios and transition strategies, including allowance for sector interdependence, as illustrated in Figure 11 (previous page). In particular, the focus is to evaluate which policies and infrastructure options are *robust* (i.e. perform well) across multiple possible futures (Wollenberg *et al.*, 2000).

The six major steps for completing the FTA are summarised as follows:

1. *Identify* the **primary drivers** that impact the future demand and capacity of infrastructure services.
2. *Construct* **three possible futures** based on these drivers extending to 2100, representing high, medium (business as usual), and low growth scenarios.
3. Each infrastructure sector *projects* the **demand** across the three scenarios.
4. *Identify* key **performance metrics** for each infrastructure sector.
5. *Construct* **three transition strategies**, which are cross-sectoral strategic plans composed of sequenced sector-specific governance and technology options. These strategies are oriented toward distinct aims and specified levels of investment.
6. *Evaluate* the **cross-sectoral performance** (according to key metrics) of the three transition strategies across the three scenarios. Robust transition strategies perform well across the range of possible futures.

In this chapter we have identified the primary drivers and quantified the three possible futures (steps 1–2). Chapter 4 reviews the current infrastructure systems and identifies the key performance metrics (steps 3–4), then in Chapter 5 the three transition strategies of the FTA are detailed and evaluated for their sector-specific and cross-sectoral performances (steps 5–6).

3 Governance of infrastructure provision

Arrangements for governance of infrastructure provision have a profound influence on the nature of NI systems and the performance of the services that they provide. Therefore, before proceeding to the Fast Track Analysis of infrastructure systems, in this chapter we review the governance of infrastructure provision.

History shows that the physical components of infrastructure co-evolve with the associated institutions, policies, regulations, organisations and social norms (Foresight, 2008). Governance arrangements will shape the form of UK infrastructure provision in future. As a precursor to our analysis of future infrastructure provision, an analysis of the evolution of UK's governance arrangements in the UK has been carried out, in order to understand how and why they have developed. Section 3.2 then discusses the current governance arrangements. The analysis focuses on the complexity of these arrangements, the impact of regulation on investment and innovation, and the role of the European Union. Section 3.3 argues that there is an economic case to be made for State intervention to strengthen investment in infrastructure sectors. Section 3.4 considers interdependencies between sectors, and what these could mean for governance. Finally, Section 3.5 offers some tentative conclusions.

Before going any further, it is important to define 'governance', and to explain the approach used in the analysis of this essential aspect of infrastructure transitions. Governance is not the same as government. As Joseph Murphy has pointed out, these two concepts have very different meanings and scopes:

> "*Many scholars agree that politics has been transformed since the late 1980s by a shift from government to governance. Or, more modestly, that governance has emerged as a more important feature of government over this period. In these debates government is understood as centralised, hierarchical and perhaps technocratic, whereas governance involves power moving away from the centre and policy making through complex networks*" (Murphy, 2007).

In other words, governance encompasses much more than what governments do. It includes the networks of non-State institutions and actors at national, international and local levels that influence policy formulation and implementation (Smith *et al.*, 2005).

Another important introductory point is that governance arrangements cannot be analysed in isolation from other aspects of infrastructure. Thomas Hughes has illustrated this co-evolutionary process with respect to the history of electricity industries in several countries. It leads him to a broad definition of what these industries contain:

> "*Large-scale technology, such as electric light and power systems, incorporate not only technical and physical things such as generators, transformers and high-voltage transmission lines, but also utility companies, electrical manufacturers and reinforcing institutions such as regulatory agencies and laws…*" (Hughes, 1989).

This close relationship between the technical and non-technical aspects of infrastructure can lead to 'lock-in' and returns to scale. Lock-in has been analysed with respect to individual technologies (Arthur, 1989) and with respect to entire systems of service provision – such as the energy system (Unruh, 2000). Whilst lock-in can be useful if it delivers benefits such as reduced costs, it can also be a significant source of inertia which can make infrastructure systems difficult to change.

3.1 EVOLUTION OF UK NATIONAL INFRASTRUCTURE GOVERNANCE

The governance system for national infrastructure in the UK has incorporated local, national and EU level actors and institutions into different roles at different stages of its evolution. In most ITRC sectors, infrastructure governance has moved from a decentralised, locally governed, publicly and privately controlled system with dispersed ownership towards a nationally centralised, market focused governance model. The evolution of various institutions, rules, regulations, and ownership arrangements is accompanied by the emergence of multiple internal and external actors. The most prominent governance actors are government departments, economic regulators and environmental regulators, accompanied by emerging salience of EU institutions in environmental matters of the member states.

Despite experiencing some similar trends, individual infrastructure sectors have not evolved in the same way, or for the same reasons. A historical review of infrastructure governance (see Annex K of this report) provides evidence that the perceived political and economic importance of individual infrastructure sectors has influenced the level of investment and political attention received. This has fluctuated significantly over time (Marshall, 2010). Much of the existing infrastructure in the UK grew initially out of a municipal system of provision that can be traced back to the 19th century. At this time, ownership and infrastructure investment decisions were more decentralised and dispersed and Local Authorities were largely responsible for many infrastructure sectors. Private sector actors operated mainly in unregulated or partially regulated markets (Marshall, 2010). The post-Second World War period is marked by increased State control and national attention given to the infrastructure sectors. Nationalisation and an emphasis on integration was particularly important in energy and transportation, each of which received significant investment from the State. The main driver of central government's policy was the need to plan and finance investment to underpin economic growth and the expansion of service provision. Public investment tended to focus on capital-intensive, supply-side infrastructure – though in the 1970s and 1980s this investment was not sustained due to increasing pressure on public budgets and slower economic growth. The 1980s saw the privatisation of almost all ITRC sectors that were in State hands. This led to a different set of arrangements to the unregulated public/private governance system of the pre-1940s era.

It was accompanied by the establishment of independent economic and environmental regulatory bodies such as Ofgem, Ofwat, and the Environment Agency (Marshall, 2010). The 1980s privatisations were driven by a strong political belief within the Conservative government at the time that the State should not be centrally involved in infrastructure provision. This was reinforced by their belief that State owned infrastructure companies such as the Central Electricity Generating Board were inefficient. The financial position of the government was such that privatisation came as a relief because it allowed the state to meet national infrastructure investment needs without placing the burden on government budgets (Helm and Tindall, 2009). The phasing in of privatisation in different infrastructure sectors was accompanied by the growing influence of environmental quality agendas, encouraging expenditure capital intensive infrastructure in order to meet the requirements of EC directives (Marshall, 2010). In some cases, the UK was ahead of the game. For example, the shift to gas-fired power plants in the electricity sector, which largely occurred for economic and political reasons, also allowed the UK to meet some of its environmental obligations.

The post-2000 era has predominantly focussed on climate change concerns and the reduction of greenhouse gas (GHG) emissions, which subsequently led to the introduction of demand management measures in conjunction with low-carbon supply side solutions (MacKerron, 2009). This way, governance arrangements have evolved and adapted over the years in different forms, playing different roles in individual infrastructure sectors. A detailed overview of the evolution of infrastructure governance is provided in Annex K.

3.2 CURRENT GOVERNANCE ARRANGEMENTS FOR NATIONAL INFRASTRUCTURE PROVISION

The historical changes in national infrastructure provision show a pattern in which the governance system is regularly adapting to deal with legacies of past decisions and new challenges. A rising concern is whether the traditional governance approach of using intermittent solutions is fit for dealing with new challenges and much needed future transformations. Do they provide the right regulatory signals to large private investors in – and owners of – UK infrastructure sectors? Are they fit for purpose to deal with challenges such as climate change, demographic changes, growing interdependencies across sectors, and an unfavourable investment environment? This section elaborates the current governance arrangements, and their potential to deal with future transitions.

Most infrastructure in the UK is built, owned, and operated by the private sector and governed within a centralised regulatory regime. This regime is, in turn, shaped by a national and international policy landscape. The post-1980s privatisation of various sectors led to the introduction and restructuring of multiple actors performing various roles in the delivery, regulation, and finance of the national infrastructure, thus creating a complex and fragmented sectoral configuration (CST, 2009). The current funding, delivery, and regulatory mechanisms for UK infrastructure are summarised in Figure 12.

The national infrastructure mechanisms (Figure 12, overleaf) clearly show that a variety of actors are engaged in different roles in different sectors. The Council for Science and Technology report delineates these mechanisms into a few main categories (CST, 2009):

- Unregulated market driven consumer paid infrastructure, such as unregulated ports, airports, telecommunications, and partially energy – particularly power plants.
- Price regulated market driven infrastructure where government plays a pertinent role in price regulation, such as energy and regulated airports.

	Funding	Ownership/delivery	Regulation
Unregulated ariports and ports	Airport and port users	Private companies	Prices not regulated. Competition
Regulated airports	Consumers Government may support investment	Private companies	Prices are regulated
Energy	Consumers Some government incentives and funds from general taxation	Private companies (apart from older nuclear stations)	Prices set by market Network charges regulated (OfGem) Environment regulation via Environment Agency
Water	Consumers Regulators (OfWat) play an important role in type of investment	Private companies in England and Wales, public sector corporation in Scotland –Scottish Water	England and Wales: price and investment regulated (OfWat) Environmental: DWI, EA Scotland: similar structure
Network Rail	Passengers and general taxation	Private companies	DfT/rail regulator sets efficiency targets and prices for the company
Roads	General/local taxation Some tolls	Publically owned (some private toll roads)	Government controlled and regulated
Telecommunication	Consumers	Private companies	Competition Regulation by OfCom
Waste	England and Wales: PFI General and local taxes Scotland: Council and Scottish Government funding	England and Wales: Delivery – private companies Scotland: Councils and waste industry	England and Wales: Government/local authority EA/Defra or SEPA Scotland: Scottish Government and SEPA

Figure 12: Funding, ownership and regulation in GB infrastructure sectors. Source: Council for Science and Technology (2009) ; HM Treasury and Infrastructure UK (2010a).

- Price regulated infrastructure where the economic regulator plays an important role in setting prices and making investment decisions, such as the water, wastewater and drainage.
- Price regulated infrastructure where consumers and tax payers are the main funders and the regulator sets targets and prices, such as the national rail services.
- Government funded infrastructure such as roads.
- Private finance initiative as the main funding mechanism alongside tax payers' funds. The ownership is private while delivery is at a local authority level. Environmental regulations by EA and Defra: Waste sector.

These current arrangements germinated from the privatisation initiatives of the 1980s and have achieved the purpose for which they were designed, such as reducing the problems of financial deficiency, inefficiency, and a lack of competition. However, CST argues that the fragmented, complex, and disconnected nature of arrangements within and between various sectors is a matter of concern, especially when various infrastructure sectors have gradually become interdependent and the breakdown of one sector may directly influence the other (CST, 2009).

The regulatory regime is designed so that multiple regulating actors operate at different levels within each sector. For example, in water and energy, Ofwat and Ofgem act as economic regulators of the industry, the Drinking Water Inspectorate (DWI), Environment Agency (EA), as environmental regulators, and Consumer Council as the consumer rights regulators (for water). Furthermore, a set of European regulations also govern the economic development and environmental impacts of these sectors (see below). Each regulator works well within their ambits, negating the fact that future transitions will likely need more interconnection between regulators across sectors as well as within a sector. Defra's recent review of Ofwat highlights the disjointed role of various regulators which can cause wasteful duplication or conflict of interests, as all interested parties work in isolation. This silo-based governance approach within and between interdependent sectors may have detrimental ramifications for future transformations (Defra, 2011c).

One response to this complex governance picture could be to call for a simpler, more streamlined set of arrangements, with fewer institutions involved. On the other hand, there are advantages to the shift towards more diffuse governance arrangements that has occurred in most UK infrastructure sectors over the past two decades. In contrast to the former State-owned era, there is arguably more transparency now – and more checks and balances within the governance system. Amongst the advantages of independent economic and environmental regulation is more open scrutiny of the activities of infrastructure providers. This can, for example, guard against the 'gold plating' of assets and promote the efficient use of consumers' and taxpayers' money. So perhaps the challenge is not necessarily one of excessive complexity per se, instead there is a need to ensure that governance arrangements are sufficiently co-ordinated to provide clear incentives to infrastructure providers (e.g. Bauknecht, 2011), particularly to respond to longer term challenges such as climate change.

3.2.1 REGULATION AND INNOVATION

The current regulatory regime has now been in place for around 20 years, though it has evolved significantly since sector-specific economic regulators such as Ofwat were established, it was designed to ensure more efficient and cost-effective delivery of services to consumers, and of investments. It intended enhancing competition and to regulate those parts of infrastructure that were considered to be 'natural monopolies' via price controls. Although this regulatory regime was clearly designed to meet the needs of the time it was created, it is now questionable whether the regulatory system will be fit for dealing with emerging issues.

The economic regulation of monopoly networks (e.g. within energy or water) is presently based on the 'RPI-X' formula, which have proven to be useful for controlling prices and ensuring operational efficiency within the respective utilities. The RPI-X formula emerged from the Littlechild report on Regulation of Telecommunications, which gave recommendations for a price cap regulation for telecom companies in 1983 (Littlechild, 1983). This formula was subsequently adopted for the privatisation of all other utilities. The formula restricts the companies from increasing tariffs on monopoly services above the RPI-X percentage (Stern, 2003). In practice, this allows Ofwat and Ofgem to set limits on the changes that water and electricity network companies can make to their user billing each year. In the case of water, these price caps, or limits, are set every 5 years through the Periodic Review Process (PRP), the last set in 2009 (PRP09) for the Asset Management Period 4 (AMP4). Ofwat and Ofgem not only intend to induce efficiency and protect consumer interest through these regulations, they also encourage the companies to meet sustainability principles (BIS, 2011b).

Although these regulatory measures have benefitted consumers by reducing costs, they have also affected capital intensive investment into long term infrastructure development. This has been particularly true in the water sector, where the Periodic Review Process with a time span of 5 years is too frequent to provide the financial certainty and strategically coherent planning needed to develop long life and large-scale capital intensive infrastructure. The price limit regulation on water companies further discourages infrastructure expenditure as a part of operational expenditure (OPEX) because of the limited ability for network companies to pass on their costs to final consumers (House of Lords Science and Technology Committee, 2006).

The economic regulations, with high emphasis on companies' operational efficiency have been instrumental in solving the post-privatisation challenges of the past. However, present day challenges such as climate concerns, water and energy security, ageing infrastructure, interdependency between sectors, etc., all demand innovative investment responses. The existing system, and its emphasis on controlled consumer pricing and operational efficiency, does not incentivise investment in long term R&D and innovative solutions. These include low-carbon water treatment techniques, water leakage reduction, smarter electricity grids, etc. (Cave, 2009). A recent Ofwat review also reflect that regulators not only restrict the scale of R&D investments in the water sector (by considering R&D expenditure as a part of the operating expenses), but also the business planning of water companies, thus R&D expenditures and business planning for long term planning is fairly dependent on consumers ability to pay and Ofwat's judgement (Defra, 2011c).

However, recent initiatives have sprung up, encouraging companies to plan and think with a long term perspective, better coordinate with consumers and other regulators, and incentivise innovative solutions. Companies in the water sector have been requested to submit Strategic Direction Statements, which are long term (25 years) plans developed in consultation with water quality regulators (DWI/EA), and designed to inform business plans.

Also quadripartite groups have been formed comprising of companies, consumer forums, EA and DWI, to contribute to the price review process. Ofwat is also in the process of reforming its price limit regulation with the introduction of its Future Price Limit (FPL) project. FPL project aims to develop a framework for future price controls without compromising the core objectives of the water sector (Ofwat, 2011a). Ofgem has also introduced a new performance based model to set price controls called RIIO (Revenues= Incentives + Innovation + Outcomes). The new model incentivises the companies to gain higher revenue if they deliver network projects under budget. It also rewards the company to be innovative and offers motivation to expand Low Carbon Network Fund (LCNF) for the growth of smart grids (Ofgem, 2010b). These initiatives have been very recent and their impact on future transformations in various sectors is yet unknown (Defra, 2011c). Various companies affiliated to the water and energy sectors also use an R&D tax credit scheme to explore low carbon solutions in infrastructure. It is a tax relief incentive-based scheme which encourages large and small companies to invest in R&D. Water and energy companies may also use the scheme, however, the evidence is not very conspicuous.

3.2.2 THE ROLE OF THE EUROPEAN UNION

The EU has played an instrumental role in bringing the environment as a major policy agenda in planning for infrastructure in UK. Early regulations in the energy and water sector were woven around issues such as acid rain, water quality improvement, etc., that sought solutions such as use of gas desulphurisation equipment to reduce emissions from coal fired plants, and investing in water and wastewater treatment plants, etc. (MacKerron, 2009). However, since 2000, the emphasis has been placed on sustainable solutions for green growth and the transition towards a low carbon economy particularly stemming from EU emission reduction targets (HM Treasury and Infrastructure UK, 2010a). The EU regulations manifest in increased environmental commitment of the UK over the years. It is also worth mentioning that the UK has taken the lead (in EU), particularly in energy liberalisation and in setting targets for emission cuts with the Climate Change Act. Some key relevant directives that have been transposed and adapted in the UK are illustrated in Table 7.

Table 7: EU Directives that have been transposed and adapted in the UK

Sector	EU Directives	Actions at the national level
	EU emission reduction targets for 2020 – 20% less than 1990 levels.	Climate Change Act 2008 – requirement to cut GHG by 80% below 1990 levels by 2050, plus 5-yearly carbon budgets to limit emissions in the short to medium term.
Energy	EU Emission Trading Scheme (ETS) under EC directive 2003/87/EC, amended in 2009/29/EC. EU ETS is a Europe wide Cap and Trade scheme that aims to reduce GHG emissions through cleaner mechanisms and joint implementation.	• UK emissions trading scheme pilot pre-dated EU ETS, and provided early experience to inform it. • A Carbon Price Floor (CPF) will be introduced in the UK from April 2013 which will offer investors some stability in carbon prices – though will not lead to additional emissions savings.

Table 7 (continued)

Sector	EU Directives	Actions at the national level
Energy (cont.)	Renewable Directive (EC 2009/28) which included a 20% renewable target for 2020. EUs climate action and Renewable Energy package (Green package) EU third package.	• UK Renewable Energy roadmap: 15% of energy demand is to be met from renewable sources by 2020 (under RE Directive). • Roadmap intends to implement this by domestic action, supplemented by international trading between member states (e.g. of offshore wind power). • The EMR white paper 2011 proposes changes to renewable incentives (currently a 'Green Certificate' scheme known as the Renewables Obligation).
	EPBD Directive 2002/91/EC. Energy Performance of Buildings Directive (EPBD), and the Energy End-Use Efficiency and Energy Services Directive (ESD). New Energy efficiency directive 2011 designed to reduce consumption by 20% but it is not binding/mandatory for the moment.	Building regulations and Housing Act of UK aims to enhance energy efficiency in buildings through: • Labelling: Energy performance certificates. • Carbon calculation of buildings • Sustainable building codes. Green Deal: Energy efficiency retrofits in homes and businesses to be financed through energy bill savings.
Water	Urban Wastewater Directive. Bathing and drinking water directives. Water Framework directive, 2000/60/EC: Aim for an integrated system of water protection, improvement, and sustainable use through binding Environmental Quality Standards (EQS).	Water Environment Regulation 2003. River Basin Management Plans. Increased policy attention toward integrated water management. High level of investment in: • Water treatment plants. • Wastewater treatment plants.
Waste	EU Waste Framework Directive (amended in 2008), the EU landfill diversion directive (1999), effective in UK, 2002–2003. Requiring compliance with EU waste targets such as recycling and reduction of waste at landfills.	Landfill regulation, Landfill Allowance Trading Scheme (LATS), Landfill tax.

Table 7 (continued)

Sector	EU Directives	Actions at the national level
Transport	Air Quality Framework Directive and the Directive on Integrated Pollution Prevention and Control (IPPC). Designed to comply with the EU ambient air quality directive to control NOX and PM levels in the air.	Air Quality (England) Regulations 2000 which saw improvement in air quality of UK. Congestion charging (in London) and Low Emission Zones.
	Renewable Energy Directive and the Fuel Quality Directive.	Renewable Transport Fuel Obligation in the UK- in relation to uptake of biofuels in transportation.
	EU's New Car CO_2 Regulation.	UK targets to achieve 130 g CO_2/km as the fleet average for each car manufacturer for all new cars registered. 2011 Budget has also announced a freeze on company car tax for low CO_2 cars from April 2013.
	2009/33/EC Directive for promotion of clean and energy-efficient road transport vehicles.	CCC 4th carbon budget report (2010) have also translated the EU aims in its chapter on decarbonising surface transport suggesting improved efficiency of conventional vehicles, increased use of electric technology in both road and rail transport, and use of biofuels.

As a whole, EU regulations are major drivers in environmental improvement and carbon reduction initiatives at a European wide scale. However, these obligations have posed additional concerns, particularly high level of demand for capital investment in infrastructure and increased trade-off between policy objectives, thus requiring balanced strategic intervention at the national level.

Most European obligations have been met through capital intensive investments, manifested in improved air quality, reduction of waste, and drinking and bathing water quality improvement through investments in treatment plants, which was crucial for improving the environmental performance of infrastructure sectors. Future actions also demand for capital-intensive investments in low carbon infrastructure, renewable infrastructure, energy recovery infrastructure, etc. However, these obligations have had a limited translation into market reforms that promote the uptake of privately funded capital-intensive projects. In energy, some market reforms have been made to encourage the market uptake of investments, but in the highly capital intensive water and waste sectors, the EU influence on market reforms is practically absent.

Furthermore, many of these directives, although instrumental in meeting environmental commitments, pose a dual challenge when two policy objectives conflict with each other. For example, water and wastewater treatment or energy recovery from waste, etc. are highly energy intensive practises which may result in increased greenhouse gas emissions. This poses dual challenges for member states – for example energy recovery along with emissions reductions. These targets therefore may lead to inevitable trade-offs between objectives that need to be negotiated by stakeholders within governance systems.

3.3 THE ROLE OF GOVERNMENT IN INFRASTRUCTURE PROVISION

The privatisation and liberalisation of the UK's infrastructure sectors was intended to enhance competition and enable a more efficient approach to investment and innovation. However, the brief reflections on past and present infrastructure governance in the UK in this chapter have shown that the impacts have been mixed in practice.

There is an increasingly widespread view that more government intervention is required to boost investment in the UK's infrastructure – and that this investment will have positive economic impacts. This is a view that is now held by senior Ministers. In a recent speech to the London School of Economics, Deputy Prime Minister Nick Clegg MP argued that particular kinds of infrastructure investment should be favoured:

> "*Investment in infrastructure stimulates demand not overnight, but more quickly than many supply side measures. And it raises productivity well into the future too. … But it doesn't all support long term prosperity. You have to be ruthless, focusing on the investments that transform growth potential: transport, energy, digital communications. Roads and rail so manufacturers can transfer goods. Better broadband so small, high-tech companies can flourish. Renewable energy so low-carbon industry can too.*" (Clegg, 2011).

But what is the evidence that a significant government role is economically beneficial? Two main arguments reinforce the need to enhance government involvement in the UK's infrastructure, instead of leaving it to the private sector. The first argument builds around the salience of infrastructure networks as an economic and public good from an economic growth perspective. The economic importance of infrastructure has long been recognised in relation to the growth and development of a nation (Rodrik, 2007) (see Chapter 1). Infrastructure systems form the backbone of the economy due to their ability to enable entry into markets (e.g. transportation and ICT) and the importance of water and energy as factor inputs for both households and industries. The recognition that infrastructure networks form part of the economic backbone of a nation and are also an essential public good, means that achieving optimal investment requires sufficient public policy attention.

The second argument elaborates upon how the observed market and systems failure in providing infrastructure reinforces the need for government attention. The characteristics of infrastructure networks are such that a purely privatised system is plagued by market failures that may also result in system failures. For example, the large-scale of investment required for infrastructure improvement, the long term pay back periods on investments, etc., all make it difficult for markets to function as expected. Furthermore, market imperfections in the UK's infrastructure systems, such as information asymmetries and monopolistic competition, etc., have induced system failures such as underinvestment in non-traditional activities (e.g. green technologies) and inadequate investment in R&D and innovation. These market and systems failures are detrimental to the physical infrastructure of the UK and thus provide economic rationale for government intervention. A large amount of work has been done by scholars supporting the link between market failure and system failure as a rationale for policy interventions into market economies.

For example, Gregory Tassey emphasises that it becomes essential to bring policy changes in private markets when market imperfections cause underinvestment in infrastructure technology (Tassey, 1982). Edquist (2000) further illustrates the need to correct the markets equilibriums in sectors such as environment, social security, infrastructure, research and radical innovations, etc., by ensuring that market mechanisms are complemented by public sector intervention (Edquist, 2000). Scholars such as Dani Rodrik also mention that the introduction of non-traditional activities does not naturally germinate within a market system and may therefore require positive enforcement by government intervention. Rodrik also points to harmonising public and private actions by developing a strategic collaboration between the government and the private sector (Rodrik, 2007).

The combined evidence of infrastructure as an economic and public good and the market failures plaguing the UK's current system provides a strong case for envisioning a new, more concerted intervention by the government and synergy between government and the private sector.

3.4 INFRASTRUCTURE INTERDEPENDENCIES AND GOVERNANCE

The interdependencies between critical network infrastructures is acknowledged by a growing body of literature (Rinaldi *et al.*, 2001; CST, 2009; Buldyrev *et al.*, 2010). In the past, economic interdependencies between sectors, for example, transportation and energy in the 1940s and energy and water in the 1960s, were the main drivers for enhanced State attention in the UK. Perhaps now, the growing risks and uncertainties associated with interdependencies (e.g. the failure of the electricity network may cause a failure of transportation or water treatment processes) make it pertinent that the current governance system is able to address these interdependencies and harness opportunities associated with them. Buldyrev *et al.* term this as *catastrophic cascade of failures* in interdependent networks (Buldyrev *et al.*, 2010). The interdependency may also trigger an *inverse effect or trade-off* between sectors. For example, improvement in water quality due to use of water and wastewater treatment water technology may manifest in energy intensity, increase in GHG emissions, and energy security issues. However, besides risks and trade-offs, interdependency also creates *opportunities* that allow interdependent sectors to benefit from each other. For example, waste and wastewater produce energy; water efficiency may induce energy efficiency; or energy efficiency may reduce excessive usage of water for cooling purposes. This section of the chapter briefly discusses the extent to which infrastructure governance in the UK recognises interdependencies. It then uses examples from the water and energy sectors to show how governance can harness opportunities or constrain investments that cut across more than one infrastructure sector.

There is some evidence of cross-sectoral analysis within government – and attempts to work across different sectors. For example, Defra is leading the cross-sectoral Climate Change Risk Assessment that attempts to enhance the resilience of infrastructure sectors to future changes in the climate. Under the auspices of Infrastructure UK, the Engineering and Interdependency expert group has a specific remit to consider interdependencies. However, such initiatives do not focus on the governance implications of interdependencies per se. One forum which could do this is the Joint Regulatory Group (JRG) which includes senior representatives from all of the sector-specific economic regulators in the UK. However, minutes from JRG meetings give little evidence of attention to cross-sectoral issues.[5]

5 http://www.ofcom.org.uk/about/organisations-we-work-with/joint-regulators-group

Similarly, a recent Department of Business (BIS) report *Principles for economic regulation* includes only two short paragraphs on cross-sector working (BIS, 2011b). This section of the report focuses on developing common approaches by regulators. It is not concerned with identifying ways in which governance might need to change to deal more effectively with cross-sector synergies interdependencies which will be dealt with in future phases of the ITRC.

3.4.1 WATER AND ENERGY

Turning to a specific example, the water sector is heavily dependent on electricity for its processes such as pumping water and treating water and wastewater. Most water treatment technologies are highly energy intensive, for example, UV disinfection, desalination, etc. Water and wastewater sectors are currently responsible for 3% of energy usage in the UK (CST, 2009). Whilst the frequency of water shortages has reduced since privatisation, a combination of demographic and climate change, alongside EU regulations means that further effort will be required to ensure security of supply in the future (ASC, 2011). Alongside other supply-side measures, this resulted in the construction of the first desalination plant by Thames Water (in 2008), to cater to the peak demand of South of East of England. However, any further initiatives to develop desalination plants are under question, and on hold, due to objections to the energy intensity of the desalination technology (e.g. by former London Mayor, Ken Livingstone). On the other hand, the electricity sector is also a highly water-intensive sector requiring sufficient water supply for its cooling systems.

Despite such interdependencies, the regulatory system has evolved over the years in a fragmented manner, which discourages companies to harness the opportunities that exist amongst interdependent sectors (for example, the use of renewable energy for the water sector). The current system encourages investors to operate within their own spheres of activity (CST, 2009). For example, a recent Ofwat review has shown that the regulatory system prefers utility companies to stick to mainstream technologies such as hydro-generation, or CHP linked to sludge treatment instead of encouraging renewable energy in water and sewerage plants. Although Ofwat has allowed companies to take up renewable schemes in the 2009 Price Review process (PR09), the uptake is far less than the potential. Ofwat argues that they do not intend to discourage the water companies from promoting renewable energy. However, they will only allow the costs of investments in renewable energy to be recovered from consumers if such projects have natural synergies with their core business. If they do not, they are not considered to be part of the Regulated Capital Value (RCV) of the water company concerned. A recent report by Defra concludes that this acts as a financial barrier to the implementation of many potential renewable schemes (Defra, 2011c).

At the implementation level, some EU and UK actions have been instrumental in ensuring synergies between sectors. For example, the UK's Renewable Obligation (RO) scheme has encouraged water utility companies to opt for solutions that use electricity generated from renewable sources (in water distribution and treatment). Various utility companies have large hydropower schemes in place to generate electricity from dams and reservoirs (for example, United Utilities, a water company, has 11 hydropower projects). Many utility companies have also begun finding opportunities in low head hydro technologies.

Recent attention has also gone towards opportunities that exist within conjoint actions in relation to energy and water efficiency. According to a Defra study, the end use of water, particularly domestic water heating, accounts for 5.5% of UK's total GHG emissions and thus it is the most significant water related energy use (Defra, 2008; Rothausen and Conway, 2011). Despite this recognition, various regulations have largely focussed on building standards and codes for energy efficiency in homes, and little attention has been given towards efficiency in end use of water. As a result, discussions have sprung around promoting water efficiency measures through the Green Deal, for example, the eligibility of water efficiency measures under the retrofit (home improvement) finance available under Green deal (by the Energy Bill committee at the House of Commons) (House of Commons, 2010-2011). The committee sees a clear case of including hot water efficiency measures in the deal in order to save water and energy, however, cold water measures are seen as separate from energy efficiency realms of the scheme. NGOs such as Waterwise feel that even though various water efficiency measures are not included in the green financing scheme, they still could be recognised as a part of the holistic package where water companies can link up with energy companies during the retrofit process. In the past major barriers to such joint actions have been due to fragmentation of the regulatory authority, as observed in the case of partnerships between energy and water companies under CERT schemes (Waterwise, 2011). Nevertheless, multiple opportunities exist in these conjoined actions in water and energy measures and potential regulatory reform may allow joint partnerships between water and energy companies.

3.4.2 THE LOW CARBON NETWORK FUND

Another good example of a governance arrangement that cuts across more than one infrastructure sectors is the recently introduced Low Carbon Networks Fund (Ofgem, 2011a). It focuses on electricity network companies – specifically the distribution network operators (DNOs), and was introduced as part of Ofgem's 5th Distribution Price Control which runs from April 2010 and March 2015. Apart from energy (or more specifically, electricity), it has implications for at least two other ITRC sectors: ICTs and, in some cases, transport. Within the eligibility criteria for the Fund, there is an explicit requirement that projects should accelerate the development of a low carbon energy sector as defined by the previous government's Low Carbon Transition Plan (DECC, 2009; Ofgem, 2010a). Within this Plan, explicit reference is made to the need to adapt networks to facilitate electric vehicle charging and to use ICTs to become 'smarter' and more flexible.

The Fund allows up to £500m to be spent by projects led by DNOs – funds that can then be recovered from consumers via network charges. There are two tiers to the Fund. The first focuses on small projects, with a proportion of DNO costs recovered from consumers. Up to £80m is available over 5 years. Eleven projects have been registered in year 1. The second tier includes an annual competition for 'flagship' projects which are larger in size. A sum of £64m was allocated to four projects in year 1 (this is the maximum allowable expenditure each year). The competition for year 2 is underway, with six projects in contention for funding. The first round of successful tier 2 projects includes:

- Customer-led Network Revolution (CE Electric, £26.8m). Includes integration of smart meters and consumer technologies (e.g. electric vehicle charging points, solar PV panels) with network technologies. Partners include Durham University and British Gas.
- Low Carbon London – A Learning Journey (EDF Energy Networks, £24.3m). New network technologies in an urban setting. Partners include Logica and Imperial College.

- Low Carbon Hub (Central Networks, £2.8m). How technologies can increase the capacity of wind in rural networks, including new commercial arrangements.
- LV Network Templates for a Low-carbon Future (Western Power Distribution, £7.8m). Impact of demand side technologies on networks. Linked to existing Welsh Assembly and RWE power programmes.

Ofgem is evaluating the Fund as it progresses. It is much too early for a full ex-post evaluation of costs and benefits. Therefore, it is also too early to evaluate the extent to which the Fund has broken down some of the traditional barriers between sectors, and whether it has unlocked positive synergies – for example, by harnessing existing ICT investments to benefit the electricity sector. So far, a 'high level' review of year 1 has been carried out to examine the LCNF bidding and evaluation process (Ofgem, 2011a). Ofgem states that the cost benefit calculations carried out by those proposing projects were so different that they were hard to compare quantitatively. In future, there will be a requirement for a standardised assessment of costs and carbon emissions benefits against a 'base case' in which the project was not implemented.

3.5 CONCLUSIONS

The analysis of governance arrangements conducted in the FTA leads to a number of tentative conclusions:

1. The infrastructure sectors that are the focus of this report have governance arrangements that have developed over long periods of time, and do not follow a common pattern. One important way in which these arrangements differ is the relative importance of governance at different levels, i.e. at the European level, the national level and the local level. Taking local governance as an example, this is very significant in some sectors (e.g. waste), but almost non-existent in other sectors (e.g. energy). With respect to EU regulations, there are cases in which these have driven action in the UK (e.g. through the landfill tax which was a partial response to the Landfill Directive) and also cases in which the reverse is true (e.g. through the UK's early move into emissions trading and energy liberalisation).
2. There has been a general shift towards liberalisation, private provision and competition in infrastructure provision. The nature and extent of this varies, but in general this process has led to a more complex governance landscape in which national and local government has to negotiate with a range of other actors to effect change. Private companies now play a large role in all sectors, and in many cases these companies are multinationals rather than UK-owned. Furthermore, the implementation of policies and regulations is carried out by a range of agencies such as sectoral economic regulators (e.g. Ofwat) and the Environment Agency. There is significant debate about the extent to which the 'liberalisation project' is able to meet the current challenges facing these sectors.
3. This complexity of governance has disadvantages, for example, where there are overlapping or unclear responsibilities amongst government agencies. However, it is also important to note that the plurality of institutions involved in infrastructure governance can also be positive in promoting transparency. There is arguably more independent scrutiny of infrastructure investments and their sustainability than there was in the days of State ownership. This suggests that the challenge may not be complexity per se (though there are likely to be cases where some simplification could be beneficial). Rather there is a need to ensure that different institutions governing a particular sector – or across sectors – are sufficiently co-ordinated to provide clear incentives to infrastructure providers.

4. The regulation of monopoly networks (e.g. in electricity, gas and water) via the 'RPI-X' formula has been useful to some extent in making firms more efficient. But this approach has been less successful in prompting the investments and innovations that are required for the medium and longer term. As this section has noted, there are some examples of reform (e.g. in the electricity sector) which are starting to deal with these deficiencies.
5. The governance of most sectors includes multiple policy objectives such as keeping services affordable for consumers, protecting the environment, and maintaining security. This can lead to opportunities for interventions that can meet more than one objective simultaneously. But it also leads to inevitable trade-offs between objectives which need to be negotiated by stakeholders within governance systems.
6. UK infrastructure governance pays too little attention to cross-sectoral synergies and interdependencies. Whilst examples have been found of governance arrangements that have started to break down boundaries between sectors, most infrastructure governance continues to operate in isolated sector-specific silos. Furthermore, there is too little evaluation of instances where there have been attempts to deal with cross-sectoral issues. In these cases, there is not enough evidence about the positive or negative consequences.

Future phases of the ITRC will elaborate upon this analysis and then go on to explore the regulatory arrangements that may help to deliver a more integrated approach to UK infrastructure provision.

4 Status and trends in UK National Infrastructure

The starting point for analysis of future infrastructure provision is to understand the current system and trends that have been identified for the near term. In the FTA, a review of current infrastructure provision has been conducted in each of the five NI sectors: energy, transport, water supply, waste (comprising wastewater and solid waste) and ICT.

4.1 ENERGY

Reliability of the energy sector is high. Major investments are anticipated in electricity generation and distribution in order to maintain and increase capacity, meet the UK's greenhouse gas (GHG) emissions reduction commitments and address EU directives. All other infrastructure sectors are dependent upon the energy sector, but of these only transport represents a significant proportion of energy demand (34%). Yet the energy sector is also dependent upon transport infrastructure and ICT and is responsible for 32% of fresh water abstraction, though 96% of that cooling water is eventually returned to rivers.

4.1.1 THE INFRASTRUCTURE SYSTEM

Reliability of supply is the primary criterion for performance of the energy sector by the three fuel distribution systems: petroleum products, natural gas and electricity. Figure 13 (overleaf) presents the percentage of final demand for each fuel. The other driving performance indicators are environmental; principally emissions of greenhouse gases and other harmful combustion products – primarily sulphur dioxide, nitrogen oxides and particulates. End use of energy is highly distributed with vehicles and buildings the dominant end users of energy in the UK (Figure 14, overleaf).

4.1.1.1 Petroleum products

The petroleum products system is the energy system's major point of interaction with the transport system (Figure 15, overleaf). This is both because the road and rail tankers form the key distribution system for liquid fuels, and more importantly, because the transport system is currently fuelled predominantly by these liquid fuels.

Figure 13: UK final energy demand by fuel in 2010 (DECC, 2011b).

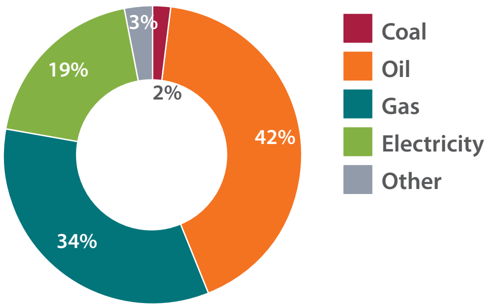


Figure 14: UK final energy demand by sector 1981–2009. Services includes agriculture (DECC, 2011f).

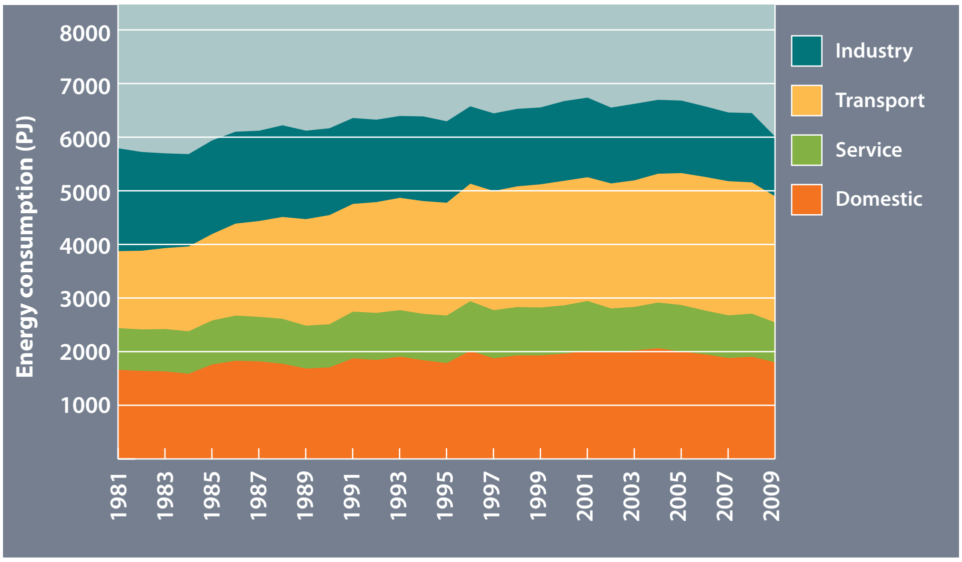


Figure 15: UK petroleum product demand by sector (left) and by mode of travel in transport (right) in 2010 (DECC, 2011b).

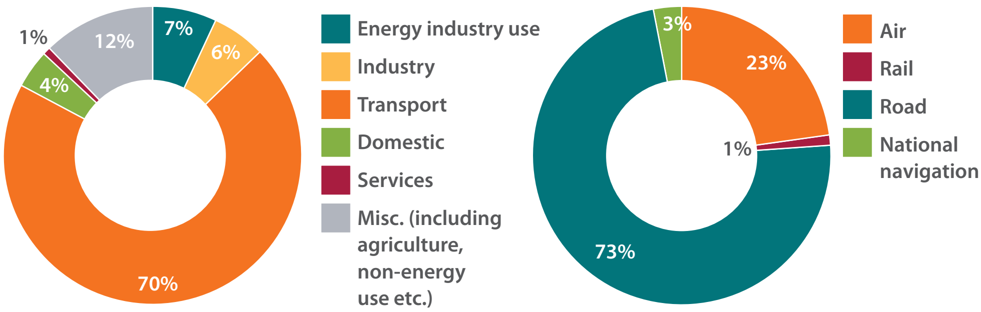
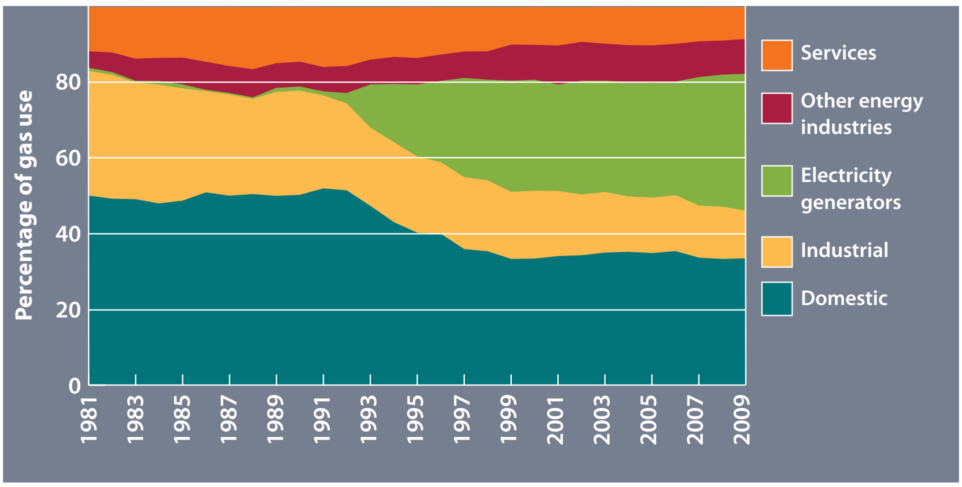


Figure 16: UK natural gas use by end use 1981–2009 (DECC, 2011b).

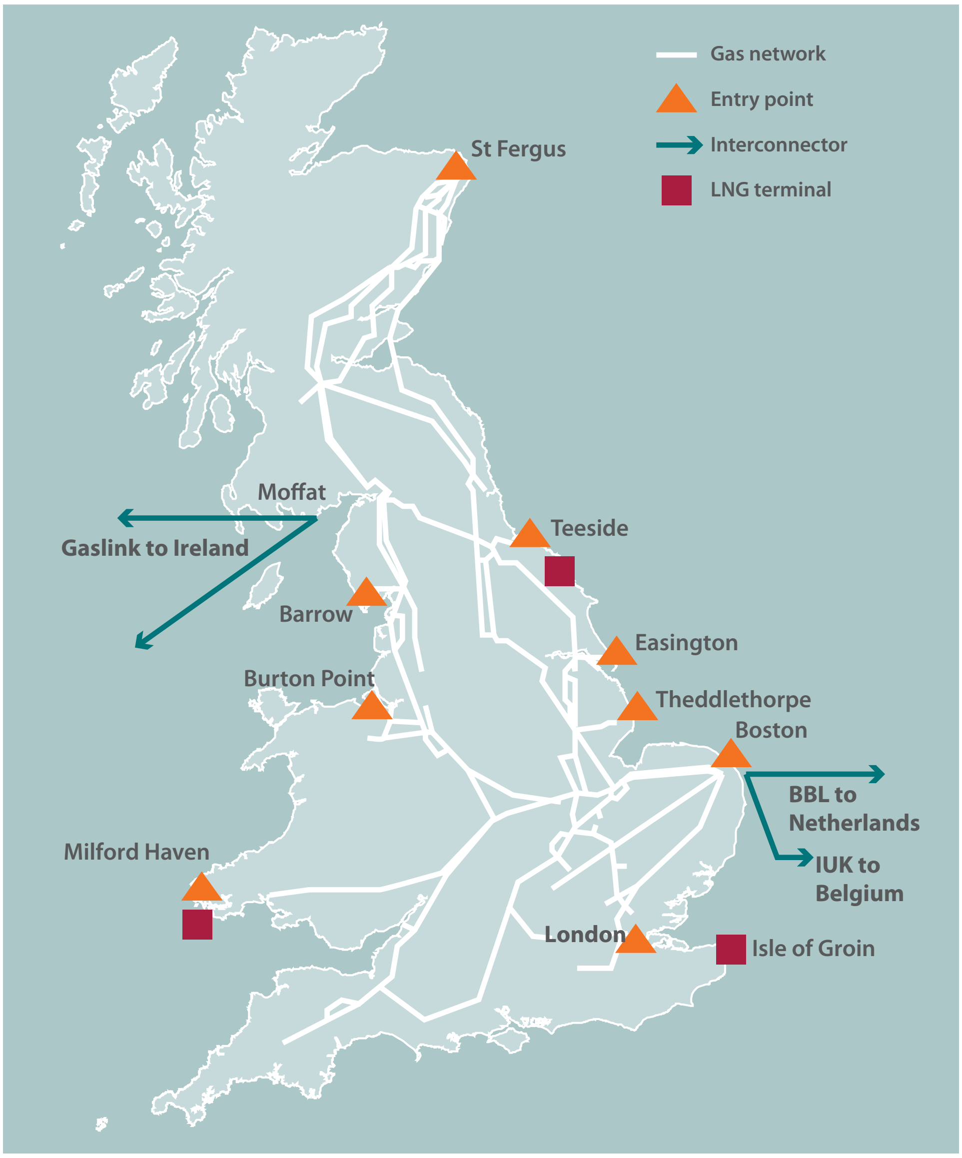


4.1.1.2 Natural gas

Natural gas replaced coal-derived town gas in the 1960s following the discovery of large reserves in the UK Continental Shelf (UKCS). Initially using the same distribution mains, the natural gas system additionally developed a national high pressure transmission network to ship gas from (largely East coast) terminals, which now reaches all significant population centres in GB. Heating, both in buildings and industrial processes, is dominated by direct use of gas (Figure 16). Following market liberalisation, gas also became the fuel of choice for power generation in the 1990s, further increasing its share of primary energy.

European market liberalisation and the decline of UKCS production in the last decade, have led to stronger interconnection of the GB gas system to other sources of supply, both by interconnection to continental Europe and Ireland, and with liquid natural gas (LNG) terminals for marine imports. International pipelines, such as between Bacton (UK) and Zeebrugge (Belgium) can transport gas in two directions to facilitate both export and import. LNG development is fairly recent in the UK with the first import terminal becoming operational in 2005, and four terminals currently in operation (Figure 17). LNG is becoming more readily available at a better price from the recent shift in US demand from LNG to domestic natural gas (from shale-gas) and greater export from mid-east and south-east Asia.

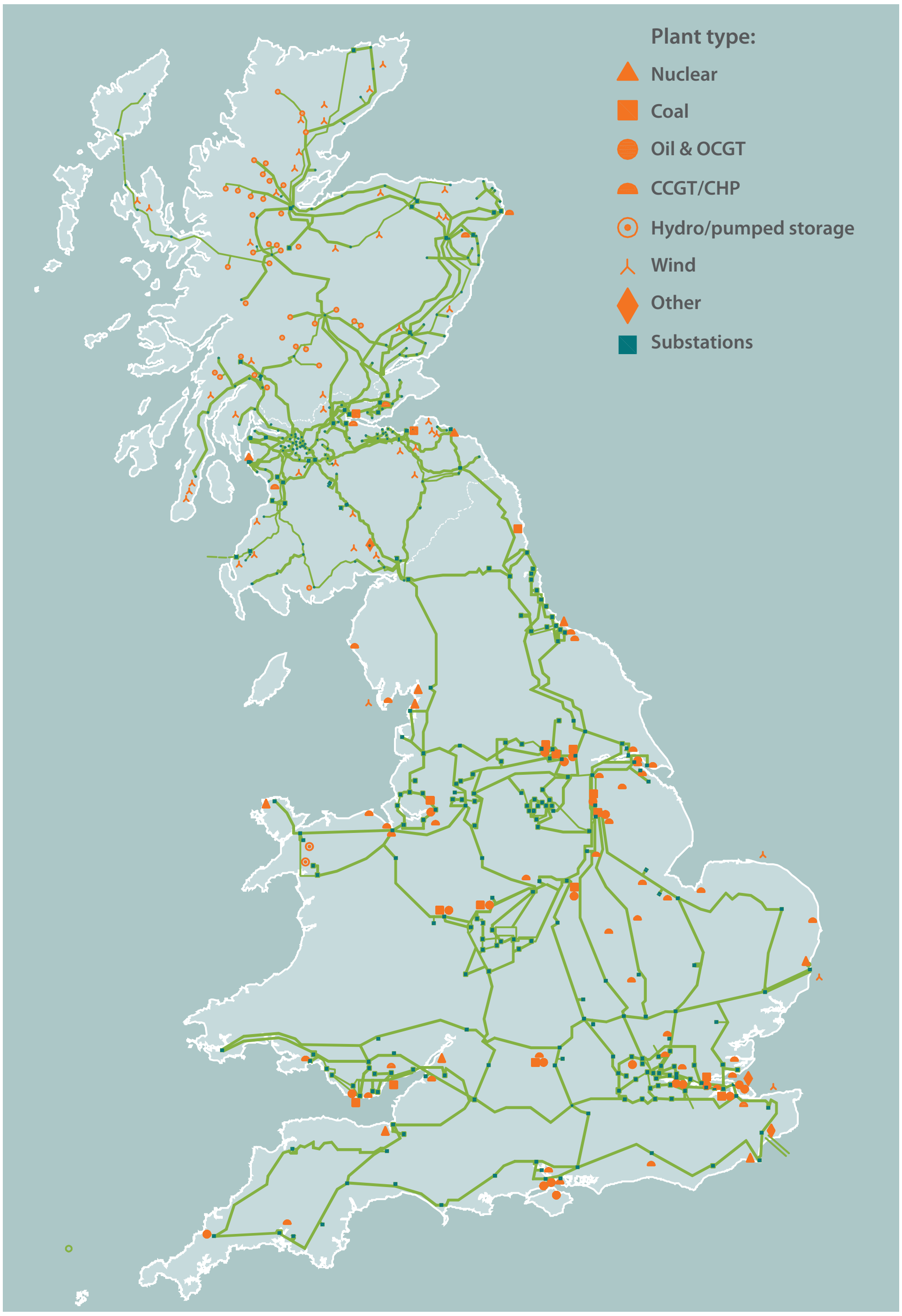
Figure 17: Map of natural gas transmission network (source: National Grid, 2011).



4.1.1.3 Electricity

The GB electricity system has developed incrementally from the post-war system of local and regional distribution systems. A high voltage transmission network has been developed which enables the GB system to function essentially as a single market (Figure 18). In 2005, interconnectors joined previously separate grid systems of N. Ireland, Scotland, England and Wales. Subsequently, grid systems of England and Wales and Scotland are integrated. Three electricity transmission companies own the National Electricity Transmission System (NETS). In addition to the existing network, several projects to build transmission networks in the UK are either underway or planned by the transmission owners.

Figure 18: Electricity transmission network with large power stations (source: NETS, 2011).



Electricity supply was historically dominated by coal with a small hydropower share (Figure 19). Coal remains a significant fuel in power generation, with production now mainly in the central coalfields of Yorkshire and the East Midlands. The share of nuclear increased in the 1960s and 70s, rising to 27% by 1997, but has since fallen to 15% (DECC, 2011f). Efforts to diversify into oil were ended by the oil crises of the 1970s. Gas took an increasing market share from the 1990s onwards and is now the largest single fuel. Gas generation is mainly close to the point of landing and therefore much closer to the main coal generation sites, resulting in a requirement for transmission to deliver a large north to south power flow to the population centres of southern England. This is likely to be exacerbated by renewables generation sites in the north and west of GB, particularly Scotland.

Electricity demand has grown consistently over the whole period of recent history (Figure 20) due largely to the penetration of electrical equipment and increasing numbers of end uses for electricity in buildings. Future projections in the context of low carbon ambitions indicate this trend may stabilise in the short term but could well then increase driven by the electrification of both vehicles and heating.

Figure 19: Electricity generation by fuel 1981–2009 (DECC, 2011f).

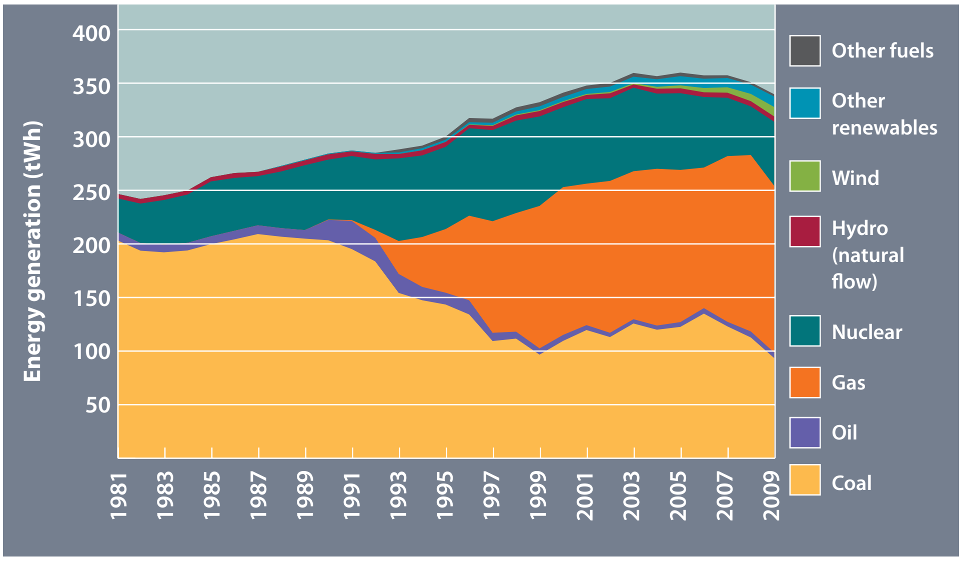
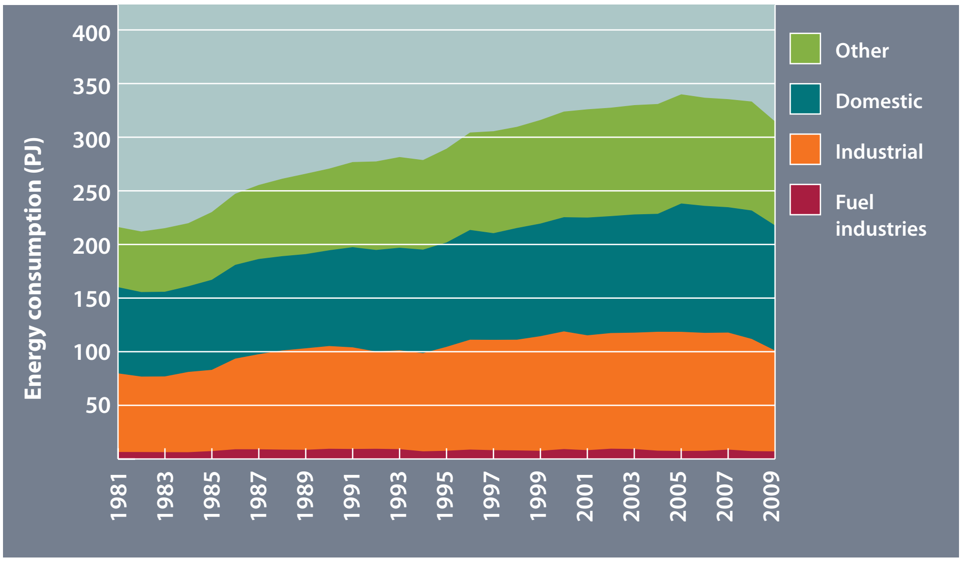


Figure 20: Electricity consumption by sector 1981–2009 (DECC, 2011f).



4.1.2 ROLE OF INTERDEPENDENCE

All infrastructure sectors have demand for energy (including the energy sectors itself), which is necessary for the operation of NI (Figure 21). The nexus between energy and the other sectors in the context of energy supply and demand is shown in Figure 22. The evaluation of critical interdependency of energy with other sectors is beyond the scope of this report and will be dealt with in future phases of the ITRC.

Figure 21: Energy by demand sector in 2010 (excluding non-energy use) (DECC, 2011f).

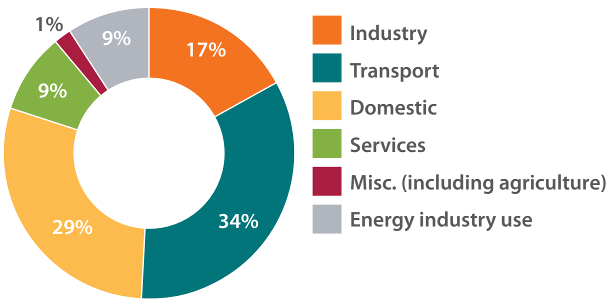
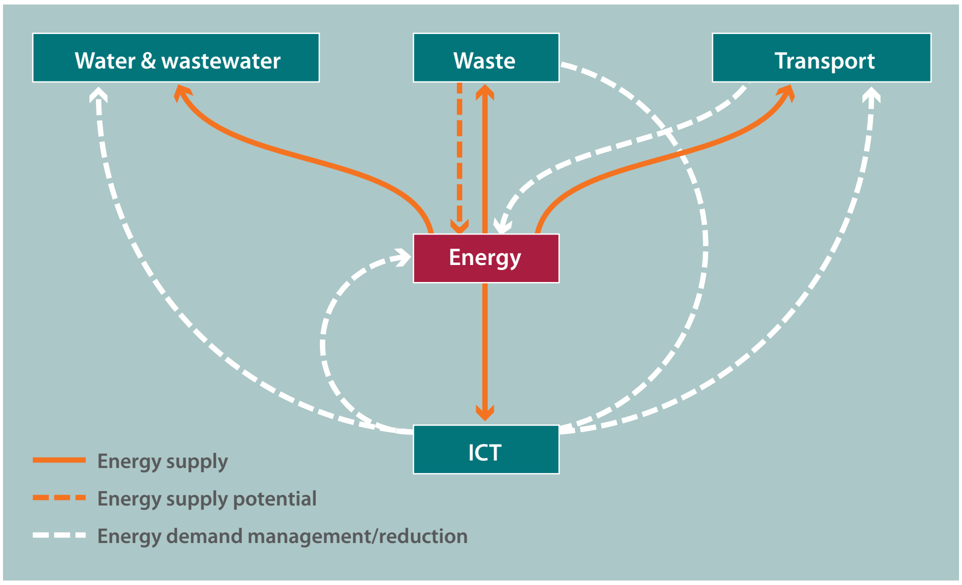


Figure 22: The nexus between energy and other ITRC sectors in the context of energy supply and demand. No critical interdependencies are shown.



4.1.2.1 Transport

Transport energy demand is an important interaction as transport uses 34%[6] of UK energy and 70% of petroleum based fuels. Transport systems are currently critically dependent on oil that is increasingly imported due to declining UKCS production. Transport demand for energy is the most challenging to reduce, which is why the exploration of alternative fuels is very important (e.g. notably electricity, biofuels and hydrogen). Major factors that can affect the energy demand regime include large-scale adoption of electric vehicles, rail electrification, and increasing biofuels use. With a high penetration of electric vehicles, systems such as Vehicle-to-Grid (V2G) have potential to provide effective demand response services (see Section 5.2.2.2). It is notable that transport infrastructure is critical for efficient supply of fuel for power generation, generation and distribution of fuel products, and manpower movements.

6 37% excluding energy industry use.

4.1.2.2 Water

Energy is essential for the operation of water treatment plants and pumping stations. It also represents the largest cost for the water industry at 28% of the total operational cost (Caffoor, 2008). Notably, the water sector demands for energy only accounts for a small portion (approximately 3%) of overall energy demand (Rothausen and Conway, 2011). However, water may account for a more significant percentage of total energy demand if supply-side energy-intensive interventions such as inter-basin water transfer, desalination and effluent recycling for potable water use are employed (see Table 17). Such water treatment processes would have potential implications for electricity demand particularly in southern and eastern England. Energy use in the water sector increased by 4% in 2009/10, and has increased 10% in the past 8 years mainly due to higher effluent standards. The energy sector is critically dependant on an adequate water supply for cooling purposes. For example, water required for cooling in electricity generation represents a significant share (more than 30%) of total abstracted non-tidal and ground water (see Figure 33), which is discharged back into the environment. Hence drought is of concern to energy supply, and future energy generation may choose a coastal location to avoid this risk (e.g. Nuclear New Build).

4.1.2.3 Waste

Almost half of the UK's renewable energy generation currently comes from the waste sector (DECC, 2011a). The greatest part of this comes from combustion of biogas generated in landfills. This source of energy will diminish over the next one to two decades as the mass of biodegradable wastes (the source of the biogas) going to landfill is reduced in line with the requirements of the EU Landfill Directive (European Parliament and Council of the European Union, 1999). It is likely that some or all of this shortfall will be met by the increasing use of other facilities for the disposal of biodegradable and other wastes (e.g. incinerators and anaerobic digesters). There is also scope for increases in the utilisation of heat from thermal waste treatments. The EA (2008a) reported that in England and Wales, energy is recovered from 11% of municipal wastes, which is lower than the EU average of 17.3% and in countries like Denmark where recovery rate is about 54%.

4.1.2.4 ICT

While energy use in ICT is relatively small compared to total energy demand, the sector is wholly reliant on electricity. The largest consumers of energy in ICT are by far Data centres used by businesses, universities and government. These centres are responsible for a quarter of ICT's GHG emissions and 2–3% of UK's total electricity use (POST, 2008).

The European Programme for Critical Infrastructure Protection identified both ICT and energy as Critical Infrastructure sectors. Energy is critically co-dependent on ICT, and future electricity system security will likely increasingly depend on ICT for load balancing and control, electricity generation, and telecom systems. The use of ICT for improved control could induce an overall reduction in energy consumption even if its direct consumption increases. There are implications for energy demand through the improved use of information for demand reduction. Convergence between electricity and telecoms infrastructure in 'smart grids' seems very likely over the period to 2030 with government planning smart meter rollout to begin in 2014.

4.1.3 KEY ISSUES

Table 8: Major policies/strategies affecting energy demand and supply

Sector	Major policy/strategy	Brief description/salient features
Energy	Energy Act 2008 – implements Energy White Paper 2007	Offshore supply infra, CCS, renewables target, cash-back renewables incentives, smart metering and decommissioning of certain infrastructures
	Climate Change Act 2008	Legally binding carbon targets for all sectors, carbon budgets, Committee on Climate Change
	National Renewable Energy Action Plan (EU Renewables Directive 2009/28/EC)	Goal and roadmap for renewable electricity, heat and transport
	Energy Act 2010 (effective 8 Apr 2010)	CCS incentives & demonstration, social price support – fuel poverty, Ofgem power on penalty
	Energy Act 2011 (effective 18 Oct 2011)	Green Deal, minimum housing efficiency, new Energy Company Obligation (CERT, CESP)
	Electricity Market Reform White Paper 2011	Carbon price floor, new renewable incentives, capacity mechanisms, demand response, emission performance standard
	Housing Act 2004 (EU EPBD Directive 2002/91/EC)	Carbon reduction and energy efficiency targets and timeline in buildings
	Large Combustion Plant Directive (EU LCPD, 2001/80/EC)	Retirement plan of 50+MW plants by 2025
	EU Energy Services Directive (2006/32/EC)	Electronic metering in energy saving measures
Transport	Renewable Transport Fuels Obligation (RTFO) (under Energy Act 2004 and in line with EU Directive 2003/30/EC) April 2009	Biofuel blend from 2.56% in 2008–2009 to 5.3% from 2013 onwards
	EU New Car CO_2 Regulation (effective 2012–2105)	Average CO_2 emissions at 130 g/km in accordance with Regulation (EC) No, 715/2007. 95 g/km 2020 onwards
Water and wastewater	EU Water Framework Directive (WFD) 2000/60/EC (effective 2000, domestic law 2003–2027	Control and manage impact on water bodies/ groundwater at source, higher treatment standards on wastewater
Waste	European Landfill Directive (1999) (effective in UK 2002–2003)	Reduction of landfill by 25% in 2020 to 65% below 1995 level. Potential to spur waste to energy, CHP

UK policy, across infrastructure sectors, is a major determinant for energy transition pathway and the demand supply regime. UK energy policies are geared towards achieving major carbon emissions reductions and renewables targets while keeping energy costs at an affordable level for consumers and maintaining security of supply. On the supply side, incentives are being used/planned to achieve the renewables targets through feed-in-tariffs, the Renewable Heat Incentives, Renewables Obligation and Renewable Transport Fuel Obligation. In transport, the Plug-in Car Grant provides incentives for ultra-low emission vehicles. Significant accelerated tax reliefs are available for businesses through Enhanced Capital Allowances scheme under the Climate Change Levy Programme when they invest in certain energy and water saving plant and machinery, low emission vehicles and natural gas and hydrogen fuelling infrastructure. Presently the Government is exploring the possibility of a Green Investment Bank to help fund low carbon projects, including renewable energy projects. Table 8 lists key UK and EU policies and strategies by sector that impact the energy regime at differing levels.

The UK is a participant in the EU's Emission Trading Scheme, EU-ETS. On the demand side, the government has been pursuing energy conservation and efficiency through obligations on energy suppliers for households, the Climate Change Levy on businesses and the CRC for large companies outside the EU-ETS. Additionally, the government has been pursuing energy conservation and efficiency in energy generation and energy intensive entities through obligatory reduction schemes (CERT and CESP) and long term carbon pricing in its unique CRC EES scheme. A more detailed discussion on the UK energy policy and influences from EU policies can be found in Chapter 3.

4.1.3.1 Infrastructure options

Energy technology supply futures will likely be characterised by an increased reliance on low carbon technologies and new energy sources. While this will require a systemic change, it will enable the UK to meet its commitments to carbon emissions reduction, while preserving high levels of supply reliability and security. Existing scenarios literature assumes that these are the key drivers in option selection.

The use of low-carbon electricity will be critical in the future. Thus, key technologies will be low carbon electricity generating technologies with high potential contributions to UK supply by the mid-century. These include nuclear fission, wind energy (onshore and offshore) and fossil fuels with carbon capture and storage (CCS). The mix is highly uncertain (as well as controversial) and has major implications for transmission infrastructure. Major uncertainties include how much of each of these resources will be developed, the continuing role of gas and the future fuel demand and mix in transport. Implications for transmission system from electricity exports from distribution networks include reduction of power flow in opposite direction resulting from embedded generation, and large-scale renewables penetration are not likely to be major. Rather, location, volume and direction of power flows from such generation are likely to demand changes in the transmission system (NETS, 2011). (See Annex E for more explanation.)

Biomass and the vectors through which it is used (solid, liquid and gaseous) will likely play an important role, as well as other renewables (e.g. marine and solar). The latter is a possible component in a decentralised generation arrangement, which represent a radical departure from existing networks. CO_2 disposal infrastructure will need to be considered in scenarios with CCS. Gas may remain a viable option.

The role of gas, as the least carbon intensive fossil fuel, in low carbon futures is more contentious. Gas is currently the dominant fuel for heating in buildings and industry. Many scenarios foresee very extensive electrification, but there is no doubt that such a transition faces significant technical, social and economic challenges. The scale of change required for any given carbon target is reduced by demand reduction.

The key options for energy demand management fall into two broad categories: those with potential to reduce demand, and those implied by transitions to low carbon vectors (primarily electricity). Demand reduction technologies tend to be grouped at the sectoral level (buildings, transport, industry) in the energy futures literature. The implications of a transition to a low carbon future have supply assumptions. High levels of electrification will need to be considered, particularly to account for the widespread use of electric vehicles and heat pumps. Both of these technologies have significant implications for power networks, and supply and demand balancing.

4.1.3.2 Risks

Environmental risks. The main environmental risk is the possible failure to deliver ambitious carbon targets. Current plans rely on substantial investment programmes being successful in a number of areas, including for technologies that are not yet commercially demonstrated (e.g. CCS). Possible scenarios that do not meet targets include underinvestment, and perennial delay/failure in deployment of key technologies and reduced investment due to financing and/or planning permission difficulties. Other environmental risks result primarily from the challenges of these of low carbon supply options, notably ionising radiation from all stages of the nuclear fuel cycle, CO_2 escape (from CCS), and landscape /amenity impacts from all large projects, but especially onshore (e.g. large wind projects).

Economic risks. Very large energy infrastructure investment is needed to meet the requirements of a secure low carbon system under any scenario. These are estimated at £200bn by 2020 in Ofgem's 'green transition' and 'green stimulus' scenario under Project Discovery (Ofgem, 2011b). Very large investment costs are also associated with electrification of heat and transport. These will rely on the willingness of private sector to invest, often in globally competitive markets. As discussed in Chapter 3, this will rely on a stable and sufficiently attractive policy framework.

Whilst future scenarios universally project a large investment requirement in electricity, there is significant uncertainty about other infrastructures. Notably the projected decline of gas and oil very sharply in some scenarios implies risks of stranded investment. Different scenarios also envisage very different potential futures for new energy infrastructures, including for carbon dioxide disposal (contingent of CCS) and the possible rise of CO_2 heat (depending on the widespread use or not of district heating).

Inevitably for long term scenarios, there are major uncertainties about key drivers, parameters, and their interrelationship. These uncertainties define energy futures such as cost of technology, rate of economic growth, and the relationship between economic growth and rate of technological innovation. All of these contribute to investment risks.

Security and social risks. Other infrastructure systems, most economic activity, and many key services depend on reliable and continuous supplies of energy, particularly electricity, which makes energy security a key driver of social as well as economic risk.

Uncertainty of fuel supply options availability has been a well-established risk since the 1970s, and now increasingly prominent with the decline of UKCS production. While oil supply is most likely to be curtailed for geo-political reasons, gas supply seems more likely to be continued at a reasonable price and from low-risk countries for decades to come (especially from shale gas and increased LNG trade). At the same time, supply and cost of key renewable technologies may be significantly affected by change with non-availability of rare-earth minerals, for which there is already globally competition, notably a scenario of export embargo by China and non-development of mines elsewhere.

Deployment of demand reduction and decentralised supply options will rely on re-training and upskilling of very large workforces in key trades, especially in the construction sectors. Rapid market introduction may therefore be constrained by non-availability of sufficient skilled labour force.

Technology and policy risks. Policy uncertainty and risks of lack of commitment of climate change targets by governments may slow the flow of needed private investments. Current Government commitment is high, but the prospect of a lack of international agreement inevitably raises concern that broader global trends may be less optimistic and eventually affect UK investment.

While technologies such as CCGT, hydro, solar PV and onshore wind are considered low-risk technologies with some higher certainty about their future performance and market penetration (hence cost profile), there are significant uncertainties arising from the technical viability and performance of some other potentially critical low-carbon electric generation technologies; game-changing technologies such as CCS, new nuclear, offshore wind and other marine technologies are commercially uncertain, as are some key technologies for low carbon heat and transport including some biomass technologies and heat pumps or wave/tidal.

The major risks identified in the existing energy literature are the failure to deliver low carbon and/or energy security goals because of under-investment in demand reduction and/or new supply. These may be for technical, economic, social and political reasons, or more likely a complex mix. In particular, the main low carbon supply technologies – nuclear, CCS and large-scale renewables – all face challenges which, whilst very different, may all be characterised as public acceptability for 'socio-environmental' reasons. There is no sensible way to predict the outcome of such concerns.

There are also potential threats to the resilience of energy systems from other infrastructure systems. These include critical dependencies on water (e.g. for power station cooling), transport (e.g. for liquid fuel transportation) and ICT (e.g. for network control). These are the focus of ongoing work in ITRC and elsewhere, and are not reported here.

Reliability of 'wires' infrastructure is currently relatively low risk and somewhat easier to evaluate. One assumption is that very high levels of reliability continue to be required in power systems, partly because of the co-dependence of other infrastructure systems. Compared to power generation, transmission and distribution will be less affected by climate mitigation, but potentially more affected by extreme weather. Reliability requirements for other existing energy infrastructures (gas, liquid fuels) are lower, as lower availabilities are acceptable and storage is easier. These issues are not included in this assessment phase.

4.1.4 CONCLUSION

The UK energy sector has provided a very high level of service reliability, with only occasional failures associated with extreme events. Our assumption is that this level of security of supply will continue to be required in future, at least for the electricity system. Ageing supply infrastructure and statutory UK emissions targets (as well as the effect of EU directives and the ETS) mean that the energy sector will see major changes (and corresponding investment requirements) over the coming decades.

4.2 TRANSPORT

Demand for transport infrastructure has grown steadily over the years for a variety of reasons, including economic growth combined with relatively low costs making travel affordable for most, population growth and societal changes such as increasing numbers of female drivers. Growth seems likely to continue, although demand for passenger car transport may reach a saturation point. Continued growth in demand will result in increased congestion and delays, particularly on roads and rail, which will in turn tend to inhibit further growth. Ambitious carbon reduction targets will drive development in vehicle and fuel technologies and result in increased use of electric vehicles on roads, increased rail electrification and lower use of carbon fuels. This will require substantial investment in energy infrastructure, particularly for electricity. For example, ports infrastructure will be affected by changes to shipping if fuel imports were to change in the future. Building new transport infrastructure will alleviate congestion and delays in the short term but will also induce further demand. If transport costs continue to increase, it will inhibit demand, and so adversely affect the economy, unless transport growth can be decoupled from economic development.

4.2.1 THE INFRASTRUCTURE SYSTEM

The transport infrastructure system being considered in the ITRC comprises the trunk road network, the rail network, major airports and major seaports. Although vehicles are not normally considered to form a part of 'infrastructure' they are nevertheless an important consideration in this study, in particular in terms of vehicle technology and alternative fuels. Measuring the performance of transport systems is complex because (i) performance is highly variable both geographically and temporally, and (ii) unlike other sectors there is no assumption that 'security of supply' should be preserved – whilst undesirable, congestion is commonplace on the network. Thus a range of metrics are employed to track the performance of the transport network, including:

- Vehicle kilometres
- Passenger kilometres
- Tonne kilometres (freight)
- Delays on the trunk road network[7]
- CO_2 emissions
- Fuel and energy use[8]

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7 Measured in minutes per 10 miles, and recorded for the slowest 10% of routes (as published by the Department for Transport).

8 Fuel use for road vehicles is estimated in terms of litres of gasoline equivalent (using data from the Tosca project (www.toscaproject.org) to convert electricity use into gasoline equivalent). Energy use by rail transport is estimated in units of joules (again using data from the Tosca project).

4.2.1.1 Trunk road network

The trunk road network (or strategic road network), managed by the Highways Agency in GB, comprised a total of just over 12,000 km, of which 3,500 km was motorway (Table 9). Road capacity is defined not only by the length of road but also by the number of lanes available. Dividing the total length of trunk road lane kilometres (estimated as 43,656 lane km, based on unpublished statistics) by the total trunk road length (Table 9) gave an average number of lanes of 3.6 (the number of lanes is counted across the whole carriageway, i.e. both directions of travel).

Table 9: Trunk road length (km) (as at August 2010) (DfT, 2011d)

Region/country	Motorway	Other trunk (rural)	Other trunk (urban)	Total trunk
North East	55.6	291.2	51.3	398.1
North West	616.9	310.3	32.2	959.4
Yorkshire & Humber	380.0	354.7	15.7	750.4
East Midlands	195.4	518.3	34.7	748.4
West Midlands	427.0	414.8	41.3	883.1
East of England	265.0	736.5	33.8	1035.3
London	60.1			60.1
South East	644.0	626.1	44.8	1314.9
South West	326.8	710.4	27.5	1064.7
England	2970.8	3962.3	281.3	7214.4
Wales	141.3	1498.6	48.0	1687.9
Scotland	406.6	2718.2	87.8	3212.6
Great Britain	3518.7	8179.1	417.1	12,114.9

Published statistics for total distance travelled (vehicle km) are only available by region for all major roads (trunk and principal), rather than for just the trunk road network (Table 10, overleaf). However, the trunk road element can be estimated for GB (based on separate data indicating the ratio of trunk roads to principal roads, and given that only 1.2% of motorways (41 km) are not part of the trunk road network). If regional data on trunk road/principal road splits are available, they do not appear to have been published.

Table 10: Distance travelled on major* roads (billion vehicle km) in 2009 (DfT, 2011c)

Region/country	Motorway	Other Rural	Other Urban	Total
North East	1.1	6.3	3.9	11.3
North West	18.0	9.0	10.8	37.8
Yorkshire & Humber	9.5	10.1	7.2	26.9
East Midlands	6.6	15.8	4.8	27.0
West Midlands	12.4	10.3	7.9	30.6
East of England	8.5	20.6	5.5	34.6
London	2.3	0.6	16.6	19.5
South East	22.4	24.3	10.0	56.5
South West	8.7	17.2	5.0	30.9
England	89.5	114.1	71.8	275.4
Wales	3.4	10.9	3.2	17.7
Scotland	6.6	16.9	5.5	29.0
Great Britain	99.5	141.9	80.5	321.9
Trunk road element	**98.3**	**58.1**	**5.5**	**161.9**

* Major = trunk roads and principal roads

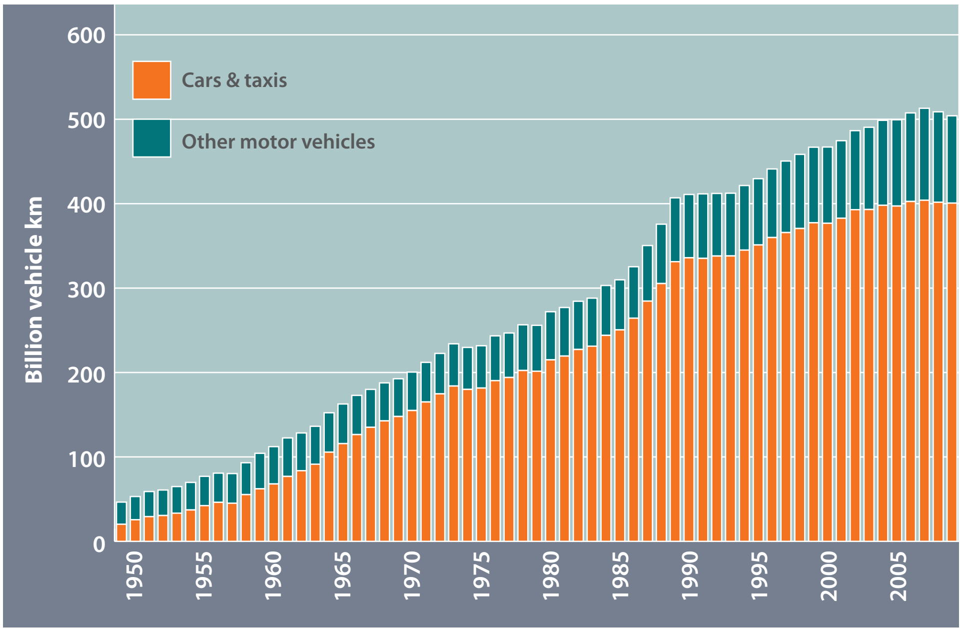
Growth in traffic has been steadily increasing over the years at an almost linear rate (Figure 23). This growth has been influenced by many different factors relating to demographics, economics, prices, transport options, service quality and land use (Victoria Transport Policy Institute, 2010).[9] While a review of these factors is outside the scope of this study a few comments are pertinent:

- The number of full driving licence holders has steadily increased over the years as has the proportion of female drivers (37% in 1986 to 45% in 2010 – DVLA).[10]
- The affordability of travel is an important consideration. Over the past few decades relatively low prices, in relation to income, have resulted in lifestyles where car ownership and travel have been commonplace. However, this may change with rising fuel prices and other travel costs.
- The development of out-of-town retail parks and hypermarkets close to the trunk road network has led to increased demand and reliance for car trips.

9 http://www.vtpi.org/tdm/tdm132.htm

10 http://dft.gov.uk/dvla/pressoffice/stats.aspx

Figure 23: Growth in traffic in GB (1950–2009) (Glaister, 2010).



4.2.1.2 Rail network

The rail network is managed by Network Rail (established in 2002), who are regulated by the Office of Rail Regulation (ORR). The whole rail network track length of approximately 20,000 miles (32,160 km) (Network Rail, 2011) was used for the FTA (although it was originally envisaged that ITRC would focus on a mainline railway network; there is no common definition of 'mainline rail' nor any readily available statistics for such an entity).

The National Rail Travel Survey (NRTS) indicated that there are around 2.7 million rail journeys undertaken in GB on any typical working day, with morning and evening peak periods; a breakdown by region is shown in Table 11 (overleaf). The ORR reported 1258 million franchised journeys in 2009–2010 .

There has been a trend of increasing demand for rail transport over the last 20 years (Figure 24, overleaf).

Total rail freight moved in 2009–2010 was 7.6% lower than 2008–2009, at 19 billion net tonne km, while the total coal freight moved was 21.2% lower (at 6.2 billion net tonne km). Oil and petroleum moved by rail also decreased (by 4.5%), but the following commodities increased in 2009–2010 compared to 2008-09: metals by 6.8%, construction by 3.0%, international by 5.7% and domestic intermodal by 6.5% (ORR, 2011).

The amount of freight lifted was 87.2 million tonnes in 2009–2010, a 15.1% decrease from 2008–2009. There was an 18.7% decreased in the amount of coal lifted (37.9 million tonnes in 2009–2010). The amount of 'other' freight lifted was 49.3 million tonnes in 2009–2010, a fall of 12.1% compared to 2008–2009.[11]

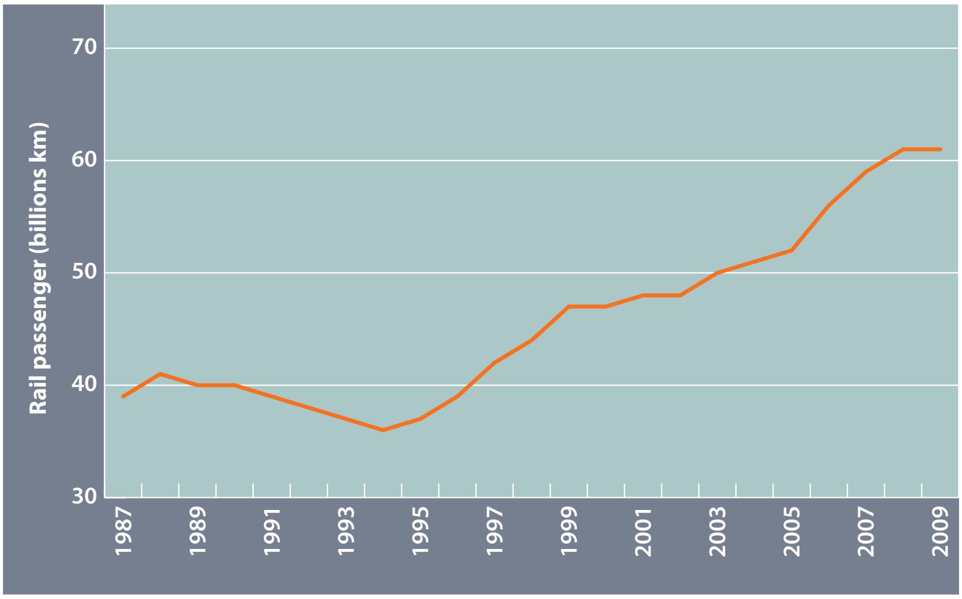
11 Non-franchised journeys totalled around 2 million, so are negligible by comparison. The ORR pointed out that their figures may be considered to be inflated, since a journey involving two trains would be counted as two journeys, whereas, for the NRTS, this would only be counted as one journey.

Table 11: Total number of passenger rail journeys, by country and region of origin (GB)

Region / country	000s	%
North East	26	1
North West	198	7
Yorkshire & Humber	127	5
East Midlands	52	2
West Midlands	121	5
East of England	209	8
London	1275	48
South East	373	14
South West	73	3
England	**2454**	**91**
Wales	**48**	**2**
Scotland	**181**	**7**
Great Britain	**2683**	**100***

*Percentages do not sum to 100% due to rounding

Figure 24: Passenger kilometres (1987–2010) (billions) (ORR, 2011).



4.2.1.3 Airports

Airports are privately owned and managed. For example, BAA own Heathrow, Stansted, Glasgow, Edinburgh, Aberdeen and Southampton airports. They are regulated by the Civil Aviation Authority and by the Competition Commission.

Airport capacity is usually described either in terms of terminal capacity (number of passengers) or runway capacity (number of flights). There seems to be rather limited information available about these (Table 12). The figures suggest that Heathrow is operating at 95% runway capacity; Gatwick at 80%; Stansted 59% and Manchester 53%.

Considering all UK airports (not just international ones), the headline statistics given by the Department for Transport were:

- In 2009 there were 2.1 million air transport movements (take-offs and landings) and 218 million terminal passengers at UK airports.
- 20% of air transport movements and 11% of terminal passengers were on domestic services.
- Heathrow was the UK's busiest airport, handling 22% of air transport movements, 30% of terminal passengers and 62% of freight tonnes. Heathrow also handled the majority of transfer passengers at UK airports; in 2009, 38% of passengers at Heathrow were transfers.
- The five London airports accounted for 60% of all terminal passengers at UK airports in 2009, down from 65% in 1999.
- Between 1999 and 2009, overall terminal passenger numbers increased by 48% at the regional airports compared with 20% at the five London airports. However, regional airports experienced a proportionally larger fall between 2008 and 2009 at 11% compared with a 5% fall at the London airports.

Table 12: Airport usage and capacity in 2010 (terminal and runway). Source: BAA, individual airport and Airport Coordination Ltd websites)

Airport	Terminal passengers	Terminal capacity per year estimate	Total movements per year	Capacity flights per year*
Heathrow	65,881,680	90,000,000	454,823	480,000
Gatwick	31,375,290	46,000,000	240,500	300,000
Stansted	18,573,803	25,000,000	155,140	264,000
Manchester	17,759,015	25,000,000	159,114	300,000
Luton	8,738,717	12,000,000	94,575	not available
Edinburgh	8,596,715	13,000,000	108,997	not available

* From capacity declaration.

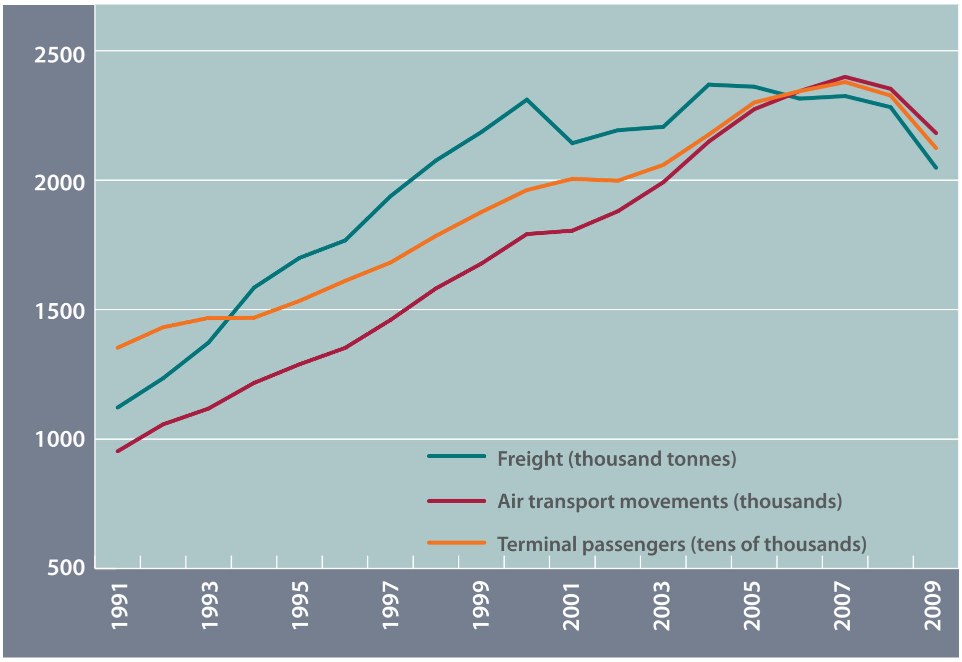


Figure 25: Trends in air traffic at UK airports (1991–2009) (DfT, 2010c).

4.2.1.4 Seaports

Seaports are privately owned and managed. The largest owner is ABP (Associated British Ports), who operate 21 ports, including Southampton, Hull, Grimsby & Immingham and Port Talbot. They are regulated by various port authorities. Port capacity is described here in terms of quay length, with an estimated volume of TEU (twenty-foot (container) equivalent unit) per annum derived from this (Table 13).

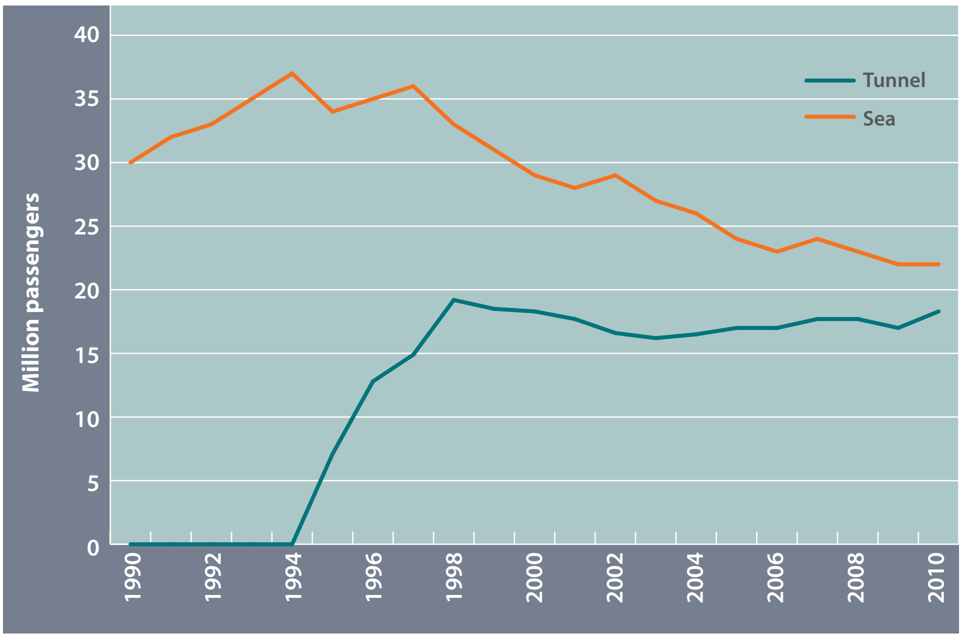


Figure 26: International sea and channel tunnel passengers (DfT, 2010a).

Since the opening of the Channel Tunnel in 1995 there has been a steady decline in the number of passengers using Britain's sea ports (Figure 26). The 3.1 million domestic passenger journeys in 2010 were on the three major routes (between mainland Britain and Northern Ireland, the Isle of Man, and the Channel Islands) virtually unchanged compared to 2009. Dover, the largest UK ferry port, handled 13 million journeys in 2010 (virtually unchanged from 2009 and 18% lower than in 2000). However, the next busiest ports in 2010 were Portsmouth (2.2 million passengers) and Holyhead (2 million passengers), where there were increases of 3 and 7% respectively on 2009. Of these sea passenger journeys, 1.3 million were for cruises and 55,000 long sea journeys.

Table 13: Port usage and estimated capacity in 2008/2009/2010 (thousand tonnes)

Ports (all traffic)	Quay length (m)	Capacity in TEU/ annum	Port Group	2008	2009	2010
Grimsby & Immingham	2289	2,540,790	Humber	65,267	54,708	54,029
London	3750	4,162,500	Thames and Kent	52,965	45,442	48,060
Milford Haven	520	577,200	West and North Wales	35,875	39,293	42,788
Southampton	1357	1,506,270	Sussex and Hampshire	40,974	37,228	39,365
Tees and Hartlepool	660	732,600	North East	45,436	39,163	35,697
Forth (incl. Dunfermline)			Scotland East Coast	39,054	36,690	34,335
Liverpool	1097	1,217,670	Lancs and Cumbria	32,204	29,936	30,063
Felixstowe	2793	3,100,230	Haven	24,988	24,267	25,756
Dover	660	732,600	Thames and Kent	24,344	25,087	24,093
Belfast			Northern Ireland	13,040	12,050	12,827
Clyde incl. Ardrossan			Scotland West Coast	14,338	12,552	12,283
Medway	650	721,500	Thames and Kent	14,971	13,150	12,235
Sullom Voe			Scotland East Coast	14,539	11,217	11,270
Hull	300	333,000	Humber	12,249	9771	9236
Port Talbot	290	321,900	Bristol Channel	8147	5156	8832
Bristol	1050	1,165,500	Bristol Channel	11,527	8999	7272
Manchester			Lancs and Cumbria	7438	6670	7127
Glensanda			Scotland West Coast	6336	5591	5846

Note: Capacity in TEU/year is given as [Quay length (m) x 1100]; Maximum weight of 1 TEU is 14 tonnes.

4.2.1.5 Inland waterways

Movement of freight by inland waterway (canals, rivers) forms a relatively small but important proportion of the total amount of freight that is moved in the UK: DfT domestic freight statistics (TSGB0499) for 2009 indicated that of the total 221 billion tonne km of freight moved, 22% was by water (short sea shipping and inland waterways) and about one third of this was by inland waterways. The majority of freight lifted on inland waters is transported to or from ports outside the UK: only about 7% of freight lifted is wholly internal (i.e. non-seagoing).

British Waterways manages 80% of the canals and rivers (3500 km) in GB.[12] Inland waterways have substantial spare capacity for carrying freight: studies carried out by British Waterways indicated that London's waterways carried up to 17,000 tonnes of freight in 2003 and there was the potential to carry 800,000 tonnes alone on the West London Canal network.

4.2.2 ROLE OF INTERDEPENDENCE

Transport is a derived demand and, as an intermediate good, an input into the production of most other economic sectors. All infrastructure sectors rely in some part on the transport network, to enable staff and goods to reach their destinations, and failures of the transport network can have serious cascading effects for other sectors. However, the main interdependency lies between transport and its future energy needs, particularly if a substantial increase in electricity generation is needed to power electric vehicles and for increased electrification of the rail network. While the majority of electric vehicle recharging is likely to take place at home, it also seems likely that substantial battery recharging infrastructure will be needed in the field (e.g. at garages, supermarkets, workplaces, etc.). Moreover, electrification of the transport sector would require large investment in additional generating capacity, national transmission networks and local distribution networks.

4.2.3 KEY ISSUES

In the past, demand growth has been strongly correlated with GDP growth, especially for freight. Some recent evidence has suggested decoupling of the two (McKinnon, 2007), however it remains to be seen if this is a new long-run phenomenon. Some limited cross-modal effects exist, such as the low cross-elasticity of car demand to rail price (Preston, 2009).

National and EU transport and energy policies are likely to be influential on transport supply and demand. Particularly important will be the response to the ambitious carbon emissions reduction targets that are in place. The Committee on Climate Change's (CCC) 4th carbon budget, in its chapter on decarbonising surface transport (Committee on Climate Change, 2010), proposes cuts in transport emissions in the 2020s through improved efficiency of conventional vehicles, increased penetration of electric vehicles (battery electric, plug-in hybrid and, potentially, hydrogen fuel cell vehicles), increased use of biofuels, change in behaviour (Smarter Choices, eco-driving, speed limit enforcement/reduction), road pricing, freight efficiency improvement and electrification of rail. Some of these options (and others) also apply to aviation, as discussed in 'Meeting the UK aviation target – options for reducing emissions to 2050' (Committee on Climate Change, 2009).

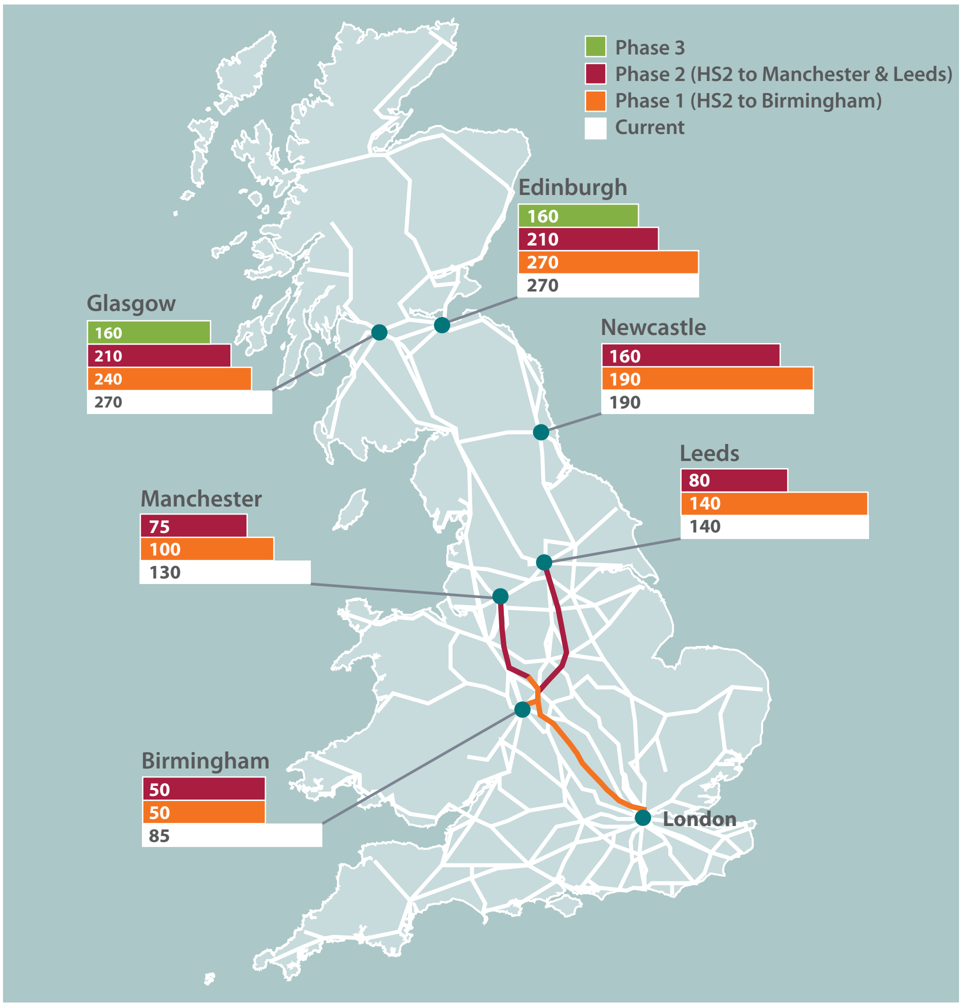
12 http://www.britishwaterways.co.uk/

4.2.3.1 Infrastructure options

The ways in which transport is taxed, and the amounts levied, will influence mode choice and future transport demand. Existing transport taxes include airport tax, vehicle excise duty (road tax) and fuel tax (e.g. on petrol and diesel). Toll charges and road pricing schemes (e.g. M6 motorway toll; London congestion charge) will also have an influence on transport demand. Depending on their implementation, the introduction of road pricing schemes may be equivalent to increases in fuel tax in terms of their impact on travel demand. Mills *et al.* (2011) considered it likely that road pricing will become a necessity to replace declining fuel duty, as electric vehicles become more commonplace.

Infrastructure investment will affect transport supply. For rail, the modelling includes additional route km provided by the introduction of specific schemes (Crossrail, HS2 and HS2+), which seem likely to go ahead. Mills estimated required road investment of £9 billion a year (a two-thirds increase over the past decade), with renewing existing road assets costing £5 billion a year and the remaining £4 billion required to address 'choke' points and to expand capacity on the most congested arteries.

Figure 27. Train travel times (DfT and HS2 Ltd, 2011) to London with and without HS2 phases 1 and 2. Phase 3 times (Greengauge21, 2009) for Glasgow and Edinburgh are indicative, based on an England–Scotland extension. Figures rounded to 5 min.



In addition to, or instead of, building new roads, additional capacity may be realised through the use of intelligent transport systems (ITS), employing advanced ICT. Existing examples include the use of variable speed limits on motorways to improve vehicle flow and allowing use of the hard shoulder at certain times, supported by ITS. Future systems may involve communications between individual vehicles and/or with roadside infrastructure, with various potential applications and benefits, in terms of capacity, safety and information provision. Such systems may provide information about queues ahead and other hazard warnings, or could actively control the vehicle to some extent (e.g. to regulate speed or vehicle headway or to avoid collisions). Vehicle flow may also be increased by raising the speed limit, as has recently been suggested for motorways (Stratton, 2011), however there are safety concerns about speed, particularly associated with variations in speed between different drivers, alongside concerns about resultant increased emissions. Limited additional capacity at Heathrow airport may be facilitated by allowing the use of both runways for arrivals or departures under prescribed circumstances.[13]

Current year (2010/11) spending on railways was reported as £7.584 billion (HM Treasury, 2011). Major schemes under development are Crossrail (scheduled for 2018) and the HS2 scheme from London to Birmingham (410 track km to be opened in 2026) and subsequent extensions (HS2+) to Leeds and Manchester (1072 track km to be opened in 2035) (HS2, 2011) HS2 would effectively increase capacity by 4.6%. In practice, it will be a greater than this: segregating homogenous high speed services will mean that initially 10 trains per track per hour will be provided on the busiest section, with an aspiration for this to reach 18. By contrast the average for the rest of the system is less than 2 per hour. Removing fast trains from the West Coast Main Line would also mean more homogeneous train speeds on that line which would also increase potential capacity.

Analysis for the 2010 White Paper implies demand of around 44 million passengers per annum for HS2 but around 57% of these would be abstracted from existing rail. The net gain of around 19 million passengers is small compared to the 1260 million journeys made on the National Rail network (1.5%). However, the mean trip length of current journeys on the National Rail Network is only around 40 km. For HS2 it might be in excess of 200 km. This would suggest an increase in passenger km of around 7.5%.

The main policy and technology options are associated with the carbon reduction targets. Conventional vehicle technology advances will reduce emissions and individual vehicle fuel consumption but in the past this has been counteracted by increased car use and/or the use of heavier/more luxurious vehicles. Fully electric and hybrid vehicles seem likely to gain a significant penetration of the car market but the timescales are difficult to predict, being dependent on advances in battery technology to increase range, allowing longer trips to be made, and the extent to which consumers overcome range fears. Other future fuel sources include biofuels and hydrogen fuel cell technology. The infrastructure requirements for electricity and other alternative fuel technologies will be large and may inhibit their rate of growth. Rail electrification will increase.

The increase in use of electricity in transport will have a significant impact on energy infrastructure and on electricity prices. The switch from highly taxed petrol/diesel to lower taxed electricity will also have an important fiscal impact, requiring government to reduce expenditures and/or find alternative income streams. Road user charging could be one such income stream. Glaister and Graham (2004) estimated that a national congestion charging scheme would increase car costs from 10.4p per km to 15.2 per km at 2003 prices, that is, an increase of 46%.

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13 http://cdn.hm-treasury.gov.uk/national_infrastructure_plan291111.pdf

Other policy options include parking charging and emissions trading. In extreme, a future policy option could be personal carbon credits and there may be tighter land use planning controls.

Transport efficiency could improve through growing utilisation of 'embedded' technologies, resulting in 'intelligent' vehicles, using combinations of ever cheaper sensor technology with real-time GPS tracking, vehicle-to-vehicle and vehicle-to-infrastructure communications and enhanced data processing and modelling, resulting in better optimisation of UK-wide transport networks, increased fuel efficiencies and reduced levels of congestion, alongside better freight management systems. Possible developments in aviation include open rotary engines and blended wings, while a possible development in shipping is the sky sail. Solar and nuclear power may be used by both air and sea transport but there is likely to be a continued high dependency on fossil fuels and close substitutes (biofuels).

The overall demand for personal transportation could be reduced if attitudes towards cycling, car-sharing, home-working and the use of public transport could be changed, although without a reliable and cost-effective public transport system, such changes may be difficult to achieve.

4.2.3.2 Risks

Future energy availability might constrain demand. In the short term, the price of oil will be a significant factor influencing the level of demand for transport, particularly for the use of private and freight road vehicles. Demand will be highest where prices are relatively low, combined with high GDP and population growth.

In the medium term, a risk may be the failure of uptake of new technologies, or if there is a lock in to a sub-optimal technology (e.g. plug-in electric vehicles rather than battery swaps).

In the longer term, climate change may require large-scale infrastructure adaptations to be made. For example, materials may need to be more resistant to extremes of temperature and infrastructure may need to be adapted to deal with greater variations in precipitation and rises in sea levels. Significant changes in the energy market for transport and other sectors could have significant impacts on requirements for port infrastructure; changes to fuel imports in the future will affect many aspects of fuel shipping and storage.

4.3 WATER SUPPLY

Great Britain supports a diverse range of consumptive and non-consumptive uses for water, all of which possess stringent levels of service with respect to both water quantity and water quality dictated by a complex legislative and regulatory framework. As well as significant geographical and seasonal variability, pressures including escalating consumptive demand, an ageing and deteriorating infrastructure, affordability, and a potentially critical redistribution of resource under future climates. This provides a potent set of challenges for the water sector through the 21st century. It is unlikely that even revolutionary change in the behaviour of consumers will be sufficient to alleviate such pressures without additional investment in infrastructure. Thus, a broad programme of measures combining systematic management of supply capacity and the growth in consumptive demand across all users of the water environment is necessary.

4.3.1 THE INFRASTRUCTURE SYSTEM

The water environment of GB consists of coasts, estuaries, rivers and lakes, and groundwater sources. It supports a wide spectrum of uses both consumptive and non-consumptive, with variable requirements of both water quantity and water quality (Table 14). Consumptive uses alter the quantity or quality of water available to other users; non-consumptive uses do not. Both may involve the relocation of water.

In order to meet consumptive (and some non-consumptive) demand, the abstraction, re-purposing or relocation of water is necessary, achieved via networks of infrastructure capable of aggregating, treating and distributing water from many sources. This infrastructure aims to provide water that is fit for purpose at the point of use, subject to specified levels of service defined by continuity of supply, pressure and water quality that vary according to the intended use. It typically comprises dams that regulate river flows and create artificial lakes; means of abstracting raw water from tidal sources; groundwater sources; non-tidal rivers and lakes; treatment works for rendering abstracted water suitable for consumption; and networks of conduits and local storage facilitating the transmission of either raw or potable water to the point of use.

Flood defence infrastructure on rivers and costs reduces the risk of flooding. Urban drainage systems mostly have a dual function shared with sewage infrastructure, as discussed in Section 4.4.

All consumptive uses of water, and some non-consumptive uses, require elements of infrastructure. Their locations, and quantification of their interactions with the water environment, are necessary for a fully comprehensive analysis of the water supply infrastructure. Although a database of physical water infrastructure asset ownership and operation across all sectors is unavailable, it is probable that the public water supply constitutes the greatest volume of infrastructure.

The performance of the system is defined by the balance between the demand for water and the capacity of infrastructure components to abstract, store, treat, and deliver water to consumers; however, only a finite volume of water exists in the environment at any one time, shared between all consumers, including the environment itself. Thus, the performance of water supply infrastructure is constrained by the availability and quality of raw water in the environment. This is a function of climate as well as land-use and management practices, and requires regulation to ensure that exploitation of the water environment by one sector does not impinge disproportionately upon the uses of water by other sectors.

Table 14: The classification of water uses as consumptive or non-consumptive

Consumptive uses of water	Non-consumptive uses of water
Agriculture and irrigation	Environmental regulation
Electricity generation (as cooling)	Hydroelectric electricity generation
Industry and manufacturing	Recreation
Public water supply	Transportation

It is not a national system of infrastructure: abstraction, impoundment and other interactions with the water environment are only possible where sufficient water exists; thus, regional or local networks distinguished by hydrological boundaries and asset ownership have developed around these foci. Few strategic interconnections exist between regions, but those that do are indispensable.

The regulation, planning and management of water resource occurs on the scale of these regional networks; strategic oversight is accomplished via a number of independent bodies with well-defined but limited remits.

In England and Wales, water utilities are in private ownership regulated by Ofwat (the economic regulator), the Environment Agency of England and Wales (EA – the environmental regulator) and the Drinking Water Inspectorate (DWI – the drinking water quality regulator). Scotland's only major actor in the water environment, Scottish Water, is state-owned and regulated via the Water Industry Commission for Scotland (WICS), the Scottish Environmental Protection Agency (SEPA) and the Drinking Water Quality Regulator for Scotland (DWQR) (see Figure 12).

Targets for the regulation of the water environment are established by the EU and enshrined in UK law; however, it is the responsibility of the UK to implement and enforce them.

4.3.1.1 Water abstraction

Between 1995 and 2008, more abstraction was made from non-tidal surface waters than from either tidal surface waters or groundwater sources (Figure 28).

Abstraction for electricity generation and public water supply combined accounted for around 85% of abstraction from all surface waters between 1995 and 2008, while the public water supply represented 75% of abstraction from groundwater sources for the same period.

Whether for consumptive or non-consumptive use, the electricity generation sector usually constitutes the principal consumer of water abstracted from the tidal (Figure 29, overleaf) and non-tidal (Figure 30, overleaf) surface waters of England and Wales. Its demand is volatile; abstraction for hydroelectric electricity generation in particular is depressed during periods of intense water scarcity and increases opportunistically when water is relatively abundant; abstraction for public water supply is generally more uniform (Figure 31, overleaf), and is consistently the largest abstractor from groundwater by volume (Figure 32, overleaf).

Figure 28: The division of abstraction between water sources in England and Wales by volume (1995–2008 data).

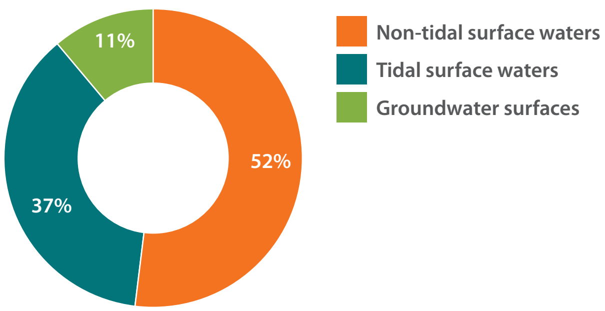


Figure 29: Estimated abstraction from tidal surface waters (England and Wales).

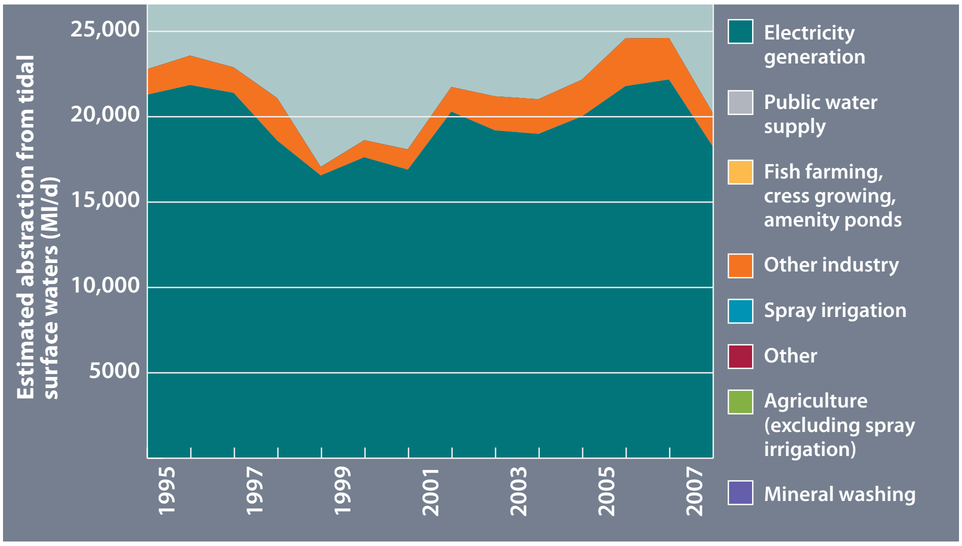


Figure 30: Estimated abstraction from non-tidal surface waters (England and Wales).

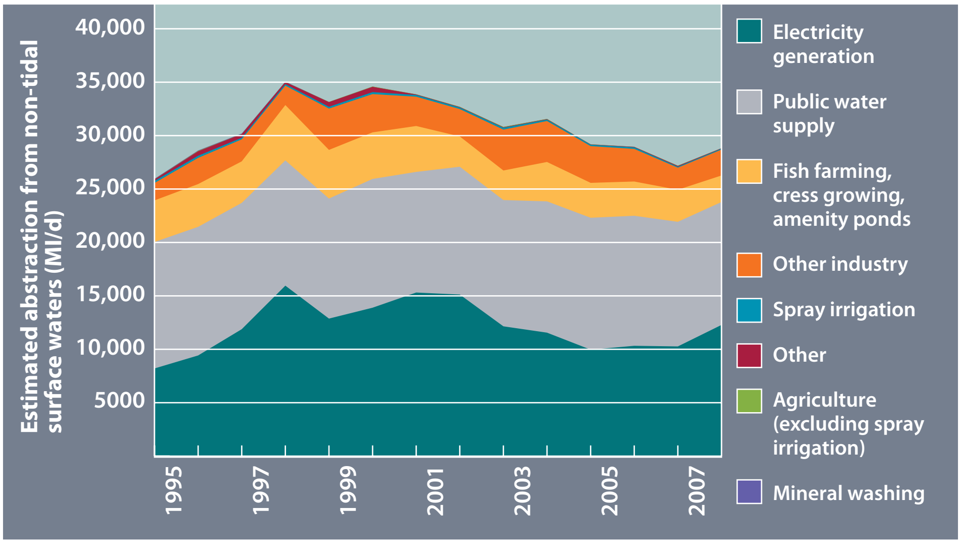
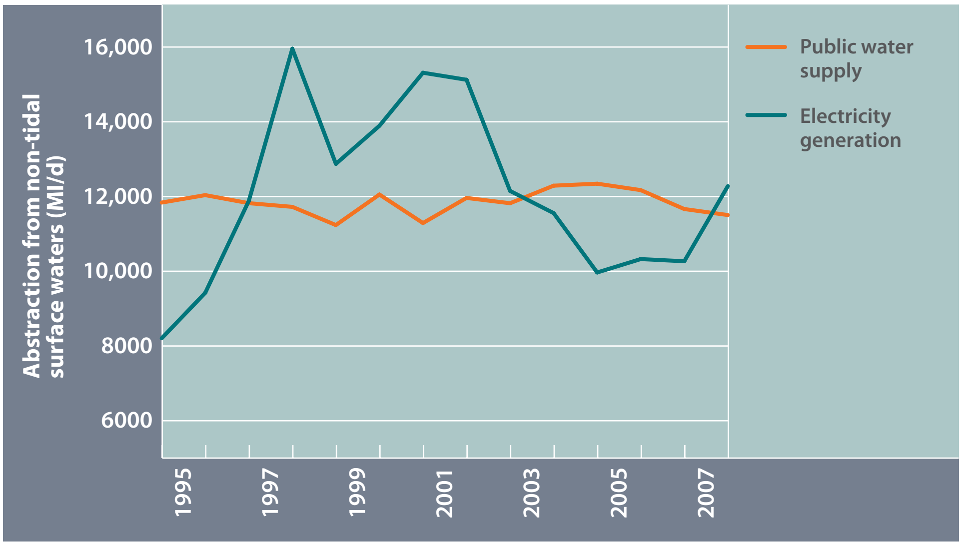


Figure 31: Abstraction from non-tidal surface waters for the electricity generation and public water supply sectors (England and Wales).



The public water supply is the principal abstractor from non-tidal surface and groundwater sources, composing some 45% of total abstraction from these sources by volume on average between 1995 and 2008 (Figure 33).

There are some important regional differences, determined by environmental constraints and land-use management decisions.

Table 15 indicates that abstraction from non-tidal sources in Wales and abstraction from tidal surface waters in the northwest of England constitute 17% and 11% of all abstraction in England and Wales between 2005 and 2008, respectively. Further subdivision by sector indicates that this is ostensibly attributable to abstraction for electricity generation and, to a lesser extent, public water supply, in both cases.

Figure 32: Estimated abstraction from groundwater sources (England and Wales).

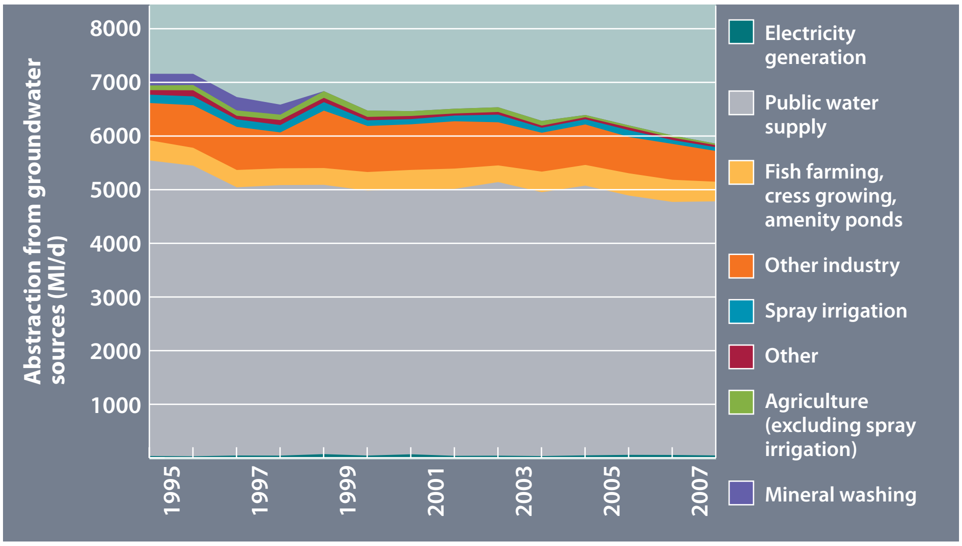


Figure 33: Abstraction from non-tidal surface waters and groundwater sources as a proportion of total abstraction from non-tidal surface waters and groundwater sources (1998 to 2005 data).

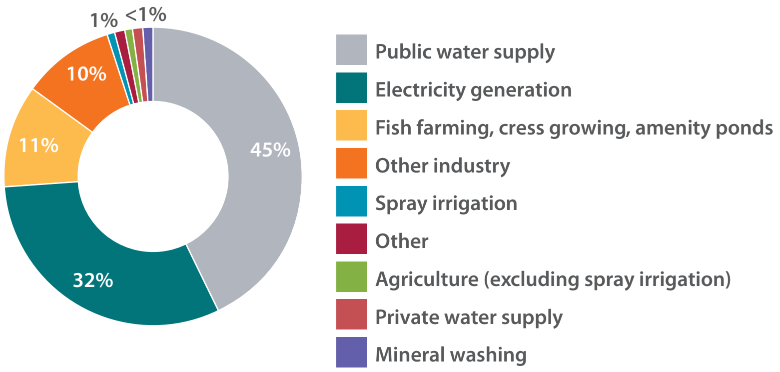


Table 15: The proportion of national abstraction contributed from each source by each Environment Agency region (2005–2008 data)

EA region	Groundwater sources (%)	Non-tidal surface waters (%)	Tidal surface waters (%)
Anglian	2	3	7
Midlands	2	8	2
North East	1	8	4
North West	1	4	11
South West	1	6	4
Southern	2	2	8
Thames	3	5	2
Wales	0	17	0

4.3.1.2 Public water supply

Great Britain possesses a large public water supply infrastructure network, many fundamental components of which are antiquated remnants of the country's industrial heritage: reservoirs and aqueducts constructed at massive financial, human and environmental expense over the preceding 150 years. Supplemented and augmented by more recent developments, the lifetime value of these assets is almost incalculable, although some estimate £250 billion (Water UK, 2009), and significant periodic investment is necessary to mitigate deterioration. Total investment in the water supply of England and Wales since 1990 now exceeds £80 billion (Water UK, 2009), and continues to grow at a rate greater than £4 billion per year (EA, 2008b; Water Industry Commission for Scotland, 2011).

Metrics to assess the performance of the public water supply include the pressure of water at the point of delivery, the frequency and duration of service interruptions, and the frequency and duration of restrictions on the use of water. A particular example of the latter, the number of drought orders issued across GB exhibits a decrease between 1976 and 2008 (Figure 34) and in particular since privatisation of the water industry in 1989; however, it should be noted that this may not be a robust performance metric as the granting of Drought Orders involves multiple considerations (ASC, 2011).

Across England and Wales, the public water supply constituted only 8% of all abstraction licences in force in 2008, and 21% of the total licensed abstraction, but accounted for almost 50% of estimated actual abstraction from non-tidal surface and groundwater sources of water. Public water supply networks serve almost 100% of the population of GB, with few, isolated, local exceptions, and comprises over 1000 reservoirs, nearly 3000 water treatment works (House of Lords Science and Technology Committee, 2006) and 450,000 km of conduit (Drinking Water Inspectorate, 2011). Although not necessarily indicative of poor performance, a significant proportion of these infrastructure assets are underground and of variable age and condition. Approximately 17,000 Ml/d are supplied with a total capacity of some 20,000 Ml/d (Ofwat, 2011b).

Figure 34: The number of drought orders issued in GB.

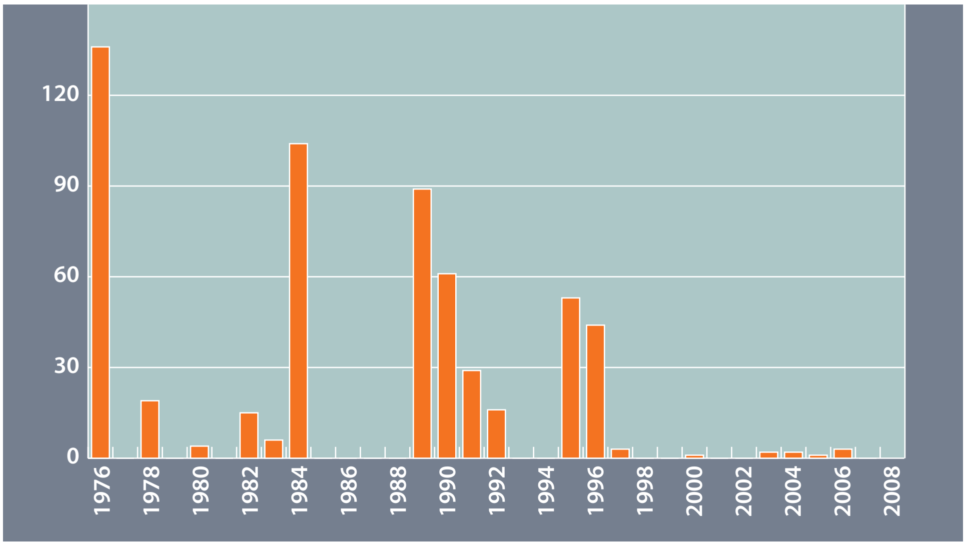


Figure 35: The ownership of water supply undertakings in the UK by revenue as a proportion of total revenue (OFT, 2010).

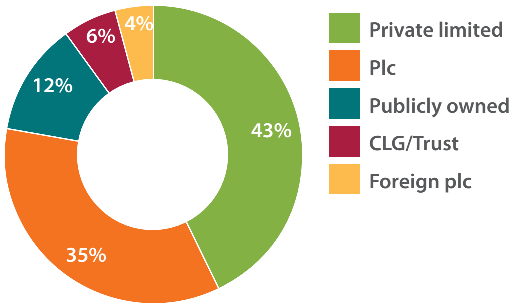
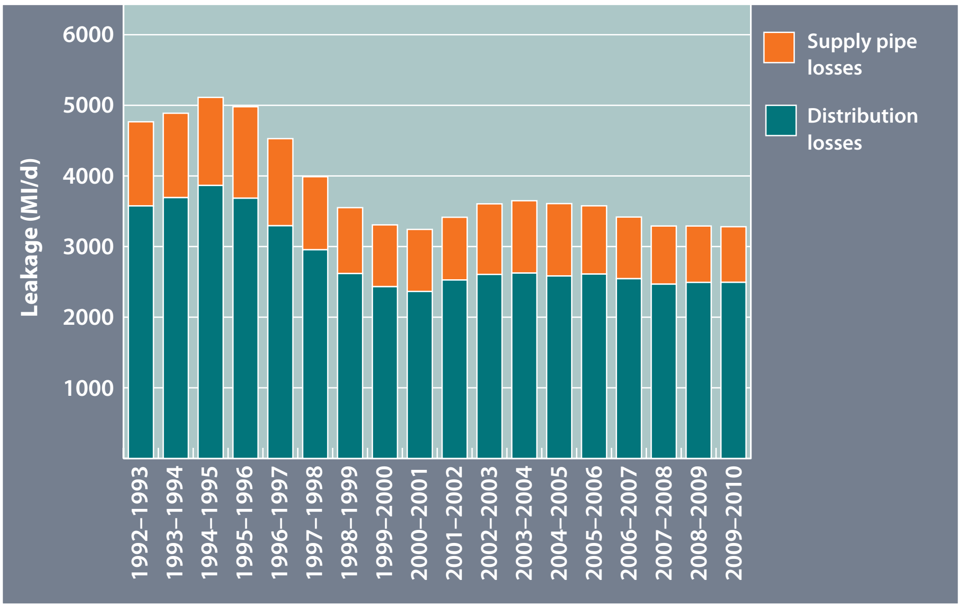


Figure 36: The volume of water lost from the water supply infrastructure of England and Wales, 1992–2010 (Defra, 2011c).



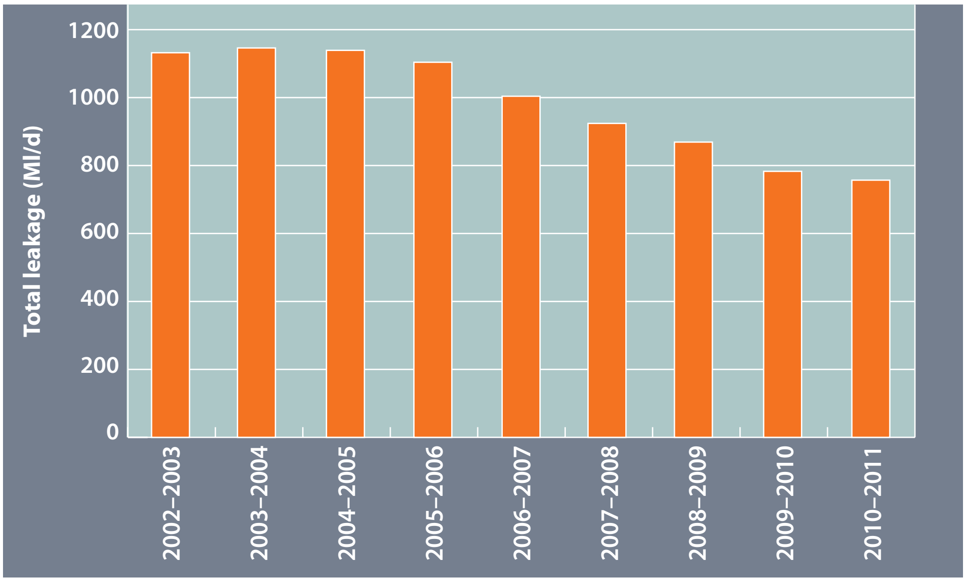
The majority of water supply undertakings are under private ownership (Figure 35, previous page), derived from historical patterns of ownership, demand and investment. This is reflected in the spatial distribution of the capacity of the water supply infrastructure, which exists as regional networks with fragmented offshoots serving populations of consumers too remote for connection to the regional networks in a cost-efficient manner.

Contemporary models highlight 11 million households across the south, southeast and east of England as being of 'serious water stress' to an extent necessitating the imposition of mandatory measures intended to reduce the demand for water across the regions (EA, 2011).

Approximately 20% of the water put into the public water supply is lost via leaks in distribution and local supply infrastructure. Subject to an annual investment of some £2bn in asset remediation, the volume lost per day in England and Wales fell by over 30% between 1992 and 2010 (Figure 36, previous page), and also by a similar proportion in Scotland between 2002 and 2011 (Figure 37), the total loss from the network exceeds 4000 Ml/d by some accounts (Water UK, 2010). This is sufficient for the needs of some 25 million people of average consumption behaviour. In Scotland, the volume of water lost per property can be between two and six times that lost per property in England and Wales; however, losses per kilometre of network are comparable (Ofwat, 2008).

Exhibiting a range of some £55m, there is significant variability in the rate of investment in leakage reduction between the 10 largest water service providers, contingent on a number of economic and environmental factors.

Figure 37: The volume of water lost from the water supply infrastructure of Scotland, 2002–2011. http://scotland.gov.uk/Publications/2011/09/05154117/24



4.3.2 ROLE OF INTERDEPENDENCE

4.3.2.1 Energy

There is a two-way interdependency with the energy sector, which requires water for cooling and hydroelectric electricity generation, while the water industry consumes significant electrical energy through the pumped abstraction and distribution of water and the treatment of abstracted water for consumption. Flooding (i.e. a surplus of water that exceeds the capacity of the water infrastructure), poses a significant hazard to energy infrastructure in particular.

Consumers of water typically couple their consumption of water and energy through the heating of water in cooking and cleaning, and the cooling of their environments via air conditioning, and further demands on energy are likely to arise from many of the technological adaptations to increased water scarcity (e.g. desalination, pumped storage, inter-basin transfer, effluent recycling, etc.).

4.3.2.2 Transport

Historically, the transport network has provided a means of transporting water during emergencies; the movement of water bowsers via road to remote areas disconnected from the main regional water supply networks remains a key component of many providers' drought plans.

4.3.2.3 Waste

Leaching from landfill poses a potential risk for contamination of the natural and engineered resources comprising the water supply infrastructure network. There may be potential for transporting elements of solid waste via the conduits of the wastewater network, which relies on a sufficient supply of water.

4.3.2.4 Wastewater

Water consumption, in combination with other biological processes, naturally generates a demand for wastewater conveyance and treatment. However, the wastewater system is affected by the volume of water entering; hazardous flooding and failure of the wastewater system may result if the capacity of the network is exceeded, but a paucity of water entering the wastewater infrastructure network may result in an inability to convey and treat wastewater effectively and safely.

Insufficient river flows at the point of discharge from wastewater treatment works, whether from natural variability or anthropogenic influences, may also limit the ability to treat and discharge wastewater safely.

Effluent recycling, which is an increasingly popular technological intervention, relies on the wastewater infrastructure network to convey raw material and waste products.

4.3.2.5 ICT

The management of water resources is increasingly reliant on ICT, with real-time telemetry playing an increasingly important role. Failure of the related ICT components could precipitate a diminution of the water supply network capacity. As for energy, water is often necessary for cooling of large data centres. The resurgent interest in, and subsequent growth of, such infrastructure may indicate a growing demand for water by the ICT sector.

4.3.3 KEY ISSUES

The water supply infrastructure must meet consumers' demands for water, but competition for the limited quantity of water in the environment and the capacity of the infrastructure to provide water that is fit for purpose at the point of use constrain its performance. Much of this conflict occurs as a consequence of the changes in consumers' demands for water associated with the transition of the UK from an industrial to a post-industrial society, compounded by persistent pressure to improve continually the benefit of water use to all consumers, including the environment.

The majority of the existing strategic water supply infrastructure of the UK resides from the industrial expansion of the 19th and 20th centuries. It is expensive to maintain and extend, requires constant investment and intelligent management to remain effective and relevant, and exists in discrete management areas inherited from historical patterns of demand and infrastructure asset ownership that possess limited interconnectivity. Its cost, design lifetime, semi-permanent nature and location limit its flexibility to meet rapid changes in use, as do the mechanisms of regulation imposed and the available methods of raising investment.

There are two commonly cited adaptation measures: constrain consumers' demand for water, thereby prolonging the useful life of existing infrastructure assets, and improve the capacity of infrastructure in order to meet demand.

4.3.3.1 Infrastructure options

Table 16: The demand-side interventions available to the water sector

Demand-side interventions	Description
Non-revenue water (NRW) / leakage reduction	• NRW includes controlled and uncontrolled losses from the water infrastructure; • In 2008, NRW accounted for 25% of water input to the public supply (Water UK, 2010); • Between 2002 and 2010, annual investment in assets of £2 billion reduced leakage by 105 Ml/d each year; • Potentially reducible to zero losses, although there is no economic incentive to do so.
Water metering and smart-metering	• Most household consumers of water are charged a flat rate per annum; • Per-volume charging via metering of each household provides improved information on consumption patterns and losses; • Annual reporting window (or better); • Allows for more targeted investment; • Often has the benefit of inducing behavioural change in consumers.
Per-volume charging and tariffs	• Active mechanism for inducing behavioural change by charging consumers based on patterns of consumption; • Differential charging by volume; • Existing economic models unproven with respect to consumers' demand for water.
Education	• It is believed that most consumers of water are wasteful through ignorance; • Coupled with other measures, education of consumers provides them with additional information; • Armed with this information, it is thought that their behaviour will change to become less wasteful in their patterns of water use.
Water efficiency improvements	• Many technological interventions are possible that reduce water consumption without the need to elicit significant behavioural change in consumers; • Some technologies, although effective, are not cost effective at the household level (e.g. rainwater harvesting).

There are a number of interventions available which either reduce the consumptive demand for water, or which directly augment the capacity of the water supply infrastructure network and/or the water resources of the natural environment. They are divisible into demand-side measures (Table 16) and supply-side measures (Table 17).

Table 17: The supply-side interventions available to the water sector

Supply-side interventions	Description
Abstraction from rivers and groundwater	• The majority of water abstracted in GB is sourced from non-tidal surface waters and groundwater; • These resources possess a threshold beyond which further abstraction is infeasible without damage to the environment; • Most of the natural resources of England and Wales are either approaching, or are beyond, this threshold (EA, 2011); • Further development of rivers and groundwater is unlikely to be entertained in the south, south east, and east of England; • Susceptible to climate change.
Reservoirs	• Reservoirs allow the adaptation of rivers or naturally occurring surface water bodies to provide a less variable, more reliable, source of water; • The use of reservoirs to augment river flows and thereby facilitate river abstraction is preferable to direct abstraction from reservoirs; • Large capital costs and land-use change; • Historically designed to meet specific needs, often in the face of significant public opposition, and difficult to redeploy flexibly; • Useful for establishing the means to meet baseline demand; • Time consuming to build, fill and recharge; • Susceptible to climate change.
Inter-basin transfers	• Relatively expensive means of transporting either raw or treated water between demand centres; • Particularly dependent on energy availability and cost; • Powerful and flexible means of redeploying water resource for short periods during times of excessive water stress; • Requires an excess of water resource at donor locations, which may require the construction of other resources; • Un-quantified environmental costs; • Used extensively elsewhere in the world where water is scarce or where populations are remote from water resource.
Desalination	• Relatively expensive means of meeting peak water requirements; • Particularly dependent on energy availability and cost; • Can be placed anywhere there are brackish or saltwater resources; • Conceptually robust to climate change; • Produces waste byproducts; • Used extensively elsewhere in the world where water is scarce.

Table 17 (ontinued)	
Supply-side interventions	**Description**
Effluent recycling	• Converts wastewater into potable water; • Conceptually robust to climate change; • Feasible anywhere wastewater is produced; • Hazardous byproduct.

4.3.3.2 Risks

The water supply sector faces future pressure from two directions.

Firstly, total water abstraction must meet the demands of consumers according to the specified level of service, driven primarily by abstraction for the purposes of public water supply. Future growth in demand is likely to be due to the increasing population of domestic consumers, and, to a lesser extent, the population of non-domestic consumers. For future levels of service to remain constant, or increase, there will need to be a reduction of the per-capita demand for water through behavioural change, technological intervention, or capital investment in the infrastructure network to improve its efficiency; however, there are hard limits to the impact of any one method of reduction, particularly in the absence of incentives for the further reduction or elimination of leakage (Walker, 2009).

Secondly, the performance of the infrastructure is constrained by resource availability. In addition to the traditional inconveniences of conveying water from locations where it is most plentiful in the environment to centres of distribution and demand, it is evident that climate variability has uncertain impact on the distribution of water both geographically and seasonally. The critical concern is that existing resources located in regions anticipated to experience the greatest negative change in water availability will become unable to meet existing levels of service.

Modelling of the impact of climate change on water resource has, until very recently, been rudimentary in its analysis of the inherent uncertainties. Such analyses, undertaken by water service providers, suggest a national aggregate decrease in the deployable output of water resources of some 3% by 2034–2035.[14]

More sophisticated analysis of the impact of climate change on mean river flows using 11 models of a comparable scenario show spatially variable impacts across GB by the 2050s (EA, 2011), the majority of the country projected to experience increases in winter of up to 40%, and decreases in summer of up to 80%. This could have particularly profound impacts on regions without strategic storage that are dependent on abstraction or regional from river sources.

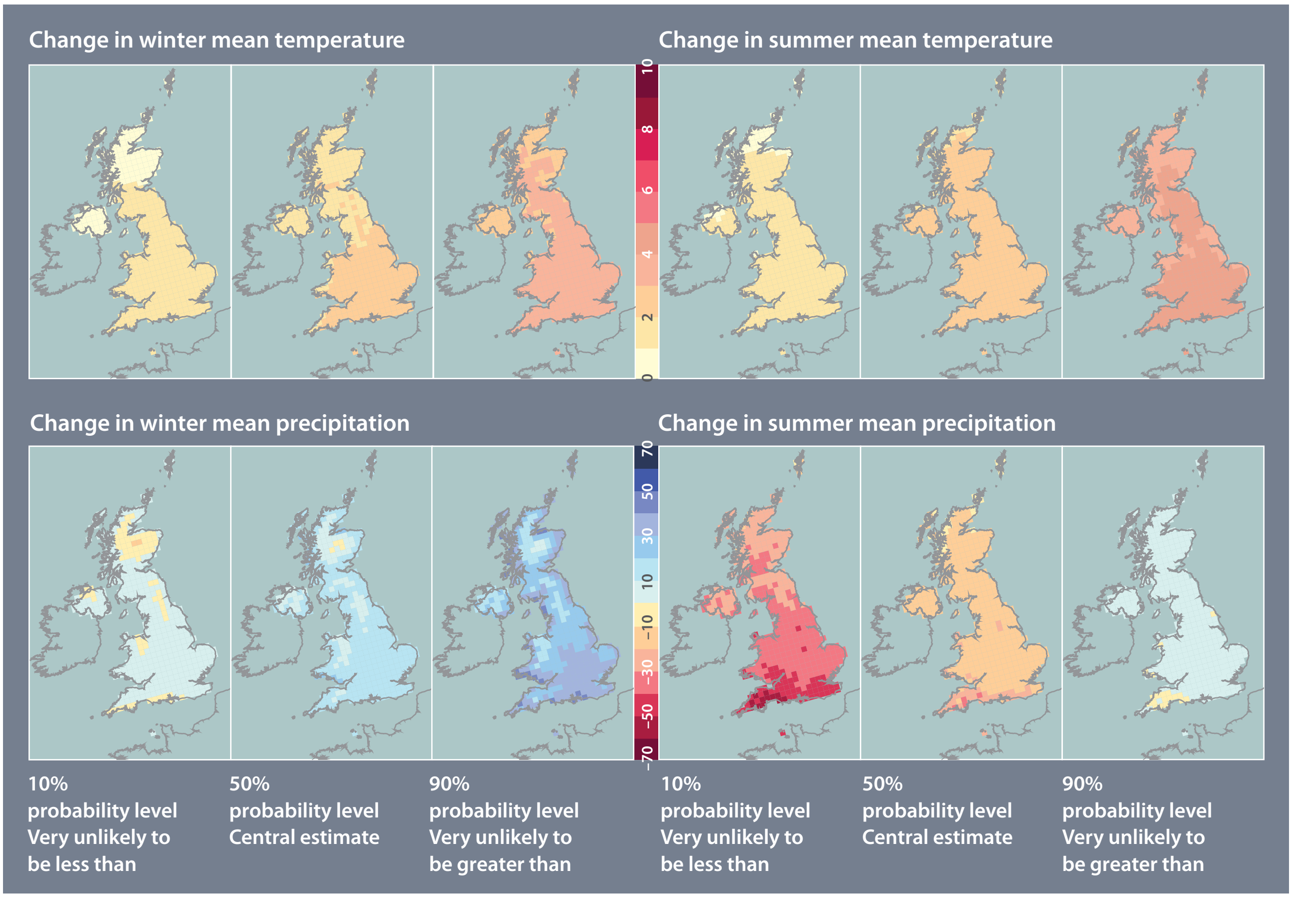
14 From water companies' AMP5 Water Resource Management Plans.

Precipitation and air temperature are key indicators of water availability: the former determines the total amount of water entering the environment, while the latter plays a crucial role in determining the amount of water available for use. UKCP09 projections for the 2050s under the Medium emissions scenario (Figure 38) suggest:

- The central estimate of projected increase in the mean winter temperature is < 2ºC (0.6 to 3.0ºC) across Scotland and the north of England, and < 2.2ºC (1.1 to 3.5ºC) across the rest of GB.
- The central estimate of projected increase in the mean summer temperature is < 2.7ºC (0.9 to 4.6ºC) across GB.
- The central estimate of projected increase in winter mean precipitation is 9–17% across GB (1 to 38%).
- The central estimate projected decrease in summer mean precipitation is 10–20% across GB (–41 to +7% change).

The values in brackets reflect a projected wider range of uncertainty. The values are, respectively, the value that the projected change is very unlikely to be less than to the value that the change is very unlikely to more than.

Figure 38: Changes in winter mean temperature, summer mean temperature, winter mean precipitation and summer mean precipitation projected for the 2050s under a Medium emissions scenario (© UKCP09 Climate Projections, 2009).



The Government White Paper 'Water for life' (Defra, 2011d) warns that current water stress is set to worsen and makes several proposals to enable more efficient abstraction whilst maintaining environmental protection. Key commitments are reform of the regulation of abstraction to enable transitions under climate change and increasing interconnection and the trading of bulk supplies of treated water. A further commitment is for Government, the Environment Agency and the water industry to consider whether strategic NI projects are required.

Adaptations to this increasing vulnerability include superior distribution of existing water resource through inter-basin transfers and the development of new sources via impoundment or desalination. All are long term strategies incurring significant capital and operating costs, and face uncertainty as to their future performance and financial viability. In addition, there are major issues of affordability and governance requiring resolution.

Contemporary estimates of the impacts yielding a risk-based approach to analysis are forthcoming; however, they are not available at this time.

4.4 WASTEWATER

In its day, the provision of sewers, and latterly sewage treatment was a triumph of British engineering and a totemic example of civil works as a civilization. Today there are over 347,000 km of sewers collecting over 11 billion litres of wastewater every day. There has been extensive investment in wastewater treatment in order to improve water quality standards in rivers and coastal waters, though improved treatment standards has raised energy costs. Energy use in wastewater treatment now averages roughly 300 MW. Both sewage treatment and sewerage are capital intensive, with a long design life ranging from 40–100 years. Options that would reduce or eliminate energy input to wastewater treatment are needed to ensure the future affordability of service. Projected changes in rainfall patterns due to climate change and major and minor flooding pose a risk to the existing drainage infrastructure.

4.4.1 THE INFRASTRUCTURE SYSTEM

The wastewater sector consists of networks of sewers, pumps and sewage treatment works that vary tremendously in size with most people being served by a relatively small number of large systems and small numbers of people being served by a relatively large number of smaller systems. Large systems are typically far more efficient. These infrastructure systems have a long design life: 40–50 years for the civil works in sewage treatment plants and potentially over 100 years for the sewerage infrastructure. Though sewerage assets are still functioning adequately 150 years after construction, change to many of the assets could imply a very significant write off cost.

The overall strategy of large reticulated sewers collecting wastewater and surface drainage that is transported to a centralized treatment facility is 19th century in origin. Sewers were proposed to meet fears about the health, and associated economic impacts of miasma.[15] Sewage treatment technologies were then developed to prevent the associated river pollution. The relevant technologies are still sometimes referred to as public health engineering. Miasma are no longer feared and the public health aspects of sewerage and sewage treatment are now often overlooked or forgotten.

15 Miasma was considered to be a poisonous vapour or mist filled with particles from decomposed matter (miasmata) that caused illnesses.

Nevertheless, strong evidence, both epidemiological (Germany in 1946) and anecdotal (Iraq in 2007) suggests that a breakdown or abandonment of the sewerage infrastructure will lead to severe public health problems both today and in the future.

The management philosophy and the technology for sewerage and sewage treatment have evolved over the years. These changes are frequently driven by increases in environmental standards, latterly driven by European legislation. However, rising customer expectations and the introduction of new technology (often, but not always, in response to environmental regulations) can also drive change. At its best the industry considers the entire network holistically, integrating loads placed on the sewerage network by people and rainfall with the location and performance of the treatment plant and the capacity and sensitivity of the environment. However, such an effective and integrated approach is not always attained.

Improvements to the infrastructure system, though substantial, have been largely incremental; it is widely recognized that step changes may be required to cope with plausible change in energy costs, climate, carbon-costs and environmental regulation in the future.

Capacity and demand

Today there are over 347,000 km of sewers which collect over 11 billion litres of wastewater per day which is treated at around 9,000 sewage treatment works before being discharged to inland waters and the sea (Defra, 2002). It accounts for the majority of the total asset value of the UK water industry (> £250 billion), with capital expenditure on sewerage services programmed to exceed £12 billion between 2010 and 2015 (Ofwat, 2009). The system requires sustained multi-billion pound investment to remain operational, efficient and to ensure compliance with environmental regulation. The services are owned and managed by the 10 regional water companies in England and Wales and by state owned Scottish Water respectively. The private companies in England and Wales are subject to economic regulation overseen by the Office of Water Regulation. Environmental regulation, which is key to the industry, is overseen by the Environment Agencies for England and Wales, and Scotland.

The energy required to collect and treat 1 Ml of wastewater in England and Wales varies with location and effluent standards, typically varying between 600 kWh/Ml and 800 kWh/Ml: a figure that is broadly in-line with other countries, despite recent attempts to reduce it (Figure 39, overleaf).

For the same regions, greenhouse gas emissions per mega-litre of wastewater treated increased from 0.64 tCO_2e to 0.70 tCO_2e between 2004 and 2010 (Figure 40, overleaf).

A key performance metric of the wastewater infrastructure network is the frequency and severity with which the volume of wastewater collected by the network exceeds its hydraulic capacity, of which there are two principal consequences: intermittent discharge from the sewer network into receiving waters, and flooding.

There are approximately 25,000 intermittent discharges from the sewer network across England and Wales. Investment influenced by a number of water quality and aesthetic drivers, including the Water Framework Directive (2000/60/EC) and its subordinate instruments, has dramatically reduced the number of these considered unsatisfactory (Figure 41, overleaf).

Figure 39: Energy consumption attributable to wastewater collection and treatment by the UK water industry 2002–2007.

Figure 40: GHG emissions attributable to wastewater treatment by the UK water industry 2004–2010.

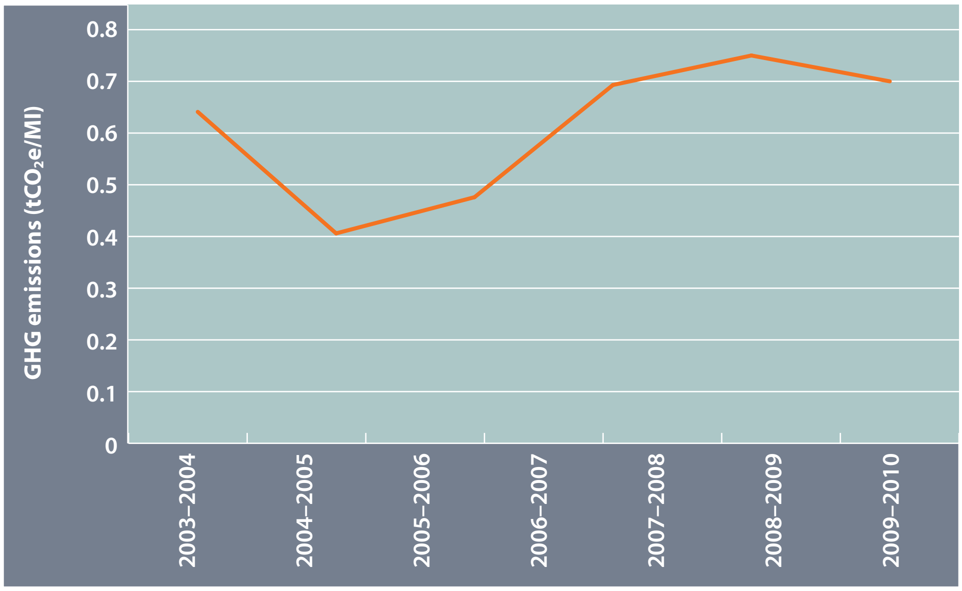
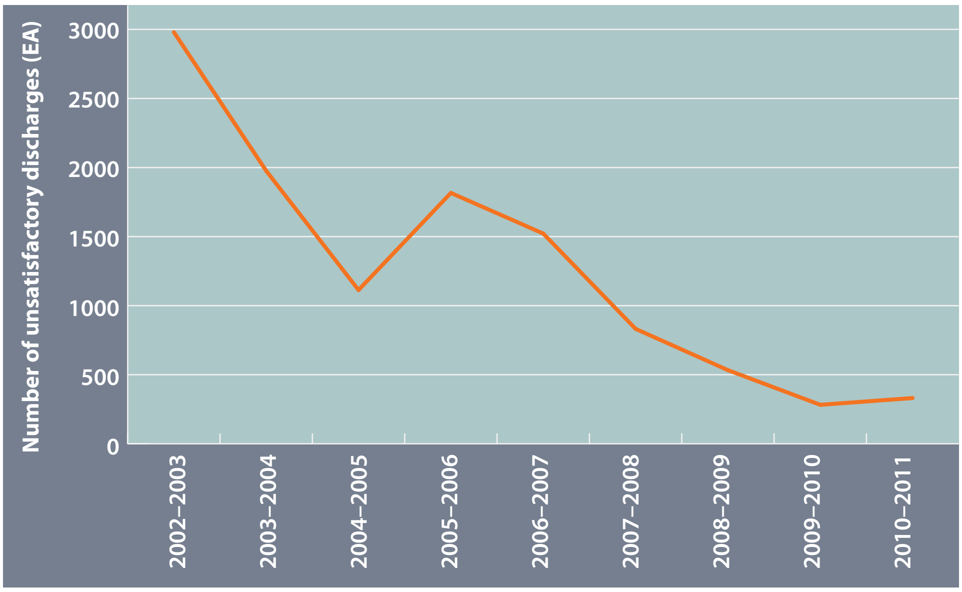


Figure 41: The number of unsatisfactory intermittent discharges in England and Wales, 2002–2011 (Ofwat, 2007; Ofwat, 2010).



The Thames Tideway is a major scheme of this type, collecting 39 million tonnes of sewage per year from 35 of the most polluting discharges on the River Thames. With an estimated cost of some £3.6 billion, it comprises a programme of improvements to five sewage treatment works and some 30 km of tunnel anticipated to reduce both spill frequency and volume by around 95%.

Between 1990 and 2010, around 0.03% of properties in England and Wales remained subject to flooding from sewers although the proportion of properties at risk from sewer flooding declined over the same period (Table 18).

Demand for wastewater treatment is a function of population and industrial growth and the costs are dictated by the technologies and effluent standards. The prevalence of energy-intensive processes within the existing wastewater treatment infrastructure, coupled with the long design-life of infrastructure assets, creates a binding interdependency between the wastewater sector and energy prices. The energy demand is affected by the effluent quality and so plausible climate change scenarios might lead to greater demand for wastewater reuse and lower flows in receiving waters and thus higher standards and even greater energy demands. Population density is more important than the total population for both sewerage and sewage treatment and is vital to the scaling of cost and the relative merits of maintaining the existing large-scale networks or transitioning to a new, decentralised system.

Demand for the drainage function is strongly linked to the rainfall and land use. Changes in the intensity of rainfall would be a particular issue and, in certain areas, changes in land use. Finally economic changes and the related cost of capital are particularly important to both sectors. Though obviously physically linked, the drainage and treatment functions of the system have differing drivers and interdependencies.

Table 18: The performance of the water industry in England and Wales with respect to sewer flooding: 1990–2010 (Ofwat, 2010).

Description	1990–1995 (%)	1995–2000 (%)	2000–2005 (%)	2005–2006 (%)	2006–2007 (%)	2007–2008 (%)	2008–2009 (%)	2009–2010 (%)
DG5: Properties subject to sewer flooding incidents (overloaded sewers and other causes)	0.03	0.03	0.02	0.02	0.02	0.032	0.02	0.03
DG5: Properties at risk of sewer flooding incidents (once in ten years)		0.07	0.05	0.02	0.02	0.02	0.01	0.01
DG5: Properties at risk of sewer flooding incidents (twice in ten years)	0.08	0.05	0.02	0.01	0.01	0.01	0.01	0.01

4.4.2 ROLE OF INTERDEPENDENCE

The primary interdependency in wastewater treatment is the energy sector, since treatment and, to a lesser extent, transit are wholly dependent on a constant electricity supply. However, environmental standards may reflect the prevailing water resource (e.g. the need for reuse) and will affect costs, especially electricity demands. Other subtler interdependencies include agriculture and the demand for the water and nutrients in wastewater. Though the functioning sewerage system only impinges modestly on transport, any substantial revamping of sewers causes a great deal of disruption to road traffic.

4.4.3 Key issues

The sewerage network is designed to carry both the wastewater from the contributing population (about 150 litres/capita) and the run-off that depends on the amount of rainfall and land use. Change in any of these factors could lead to problems in system performance. However, the quantity of organic matter and other pollutants in the wastewater, and the effluent treatment standards primarily determine the wastewater treatment costs. As the generation of organic waste is inevitable, and it is inconceivable to not dispose of waste in a sanitary manner, affordability and sustainability are key issues especially with respect to sewage treatment.

The amount of organic matter is typically a function of the number of people served and is thus an inexorable fact of life. In some regions, industrial wastewaters, which are subject to seasonal and economic variation, are important. Energy use is a notable aspect of treatment costs and the energy use per unit volume of wastewater has been increasing steadily for a number of years. However, there is far more energy (8–17 kJ/l) in wastewater than is required to treat it, assuming that this energy can be utilised.

To enable the water industry to make the transition to a low carbon low energy future will require the implementation of technologies (e.g. zero power treatment plants) and management strategies (e.g. real time drainage management) that, though conceivable, do not yet exist in the UK. Three interlinked policy issues have been identified to assist in this process

- Economic regulation that permits and promotes transformative innovation to ensure that these technologies and management strategies are brought forward in a timely fashion;
- Excellent risk based environmental regulation to avoid overdesign and excessive running costs;
- Continued access to affordable capital to help minimise the costs of implementation.

4.4.3.1 Options

Both sewage treatment and sewerage are at present, capital intensive. A move towards more decentralised systems could permit much of the existing sewerage system to be abandoned. However, this would have to be set against the benefits of high-density living and the increased costs and lower effluent standards associated with smaller works. A more extreme option still would be to abandon the use of water to convey human waste all together and a return to a night soil system. Though treatment would still be necessary, resource capture would be facilitated. Such systems are in use in Japan and should be evaluated for British application. Neither decentralisation nor a night soil system would obviate the need for drainage, but they might simplify the provision of such infrastructure.

Options that would eliminate energy use in wastewater treatment would reduce the sensitivity of affordability to the price of energy. This is thermodynamically conceivable, as wastewater contains 16–20 kJ/k COD: more than twice the energy required to treat it. Wastewater treatment could, therefore, become energy neutral, or even a net energy producer. Furthermore, the resources in the waste, notably nitrogen and phosphorous are already becoming more valuable, the former due to the cost of energy, and the latter due to absolute scarcity. However the capture of these resources, nitrogen, phosphorous or energy at a reasonable scale presupposes the development of technologies that do not yet exist.

Table 19 summarises the range of technological options available for wastewater treatment. Specific energy demand will reflect the technology chosen with local variation attributable to geography and effluent standards. For example, the inclusion of UV disinfection to ensure compliance with bathing regulations may add 10% or more to the electricity demand of a treatment works.

Sludge disposal is a particularly important issue. Conventional aerobic treatment generates 800–900 kg of sludge per tonne of organic matter treated, while anaerobic wastewater treatment technologies (still experimental in temperate regions) yield approximately 100 kg/tonne. Although its disposal is costly, sludge is a significant source of energy (through anaerobic treatment and incineration or pyrolysis) and nutrients. Increasing the benefit of sludge generation via reuse on the land requires managing and meeting the needs and expectations of farmers, their customers in the grocery business and consumers, particularly with respect to issues of food safety. Wastewater reuse, though at present rare, is also heavily influenced by health concerns and standards.

Table 19: Summary of current and future technology options within the wastewater sector

Innovation ↓	Technology	Example	Energy cost	Relative sludge yield	Comment	Energy cost ↑
	Suspended growth	Activated sludge	Positive (High)	High	High-density, high-throughput technology; scope for energy reclamation	
	Attached growth	Trickling filters	Positive (Moderate)	Low	Reliable; infeasible on large scale	
	Extensive	Wetlands	Neutral (Zero)	Very low	Significant land area required; impractical in urban areas	
	Anaerobic digestion	Upflow Anaerobic Sludge Blanket (UASB)	Negative	Very low	Only used thus far in the tropics	
	Fuel cell	Microbial electrolysis	Negative	Negligible	Could be used to produce high-value products, e.g. H2	

Considerable investments have and will be made in sludge digestion in the UK. In principle, the capital efficiency of sludge digestion could be improved by digesting domestic wastes, especially food, in sludge digesters; however, this too must meet stringent public health criteria.

4.4.3.2 Risks

A key risk to wastewater infrastructure services is rising energy costs, which raise questions of affordability of treatment and operational costs. Hence, the development of options that reduce or eliminate energy use in treatment would help to reduce these risks. Similarly, more stringent environmental legislation is a risk which would demand increased capital investment. Another risk is a change in rainfall patterns and the risk of major and minor flooding as existing drainage infrastructure is found wanting in the face of more intense rainfall. Options in this eventuality include rebuilding the drainage system and the more intelligent management of the existing system, or an appropriate combination of the two.

More intense storm events could also precipitate the discharge of greater volumes of untreated wastewater from the infrastructure network: studies (UKWIR, 2006; EA, 2007a) suggest increases of up to 180% by the 2080s, coupled with between 3 and 12 additional spills per year, depending on location. To maintain current levels of service would require additional storage volumes of between 10 m^3/ha and 70 m^3/ha at a cost of some £15 billion, with particular stress placed on networks discharging to shellfish waters and/or waters supporting salmonids.

Although changes in the flow-to-treatment at wastewater treatment works are unlikely to seriously impede treatment processes: a decrease in water quantity in the receiving waters is significantly more hazardous to water quality, and may be exacerbated by regional changes in precipitation.

Finally, there is an overarching risk that technical and institutional inertia and complacency will prevent solutions being sought, found and implemented on a sufficiently rapid time scale to prevent technical or economic failure. There is a lack of urgency, funding and training with respect to the needs to transform this infrastructure in the 21st century. Research activity is low in relation to the asset base at risk, the environmental and economic consequences of failure and the required time scales of change. The conception and implementation of the necessary reforms, whatever they prove to be, will as great and as necessary a triumph as that of our 19th century predecessors.

4.5 SOLID WASTE

The UK solid waste sector deals with approximately 300 million tonnes of waste annually. In the last decade, the sector has transformed rapidly, responding to EU and national legislation. This has increased the amount of waste recycled, composted or reused and nearly halved waste going to landfill. Historically, economic growth and household waste generation were coupled, but there is some evidence that this may no longer be true. National and EU directives (e.g. possible banning of all biodegradable municipal waste to landfill in the next decade) for reducing solid waste will affect the levels of investment needed in the near term. There is the possibility of a complete paradigm shift towards solid waste becoming a resource recovery industry.

4.5.1 THE INFRASTRUCTURE SYSTEM

The solid waste infrastructure system includes both waste management and resource management (i.e. not only waste going to landfill but also resources reclaimed by recycling and processing). The infrastructure comprises landfill, material recovery facilities (MRFs);[16] transfer stations,[17] recycling or other processing facilities and incinerators. There are three main sub-systems of the infrastructure system, including collection, treatment and final disposal.

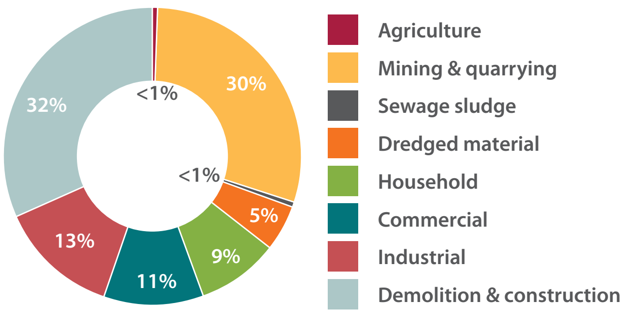
Waste tends to be categorised by generating sector, for example, by households,[18] commercial and industrial (C&I), construction and demolition (C&D), mining and quarrying, agricultural, and hazardous waste. For household waste, collection is from the kerbside or bring site. Some commercial and industrial waste is collected along with green waste from parks and gardens and household waste from the kerbside; this forms municipal solid waste (MSW) or local authority collected waste. Licenced waste management companies collect the majority of remaining commercial and industrial waste.

MSW recycling, recovery and disposal are the responsibility of the local authorities, often county councils or unitary authorities. These bodies are also responsible for waste planning; providing facilities; assessing suitability of sites; producing policy through their Development Plans and approving planning applications. MSW collection is often the responsibility of district councils and unitary authorities. Much of the MSW collection and the majority of waste treatment, recycling, recovery and disposal are actually performed by large, multinational, waste management companies.

4.5.1.1 Waste generation

Household, C&I and C&D wastes together amount to two thirds of total UK waste arisings, with mining and quarrying wastes accounting for most of the remaining third (Figure 42). Until recently, total UK waste generation was increasing, but the latest figures show a decline from 325 Mt in 2004 to 289 Mt in 2008 (Figure 43, overleaf). Household waste generation rates have remained relatively unchanged over this period. The latest figures from 2009–2010 reveal that household waste generation was 31.5 Mt per annum, an average of 457 kg per person per year. While household waste reduced between 2006 and 2008, this may be due to the economic downturn. Historically, economic growth and household waste generation were coupled, but there is some evidence (Figure 44, overleaf) that this may no longer be true (for additional information see Annex I). C&D and C&I have both shown reductions since 2004, but this is based on limited data.[19]

Figure 42: Waste generation by sector. Data from Defra (2007).



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16 That is, where waste is sorted prior to transport for recycling.

17 That is, sorting, recovering and consolidating waste prior to onward carriage to processors or disposal.

18 Often used interchangeably with municipal solid waste (MSW) and local authority collected waste.

19 For example, C&I figures are extrapolated from a single national survey in 2002/03 and subsequent regional surveys.

Figure 43. UK generated waste mass (Mt) by sector: 2004–2008.

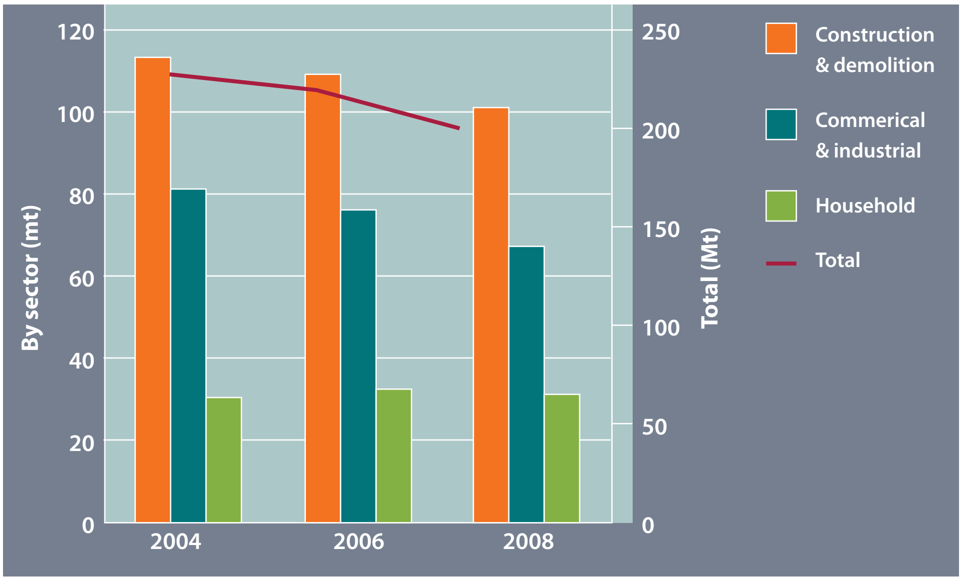


Figure 44. Recent relationship between household waste generation and GDP: have they decoupled?

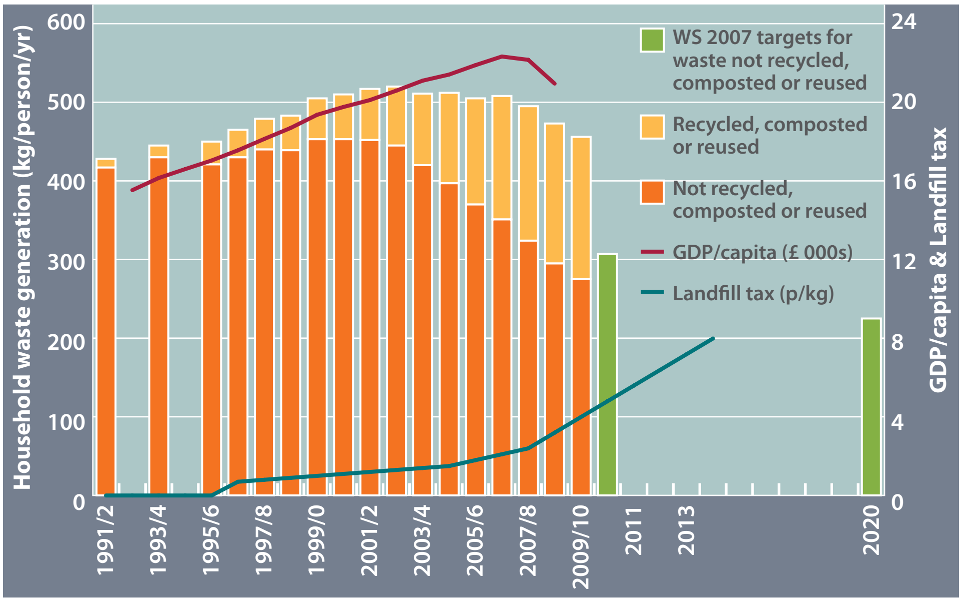
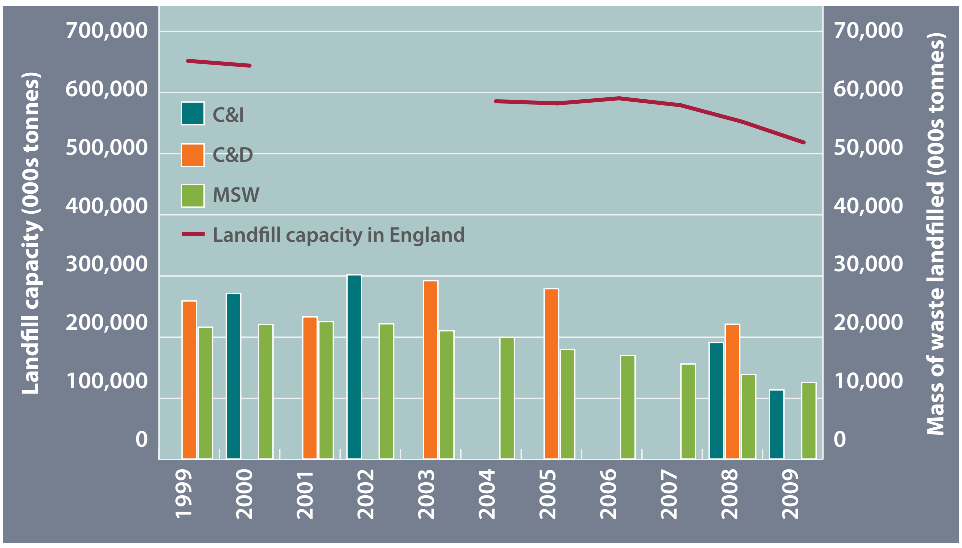


Figure 45: Waste landfilled in England and landfill capacity: 1999–2009.



4.5.1.2 Waste capacity

The amount of landfill capacity in the UK is declining (Figure 45). For example, capacity in England and Wales decreased 19% from 2000 to 2009 to 614 million m^3. In 2007, the Environment Agency raised concerns about the rapid reduction of landfill capacity, especially in the southeast of England. However, the overall amount of waste going to landfill has declined (e.g. from 64 Mt in 2007 to 45 Mt in 2009 in England and Wales) as a result of government policy that encourages the recovery of resources from waste. The economic recession may be responsible for an 18% decline in material landfilled between 2008 and 2009. In England and Wales, at any given time the void space at landfill sites is typically 8–10 years of landfilling, suggesting that capacity is problematic. However, operators are currently searching for alternate revenue streams from landfill suggesting that capacity is not likely to be a problem in the near future, although this situation may well change as landfill becomes a less profitable sector and hence attracts less investment.

There is currently significant overcapacity in MRF, but by 2015 nearly all of the current capacity will be utilised, with almost 60% of areas having insufficient capacity (WRAP, 2007). This is mainly due to the increase of dry recyclable arisings in order to comply with the waste reduction and diversion targets. Notably, the amount of dry recycling in England alone was considerably greater than the amount processed in MRFs or their total capacity for 2006/2007 (5 Mt). This suggests that the bulk of dry recyclables are not sorted in MRFs. Further, there would seem to be a significant over-capacity or underutilization in EfW plant (WRAP, 2007). However, this is an overestimation of capacity in mass terms, as permitted capacity is calculated on the basis of a maximum calorific value of waste that can be processed in a given period of time, and then converted to mass on the basis of the waste with the lowest feasible calorific value.

4.5.2 ROLE OF INTERDEPENDENCE

4.5.2.1 Energy

Solid waste infrastructure depends on the energy sector. For example, the failure of electricity or loss of fuel supply would affect waste treatment, necessitating the storage or stockpiling of waste and disposal to landfill. It could also prevent leachate pumping in landfills, increasing the risk of pollution events.[20] Waste management infrastructure uses energy (electricity, gas and liquid fuels), but energy is also recovered from waste by combustion, recovery of high calorie materials such as plastic and paper in the form of fuels and the generation of electricity from landfill gas or biogas from anaerobic digestion.

Whilst energy generated from waste forms a very significant portion of renewable energy, the overall contribution of renewables to the energy sector is small at present. However, it may become more important in the drive to increase the use of renewable fuels. In addition, recycling saves energy when compared to the use of virgin material; however, this will only appear to affect the UK directly if the recycled materials are reused here (i.e. closed loop recycling). Energy outputs are primarily electricity with the potential for heat, biogas (from AD or landfill) and syngas (from gasification or pyrolysis) to become more important in the future. Energy also contributes to the cost of solid waste services, for transportation and processing of waste.

20 This risk can be mitigated through the use of on-site generators.

4.5.2.2 Transport

The majority of waste is moved by road transport involving refuse collection vehicles (RCVs) collecting from households and businesses and haulage vehicles moving consolidated wastes and treated recyclables for recovery or disposal. Increasing demand for waste management will therefore increase the number of vehicle movements, these are unlikely to make large demands on transport infrastructure but the energy used by collection and haulage vehicles may be significant. In the event of failure of road infrastructure (e.g. heavy and prolonged snow fall), delays in getting putrescible waste to treatment or disposal facilities may cause health or nuisance problems. However, if delays are caused by snow, the risks are at least partially mitigated by the low temperatures. It is likely that periods of disruption to collection (e.g. snow, floods, fuel shortages, etc.) would create a backlog of waste which treatment plants would struggle to clear, hence a requirement for landfill.

As most waste is dealt with locally, this will primarily involve the road network. Some large sites and co-combustion sites (those which burn waste along with other materials to generate electricity (e.g. coal fired power station,) or heat (e.g. cement kilns) are located by railways or rivers (e.g. Rainham landfill and Belvedere EfW which is London's largest MSW treatment plant are both dependent on the Thames for delivery of waste to site). In the future, the availability of low energy transport options may be a requirement for siting of new plants.

In the first half of 2011, the EA granted permits for the shipping of 713,000 tonnes of UK RDF to continental Europe, although only 13,000 tonnes were actually shipped during this period (letsrecycle.com, 2009a). The EA stated that this was a short term solution due to lack of UK markets for RDF, which is principally sent to cement kilns, many of which may have been affected by the economic downturn. Observations have previously been made of shortages of waste for mainland European incinerators, which could potentially be a driver for future shipments. This would have some impact on the transport sector (although it is not clear how large).

Waste arising from the transport sector is likely to be primarily end of life vehicle (ELV) and construction waste (from building of transport infrastructure). Both of these are likely to be influenced by the scenario.

4.5.2.3 Water

Some waste treatment facilities require a water supply for treatment of wastes, e.g. composting and anaerobic digestion, in which water is used to aid biodegradation. Failure of water supply to such facilities would lead to cessation or a reduction of treatment capacity and the need to dispose of the waste by alternative means.

4.5.2.4 Wastewater

Landfill produces large amounts of potentially polluting leachate which is typically treated on site before being disposed of through the wastewater network or direct to rivers. If local wastewater treatment facilities failed, the leachate could be tankered to alternative plants or treated to a higher standard, so the impact on landfilling would be minimal. Changing waste streams may make the leachate impossible to treat with the current biological systems. As has previously been mentioned, sewage AD plant could be used to process biodegradable municipal waste (BMW).

This would significantly increase the plant throughput (especially in high growth scenarios), significantly increase gas yields and would necessitate plant upgrades and probably upgrading the transport network but at present seems not to be cost effective due to the need to macerate the MSW first. It may be that AD systems suitable for solid wastes could be developed on sewage treatment sites which could than treat MSW without pre-treatment, as well as sewage, farm wastes and other material suitable for AD.

4.5.3 KEY ISSUES

EU Directives relating to waste and the UK regulations transposing them are the main drivers for reduction of waste generation and the increase in recovery of waste. This is likely to continue for the foreseeable future, however, additional drivers such as low carbon and energy from renewables may gain importance. The possible banning of the disposal of all biodegradable municipal waste to landfill in the next decade may require new infrastructure. However, the rate at which MSW is being sent to landfill has reduced faster than has been required either by the 1999 EU Landfill Directive or subsequent national policies (e.g. Waste Strategy for England 2007).

The UK strategy for waste management follows the EU Waste Framework Directive (WFD) waste hierarchy: prevent waste, prepare for reuse, recycle, recover energy from waste, and dispose to landfill as a last resort. The need to adhere to the hierarchy now applies to businesses as well as those who manage waste. Waste is increasingly being viewed as a resource to recover, rather than material to be disposed of. Waste that is disposed in landfills is currently taxed at £56/tonne (2011/12), and a rate that will keep rising £8/tonne until it reaches £80/tonne in 2014/15, persisting at this level at least until 2020.

The 2007 Waste Strategy for England (Defra, 2007) gave targets for recycling of household waste and for reduction of waste going to landfill. Currently, local authorities are meeting targets for diversion of biodegradable waste from landfill, but it remains to be seen whether this will be achieved in future. In terms of recovery of resources from waste, the UK lags behind many other countries in the EU. This is in part because of our legacy of a large number of landfill sites and historical reliance on this type of waste management, as well as a very strong public antipathy towards any kind of waste combustion. There is very little data available for C&I or C&D wastes with the bulk of the data coming from surveys of companies in a single region (e.g. Northwest England) which is then extrapolated both spatially and temporally. Without good data, targets cannot be imposed or checked, as recognised in the 2011 National Infrastructure Plan[21] (HM Treasury and Infrastructure UK, 2011). It is clear that the landfill tax has had and will continue to have an effect in reducing C&I disposal to landfill.

The UK government has supported a number of initiatives to help increase recycling (e.g. the creation of WRAP – the Waste and Resources Action Programme), reduce the production of waste and to promote the use of waste management treatment (e.g. through the Defra New Technologies Demonstrator Programme); examples include mechanical biological treatment, mechanical heat treatment, anaerobic digestion and composting. Energy from Waste (EfW) plays a significant part in waste management and the production of solid recovered fuel (SRF) from waste will be increasingly important as the percentage of energy recovery from renewables increases in line with government policy. However, most waste disposal techniques still produce greenhouse gases (e.g. fossil carbon is burned in incinerators and fossil fuels are used in the aerobic composting of waste).

21 The Responsibility Deal with the waste management industry requires sharing C&I data with Defra by 2014.

An alternative approach may be to bury carbon rich wastes including both fossil and non-fossil carbon (e.g. plastics and paper) in carbon sinks. However, there are currently no policies that include this strategy, and the current European opposition to the use of disposing of waste to landfill makes this exceedingly unlikely in the near future.

4.5.3.1 Options

Waste may be transported to large-scale waste treatment facilities for processing. The number of transfer stations and processing facilities involved in the recovery of recyclables from waste has increased over recent years. For example, the number of treatment facilities in England and Wales has increased from 950 in 2007 (EA, 2007b) to 1380 in 2009 (EA, 2009a). Treatment facilities may include:

- **Materials Recycling Facilities (MRFs)** – of two types: dirty and clean. Dirty takes black bag MSW and clean takes dry, co-mingled recyclables, although the former are becoming less common. In both cases, the mixed waste is mechanically, and/or hand-sorted. Outputs include recyclable fractions including paper, cardboard and metals. The non-recyclable residue will either be sent for further processing, e.g. in-vessel composting (IVC), be used as refuse derived fuel (RDF), be recovered to land (i.e. used to replace fertilisers for soil improvement) or sent to landfill.
- **Mechanical Biological Treatment Facilities (MBT)** – an extension of MRFs with an anaerobic or aerobic biological treatment stage to reduce the biodegradability of residual material. Outputs include recyclables, sometimes solid recovered fuels (SRF), and treated residual waste which may go to landfill.
- **Mechanical Heat Treatment Facilities (MHT)** – an MRF where the mixed residual waste is heat treated to sanitise it. Outputs include recyclables, SRF and a residual waste fraction to landfill.
- **Composting Facilities** – large-scale open windrows treating garden waste. IVC for food and green waste. Outputs include mature compost which may be used for soil improvement, the nature of which depends on the waste stream and the treatment process.
- **Anaerobic digestion plants (AD)** – to treat food and green wastes. Outputs include digestate (which may be used for soil improvement) and biogas (fuel).
- **Energy from Waste (EfW)** – including incineration plants. These may be combined with an MRF to recover recyclables prior to incineration. Outputs include electricity (& heat), recyclables, aggregate and ash as well as CO_2 and nitrous oxides.

Other technologies, such as gasification, pyrolysis and plasma arc gasification of waste, are relatively new to the GB market and have only had limited trials here. Although more experience is available elsewhere (e.g. two MSW plasma gasification plants at commercial scale in Japan), there is still some debate about the large-scale future of all of these technologies. Any residual waste not recovered by treatment is diverted to landfill. Despite the Defra-funded New Technologies Demonstrator Programme showing the commercial viability of waste management technologies less commonly used in the UK, further funding support for these technologies may be required due to the reluctance of banks to finance relatively unproven technology for waste management infrastructure. This tends to force operators to propose more commercially proven recycling, composting or waste to energy technologies that may not always be the most effective solutions for maximising utility from waste.

It is notable that landfill operators currently make most of their profits from the sale of landfill gas (LFG) or the energy it produces. The amount of biodegradable wastes being landfilled is declining due to the EU Landfill Directive. It is very likely that future regulation will lead to decreased production of LFG and hence profits for operators, making landfill less attractive to investors. Whilst this may not be problematic in the near future, there will be some requirement for landfill for the foreseeable future to dispose of residual wastes (e.g. 10% of waste input into MRFs is not suitable for recycling) and to deal with waste backlogs due to disasters (e.g. floods, terrorist attack) or treatment plant failure. There may be a need for a contingency for publicly funded and operated landfill to meet this need. Discussions with operators and the EA suggest that operators are attempting to find alternate sources of revenue for their landfill sites due to an insufficient supply of waste for landfilling. The situation in Scotland is broadly similar.

Waste reduction targets have two forms: obligatory targets imposed by the European Union and policy or strategy targets set by individual nations. Failure to meet the EU targets results in fines for member states. Nations' own targets (Table 21) are not as rigorously enforced.

Table 20: Examples of technology options is the waste sector

Technology	Current status
Gasification	Energos built UK plant using Defra New Technologies Demonstrator Project funding. Not clear if there was any advantage over conventional incineration.
Plasma arc gasification	Two commercial scale plants in Japan processing MSW.
Gasification to synthetic liquid fuels	British Airways is developing a London plant to convert 500 kilotonnes per annum (ktpa) of varied waste into 61 million litres of aviation fuel. Production starting in 2014.* Not clear if this would be viable without European Industrial Bioenergy Initiative assistance.
Pyrolysis of plastics to liquid fuels	SITA planning 10 plastic to diesel plants a year to convert 60,000 tonnes/year. First plant end of 2011.** Fuels to be used for site and collection vehicles. Not clear if there is any energy/emissions advantage over incineration.
Landfill mining	Extracting materials from existing landfill. This has been discussed by at least one operator. Raw materials/fuel prices would not need to rise much before it was financially viable to mine landfills. Trials have been run elsewhere in Europe but not in UK.
Pneumatic collection systems	Have been used elsewhere (notably in Finland) but are best suited to new developments, particularly new towns. With proper implementation can monitor and charge households for their waste.

* http://www.waste-management-world.com/index/display/article-display/1306426883/articles/waste-management-world/volume-12/issue-6/features/biowaste-driving-fuels.html

** http://www.cynarplc.com/news-display.asp?action=change&ID=55 downloaded 8/12/11

Table 21: Summary of key municipal solid waste (MSW) reduction targets and regulations

Location	Reduction Targets and Regulations
England	• Recycling & composting 40% by 2010; 45% by 2015; 50% by 2020 (Defra, 2007) • Recovery of value (above + energy recovery) 53% by 2010; 67% by 2015; 75% by 2020 (Defra, 2007) • Reduction of mass not reused, recycled or composted from 22 Mt in 2000 to 15.8 Mt in 2010 and 12.2 Mt in 2020 (Defra, 2007) • Reduction of BMW going to landfill (European Parliament and Council of the European Union, 1999)
Scotland	Landfill Directive (European Parliament and Council of the European Union, 1999) and the Waste Framework Directive (WFD) (European Parliament and Council of the European Union, 2008) require that: • by 2010 no more than 1.32 million tonnes of biodegradable municipal waste (BMW) can go to landfill; • by 2013 no more than 880,000 tonnes of BMW to landfill; • by 2020 no more than 620,000 tonnes of BMW to landfill; and • by 2020, 50% of household waste and similar to be reused or recycled. Scotland's ambitious zero waste policy for MSW also requires that: • MSW arisings do not increase after 2010; • EfW is limited to a maximum of 25%; • <5% waste to landfill by 2025; and • recycling & composting rates of at least 40% of MSW arisings by 2010, rising to 50% by 2013, 60% by 2020 and 70% by 2025.
Wales	Comply with the Landfill Directive and landfill no more than 35% of its 1995 levels of BMW by 2020. • by 2010 no more than 710,000 tonnes of BMW to landfill; • by 2013 no more than 470,000 tonnes of BMW to landfill; • by 2020 no more than 330,000 tonnes of BMW to landfill; and • by 2020, 50% of household waste and similar to be reused or recycled. Zero waste targets are set out below: • by 2025 all sectors should be recycling at least 70% of their waste; and • by 2050, the Welsh Assembly "hope to have achieved zero waste" (Welsh Assembly Government, 2009).

The WFD (European Parliament and Council of the European Union, 2008) has for the first time added transnational targets for non-MSW wastes. This joins the target for waste reduction that has been adopted by the UK construction industry:

- To reduce the levels of C&D waste going to landfill to 50% of 2008 levels by 2012 (BERR, 2008).

- Reuse, recycle or recover 70% non-hazardous C&D waste by 2020 (European Parliament and Council of the European Union, 2008).

As in other infrastructure sectors, there is a complex relationship between demand and capacity in the solid waste sector. The final destination of a discarded item may be influenced by the availability of particular waste facilities. For example, the provision of bottle banks or kerbside collection schemes has a positive effect on recycling behaviour and demand for such services in reinforced. Reducing waste generation would result in less demand for waste management capacity. However, there is a lack of transparency in the cost of waste management services to the public in the UK, so that there is no economic pressure to reduce waste generation by householders. The introduction of 'pay-to-throw' is a potential waste reduction strategy, although not current UK policy and comes with attendant risks of illegal and irresponsible disposal.

4.5.3.2 Risks

Local authorities are currently meeting government targets for reduction of waste disposal to landfill and recycling targets, which demonstrate that infrastructure capacity is currently meeting demand. The waste management sector is relatively robust, and there has been significant investment in the industry over the last 10 years. However, lack of investment, due to economic recession, reduction in demand, or lack of support from government, may pose a risk to development of infrastructure especially for large-scale treatment plant, and complex or untried technologies. The nature of municipal waste finance has meant that in order to secure funding for large infrastructure projects (e.g. EfW plant), long term contracts (typically of 25 years) are often required. This could lead to a waste disposal authority being locked into a treatment technology even when better waste disposal options may be available.

Short term, localised increases in demand (e.g. as flood events) or reduction in treatment capacity (e.g. through breakdown) may present difficulties. In the past, landfill has been available and able to deal with sudden increases in waste inputs after such events. A decreasing trend in landfill capacity may present problems, at least in some regions since other waste facilities have limited waste treatment and storage capacity.

Hotter, drier summers and warmer, wetter winters due to climate change may promote increased disease transmission and nuisance from pests, together with odour and dust at open air waste management facilities. Increased seasonal precipitation may impact on landfill hydrology with potentially increased runoff and pollution from sites. Stability of landfill sites may be affected by extreme weather events, though there is limited data on the impacts of climate change on waste infrastructure or demand.

Climate change policy is likely to affect waste management, leading to further reductions in the amount of biodegradable material going to landfill which will reduce the amount of renewable energy derived from waste and may even increase total GHG emissions from landfill as the long period of low LFG emissions will be impossible to utilise and difficult to collect and manage. Uncertainty regarding policy changes coming from the EU or UK government may impact on investment and supply of the necessary infrastructure. Any future waste management targets should have a maximisation of resource use and sustainability at their core, rather than a dogmatic opposition to certain technologies, e.g. landfill.

4.6 ICT

In comparison to the physical infrastructure sectors already discussed, ICT is a new and rapidly changing sector, but it is less clearly defined and understood. ICT infrastructure is considered to comprise communication (including fixed and mobile telephony, broadband, television and navigation systems) and computation (including data and processing hubs) systems. Significant increases in ICT capacity have been provided via a competitive industry, which has innovated to provide new technologies and respond to consumer demand (which is itself largely driven by innovations in consumer technologies and business practices). Further rapid increases in coverage, in particular in superfast broadband, are anticipated, though there are some locations where the market alone cannot deliver. Use of the electro-magnetic spectrum may also become a constraint without spectrum reallocation and technological solutions to support more efficient use of existing spectrum. ICT has a critical role in infrastructure interdependence and failure, which will be the target of future work in ITRC.

4.6.1 THE INFRASTRUCTURE SYSTEM

ICT infrastructure is the collection of all IT technologies, physical facilities and human systems that are operated in a coordinated way to provide these services, namely to provide for transmission, processing and storage of information, which for most purposes is now in some digital format.

ICT is a combination of communications technology and information technology (IT):

- **Communications** cover the whole of networks, systems and artefacts which transport and store data. These include wired and wireless networks and their components (cables, masts, satellites, etc.), as well as broadband, voice, data, positioning and broadcast services.
- Within **IT**, software and systems that store and process the information are included. This is generally shared with the different sectors or infrastructures, such as transport, health, governance, etc. Examples include traffic control, smart grid, health, bank and other IT systems.
- Within both communications and IT, people must also be considered as part of the systems. These include operators, developers and other ICT specialists.

Many reports on ICT consider only the communications part of the ICT infrastructure, using the term 'digital communications' to describe the infrastructure sector. However, IT is considered to be part of ICT infrastructure as well, because these systems manipulate and transform the information and participate in the information routing process.

The ICT sector differs significantly from physical infrastructures. The rapid growth and frequent changes of ICT sector, with continual introduction of new technologies and usage patterns, make it harder to use the methods of analysis and forecasting appropriate to the physical infrastructures. The ICT sector is mostly commercially driven with private providers responding rapidly to changes in technology and consumer demand. The sector also has a strong international dimension and dependence, which further increases the complexity of analysis.

ICT artefacts are generally smaller, less expensive and have shorter lifetimes, thus infrastructure expansion can mostly be made in a rapid fashion without constructing large, physical objects. However, some artefacts such as IT systems can be considered large, expensive and with long development times. Furthermore, ICT systems are subject to 'generation' upgrades, development and deployment of which is also significant and costly.

4.6.1.1 Current state of ICT in the UK

The overall strength of ICT infrastructure in the UK is among the leading in the global context. The evaluations differ in various reports, but the UK is ranked within the top 15 global economies. According to the ICT Development Index, the UK is 10th out of 152 world economies. The index reflects the level of network infrastructure and access to ICTs; the level of use of ICTs in the society; the result/outcome of efficient and effective ICT use (ITU, 2011). The World Economic Forum ranks the UK at 15 for ICT infrastructure strength using Network Readiness Index[22] (WEF, 2011b).

Remaining competitive in the ICT industry and keeping up with the development in a global context was stated as a goal for ICT infrastructure investment strategy in the UK. It must however be remembered that having led the world in computer innovation, currently the UK has hardware companies only in niche markets and that there are very few major software manufacturers (Hendry, 1989).

Table 22 provides a short overview of the current state of ICT sector.

22 The Networked Readiness Index (NRI) featured in the report examines how prepared countries are to use ICT effectively on three dimensions: the general business, regulatory and infrastructure environment for ICT.

Table 22: Current State of ICT

ICT Area	Overview of the current status
Computation	The speed increase of raw computation is exponential (well described by Moore's law*). It can be argued that available computation power will be enough to support foreseeable developments of physical infrastructures. The power efficiency of computation has on average doubled every 1.57 years over the period of years 1975–2009 (Koomey *et al.*, 2011).
Radio spectrum	The radio spectrum is used by all wireless services: mobile communications, sound and television broadcasting, satellite and others. The resource is finite and certain users (e.g. mobile communications) are at their allocation limits. The public sector is a major holder of spectrum with almost 50% of spectrum below 15 GHz allocated (DCMS, 2011b). The radio spectrum allocation results in inequalities and inefficiency of spectrum use: according to some reports, less than 14% of radio spectrum is busy at any given time (Rubenstein, 2007). The UK government is auctioning parts of public spectrum to satisfy the demand (DCMS, 2011b).

* Moore's law: The number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every 2 years. (The common simplification that "computing capacity doubles every two years" is thus not quite accurate.)

Table 22 (continued)

ICT Area	Overview of the current status
Communication	Analogue terrestrial TV and Dial-up Internet have become things of the past. Their take-up in the UK in 2011 is 4% and 2%, respectively. Fixed line telephony continues to decline: the saturated fixed-lines market has been overtaken by mobile-cellular telephony. Mobile-cellular telephony has also reached saturation levels recording penetration rates of over 91% (Ofcom, 2011a). Ofcom reports an increase of fixed-broadband take-up from 3% in 2002 to 74% in 2010. Current (May 2011) average actual broadband speeds are at 6.8 Mbit/s (Ofcom, 2011a). Mobile Internet – at broadband speeds – was practically non-existent in year 2000. Now, the take-up of mobile broadband continues to rise and stands at 17%, while 7% of population rely solely on a mobile broadband service in 2011 (Ofcom, 2011a). The UK government has allocated £830m to assist in providing the UK broadband network of at least 2 Mbit/s broadband to all UK homes by 2012. In addition, superfast broadband should be available to 90% of people in each local authority area.***
Satellite communications	The global demand for fixed satellite services is within the available capacity, expected to be at about 79–82% of available capacity in 2011, according to various estimates (GAO, 2011). The global satellite industry posted growth of 11% in 2009 and 5% in 2010 (SIA and Futron, 2011). The growth is expected to continue. Euroconsult estimates 1145 satellites will be built and launched in the period 2011–2020, an increase of about 51% compared to the previous decade (2001–2010) (Euroconsult, 2011).
IT & data processing	IT is a significant component of all physical infrastructure and of government itself. Large IT projects are time consuming and expensive parts of the ICT infrastructure. In 2003, government had 100 major IT projects with a total value of £10bn (POST, 2003). Newer data shows £16bn annual expenditure on IT in 2009, with some IT projects being huge (e.g. £12bn NHS IT project, National Programme for IT) (HM Treasury, 2009). The recent emergence of cloud computing is providing greater business efficiency and lower start-up costs. Private cloud computing is being considered within the UK government (G-Cloud, which could enable £3.2bn savings (Cabinet Office, 2010a)) and academia (e.g. e-Science Central).

** 2nd generation mobile services (2G) only provided SMS data services, but no internet (this was 2.5G).

*** Recent information about investments on 14 August 2011 in Guardian http://www.guardian.co.uk/business/2011/aug/14/superfast-broadband-go-uk-wide

Table 22 (continued)	
ICT Area	Overview of the current status
GNSS	• The US-owned GPS is used most widely for navigation services but Europe's Galileo and the latest generation of Russian GLONASS systems are expected to be completed in the near future (European Parliament, 2011; GPS World, 2011). • Each system will have full global coverage and it is expected that new consumer devices will support more than one GNSS system (Amos, 2011; BBC, 2011b; RAE, 2011).
Legislation and regulation	The UK communications industries are regulated by Ofcom as well as various international bodies.

4.6.1.2 Digital communications infrastructure

Upgrade to the next generation of super-fast fixed broadband is underway, started in 2010. This is driven by the private sector (primarily Virgin Media and BT) and the UK government. Over half of all UK households are within easy access to super-fast[23] broadband lines, with possible speeds of 40–100 Mbit/s (Ofcom, 2011a).

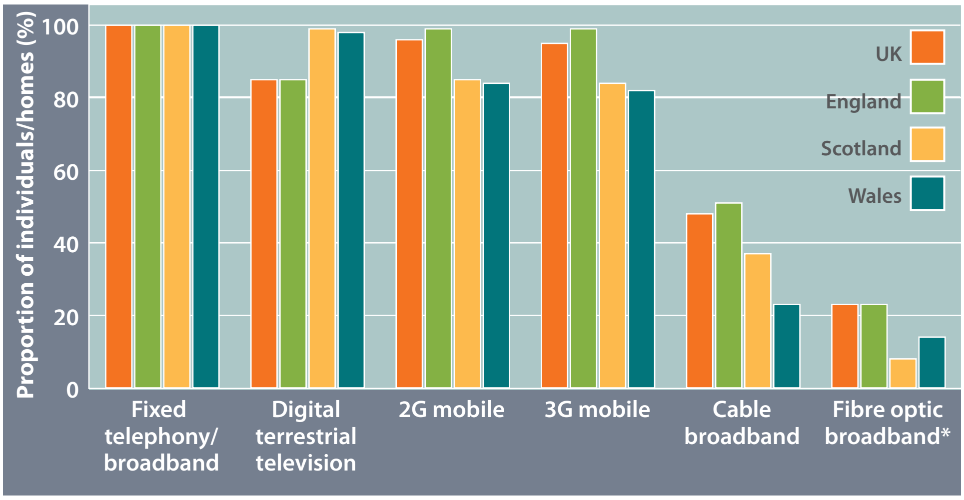


Figure 46: Communications infrastructure availability by percentage of population covered (Ofcom, 2011a). *Note that Fibre optic broadband refers to Fibre-to-the-cabinet (FTTC).

Figure 47 (overleaf) shows increase in broadband take-up – Internet penetration now exceeds PC penetration. The use of the Internet on a mobile phone has grown substantially, driven by the growth in the smartphone market and mobile networks offering competitive mobile data packages, both allowing easier and more affordable access to mobile Internet services than before.

The demand for mobile Internet is increasing with the 'smartphone revolution': 27% of UK adults now claim to own one, 32% of people use their mobiles to access the internet. Year 2010 saw a 67% increase in data transferred over the UK's mobile networks (Ofcom, 2011a).

23 Super-fast broadband is classified as connections with headline speeds above 'up to' 24 Mbit/s.

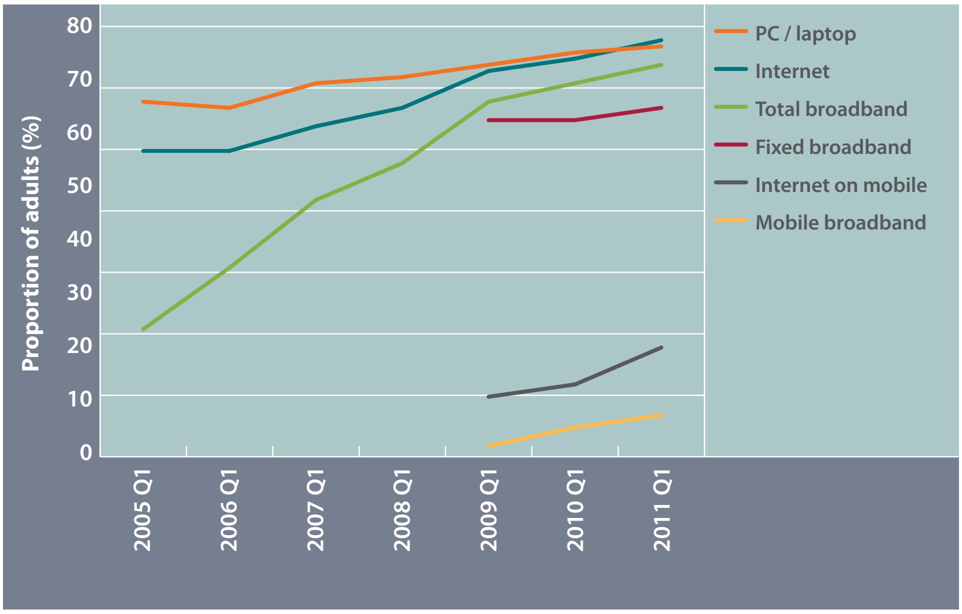


Figure 47: Household penetration of broadband: 2005–2011 (Ofcom, 2011a).

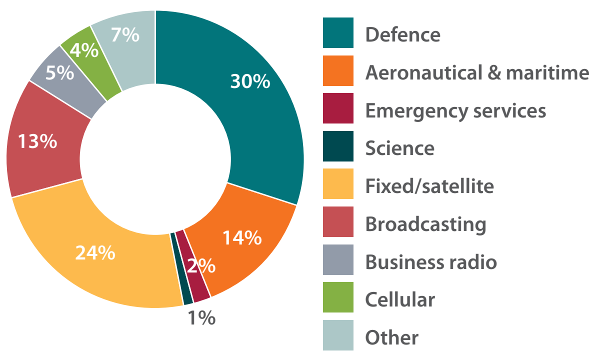
Increase in demand has shifted the strategic focus of telecoms service providers towards driving up the availability of higher-speed networks. Mobile operators are continuing to upgrade their 3G[24] networks to offer higher data speeds. Next-generation 4G[25] networks would exceed super-fast fixed broadband speeds.

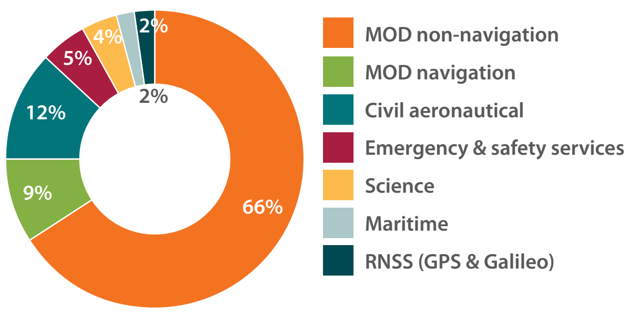
4.6.1.3 The radio spectrum

Wireless communications and broadcasting infrastructure depend on available radio frequency spectrum to transfer the information. Demand for radio communications grows both in number and variety of applications: mobile communications, sound and television broadcasting, aviation, railway and maritime transport, defence, medical electronics, emergency services, remote control and monitoring, radio astronomy and space research.

The radio spectrum is a finite resource and is controlled by the government. It controls the frequency usage and sells licenses. The public sector is a major holder of spectrum with almost 50% of spectrum below 15 GHz allocated (see Figure 48) (DCMS, 2011b). The historical circumstances yielded the most desirable ranges of the radio spectrum to radio and television broadcasting. Furthermore, certain parts of the spectrum work the best for certain radio applications (Rubenstein, 2007).

Figure 48: Weighted use of spectrum and composition of public sector spectrum holdings below 15 GHz (DCMS, 2011b).





24 3G specifies 100 kbit/s broadband speeds.

25 specification defines 100.Mbit/s speed for moving (cars, trains), 1 Gbit/s for pedestrians & stationary.

The radio spectrum allocation results in inequalities of spectrum use. For example, mobile-broadband technologies are limited by the available spectrum, while other applications do not use their spectrum efficiently. By some accounts less than 14% of radio spectrum is truly busy at any given time (Rubenstein, 2007).

The finiteness of radio spectrum availability is an important issue for wireless communications. Various options to address this, e.g. by increasing the efficiency of spectrum use via better technology or spectrum reuse, are available. See further discussion in Annex J.

4.6.1.4 Satellite communications

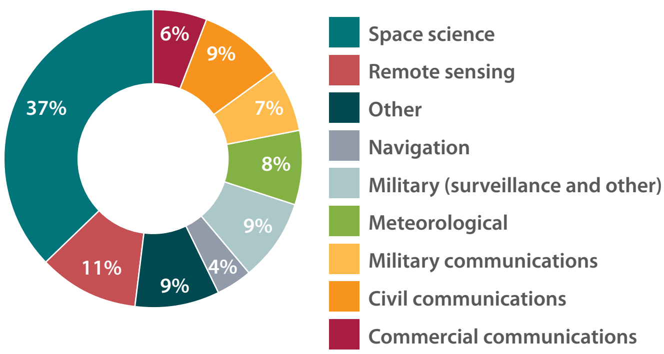
Satellite communications are comprised of satellites orbiting the Earth and a number of ground stations communicating with the satellites. The satellites mostly act as signal reflectors, whereas ground stations can send signals to satellite (e.g. telephones, TV broadcaster), receive the signals (e.g. telephones, TV receivers) or both (Hart, 2000).

The main advantage of satellite services iss that it requires little terrestrial infrastructure, thus services can be available in remote areas with poor or no communications infrastructure. The most common consumer services include satellite television, radio, broadband, telephony, positioning, and others (SIA and Futron, 2011).

The satellite industry is a subset of both telecommunications and space industries, with very high involvement of non-commercial organisations. As shown in Figure 49, of the 986 satellites on orbit, 37% are commercial communications satellites. The industry represents only 4% of telecommunications industry revenues, and 61% of space industry revenues (SIA and Futron, 2011).

The global demand for fixed satellite services is within the available capacity, expected to be at about 79–82% of available capacity in 2011, according to various estimates(GAO, 2011). The global satellite industry posted growth of 11% in 2009 and 5% in 2010 (SIA and Futron, 2011). The growth is expected to continue. Euroconsult estimates 1145 satellites to be built and launched for the period 2011–2020, an increase of about 51% compared to the previous decade (2001–2010). This is fuelled by expansion of satellite services, by both government and commercial organisations (Euroconsult, 2011).

Figure 49: Operational satellites by function (June 2011) (SIA and Futron, 2011)).



4.6.1.5 Global navigation satellite systems

Global Navigation Satellite Systems (GNSS) provide position, navigation and timing services via satellites. The original implementation of GNSS is the Global Positioning System (GPS), which is operated by the US. Alternative GNSS systems also exist or are being developed, notably Russian GLONASS system, Galileo in Europe and Compass in China, which operate in approximately the same way (RAE, 2011).

The demand for and reliance on navigation systems is growing, with applications encompassing road, air, maritime and rail transport, cellular and data networks, emergency services, and others (RAE, 2011). The high reliance on GNSS services requires improved resilience, which could be achieved with availability of multiple systems and technological upgrades.

The US-owned GPS is used most widely for navigation services, but Europe's Galileo and the latest generation of Russian GLONASS systems are expected to be completed in the immediate future (European Parliament, 2011; GPS World, 2011). Each system will have full global coverage: GPS had 32 satellites in service in January 2011, GLONASS had 24, Galileo will also have 24 satellites and it is expected that consumer devices will support more than one GNSS system (Amos, 2011; BBC, 2011b; RAE, 2011). For example, Galileo is designed to be inter-operable with GPS and GLONASS (ESA, 2011).

4.6.2 KEY ISSUES

This section outlines main issues appearing within the ICT sector, with an issue upon issue of reliability and interdependence. The ICT sector has been witness for rapid change and a number of issues relate to keeping with the change and growth for the upcoming years. Some of the options given for the issues are already being put in place, or are in the future plans. Within ICT, the majority of options are technological – this comes from the fact that ICT is highly privately driven. Furthermore, reports advise against prescriptive policy, instead encouraging creating economic pull-through. The government cannot drive the sector – government decisions should be driven by the requirements/developments in the ICT sector (Horrocks *et al.*, 2010).

4.6.2.1 Increasing dependability of/dependence on ICT

Many computers are deployed in systems that are financially, militarily or safety critical. Computer failures can stop a bank functioning (seen most rapidly in the loss of ATM support to customers); the primary protection systems of nuclear power reactors are commonly computers running software designed to protect safety; modern cars contain tens to hundreds of embedded computers that control things as crucial as their braking systems.

Any complex system can fail but today the failure can come from other than the obvious physical components such as turbines and motors; system failure can be caused by embedded control systems. This can be hardware (although this is the easiest thing to protect by redundancy), software or malicious attack. A dramatic example of software failure contributing to a major power outage was the U.S. Northeast Blackout of 2003.

4.6.2.2 Rapid development

ICT components (especially end-user ones) have short lifetimes and are frequently updated and refined to meet changing needs. However, certain components are planned for longer lifetime (e.g. networks, cables/masts, data centres, etc.). To accommodate the rapid growth, each generation of networks is planned with exponential growth in capacity.

4.6.2.3 Security

The role of ICT has been increasing within the national infrastructure and general usage, making it a more important target for various threats, such as hackers, viruses, identity thieves, etc. The general threat of hacking and cyber espionage (e.g. banking fraud and identity theft) has been a persistent concern for general public and organisations. Cyber-crime has been estimated to cost as much as $1 trillion per year globally (Cabinet Office, 2010b). Furthermore, a recent example of Stuxnet virus[26] shows that cyber-attacks have become sophisticated, and can be stealthy, directed and able to disrupt critical infrastructure around the world. Cyber security has been identified by the UK Government as a high priority risk (Cornish *et al.*, 2011).

New challenges for cyber security appear, with ICT usage trending towards information mobility and cloud computing: the data needs to be readily accessible yet secured. The points of attacks can be small and plenty, and the vulnerabilities often go unrecognised within the wider supply chain. The growth of such attacks has triggered reports from organisations that the volume and sophistication of cyber threats are outstripping their capacity to respond (Cornish *et al.*, 2011).

The UK Government has allocated £650 million to National Cyber Security Programme in 2010. Furthermore, recent attacks have prompted increased awareness of cyber dependencies and vulnerabilities within the private sector as well (Cornish *et al.*, 2011). The legislation to improve security and resilience in communications sector is being developed within EU as well as UK government offices (Cabinet Office, 2010a).

4.6.2.4 Resilience of communications infrastructure

ICT performance under stress (and human performance when the technology does fail) can be unpredictable and it is subject to node failure in which damage or compromise of a key element (a node, router, switch or exchange) causes a service failure to multiple users. Risks of failure increase where ICT network systems are working close to capacity (i.e. above 40%) (CST, 2009).

The resilience of ICT networks is improved by their nature and availability: multiple networks and/or ICT services (e.g. wired or wireless) are available to switch among, networks can utilise multiple links simultaneously and re-route dynamically in real time. Still, link failures can be of high severity, causing stress on bottlenecks in the network and producing a cascading failure (Horrocks *et al.*, 2010). The ripple would affect a large number of users due to shared ICT infrastructures (e.g. several providers share the same cables or masts), outsourced data and computation (clouds, data centres), which require high connectivity, etc.

4.6.2.5 Supplier and international dependencies

The ICT infrastructure is almost exclusively commercially driven. While this improves resilience with multiple suppliers (and thus solutions) available, recent trends show that it is increasingly dependent upon a small number of major suppliers of component subsystems (Microsoft, Google, Cisco and Intel) (CST, 2009). Massive investments necessary for 'next generation' improvements in the sector may result in the reduction of the number of providers in the future, and therefore pose dependency (lock-in) issues.

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26 Stuxnet virus was designed to target Iran's nuclear power plants directly and succeeded in disrupting operation of a nuclear power plant for months (Nicol, D. M. (2011). Hacking the lights out. *Scientific American* **305**: 54–59.)

The international presence of ICT sector makes it susceptible to foreign laws and international dependencies. Most of ICT hardware is manufactured abroad; a large amount of IT services are based in foreign countries as well. Changes in international relations could have impact on the provision of these ICT components. A significant issue is using public data centre services, e.g. for data storage, which are located in a foreign countries. In many cases, laws within the country would apply to that data, e.g. USA PATRIOT act of 2001, which would allow US government agents to access sensitive data stored in data centres on US soil.

4.6.2.6 Satellite communications and GNSS

Satellite communications have a number of vulnerabilities that can impact signal strength and service availability. Satellite signal strength has to travel great distances, and can be reduced by terrestrial weather conditions (e.g. rain), as well as events in space, such as solar flares or scintillation (Rooker, 2008). A prominent problem in satellite communications is signal interference. Jamming is the simplest form of attack, when a noise signal of a correct frequency is used to overpower the actual signal.

The availability of GNSS (GPS) has led to over-reliance on the system. A study by the Royal Academy of Engineering has identified that no alternative or back-up systems are in place when GNSS is used (e.g. paper maps). With increasing use of GNSS in life critical systems, its integrity is insufficient for these applications, if inadequate alternatives or backups are available (ESA, 2011). This is in particular important when considering that GNSS can be jammed easily (see above).

4.6.2.7 Radio spectrum

The radio spectrum is a finite resource – bands below 15 GHz are considered the most valuable part of the radio spectrum due to the technical characteristics used by various applications. For mobile communications, frequencies below about 4GHz are used, with the prime bands being in 300 MHz–3 GHz area (see ESA, 2011; DCMS, 2011a).

The mobile communications have been the fastest growing market that utilises the radio spectrum. While wired-broadband can be expended (theoretically) unlimitedly, the quality and speed of mobile-broadband connectivity relies on the available spectrum. The limited amount of spectrum means a limited amount of bandwidth, and hence speed (ITU, 2011). The demand for mobile bandwidth has been surging with increase of smartphones, tablet and mobile computing devices. Cisco expects the mobile data traffic to have a compound annual growth (CAGR) rate of 91% in 2010–2015 (see Figure 50) (DCMS, 2011b). Furthermore, the move to HD television will also increase demand for similar radio spectrum range.

Several options have been proposed to address the so-called 'spectrum crisis', including technological and governmental actions. Service providers are investigating more efficient use of the available spectrum. Moving to digital signal (e.g. for TV or radio broadcast) could save three quarters of the bandwidth, next-generation networks (e.g. 4G, LTE-Advanced) also aim to reduce the bandwidth required for signals (BBC, 2006). Cognitive radio techniques (e.g. software radio, 'white space' wireless broadband) would allow devices to utilise assigned but unused spectrum areas (Ofcom, 2011b).

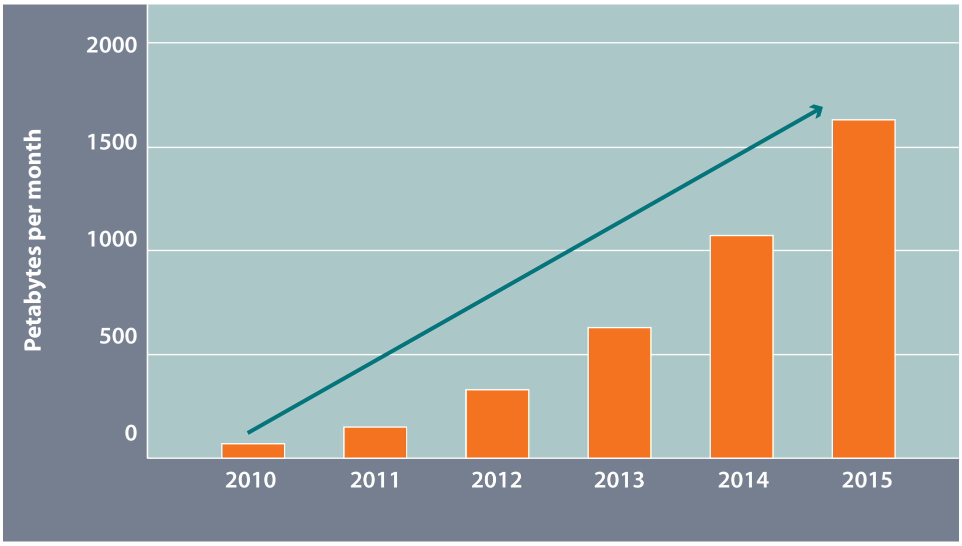


Figure 50: Mobile data traffic forecast – Western Europe (2010–2015) (DCMS, 2011b).

Furthermore, large ranges (close to 50%) of radio spectrum are allocated to public sector use, especially military (Figure 48). These bands are not effectively used; therefore the UK government aims to release significant amounts of this spectrum to commercial use, especially for mobile bandwidth. The current government plans consider releasing at least 500 MHz of public sector spectrum below 5 GHz within the next 10 years (DCMS, 2011b).

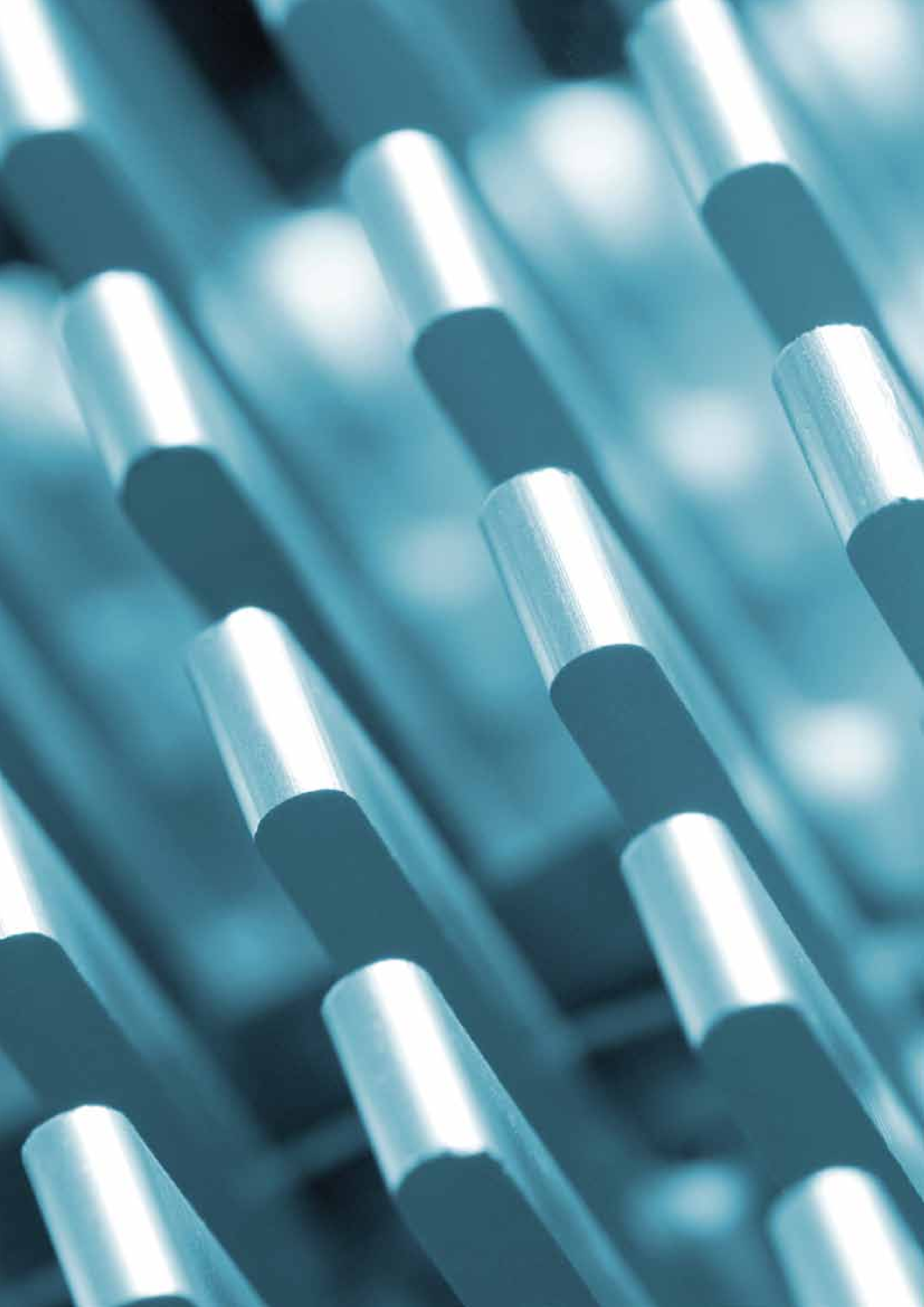
4.6.2.8 Grid capacity/power shortage

The rapid rates of growth in data centre electricity use that prevailed from 2000 to 2005 slowed significantly from 2005 to 2010, yielding total electricity use by data centres in 2010 of about 1.3% of all electricity use for the world, and 2% of all electricity use for the US (Koomey, 2011). Nonetheless grid capacity is at limits in some places, so there are places where new data centres are not allowed (e.g. Canary Wharf). Companies are building data/cloud centres in areas where energy is cheap and plentiful (to a lesser extent, the same is true of cooling).

4.6.2.9 Climate change

The impacts of climate change to the ICT sector are likely to be at most minor ones. While specific incidents (e.g. floods, winds) may impact certain components, there seems to be no substantial empirical data evidence to indicate more significant effects.

Furthermore, international design standards for ICT components also aid mitigation of climate change effects, where components are designed to operate in extreme heat or cold (i.e. the same kit may be used in different climate areas); for example, for this reason heat and drought are not considered an issue by ICT network operators (Cabinet Office, 2011).



5 An analysis of long term strategies for National Infrastructure

This chapter presents an analysis of long term strategies for future National Infrastructure (NI) provision in Great Britain. The analysis is a demonstration of the feasibility of the quantified system of systems approach being pioneered by the ITRC. The Fast Track Analysis (FTA) is limited to the future scenarios identified in Chapter 2, and the three representative cross-sectoral strategies for NI provision. Where possible, each of the NI sectors has made use of existing quantified models to conduct the analysis. This is a first step, and the methods and modelling tools now being developed in ITRC will enable much more extensive quantification of the range of future possibilities and strategies, including considering interactions between sectors and addressing the views of our stakeholders.

5.1 INTRODUCTION TO THE FTA TRANSITION STRATEGIES

In this report we have argued that the benefits of infrastructure can be more effectively achieved, and the systemic risks minimised, through the development of an integrated, long term strategic approach to infrastructure provision. This involves proposing an overall direction for NI systems and developing of pathways to achieving the desired outcomes in the long term. In order to demonstrate this approach in practice, we have introduced the concept of NI *transition strategies*, which are cross-sectoral strategic plans for NI service provision, comprised of sequenced, sector-specific governance and technology options. As discussed in Chapter 2, the *transition* to a sustainable NI system is the process that leads, over a period of decades, to a system configuration that performs well with respect to multiple economic, social and environmental criteria.

In order to demonstrate this approach, in the FTA we have developed three contrasting transition strategies, which are intended to provide the opportunity to explore a range of approaches to NI provision, and associated levels of investment. These three strategies are called: *Capacity-Intensive* (CI), *Decentralisation* (DC), and *Capacity-Constrained* (CC). They are described in more detail in the following sections.

Each of the transition strategies has goals and principles that guide the individual selection of options for each infrastructure sector in the strategy portfolio. As the legacy of today's infrastructure system is a key characteristic of NI, all of the strategies have as a starting point the current infrastructure systems, which limits, to some extent, the potential for radical change.

5.1.1 CAPACITY-INTENSIVE (CI) TRANSITION STRATEGY

The **Capacity-Intensive** (CI) transition strategy is a high investment strategy that focuses on the use of centralised options across sectors, both in terms of governance and technology. The aim of this strategy is to minimise the capacity constraints on demand, creating surplus[27] capacity across the sectors and potential for unconstrained growth in supply of infrastructure services. Cost-effective demand management measures are included, but are not a priority in this strategy. The strategy includes a commitment to decarbonisation of the energy and transport sectors.

5.1.2 DECENTRALISATION (DC) TRANSITION STRATEGY

The **Decentralisation** (DC) strategy seeks to orientate infrastructure provision towards decentralised options, while existing centralised infrastructure (e.g. national grid, highways network, intercity rail) is still maintained. Whilst the level of service provision and reliability is not necessarily as high as in the CI strategy, we do not assume major resource constraints – we find in practice that a DC strategy involves major investment. This strategy focuses on the utilisation of beneficial local interdependencies between electricity and heat, energy and solid waste, as well as wastewater and water. The focus on decentralised technology options creates a more varied strategic portfolio than the CI strategy. This transition strategy includes environmentally friendly objectives; investment in the transportation sector, for example, concentrates on energy efficient options (e.g. electric vehicles and rail).

5.1.3 CAPACITY-CONSTRAINED (CC) TRANSITION STRATEGY

The **Capacity-Constrained** (CC) strategy is a low investment strategy that focuses on maintaining near current levels of NI capacity, while ensuring security of supply through demand management. Demand is reduced through a combination of demand-side technologies (e.g. options that increase efficiency, thus reducing demand), policy options (e.g. tax or regulation), and behavioural change. While new capacity is not added in this strategy, existing capacity is replaced when it reaches the end of its life with lower-carbon technologies.

5.1.4 EXPLORATION OF KEY QUESTIONS

The performance evaluation of the above three strategies across the three growth scenarios enables the exploration of the key questions in NI provision. For example, the CI strategy gives an impression of the level of infrastructure that could be provided with investment levels that are high by historical standards. Comparing the performance of the CI and DC strategies provides insight into whether accounting for local interdependence in NI unlocks performance increases. Evaluating the performance over time of the DC strategy provides insight into the attributes and benefits (or lack thereof) of a decentralised arrangement. Additionally, evaluating the performance of the CI strategy gives perspective on the level of service that could be provided at fairly modest levels of capital investment.

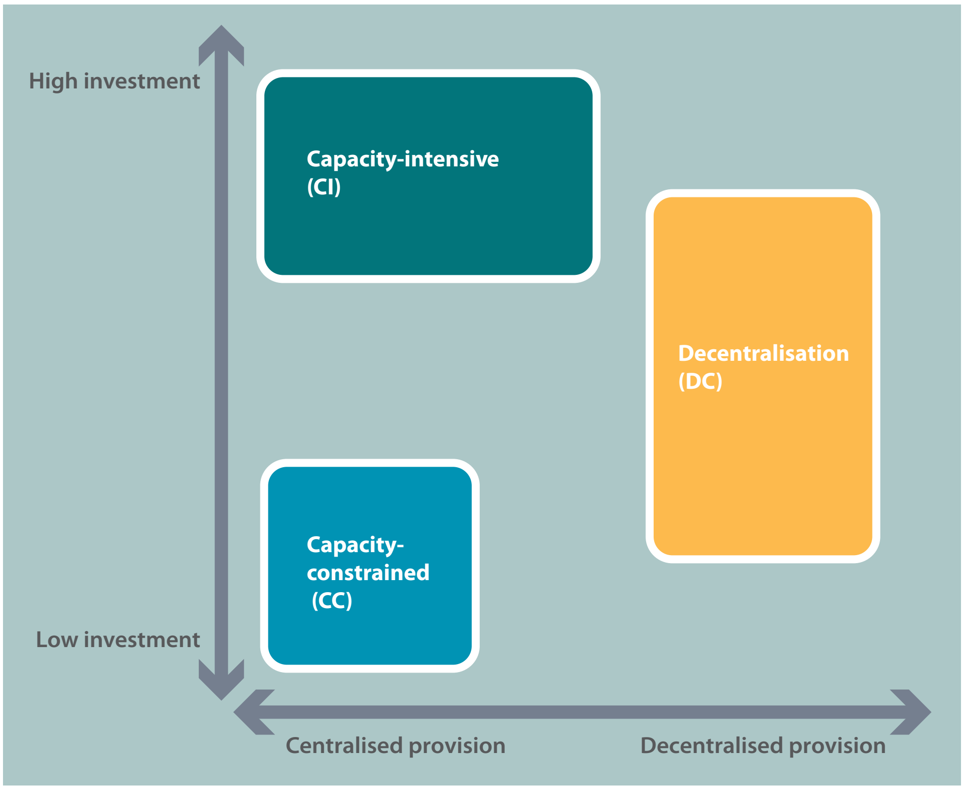
27 Except in road transport, where complete elimination of congestion (a capacity constraint) either via supply-side measures or increased capacity is likely to be unrealistic.

KEY QUESTIONS:

1. **What are the implications of growing demand for infrastructure services?**
2. **What are the implications of constrained investment in UK infrastructure capacity?**
3. **What are the implications of a carbon-constrained future?**
4. **What are the implications of a decentralised National Infrastructure system?**
5. **What are the implications of interdependence between infrastructure sectors?**

Thus, the key dimensions explored by the transition strategies are centralism to decentralism, low to high investment, and carbon constraint (e.g. environmental friendliness). Figure 51 illustrates these key dimensions with the associated transition strategy.

Figure 51: Dimensions of the FTA transition strategies.



5.1.5 POTENTIAL FUTURE NI INVESTMENT LEVELS

Specification of the infrastructure transition strategies requires an indication of the level of investment across infrastructure sectors. The historical and current levels of investment in NI were explored in order to provide sensible bounds on these levels of investments.

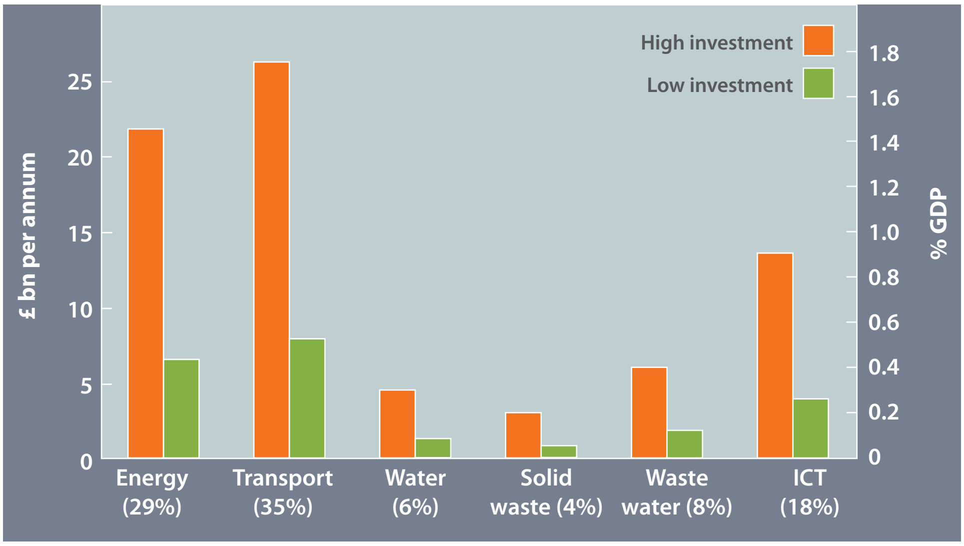
In the Strategy for National Infrastructure (NIP) (2010b), HM Treasury (HMT) and Infrastructure UK (IUK) state that £150 billion was invested in infrastructure in the UK in the past 5 years. This represents an investment of approximately 2.1%[28] of GDP. According to the NIP 2010,[29] over the next 5 years, HMT/IUK estimate £195 billion of planned investments in infrastructure. Using projected UK GDP data[30] for 2011–2015, this investment would represent 2.59% of GDP. The planned investment is lower than OECD's projections of £50 billion per annum (i.e. approximately 3.32% of GDP). A summary of this analysis can be seen in Table 23.

These figures provide median infrastructure investment levels over the next 5 years at 2.5% of GDP. Hence, 'High' and 'Low' investment levels are taken at 5% and 1.5% of GDP, respectively. These values are near to the upper (5.2%) and lower (1.5%) bounds of public investment in infrastructure for the last 40 years (Blanc-Brude *et al.*, 2007).

Table 23: Per cent GDP investment in infrastructure over a five year period

Period (source)	GDP (%)
2005–2006 to 2010–2011 (HMT/IUK), Actual	2.1
2010–2011 to 2014–2015 (HMT/IUK), Planned	2.59
2010–2011 to 2014–2015 (OECD), Expected	3.32

Figure 52: High and low investment levels by sector as a percentage of GDP (right axis). Absolute investment by sector per annum for the high and low investment over the next 5 years is provided for illustrative purposes, with values assuming an equal annual investment over the 5-year period (left axis).The percentage of total NI investment by sector is provided in parenthesis below the sector name. All values are in 2009 prices.



28 UK GDP data used for calculation from the International Monetary Fund's (IMF) World Economic Outlook (WEO) from 2005 to 2009.

29 Values from NIP 2010 were used for the construction of the transition strategy investment levels, as the NIP 2011 values were unavailable at the time of the analysis.

30 UK GDP data used for calculation from the IMF's WEO from 2011 to 2015.

To allocate investments across infrastructure sectors, the planned distribution[31] (in terms of percentage of total investment) was used for the next five years (HM Treasury and Infrastructure UK, 2010b). These values were then translated into percentage GDP investment for each NI sector. Figure 52 summarises these results, and provides the average absolute annual investment value using UK GDP projections for the next 5 years for illustrative purposes.

5.2 ENERGY

The FTA adapts and uses several of the numerous studies of energy futures for the UK. Specifically, the MARKAL model is used to evaluate the three ITRC transition strategies. The UKERC Energy 2050 low carbon and low-carbon lifestyle scenarios are modified to correspond to the ITRC FTA scenarios.

Under the current policy landscape, UK energy system transition will be driven by low carbon and renewable goals, security of supply and affordability of energy. Thus, these aspects are used to evaluate the performance of the three transition strategies. The Capacity-Constrained strategy was found to be consistently least cost and the Decentralisation strategy consistently produced the least CO_2 emissions with greatest diversity of supply sources to 2050. Evaluating the overall performance of strategies across the three metrics suggests that the Decentralisation and Capacity-Constrained strategies had the best overall performance.

5.2.1 ASSESSMENT METHODOLOGY

A review of a range of existing energy models, scenario exercises, and their outputs, revealed that the UK Energy Research Centre's (UKERC) Energy 2050 exercise was most appropriate to model demand and supply options of the energy sector. The outputs of the Energy 2050 exercise use an internationally peer-reviewed energy model (MARKAL) that is technologically disaggregated, and therefore consistent with the ITRC approach. The Energy 2050 scenario set is extensive, providing the scope of choices that match the needs of the FTA. Further, the model and results have been extensively used for UK public policy analysis. The input assumptions and outputs are well documented and in the public domain. Similar scenarios and underpinning logics are evident in other major scenario exercises, notably those of the DECC 2050 pathways analysis and the work of the Committee on Climate Change.

The UKERC MARKAL modelling work was completed in early 2009. The UKERC Energy 2050 scenarios use a back-cast approach, but additionally constrain the rate at which infrastructure is built to ensure technically feasible solutions. MARKAL has models for both supply- and demand-side technologies. The temporal resolution in MARKAL is limited and therefore intermittency and peak demand modelling is handled in a crude manner.

31 The proportion of water and wastewater allowed capital expenditure (Ofwat, from 2010 to 2015) was used to disaggregate water and wastewater investment. Note that the absolute values are provided for illustrative purposes.

In the UKERC scenarios, security of supply is ensured with sufficient capacity margins and reliability checks with the Wien Autonomous System Planning (WASP) model. The MARKAL and WASP models used in the UKERC analysis take into account plant closure and decommissioning, costs, emission factors and technology availability to determine capacity to be installed. WASP uses three sophisticated reliability indicators: the value of lost load (VOLL), loss of load expectation (LOLE) and number of years in a century to ensure capacity is installed to meet demand (Skea *et al.*, 2010). These capacities are generally above the capacity margin of 20% considered satisfactory by NGC. The actual capacity margin in 2010/11 was 36% for electricity and 20% for gas (DECC, 2011f). These capacity margins are extremely important in generation and transmission (of electricity and gas) to ensure planned and certain unplanned outages are dealt with in an orderly manner without loss of load.

Due to capacity margin requirements, different patterns of demand are associated with the different transition strategies. The FTA approach to modelling energy demand is therefore a combination of engineering and behavioural demand modelling. For each transition strategy reference case, a simple econometric approach was utilised to evaluate sectoral fuel demand, driven by price, GDP and population in the underlying transition strategy, and an econometric approach to the effects of population, income and price. The range of econometric drivers and the elasticities employed in the demand space may differ substantially depending on these assumptions. The mathematical formulation of this approach can be seen in Annex E.

There are a number of simplifications for the FTA. The treatment and the separation of demand projections and supply changes are a significant simplification for the assessment. More integrated and spatially disaggregated treatment will be undertaken in the later phases of the ITRC. Similarly, expected changes to power systems pose challenges for supply and demand balancing due to increased use of inflexible and intermittent plant. This is a complexity that will not be addressed in detail in the FTA. While elasticities are assumed to be constant over time, they would likely change significantly over the four decades for which the assessment has been applied here.

5.2.2 DESCRIPTION OF TRANSITION STRATEGIES

The implication of the capacity margin requirement adopted in the FTA analysis is that future demand scenarios inform the energy sector transition strategies (i.e. are not independent). Thus, different energy supply scenarios are developed in parallel to the transition strategies. Generally, the UKERC scenarios are adapted to mimic the FTA transition strategies. An overview of the supply options and technologies assumed in each of the strategies is given in Table 24, and further discussed below.

5.2.2.1 Capacity-Intensive transition strategy

Capacity-Intensive (CI) strategies for the energy sector (i.e. transitioning the electricity sector to capital-intensive low carbon supply options) such as renewable electricity, nuclear power, and the addition of carbon capture and storage (CCS) to fossil fuel generation all require significant investments. Further, most scenarios imply that the decrease in direct use of fossil fuels in heating and transportation would result in an increase in demand for centralised electricity capacity.

Table 24: Supply options, representative technologies and cost sources by transition strategy in the energy sector

Transition strategy	Supply option	Chosen technology for cost calculation	Cost source (Capital & fixed O&M, learning rate)
Capacity-Intensive; Capacity-Constrained	Coal	USC retrofit (Existing coal – FGD)	(Marsh *et al.*, 2005; IPCC, 2007)
	Coal CCS	New PF with CO_2 capture	
	Gas	New GTCC	
	Gas CCS	CCGT PC-CCS	(Mott MacDonald, 2011)
	Nuclear	EPWR (URN) from 2010–2020 Block of EPWR (URN) from 2020	(Sustainable Development Commission, 2006; IPCC, 2007)
	Hydro	Hydro small (1.25–20 MW)	(Enviros, 2005; IPCC, 2007)
	Wind	Wind – off shore (two step resource curve)	
	Marine	Offshore wave	
	Biowaste & others	MSW-SRF	(Mott MacDonald, 2011)
	Solar PV	Solar PV Crystalline	
Decentralisation	Mini-wind	Mini-wind	(Assumed; IPCC, 2007)
	CHP-Stirling	Natural Gas Engine CHP plants	(DTI, 2003)
	Fuel cell-small	Gas driven MCFC – CHP	(Hawkins *et al.*, 2005)
	Fuel cell-large	Gas driven MCFC – CHP	

For the CI strategy, the FTA uses the 'low carbon scenario' from the UKERC Energy 2050 scenario set which has a high reliance on centralised power generation technologies to meet ambitious (80%) carbon mitigation targets. Centralised capacity is added to meet demand under a strict supply security criterion. Information on imminent plant closures and upcoming projects (at the time of modelling) is incorporated in determining capacity. Within these constraints, the MARKAL model generates a cost-minimum energy pathway. To simulate market barriers of investment in technology, a technology specific discount rate is employed. Supply options and mix are outputs from the UKERC Energy 2050 scenarios. A 26% CO_2 reduction is achieved by 2020 (CCC interim target equivalent), extrapolated to -80% by 2050. The scenario includes near- and long term policies (according to the Climate Change Act 2008 and adopted by UK Government) along with the financial budget in 2009. The scenario pathway has explicit carbon emission constraints at 2015, 2020 and 2050, with a straight-line trajectory between 2020 and 2050.

5.2.2.2 Decentralisation transition strategy

For the Decentralisation (DC) strategy, the need for increased electricity capacity remains unchanged, but production of electricity is at or near the point of consumption.[32] Decentralised variants of nuclear power and CCS are not considered able to meet the whole of projected demand, so are unfeasible for this strategy. However, decentralised renewables (e.g. onshore wind, solar and biomass) can make a substantial contribution.[33] Investment requirements remain much higher than historic trends, but much can be undertaken within the building stock (e.g. in photovoltaics or fuel cells) by energy users and therefore falls outside the usual definition of the infrastructure investment.

Building thermal efficiency improvements are not considered although penetration of decentralised energy often involves policies and incentives for simultaneous improvement of building energy performance of the type assumed in the CC strategy.

The DC strategy employs small-scale decentralised energy (i.e. microgeneration) from on-site renewable energy, small and medium combined heat and power (CHP) systems, and community-scale energy from waste (EfW) schemes. Under the EU Renewable Energy Directive goal, the UK has set a legally binding goal of 15% renewable energy by 2020, which UK Government translates to 30–35% of renewable electricity, 12% of renewable heat and 10% renewables in transport. In mid-2011, DECC unveiled its latest Microgeneration Strategy (DECC, 2011d) and UK Renewable Energy Roadmap (DECC, 2011g) on how this goal would be achieved using microgeneration. Currently about 5% of generation is from decentralised energy. Elsewhere in the EU, decentralised energy generates up to 50% and 40% of electricity in Denmark and Netherlands respectively. Globally decentralised energy generation is rising and both EST (Walker, 2005) and AEA (AEA Technology, 2010) estimate substantial potential for decentralised energy in the UK, as is evident from recent estimates by the CCC (2011) Table 25.

However, with only 3% of total energy currently supplied from renewables, most renewables markets in the UK are in their early stage of growth and have barriers to reach their full potential. It would be impractical to meet electricity demand up to 2050 from microgeneration alone.

Additionally, balancing peak electricity demand and supply in a distributed supply system dominated by plethora of renewable generation and CHP will be challenging, since the generation output of renewable energy varies with weather conditions, and it is neither straightforward or desirable to modulate the output of renewables to follow a particular load shape (Strbac, 2008). Similarly, the electrical output of domestic CHPs will be primarily driven by the demand for heat rather than electricity.

This intermittency creates limitations for renewable generation to displace conventional plant capacity. It will be necessary to retain a certain amount of flexible conventional capacity to ensure security of supply, or to deliver an equivalent service from storage or demand response. In the future, suitable storage technologies, innovative peak load levelling and Demand Side Management (DSM) methods will play a major role in compensating for this generation–consumption mismatch (Luo *et al.*, 2010).

32 Ofgem defines decentralised energy as energy from generating plant of under 50 MW connected to a local distribution network system, rather than to a high voltage transmission system.

33 Note that highly decentralised scenarios require a further contribution from 'medium carbon' options, notably small scale, gas-fired CHP, implying some trade-off with climate mitigation options.

Table 25: UK Practical renewable energy resources (Committee on Climate Change, 2011)

Technology	UK practical resource (tWh/yr)
New nuclear	175*
Onshore wind	80
Offshore wind	400
Tidal stream	18–200
Wave	40
Solar PV	140**
Tidal range	40***

* From 8 approved sites with 20 GW;
** With current technology;
*** About half of Seven Barrage.

Recent research finds that Vehicle-to-Grid (V2G), possible with high penetration of electric vehicles, when combined with DSM can substantially increase this compensation and save electricity purchase costs (Guttinger and Ahcin, 2011; Ricardo, 2011).

A DC strategy involves aggressive uptake of solar photovoltaic, and onshore micro/mini-wind and CHPs (both stirling and fuel-cell type). The Energy Saving Trust (EST) (Walker, 2005) assumes estimated generation by decentralised energy technologies in year 2030 and 2050 as fractions of demand in 2005 (380 tWh) (see Table 26). The FTA assumes a conservative generation below those figures in 2030 and 2050 except for solar PV.

Solar PV on buildings and in small scale ground arrays is currently stimulated by a feed-in-tariff (FiT) arrangement, although support levels are reduced from December 2011 and a new FiT scheme with Contract for Difference over the current premium FiT is being proposed in the Electricity Market Reform white paper. Aggressive financial incentives for solar PV are assumed till 2030 delivering 25 tWh generation. Robust growth is assumed to continue till 2050 when all 20 million homes have adopted the technology with an average capacity of 2 kWp. Similar incentives operate in commercial and public buildings, with larger arrays averaging 50 kW on 200,000 buildings, giving a commercial capacity of about 10 GW. A total generation of about 45 tWh in 2050 is targeted.

Small wind turbines can be located on buildings (up to 1.5 kW) or 'pole-mounted' (up to 6 kW), although application is limited by wind speeds. A total of 10 TWh is assumed to be generated by 2050. Fuel cell CHP at the scale for individual houses is at the demonstration stage. Estimates for the UK indicate a potential of 10M homes. Calculations based on a 3 kW device, a heat:power ratio of 1:1 and a typical heat requirement (for heat and hot water in a well-insulated home in 2050 of ~10 MWh/year) indicate a load factor of about 40%. A total generation of 100 tWh by CHP is assumed.

The generation mix is temporally varied to increase the share of decentralised energy until it reaches the assumed generation amount (Table 26). Simultaneously generation from nuclear, coal and coal CCS is reduced while increasing generation from gas where needed to meet total generation needs. Thus, supply options under this transition are not consistent with the least-cost approach in the other two strategies. Installed capacities are then estimated using generation efficiency and availability from MARKAL-MED model and cost sources listed in Table 24. The CHP output is broadly correlated with heat demand, and therefore may be overall beneficial, it is assumed that no additional backup capacity is required. Also, CHPs will displace large number of heat pumps.

Table 26: Generations in EST (Walker, 2005) scenarios and assumed generation in the decentralisation strategy

Technology	Assumption in EST (2005), % of 2005 generation		Assumption in EST (2005), tWh/yr (P x 380 tWh/yr)*		Actual in 2010, tWh/yr	FTA assumption, tWh/yr	
Year*	2030	2050	2030	2050	2010	2030	2050
PV-domestic	0.10	0.30	0.38	1.14	0.033[1]	25.00	45.00
Small wind**	1.20	5.90	4.56	22.42	0.055[2]	3.50	10.00
CHP Stirling**	1.00	6.30	3.80	23.94	0.010[3]	5.00	25.00
Fuel cell small***	0.70	9.40	2.66	35.72	0.010[3]	5.00	35.00
Fuel cell large***	0.60	18.40	2.28	69.92	0.010[3]	2.00	40.00

* EST(2005) assumes 2005 total generation as 380 TWh.
** From EST(2005) Capital subsidies of 25% and cost reduction scenario.
*** From EST(2005) Energy export equivalence scenario.
1 RenewableUK, 2011.
2 NS, 2011a
3 Assumed by author

UKERC Scenario

The DC strategy is designed to meet the demand from the UKERC Low Carbon scenario from the UKERC 2050 scenario set, with the same set of energy demands, but with explicit modification of the electricity supply sector to increase the use of decentralised power generation technologies.

5.2.2.3 Capacity-Constrained transition strategy

Capacity-Constrained (CC) strategies have been examined in some detail in the literature. Usually, it is in the context of social change or energy security driven trends that focus on energy efficiency improvement and energy demand reduction. Under these conditions, energy demand trends vary from the conventional econometric assumption that they are driven principally by population, income and cost drivers. Lower demand is reflected in low demand growth, although climate mitigation still implies a very much higher trend for electricity demand than for direct use of fossil fuels.

The 'low-carbon lifestyle scenario' is used for the CC strategy as lifestyle changes in residential and transport sector are incorporated to assist in achieving 80% CO_2 reduction by 2050 (Eyre *et al.*, 2010). The residential sector uses the UK Domestic Carbon Model (Palmer *et al.*, 2006) which enables different scenarios of house building, demolition, fabric improvement, and installation of microgeneration. It also evaluates the effects of changes in lifestyle-related attributes such as in internal temperature, hot water use, and other energy saving behaviours. The transportation sector uses the UK Transport Carbon Model (Brand *et al.*, 2012), a strategic transport–energy–environment model for simulation of passenger and freight transport. It uses detailed fuel consumption and vehicle stock projections from shifts in travel patterns (car occupancy, modal split, technology choice etc.). Further, energy service demand is based on an evidence review (Anable *et al.*, 2006) of the impact of transport policies and travel patterns in and out of UK. The demands from both models are used as energy demand inputs into MARKAL which was again used to optimize costs to meet an 80% CO_2 reduction.

5.2.3 EVOLUTION OF THE TRANSITION STRATEGIES' SUPPLY OPTIONS

Coal CCS is an early choice for decarbonisation in MARKAL-MED for power generation in both transition strategies from 2020 onwards as seen in the CI and CC strategies (Figures 53 and 54). It remains a main supply option in both transition strategies with nuclear later selected in part to meet carbon target. With more wind electricity to the grid, gas capacity is also gradually increased. Interestingly, in the CC strategy, coal generation is present but as the need for new generation is reduced, the carbon goal is met through aggressive electricity demand reduction in all sectors, especially residential. Also, solar thermal, micro-wind and solar PV penetrations are respectively at 50%, 5% and 15% of dwellings by 2050.

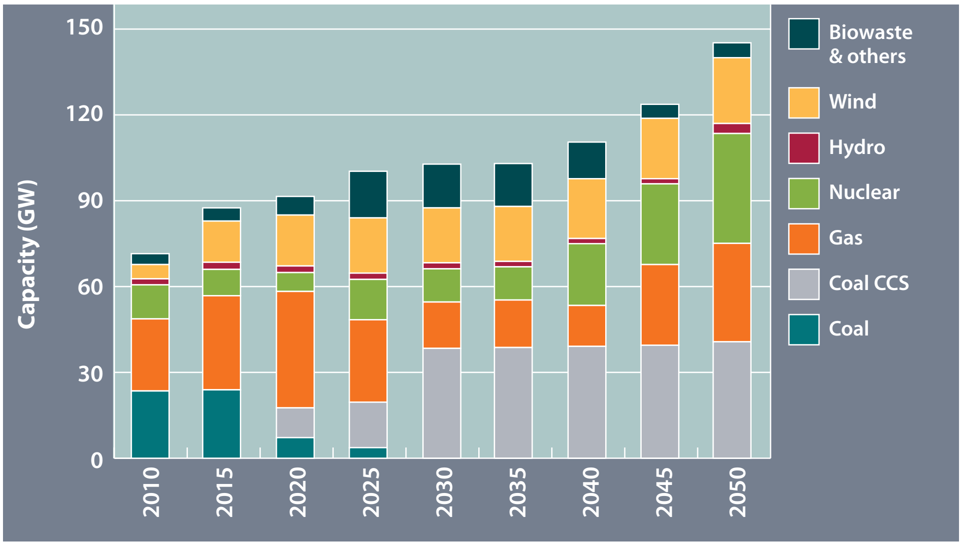


Figure 53: Supply options and capacity in the Capacity-Intensive transition strategy (High growth scenario).

Figure 54: Supply options and capacity in the Capacity-Constrained transition strategy (High growth scenario).

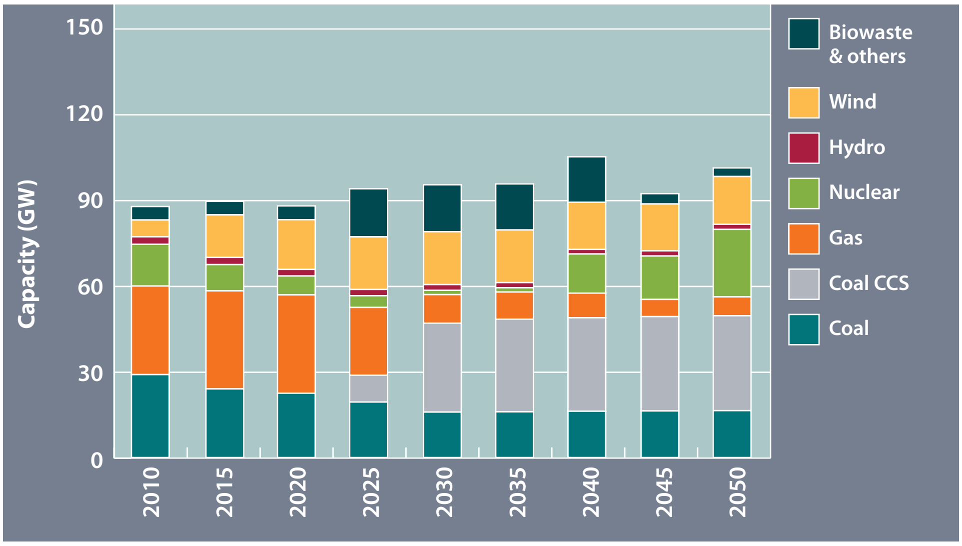
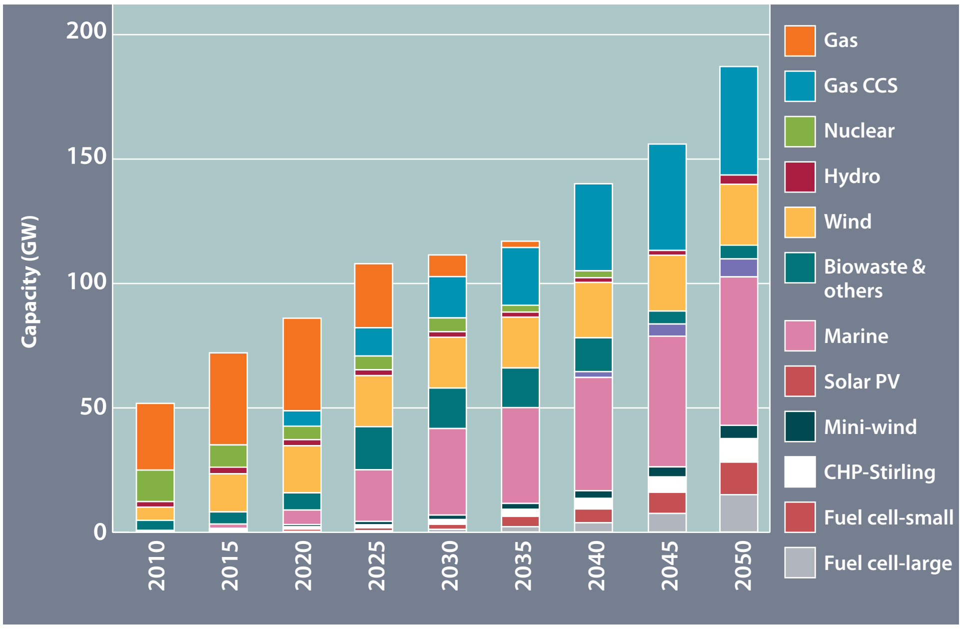


Figure 55: Supply options and capacity in the Decentralisation transition strategy (High growth scenario).



Gas remains a major supply option both in the CI (Figure 53) and DC (Figure 55) strategies in order to ensure sufficient standby capacity to account for intermittent supply options (e.g. wind) in the generation mix. A recent IEA special report (WEO, 2011) reports fewer uncertainties over the outlook for natural gas with both demand, and supply side forces pointing to a possible 'Golden Age of Gas'. With recent discoveries of vast unconventional gas reserves (shale-gas) and favourable LNG trade, a high-gas scenario in future supply mix is also a reasonable possibility. A recent scenario analysis by Redpoint Energy for the Electricity Network Association found that gas could continue to play a major on-going role in GB market mix in the foreseeable future while meeting both renewable and carbon targets (ENA, 2010). The case for continued gas use becomes even more attractive with an existing network, given the uncertainties and risks associated with key emerging low-carbon technologies. However, it remains to be seen how environmental concerns regarding recovery of shale-gas (mainly from large amounts of freshwater use and disposal, and possible earthquakes from such operations) play out on the production volume.

5.2.4 FUTURE DEMAND UNDER THE FTA SCENARIOS

The CI and CC strategies provide the greatest contrast in future demand. Thus, Table 27 presents the estimated sectoral fuel demand space for the UK for the high (scenario 3), medium (scenario 2), and low (scenario 1) growth scenarios to 2050.

Table 27: Estimated fuel-wise sectoral demand space for the UK to 2050. (Central demands are from the respective UKERC 2050 scenarios)

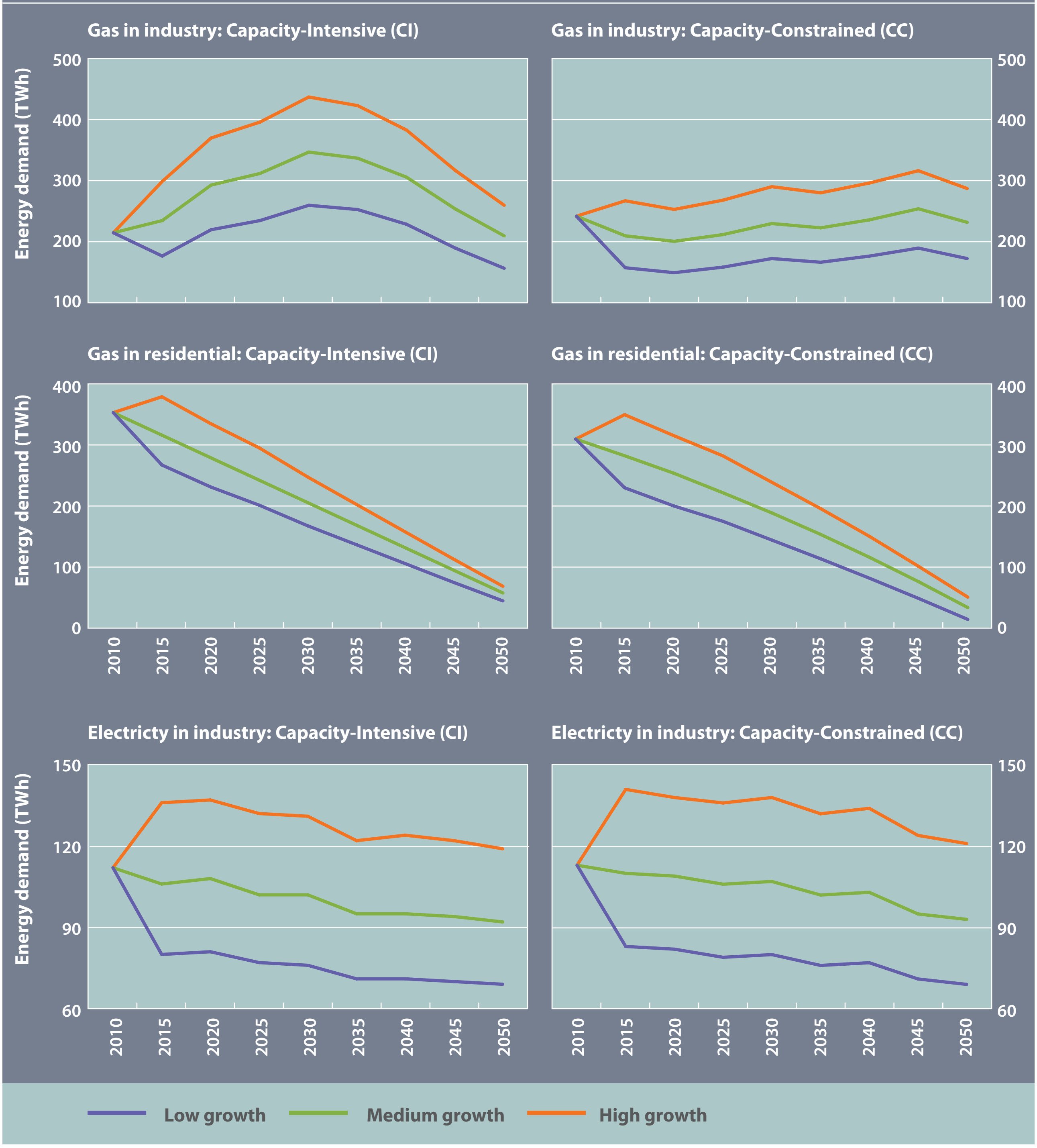
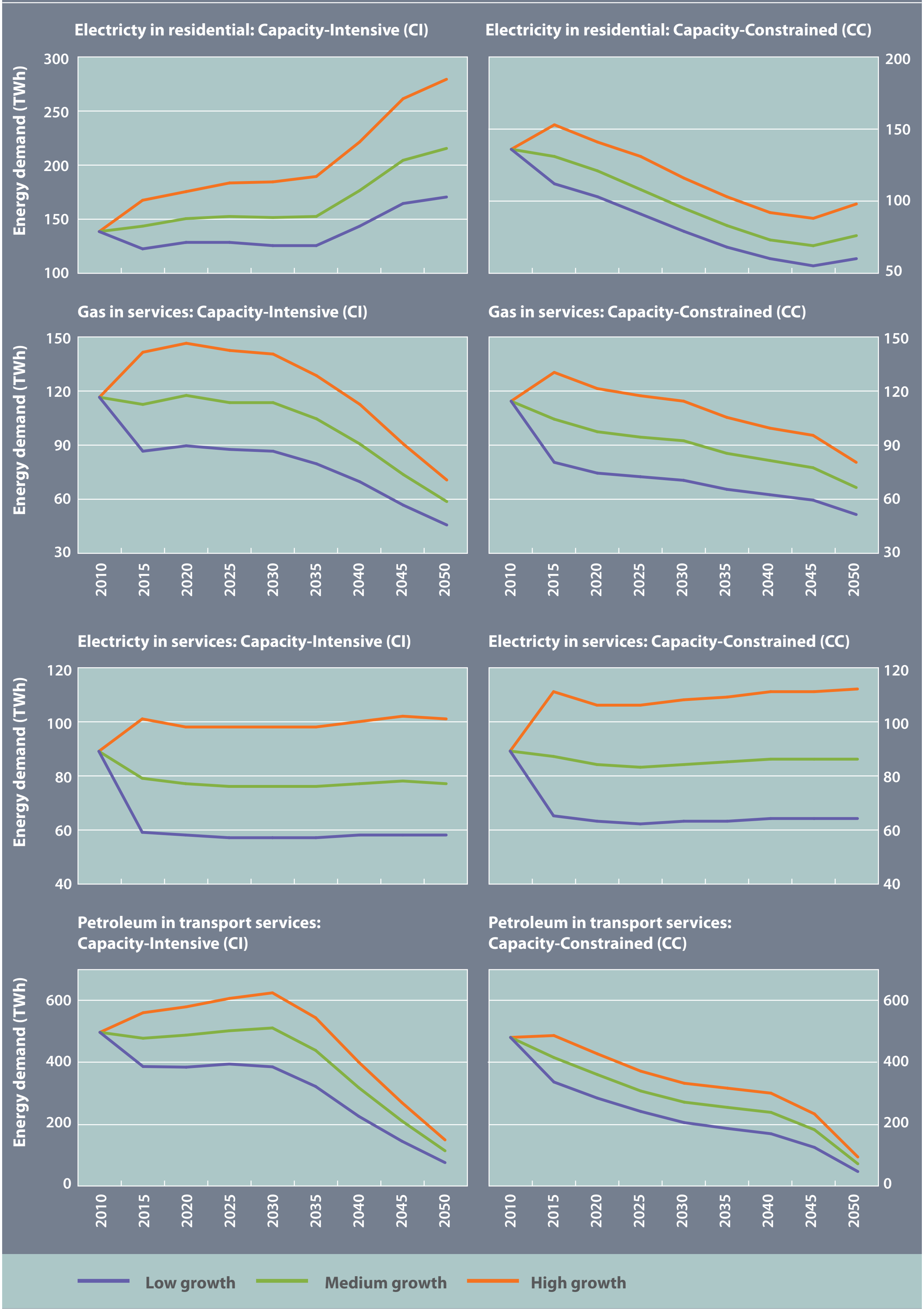


Table 27 (continued)



In both CI and CC strategies, electricity generation from fossil fuel sources is decreased in line with ambitious carbon targets, and decarbonisation is achieved through end-use efficiency and demand reduction in end-use sectors. However, with the tightening of decarbonisation targets from 2035 to 2050, shifts in low carbon electricity outweigh the efficiency improvement and demand reduction and low carbon electricity generation rise to meet carbon goals across sectors. Transport petroleum demand falls sharply to decarbonise the sector mainly through electrification (efficient hybrid-plugin) with low ethanol and battery operated vehicles.

In the CI strategy, the residential sector decarbonises mainly by shifting from gas to electricity with increasing equipment of higher efficiency especially heat pumps for space and water heating. Demand reduction methods such as electric boiler night storage also play an important role. The service sector is decarbonised by shifting to biomass and electricity while employing efficient electric equipment such as heat pumps for heating.

In the CC strategy, gas demand is shifted to electricity in the residential sector while reducing this electricity demand through lifestyle changes in internal temperature, hot water use and other energy saving behaviours. Consequently, energy efficient appliances and equipment are used in the CC strategy and housing stock energy efficiency is increased with increased insulation. New houses after 2020 are built with improved building standards, passive and low-tech approaches (to tackle increasing heating degree days) and high insulation levels. Incandescent lighting is phased out and district CHPs are applied to about 10% homes by 2050. Transport lifestyle changes are obtained through a decrease in the average distance travelled, an increase in car occupancy, on-road fuel efficiency, transition to EV/PHEV/HEV, modal split from personal vehicles to mass transportation and decreasing share of large cars.

5.2.5 PERFORMANCE EVALUATION

5.2.5.1 Cost

From 2011 to 2015, the lowest and highest investment requirements across transition strategies and demand scenarios were £4.3 billion and £19.4 billion respectively. The CC strategy is consistently least-cost over the three scenarios, followed by the CI and DC strategies over the time period 2011–2050 (Figure 56, overleaf). To evaluate the costs of transition strategies, capital (for installation of new capacity) and fixed O&M costs are included. Variable O&M costs and costs of plant decommissioning and closing are not included. Costs are often controversial, particularly for renewable technologies that are yet to mature and reach full market penetration. Representative technologies for supply options and sources of future costs used are listed in Table 24. Costs for solar PV, biowaste (MSF) and gas CCS are taken from estimations in MML (2011) for high renewables scenario until 2040. For coal, coal CCS, gas and nuclear, costs are linearly interpolated between 2010 and 2020 from available costs in these years; costs for 2020 are assumed constant throughout to 2050. Costs for other technologies are estimated using published learning rates (mostly from IPCC (2007)) and technology costs in the year 2000. Table 24 lists the specific technologies considered for cost estimation with the relevant sources.

Figure 56: Total cost of capacity installation over 40 years (2011–2050) for the three transition strategies against the ITRC FTA scenarios.

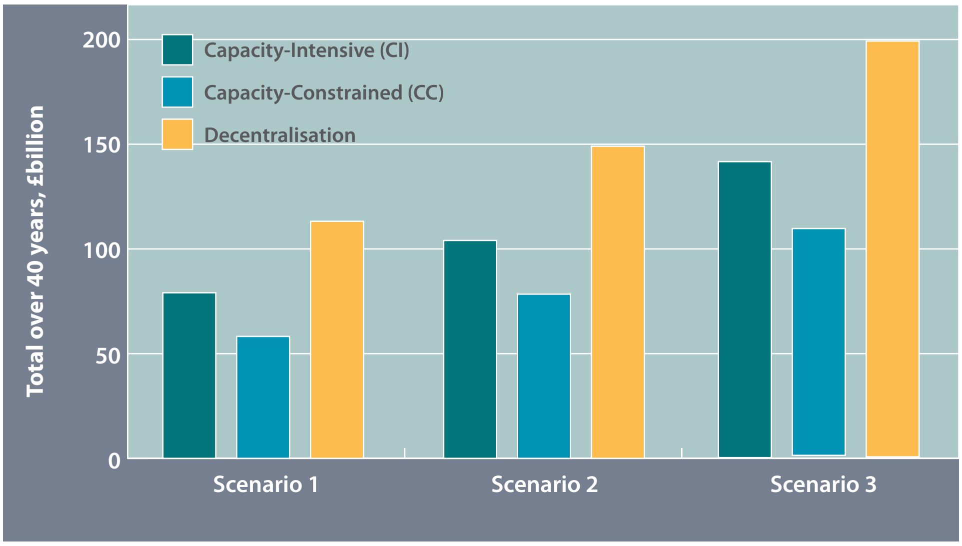


Figure 57: Total electricity sector CO_2 emissions (2011–2050) by transition strategy against the ITRC FTA scenarios.

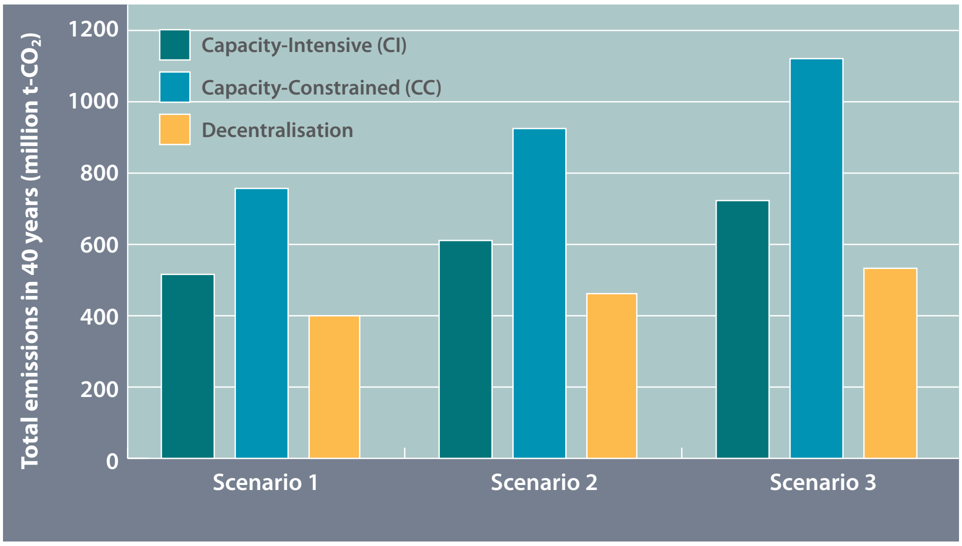
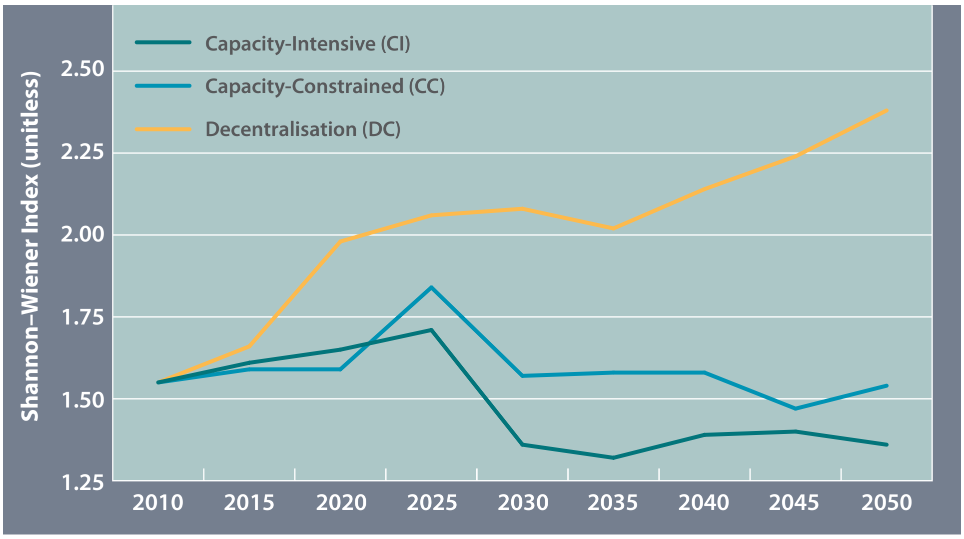


Figure 58: Diversity of supply options, high growth scenario (Shannon–Wiener index). Higher index denotes greater diversity of supply.



5.2.5.2 CO_2 emissions from electricity generation

The DC strategy consistently produced the least CO_2 emissions, following closely by the CI strategy to 2050 (Figure 57). The CC strategy resulted in the most CO_2 emissions. Several assumptions were made in estimating CO_2 emissions. With the exception of emissions from fuel used in electricity generation, other life cycle emissions were not considered. Thus, renewable generation technologies including nuclear effectively produce zero emissions. Also, emissions from electricity generated by CHP is taken as zero carbon. Any emissions generated by CHP are allocated to the generated heat part and are not considered in this estimation. Finally, emissions from electricity generation are estimated based on emissions factors and capture rates (for coal/gas CCS) from Killip (2005) and Skea *et al.* (2010). Emission factors are assumed constant through to 2050.

5.2.5.3 Electricity supply security

The DC strategy resulted in consistently greater supply security using the the Shannon–Wiener index (Stirling, 1994), a simple measure often used to assess security of supply emanating from diversity of supply options. This is particularly important for an increasingly net primary energy importer such as the UK. Since becoming a net importer, the share of UK's imported primary energy to total has grown to 27%, with the major share belonging to coal and gas, the primary sources of fuel in hydrocarbon-based electricity generation. In a BaU case, the share of gas in primary energy supply is predicted to increase to 30+% by 2020 (Bolton, 2010). A single fuel system has a Shannon–Wiener index of 0. A value above 2 will indicate a system with diverse sources with none playing a dominant role – such a system can be reasonably considered secure in case of individual supply option interruptions.

5.2.5.4 Summary

Figure 59 presents a visual summary of the performance of the three transition strategies across the three growth scenarios for the two time-periods: 2010–2030 and 2030–2050 for electricity generation. This visualisation was created using the highest and lowest figures for Cost and Emission as benchmarks, and relative value for supply security.

As previously stated, the CC strategy resulted in the lowest cost, in part due to an emphasis upon demand reduction. The DC strategy resulted in the highest cost, with a possible reorganisation of the sector towards higher-cost distributed energy technologies requiring investment in the earlier years. The DC strategy offers benefits in terms of increased supply diversity, although the Shannon–Wiener index does not account for the security benefit provided by over-capacity in the CI transition strategy. Evaluating the overall performance over the entire time period revealed that the DC had the best aggregate performance across the time periods and the three metrics, followed by CI and CC.

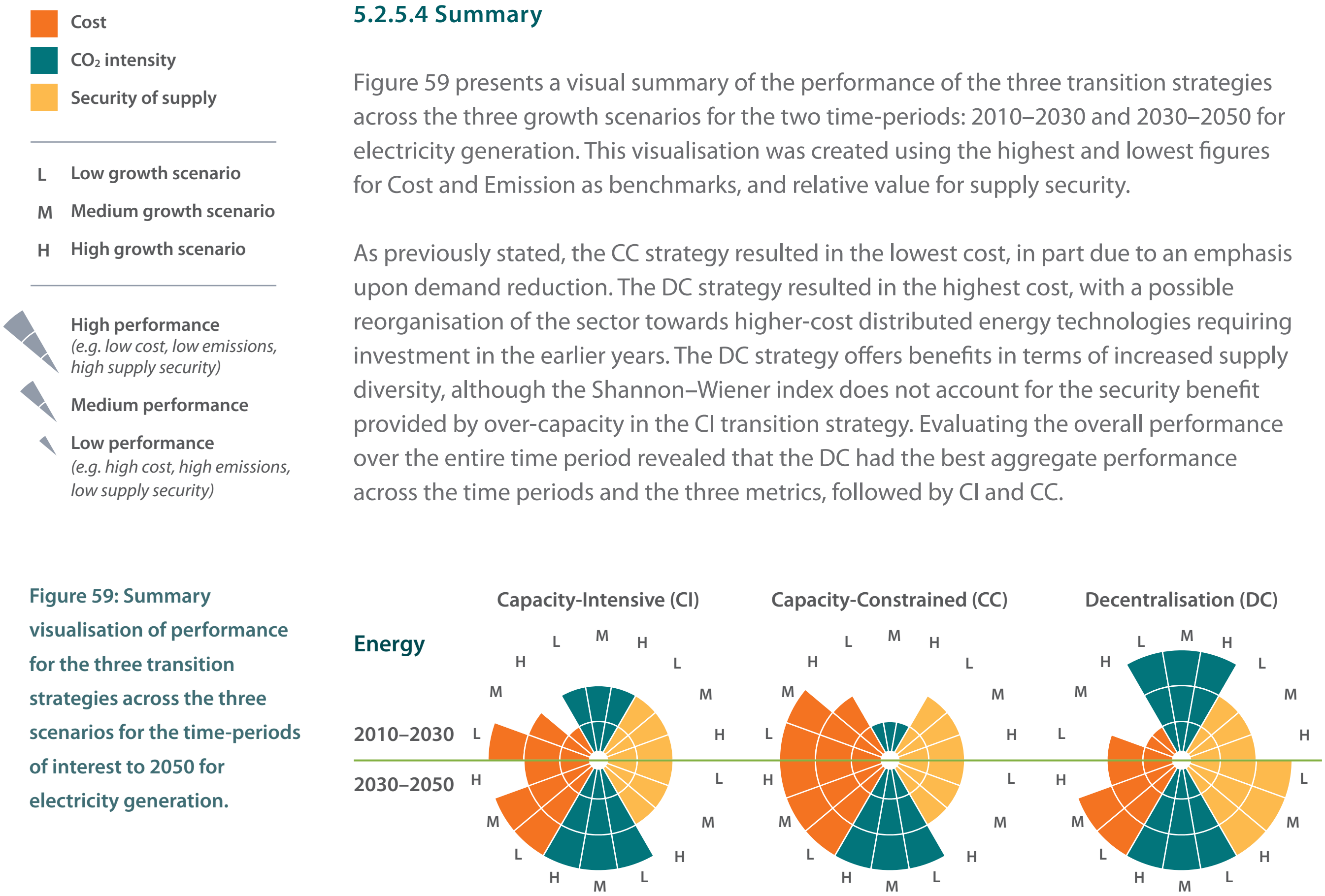


Figure 59: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050 for electricity generation.

5.2.6 CONCLUSIONS

Under the current policy landscape, UK energy system transition will be driven by low carbon and renewable goals, security of supply and affordability of energy. Commitment to carbon targets is likely to be one of the biggest sources of uncertainty. The envisaged shift to a low carbon electricity system is critical in all scenarios. Potential major supply options are fossil fuels with CCS, nuclear and wind. Numerous previous studies have demonstrated that the change is technically achievable; however, it will require significant investments and the options each raise potential implementation problems. The challenges associated with such a change are exacerbated by the projected need for more capacity to electrify transport and heating.

Nearly all end uses of energy are subject to significant quantitative uncertainty by the mid-century due to the combined effect of uncertainties in population, GDP and world fuel prices, as well as technical, social and policy change. The use of natural gas in buildings (residential plus services) may fall to low levels, driven by carbon emissions reduction targets with heating becoming largely electrified. A significantly reduced use of natural gas raises concerns about the economic sustainability of the distributed gas infrastructure by the mid-century. This requires further investigation. Re-use of the existing infrastructure for either hydrogen or biomethane is technically possible, however, is not considered in this report. The use of petrol and diesel in transport is subject to the same pressures of carbon emissions and therefore falls to low levels by the mid-century in scenarios meeting stringent carbon emissions targets (alternative fuels include biofuels and electricity).

The widespread electrification of both heating and transportation would reduce demand for the two fuels that are of most energy security concern – petroleum and natural gas – so that ambitious carbon emissions reduction targets are consistent with some energy security objectives. This shift would require significant changes to user practices in buildings and travel. The implied social changes have not been extensively studied, thus could present unforeseen challenges in adoption of the low carbon energy infrastructure.

Natural gas in industry is more difficult to substitute, reflecting the assumed need for (or major cost advantage of) gas in key industrial processes. Further attention to more fundamental process change is warranted. Continued use of gas at current and higher levels in the foreseeable future is a possibility given current developments on large discoveries of reserves and favourable LNG trade.

As the FTA scope is limited by design, the current analysis is limited in its ability to recommend policy options based solely on the analysis of infrastructure implications with the limited sets of given transition strategies. The next modelling step would aim at analysing numerous plausible transition paths and test them for robustness. Along with factors such as GDP, population and energy price, transition strategies influence final demand depending on supply technologies, behavioural changes and policy inventions etc., at play (as in MARKAL). Unlike in FTA, transition strategies are endogenous in the disaggregated demand model under development.

5.3 TRANSPORT

The approach taken in the FTA was to estimate transport demand using an elasticity model that relates changes in demand to change in population, fuel prices and GDP in the ITRC FTA scenarios. The low growth scenario is most consistent with previous trends. Demand suppression was modelled using feedback relationships between demand and resulting journey times to estimate constrained demand.

The Capacity-Intensive transition strategy (high investment and fast uptake of electric vehicles) would result in higher growth in demand (e.g. 23.4% more car/van km in 2050 compared to the reference case) but reduced CO_2 emissions (18.9% fewer emissions from cars and vans, and 25.2% fewer emissions from HGVs in 2050 compared to reference case) due to fuel efficiency improvements of 70%. The Decentralisation transition strategy (medium uptake of electric vehicles, introduction of a national congestion charging scheme) would result in around 5% more car/van vehicle km but 10.7% lower CO_2 emissions in 2050 compared to the reference case. The Capacity-Constrained transition strategy (low investment, low uptake of electric vehicle, introduction of a national congestion charging scheme) was estimated to reduce car/van km by 3% with reduced CO_2 emissions of 7.3% for car/vans and 2.4% for HGVs in 2050 compared with the reference case.

5.3.1 ASSESSMENT METHODOLOGY

The assessment approach taken in the FTA was firstly to estimate transport demand for the whole transport infrastructure, unconstrained by any capacity considerations, using an elasticity model to relate transport demand growth to growth in population, fuel prices and GDP, with any added taxes or charges also being factored in (e.g. national congestion charge). It should be noted that 'carbon taxes' were not included in the transport FTA so there was no assumption that carbon reduction targets would be met. It is noted that this differed from the energy FTA where it was assumed that carbon reduction targets would be met. Subsequent analyses will address these differences. Demand suppression was then modelled using feedback relationships between demand and resulting journey times to produce 'constrained demand'. This procedure is elucidated in Section 5.3.1.2 (unconstrained demand) and Section 5.3.1.3 (constrained demand).

The constrained demand estimates were then used to derive projections of the performance indicators used here: delays on trunk road network (minutes per 10 miles); CO_2 emissions (106 tonnes); and fuel/energy use (109 litres or Mjoules). Future year vehicle emission rates and fuel/energy consumption rates, for different types of vehicle and fuel type, were taken directly from the Tosca project.[34] These estimates were based on what the Tosca project considered to be realistic future developments in fuel technologies and vehicle/engine performance, so these data take into account, for example, improvements in hybrid engines, both for passenger cars and for freight vehicles. These data were used as they were readily available and provided comprehensive coverage – one known 'error' associated with the use of TOSCA data is that the emission and fuel consumption rates are for new vehicles and the proportions of older vehicles being used have not been estimated – this is something that will be considered later in the study. It is also noted that the Tosca data included production emissions as well as emissions at the point of use, so there would be double counting if the transport FTA results were to be added to the energy FTA results, which already considered production emissions.

34 http://www.toscaproject.org/

It should be noted that the transport FTA is a broad brush assessment of transport infrastructure and travel demand as a whole and is not concerned with individual trip-making behaviour. In reality, transport infrastructure has its highest stress levels at certain times of day (i.e. peak periods) and in certain locations (e.g. bottlenecks), however, the FTA has not considered these. These more detailed considerations of transport infrastructure will be investigated later in the ITRC study.

5.3.1.1 The modelled infrastructure options

A single reference (base case) set of infrastructure options was used in the transport FTA. In the reference case there is a negligible use of electric road vehicles. However, different levels of electric vehicle take-up were modelled, in addition, to assess impact on demand. A 'medium uptake' level in passenger rail electrification of 0.75% per annum, resulting in 80.7% rail electrification by 2050 and 100% by 2076, but a more limited increase in rail freight electrification. Increased road capacity of 100 lane km per annum on the trunk road network, corresponding to 'medium capacity growth'. Increased rail capacity through the introductions of Crossrail, HS2 and HS2+ but no other increases. Finally, there is no introduction of congestion charging or similar road charging schemes.

Delays on trunk road network

Projected vehicle delays on the 10% slowest routes of the trunk road network (minutes per 10 miles) are shown in Figure 60 for the low, medium and high growth scenarios. It can be observed that delay increases from around 3.5 min for the base year (2008) to around 6.5 min for the high growth scenario, by 2050.

CO_2 emissions

Projected CO_2 emissions for cars/vans and lorries are shown in Figure 61 (similar data have been derived for rail transport but are not presented here as the emissions are considerably lower). It can be seen that emissions are modelled to increase in most cases due to increasing demand, with the exception of the low growth scenario for cars/vans, where the assumed improvements in vehicle engine technology counteract the increasing demand and bring about a small decrease in emissions.

Fuel/energy use

Projected fuel use (billion litres) for cars/vans and lorries (litres) is shown in Figure 62. The fan shape reflects the differences in demand between the scenarios. Projected energy use for rail transport, both passenger and freight, is shown in Figure 63.

5.3.1.2 Unconstrained demand

Unconstrained future demand for transport was estimated by considering demand elasticities with population, GDP and fuel prices. Fuel prices were modified by the introduction of a congestion charge or an added tax on electric vehicles, in some cases. A standard formula for treating elasticities was used which assumes that the elasticities are constant over time. A potential criticism of the approach adopted here is that future relationships may not necessarily be well predicted from previous observations and that elasticities may well change over time. For example, car driving rates may be reaching saturation levels with limited scope for expansion. Annex F presents the formulation of unconstrained demand.

Figure 60: Delays in reference case.

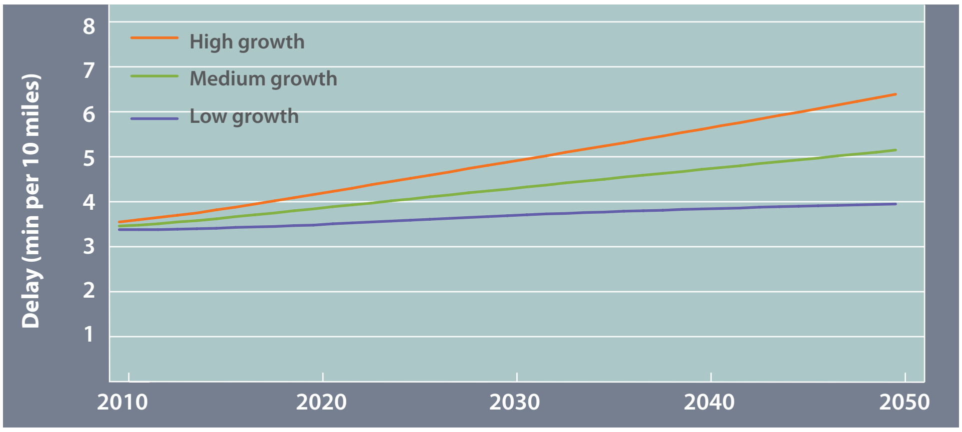


Figure 61: CO_2 emissions.

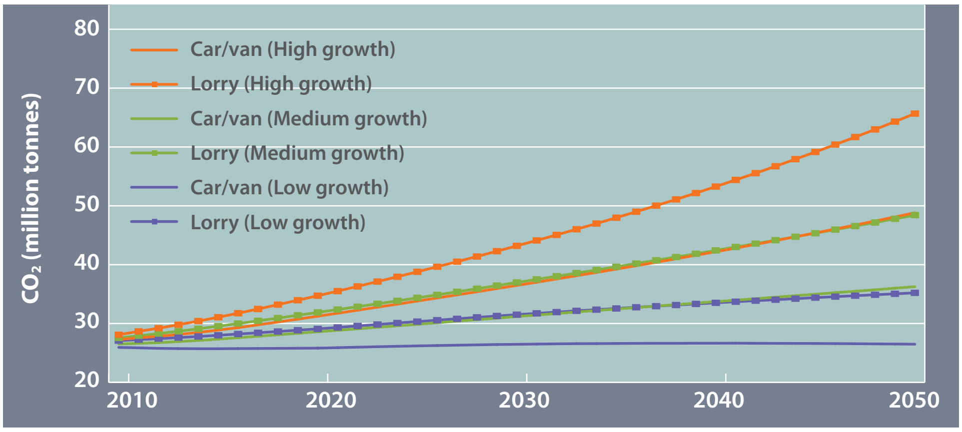


Figure 62: Fuel use in road transport.

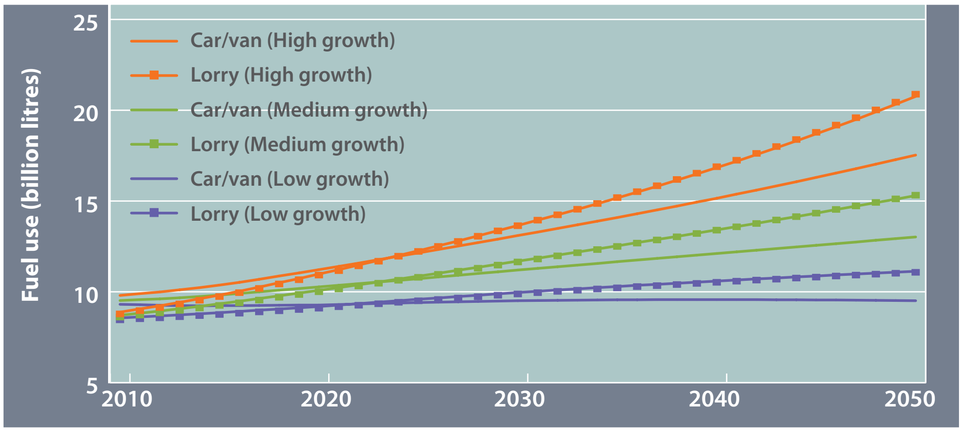
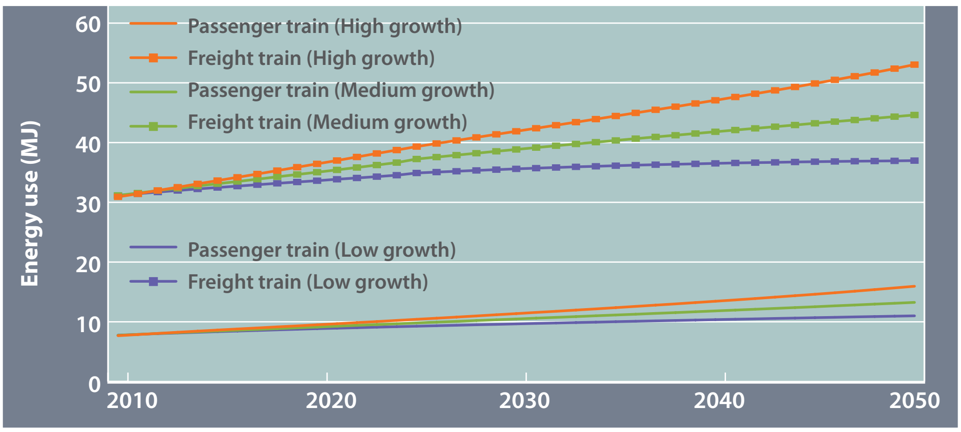


Figure 63: Energy use in rail transport.



5.3.1.3 Constrained demand

Demand constraints reduce demand to a lower level than might otherwise occur. They come in three main forms:

1. Physical constraints such as the number of seats in a train or aeroplane.
2. Delay constraints that deter people from making the journey or that encourage them to travel by an alternative mode of transport or at a different time.
3. Cost constraints.

Constraining transport demand may have a negative impact on economic development, however, this may not necessarily be the case if transport growth can be decoupled from GDP growth through a combination of planning, pricing, policy, technology and assessment methods (Victoria Transport Policy Institute, 2010).[35] Suppressed demand may either disappear (the trip is not made) or may transfer to another mode. Using diversion rates for interurban travel, 42% of those switching from car will go to rail while, in the reverse direction, 60% of those switching from rail will go to car (Balcombe *et al.*, 2004). The number of people transferring from rail to car is likely to be modest whereas the number of people transferring from car to rail may be more significant. These effects have not been modelled in the FTA, however, but will be included in later analyses.

Road transport

An increase in road transport demand will lead to an increase in traffic and an increase in journey times. DfT's Long Distance Model (LDM) (Scott Wilson *et al.*, 2007) seems to suggest an elasticity of journey time with respect to traffic of around 0.3. However, increases in journey times will tend to inhibit demand: the LDM suggested an elasticity of –0.41. Annex F presents these two formulations. Iterating between the formulation results for journey time and demand inhibition gives convergence to a stable solution.

Rail transport

Capacity utilisation is based on the ratio of actual train km per track km to maximum capacity, with a typical existing utilisation of around 50%. However, increases in delays will tend to inhibit demand and capacity utilisation, with an elasticity of demand with respect to delays of –0.34 (Preston and Dargay, 2005). An iterative procedure, similar to that used for road transport above, was used to try to obtain convergence to the constrained demand. Annex F presents the formulation of the rail transport.

Air transport

Capacity constraints for air transport are generally considered either in terms of the maximum number of passengers that can pass through a terminal or the maximum number of aircraft movements that its runway(s) can support (Scott Wilson *et al.*, 2007), from which maximum passenger capacity can be derived. The latter approach was adopted by the comprehensive study of forecasting future UK air demand (DfT, 2009). This study also considered the potential for reallocation of demand between different airports and options for additional infrastructure (e.g. a second runway and associated terminal infrastructure at Stansted and a third runway and sixth terminal at Heathrow).

35 http://www.vtpi.org/tdm/tdm54.htm#_Toc218750000

Their forecasts for 2030 (low, central, high) went from unconstrained figures of (415, 465, 500) million passengers per annum to constrained figures of (410, 455, 480) million passengers per annum, equating to fairly small reductions of (1.2%, 2.1%, 4%). These percentage reductions were adopted for use in the FTA, using linear interpolation and extrapolation to obtain reduction percentages for other years.

However, it was found that the unconstrained demand for air transport was very high (increasing by a factor of 120 by the year 2100 for the high growth scenario) so it seems that either additional capacity would be needed (not modelled in the FTA) or that the demand would need to be capped drastically (not modelled in the FTA). Also, the recently published National Infrastructure Plan suggested considerably lower demand for air travel (335 million passengers per annum in 2030) than assumed here, based on an assumption of no new runways and only incremental developments of airport terminals. These issues will be considered in later analyses.

Sea ports

How sea transport is constrained has yet to be considered. The same formulae as used for road transport were used for the FTA in order to introduce some reduction in the modelled demand, however, it is recognised that this should be corrected in later analyses.

5.3.2 ANALYSIS OF FUTURE DEMAND IN THE FTA SCENARIOS

The projected constrained growth (low, medium and high) in **passenger kilometres**, for road, rail and air, up to 2050, are shown in Figures 64–66 (65 and 66 overleaf). It can be seen that for the low growth scenario there is a steady increase in demand whereas for the high growth scenario the growth appears to be exponential. In addition, car/van demand was modelled for alternative scenarios of electric vehicle penetration (none, low, high) (Figure 67). It can be seen that an increase in the number of electric vehicles is modelled to result in an increased demand for car/van travel due to the assumed reduced running costs; however, this would not be the case if running costs for electric vehicles were broadly similar to those for petrol/diesel vehicles.

The projected constrained growth (low, medium and high) in **vehicle kilometre**s and in **vehicle km per lane km**, up to 2050, are shown in Figures 68 and 69 (overleaf). These display similar curves as for passenger demand.

Passenger kilometres

Figure 64: Medium growth, passenger demand, reference case.

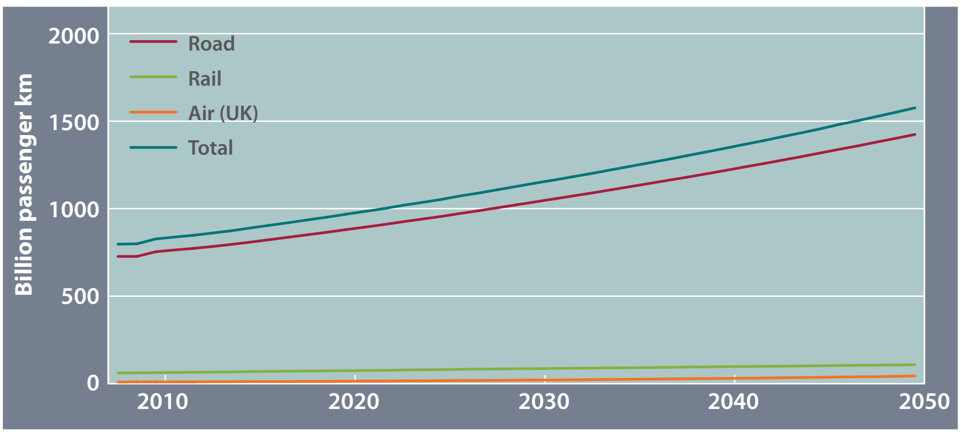


Figure 65: High growth passenger demand, reference case.

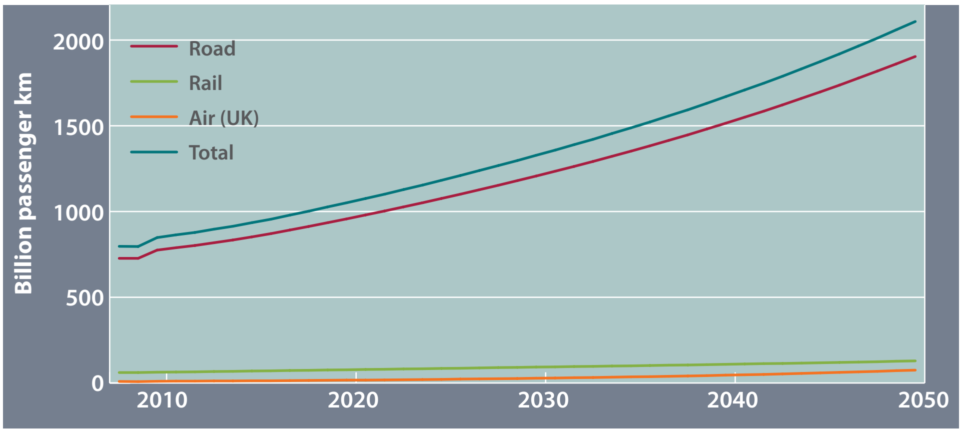


Figure 66: Low growth passenger demand, reference case.

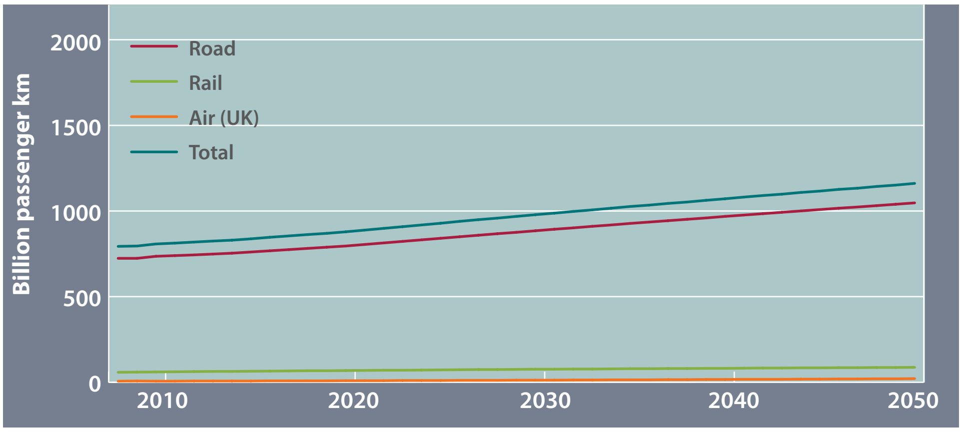
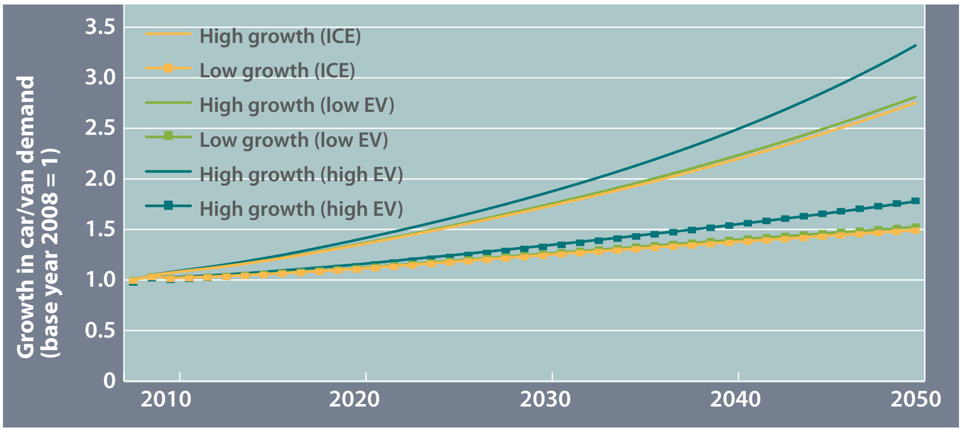


Figure 67: Impact of future technology scenarios. Note: ICE = internal combustion engine; low and high EV refer to penetration rates of electric (and hybrid) vehicles.



Vehicle kilometres (km); Vehicle km per lane km

Figure 68: Vehicle km per lane km. Note: base provision of ~388 vehicles per lane per hour.

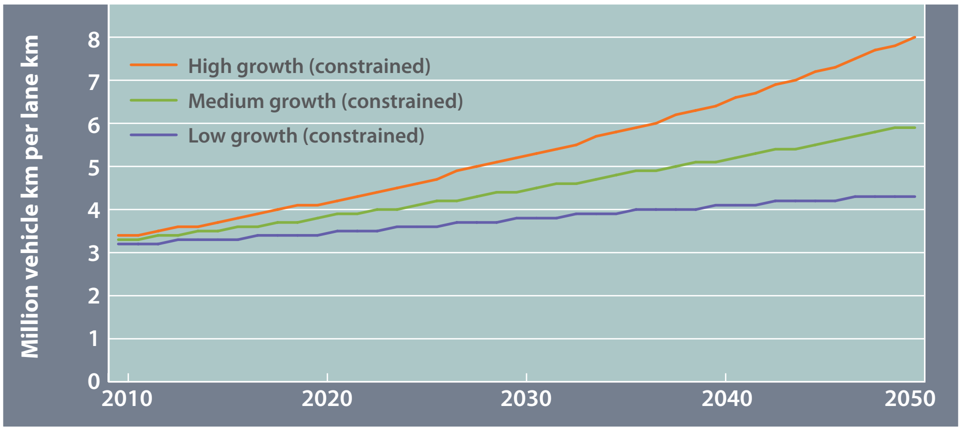
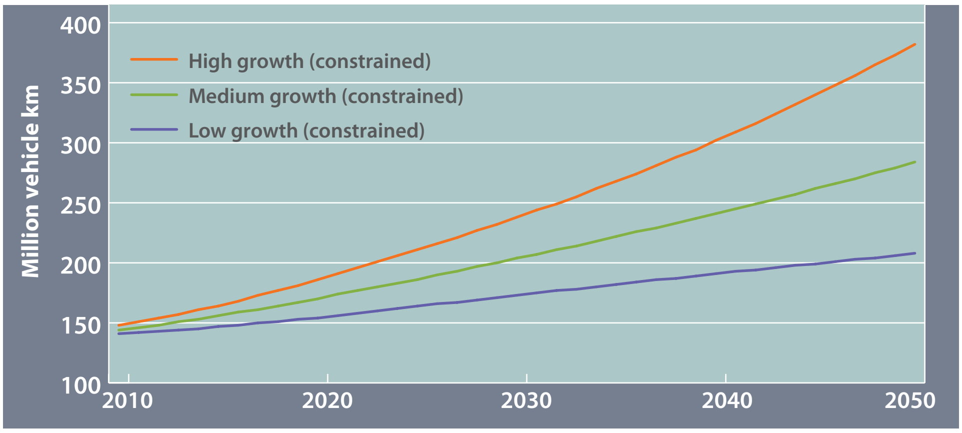


Figure 69: Vehicle km.



The projected growth (low and high) in train kilometres is shown in Figure 70. The projected growth (low, medium and high) of train km per track km is shown in Figure 71 (overleaf).

Figure 70: Train km.

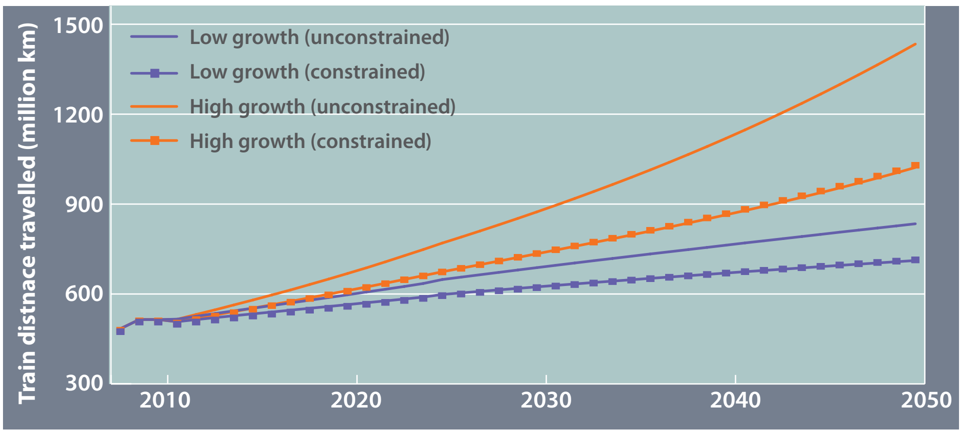
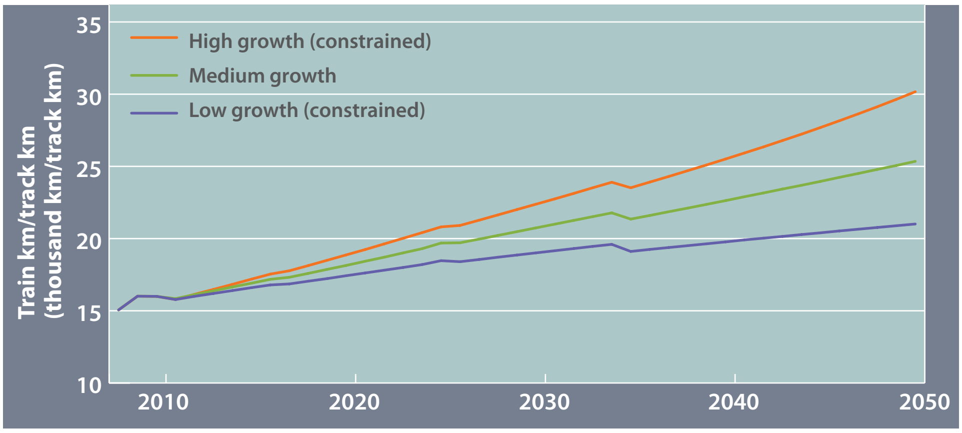


Figure 71: Train km per track km. Note: Base year provision is around 1.77 trains per hour per track km.



The projected growth (low and high) in freight tonne kilometres, for road, rail, water and pipeline, is shown in Figures 72 and 73.

Figure 72: Tonne km, low growth.

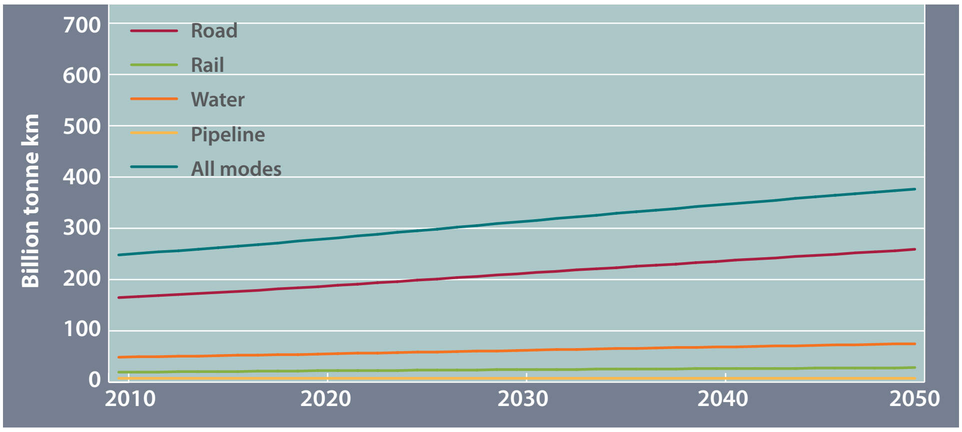
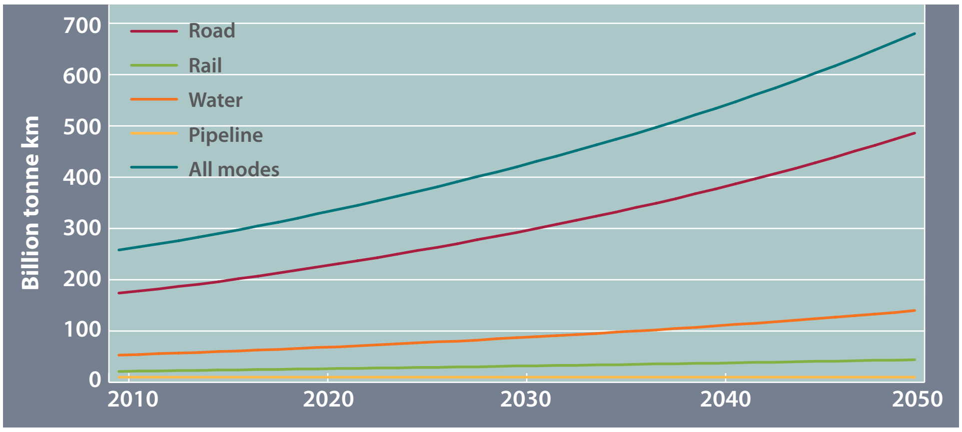


Figure 73: Tonne km, high growth.



5.3.3 DESCRIPTION AND PERFORMANCE EVALUATION OF TRANSITION STRATEGIES

5.3.3.1 Capacity-Intensive transition strategy

The CI strategy for transport was assumed to result in low demand constraints, high or medium uptake of vehicle technology and high or medium capacity growth, depending on the demand growth scenario (Table 28, overleaf). The specific meanings of 'medium vehicle technology uptake', 'medium demand constraint' etc., as modelled here, are summarised in Tables 29–31 (overleaf).

Supply options

The CI strategy, combined with either the high growth scenario (1a) or the medium growth scenario (2a), was modelled as:

- 23.3% additional capacity provided for the trunk road network by 2050.
- 8.6% growth in the amount of rail track.
- High uptake of electric road vehicles: 50% hybrid vehicles and 50% fully electric by 2050.
- High uptake of alternative fuel for lorries: 50% use of hydrogenated vegetable oil by 2050.
- High rate of rail electrification: 100% electrification for both passenger and freight transport by 2050.
- No introduction of road user charging.

Infrastructure investment costs were estimated to be 1.75% GDP (£26 billion per annum at present).

The CI strategy, combined with the low growth scenario (3a), was modelled as:

- 9.6% additional capacity provided for the trunk road network by 2050.
- 5.4% growth in the amount of rail track.
- Medium uptake of electric road vehicles: 30% hybrid vehicles and 20% fully electric by 2050.
- Medium uptake of alternative fuel for lorries: 25% use of hydrogenated vegetable oil by 2050.
- Medium rate of rail electrification: 81% passenger rail electrification and 50% freight rail electrification by 2050.
- No introduction of road user charging.

Infrastructure investment costs were estimated to be 0.88% GDP (£14 billion per annum at present).

Table 28: Summary of Capacity-Intensive transition strategy

Scenario	Vehicle technology	Infrastructure capacity*	Demand constraints
High growth	High uptake	High capacity growth	Low demand constraint
Medium growth	High uptake	High capacity growth	Low demand constraint
Low growth	Medium uptake	Medium capacity growth	Low demand constraint

* Based on level of investment.

Table 29: Vehicle technology options

Mode	Description	Level of uptake by 2050		
		Low	Medium	High
Car/van	Hybrid	20%	2.5%	30%
	electric	20%	50%	50%
Bus/coach	Hybrid	40%	0%	50%
	electric	25%	50%	50%
Lorry	HVO	0%	25%	50%
Passenger rail	Electrification	57%	81%	100%
Rail freight	Electrification	2%	50%	100%

Notes: (1) HVO = Hydrogenated vegetable oil. (2) The 'remaining' unaccounted percentage figures are for use of petrol/diesel.

Table 30: Infrastructure investment options

	Capacity growth by 2050		
	Low	Medium	High
Trunk road network	0%	9.6%	23.3%
Rail network	0.74%	5.4%	8.6%

Table 31: Demand constraints		
Multiplier on fuel price from 2015		
Low	Medium	High
0%	20%	46%

Performance evaluation of the CI strategy

Passenger demand (Figure 74) is almost 20% higher than in the reference case, by 2050. The main reason for this is the assumed high uptake of electric vehicles with assumed cheaper fuel costs (one tenth of petrol cost). If electric vehicle use was taxed, somehow, to bring running costs broadly similar to those for petrol/diesel cars, then demand (Figure 75) would be similar to the reference case and the results for delays, emissions and fuel use would improve upon those shown below. Delays on the 10% slowest routes on the trunk road network were modelled (Figure 76). Comparing this with the results for the reference case (Figure 60), it can be seen that delays are only slightly greater here, despite the increase in demand, due to the additional capacity provided. The introduction of electric vehicles reduces CO_2 emissions, despite growth in passenger demand (particularly for road traffic). This can be seen by comparing the result here (Figure 79) with that obtained for the reference case (Figure 61).

Fuel use (billion litres) by road transport on the trunk road network is shown in Figure 77 (overleaf) for cars/vans and for lorries. It is noted that there are large differences between the high and low projections due to the large differences in demand. For the low growth scenario there is a fall in fuel use for cars/vans, from around 9.25 billion litres, in the base year, to 8.33 billion litres in 2050, with the assumed phasing out of the internal combustion engine counteracting the demand growth. Also, fuel use for the CI strategy is lower than in the reference case as the numbers of electric vehicles and hybrids are greater.

Figure 74: Passenger demand growth.

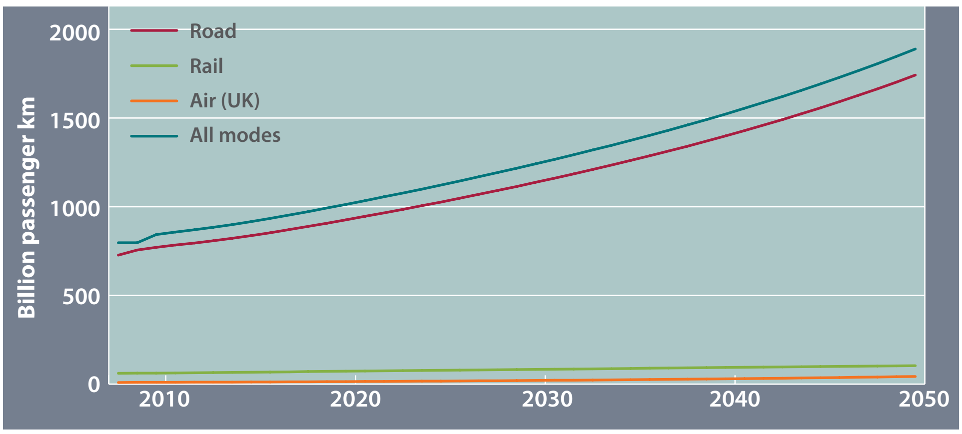


Figure 75: Passenger demand, medium growth assuming tax on electric vehicles (introduced in stages in 2020 and in 2040).

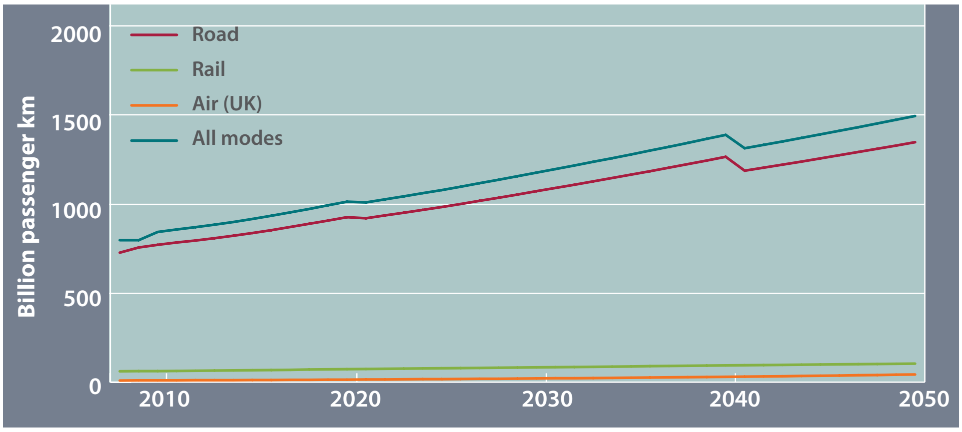


Figure 76: Delays.

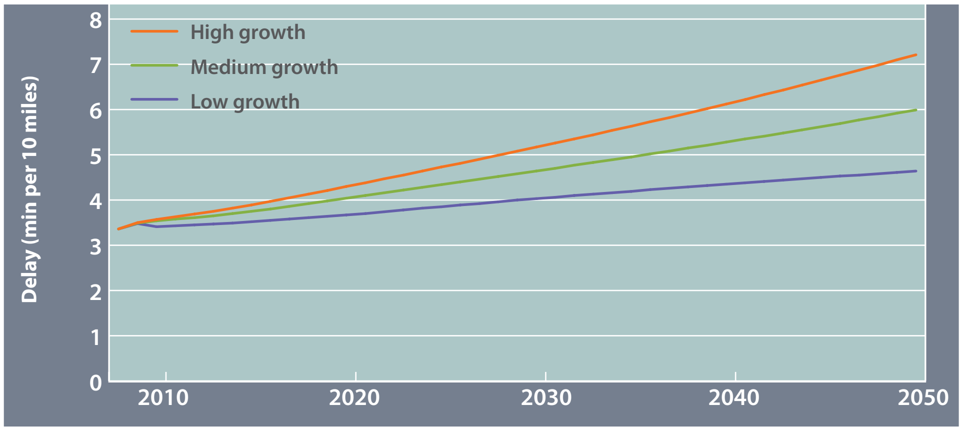


Figure 77: Fuel use by road transport on the trunk road network.

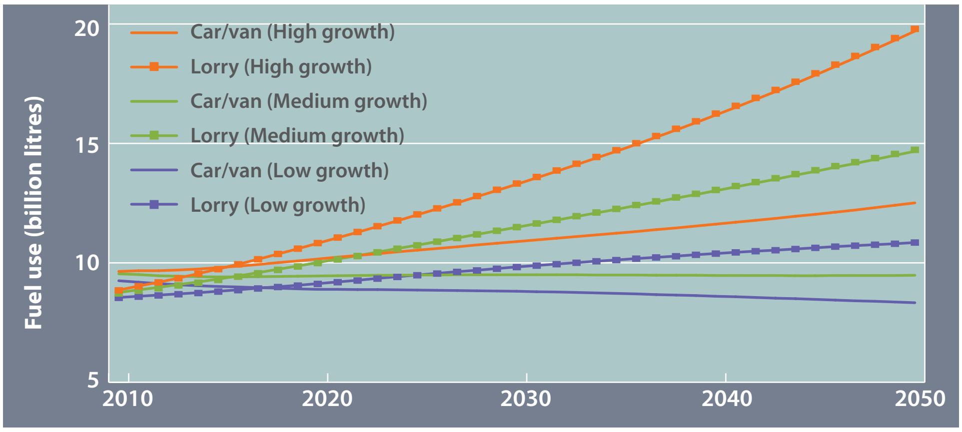
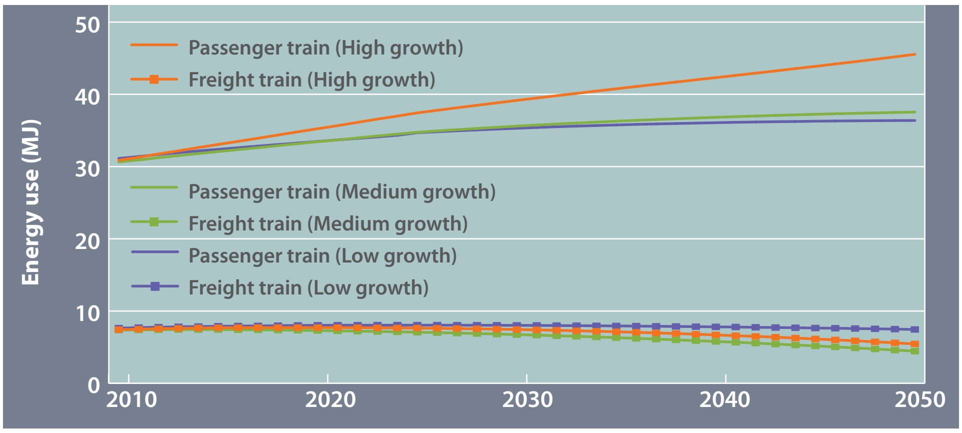


Figure 78: Energy use by rail transport.



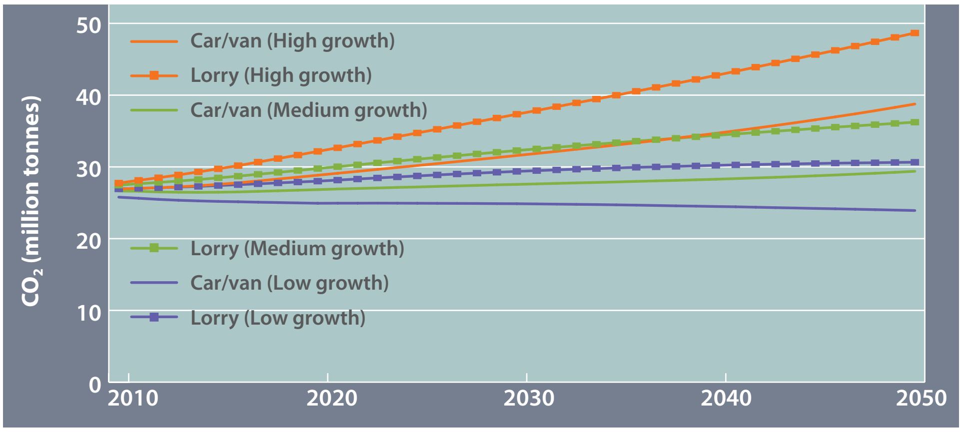


Figure 79: CO_2 emissions, Capacity-Intensive strategy.

Energy use (mega joules) by rail transport is shown in Figure 78 for both passenger rail and freight rail. It can be seen that the passenger sector has the much higher usage, at over four times as much (around 31 MJ compared with 7.5 MJ for freight in the base year). Energy use is lower here than in the reference case, particularly for rail freight, due to the higher assumed take-up of rail electrification. There is not much modelled difference here between the low and medium growth scenarios as the greater demand for the medium growth scenario is counteracted by the assumed differences between the levels of rail electrification between the two scenarios.

5.3.3.2 Decentralisation transition strategy

As transport infrastructure is, by its nature, already decentralised, the 'DC strategy' is not particularly well-named for analysis of transport; however, it was assumed that this transition strategy would result in medium demand constraints, medium or low uptake of vehicle technology and medium or low capacity growth, depending on the demand growth scenario (Table 32). The specific meanings of 'high vehicle technology uptake', 'low demand constraint' etc., as modelled here, are summarised in Tables 29–31.

Supply options

The DC strategy, combined with either the high growth scenario (1b) or the medium growth scenario (2b), was modelled as:

- Medium uptake of electric road vehicles: 30% hybrid vehicles and 20% fully electric by 2050.
- Medium uptake of alternative fuel for lorries: 25% use of hydrogenated vegetable oil by 2050.
- Medium rate of rail electrification: 81% passenger rail electrification and 50% freight rail electrification by 2050.
- Medium levels of investment resulting in 9.6% additional capacity provided for the trunk road network by 2050 and 5.4% growth in the amount of rail track. Medium transport investment costs may equate to around 0.88% GDP (=£13.19 billion), however, the transport FTA has not specifically considered costs.
- Medium demand constraint resulting in a 20% added running cost for private road vehicles due to the introduction of some form of road user charging scheme by 2015.

The DC strategy, combined with the low growth scenario (3b), was modelled as:

- Low uptake of electric road vehicles: 20% hybrid vehicles and 2.5% fully electric by 2050.
- Low uptake of alternative fuel for lorries: negligible use of hydrogenated vegetable oil by 2050.
- Low rate of rail electrification: maintained at current planned level of 57% by 2019 for passenger rail and negligible use for rail freight.
- Low levels of investment resulting in no additional capacity provided for the trunk road network by 2050 and only 0.74% growth in the amount of rail track. Low transport investment costs may equate to around 0.53% GDP (=£7.91 billion), however, the transport FTA has not specifically considered costs.
- Medium demand constraint resulting in a 20% added running cost for private road vehicles due to the introduction of some form of road user charging scheme by 2015.

Table 32: Summary of the Decentralisation transition strategy

Scenario	Vehicle technology	Infrastructure capacity*	Demand constraints
High growth	Medium uptake	Medium capacity growth	Medium demand constraint
Medium growth	Medium uptake	Medium capacity growth	Medium demand constraint
Low growth	Low uptake	Low capacity growth	Medium demand constraint

* Based on level of investment.

Performance evaluation of the DC transition strategy

The impact of the DC strategy on **passenger demand** is shown in Figure 80 for the medium growth scenario. Modelled demand is higher than in the reference case but lower than for the CI strategy. The projected **delays** on the 10% slowest routes of the trunk road network (Figure 81) are similar to those found for the reference case. There is a modelled reduction in delays at 2015 due to the introduction of a national congestion charging scheme. **CO_2 emissions** for the DC strategy (Figure 84, see page 142) lie between those found for the reference case (Figure 61) and for the CI strategy (Figure 79).

Fuel use (billion litres) by road transport on the trunk road network is shown in Figure 82 for cars/vans and for lorries. Fuel use tends to be greater than in the CI strategy, particularly for cars/vans, due to the greater reliance on the internal combustion engine.

Energy use (mega joules) by rail transport is shown in Figure 83 for both passenger rail and freight rail. The trends found here are similar to those found for the CI strategy but with slightly greater energy use here, particularly in the low growth scenario, due to the assumed low take-up of rail electrification.

Figure 80: Passenger demand, medium growth, Decentralisation.

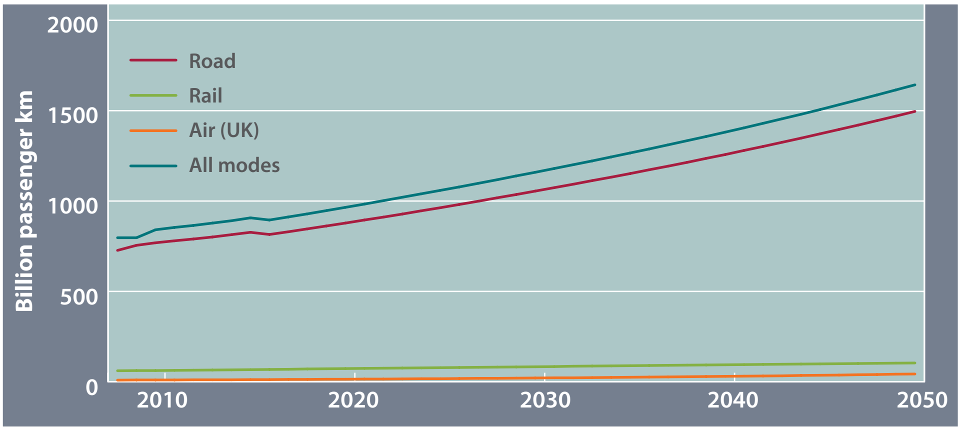


Figure 81: Delays.

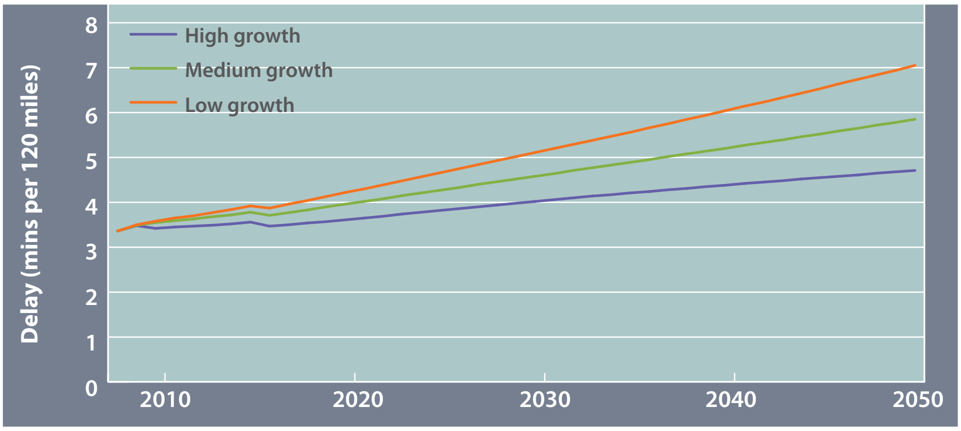


Figure 82: Fuel use in road transport, Decentralisation.

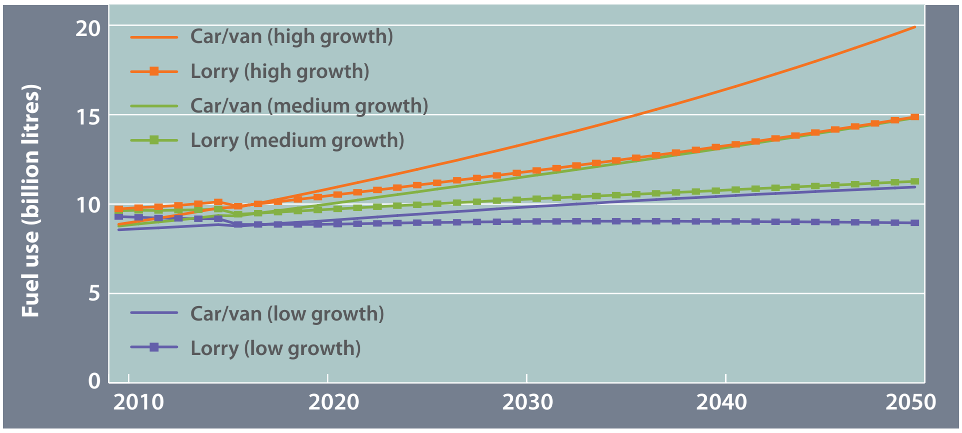


Figure 83: Energy use in rail transport, Decentralisation.

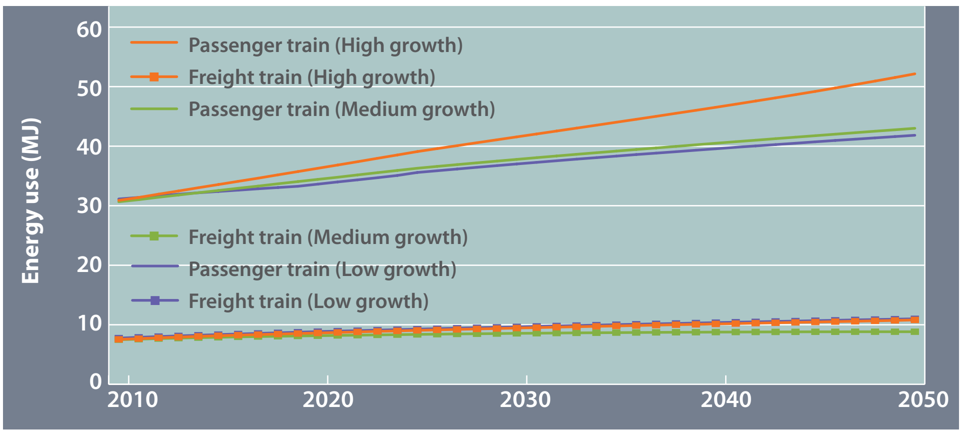
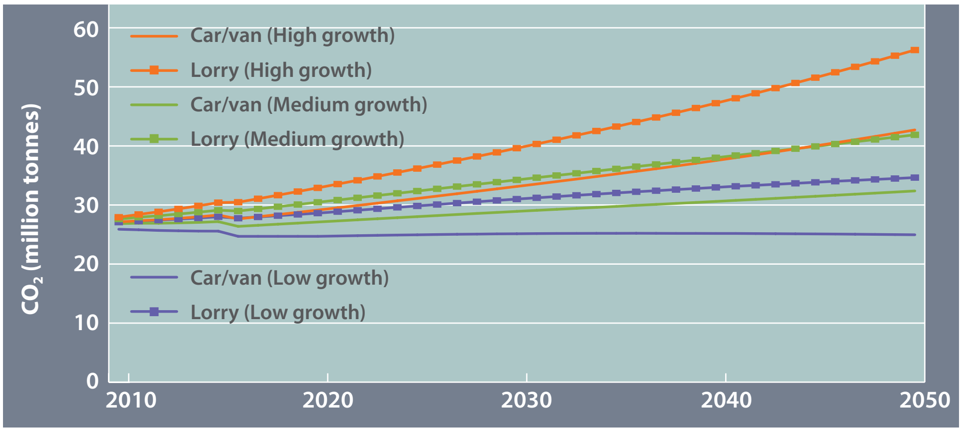


Figure 84: CO_2 emissions, Decentralisation.



5.3.3.3 Capacity-Constrained transition strategy

The CC strategy for transport was assumed to result in high demand constraints, low uptake of vehicle technology and low capacity growth (Table 33). The specific meanings of 'low vehicle technology uptake', 'high demand constraint' etc., as modelled here, are summarised in Tables 29–31.

Supply options

The CC strategy, for all growth scenarios, was modelled as:

- Low uptake of electric road vehicles: 20% hybrid vehicles and 2.5% fully electric by 2050.
- Low uptake of alternative fuel for lorries: negligible use of hydrogenated vegetable oil by 2050.
- Low rate of rail electrification: maintained at current planned level of 57% by 2019 for passenger rail and negligible use for rail freight.
- Low levels of investment resulting in no additional capacity provided for the trunk road network by 2050 and only 0.74% growth in the amount of rail track. Low transport investment costs may equate to around 0.53% GDP (=£7.91 billion), however, the transport FTA has not specifically considered costs.
- High demand constraint resulting in a 46% added running cost for private road vehicles due to the introduction of a national road user charging scheme by 2015.

Table 33: Summary of the Capacity-Constrained transition strategy

Scenario	Vehicle technology	Infrastructure capacity*	Demand constraints
High growth	Low uptake	Low capacity growth	High demand constraint
Medium growth	Low uptake	Low capacity growth	High demand constraint
Low growth	Low uptake	Low capacity growth	High demand constraint

* Based on level of investment.

Performance evaluation of the CC transition strategy

Projected **passenger demand** for the CC strategy is shown in Figure 85. There is a slight reduction in demand compared with the reference case, due to the introduction of assumed additional motoring costs associated with the introduction of a national congestion charge (in 2015). The **projected delays** on the 10% slowest routes of the trunk road network (Figure 86) are slightly lower, but similar to, those found for the reference case. There is a modelled reduction in delays at 2015 due to the introduction of a national congestion charging scheme. The **CO_2 emissions** for the CC strategy (Figure 89) are slightly lower than those found for the reference case (Figure 61). **Fuel use** (billion litres) by road transport on the trunk road network is shown in (Figure 87, overleaf) for cars/vans and for lorries. Fuel use tends to be slightly greater than for the CI and DC strategies, except for in the low growth scenario, due to the greater reliance on the internal combustion engine.

Energy use (mega joules) by rail transport is shown in Figure 88 (overleaf) for both passenger rail and freight rail. The trends found here are similar to those found for the CI and DC strategies but with greater energy use here due to the assumed low take-up of rail electrification.

Figure 85: Passenger demand, medium growth, Capacity-Constrained.

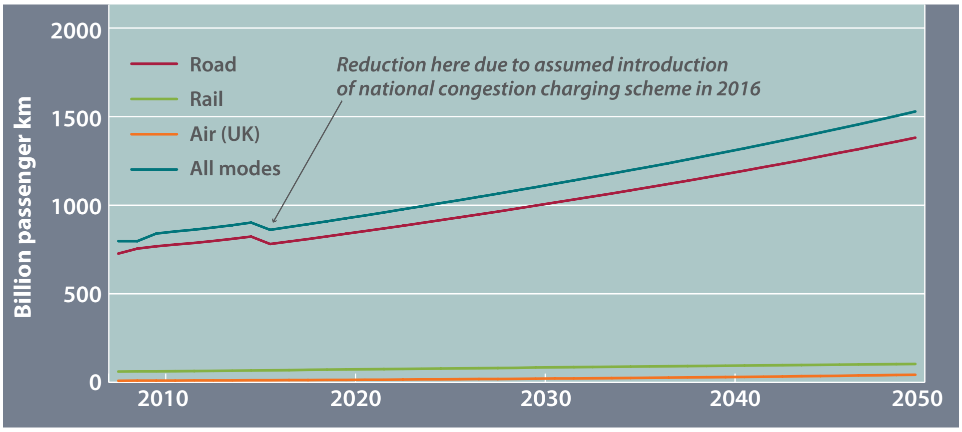


Figure 86: Delays, Capacity-Constrained.

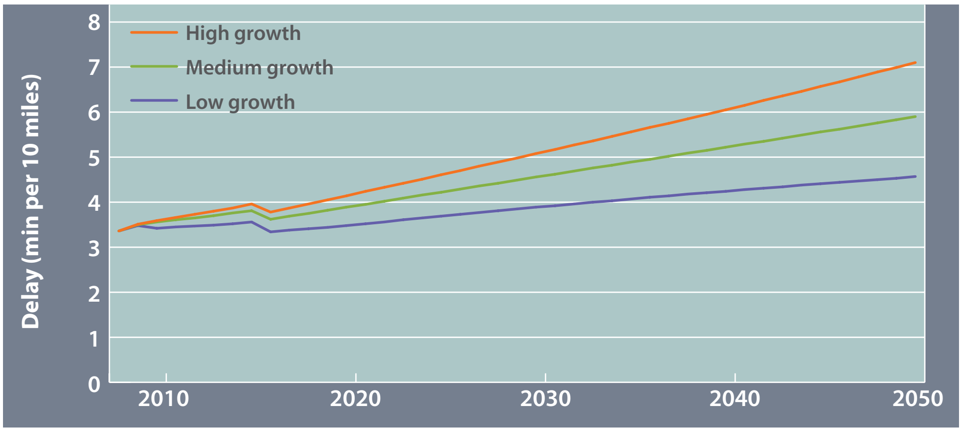


Figure 87: Fuel use in road transport, Capacity-Constrained.

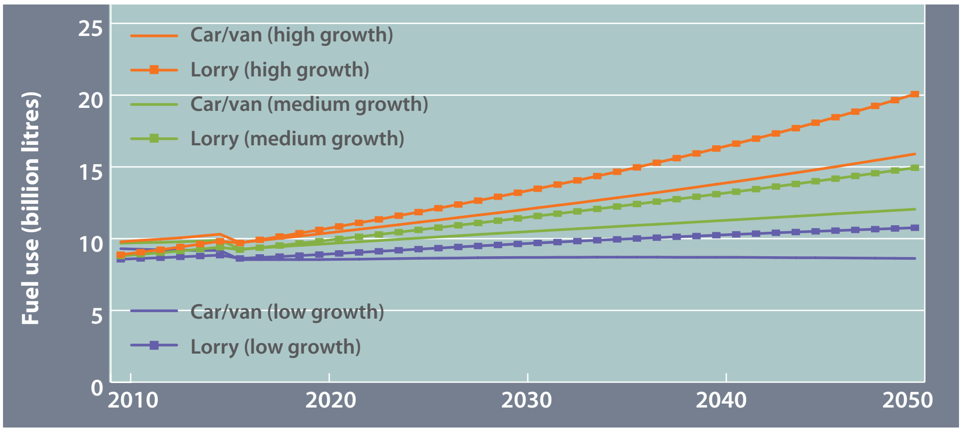


Figure 88: Energy use in rail transport, Capacity-Constrained.

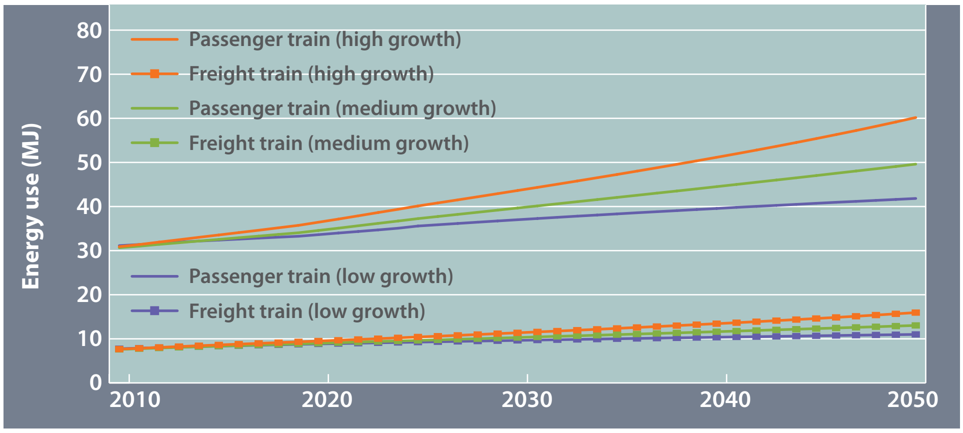
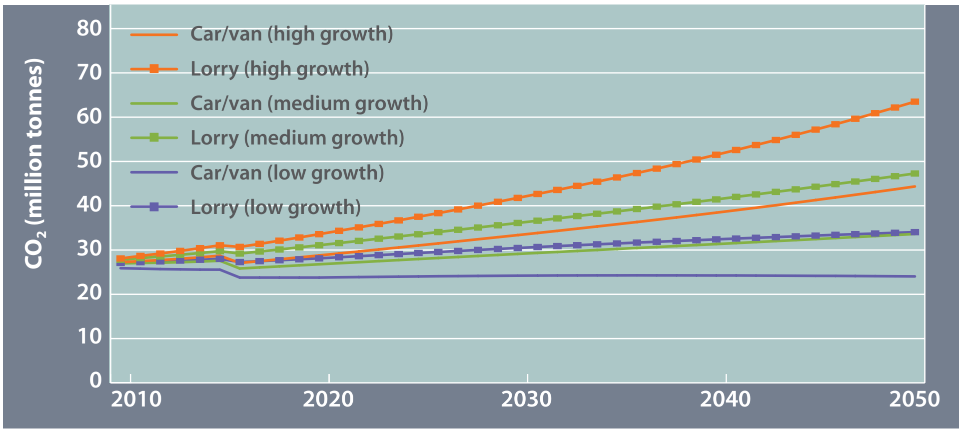


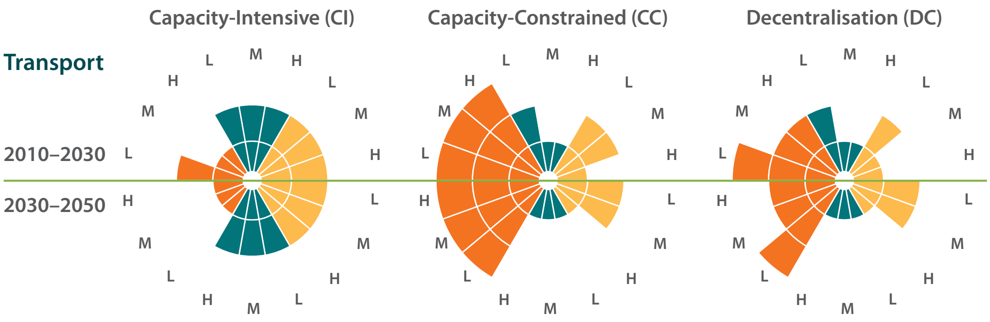
Figure 89: CO_2 emissions, Capacity-Constrained.



5.3.3.4 Summary performance

Figure 90 presents a summary visualisation of the performance of the transition strategies across two time periods: 2010–2030 and 2030–2050. As the CI strategy results in higher growth in demand, it results in greater congestion, and an increase in delays. However, this growth in demand is compensated by improved fuel efficiency, resulting in the greatest reduction in CO_2 emissions compared with the other strategies. The CC strategy would result in the lowest growth of demand, with reductions in car and van km and reduced CO_2 emissions for cars and vans and for HGVs in 2050 compared with the reference case. The CC strategy results in the best aggregate performance across the entire time period. Notably, there was little change in performance over the two time periods, and emissions were most problematic in the high growth scenarios.

Figure 90: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.



Cost

CO_2 emissions

Delay on trunk road network

L Low growth scenario

P Principal growth scenario

H High growth scenario

High performance
(e.g. low cost, low CO_2, high supply security)

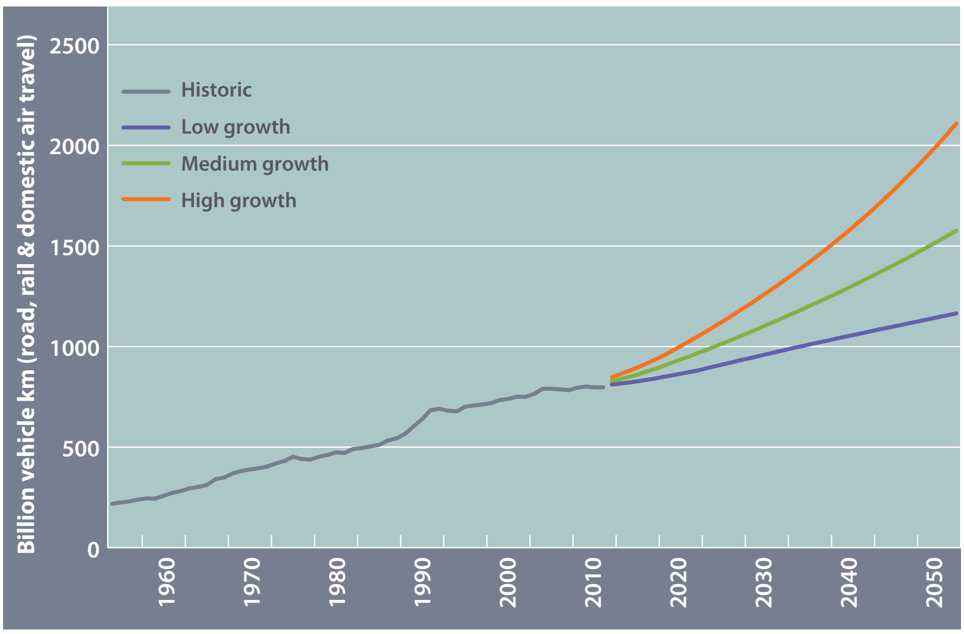
Medium performance

Low performance
(e.g. high cost, high CO_2, low supply security)

5.3.4 DISCUSSION

The transport sector has seen a long run increase in demand, although there is some indication that this has slowed down recently. However, it is not clear whether this is due to the recent economic downturn or is a more permanent phenomenon. Past trends seem consistent with the low growth scenarios but this may reflect supply side constraints (Figure 91). The FTA results demonstrate that capacity constraints are likely to be important for both road and, particularly rail, in the future. This is also expected to be true of airports and seaports, at least in respect of container traffic. The results indicate that infrastructure would be particularly stressed under high growth rates. At existing electricity prices and taxation, electrification of the road transport sector would reduce transport prices and lead to additional stress on road infrastructure. Although it would reduce environmental impacts, at least at the point of use, it would lead to increased congestion. This suggests policies need to be investigated that either reduce congestion (such as congestion pricing) or increase capacity (such as advanced traffic control). Alternatively, there is a need to examine behavioural changes policies that induce modal switch and reduce the demand for travel.

Figure 91. Past transport demand and the FTA growth scenarios.



There is some evidence that the UK's economic competitiveness is hampered by the transport system (Eddington, 2006) and transport a poor performer environmentally (Stern (2007), Royal Commission on Environment Pollution, Commission for Integrated Transport etc.). Large co-dependencies with other economic sectors exist. Although spatiality has not yet been introduced into the analysis, there is a high level of dependence on some key transport links and nodes, in particular the main radial routes into London, the main orbital roads around London and some other major cities (Birmingham, Manchester) and some key international gateways (Heathrow, the Haven Ports). Infrastructure policy has shifted from 'predict and provide' to something more akin to 'predict and prevent' but with little palpable effect on key trends, to date.

Transport infrastructure has relatively high stress levels, in terms of congestion and poor environmental performance, and these are likely to increase substantially for air, road and rail. Supply-side constraints would mean a high level of unmet demand, particularly in high growth scenarios. Low growth scenarios are considered more likely as they are more consistent with past trends and the recent forecasts of others. Technological change, where it reduces transport costs, could exacerbate the mismatch between latent demand and capacity.

Surplus capacity is not really an issue for national transport infrastructure, as any such additional capacity provided rapidly fills up, at least for road and rail. Nor is decentralisation a particular issue. The key coupling is with the energy sector where substantial investment will be required to permit the electrification of the road transport fleet. Lack of this investment is likely to be a major constraint. Subsequent analyses will need to consider the impact of excess demand on the price of electricity. Also, changing compositions of the energy and waste sectors are likely to have an influence on freight demand and, in particular, the capacity requirements for ports.

5.3.4.1 Key uncertainties

A large area of uncertainty is associated with the uptake of electric vehicles which in turn relates to their future performance, in terms of speed and acceleration characteristics, range (distance travelled before recharging), recharging requirements (e.g. where this can be done and time required) and costs (purchase, running, maintenance etc.), particularly in comparison to ICE (Internal Combustion Engine) vehicles.

Another area of uncertainty is the extent to which the 'Smarter Choices' agenda (DfT, 2010b) could stimulate behavioural change in terms of reducing travel (including substitution by information technology and communications) and modal switching (including 'Active Travel').

Making long run forecasts is, in itself, inherently risky. For rail we note that under high demand growth, the mismatch between demand and supply becomes so acute, that beyond 2050 sensible predictions become difficult.

5.4 WATER

The FTA focuses on public water supply, balancing the average daily rates of water available for use and consumers' demand for water with the ITRC population projections.

The Capacity-Intensive transition strategy implies high investment in supply infrastructure (including reservoirs, transfers and desalination) as well as in capital programmes of leakage reduction. These measures contribute to security of supply in terms of both capacity and flexibility of use of resources. The strategy is threatened by the possibility of climate change reducing water availability, the requirements for restoring aquatic environments and the energy implications of desalination and inter-basin transfers. The Decentralised strategy implies more local self-sufficiency, which is vulnerable to supply and demand side uncertainties. Economies of scale indicate that this approach is only cost-effective in low population density localities. The Capacity Constrained strategy emphasises vigorous price and regulatory measures to reduce demand to an average of 110 litres per person per day by 2050, which have the added benefit of reducing energy use, in the water sector and by water consumers. At the same time, margins between supply and demand are eroded, with implications for security of supply.

5.4.1 ASSESSMENT METHODOLOGY

The FTA considers public water supply in isolation, focusing on the balance between the average daily rates of water available for use and consumers' demand for water. The sole consideration of public water supply is due to the lack of detailed data concerning existing water supply infrastructure across all sectors. The FTA considers each water supplier of England, Wales and Scotland independently, aggregating available water supply capacity and demand across all company resource management zones, with results presented at a national level.

Focusing again on the public water supply, this study assumes that population is a principal driver of consumers' demands for water from the public water supply. It estimates a mean daily expectation of household demand from the per-capita daily demand of household consumers, and that both non-domestic water consumption and leakage are assumed a constant proportion of total demand, based on 2008 measurements (Ofwat, 2011b) (data in Annex G). The ITRC population projections are divided between each water company in England and Wales according to the proportion of those countries served by each company in 2008, assuming that 100% of the population is served by the public water supply. Scottish Water is assumed to serve 100% of the population of Scotland. These proportions are assumed constant for the duration of the study. These values are in Annex G.

The focus upon domestic demand limits analysis of the interaction between non-domestic water use and economic growth. Most projections of non-domestic and/or industrial water consumption disaggregate the quantity by industrial sector, and exploit the relatively strong regression relationship between Gross Value Added and water consumption. By way of contrast, the link with GDP is weak at best; hence, this analysis adopts a simple proportional relationship between non-domestic water demand and domestic water demand based on an estimate of the former and the relationship between the two valid in 2008.

Estimation of the capacity of the public water supply is complex. It exhibits large variation across water suppliers and is dependent on a number of factors, including climate, land-use and management practices. The amount of water available to meet demand in England and Wales was 17,016 Ml/d in 2010–2011 (Ofwat, 2011b); the combined yield of all sources in Scotland was 3564 Ml/d in 2001 (Scottish Executive, 2003). These quantities may have slightly differing definitions; however, the FTA assumes no discernible difference between deployable output and the water available to meet demand. Thus, the combined water resource of Great Britain is 20,580 Ml/d, which is adequate for an aggregate 2008 baseline value. Values for each company were compiled from the available data, and adjusted for existing imports and exports (see Annex G). Assuming constant per capita demand, the effects of the FTA population scenarios on demand can be compared in Figure 90.

The effects of climate change on water resource yield are projected to vary strongly across GB and whilst some impacts may be severe there is substantial uncertainty, as they are a combined result of a number of possible changes. These include changes in seasonal mean precipitation and evapotranspiration (driven by several meteorological variables such as temperature and solar radiation) affecting long term average availability as well as more critical multi-seasonal variability causing droughts. Droughts are not well reproduced by climate models and in the absence of a definitive study incorporating the full UKCP09 uncertainty range a simplified approach has been followed here. The FTA applies three scenarios of the impact of climate change on water resource yield (Table 34). They derive from analysis of the relationship between company deployable outputs and simple metrics combining precipitation and evapotranspiration estimates using UKCP09 outputs. The spatial pattern across GB is broadly similar to that found by Blenkinsop and Fowler (2007) for drought frequency using the Hadley Centre Regional Climate Model with the most severe impacts in SE England. The central estimate of impact in 2020 is similar to the decrease in deployable output anticipated by the water suppliers of England and Wales (Charlton and Arnell, 2011). Analysis proceeds under the assumption of a smooth interpolation of values between 2008 and 2050 using a natural spline.

In the absence of active intervention, the combined effects of population increase and climate change represent a strategic challenge for the UK water industry (Figure 92), representing a progressive erosion of security of supply. Figure 92 masks considerable regional variation. Table 35 summarises the decade in which demand may exceed capacity when accounting for the impact of climate change. It underlines that the high demand scenario places significant strain on the water resource infrastructure, and also suggests that the medium and even low growth scenarios may overwhelm national capacity.

Table 34: The impact of climate change on water resource yield, as a percentage of the baseline resource yield

Year	Lower estimate	Central estimate	Upper estimate
2020	+5.6%	-3.8%	-14.9%
2050	-1.4%	-18.5%	-33.8%

Figure 92: The relationship between demand and capacity under low, medium and high growth scenarios and low, central and high climate scenarios.

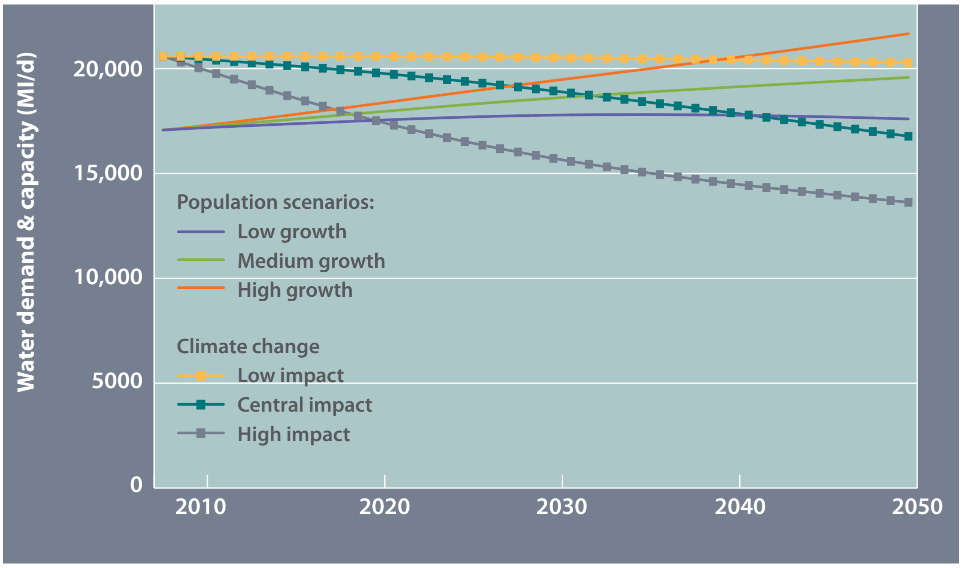


Table 35: Decades in which demand exceeds supply				
		Low	Central	High
Demand scenario	Low growth		2040s	2020s
	Medium growth		2030s	2020s
	High growth	2030s	2020s	2020s

5.4.2 DESCRIPTION OF TRANSITION STRATEGIES

There are two commonly cited adaptation measures: (i) constrain consumers' demand for water, thereby prolonging the useful life of existing infrastructure assets, and (ii) improve the capacity of infrastructure in order to meet demand. The infrastructure options considered in the FTA are reductions in per capita demand, leakage reduction and the development of new resources to augment the yield of the water supply network.

5.4.2.1 Per capita demand

The per capita demand of household customers has remained fairly constant between 2005 and 2010, at between 145 and 155 l/p/d (EA, 2009b; Water UK, 2010). Between 2010 and 2011, it ranged from less than 120 l/p/d to over 160 l/p/d, with customers in the southeast of England consuming more than customers elsewhere in England and Wales (Defra, 2011d).

It is widely accepted that customers whose consumption is measured using water meters consume less than those whose consumption is unmeasured. In 2008, the mean per capita demand of metered and unmetered customers in England and Wales was around 125 l/p/d and 150 l/p/d, respectively (Ofwat, 2011b). The former may represent the lowest feasible limit of the impact of behavioural change on household demand (Walker, 2009). Around 30% of household customers in England and Wales were metered in 2008, with the penetration of individual companies ranging from 10% to 60% (Ofwat, 2011b).

Water companies anticipate meter penetration to increase to around 50% by 2014, with an upper limit of 90% feasible in the future (Walker, 2009). Although the costs and benefits of metering are not yet well-known, studies suggest that an investment of £2000 in behavioural change and retrofit in existing homes can yield savings of around 1 Ml/d (Walker, 2009).

In accordance with established projections (EA, 2009b), the FTA established three scenarios of per capita demand:

1. Major efforts to reduce per capita water consumption, including metering and uptake of water-efficient devices, leading to an average household consumption of 110 l/p/d in 2050;
2. No active measures to reduce per capita consumption allows consumption to drift upwards towards the highest rates currently observed in the UK (170 l/p/d);
3. An intermediate case which sees gradual reduction in per capita demand.

These three demand scenarios will be associated with the CC, CI and DC strategies respectively. They are a summarised in Figure 93.

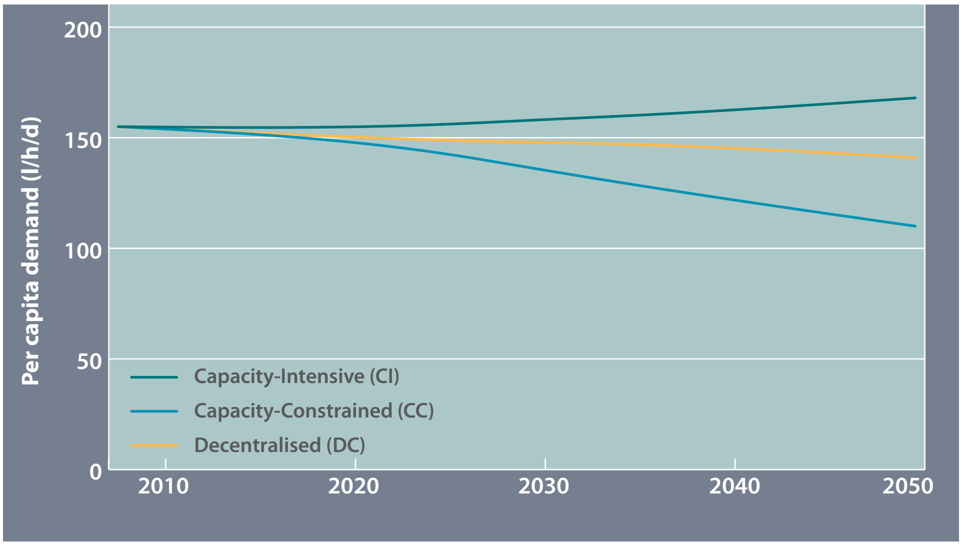


Figure 93: Assumed per capita demand profiles.

5.4.2.2 Leakage

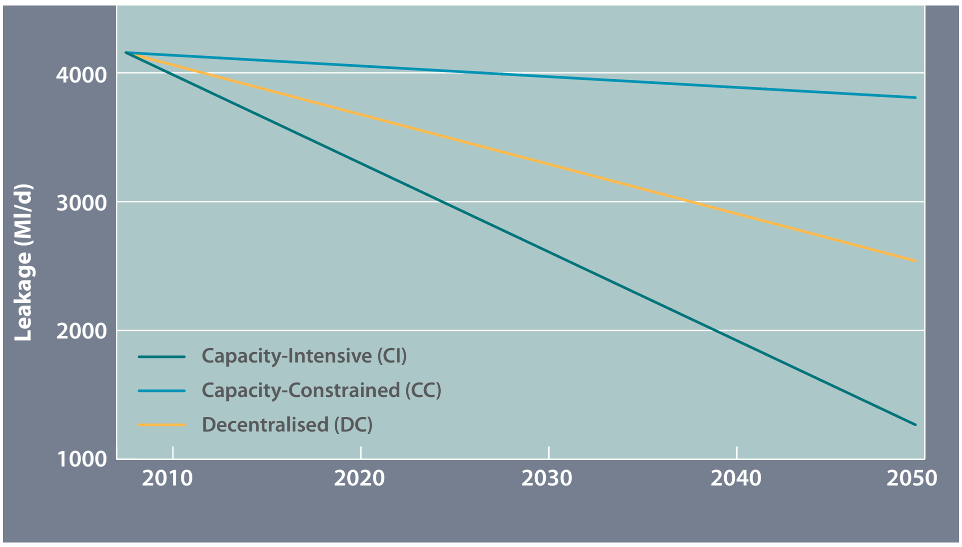
More than 4000 Ml of water are lost each day from the water supply infrastructure of GB, constituting 20%–25% of the total demand for water (Water UK, 2010; Ofwat, 2011b). Individual companies' estimates of leakage having a range of over 850 Ml/d, and are differentiated by network characteristics, asset condition and consumer behaviour (Ofwat, 2011b). The majority of leakage emanates from the failure of underground assets, such as distribution and supply pipe infrastructure, which deteriorate over time. To manage the risk of failure, assets are replaced or rehabilitated systematically before they fail as they age or their performance becomes unacceptable. Assets that fail unexpectedly are replaced immediately.

Although it is currently prohibitively expensive to eliminate leakage, the economic regulator provides incentives to achieve and maintain an affordable rate of investment in asset management via the definition of an 'economic' rate of leakage, below which the costs of leakage reduction exceed the benefits. Most water companies in England and Wales already maintain their infrastructure at this level, about 20% of the total water input to supply; however, the regulator anticipates a further 2% reduction in the national aggregate level of leakage between 2010 and 2015, with some companies expected to reduce leakage by as much as 7% over this period (EA, 2009b; Ofwat, 2009). In Scotland, where the current rate of leakage greatly exceeds that of England and Wales, Scottish Water anticipates a reduction of 50% for the same period (Scottish Water, 2011). Between 2002 and 2010, the water industry invested around £2 billion annually in asset replacement, corresponding to an annual reduction in leakage of just over 105 Ml/d, or an annual decrease of around 2% (Water UK, 2010). Projections of leakage rates for England and Wales (EA, 2009b) suggest:

- Under a Capacity-Constrained transition, representing 'business as usual', leakage might tend towards 3000 Ml/d in 2050: a reduction of nearly 10%;
- A decentralised transition, utilising existing management practices in combinations with the best available technology, could reduce leakage by as much as 40% by 2050, to around 2000 Ml/d.
- A Capacity-Intensive transition might involve the implementation of the best available technology coupled with a significantly more capital-intensive programme of asset maintenance, raising their average condition. A suitably ambitious target for leakage across England and Wales under a Capacity-Intensive transition might be as little as 1000 Ml/d, or around 30% of the current level of leakage.

Figure 94 summarises the extension of these assumptions to GB.

Figure 94: Annual rates of leakage by transition.



5.4.2.3 Supply infrastructure

The FTA considers three mechanisms for the provision of additional capacity:

- Reservoirs;
- Inter-basin transfer;
- Desalination.

It is considered unlikely that additional abstraction from rivers and groundwater sources will provide strategic resource without major reservoir or transfer investments. Reservoirs are a traditional means of enhancing water supply, involving the repurposing of naturally occurring surface water bodies and/or the impoundment of watercourses to create an artificial lake. Smaller bodies can be created by pumping water from rivers into natural or artificial depressions. They can be used to provide water via direct abstraction from the reservoir itself, or as a means to regulate downstream watercourses and support abstraction elsewhere. The use of reservoirs as strategic assets is limited by upstream and downstream hydrological conditions, as well as the performance and extent of the infrastructure networks they support.

The typical cost of developing a reservoir is considerable, extending beyond the construction of a dam and supporting infrastructure, to the environmental and social costs of repurposing massive swathes of land: current estimates place the cost of a new reservoir providing 200 Ml/d to the southeast of England at around £2 billion. Over time, however, reservoirs can become important environmental and social assets in their own right. In addition, once established, reservoirs without pumped storage entail relatively low operating costs, although periodic de-silting is often necessary to maintain capacity.

Inter-basin transfer (IBT) involves the abstraction of water from a donor region with excess resource, and its movement via pumped and gravity-driven transfer in pipelines to one or more receptor regions. That receptor regions can be hydrologically distinct from the donor region makes IBT a powerful and flexible tool for deploying water resource, and as such, it forms an important component of the water resource infrastructure of GB, with numerous schemes of strategic significance in operation across the country.

IBT is expensive to construct and operate: pipelines are often built underground, pumped transfer entails significant energy consumption and the environmental and social costs of IBT are thought to be high. Thus, IBT is mostly used intermittently where alternative technologies, such as reservoirs, are not viable. In addition, major IBT schemes are often coupled with a major strategic reservoir, the storage of which can be redeployed using the transfer infrastructure.

In their revised draft Water Resource Management Plan, Thames Water identified a number of feasible inter-basin transfers of varying length, transfer capacity and environmental and social impact (Thames Water Utilities Ltd, 2009). On average, their costs are as follows:

- £5 million per Ml/d capital cost;
- £1 million per Ml/d operating cost;
- 484 MWh/Ml/d electricity consumption;
- 845 tonnes of CO_2 per Ml/d during construction;
- 260 tonnes of CO_2 per yr/Ml/d during operation.

Formerly considered esoteric, desalination now plays a role in water resource provision in the UK. The only desalination plant on the mainland of the UK, Beckton water treatment works produces some 150 Ml/d at a capital cost of £250 million (water-technology.net, 2011). Costs for seawater reverse-osmosis desalination have fallen substantially in recent years and are currently around \$0.50 m^3 (Sauvet-Goichon, 2007), equivalent to around £320 Ml. Beckton is estimated to consume 2 kWh m^3 of electricity and emit 2 kg CO_2 m^3 (Way *et al.*, 2010). Comparison may be made with the Ashkelon plant in Israel operating with higher salinity feed water (41,000 ppm salt compared with average 35,000) and requiring around 4 kWh m^3. Note that the thermodynamic limit for desalination is around 0.9 kWh m^{-3}. Values of 3 kWh/m^3 and £320 Ml have therefore been assumed for future desalination operations in the UK.

5.4.2.4 Summary of transition strategies

The CI strategy meets demand for water through the development of new sources of water. This is achievable through the construction of new abstraction points to exploit existing rivers, lakes and groundwater sources, the impoundment of rivers to form artificial reservoirs, and the implementation of technologies such as desalination, IBT and effluent re-use. A strategy of high investment, it assumes that there is always sufficient water availability in the environment, or else deployed inefficiently in the infrastructure system, such that there is no limit to the augmentation of capacity. As such, consumers are under no pressure to change their behaviour, and per capita demand increases without constraint, but leakage is reduced at a high rate. The driving principle of the strategy derives from the assumption that the margin between capacity and demand observed in 2008 provides satisfactory security of supply, and that the capacity of the infrastructure system should be continually expanded to maintain that margin at all times. The CI strategy considers the following interventions:

- Increase in per capita demand to approximately 170 l/p/d by 2050 (Figure 93);
- Decrease in leakage rate to approximately 1000 Ml/d by 2050 (Figure 94);
- One-third of additional capacity provisioned through any amount of IBT at a cost of £1 million per Ml/d, and an incremental cost of £5 million per Ml/d;
- One-third of additional capacity provisioned through any amount of reservoir support at an incremental cost of £5 million per Ml/d;
- One-third of additional capacity provisioned through any amount of desalination at a cost of £320 per Ml/d and an incremental cost of £1.7 million per Ml/d.

By way of contrast, the CC strategy is a low-investment strategy. It does not provide additional capacity through the construction or augmentation of sources of water, focusing instead on the use of demand-reduction measures, such as retrofitting of existing properties. Consumers react to increasing scarcity of resource by reducing their per capita demand, but leakage is reduced at a low rate. This strategy allows reduction in the margin between capacity and demand observed in 2008 by 50% by 2050. This is interpretable as a decrease in the security of supply of the infrastructure system. The CC strategy considers the following interventions:

- Decrease in per capita demand to approximately 110 l/p/d by 2050 (Figure 93);
- Decrease in leakage to approximately 3000 Ml/d by 2050 (Figure 94);
- Demand reductions at an incremental cost of £2000 per Ml/d of water saved.

The existing water resource is already decentralised to a large extent, with few strategic interconnections between discrete regional infrastructure networks. In effect, a DC strategy would operate much like a CI strategy: the balance of capacity and demand would remain constant, with capacity augmented by all available technologies, excluding IBT. An important distinction is the local implementation of the best available technologies, retrofit and increased rates of asset maintenance, which would yield decreases in per capita consumption consistent with the observed trend, or better.

Table 36: Summary of transition strategies

Capacity-Intensive	Capacity-Constrained	Decentralisation
• No effort to reduce per capita demand • High rate of leakage reduction • No loss of infrastructure performance • No restriction on the range or scope capacity enhancements	• Radical decrease in per capita demand • Low rate of leakage reduction • Decrease in infrastructure performance • No new capacity provisioned	• Moderate decrease in per capita demand • Moderate rate of leakage reduction • No loss of infrastructure performance • Only local capacity enhancements provisioned

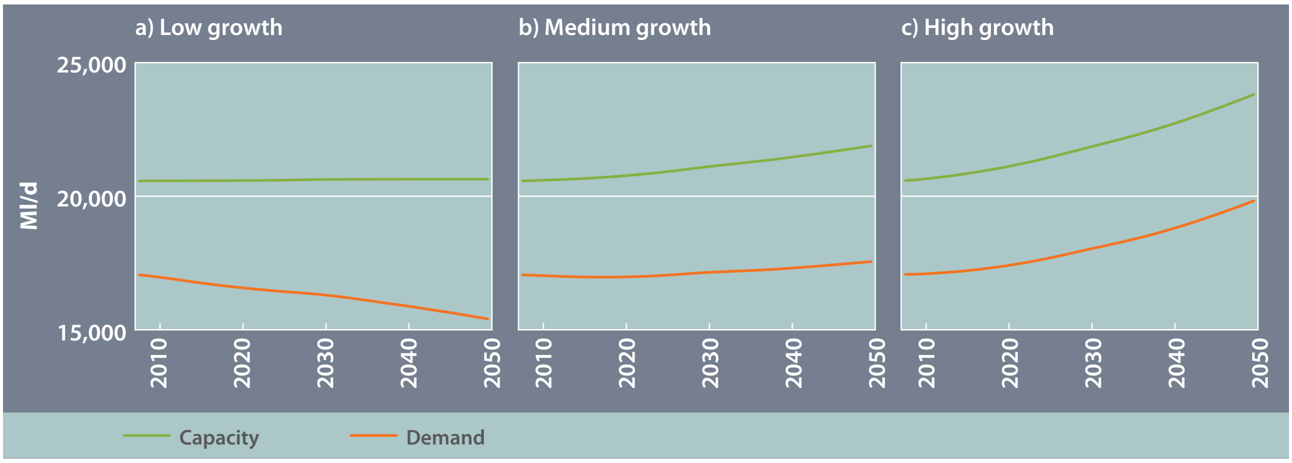
* This results in an increase in per capita demand.

5.4.3 EVALUATION OF THE TRANSITION STRATEGIES

5.4.3.1 Capacity-Intensive transition strategy

The CI strategy preserves the capacity-demand balance throughout the study period, regardless of the impact of climate change and increasing per capita demand (Figure 93). In a low growth and in the absence of high climate change, this can be achieved largely by leakage reduction (which according to convention in Figure 95 is included as part of the demand calculation). In the case of high growth, considerable additional investments in water supply are required.

Figure 95: The relationship between capacity and demand under a Capacity-Intensive transition strategy.



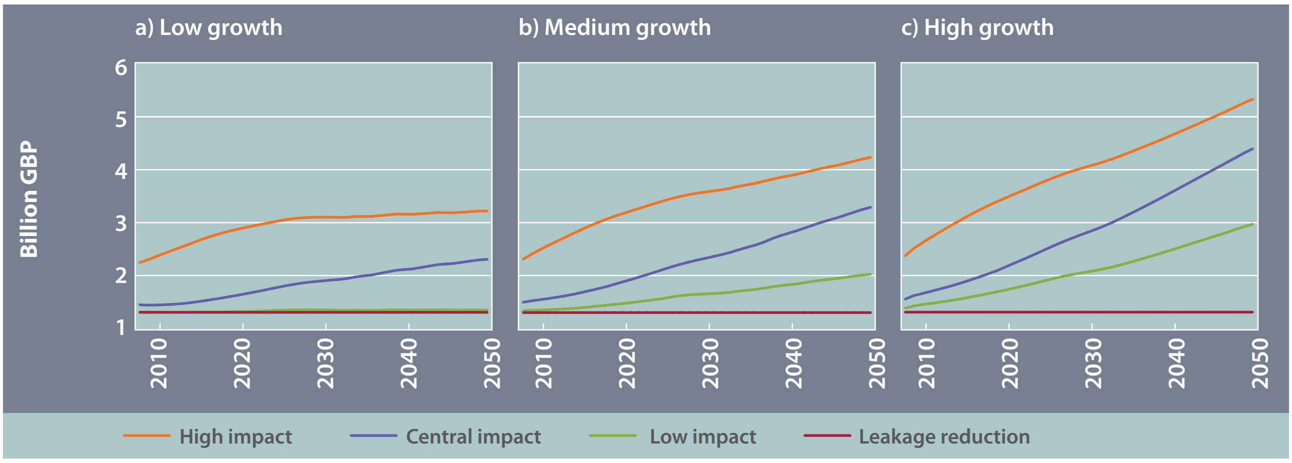


Figure 96: The cost of a Capacity-Intensive transition strategy.

Figure 96 shows the costs of a Capacity-Intensive transition for each demand and climate-change impact scenario. Leakage reduction costs are approximately £1.3 billion per year under this strategy, with remaining costs tracking the additional capacity required to maintain network performance.

5.4.3.2 Capacity-Constrained transition strategy

Figure 97: The relationship between capacity and demand under a Capacity-Constrained transition strategy.

The CC strategy involves reducing demand and modest leakage reduction, which means that in low climate change scenarios the margin between capacity and demand can be preserved. In central and high climate change scenarios, the margin between supply and demand is allowed to erode, but even so additional capacity is still required (Figure 97).

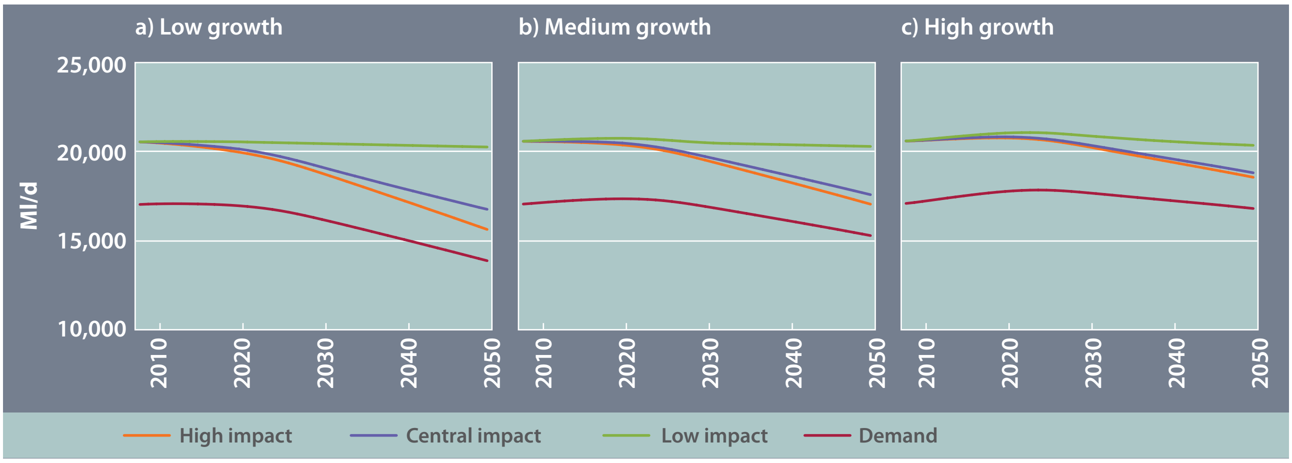


Figure 98 (overleaf) shows the costs of a Capacity-Intensive transition for each demand and climate-change impact scenario. Leakage costs are approximately £160 million per year under this transition, with remaining costs strongly influenced by the climate change impact scenario. In any case, total costs are much less than in the CI strategy.

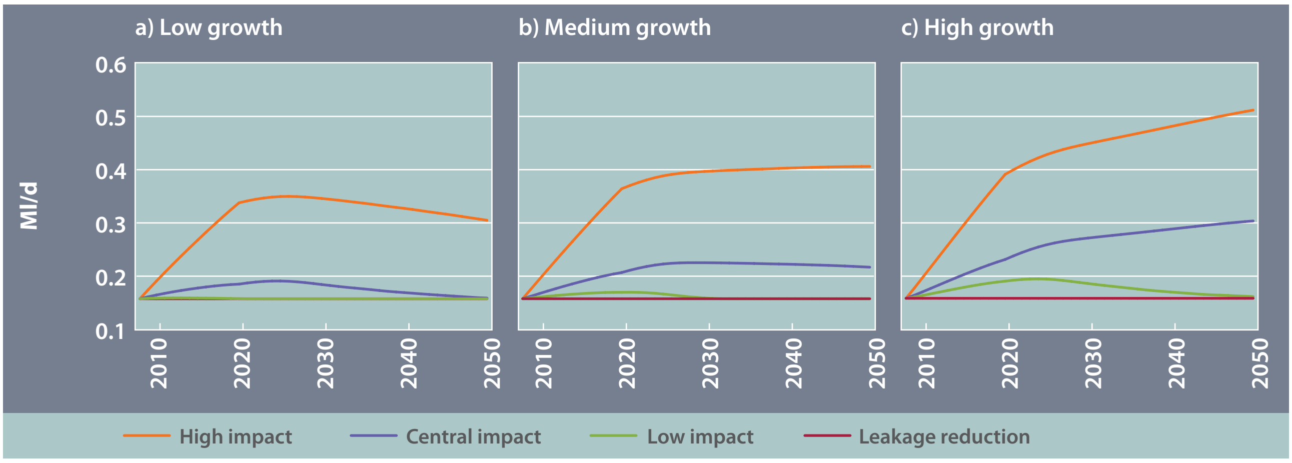


Figure 98: The cost of a Capacity-Constrained transition strategy.

Figure 99: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.

Cost
Electricity
Deficit

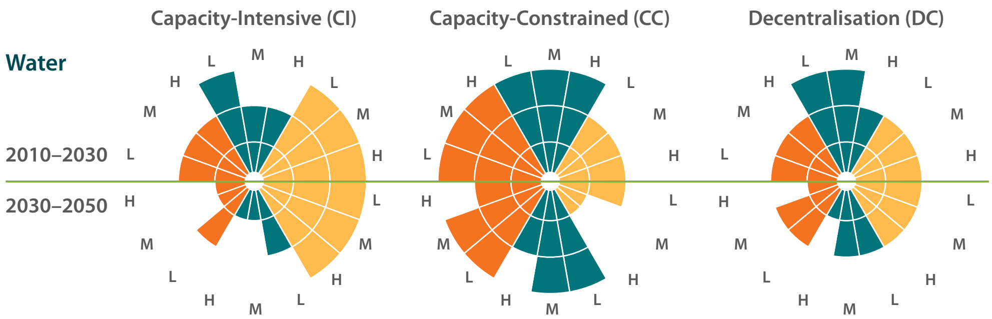
L Low growth scenario
P Principal growth scenario
H High growth scenario

High performance *(e.g. low cost, low CO_2, high supply security)*
Medium performance
Low performance *(e.g. high cost, high CO_2, low supply security)*

5.4.3.3 Decentralisation transition strategy

The relationship between capacity and demand under the DC strategy would be very similar to Figure 95, as the DC and CI strategies both ensure adequate provision of water resources to maintain current network performance.

Differences may occur on a regional level, where, in the absence of inter-basin transfers, a different blend of technologies is necessary to maintain performance. This would be reflected in the cost of the transition, as well as the robustness of interventions implemented on a local scale to climate change.



5.4.3.4 Summary performance evaluation of transition strategies

Three metrics are used to compare the transition strategies, security of supply, energy use and cost.

Security of supply: The CI strategy will always provide adequate security of supply. The CC strategy allows erosion in security of supply, though the rate at which this takes place is dependent on the climate change scenario. The DC strategy may be less robust than CI, as opportunities for new capacity are more scarce at the local scale, and could become more so under future climates.

Energy: The CI strategy maximises leakage reduction, which in low growth and low climate change scenarios is sufficient to keep up with demand and so is a low energy solution. Where additional capacity is required, high energy solutions such as desalination and IBT are adopted. By relying upon demand reduction, the CC strategy is a low energy strategy. The DC strategy achieves some energy saving relative to CI, by not employing IBT and making more progress with demand reduction.

Cost: The CI strategy is the most costly, involving ambitious leakage reduction and costly supply-side measures to preserve security of supply. The CC strategy, by contrast, relies on less costly demand reduction and less leakage reduction, though additional supply side measures will be required towards the end of the assessment period in high growth and high climate change scenarios. The DC strategy lies between the two, though without costly investment in IBT.

The performance of this analysis at a national scale, projection of the impacts of climate change at a similar level, and the assumption of adequate scope for resource augmentation mask local variation in the capacity-demand balance of water. In aggregating the amount of water available to meet demand across all water suppliers in GB, this analysis substantially overestimates the capacity of the infrastructure network to meet demand, and its resilience to climate change. The national water supply infrastructure consists of numerous regional and local networks that are (currently) relatively unconnected. Some networks are already close to capacity, while others are massively over-supplied, and there are few means to relieve those at risk of failure to meet standards of service with excess water resources from other regions. The spatially variable impacts of climate change may exaggerate these regional variations in the balance of water supply and demand in a non-linear and more severe way than presented here, pushing networks beyond their capacity to adapt in isolation.

The analysis is also limited in its treatment of the competition between sectors for the limited quantity of water in the environment. The Government White Paper 'Water for Life' is introducing reform of the abstraction licencing regime in order to deal with the legacy of over-abstraction from rivers (Defra, 2011d). The quantification of more complex interactions, such as abstraction licence trading and the impact of projected climate change, requires a more comprehensive, consistent and detailed approach. Changes in water use across the electricity generation and hydroelectricity generation sectors may be particularly influential as the nation's energy infrastructure portfolio and energy consumption profile evolves.

5.5 WASTEWATER

The main demand driver for wastewater is population. However, population density and the treatment technologies implemented determine the unit cost of treatment.

As with water supply, economies of scale favour centralised strategies and increasing population density reduces costs low-energy treatment technologies exist but have not been deployed extensively to date. In the CC strategy, for which we assume incremental changes to current sewage treatment infrastructure, energy costs increase steadily. The performance of the CI transition strategy is characterised by replacement of existing energy-intensive treatment capacity to new energy recovery technologies. These technologies could allow wastewater treatment to become an energy-neutral or energy-generating process. However, these new treatment technologies still require extensive research and development. The high cost and long design lives of the existing sewerage technologies means that we cannot easily transition away from 'business as usual' with this technology in the period to 2050. This will mean managing the existing assets actively and intelligently, perhaps accelerating the adoption of the active monitoring and control of sewerage systems, and developing strategies to incrementally replace or renew the network.

5.5.1 ASSESSMENT METHODOLOGY

The costs of treatment and sewerage are largely driven by the number of people and scale (see Annex H). The scaling of the costs is important to consider. For sewerage, the per capita costs depend on the nature of the development. Typically, density increases with population size in which case sewerage capital costs/capita scale with population approximately to the power of -0.8. If density is constant with population (i.e. sprawl), then per capita costs increase with density, reaching an asymptote. The key elements in the costs are pipe diameter, depth of excavation and location (urban or green field). The running costs of sewers are a function of the natural log of the density of the sewer network and the number of connections per kilometre, which are themselves functions of the population density.

For sewage treatment plants, running costs and capital costs decrease with size, and are dictated by the number of people (not the volume of waste, but its physical and chemical composition). Running costs are probably more important and scale (to the power of -0.2) with the amount of waste treated, which is in turn a direct function of the population. About half these running costs is electricity.

5.5.1.1 Demographics

The cost of wastewater treatment is a function of the number of people being served not the volume of wastewater consequently 6500 people produce 1 Ml of wastewater per day, and each person produces about 50 g of BOD per day that must be treated. An increase in population will mean a modest increase in treatment capacity. However, it will also mean an increase in the number of customers, so if the treatment is affordable and feasible this will not be a serious problem.

The number of households is not a problem per se. However, if those households are in low-density settlements with small-scale treatment then the per capita running and capital costs will be higher than if they are in high-density urban areas.

5.5.1.2 Economics

The load, and thus the cost of sewage treatment, is probably relatively insensitive to rises in GDP. However, rises in GDP may be necessary to ensure that sewerage remains affordable. The cost of treatment is strongly linked to the cost of electricity, which is used for pumping and especially aeration. The demand for electricity is likely to increase as higher effluent standards are promulgated and where there is increased demand for reuse. This will be further exacerbated by the need to purchase carbon credits in order to obtain electricity.

5.5.2 Analysis of future demand in the FTA scenarios

Applying the drivers of change, the demand and under the three FTA demand scenarios can be seen in Figure 100. The treatment capacity, shown in Figure 100 at its value in 2008, must always exceed demand.

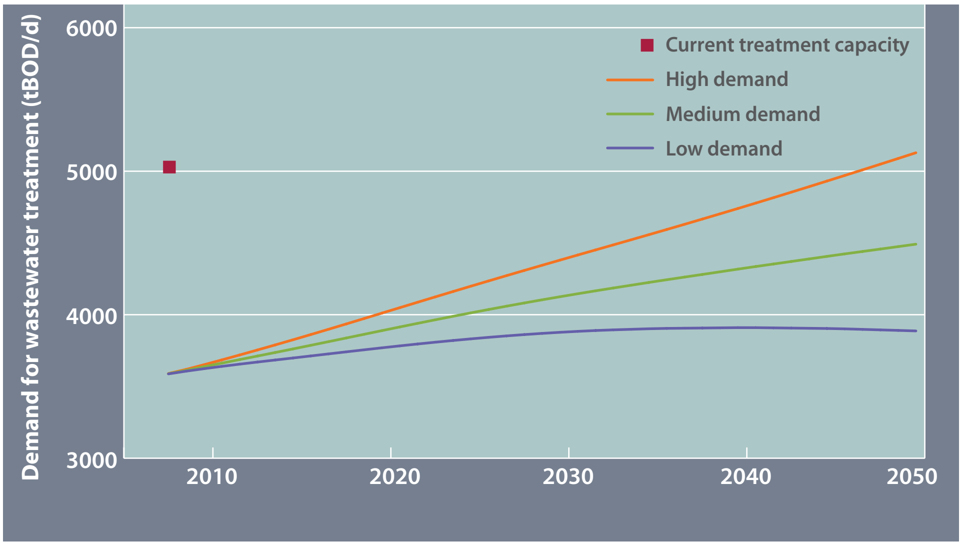


Figure 100: The demand for wastewater treatment under the FTA population growth scenarios at a production rate of 50 g BOD per person per day. The treatment capacity (shown here for 2008) must always exceed demand.

5.5.3 Description of transition strategies

5.5.3.1 Capacity-Intensive transition strategy

For the CI strategy, low energy strategies are invented and deployed for treating wastewaters that at worst use no energy and may at best generate energy and increasingly valuable nutrients. It assumes the implementation of technologies not yet invented.

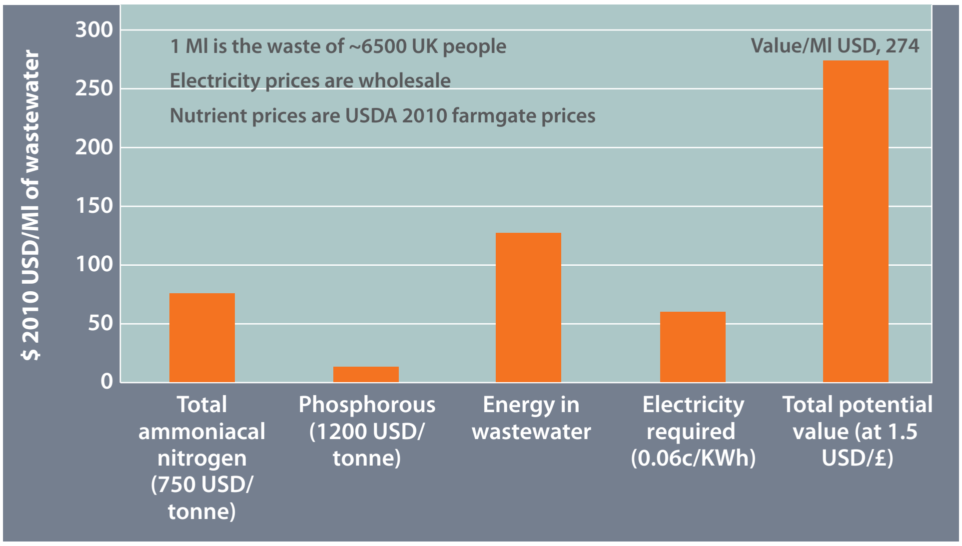
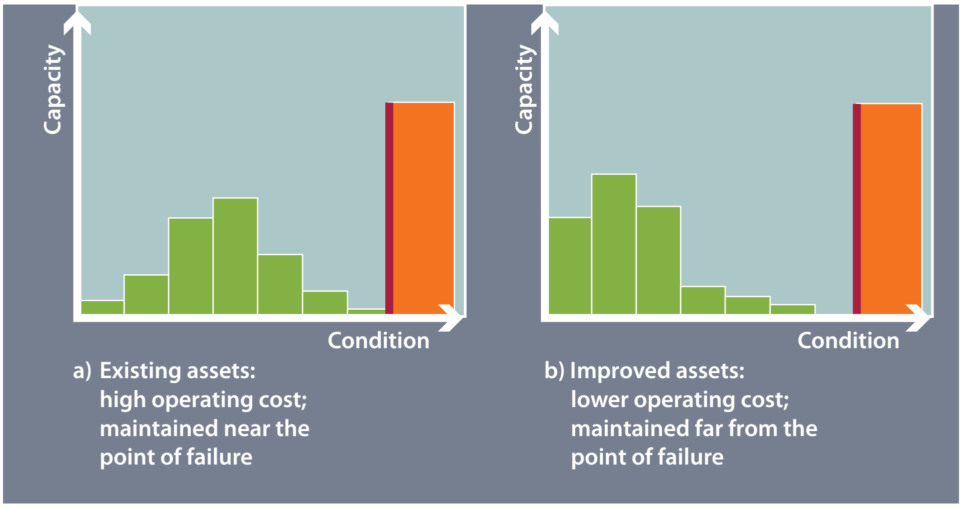


Figure 101: The current (2010) value of the nutrients and energy in a mega-litre of wastewater and the energy costs of treatment.

Increased scope for investment under a CI strategy also facilitates the replacement and rehabilitation of infrastructure at rates exceeding contemporary levels of asset management. Eliminating those infrastructure components that are most expensive to run (Figure 102, overleaf) would diminish the operating cost of the network.

Figure 102: Skew of wastewater capacity towards assets of superior condition, and lower operating cost, following a surge in asset maintenance under a Capacity-Intensive strategy.



The improvement of assets, and the construction of new assets using new technology, would result in a rapid increase in capacity at the beginning of the programme of improvements. Eventually, such over-provision would become unnecessary, and capacity would follow the trend in demand. A slight decrease in capacity may occur as obsolete assets are decommissioned.

Sewage treatment

A business-as-usual scenario will see a steady increase in costs year-on-year, as the price of electricity rises inexorably. The electricity demand is dictated by the available technology and there is only very limited scope for energy saving (good housekeeping and the anaerobic digestion of sludge) at present and these initiatives are being actively sought by water undertakings. Furthermore, as there is no alternative technology available at each time a new plant is built, we are locking ourselves into these costs for at least 25 years. However, our energy scenarios suggest that electricity costs will at least double during the lifetime of these plants. Using a simple econometric model and assuming that power is about half of the running costs of a large plant, we can see the effects on per capita costs under the high and low price assumptions (Figures 103 and 107). Most people's waste is treated in such plants; the costs for smaller plants are typically higher. Thus, significant price rises are inevitable unless we can transition to low energy technologies relatively quickly.

Such technologies do not yet exist in temperate climates, though very large plants (> 1 million PE) are operated in the tropics. In principle, anaerobic treatment systems and microbial fuel cells could, provide low energy treatment systems and might even produce energy. The amount of energy in waste exceeds that required for its treatment. The introduction of this mode of treatment would be part of a valorisation strategy in which energy and nutrients were recovered. The value of energy and nutrients in wastewater already exceeds the treatment costs (Figure 98). The value of N and P is expected to rise in the future. The cost of ammonia is related to the price of energy, typically natural gas, and the value of phosphorus is expected to increase as geological resources are exhausted.

It may already be too late to develop the technologies to avoid the costs in the next 20 years; however, it seems very likely that these costs will make the transition to low-energy wastewater treatment systems inevitable. Thus, we can expect costs to rise in the short term and then decline as energy neutral treatment plants replace existing technologies. These technologies will be at existing treatment plants initially. They may be decentralised in the next generation (after 2050) depending on how the costs of the technologies scale.

Sewerage costs

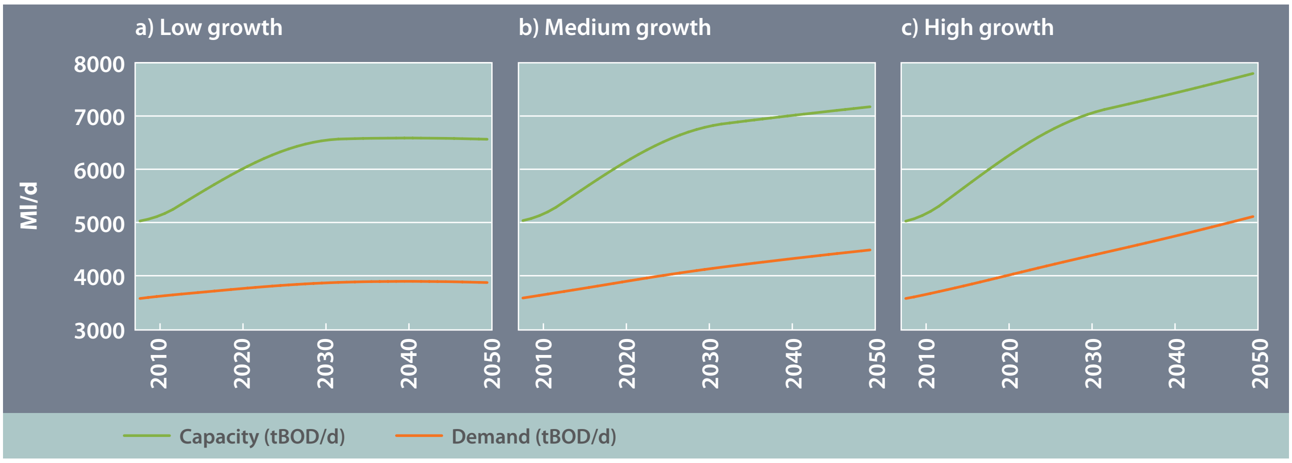
The very long life of the assets we have implied that we will, in the short term at least, have to intelligently manage the assets we have rather than to undergo wholesale replacement. This is in principle possible but may require an as-yet unrealised synthesis of measurement, modelling, control and physical intervention. This may require very little new technology; however, it will require extensive investments in human and physical resources. This will increase the cost of managing the sewage network. However, this will also allow us to gather the expertise required to make logical and cost effective choices about the long term replacement of the existing sewerage network in the light of both the changes in the climate and improved treatment technology.

A CI strategy may focus on the refurbishment of existing works and the augmentation of existing capacity with new technology. The benefits of this may include reduced per capita cost of treatment in terms of energy consumption, GHG emissions and other long term operating costs, as well as increased capacity in terms of chemical composition, hydraulic capacity or population equivalents. They depend strongly on the technology implemented and the constraints placed on the quality of processed water discharged (Foley *et al.*, 2010).

The lowest value of energy consumption and GHG emissions per unit wastewater reported for the UK wastewater industry are around 630 kWh/Ml and 0.4 t BOD Ml, respectively.

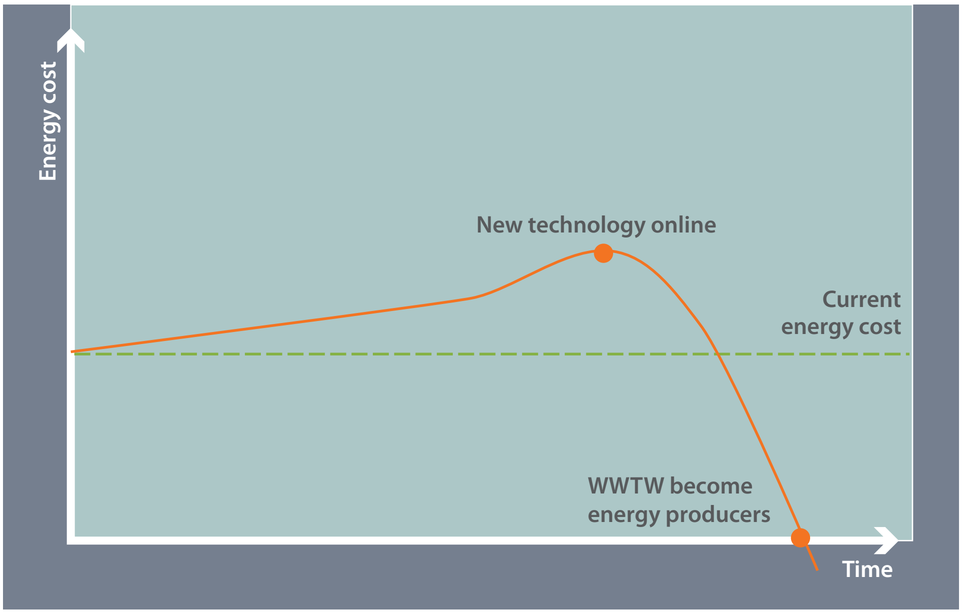
Figure 103 illustrates the impact of a CI strategy on the demand-capacity relationship for wastewater treatment.

Figure 103: Demand-capacity relationships for wastewater treatment under a Capacity-Intensive transition for: a) low growth; b) medium growth, and; c) high growth scenarios.



Energy consumption (Figure 104, overleaf) would again grow rapidly until new assets using more efficient technologies come on-line, at which point, energy use will decrease rapidly. If all energy-consuming assets are replaced with energy-neutral technologies, the overall consumption of the system could fall to zero. There is also scope for energy generation at wastewater treatment plants.

Figure 104: The energy cost of wastewater treatment under a Capacity-Intensive transition.



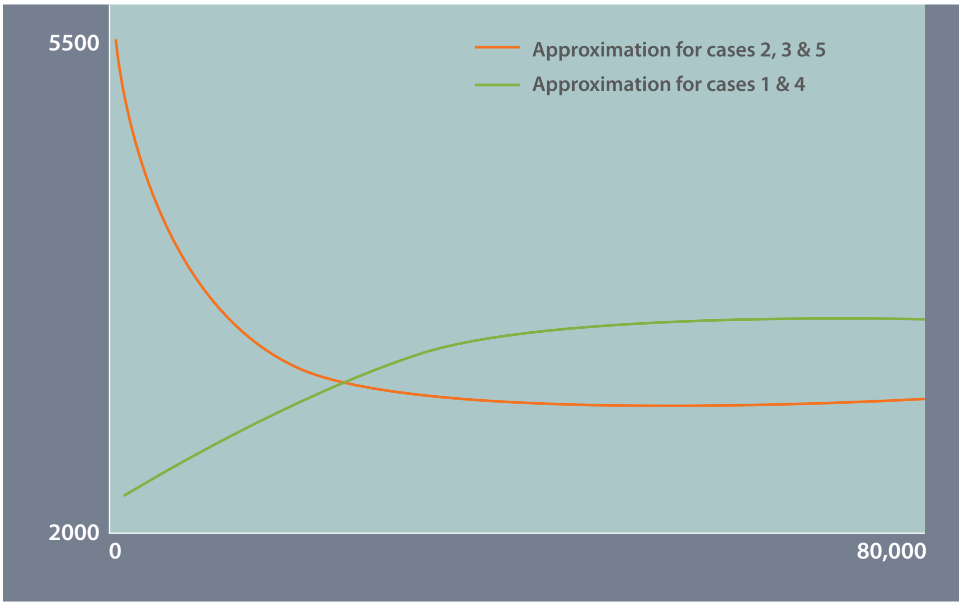
5.5.3.2 Decentralisation transition strategy

In the DC strategy, there is a gradual abandonment of current combined (centralised) treatment processing in favour of smaller decentralised foul systems with many small treatment plants in lieu of trunk sewers, and increased use of grey water recycling. However, the benefits of such an approach will depend on how costs scale in treatment plants and networks. Much of the enthusiasm for decentralised treatment has overlooked the manner in which treatment and sewerage costs scale.

Small treatment plants are very expensive to run (on a per capita basis) and large sewerage networks are very efficient at high population densities. A recent Swiss study (Maurer *et al.*, 2010) has demonstrated this convincingly (Figure 105), and should be repeated in the UK.

In this context, grey water recycling may be something of a 'red herring'. The benefits accrue to the water supply problem, not the wastewater problem, and the issue of scaling of treatment costs must be confronted.

Figure 105: Sewerage construction costs under differing population density assumptions. In cases 3, 5 and 2, density increases with destination, and centralised networks are preferred. In cases 1 and 4, density is constant with population (sprawl) and decentralised systems are cheaper (Maurer *et al.*, 2010).

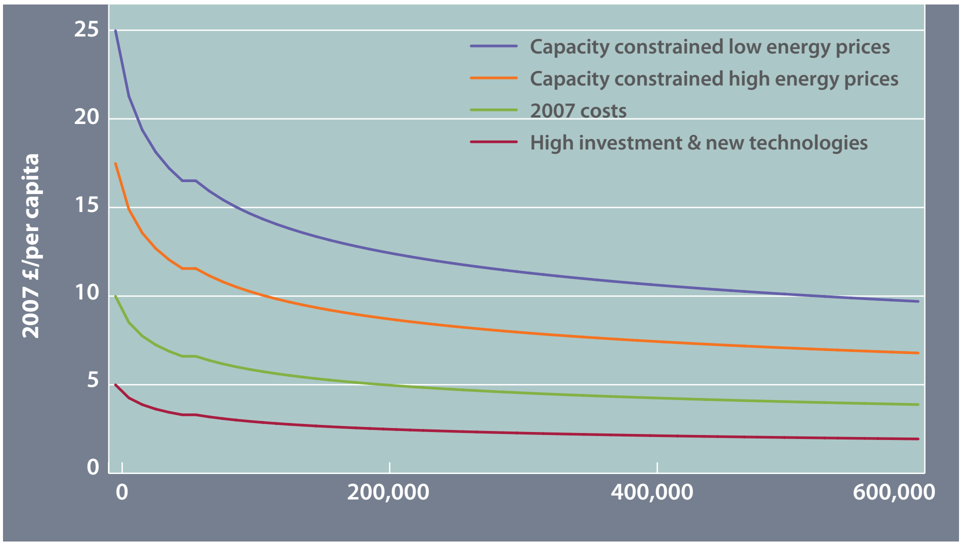


5.5.3.3 Capacity-Constrained transition strategy

The FTA considers the CC strategy as a 'Business as usual' strategy. It is the most likely strategy, as there is a lack of workable alternative technologies at present. However, contrasting with the general transition strategy approach in the FTA, it is not necessarily a low-investment strategy.

As stated in Section 5.3.3.1, a business-as-usual scenario will see a steady increase in costs year-on-year as the price of electricity rises, and that newly built plants will inevitably incur increasing per capita costs. Most waste is treated in such plants; the costs for smaller plants are typically higher. Thus, significant price rises are inevitable under this scenario, though the costs would be ameliorated by using larger treatment plants.

Figure 106: Scaling of costs in large treatment plants in the UK under differing demand scenarios and transition strategies. The median size of a wastewater treatment plant is a population of 60,000.



It is unacceptable for the wastewater infrastructure to fail through insufficient provision of treatment capacity.

In a risk-based framework, the capacity of the wastewater network is managed not in terms of total capacity for conveyance and treatment versus total demand, but in terms of the distribution of capacities across infrastructure elements in the network, where the probability of failure often relates to depreciation in the condition of the infrastructure, rather than its age alone. If demand exceeds capacity in any one element of the network, this effectively constitutes unsatisfactory performance across the entire system. Figure 107 (overleaf) illustrates this concept.

Cyclical programmes of risk identification and asset management result in a constant turnover, where capacity from old infrastructure is seamlessly supplanted by capacity from new. Combined with regional buffers against failure, this yields an apparent over-provision of wastewater treatment capacity at the national scale; however, this effectively 'tracks' demand for wastewater services as capacity is constantly renewed (Figure 108, overleaf).

Energy consumption and cost would escalate rapidly (Figure 109, overleaf).

Figure 107: Wastewater infrastructure capacity in a risk-based framework.

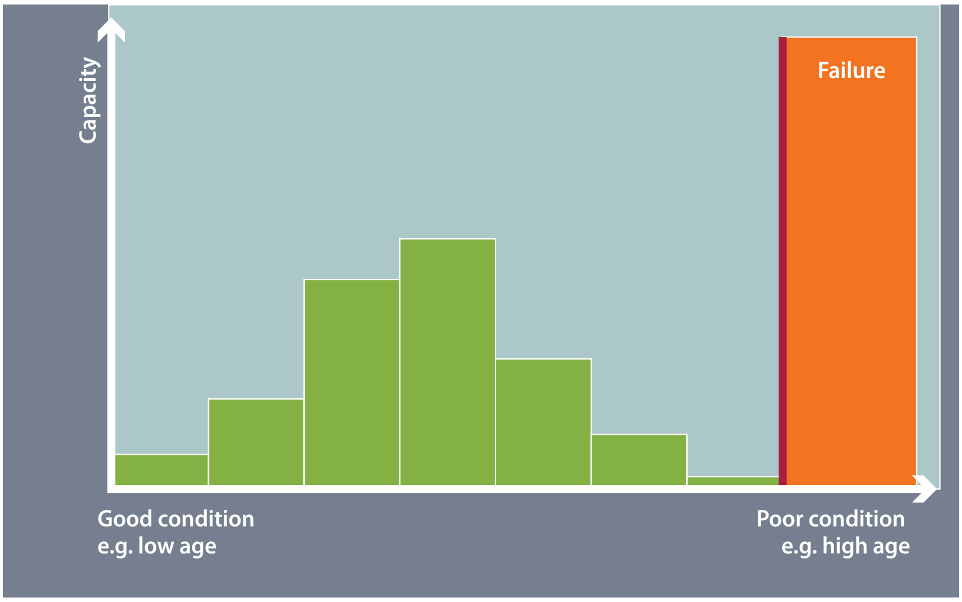


Figure 108: Demand-capacity relationships for wastewater treatment under a business-as-usual transition for: a) low growth; b) medium growth, and; c) high growth scenarios.

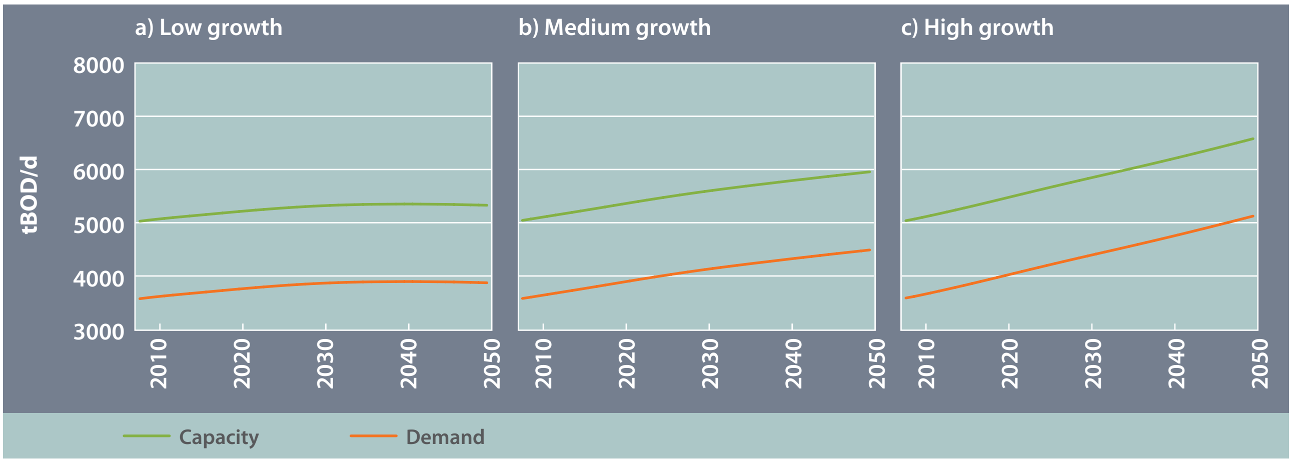
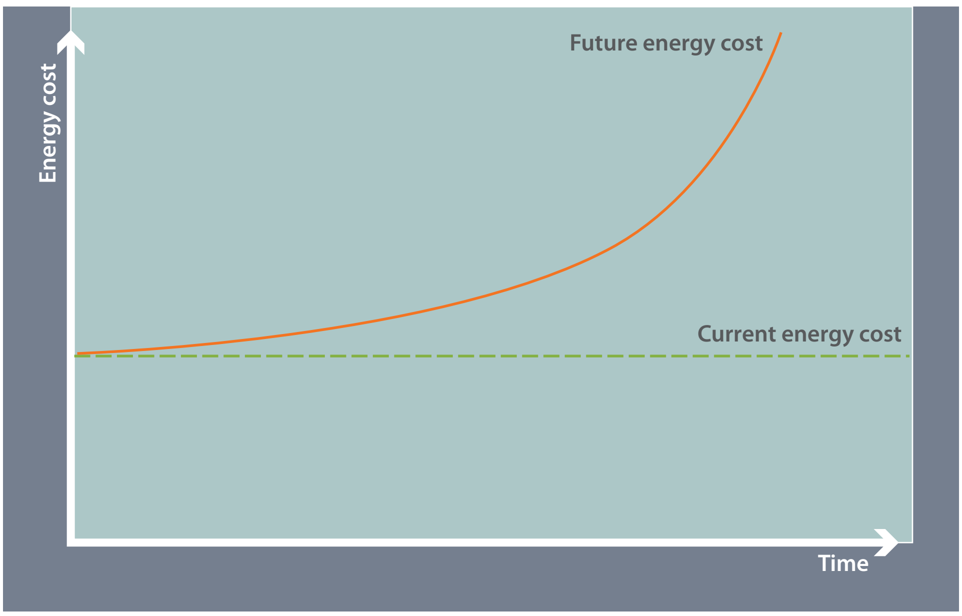


Figure 109: Energy cost under a Capacity-Constrained strategy.



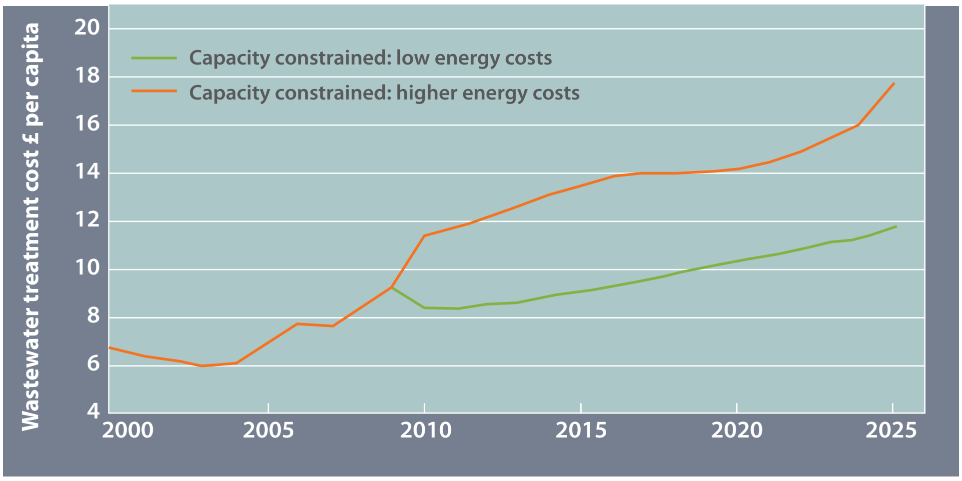
Sewage treatment

A modest warming in the climate will have relatively little effect on wastewater treatment per se. However, it may exacerbate issues of cost as lower flows in the receiving waters and reuse in agriculture will lead to higher effluent standards.

Sewerage

The number of households served, and the number of people served, is expected to increase. The increased hydraulic load on the systems will be offset in part or in whole by reduced water use. However, the number of people and households per se may be less important than their density. Increasing the number of connections in an area will bring down both the running costs and increases the efficiency of use of existing assets in established networks and the per capita capital expenditure for new builds. The envisaged growth in GDP will help ensure the affordability of sewerage. The per capita costs of running the network are of a similar order to those for wastewater treatment and the impact of rising electricity prices will depend on the amount of pumping which is highly variable. There are data for terminal pumping costs and these at present are 9% of the costs of running a network. This element will double or quadruple in the life of the network. The only alternative to pumping would be the development of small footprint treatment plants. However, the designs we have at present are some of the most energy intensive forms of wastewater treatment plants and may in many circumstances use more electricity than a pumping station.

Figure 110: Cost of wastewater treatment in a median (60,000 people) sized wastewater treatment plant under differing energy cost regimes.

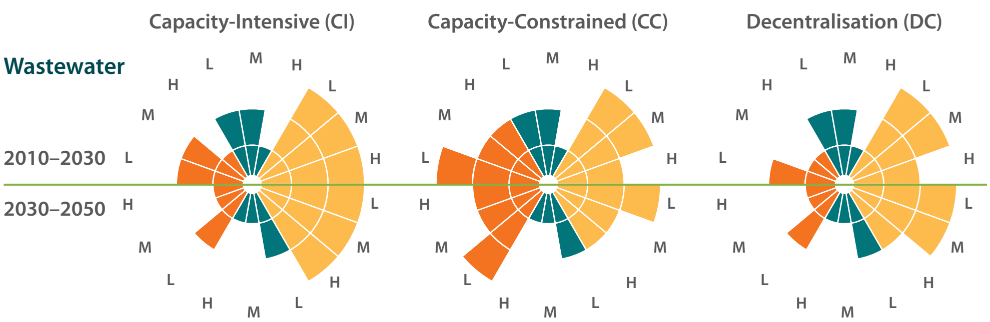


Increases in rainfall and, to some extent temperature, have important implications for the sewerage. These implications were the subject of a relatively recent study (Ashley *et al.*, 2007), and include sewer flooding and the excessive discharge of combined sewer overflows under a business-as-usual strategy. This will plainly be unacceptable and lead to change.

5.5.3.4 Summary performance evaluation of transition strategies

Figure 111 presents a summary visualisation of the performance of the three transition strategies across the three growth scenarios for key performance metrics. In the CC strategy, energy demand increases rapidly over the time periods. In the CI transition strategy, treatment capacity is increased using new energy recovery technologies, which may also result in wastewater treatment to become an energy-neutral or energy-generating process towards the end of the century. For the aggregate performance across the three growth scenarios and the two time periods, the DC strategy had the lowest overall performance, mostly due to the associated cost of the strategy.

Figure 111: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.



Cost
Electricity
Capacity margin

L Low growth scenario
P Principal growth scenario
H High growth scenario

High performance *(e.g. low cost, low CO_2, high supply security)*
Medium performance
Low performance *(e.g. high cost, high CO_2, low supply security)*

5.5.4 CONCLUSIONS

Population determines the volume of wastewater requiring treatment; however, it is the population density, the physical and chemical composition of sewage, and the treatment technologies implemented that determine the cost of treatment.

The most important interdependency is electricity. Low-energy treatment technologies are plausible but do not exist yet. We could transition to such technologies in the current network in 10 years' time, at a rate dependent on the relative merits of alternative technologies.

The other key dependency is population density, which appears to affect strongly the scaling of the cost of sewerage. This in turn affects options for treatment.

Other potentially important interdependencies include agriculture, the value of nutrients, the role of the drainage network in collecting and conveying run-off, and the relationship between effluent quality and receiving waters' capacity for dilution.

Although adaptation options include the promotion of high-density settlements and the charging for water and sewerage services by density rather than rateable value, future policies for wastewater infrastructure provision must necessarily prepare for higher charges for water and sewerage services.

In particular, the cost and very long design-lives of the existing sewerage technologies means that we cannot easily transition with this technology in the period to 2050. This will mean managing the existing assets actively and intelligently, perhaps accelerating the adoption of the monitoring and control of sewerage systems (to 2050) and developing strategies to either abandon or renew the network (beyond 2050).

5.6 SOLID WASTE

Demand scenarios are constructed for municipal solid waste (MSW), commercial and industrial (C&I), and construction and demolition (C&D). Each of these sources of waste interact differently with the drivers of change.

EU and local government imposed targets will require new capacity for some treatments (e.g. composting and recycling), but capacity may be sufficient in landfill. Even under the highest growth scenario (a tenfold increase in waste arisings), and lowest investment option, the investment levels are sufficient to build the infrastructure required to process waste arisings throughout the century. For this reason, the analysis of transition strategies in the FTA is limited to this 'worst case' combination, with an assumption that other combinations of growth scenarios and transition strategies will result in fewer waste arisings and higher levels of available investment.

There are implications for higher recycling targets to be met for this to be achieved, and issues related to provision of sufficient treatment sites. The investment levels across the transition strategies were sufficient (i.e. did not impose restrictions) across all the FTA scenarios to meet demand.

5.6.1 ASSESSMENT METHODOLOGY

The assessment will concentrate on MSW, C&I and C&D wastes; mining and quarry wastes and agricultural wastes will not be considered. Waste arisings for MSW, C&I waste and C&D waste together constitute the greatest mass of waste recovered or disposed of in the UK to waste management facilities. Mining and quarry wastes tend to be reused for site restoration. Agricultural manures are reused on farmland and are therefore not deemed to be wastes. Other wastes generated on farms, such as plastic wrapping, containers, etc. constitute only a small fraction of total waste arisings. Hazardous waste treatment will not be considered in the FTA, but given its importance it should be considered in the next phase of the research.

For the FTA modelling exercise, existing demographic projections combined with per capita waste generation are used to predict waste demand. The economy is strongly linked to waste generation despite efforts to decouple. The relationship of waste generation with economic change is assumed to continue; projections for economic growth or decline in the UK will be used to estimate future trends in waste generation.

It has also been assumed that there will be no further changes in government policy up to 2020. This is likely to encourage further waste reduction and increased recovery of wastes. The impact of meeting targets for recycling and reduction of disposal to landfill on waste infrastructure and failure to meet these targets will be modelled. The impact of social factors (human behaviour, age, social class, etc.) on waste demand will not be included in the FTA since the results are often variable and based on small scale studies.

5.6.1.1 Demand drivers

It is clear that MSW arisings are likely to be driven by population (a greater number of people implies more waste is produced) and GDP (wealthier people consume more) and this proves to be the case, at least over part of MSW datasets.

For C&I the drivers are less clear. It seems likely that population and GDP are linked to the waste arisings from the commercial and industrial sectors but there is no strong correlation between either population or GDP and the waste arisings in this sector. There is, however, a good correlation between waste generation and the index of production (IoP). For the purpose of the FTA, a static per capita lower limit has been assumed, and that the per capita upper limit will follow IoP (which increases linearly with time). This has been carried out for Scotland and England but there is only a single year of Welsh C&I data; this has not been considered, although this will only have a relatively small impact on the total figures.

For C&D waste, again there is no strong correlation with either population or GDP. There has been a correlation between the volume of new construction orders and waste arisings in the sector, however this link has only been strong since the start of the economic downturn and it is not known how new construction orders will continue into the future. The FTA assumption is for static per capita upper and lower limits to waste generation for each country, although the validity of this assumption is questionable.

The majority of future projections in the FTA suggest increases in the amount of waste being generated, despite some of the data showing falls in recent years. The decline in waste production may simply be a product of the recession but may also be due to greater awareness in the public of the need to reduce their waste generation, although it is difficult to see what would cause this, given the lack of transparency of waste disposal costs to the taxpayer. It is not easy to see how the public can reduce their waste arisings without reducing their consumption. Figures from WRAP (2009) suggest that some of the decrease in waste arisings could be due to diversion of biodegradable waste to home composting.

Resource costs might have an impact on solid waste management, but discussions with operators suggest that the impact is likely to be fairly small. When the value of recyclables increases above a certain threshold, the extra profits will be shared between the local authority and the waste management company. This is only likely to inform the waste management decisions at the planning stage rather than during the 25 year life of waste management plant/contract. At least one waste management company has carried out detailed cost benefit analyses for the excavation of an existing landfill to recover resource and consider that resource costs would not have to rise very significantly before it would be cost effective. Further investigation of the drivers will be needed for the next phase.

5.6.2 ANALYSIS OF FUTURE DEMAND IN THE FTA SCENARIOS

5.6.2.1 MSW generation scenarios

In England, MSW generation may have become decoupled from economic growth in 2002/03. In the worst case (i.e. maximum waste generation), per capita waste generation continues to follow economic growth (starting from 2009/10 levels). In the best case (i.e. minimum waste generation), per capita waste generation remains static at approximately 500 kg/person/yr.

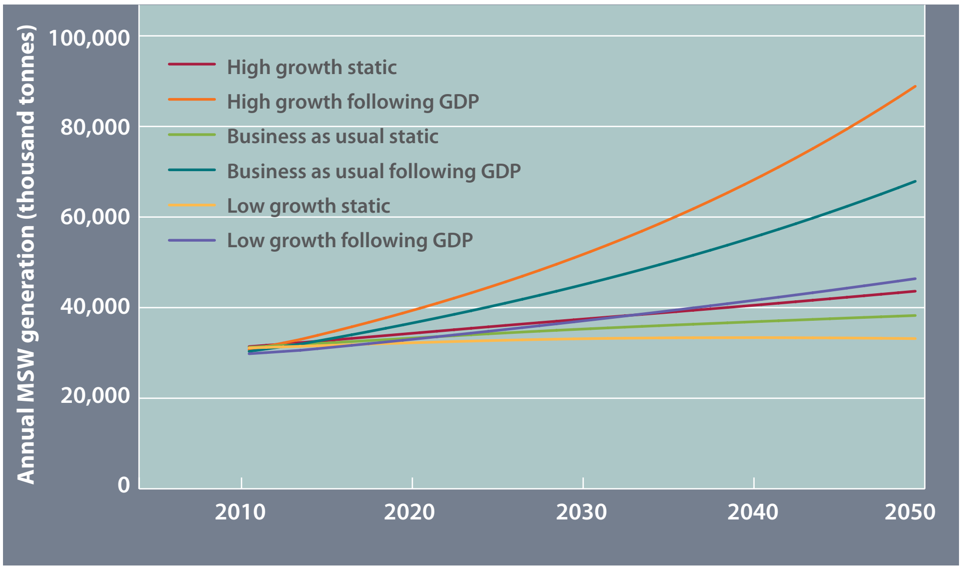
In Scotland, MSW generation may have decoupled from economic growth after 2005/06. In the worst case (i.e. maximum waste generation), the per capita waste generation continues to follow economic growth (starting from 2009/10 levels). In the best case (i.e. minimum waste generation), per capita waste generation remains static at approximately 600 kg/person/yr.

For Wales, there is no correlation between GDP and waste arisings. Since 2004/05, waste arisings have been falling and there is a very strong inverse correlation (R2 =0.97) with landfill tax. Since Wales has failed to meet some of its BMW diversion targets, this is not surprising and suggests that the level will continue to fall in the short term as landfill tax continues to rise, although it is not clear how landfill tax could have an effect on the population who generate MSW due to the social decoupling of MSW generation from the costs of dealing with it. In the worst case (i.e. maximum waste generation), per capita waste generation remains static at approximately 600 kg/person/yr. In the best case (i.e. minimum waste generation), per capita waste generation continues to fall following the landfill tax rises and then remains static at 2014 levels. It is known that landfill tax will be at least £80/tonne from 2014 to 2020 but beyond this has yet to be decided.

The FTA focuses on English MSW as:

1. MSW is the only waste type which has high quality current and historical data.
2. England has by far the largest population in Britain and hence the largest waste arisings.
3. According to senior industry figures, the vast majority of UK waste infrastructure has been built for MSW with C&I being dealt with in the same facilities on an ad-hoc basis. This may be changing with investment into C&I waste infrastructure likely to be significantly more attractive in the short term and changes in the national waste targets made in 2010 (ICE, 2010b) in which BMW was redefined to included C&I waste.

Figure 112: Projections of British MSW generation.



5.6.2.2 C&I and C&D generation scenarios

In comparison with MSW, there is a relative paucity of data and most of the data is based on extrapolations from a limited set of survey data (e.g. NW region of England survey 2006/7 which provided the basis for 2009 England data). There is only a single year of data for Welsh C&I data and so this has not been included here as it is impossible to judge future trends on this basis.

Figure 113: Projections of English C&I generation.

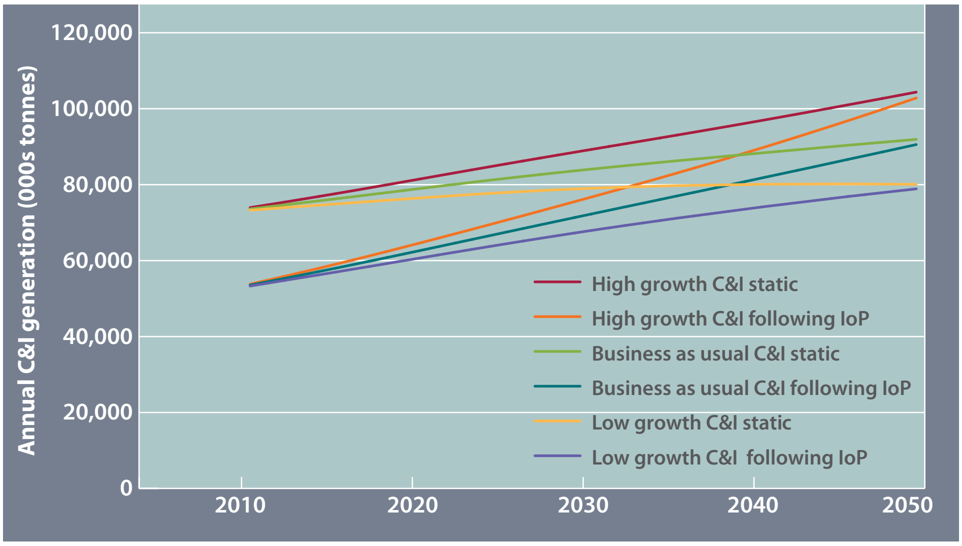


Figure 114: Projections of Scottish C&I generation.

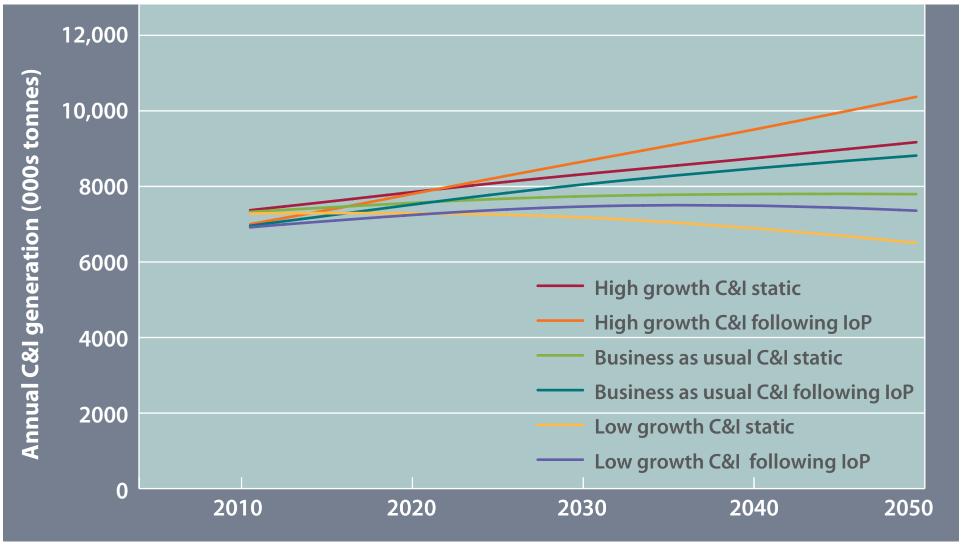
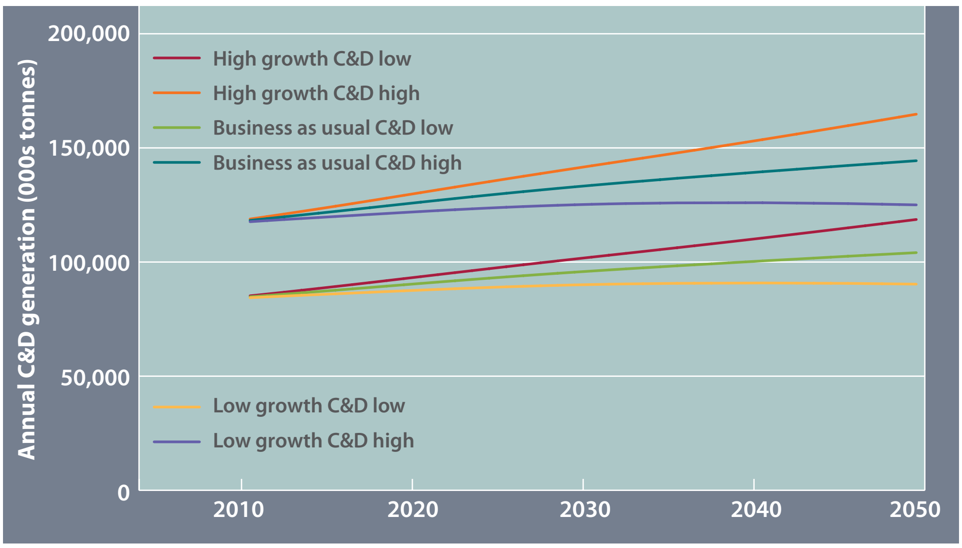


Figure 115: Projections of British C&D generation.



The following are the assumed static upper and lower per capita arisings for each region for C&D:

- England (1.4 t/capita lower and 1.8 t/capita upper)
- Scotland (1.5 t/capita lower and 2.2 t/capita upper)
- Wales (1.1 t/capita lower and 4.0 t/capita upper)

5.6.3 DESCRIPTION OF TRANSITION STRATEGIES

The waste management industry is already decentralised with policy and guidance being issued centrally (and shaped by European directives) and waste management decisions made at the local authority level. Waste management has been handled at the town/borough level since the first waste decrees appeared in the Middle Ages and this seems likely to continue. Government may wish to encourage/discourage different types of decision making, e.g. encouragement for AD through Defra's Waste Strategy for England 2007; changes to planning regulations to make it easier or harder to build certain types of facility etc., but it seems unlikely that it would ever be managed centrally nor that responsibility could be decentralised further.

5.6.3.1 Capacity-Intensive transition strategy

The CI strategy has a high investment in the sector (0.2% GDP). Thus, it is possible to invest in new technologies including advanced thermal treatments (ATT) including EfW, gasification, plasma arc gasification and pyrolysis as well as AD. Gasification and pyrolysis both produce syngas which, after cleaning, can be used as a primary fuel, although there may be significant technical difficulties with this and it is not clear it this has been achieved anywhere with MSW; it may also be that this is less efficient than immediate combustion for the generation of electricity. AD and landfill produce biogas, which in some instances might be better used as a primary fuel, rather than for energy generation. To be used in this way they need to be cleaned. The technology for this is available but might benefit from government funded demonstrator projects.

The output from MBT and MHT plants as well as the residue from MRFs can be used as a fuel SRF or RDF which can be used in any of the above ATTs or co-combusted with coal or biomass, although these latter two are likely to be problematic due to Waste Incineration Directive (WID) regulations, which impose much tighter emissions regulations on waste combustion than combustion of other materials (IMechE, 2010). Thermal treatment should ideally be combined heat and power (CHP) schemes and may need to be coupled with significant investment in district heating (DH) infrastructure or preferentially co-located where there are requirements for heat.

Planning should be carried out on a regional level (CIWM, 2005) with treatment plant being optimally sized and co-located with potential customers for waste heat. As can be seen in the gate fees, the landfill tax has an important influence on waste management practices and this should continue.

5.6.3.2 Decentralisation transition strategy

The DC strategy focuses on investments that favour local treatment/disposal (proximity principle), with local plants that are smaller and sub-optimal in size. These may include modular facilities, e.g. AD, gasification, that are more efficient at small scales than incineration. Thermal processes are used to maximise energy recovery by utilising CHP. Localised treatment would include MBT for the purposes of producing SRF which could be either used locally or transported.

Table 37: Waste arisings by sector for each growth scenario. Colour indicates scale of challenge: green – limited problems; orange – possible problems (annual capacity increase of 400–1200 Kt); red – likely problems (annual capacity increase >2 Mt).

			Annual waste production (Mt)	
			2020	2050
Low growth	MSW 2009: 30.3 Mt 2006: 33.5Mt	Lo (static)	32.2	33.2
		Hi (GDP)	32.8	46.4
	C&D 2005/6: 112.4 Mt	Lo	87.4	90.3
		Hi	121.7	125.0
	C&I 2009: 54.6 Mt	Following IoP	67.2	86.3
		Static	83.5	86.6
Medium growth	MSW – 2009: 30.3 Mt 2006: 33.5 Mt	Lo (static)	33.2	38.3
		Hi (GDP)	36.2	67.9
	C&D 2005/6: 112.4 Mt	Lo	90.0	104.1
		Hi	125.4	144.4
	C&I 2009: 54.6 Mt	Following IoP	69.2	99.4
		Static	86.0	99.7
High growth	MSW 2009: 30.3 Mt 2006: 33.5Mt	Lo (static)	34.2	43.6
		Hi (GDP)	38.8	88.9
	C&D 2005/6: 112.4 Mt	Lo	92.7	118.6
		Hi	129.2	164.8
	C&I 2009: 54.6 Mt	Following IoP	71.3	113.2
		Static	88.6	113.5

5.6.3.3 Capacity-Constrained transition strategy

The CC strategy is the lowest sectoral investment strategy (0.06% GDP). The policy focus is on demand reduction measures, with an increased effort from WRAP and other entities to reduce waste at source. Policies would include continued increases in landfill tax. SQWenergy (2010) found that the most cost effective way of meeting Scotland's zero waste MSW targets was to maximise source segregation of the waste (maximisation of recycling; recyclables less contaminated, hence have greater value; reduced MRF requirement). However, WYG (2011) and WRAP (WRAP, 2011) found that recycling rates were significantly higher when recyclables were co-mingled (wheelie bins have much larger capacity than the green boxes required for kerbside sort schemes) and collection was fortnightly rather than weekly.

5.6.3.4 Performance evaluation

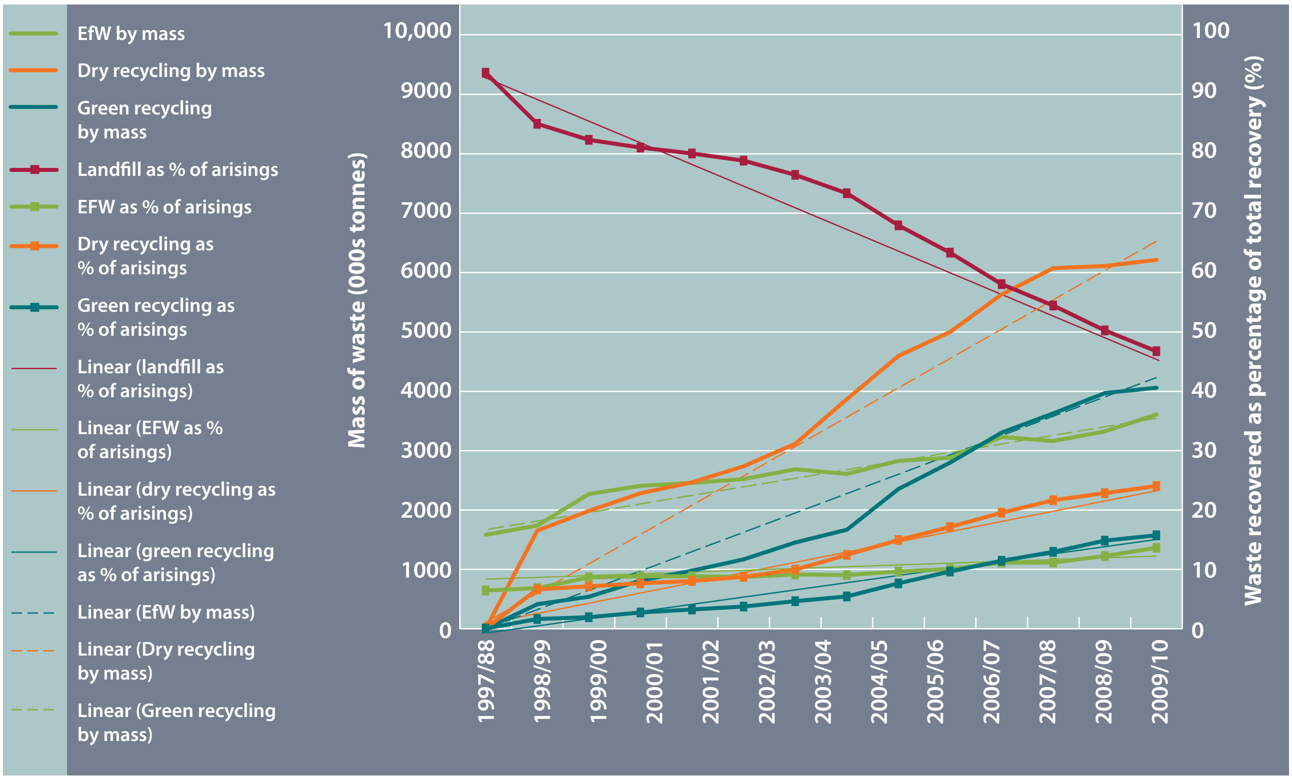
Table 37 summarises the waste arisings by sector for each growth scenario. All data is GB except for C&I data which is England & Scotland only as previously discussed. A more detailed version is shown in Annex I.

5.6.4 CONCLUSIONS

There is a gap between English MSW treatment facilities and generation, assuming that the mass of MSW to landfill remains at 2020 level (i.e. in compliance with Landfill Directive), and the 2020 requirement that at least 50% of MSW must be recycled/composted is retained. The worst case scenario for England in 2050 is that 38.5 Mt recycled/composted (~10 Mt in 2009), 12.2 Mt landfilled, and 26.3 Mt other (3.6 Mt incinerated in 2009). If the shortfall is to be met by thermal treatment, this would imply a need for 67 (400,000 tpa) incinerators in England alone by 2050 in this scenario, although clearly more waste could be composted or recycled which would reduce this requirement. Whilst it is hard to imagine a UK market for nearly 40 Mt of recyclables and compost, the increased population and economic growth required to reach this level of waste generation imply significantly increased markets for recyclables. It is not clear if the same would be true for residual wastes from AD and aerobic treatment. The increase of population may lead to a loss in the availability of land on which these soil improvers can be spread.

In some of the waste generation (demand) scenarios, there is a clear need for greater treatment capacity. In the majority (or possibly all) of the scenarios, the EU and local government imposed targets will require new capacity for some treatments (e.g. composting/recycling) but there may be sufficient capacity or even over-capacity in landfill, although in the longer-term lack of landfill capacity may become problematic.

Figures 116 and 117 (overleaf) show two approaches to predicting the changes in treatment growth trajectory which is required in order to judge the timing and nature of required infrastructure investment in each of the transition strategies. As can be seen, if the entire period shown in Figure 116 is considered, the annual growth by mass can vary significantly when compared to the growth between 2007/8 and 2009/10. It seems sensible to use growth by mass rather than by proportion as it is independent of future growth and so will perhaps better show the requirement for extra capacity.



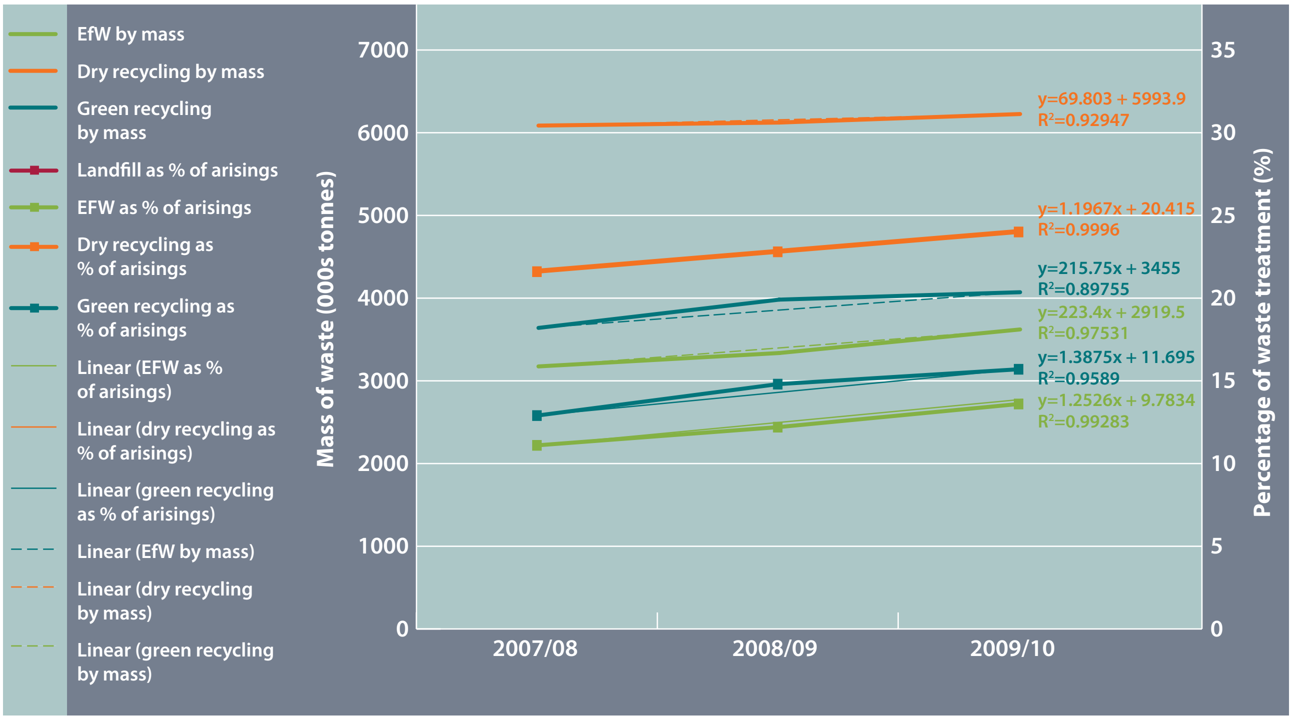


Figure 116 (top): Treatment routes by mass and proportion of arisings for English MSW between 1997–1998 and 2009–2010.

Figure 117 (bottom): Treatment routes by mass and proportion of arisings for English MSW between 2007–2008 and 2009–2010.

The existence of over-capacity in MRFs suggests that the low annual increase in recycling between 2007–2008 and 2009–2010 was due more to the reduction in overall waste or to changing habits, rather than anything more significant. However, for household waste in England, the only recycling target successfully met is the 2015 recycling target and only in the low growth scenario. It may be that the growth trajectories slowed during the recession leading to lower growth in green and dry recycling from 2007 to 2008 onwards than in the previous decade. The accompanying reduction in waste arisings would mean that recycling rates continued to rise.

The approach of using different processing trajectories for the different waste materials needs to be compared to the production of waste suitable for each treatment. The most comprehensive review of the material make up of MSW was carried out for Defra (2009b).

Table 38 has been used to determine the amount of different type of wastes materials in MSW. This is required in order to estimate the requirement for new infrastructure. It has been assumed that:

- These arisings include the material which is source separated for recycling. The total amount of waste strongly supports this assumption.
- Some wastes can be processed in multiple ways (e.g. paper & card can be recycled, biologically degraded or used as a combustible; plastic could be recycled or burnt).
- All the materials which do not clearly fit into a single processing group will be landfilled. This includes the following groups – textiles, hazardous, sanitary, furniture, mattresses, miscellaneous non-combustible, soil, other wastes and fines. It is recognised that some of this material can be recycled and also that textiles could be banned from landfill in the near future.
- The proportion of each type of waste remains the same. This is unlikely to be true given the effort by expended by government on reducing certain waste streams (e.g. WRAP's 'Love Food, Hate Waste' campaign), but would represent too much complexity for the FTA.

In Table 38, paper & card and plastic have been separated as both can appear in more than one category and this may impact on the different transition strategies. Paper & card can be biodegraded, recycled or burnt as a fuel. The modified waste hierarchy in the 2011 Government Waste Policy Review (Defra, 2011b) would suggest that biodegradation and recycling would be equally acceptable, provided that the output from the degradation meets quality protocols and so could be used as soil improver. Energy use for the paper & card component through EfW would also be acceptable and have the same place in the waste hierarchy provided certain efficiency criteria are met and it can be shown that there is a better environmental outcome than the alternatives. Similarly plastic can be recycled or used as a highly calorific fuel. The minimum value for landfill is higher than necessary as it contains material which could clearly be recycled (e.g. textiles) but is not currently collected for recycling by most local authorities, despite the high commodity value (£300-£350 for clothing bank textiles in Sept 2011 according to Letsrecycle.com (2011)). The actual values in the table show that:

- Substantially less waste is being biologically treated than could be. Even the latest figures show that less than half of the lower limit of biodegradable wastes are being treated biologically. This may in part be due to the lack of markets for the end product, without which, landfill is likely to be required for disposal.

Table 38: Composition of English MSW from 2006/7 (Defra, 2009b). Preferred treatment methods for each component of the waste stream are indicated with **; possible treatment is indicated by * and blanks indicate the treatment is not suitable

	England 2006/7 All MSW	Est. total in MSW (t)	Estimated composition (%)	Potential treatment/disposal				Notes
				Green recycling	Dry recycling	EfW	Landfill	
1	Food waste	5,056,259	17.84	**		*	*	Gov't to discuss banning biodegradable material from landfill during this parliament. Likely to include paper & card. If enacted likely to come into force in 2020/25
2	Garden waste	3,989,782	14.08	**		*	*	
3	Other organic	490,352	1.73	**		*	*	
4	Paper	4,718,113	16.65	**	**	**	*	
5	Card	1,711,499	6.04	**	**	**	*	
6	Glass	1,881,799	6.64		**		*	
7	Metals	1,217,335	4.30		**		*	
8	Plastics	2,831,585	9.99		**	**	*	
9	Textiles	802,816	2.83		**	*	*	A ban is being discussed
10	Wood	1,056,748	3.73	*	*	**	*	Gov't to discuss banning during this parliament
11	WEEE	620,566	2.19		**			Banned from landfill
12	Hazardous	149,396	0.53				**	
13	Sanitary	712,015	2.51	*		*	*	
14	Furniture	379,783	1.34		*	*	*	
15	Mattresses	72,162	0.25		**	*	*	
16	Misc. combustible	671,666	2.37			**	*	
17	Misc. non combustible	798,836	2.82				**	
18	Soil	52,144	0.18				**	
19	Other wastes	658,130	2.32				**	
20	Fines	469,127	1.66				**	
	TOTAL	28,340,112	100					

- In 2009/10, whilst dry recycling and EfW both used more than twice the lower limits for their respective waste streams, both have the potential for further development.

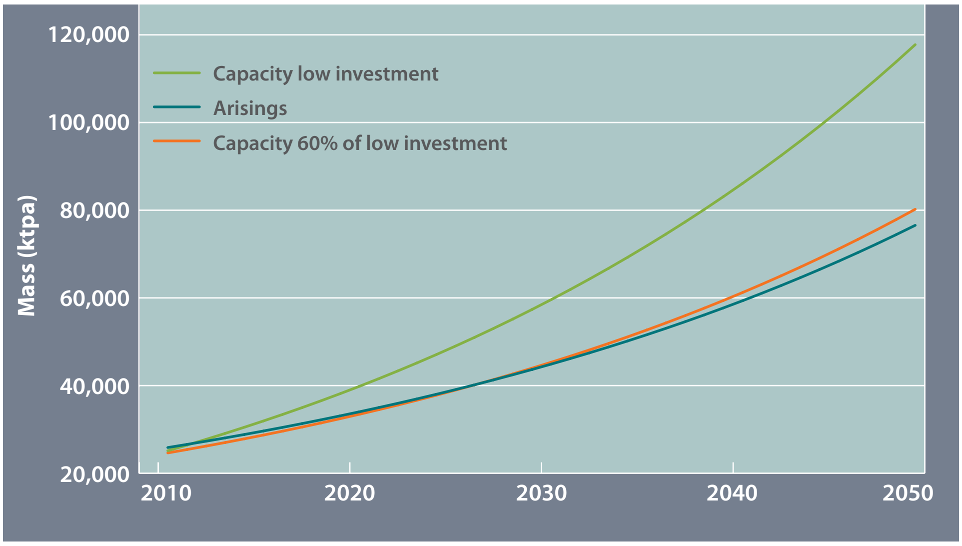
It is difficult to accurately state the current capacity for waste treatment. This creates difficulties when deciding how much capacity needs to be added and on what timescale.

Increasing capacity

Figure 118 shows capacity and arisings for English MSW projected out to 2050, showing the lowest investment strategy and the highest waste growth scenario (high growth and waste arisings following GDP). Capacity increase was calculated conservatively assuming:

- Each tonne of additional annual processing capacity costs £500. This is at the top end of infrastructure (i.e. maximum costs for gasification and incineration plant) and most infrastructure can be built more cheaply than this.
- Ten per cent of the infrastructure is assumed to be lost each year (operational life is expected to be 25 years for much infrastructure, especially if PFI funded).
- This write-down was also included in the start year which would imply insufficient capacity now which is not the case.
- All the investment is aimed at MSW with other waste streams utilising any over-capacity. This is essentially how the market has operated up until now but needs to be approached in a more sophisticated way in the next stage of the project. A second line is shown in which 60% of the investment is used for MSW.

Figure 118: Projected capacity and arisings for English MSW in the high growth with arisings following GDP and with low investment (0.06% GDP). See text for details of assumptions made.



In the first few years, there is insufficient capacity but this is due to taking a simplistic approach in which the current capacity is assumed to be the current arisings but this is then written down by 10%. In both investment strategies, shown in Figure 115, not only is capacity greater than demand, the capacity added is of the most expensive kind. If cheaper treatment options were chosen, even lower investment rates could lead to an excess of capacity. It should be noted that these results show an investment of £8.5 billion to 2020 for MSW, which is broadly in line with other sources.[36] In this analysis it was assumed that other waste streams would use excess capacity in MSW plant and this is likely to be an oversimplification. More sophisticated analyses will be carried out in the next phase of the project, and will include infrastructure built for C&I and C&D wastes. In lower growth scenarios, capacity will be even easier to achieve.

Modelling capacity increase

Given the uncertainties of current capacity, a simplistic modelling approach has been used: a base case of capacity is assumed for each growth scenario, with further capacity added incrementally. This approach results in increasing capacity for 'recycling/preparing for reuse' by about 325 ktpa and total recovery (including 'recycling/preparing for reuse') by about 650 ktpa. It should be noted that 'recycling/preparing for reuse' can make up a bigger proportion of total recovery than this and in some transition strategies it probably will.

As was shown earlier it would be financially possible, even in a low investment strategy, to meet the costs of new infrastructure even in the worst case scenario of high growth and waste arisings following GDP.

Market factors potentially affecting arisings

Relative poverty reduces UK consumption and/or encourages recovery and re-use, and resource scarcity drives an increase in recovery of recyclables. Waste companies become resource recovery companies (for C&I wastes, major producers may take steps to recover value themselves, e.g. Tesco no longer sends any of the 500,000 tonnes of waste it generates annually to landfill (Davey, 2009)).

Policy/societal factors potentially affecting fate of wastes

A possible EU ban on biodegradable waste to landfill by 2020/25. After 2020, it is likely that there will be further reductions in permitted quantities of BMW going to landfill (i.e. going beyond the Landfill Directive 2020 targets) , until some nominal zero point. According to operators, about 10% of the input into clean MRFs has to be landfilled (due to presence of non-recyclables or contamination) and this is also occurs in MHT and MBT plant.

A complete EU ban on landfill. Whilst there would be much sympathy elsewhere in Europe for this policy, it seems unlikely that in the foreseeable future we will have no residual wastes which require landfilling (e.g. Scotland's 'zero waste' policy allows for 5% of MSW to be landfilled). This will cause similar problems to those outlined above but to a greater extent.

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36 For example, ICE (2010b) and letsrecycle.com. (2009b, 04/12/09). "When is waste infrastructure strategic?" Retrieved 07/12/11, from http://www.letsrecycle.com/news/opinions/when-is-waste-infrastructure-strategic which suggests £10–20 billion (with £10 billion required for MSW alone) and ESA (2011) suggesting £7.5–£20 billion of waste infrastructure investment is required by 2020.

Modification of waste incineration directive (WID). At present any plant burning wastes including SRF & RDF must comply with the WID emissions regulations. Emissions from other combustion processes (e.g. coal-fired power station) are permitted to be 10 times higher than those from WID compliant plant (IMechE, 2010). This is both irrational and reduces the potential markets for SRF. At the moment cement kilns are partially exempt from WID compliance but there is a limit (due to the exemption terms and the number of cement kilns) to how much waste can be utilised in this way.

CHP directive requires member states to promote CHP. Electricity generated from waste combustion processes (gasification, pyrolysis and incineration) are typically 20–30% efficient (Castillo-Castillo *et al.*, 2009). CHP systems are often stated to be up to 80% efficient, although Castillo-Castillo *et al.* (2009) found lower efficiencies.

Table 39: Capex costs and options under different transition strategies

Strategy	Recycling	Capex costs	Recovery	Capex costs
Capacity-Intensive	MRFs; large MBT plant to feed EfW or supply SRF to kilns or co-located industry. Waste as Resource plant (WaR) with up to 1 Mt throughput	MRF ~£40–175/tpa MBT/MHT ~£85–150/tpa WaR ~?	Large scale EfW or ATT possibly funded by multiple local authorities WaR	£190–500/tpa £160–833/tpa ?
Decentralisation	Mix of small local AD & IVC for green waste and MRF for dry recyclables, probably 25–50 ktpa capacity. Maybe able to utilize larger plant and combine with local farm slurries (Defra, 2011b)	AD ~£150–300/tpa IVC ~£150–200/tpa (NB costs from IVC from Viridor) MRF ~£40–175/tpa	Gasification ~50 ktpa Pyrolysis ~50 ktpa CHP – in new developments it could supply the waste generators with district heating but probably easier to collocate with industrial heat users	£160–500/tpa £160–850/tpa
Capacity-Constrained	Change to collection – wheelie bin for co-mingled dry recyclables; fortnightly collection, separate food waste. AD?	Associated costs (e.g. for separate food waste containers and collection) likely to be met by reduction in landfilling costs of due to increase in recycling rates (WYG, 2011)	Windrow composting? But probably attempt to reach targets by forcing more recycling	£35/tpa

Renewable obligation certificates (ROCs), feed-in-tariffs, renewable heat incentive (RHI) and other renewable energy incentives may well change the waste management landscape. The Waste Framework Directive (European Parliament and Council of the European Union, 2008) has changed the regulations on EfW such that energy efficient plant will be classed as recovery, rather than disposal thus moving up the waste hierarchy, provided certain efficiency criteria are met.

Planning process may become increasingly difficult for many waste facilities. This is particularly true for ALL forms of thermal treatment. Difficulty in obtaining financing (e.g. banks already reluctant to fund unproven waste management technologies).

The size of the land bank able to take the output from aerobic and anaerobic processes. Without land upon which these outputs can be spread, there will be little choice but to landfill them.

CIWM (2005) drawing on European experience recommended that there should be strategic regional planning authorities for waste infrastructure which would be intended multiple waste streams (i.e. not just MSW as is currently the case) and funded by alternative systems of financing.

Technical factors potentially affecting fate of wastes

Incineration still produces waste (gaseous wastes, bottom & fly ash and residues from air pollution control (APC) systems, although the ashes are recycled and there are markets developing for APC residues). Various processes could be improved or optimised, including anaerobic digestion, MBT, MHT, composting and incineration. Final storage quality of landfills (i.e. when they no longer require active management) is important. Landfill mining, materials recovery and reuse of void space may also become important in the near future either due to increases in raw material prices, concerns about methane emissions from closed landfills or a combination of the two.

Possible causes of step changes

Creation of targets (coupled with the threat of significant financial penalties) has had a significant effect on both MSW treatment and its final disposal route and it is likely that this could be effectively replicated across the other waste sectors with the right drivers.

If it was shown that processed wastes currently not landfilled posed a hazard (e.g. presence of heavy metals in incinerator bottom ash; compost-like output (CLO) from aerobic degradation of MSW is used for landscaping but may also produce leachates and emit methane), alternative disposal routes may need to be found, e.g. controlled landfill.

If government policy was directed to extracting maximum benefit from all waste streams, this could potentially change the infrastructure requirement, e.g. decommissioning of aerobic composting plants and replacing with anaerobic digesters (AD). Alternatively it has been suggested that biodegradable municipal waste (the source of landfill gas) could be diverted to sewage AD plants and this would impact on the wastewater sector.

A move to strategic regional planning authorities; integration of planning across waste types; with compensation for communities hosting waste facilities (and other strategic infrastructure) (CIWM, 2005) could significantly improve planning, remove the potential biases of some local authorities and ensure efficiencies of scale are accessed.

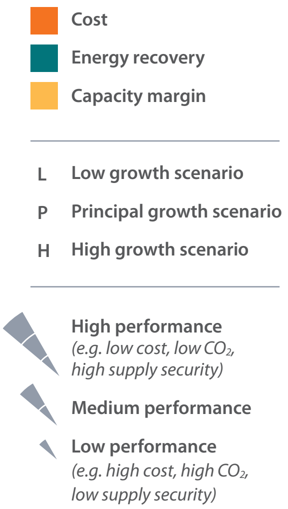
An ad-hoc version of this has already happened in e.g. the South East 7 – a group of five County Councils and two unitary authorities working in partnership (Defra, 2011b). Changing waste governance via moving to a single government department responsible for solid waste rather than the current split of departmental ownership between planning (DCLG) and policy (Defra) might facilitate strategic planning.

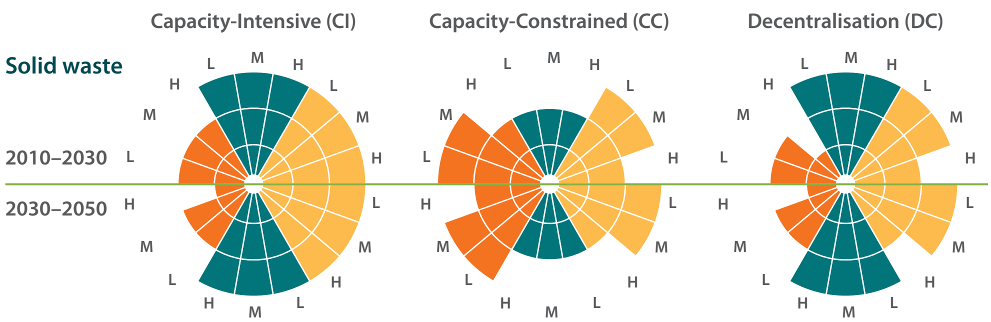
The desire to move to a 'zero waste' economy requires extensive recycling and reuse. The inclusion of infrastructure for reuse or which can use recyclates, within the planning of waste infrastructure might significantly improve closed loop recycling and reduce the necessity for shipping recyclates across the world.

5.6.4.1 Summary performance evaluation of transition strategies

Figure 119 presents the visualisation of the evaluation of the performance of the three transition strategies over the three growth scenarios. Analysis indicated that the performance of the transition strategies would not change over the two time periods. Due to the available investment levels, the CI strategy results in the greatest capacity margin. Both CI and DC implement energy recovery technologies, thus perform better than the CC strategy with respect to energy recovery. The aggregate performance over the two time periods and three growth scenarios resulted in CI having the best overall performance.

Figure 119: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.





5.7 ICT

ICT capacity has continued to rapidly expand keeping well ahead of demand thanks to on-going innovation in a competitive market. It is anticipated that this arrangement will continue, so the sector has not been subject to the same quantified analysis as other sectors. In 2010, ICT consumed an estimated 13–16% of the total electricity in the UK. Projections indicate that global electricity usage in ICT will grow by approximately 9% per year, a trend that may continue up to 2020. However, since 2000 there has been a continuing decrease in growth for home computing and other electronic consumer goods in the UK, and new products have greater energy efficiencies, which may serve to depress future growth of energy use in ICT. Beyond 2020, technological changes make electricity demand from ICT very difficult to project.

The exponential growth in ICT capacity means that analysis of future capacity under the transition strategies is inappropriate. Thus, although the carefully chosen growth scenarios below will certainly lead to varying degrees of demand for everything from home PCs to high-speed networking, the question that is to be addressed is the possibility that ICT provision could constrain the main infrastructures under the three scenarios.

A more subtle question is whether the continued exponential growth in ICT availability could open up new possibilities to optimise use of the physical infrastructures. An example would be that the sort of traffic information that is currently only available by SatNav and mobile phone links (or very coarsely on overhead gantries) might be made available over motorway-side wireless that could be picked up on extremely inexpensive receivers in cars.

5.7.1 ASSESSMENT METHODOLOGY

In the future development of ICT sector, we do not consider end-user devices and applications due to their short lifespan, low cost, high turnover, etc. Furthermore, it was mentioned that we do not expect any capacity constraints from computing power of end-user devices. Finally, even the current computation capacity would enable us to perform the necessary tasks of all future scenarios.

Instead we aim to consider the development of the following parts of ICT infrastructure: communication networks, data centres, IT systems, people (specialists). Historical accounts shows that breakthroughs in ICT solutions completely change the situation, therefore, the following scenarios would hold only in absence of such breakthroughs.

> "*640 kb ought to be enough for everybody*" – attributed to Bill Gates, 1981;
>
> "*I think there is a world market for maybe five computers.*" – Thomas Watson, chairman of IBM, 1943.[37]

Due to the commercial dimension of ICT infrastructure, we evaluate the transition strategies as being a decision by both government and commercial entities. For example, in the Capacity-Constrained strategy we envisage capacity constraints from both government and companies combined (e.g. lack of investment).

5.7.2 DEMAND FUTURES UNDER SCENARIOS

Demand futures for ICT sector should be considered under different facets: computation, communication (fixed, wireless, spectrum), IT services, etc. It would be difficult to construct a unified model, and separate demand futures should be modelled.

Furthermore, historically, ICT sector has witnessed exponential growth in capacity for most of its components, in contrast to linear growth in physical infrastructure sectors. The growth can usually be related to new technologies, new generation components, or breakthrough changes in the sector, rather than economic or population drivers. Still, these drivers could influence overall demand futures in the long run. Furthermore, technological breakthroughs and demand trends have high a level of unpredictability in the sector, which results in difficulties of forecasting (or modelling) demand in the future. Most reports avoid forecasting ICT trends and demand more than 5–10 years in the future.

ITRC analysis focuses on the ICT sector in its interdependence with physical infrastructures. For this reason, we are more interested in demand futures by other infrastructure sectors, rather than end-user ICT demands. For the latter, we may witness capacity constraints for radio spectrum, broadband speed, etc. (Table 40). However, for the needs of physical infrastructure, we do not believe in any capacity constraints forming in ICT sector.

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37 http://www.rinkworks.com/said/predictions.shtml

Table 40: ICT sector possible end-user capacity constraints

ICT component	End-user capacity constraint examples
Radio spectrum	See examples in Section 4.6.2.7.
Fixed broadband	Internet Service Providers applying Traffic Management policies to limit demand for bandwidth during peak hours.
Mobile broadband	3G not available universally; shaky connections and weak signals; still very slow.
IT services	IT systems, which lack investment to stay up-to-date, age very quickly (e.g. recently upgraded banking system is quick and useful, but one that lacked upgrades is frustrating to use).
Computation	Very large scale computations still exceed current capacity, e.g. super computers to calculate weather forecast models, or distributed computing for Folding@ home, SETI@home, etc.

One area where ICT demand for physical infrastructure sectors may play an important role is availability of people. An AEA study records the ICT professional workforce doubling in the last 12 years, and forecasts requirement of 140,000 new ICT specialists annually over the next 5 years (AEA Technology, 2010).

ICT electricity usage

The rapid changes in the ICT sector make it hard to project ICT needs for electricity. On the one hand, exponential ICT growth increases the electricity usage, however the greater efficiency of new technologies counters the increase significantly. Different estimations of ICT electricity usage have been suggested. Reports put the worldwide ICT electricity consumption at around 8% (UK at 10%) in 2007/2008 (Global Action Plan, 2007; Pickavet *et al.*, 2008; Akoush *et al.*, 2011). Alternative figures suggest ICT had consumed around 13–16% of the total electricity in the UK in 2010, depending on assumptions about industrial ICT usage (data centres, etc.) (DECC, 2011c).

If we assume worldwide projections for UK's ICT electricity usage, they give around 20% ICT share of total electricity consumption in 2020. The figure is based on projected annual growth of about 9% for the whole of ICT (Pickavet *et al.*, 2008), starting from 10% share in 2008, assuming 3% annual growth in total electricity consumption.

However, trends from the last 10 years (2000–2010) show slowing down of ICT electricity usage growth. Data centre electricity usage worldwide showed 16.7% annual growth in 2000–2005 (Koomey, 2008), but 9.3% annual growth in 2005–2010 (Koomey, 2011). Furthermore, in the UK, home computing growth slowed down from 13% to 1.5% per annum in the period 2000–2010, consumer electronics from 3.75% to ~1% growth per annum (DECC, 2011c). This hints towards new efficient units replacing older ICT devices.

5.7.3 DESCRIPTION OF TRANSITION STRATEGIES FOR ICT

Although there are no expected limitations to meeting demand for ICT in the future, the focus of each transition strategy could affect the nature of ICT usage and data provision. Some of these differences are shown in Table 41.

Table 41: Description of the transition strategies for ICT

Capacity-Intensive	Decentralisation	Capacity-Constrained
• Comprehensive national provision • High growth in digital demand • IT projects: risk of failures increases with project size. Vulnerabilities in deploying nationwide IT systems – do we have experience? • Comprehensive investment into training/academia/colleges to provide with academics and IT specialists in the area • Investment and uptake of new technologies. Development of custom-made solutions • Promoting resilience of networks: multiple networks from different providers. Availability of different of kinds of networks.	• Technological diversification • Localised systems. IT systems: e.g. instead of building a comprehensive centralised NHS database, invest into interoperability and standards, while allowing single hospitals to choose their own providers (or use existing systems) • Increasing home working. Need additional investment to achieve good connectivity to remote areas. Direct these investments from city centres • Peer-to-peer networks • Investment into off-the-shelf IT solutions	• Broadband capacity still exceeds demand • Remaining gaps in geographical coverage of broadband and mobile • Limit to existing technology. Investment for maintenance only. Providing services within current capacities and conditions • Enforce sharing of ICT assets • Provide at least one connection type for users, but do not aim for comprehensive provision.

Summary performance evaluation of the transition strategies

Figure 120 presents the qualitative evaluation of the three transition strategies over the two time periods. As previously discussed, in the time-horizon of interest the assumption is that there are no foreseeable limits to meeting demand for ICT (with respect to supply). Thus, the three strategies perform equally well with respect to the capacity margin metric. Since the CI strategy results in greater investment, the resultant network and data provision coupled with new technologies results in greater costs and energy usage, particularly in a high growth scenario. Costs are reduced in both DC and CC strategies by adopting less sophisticated solutions to future demand growth.

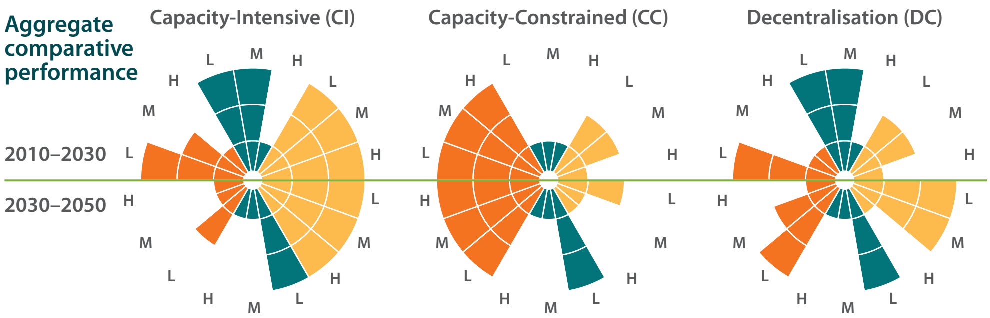


Figure 120: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.

Cost
Electricity
Capacity margin

L Low growth scenario
P Principal growth scenario
H High growth scenario

High performance
(e.g. low cost, low CO_2, high supply security)
Medium performance
Low performance
(e.g. high cost, high CO_2, low supply security)

5.8 GOVERNANCE IMPLICATIONS FOR THE TRANSITION STRATEGIES

This section considers what the three transition strategies might mean for the governance of UK infrastructures.

5.8.1 CAPACITY-INTENSIVE TRANSITION STRATEGY

The CI strategy is more focused on centralised options across sectors, both in terms of governance and technology. The aim is to minimise the capacity constraints on demand thus creating surplus capacity across the sectors and potential for unconstrained growth in supply of infrastructure services. The nature of the CI strategy also makes it capital intensive, with requirements for large-scale, 'lumpy' investments in new infrastructure.

Within the **energy sector,** the CI strategy would include the decarbonisation of the sector thus requiring large scale infrastructure investment in offshore wind, fossil fuel plants with carbon capture and storage, nuclear plants, etc. This suggests a governance strategy which reduces risk for such capital intensive investments, and focuses most on established utilities and other large investors that would make such investments. The current proposals for Electricity Market Reform are designed to do this, although questions remain about whether the chosen approach will reduce risks sufficiently for investors. Under this strategy, there may be a need to go further, for example, to a 'single buyer' model for electricity capacity investment. This would involve either government or an agency specifying what should be built and offering contracts to firms to deliver this capacity. The risks of this strategy are significant, for example, the predictions by the government or the agency of how much capacity is needed might be wrong. It may also mean much less (or no) emphasis on competition and a risk that assets would be 'gold plated' and more expensive than they need to be. It is less clear what this strategy means for gas infrastructure. It may mean a more permissive planning regime so that more gas import facilities, pipelines and storage facilities can be built (to the extent that they are needed).

In the case of the **water sector**, water security is provided through capital intensive options such as leakage reduction, by asset management and renewal, or large scale inter basin transfers, intensified main replacement, and water treatment options such as desalination. These strategies may prove to be very instrumental in demand management particularly in areas with a high rainfall deficit such as the South East. However, the government's ability to implement these centralised options in the current governance system is significantly determined by two main concerns: (a) the cost/ investments required for implementing these options; (b) the environmental impacts of the suggested options which may give rise to public opposition. These concerns suggest a governance strategy that will use an amalgamation of regulatory change and incentives. To assure continued investment in modern and updated water and sewerage assets, the government would require a steady regulatory regime that continues to attract private investment and finance. Furthermore, investment in leakage reduction practises particularly in densely populated areas such as London, would require more government support for R&D and innovation to explore innovative ways to manage and renew pipes for leakage reduction in dense areas (in a cost effective manner). This suggests a governance intervention in amending the regulatory approach of Ofwat where regulators limit the scale of R&D investments in the water sector (by considering R&D expenditure as a part of the operating expenses) (Defra, 2011c).

Furthermore, the adoption of capital intensive water treatment technologies such as desalination, UV disinfection, etc., may raise arguments around their high energy usage, and resulting greenhouse emissions that can have implications for the future adoption of these options. This suggests government strategies that incentivise the uptake of energy efficient and low carbon technologies in water infrastructure. This may require further reconsideration of the current regulatory approach. Ofwat performs the role of consumer champions and often accepts the water company plans or proposals if they seek full approval by customers. Ofwat expects the water companies to undertake a cost benefit analysis of each project that they propose and also consult these proposals and the respective costs and benefits with the customers. Whilst investment in water treatment, pumping mains, etc. directly impacts the users and they see value in such projects, investment in low carbon and energy efficient water infrastructure is not directly close to the needs of the users, as they are unaware of the indirect benefits of investing in low carbon infrastructure. This suggests a governance strategy that encourages the water companies to remove such information asymmetries by making the customers aware of the cost and benefits of investing in low carbon water infrastructure. Furthermore, Ofwat indirectly happens to encourage technologies that are more in line with core business of the water sector such as CHP, thus companies see no incentives to harness more renewable sources in the water sector. This suggests policy attention towards enhancing Ofwat's cross-sectoral perspective so as to ensure the uptake of sustainable capital intensive transition strategies.

Within the **waste secto**r a CI strategy would include investment in low carbon technologies and infrastructure for waste treatment as well as energy recovery. The current system fairly achieves the waste reduction and recycling targets through significant investment in processing and treatment facilities over the last 10 years. This includes use of various pre- treatment and treatment technologies such as MBT, MHT, AD and composting. However, in terms of resource/energy recovery from waste, the UK lags behind many other EU countries. One of the barriers to the development of waste to energy infrastructure is its susceptibility to planning barriers such as opposition from local populations (Tunesi, 2010). A governance strategy that overcomes limitations such as local opposition, would require efforts towards removing information asymmetries between local communities and government agencies. Additionally, another option would be to further strengthen the authority of the central planning structure to discourage local objections. A stronger planning guidance to local authorities so that they have a presumption in favour of facilities such as EfW and AD plants can also be implemented. Large scale uptake of newer technologies for energy recovery such as Advanced Thermal Treatment (ATT) plants with Combined Heat and Power including gasification, pyrolysis, etc., also require governance intervention to attract Private Finance Initiative (PFI) funding. Demonstration projects are needed to prove the commercial viability of new technologies to investors. Alternatively, long term contracts with Waste Disposal and Waste Collection Authorities for specific volumes of waste may provide some long term certainty to commercial firms to invest in such facilities (Kern, 2011). In addition to removing financing and planning barriers, government intervention to enhance energy recovery would require more synergies between recycling, which is overseen by local authorities, and the residual treatment by the private sector. Currently there appears to be a missing link between these two waste streams and the public and private actors engaged in these waste streams (Tunesi, 2010).

Within **transportation** the capital-intensive strategies would likely include investment in capacity enhancement of transport infrastructure in rail, road, airports, ports, etc. Specific attention would be placed on the decarbonisation of surface transport through the improved efficiency of conventional vehicles, and increasing the spread of electrical vehicle infrastructure.

The governance strategy would also need to go ahead with the implementation of proposed schemes such as the construction of Crossrail and successor urban rail projects, and investment in a more extensive interurban High Speed Rail Network.

However, decarbonising transport infrastructure would require specific government intervention in order to remove barriers to investment in green infrastructure (such as rail and vehicular electrification). Governance intervention designed to enhance investment in **rail electrification** would require the removal of policy uncertainties and procurement barriers for the investors and the other actors within the supply chain. A recent BIS report highlights that policy uncertainty around the electrification programme, which was ruled out in 2007 and regained importance later, discouraged investors, due to lack of direction and the associated risks, and acted as a barrier to future growth of electrified transport (BIS, 2011a). The High Speed Rail Network on the other hand has received committed policy direction reflected in proposals for HSR-2. However, government intervention is required to do away with weaknesses within the procurement processes to enhance the uptake of High Speed Rail and rail electrification. Also, the procurement process should be able to engage more innovative small companies working in the area of low carbon infrastructure, whose engagement and visibility seems to be lacking under the current system (BIS, 2011a). A recent joint study funded by DfT and ORR also recommends that the government may impose less prescriptive franchises procurement so that the Train Operating Companies (TOCs) have more flexibility to react to market conditions (DfT and ORR, 2010).

The uptake of Electric Vehicles (EV) will also require governance intervention, particularly to help establish new charging infrastructure where this is required. Though increasingly there is a view that home charging for people with parking at their home would be a good way to get round the need for a national charging infrastructure. However, this would only work for people who do limited mileage between charges, and not necessarily for long distance journeys by EV. Having said this, it is a capital intensive transition strategy and it is therefore the one most likely to involve investment in a national network of charging and/or battery swap stations on motorways. In the absence of complete investment in EV infrastructure, it is feared that behavioural change amongst the users to switch to EV will be very difficult. For example, currently there is still a lack of clarity about who is best placed to provide and maintain public and outdoor recharging posts (POST, 2010) Governance changes are needed to provide market signals and further the development of prototype arrangements which encourage growth in the supply chain and investments for the EV industry. The high initial investment required by the users has also been a major deterrent for the uptake of the technology. To address these costs, further Government intervention can be used to provide incentives and subsidies for using EVs (for example, tax credits for buying EVs, etc.).

Further government attention may be needed to remove uncertainties associated with the unintended consequences of the uptake of EVs. The increased uptake of the EV in the future may result in a reduction of emissions at the start, but may have rebound effects if consumers start overusing these vehicles due to a total reduction in their fuel cost (Sorrell, 2010). This may cause stress on both electricity and road infrastructure. Government intervention may be introduced to balance technological advances with mechanisms such as road user charges, High Occupancy Vehicle fast lane programme, etc. Furthermore, the increased use of EVs may induce high scale use and demand for energy. Thus government intervention may require a balanced approach synergising Electric Vehicular use with use of other alternative fuels such as biofuels and encouraging the use of mass transit.

In the case of Road Infrastructure, supply side measures alone seem to be unrealistic. Governance suggestions would thus include efficient operation, maintenance, and better use of existing assets.

Capital Intensive strategies for **ICT and digital technologies** include comprehensive national coverage with high investment in digital technology infrastructure such as high speed broadband. This will also include promoting the resilience of networks by involving multiple networks from different providers. This would require increasing the coverage, speed and reliability of data networks in all forms of digital communication. For superfast broadband network, the private sector has been very instrumental in making ample investment in the past and has allocated investments for the future as well (HM Treasury and Infrastructure UK, 2010a). However, policy and regulatory attention may be required to provide support and spread coverage in areas which are difficult to serve (for e.g. rural regions where it is uneconomical for the private sector to invest). This may require Ofcom's regulatory intervention in allowing the private companies to get access to the existing networks and infrastructure. Furthermore, the scale and fast rollout of fixed line network infrastructure is largely limited by availability of skilled human resource (such as IT specialists and engineers) (BIS, 2011a). Government support may be secured to enable comprehensive investment in professional training schools to provide with IT specialists and engineers.

The increased demand for mobile and broadband networks require installation of new infrastructure such as base stations, networks, and up gradation of existing networks. Planning permissions required to acquire right of way access to install or upgrade infrastructure for broadband and mobile networks, hinder the rollout of technology required to meet the market demand causing impediments for the network operators (BIS, 2011a). Governance intervention to make the planning process less cumbersome may suggest network companies to use the same network as used by the water and sewerage companies. The use of already laid network may help the network operators get access to the existing 'right of way' instead of entering into a new process for acquiring planning permissions.

5.8.2 DECENTRALISATION TRANSITION STRATEGY

The DC strategy emphasises utilisation of decentralised technological options and exploits beneficial local interdependencies between electricity and heat, energy and solid waste as well as wastewater and water.

In the case of **energy** these decentralised technologies will include micro-generation, onshore wind, anaerobic digesters (biogas), and solar (both PV and thermal) technology. A key question in this strategy is whether infrastructure can be significantly decentralised without governance also being decentralised. If governance also needs to be decentralised – which is likely, at least to some extent – this implies radical change as local actors would not only invest in infrastructure, but also finance and regulate it. Local Authorities would be granted more power and influence over energy system development and regulation. Local utilities might start to proliferate, perhaps in some cases part owned by Local Authorities. This may also imply greater variation across the UK in governance – with some areas pursuing the decentralisation of governance whilst others being less enthusiastic. Another potentially important implication is a breakdown in traditional divides from a governance perspective – between generation, networks and supply to consumers. More integration of generation and network operation might be expected, building on the Low Carbon Networks Fund experience. This would mean changes for Ofgem such as a relaxation of rules that discourage network companies from investing in generation. The strengthened role for local government within this strategy might mean limits to Ofgem's jurisdiction – or perhaps even its abolition.

Similar trends may be seen in the **water sector** too where localisation of water measures (such as local level domestic water storage, grey water use, sustainable urban drainage strategies) may direct towards localised decision-making, regulation, financing and investment. For example, development of rainwater harvesting systems in new developments has sprung up with initiatives by local developers, local authorities and regional water companies. Kingspan Water is one of the water companies which have supported the installation of an integrated rainwater harvesting system in the new housing development called Severnside Housing in Ford, Shropshire. Although various such strategies have sprung up at the local level so as to increase local water resilience, the sustainability or the large scale uptake of these options is under question. A larger uptake of such decentralised options in newer developments would require government action towards building synergy between local water infrastructure planning and regional spatial planning (which requires policy intervention as Regional Spatial Strategies have most recently been revoked). Barriers such as high individual costs, maintenance burdens, and lack of reliability of supply may manifest in sustainability of decentralisation options. This may suggest governance strategies that provide household level incentives such as subsidies or allowing payment of RWH installation costs in instalments. For example, Infrastructure UKs suggestion on water savings through household efficiency can be encouraged under a joint energy and water programme within the Green Deal (HM Treasury and Infrastructure UK, 2010a). Furthermore local support agencies may be established that provide free maintenance services for such options. These local level strategies are expected to be very instrumental in ensuring local supply management; nevertheless, in order to ensure reliability and security of supply, it is essential that the centralised infrastructure is maintained in synergy with the decentralised system.

For **waste**, governance intervention may include measures that enable greater investment in local treatment/disposal systems, and encourage localised treatment (i.e. thermal processes utilising CHP and MBT for the purpose of producing SRF). Local councils are responsible for contracting new waste infrastructure, providing planning permissions, etc. Therefore, the achievement of local infrastructure objectives largely depends on governance strategies that support local authorities. This would imply genuine decentralisation of decision-making under this strategy such that local authorities are free to decide what they would like to do with their waste, without interference from the central government. Strategies could include government measures to ensure the adequate availability of finance for local authorities. The Waste Infrastructure Development Programme (WIDP) established by Defra in 2006 has been instrumental in encouraging local authorities to develop the large scale infrastructure required to treat waste, by helping them access Private Finance Initiative (PFI) credits and promote a supply chain for building treatment and disposal facility such as SRF (Tunesi, 2010). However, in the 2010 Spending Review, the government has cut the PFI credits for waste disposal investments for new incinerators and MBT plants from seven councils. The 2011 waste policy review recommends governance strategy to promote more collaboration between local authorities and private companies in times of funding cuts in order to ensure better economies of scale through combined efforts, increasing cost effectiveness, and increasing efficiency through combined procurement partnerships (Defra, 2011b). Incentives are likely to be used in this strategy to encourage the local adoption of technologies such as AD and which may increase the investment in AD and other similar technologies.

A decentralised governance strategy could also include reducing the institutional gap between local waste authorities that develop waste management strategies and spatial planning authorities. When waste strategies are disjointed from spatial planning of waste management facilities this fragmentation acts as a barrier to acquiring planning permits for plant sites (Tunesi, 2010). Furthermore, governance intervention is required to develop common visions between local authorities and private actors.

The government in its recent initiative has attempted to reduce procedural burdens on local authorities which allows them to develop partnerships between local authorities and private actors and ensures cost effective waste management. These burdens include reducing the data requirement from local authorities and ending the Landfill Allowance Trading Scheme by 2012–2013 which had been useful in the past but was acting as a barrier for local authorities (Defra, 2011b). Additionally, the Treasury might also allow local authorities keep some of the income from the landfill tax that is collected within their area and this income could then be used to invest in alternatives to landfills.

Within **transportation**, the DC strategy include measures that promote a modal shift towards the local energy efficient options such as short range Electric Vehicles for urban use light rail and tram systems, and walking and cycling. The government strategy suggests soliciting the support of local authorities towards planning infrastructure for Electrified Vehicles and cycling. The implementation of the DC strategy will also require refined cooperation and facilitation by local authorities to large-scale modal shift from cars to public transportation through incentivised car sharing and bus usage. The recent Transport White Paper clearly recognises the crucial role of local governance to achieve the UK's overall transportation goals (DfT, 2011a). The recent schemes introduced by the government, such as financial support for local authority transport schemes and the local sustainable transport fund, may be effectively used to support local transport priorities. Within this transition strategy, it is likely that the scope of local government involvement would be extended further, for example, to include the ability of Local Authorities to raise their own finance for public transport schemes through borrowing or specific local taxes (as London does now through the Congestion Charge).

ICT/ digital technology within a DC strategy may require technological diversification to meet specific needs at the local level (instead of requiring a standardised level of coverage across the UK). In order to encourage private investment in diversified technological ventures, governance intervention may be required to encourage the local authorities and the local society to identify specific needs and projects before beginning the procurement process. This shall reduce the unnecessary preliminary scoping hurdles for private actors that often act as a barrier for investments. Within this transition strategy, it is likely that local diversification may induce disparities between different regions in terms of infrastructure provision and access.

5.8.3 CAPACITY-CONSTRAINED TRANSITION STRATEGY

A CC strategy emphasises the reduced demand to the current level of capacity. There is no new capacity added in this strategy, though existing capacity is replaced when it reaches the end of the life, with low carbon technologies. Demand is reduced from both technology and policy options. The aim is to maintain security of supply through demand management.

For **energy** this includes intensive demand management, and the replacement of nuclear and coal electricity capacity with gas-fired capacity which is less capital intensive. This strategy implies radical regulatory changes which would be likely to go well beyond current proposals such as the Green Deal (which will allow consumers will be able to pay back the costs of energy efficiency investments through their bills). For example, the UK could unilaterally tighten up appliance standards so that only the most efficient appliances can be sold. Building regulations would be more strictly enforced – with more stringent requirements for existing buildings enforced, for example, though a new home 'MOT' (Foresight, 2008).

Governance changes might also include a shift to an integrated resource planning approach – with energy companies having a greater incentive to consider demand and supply side investments at the same time, and to favour energy saving more than they do now. Another possible governance change would be a greater commitment to green tax reform to increase prices to align them better with external environmental costs – and therefore to encourage efficiency. This would also be likely to require more emphasis on the fuel poor, and investing in poor housing stock so that high energy prices do not mean large bills.

For **water**, governance changes may include measures that incentivise water savings or a shift towards regulations that compulsorily induce water saving. Metering is one such demand side option. Currently meters are installed by the companies on the voluntary demands of users. Compulsory metering is currently expected in those areas which have been legislatively declared as 'water scarce'. Dover and Folkestone are the areas with such a designation so far. This strategy is likely to include universal compulsory metering, especially if voluntary uptake continues to be slow. However, the imposition of compulsory metering option may also face severe political criticism which may have implications on fully fledged implementation of metering. For example, it is argued that the implementation of compulsory metering system, may compromise the health standards of poorer families who shall restrict their usage of water. The roll out of smart meter and variable tariff rates have also been suggested as possible options to deal with such risks. Besides metering incentivising installation of water efficient fittings and appliances can be an effective demand management strategy. However, it is often refrained due to expensive costs of retrofitting in replacing old fittings. Innovative financing incentives can also be offered to the households in order to reduce the burden of costs. For example, two Australian companies, Yarra Valley Water and Sydney Water have developed new schemes such as the Ecosaver retrofit programme. This programme offers discounted loans to users on the condition that the savings are used for water efficient devices (House of Lords Science and Technology Committee, 2006). Similar incentives can be offered to enable water efficiency amongst households. Furthermore, the capital expenditure bias of some companies may discourage or dis-incentivise the implementation of voluntary demand measures. Radical regulatory changes may also be required to incentivise the water companies to implement the demand and supply measures in parallel to each other.

For **waste**, the CC strategy will require government interventions that reduce the demand for waste services by promoting waste prevention, reduction, reuse, segregation, recycling, and resource efficiency. The Landfill Directive, which is intended to divert biodegradable waste from landfills by 2020, and the Waste Framework Directive that aims to ensure that by 2020, 50% of household waste is recycled and 70% of commercial waste is recovered, have been major drivers towards demand management strategies. The associated governance interventions require tackling waste management higher up in the waste stream both at the household and at the businesses level. Waste prevention, reduction, and recycling can be encouraged by carrot and stick measures and by removing information barriers amongst the users. Under the current system the public sees no incentive to prevent waste as they lack clarity about the cost of waste management.

The governance changes might include using a 'polluters pay' principle or the introduction of a 'unit based' pricing system. For example, in the Netherlands pricing of rubbish generation is based on per unit (bags specially earmarked for rubbish) and has been an ongoing practise for decades. Based on a study of 428 Dutch municipalities, it has been shown that per unit pricing (in combination with the availability of alternatives such as kerbside recycling collection and home composting) has significant implications on changing user attitudes and reduces the amount of unsorted and biodegradables in general waste (Allers and Hoeben, 2010); however, it should be noted that Dutch per capita MSW arisings are almost 20% higher than in the UK (HM Treasury and Infrastructure UK, 2011), so their measures have had little or no effect on reducing MSW arisings. Unit based pricing is also considered equitable as households that produce less rubbish pay less.

In addition to proposed waste reduction measures, there is also a need for regulatory support to avoid offences such as illegal dumping of waste. Fearing the problem of non-compliance, the recent waste review has abolished proposals to introduce new bin taxes for householders. Instead of charging, the UK waste policy places more emphasis on incentive schemes that reward or recognise good habits amongst waste generators. The recent waste review also aims to decriminalise household bin offences and reduce the burden of regulation on legitimate businesses whilst targeting those who are serious offenders (Defra, 2011b). The policy also suggests voluntary responsibility as a means to encourage recycling, waste reduction and resource efficiency within the business sectors such as hospitality, retail, construction, waste, direct mail, etc. Despite the known benefits of incentive based measures, their success largely depends on the behavioural and voluntary response of the users and they may or may not achieve the waste management targets in the most effective manner. Thus a governance strategy that uses a combination of incentives and pricing mechanisms alongside the continued imposition of landfill tax may be more effective at ensuring a reduction in waste and increase in recycling. Furthermore, the implementation of the comprehensive waste prevention programme (to be developed in 2013) alongside the use of the waste prevention fund proposed by the recent waste review may also encourage waste reduction amongst small businesses, social enterprises, and local authorities (Defra, 2011b).

Within **transportation,** the CC strategy will include measures that reduce the demand for new transport infrastructure in the UK. Such measures will be needed to alter user choices to reduce demand and to encourage modal switching to public transportation and other sustainable modes of commuting. It is estimated that nearly two thirds of the journeys undertaken in the UK are under 5 miles and these can easily be done by walking, biking, or using public transport (DfT, 2011a). Behavioural change towards 'smarter choices', such as public transportation, sustainable workplace travelling, telecommuting and working from home, using car clubs, cycling, etc., require governance strategies that are more fine-tuned than simple information and awareness dissemination. Various systems (i.e. Sustainable Transport Systems) have been put in place by the government to promote these 'softer' measures. However, increased government support is required to enhance their uptake and address challenges such as growing population and emissions from transportation.

Some government strategies suggest encouraging commuter behaviour towards enhanced bus usage. Past initiatives enhanced partnerships between local authorities and bus operators to improve the quality of bus travelling for users, which resulted in increased bus use (Sloman, 2003). Nonetheless, there is still a lot of potential for increasing bus usage by making buses more convenient and cost effective. One of the main deterrents of bus usage is the cost and inflexibility of fares. Reduced fares, discounts for multiple uses, and combined (single) tickets can be promoted for all modes of transportation (train, bus, etc.). However, the existing deregulation rules make it difficult to reduce prices in GB.

Government attention has also gone into the promotion of car sharing in UK. Decline in car ownership and car usage are the direct outcomes of car sharing. Significant impacts can be seen in countries like Switzerland and Germany where direct correlation exists between increase in car sharing (particularly among new car drivers) and reduced car mileage (Sloman, 2003). Government changes to promote car clubs/car sharing can include engaging local authorities to plan and encourage local car sharing, particularly in newer residential areas and amongst new car drivers. Learning from the Swiss example, partnerships can also be established between car club companies and railways to ensure smooth onward travel by users (Sloman, 2003).

The shift to other transportation modes such as bicycling has been promoted by various local authorities but has only seen an increase in uptake in cities like Cambridge, Oxford, etc. The lack of designated biking paths and piecemeal biking infrastructure is often perceived as a safety concern by potential biker commuters. Government changes to enhance the uptake of biking culture require assigning more independence to local authorities in designing innovative bike plans, which are currently often hindered by the Highway Agency's design standards for public spaces (Sloman, 2003).

Employers can also play a very critical role in changing the behaviour of the employees towards car usage for work related travel. Governance initiatives to encourage employers include increasing the role of local authorities in facilitating companies to get bulk discount deals from public transport operators within their region. Employers can also encourage a 'work from home policy' on certain days or whenever possible.

Finally, the continuation of toll charges and road pricing schemes could also lead to reduced demand for road infrastructure in some areas – even if there is a switch to technologies such as electric vehicles that have the potential to lower emissions.

The CC strategy for **ICT/digital technology** includes investment in maintenance of existing infrastructure and sharing of assets and networks between companies in the ICT sector and amongst ICT companies and utility providers. This would imply governance intervention to encourage solutions that promote sharing of infrastructure and ICT assets. As with demand management measures in other sectors such as water, it is likely that any restrictions imposed by government or by infrastructure providers would lead to political controversy. Governance mechanisms would be needed to negotiate which services and groups of users might be affected.

5.8.4 COMPATIBILITY OF CURRENT ARRANGEMENTS

Having set out some of the potential governance implications of the three transition strategies, it is then important to analyse how compatible they are with the current governance system. One important general consideration is the phenomenon of lock-in that was mentioned earlier in this report (Unruh, 2000). For some UK infrastructures, lock-in to particular forms of provision and technologies – whether they are centralised or decentralised for example – might make some transitions more difficult to implement than others.

With respect to the **energy sector**, there are a range of policy changes being implemented including Electricity Market Reform (DECC, 2011e) and the Green Deal for energy consumers. Looking at the package of current and announced policies as a whole, a number of observations can be made about the transition strategies:

- The CI strategy most closely matches the direction of current policy. The Electricity Market Reform proposals in the White Paper 'Planning our electric future' (DECC, 2011e) are designed to foster new investment in large scale low carbon electricity supply technologies such as offshore wind, nuclear power and carbon capture and storage.
- The White Paper also discusses the potential for demand side flexibility, which could be said to be more in line with the DC or CC strategies. However, there is a lack of detailed policy proposals in the White Paper that might unlock this potential. Other policies such as Feed in Tariffs for micro-generated electricity and the Green Deal are more in line with the DC and CC strategies.
- The CC strategy is reflected to some extent in current changes to policies and governance arrangements. But it would require much more emphasis on policies to promote energy efficiency, and perhaps to reduce energy demand. In the Electricity Market Reform White Paper, the government acknowledges that more action is likely to be needed to support energy efficiency in households for example.
- Lock-in in the energy sector is a particularly important consideration. The historical momentum of the UK energy system – particularly the electricity sector – has meant increasing centralisation (Foresight, 2008). This applies both to the technical architecture of the system (with, for example, large scale power plants and centralised networks) and the governance of it (largely through national and international policy frameworks, actors and institutions). Despite recent moves by government to recognise the potential of smaller scale energy generation and other local actions, this lock-in means that the DC strategy is likely to require more extensive governance changes than those currently envisaged.

With respect to the **water sector** this should analyse the extent to which the three strategies represent continuity or change with respect to the current proposals for water sector reform.

- The current policy direction has significantly promoted a twin track approach where capital intensive strategy can go hand in hand with demand management (as reflected in Defra's Future Water Strategy) (Defra, 2008). However, in practise the twin track approach is not being used in parallel. The CI strategy closely matches the strategies adopted by the water supply companies to date, where water policies and strategies are closely geared towards supply fix and capital intensive solutions. For example, the construction of water resource infrastructure during the pre-privatisation era and the construction of treatment plants under the influence of EU obligations. Leakage reduction through asset management and infrastructure renewal has also been a priority for Ofwat's regulation. Various fines have been imposed on utilities like Thames Water, United Utilities, etc., for failure to meet leak reduction targets.
- The growing scarcity of water in summer months, particularly in some regions, is now directing water authorities towards water efficiency solutions (Capacity-Constrained solutions). This is evident within the Water Resource Management Plans developed by various Utility companies, particularly in the South East region. Despite the growing attention towards demand management strategies, it appears from the recent views of Waterwise (in the Ofwat review), that Capital Expenditure (CAPEX) bias is one of the main disincentives for some companies to engage in demand side efficiency measures (Defra, 2011c).

- Presently, most of UK's water systems use fairly centralised technologies that have proven to ensure economies of scale. However, recent initiatives in local decentralised level water and wastewater management have emerged where the local water authorities are encouraged to coordinate with water companies, local developers, the Environment Agency, and the users to bring forward proposals in promoting more sustainable surface water drainage systems. In contrast to the conventional method which allows the surface water to run through drains causing pollution, drain flooding, and wastage of water, the Sustainable Urban Drainage Strategy (SUDS) aims to promote new options such as permeable paved roads, rainwater harvesting, ponds and wetlands, etc. which reduce or prevent run off. This is one of the local strategies if implemented effectively may help (in reducing the central burden) in reducing water treatment costs, flood management costs, and reusing harvested water at the household level (CIRIA, 2007).
- Thus a policy shift towards more decentralised technologies and the CC strategy is becoming evident.

With respect to the **waste sector**, we intend to analyse the extent to which the three strategies represent compatibility with current waste management system and current proposals for the waste sector reform.

- The past and the existing system significantly match with the goals of a DC strategy with an element of capital intensive investments. The recent government waste policy review by Defra (2011b) stresses continued support for local authorities in the provision of waste infrastructure and meeting the obligations required under the EC Landfill Directive (Defra, 2011b). The Waste Infrastructure Development programme (WIDP) established by Defra in 2006, has also been very instrumental in encouraging local authorities to develop the large scale infrastructure required to treat waste through helping them access the Private Finance Initiative (PFI) credits and promote a supply chain for building treatment and disposal facility such as SRF (Tunesi, 2010). However most recently the level of financial support has gone down and more emphasis is being given to targeting waste at the highest level of the waste hierarchy (Defra, 2011b). Another barrier to development of waste infrastructure is its susceptibility to the planning barriers due to opposition from local population. The planning act that was introduced in 2008 was one such initiative that provisioned a more transparent, faster, and efficient planning system for Nationally Significant Infrastructure Projects (NSIPs), such as energy, transport, water, waste, and ICT. The act also reformed the public consultation process whereby it laid greater onus of public consultation on the promoter of the infrastructure projects (CLG, 2011). However, in reality it has been unable to achieve swifter planning for infrastructure projects (Moor, 2011). Further changes were introduced in 2010 with the new localism bill which abolished the Infrastructure Planning Commission (IPC) and appointed responsibility for decision making in infrastructure projects to government ministries. It is believed that the 3 month time limit for ministerial signoff for infrastructure projects may ensure timely decision-making (CLG, 2011). However, it is feared that increased community powers through referendums and neighbourhood planning under the localism bill may constrain the development of infrastructure projects and thus a dual approach that incentivises community acceptance of infrastructure projects and timely decision-making is essential. For example, the use of incentives (as suggested by the APSRG) such as offering discount on household utility bills to areas that allow establishment of new infrastructure or local shareholding schemes such as the community ownership of wind turbines in Cumbria (APSRG, 2010).

- Recent attention is being given to tackling waste at the topmost level of the hierarchy. Thus, the CC strategy closely matches the proposed future policy direction reflected in the Government Waste Policy Review by Defra (2011b). The review particularly prioritises the prevention of waste followed by other subsequent activities as reuse, recycling, waste recovery, and lastly waste disposal. The government has also introduced reward and recognition based incentives for businesses and households that may induce demand management and more responsible behaviour towards waste management. Voluntary Responsibility agreements are expected to be signed with businesses in the sectors such as: hospitality, construction, direct mail, etc. Government has also proposed to introduce the comprehensive waste prevention programme (to be developed in 2013) alongside the availability of waste prevention fund in order to encourage waste prevention amongst small businesses, social enterprises, and local authorities (Defra, 2011b).
- In transportation, the CI strategy closely matches the past governance direction. Publicly funded road building and widening measures has significantly dominated the past supply side measures. However, these supply solutions and their inability to deal with congestion issues clearly reflect the lack of realistic strategies to deal with transportation issues. Gradually investment in capital intensive rail infrastructure received significant attention. Proposals for Crossrail and High Speed Rail network in the High Speed Rail white paper 2010 are the recent initiatives that will induce investment in capital intensive infrastructure. The DfT White Paper on Transportation 'Creating Growth Cutting Carbon', 2011 further makes suggestions for decarbonising transportation by public transport investment, electrification of key rail routes, and High Speed rail for long distance travel (DfT, 2011a).
- The DC strategy is now being reflected to a large extent in the recent transport White Paper (2011) that clearly recognises the crucial role of local governance to achieve the UK's overall transportation goals (DfT, 2011a). The schemes introduced by the government, such as financial support for local authority transport schemes and the local sustainable transport fund, give clear indication of the important role local governance can play to support local transport priorities.
- The CC strategies such as shift to use of public transportation are largely discussed in the transport White Paper and local policy decisions; however, the current pricing of public transportation often discourages users to use buses and trains. This is particularly due to the existing deregulation rules that make it difficult to reduce prices in GB. Biking is also used in a limited scale due to inadequate biking infrastructure. The limited infrastructure such as biking paths are often hindered by the Highway Agency's design standards for public spaces.

With respect to the **ICT/digital technology secto**r, the CI strategy closely matches the direction of current policy in digital technology. Government is investing around 530 million pounds to ensure comprehensive coverage of broadband service along with superfast broadband (BIS, 2011a). The government also published a National Broadband Strategy in 2010 which provides a detailed account of the support available for broadband vision (HM Treasury and Infrastructure UK, 2010a). However, large scale spread of mobile and broadband networks require installation of new infrastructure such as base stations, networks, and up gradation of existing networks. The existing planning permissions to install or upgrade infrastructure requires various 'right of way' clearances that may hinder the comprehensive coverage programme (BIS, 2011a).

5.9 CROSS-SECTORAL PERFORMANCE ANALYSIS OF STRATEGIES

As previously mentioned, the transition strategies focus on exploring the dimensions of investment level and decentralisation by design. Key questions of interest to stakeholders and decision makers can be analysed by choosing strategy options from aims that aligns near the boundaries of the continuum of these dimensions.

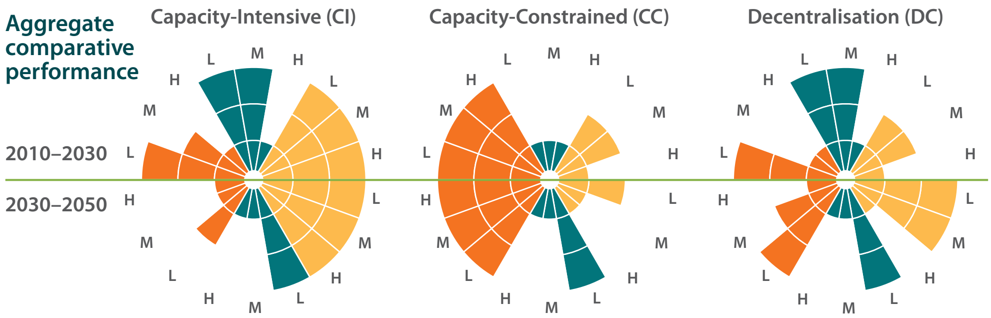


Figure 121: Summary visualisation of performance for the three transition strategies across the three scenarios for the time-periods of interest to 2050.

- Cost
- Emissions
- Capacity margin

- L Low growth scenario
- P Principal growth scenario
- H High growth scenario

- High performance *(e.g. low cost, low CO_2, high supply security)*
- Medium performance
- Low performance *(e.g. high cost, high CO_2, low supply security)*

What are the implications of growing demand for infrastructure services?

High growth in demand for infrastructure services is associated with increasing costly needs for infrastructure provision, in particular given the CI and DC transition strategies, but high growth in demand is associated with scenarios in which more resources would be available for infrastructure investment. High growth in demand is also associated with higher GHG emissions, unless the CI transition strategy is adopted, in which case innovation and investment enables a successful transition to infrastructure systems that are all effectively decarbonised. Higher transport demand is associated with increased transport congestion even given a CI approach to transport infrastructure provision, as, without demand management measures, demand continues to expand to fill the available capacity.

What are the implications of constrained investment in UK infrastructure capacity?

Evaluating the performance of the CC strategy provides insight into the implications of constraints on investment levels for NI. For example, in the water sector the CC strategy requires vigorous price and regulatory measures, over many years, in order to achieve the per capita water demand target of 110 l/d. Security of supply is eroded, especially in high growth scenarios. The CC strategy is the least cost approach, as costly supply-side measures are avoided through demand management. However, whilst demand reduction can under some circumstances result in efficiency improvements without deterioration in the quality of the infrastructure service (for example, by building insulation reducing requirements for space heating), in other sectors, notably transport, stringent demand reduction will have implications for the economy and society.

What are the implications of a carbon-constrained future?

As a consequence of the Climate Change Act (2008) the UK is committed to a reduction in greenhouse gas (GHG) emissions of at least 80% (relative to of 1990 levels) by 2050. Increasing global demand for fossil fuels at a time of reducing global oil reserves reinforces the case for reducing dependence upon fossil carbon. The UK's GHG mitigation commitments imply a major restructuring of the UK's energy supply infrastructure and ripple through other NI sectors, which are all dependent upon energy. Changes within these sectors in turn influence the energy sector, in particular in the case of a transition to electric vehicles. For both wastewater and solid waste, there is the potential for the energy demand from these sectors to be met through conversion of the waste streams to energy.

What are the implications of a decentralised National Infrastructure system?

The FTA revealed that reorientation towards a decentralised arrangement of infrastructure (both in terms of technology and governance) could result in NI performance increases. The energy sector analysis, for example, revealed that the DC strategy resulted in the greatest diversification of energy supply options. Decentralisation also has the potential to capitalise upon interdependencies (e.g. via local waste to energy conversion or combined heat and power plants) and provide new supply options (e.g. rainwater harvesting in the build environment). However, the evaluation of the cross-sectoral performance of the DC strategy indicated that there are significant front-loaded capital investment requirements to transition towards a decentralised arrangement, particularly in the high and medium growth scenarios.

What are the implications of interdependence between infrastructure sectors?

Demand for different infrastructure sectors is highly correlated, both due to the final demand associated with population and economic growth and because of intermediated demands between infrastructure sectors. The FTA has revealed the importance of cross-sectoral interdependence, in particular via energy demand from all sectors. Potential changes in demand (e.g. from electric vehicles and as a consequence of ICT) need to be accommodated in the energy sector. Changes in other sectors, for example in transport congestion or water availability will also have cross-sectoral impacts. The FTA has not revealed new opportunities that could be accessed by taking interdependence into account, though these may exist at the scale of individual facilities or infrastructure corridors. However, understanding interdependence is essential to avoid cross-sectoral demands that cannot be accommodated and to minimise the risks of infrastructure failure.

6 Taking forward the ITRC's research programme

The FTA has made important methodological first steps for the ITRC by:

- **Establishing key definitions;**
- **Establishing a framework for analysis of future drivers of change and their associated uncertainties;**
- **Setting out common understanding of each infrastructure sector according to a consistent format;**
- **Establishing understanding of interdependencies in demand between infrastructure sectors;**
- **Analysing past and current governance arrangements;**
- **Developing and analysing three integrated transition strategies;**
- **Working collaboratively with ITRC stakeholder network to agree key principles, assemble knowledge and validate the analysis.**

This initial analysis has helped to prioritise issues for further analysis in the next 4 years of the ITRC. Future research will develop advanced methodologies for analysing capacity and demand over the long term, building upon the FTA. In parallel the ITRC will develop methods for national strategic assessment of vulnerability and risk due to interdependence between networks and will pioneer work on understanding the co-evolution of interdependent infrastructure with the economy and society. The work will be brought together in two further cycles of national assessment, which will supersede the FTA by using more advanced models, datasets and infrastructure transition options. The next cycle of analysis will be delivered at the end of 2013.

6.1 CONTRIBUTIONS OF THE FTA

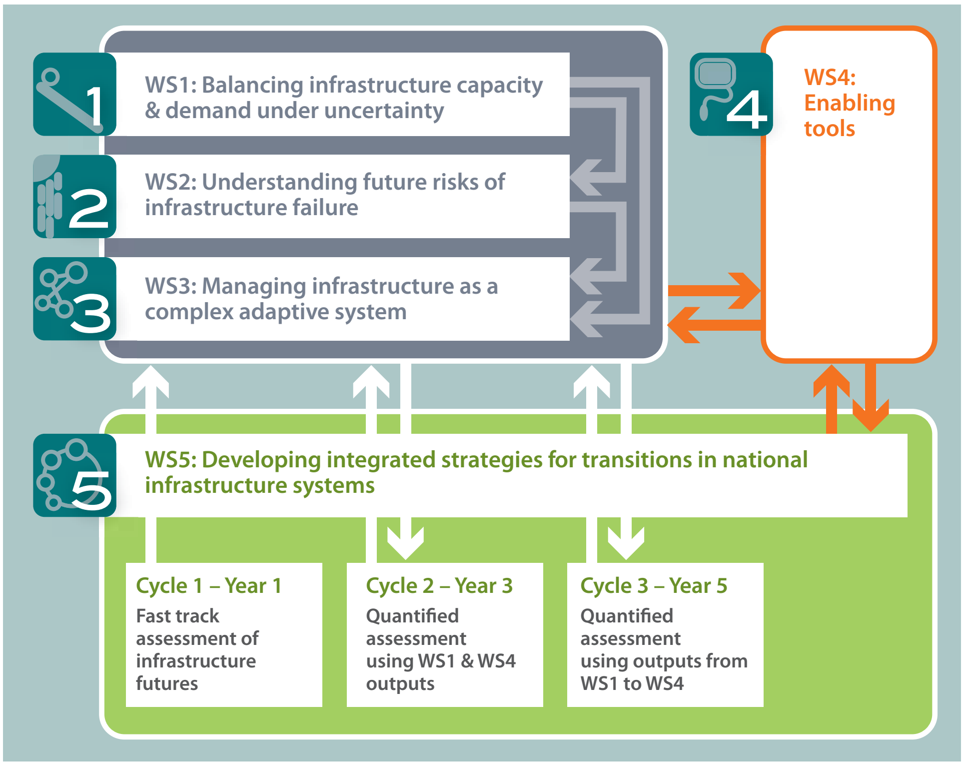
The FTA has accelerated the delivery of preliminary messages from the ITRC research programme to partners in industry and government. These messages are the results of the cross-sectoral review of the current status and governance of NI, and the exploration of future uncertainties in the demand and capacity of NI services. Backed by significant quantitative analysis, the messages serve to corroborate, or question the key assumptions and findings of earlier studies and reports on NI in GB.

It was critical that the ITRC fast-tracked these results, as the challenges facing NI are pressing and decisions about significant investments are presently being made. For example, an extra £5 billion of capital investment was announced in the Chancellor of the Exchequer's autumn statement (2011), with a view to stimulating economic growth. The National Infrastructure Plan (2011) has stressed the urgency of measures to improve understanding of infrastructure provision and to mobilise investment.

The FTA also facilitated early and intense collaboration amongst the members of the ITRC consortium, who are distributed across the UK, as are their partners in industry and government. As NI sector planning and design often occur in sectoral silos, this was particularly important to enable the cross-sectoral integration and analysis that the research programme aimed to achieve. The FTA ensured early and active guidance and input from partners in industry and government. This was critical to ensure that the models developed address the current and emerging challenges in the analysis, planning and design of national infrastructure.

From a methodological perspective, the FTA was an essential first step of the ITRC research programme. The completion of the FTA established and illustrated key terms and concepts, such as the long term capacity, demand and performance of infrastructure services, and cross-sectoral transition strategies. Additionally, inconsistencies identified in the core methodology were recognised and addressed prior to large-scale implementation.

Figure 122: Overview of the ITRC Work Stream (WS) structure



6.2 DIRECTION OF FUTURE RESEARCH

By design, the scope of the FTA was limited in order to complete the analysis on a short timescale. These limitations of the FTA will be addressed in the future work of the ITRC research programme focusing on balancing capacity and demand over the long term, planning for resiliency against risk, understanding the evolution of interdependent infrastructure with the economy and society, including feedbacks and constraints, and developing integrated strategies for NI provision.

Going forward, the ITRC is adopting three methodological perspectives in its development of tools for analysis of NI provision. The development of models and tools is taking place in the first three ITRC Work Streams (Figure 122).

6.2.1 CAPACITY AND DEMAND FOR INFRASTRUCTURE SERVICES IN THE LONG TERM

For expediency, the FTA adapted pre-existing models for the evaluation of the capacity and demand for infrastructure services. However, most of these models were originally designed for use over short time horizons. Models that use elasticities for future demand estimation are often challenged for failing to account for step changes in behaviour or technology. Additionally, as the FTA was constrained to three demand scenarios, the exploration of uncertainties associated with future capacity and demand was illustrative rather than comprehensive.

The next phase of the ITRC research will develop new models for the long term change in capacity and demand (under uncertainty) of NI as interdependent systems. In that sense it will resemble the FTA but will be based upon more quantified and more fully integrated models.

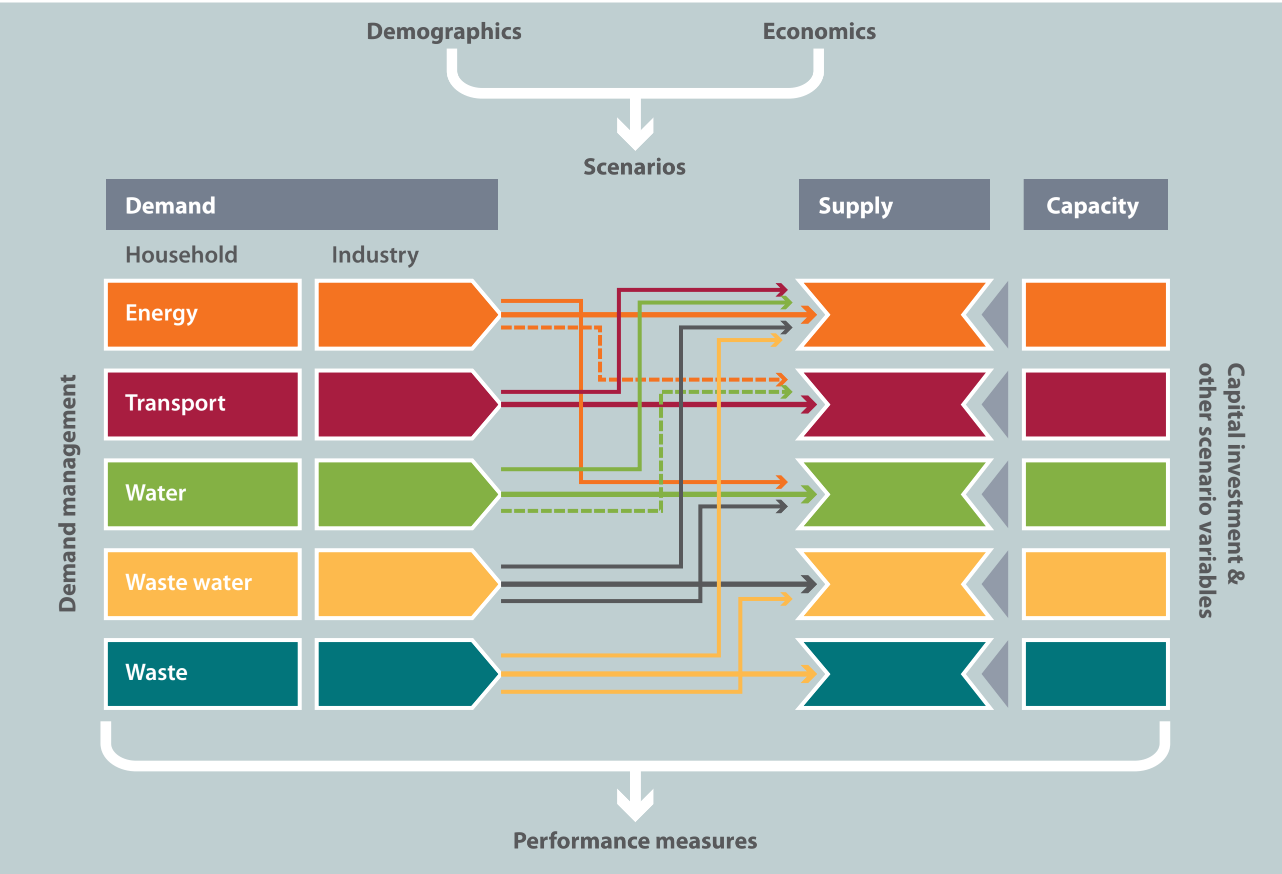
Work Stream 1 (WS1) is developing a system of quantified capacity/demand assessment modules (CDAM) for analysis of long term strategies for infrastructure provision. In that sense it will resemble the FTA but will be based upon more quantified and more fully integrated models including:

- A micro-simulation model for generation of high resolution demographic and demand scenarios.
- A regional economic model that will generate regional multi-sectoral projections of industrial demand for infrastructure services.
- A model of the UK electricity and gas networks and a new disaggregated energy demand module.
- A national strategic model of trunk road, rail, port and airport infrastructure.
- A national water resources system model, coupled with a model of wastewater treatment systems.
- A national solid waste assessment model.

Models will be geographically explicit at the national-scale. The identification of key interdependencies between sectors enable the models to be integrated as far as is necessary to capture salient behaviours and test integrated transition strategies. odels will be geographically explicit at the national-scale for energy, transport, water, wastewater and solid waste systems. The identification of key interdependencies between sectors enable the models to be integrated as far as is necessary to capture salient behaviours and test integrated transition strategies.

In the following paragraphs, the limitations of the FTA modelling for energy, transport and water sectors is contrasted with the approach to be used in the next phase of the ITRC for illustrative purposes.

Figure 123: The Generic ITRC Model Framework.



6.2.1.1 Further development of drivers and scenarios

The FTA dealt with only three high level drivers of change, namely population, economic growth and global energy prices, along with the sector specific driver of climate change in the water sector. Work Stream 2 is extending this analysis to the secondary drivers listed in Table 4. These will be quantified and will provide the dimensions of a high-dimensional uncertainty sampling methodology.

6.2.1.2 Regional multi-sectoral economic scenarios

The FTA has made use of the MDM regional multi-sectoral model of the UK economy. Three scenarios have been analysed, which are reported in detail in Annex D. These results provide the basis for the regional spatial disaggregated analysis that is now under way in Work Stream 1. The scenario space will be more extensively sampled and issues of consistency between the assumptions in the economic model and the infrastructure sectors (in particular the energy sector) will be addressed.

6.2.1.3 Geographical patterns of urbanisation and demand

The FTA has made use of ONS population projections, with additional regional disaggregation. In Work Stream 1 this approach will be supplemented with a household level micro-simulation model. The model is expected to present similar aggregate results as ONS but much greater spatial disaggregation, allowing for detailed spatial analysis of demand for infrastructure services.

6.2.1.4 Energy

Modelling the energy sector in the FTA adopted engineering-economy models (e.g. MARKAL) together with elasticity-based demand estimation. The econometric model has difficulty in incorporating step changes in drivers over the long term. Further, engineering-economy models are not designed for disaggregated modelling. They assume a perfect market with no asymmetry of information, where technologies are chosen mainly on cost considerations. However, non-cost considerations such as economic, policy, or security factors (e.g. carbon targets) may take precedence over costs. Further, rather than using sector model output, the sector demand for energy was projected independently using the energy model.

In the next phase of ITRC research, the energy sector will be modelled through the development of a demand and capacity model. The demand model will evaluate demand for a number of different energy services within each of seven sectors of the economy: residential, transport, industry and commercial services, agriculture, water, wastewater, solid waste, and ICT. As it will include cross-sector energy demand, the results of the other sectors will be used as input. These projections will be spatially explicit for the nine different energy carriers throughout GB.

To evaluate the capacity for energy service, the next phase of research will use an extended version of the combined gas and electricity network (CGEN) model. This model provides a cost-minimal configuration and operation of the combined gas and electricity networks while meeting demand. The model consists of a load flow analysis of the electricity network and detailed modelling of the gas network including facilities such as gas storage and compressor stations. The interaction between the two networks is through gas turbine generators connected to both networks.

6.2.1.5 Transport

There are a number of limitations to the transport modelling in the FTA (e.g. using a constant elasticity model designed for marginal changes). As the model is being used to examine non-marginal changes, it is likely that elasticities would vary with price and income levels. For road and rail, the FTA attempts to incorporate the impact of supply-side constraints on demand and have shown these constraints to be significant even with low demand growth, indicating that infrastructure is already stressed. However, the FTA does not introduce supply-side constraints for airports and seaports, but rather suggests capacity caps. The treatment of the FTA in road and rail does not consider intermodal cross-effects (e.g. suppressed road demand, switching to rail, and suppressed rail demand switching to road). Finally, the FTA does not introduce spatiality into the model.

Many of the limitations mentioned will be addressed in Work Stream 1 through the development of a strategic model based upon the principles of DfT's Long Distance Model and Network Modelling Framework, plus specific demand forecasts for airports and seaports. The model will be spatially disaggregated, enabling analysis of bottlenecks in the network and the benefits of targeted provision of new infrastructure.

6.2.1.6 Water and wastewater

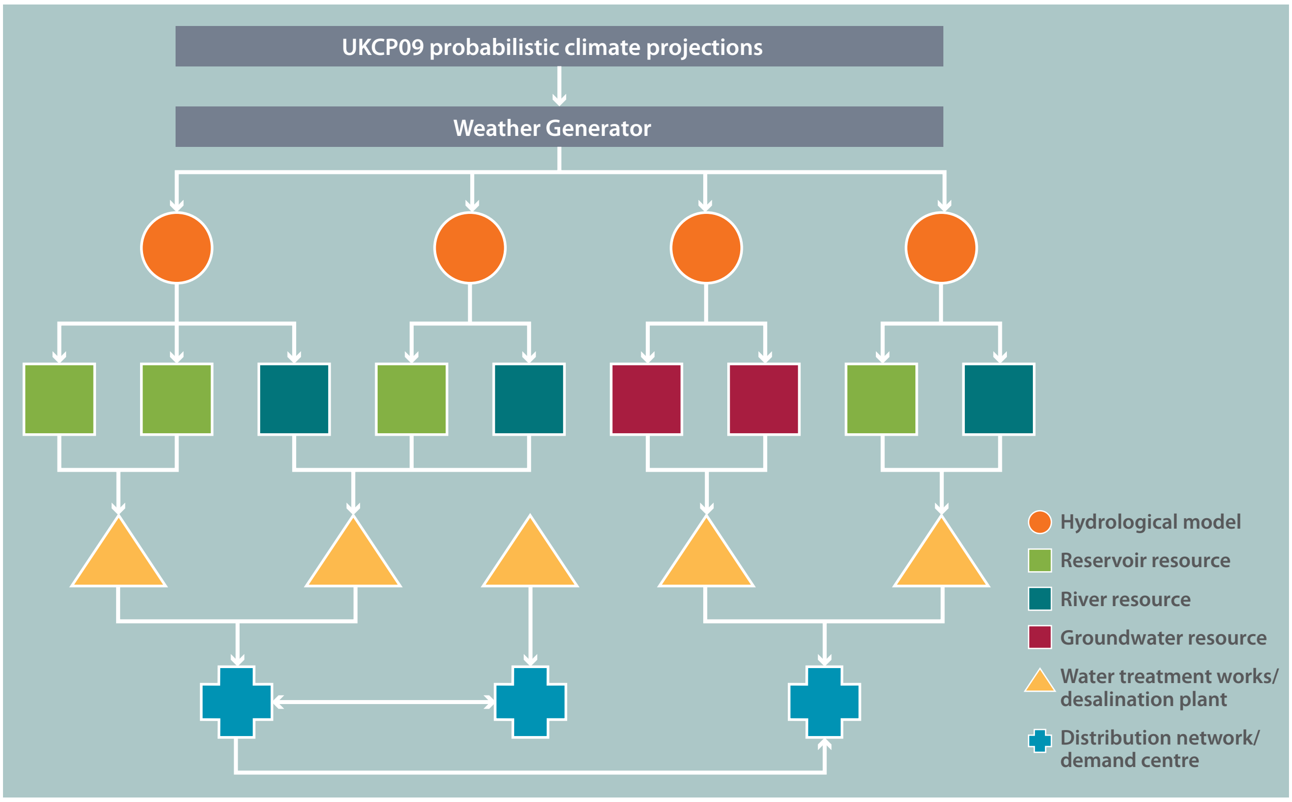
A national strategic model of water supply infrastructure will be employed which expands considerably on the notion of water supply infrastructure as expressed in the FTA. It uses a schematic spatial representation of the water supply infrastructure network, including:

- Reservoirs;
- Surface water abstractions;
- Groundwater storage and abstractions;
- Water treatment works;
- Wastewater treatment works;
- Demands representing a wide range of consumers from multiple sectors.

It is coupled to the UKCP09 probabilistic climate projections via a Weather Generator and a hydrological model to model explicitly the dependence of water resource on climate change at spatial and temporal scales relevant to long term planning scenarios (Figure 124).

The demands for water and wastewater are closely related, as are the infrastructure networks providing the capacity to service those demands. At the level of abstraction programmed, future research models will incorporate the wastewater network as an additional layer of vertices and edges. These would represent wastewater treatment works and the collection network, respectively.

Figure 124: Water model for use in the future ITRC research programme.

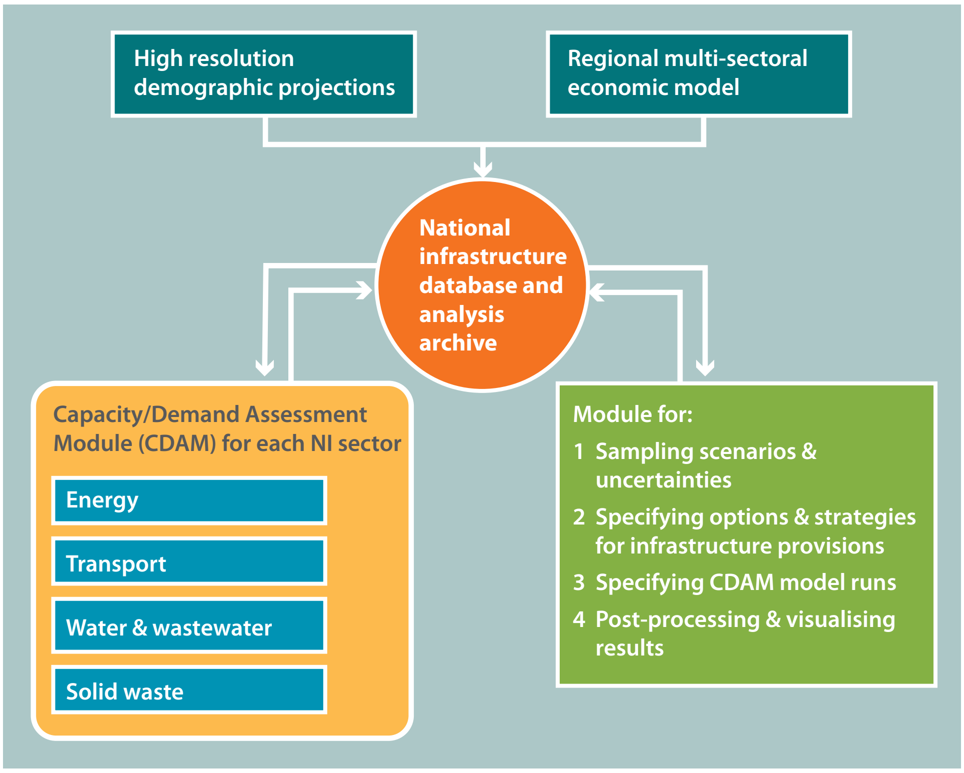


6.2.1.7 Implementation of the integrated assessment

These models will be coupled in an overall simulation framework in which the main scenario uncertainties are extensively sampled, expanding upon the small number of scenarios analysed in the FTA. A set of infrastructure investment options will be developed for each sector and assembled flexibly into cross-sectoral packages, representing a major extension of the three transition strategies analysed in the FTA. New tools will be developed to explore and visualise the results of the analysis.

The interaction between this overall modelling system and the NI database being developed in Work Stream 4 (WS4) is illustrated in Figure 125. The WS4 database, which is built using an open source spatial database architecture, already contains more than 300 different layers of infrastructure and demand data and is rapidly expanding.

Figure 125: Structure of the system of assessment models and databases now under development in Work Streams 1 and 4 of ITRC ICT is excluded from the capacity/demand model development as the FTA has illustrated that new capacity is being provided for the foreseeable future and demand is very sensitive to unforeseen technological developments.



6.2.2 RESILIENCY AND RISK EVALUATION

The FTA has not examined in any depth the risks of infrastructure failure and the ways in which interdependence between infrastructures may exacerbate those risks. This topic is the focus of ITRC Work Stream 2 (WS2). Given the severe long term threats posed by climate change, WS2 has begun by focussing upon climate-related hazards, though opportunities to extend to other natural hazards and man-made hazards will be explored later in the research programme. Spatially coherent probabilistic scenarios of extreme climate related hazards and their associated uncertainties are being developed. Working with our industrial partners and building upon previous studies, WS2 will characterise the vulnerability and interdependence of energy, transport, water, waste and ICT systems.

Central to WS2 will be the development and testing of network models for analysis of interdependent NI failure and risk. Quantification of the direct consequences of infrastructure failure will use the economic and demographic scenarios developed in WS1. The indirect economic consequences of failure and recovery will be analysed at regional and national scales using an input-output modelling approach. Results will be presented as a range of metrics of vulnerability and risk.

ICT

Whilst ICT capacity will not limit the growth of the physical infrastructures, there are risks of cascading failure that will be explored in future research. The danger of malicious attack on infrastructures (e.g. energy) via ICT presents a serious threat (cf. Iranian story (Nicol, 2011)). The risks associated with ICT arise from the interdependencies between ICT and the physical NI systems. ITRC will study chains of failures and make proposals as to how the risks can be reduced. While the progress of ICT opens up new possibilities (e.g. air traffic control systems make it possible to fly more aircraft safely through the same airspace), the dependability of such systems and strategies for addressing failures must be analysed, which will be undertaken by the ITRC in future research.

6.2.3 INFRASTRUCTURE AS A COMPLEX ADAPTIVE SYSTEM

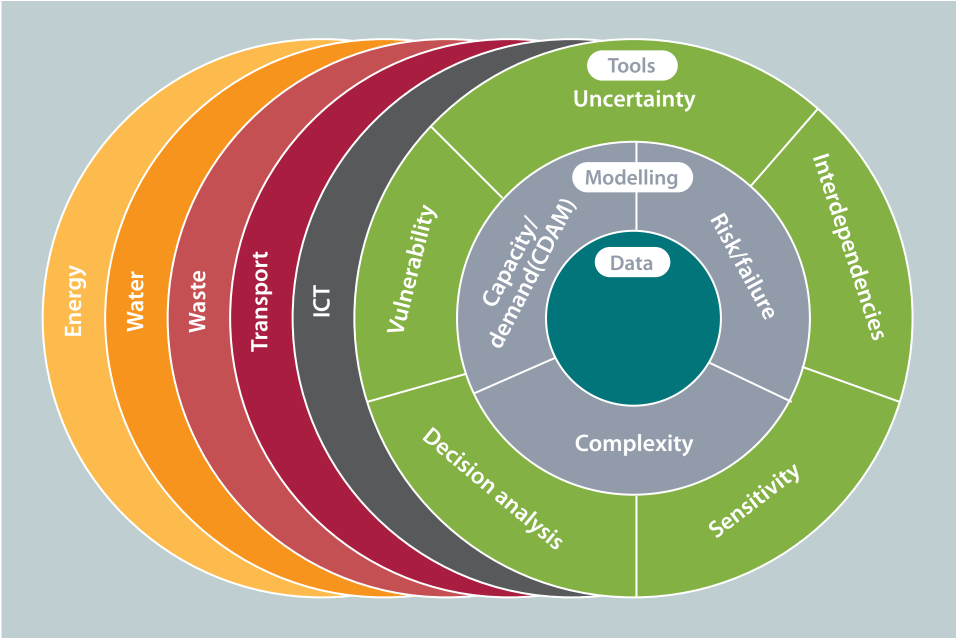
Scoping of Work Stream 3 (WS3) is now under way, exploring a variety of complex systems approaches to simulate and interpret the long term interactions between infrastructure, society and the economy. The research in WS3 will start with exploratory simulations of synthetic examples and work up to more realistic models. Complex systems methodologies under examination include land use and transport spatial interaction models, dynamic network models and a variety of methods in evolutional economics. The most promising approaches will be tested in order to identify patterns of emergence and to understand how in the real world these new insights may be used to steer NI systems towards sustainable outcomes..

6.2.4 DEVELOPING ENABLING TOOLS

Work Stream 4 of the ITRC research programme is developing tools to support the model development activities elsewhere in the consortium. One such tool is the implementation of national scale spatial database to map the location and represent the properties of infrastructure assets and networks within the UK. This database will also explicitly represent the interdependencies that exist between infrastructure assets and networks to facilitate analysis by the simulation models developed in ITRC.

Future planned phases of development of the spatial database include: (i) full integration of project partner data on NI resources into the database (where feasible); (ii) development of interdependent NI network models in the database for simulation modelling; (iii) integration of spatial fields of current day and future predicted hazards including flooding, wind and heat; (iv) development of a suite of user interface tools for analysis, simulation and visualisation of the database contents.

Figure 126: An illustration of the central role data plays in ITRC. Data is pivotal to providing any of the suite of tools required to assess the current and future state of national infrastructure.



6.3 TIMESCALE FOR DELIVERY

At the same time as the FTA, work has begun in 2011 in all of the other Work Streams:

Work Stream 1:

- The methodological framework for WS1 has been established and the modelling components that will fit within this framework have been specified.
- A working simulation architecture for interaction between distributes assessment modules and the WS4 spatial database has been established.
- A PhD project on long term appraisal of the benefits of interdependence is under way.

Work Stream 2:

- Methodological development in WS2 has begun, building upon several recent projects on infrastructure resilience.
- PhD projects on reliability of ICT systems and resilience of interdependent networks are under way.

Work Stream 3:

- A scoping study of complex systems issues and methodologies to address in WS3 is under way.
- A PhD project on evolutionary economics is under way.

Analysis of governance arrangements for infrastructure provision is also under way, building upon the governance analysis presented in the FTA.

The first phase of development of the Work Stream 1 models is due to be completed in March 2013. These models will be used to conduct a much more complete and quantified national analysis of infrastructure transition strategies than has been feasible in the FTA. Our aim is to build upon the cooperation with partners in government and industry that was established in the FTA so that the second cycle of NI assessment further deepens our processes of co-producing knowledge. This co-production process will help to ensure that our research is directly addressing the UK's infrastructure challenges, whilst also being recognised internationally for research excellence and impact. This second cycle of national infrastructure assessment is due to be delivered at the end of 2013.

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Glossary

ABP	Associated British Ports
AD	Anaerobic digestion
APC	Air pollution control
ATT	Advanced thermal treatments (including eFw, gasification, plasma arc gasification, pyrolysis
BAA	British Airports Authority
BIS	Department for Business Innovation & Skills
BMW	Biodegradable municipal waste
BOD	Biochemical oxygen demand
C&D	Construction & demolition waste
C&I	Commercial and industrial waste
CAPEX	Capital expenditure
CAR	Compound annual growth rate
CCC	Committee for Climate Change
CCGT	Combined cycle gas turbine
CCS	Carbon Capture and Storage
CERT	Carbon Emissions Reduction Targets
CESP	Community Energy Saving Programme
CGEN model	Combined gas and electricity network model
CHP	Combined heat and power
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CPF	Carbon Price Floor
CST	Council for Science and Technology
DECC	Department of Energy and Climate Change
Defra	Department for Environment Food and Rural Affairs

DfT	Department for Transport
DNO	Distribution network operators
DSM	Demand Side Management
DUKES	Digest of UK Energy Statistics
DWI	Drinking Water Inspectorate
DWQR	Drinking Water Quality Regulator for Scotland
EA	Environment Agency
EC	European Community
EfW	Energy from Waste
ELV	End of life vehicle
EPBD	Energy Performance of Buildings Directive
EQS	Environmental Quality Standards
ESD	Energy Services Directive
EU	European Union
EU-ETS	EU Emission Trading Scheme
EV	Electric vehicle
FiT	Feed-in-tariff
FPL project	Future Price Limit project
FTA	Fast Track Analysis
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIB	Green Investment Bank
GLONASS	Russian owned GPS
GNSS	Global Navigation Satellite Systems (US-owned GPS)
GPS	Global Positioning System
HEV	Hybrid electric vehicle
HS2, HS2+	High speed rail projects
HVO	Hydrogenated vegetable oil
ICE	Institution of Civil Engineering
ICE	Internal combustion engine
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
IT	Information technology
ITRC	Infrastructure Transitions Research Consortium
ITS	Intelligent transport systems
IUK	Infrastructure UK, part of HM Treasury

LATS	Landfill Allowance Trading Scheme
LCNF	Low Carbon Network Fund
LCPD	Large Combustion Plant Directive
LDM	DfT Long Distance Model
LFG	Landfill gas
LNG	Liquid natural gas
LOLE	Loss of load expectation
MARKAL model	UKERC energy model
MBT	Mechanical Biological Treatment Facility
MDM-E3	Multisectoral Dynamic Model – Energy-Environment-Economy
MHT	Mechanical Heat Treatment Facility
Ml/d	Mega-litres per day
MRF	Material recovery facility
MSW	Municipal solid waste
Mt	Mega-tonne
MW	Megawatt
NETS	National Electricity Transmission System
NGO	Non-government organisation
NMF	Network Modelling Framework
NOx	Nitrous oxides
NRTS	National Rail Travel Survey
NRW	Non-revenue water
NTM	National Transport Model
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
Ofcom	Office of Communications (communications regulator)
Ofgem	Office of Gas and Electricity Markets (energy regulator)
Ofwat	The Water Services Regulation Authority
ONS	Office of National Statistics
OPEX	Operational expenditure
ORR	Office of Rail Regulation
PFI	Private Finance Initiative
PHEV	Plug-in hybrid electric vehicle
PRP	Periodic Review Process
PV	Photovoltaic
R&D	Research and Development

RCV	Regulated Capital Value
RCV	Refuse collection vehicle
RO	Renewable Obligation
SEPA	Scottish Environmental Protection Agency
SRF	Solid recovered fuel
TEU	Twenty-foot (container) equivalent unit
UKCS	UK Continental Shelf
UKERC	UK Energy Research Centre
V2G	Vehicle to Grid
VOLL	Value of lost load
WASP model	Wien Autonomous System Planning
WEF	World Economic Forum
WFD	Waste Framework Directive
WID	Waste Incineration Directive
WIDP	Waste Infrastructure Development Programme
WRAP	Waste and Resources Action Programme

Capacity of infrastructure services	The extent and amount of activities that may be enabled.
Demand for infrastructure services	The amount and extent of actions enabled by infrastructure services that consumers seek to conduct
Infrastructure	The collection of all physical facilities and human systems that are operated in a coordinated way to provide infrastructure services
Infrastructure Services	The provision of an option for an activity by operating physical facilities and accompanying human systems to convert, store and transmit flow entities
National Infrastructure (NI)	CST (2009) and Infrastructure UK (HM Treasury and Infrastructure UK, 2010b) adopted approach based on the five sectors and networks that directly contribute to the economic growth by providing infrastructure services. Composed of the five economic infrastructure sectors of energy, transport, solid waste, wastewater, water, and information and communication technology (ICT)
Scenario [planning]	"…a strategic planning process that generates multiple stories about possible future conditions, allowing an organization to look at the potential impact on them and different ways they could respond." (Stamatis, 2003)

Scenarios	"…stories about the future, a way to understand the impact of conditions… [and] focus on the external world and the implications of alternative futures for the policies being considered." (Bodde, 2007) "…stories… of what might be. Decision makers use them to evaluate what to do now, based on different possible futures. The options for the future reflect either an extrapolation of current trends or introduced changes, such as policies and management plans… [and] they are most appropriate under conditions where complexity and uncertainty are high." (Schoemaker, 1993; Wollenberg *et al.*, 2000)
Supply of infrastructure services	The amount and extent of actions that are actually enabled
Transition Strategy	Cross-sectoral strategic plans composed of sequenced sector-specific governance and technology options for national infrastructure oriented towards distinct aims

UK INFRASTRUCTURE TRANSITIONS RESEARCH CONSORTIUM

The UK Infrastructure Transitions Research Consortium is informing the analysis, planning and design of national infrastructure, through the development and demonstration of new decision support tools, and working with partners in government and industry.

The research is taking a national-scale 'system of systems' approach which integrates energy, transport, water, waste and ICT (Information and Communications Technologies) infrastructure.

FAST TRACK ANALYSIS

In its first year, the ITRC has begun the development of a new generation of simulation models for national infrastructure assessment that will be ready for piloting in 2013. In parallel the ITRC has undertaken a Fast Track Analysis (FTA) in order to:

1. Ensure that the ITRC research programme is building upon existing knowledge.
2. Review and refine the scope of the ITRC research.
3. Pilot and communicate new analysis concepts.
4. Strengthen the relationship between the research team and the consortium's partners in government and industry.

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