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## **Title: Strategic analysis of the future of national infrastructure**

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## **Abstract**

There have been many calls for a more strategic, long-term approach to national infrastructure in the UK and elsewhere around the world. Whilst appealing in principle, in practice developing a national infrastructure strategy poses major challenges of complexity and uncertainty. The UK Infrastructure Transitions Research Consortium (ITRC) has set out a systematic methodology for long term analysis of the performance of national infrastructure systems, which deals with each infrastructure sector (energy, transport, digital communications, water supply, waste water, flood protection and solid waste) in a consistent framework and assesses the interdependencies between infrastructure sectors. The methodology is supported with the world's first infrastructure system of systems model (NISMOD), which has been developed for long term decision analysis in interdependent infrastructure systems. This paper presents the application of NISMOD to analysis of the national infrastructure strategy that has been developed in the National Needs Assessment led by ICE President Sir John Armitt.

## **Keywords**

Infrastructure planning, Economics and finance, Mathematical modelling, Sustainability

## **The challenges for national infrastructure in the UK and globally**

National infrastructure systems form the basis for a society's economic and human wellbeing and environmental sustainability. These systems, which include energy, transport, digital communications, water supply, waste water, flood protection and solid waste, require very significant capital investments that have long lead-times and life-times. Building infrastructure is a long-term commitment that is very difficult to reverse, which means that infrastructure decisions have major implications for sustainability, notable mitigation of carbon emissions and adaptation to the impacts of climate change.

Governments in advanced economies worldwide have to cope with an aging stock of infrastructure that must cope with growing needs from people and the economy. Meanwhile, in emerging economies major infrastructure investments are presently being made that will lock in patterns of development for decades to come. Least developed countries struggle with the greatest deficit in infrastructure provision, including basic energy, water and sanitation services and transport connectivity that, were it present, would enable trade and growth. Overall, Standard & Poor's (S&P) and McKinsey estimate that \$57 trillion, or \$3.2 trillion a year, will be needed to finance infrastructure development around the world over the next 15 years.

Infrastructure is the second pillar of the World Economic Forum's (WEF) Global Competitiveness Report. Britain was ranked 10<sup>th</sup> for infrastructure in the WEF league table in 2014/15, behind France (8<sup>th</sup>), Germany (7<sup>th</sup>), but ahead of the USA (12<sup>th</sup>). The American Society of Civil Engineers' 2013 Report Card for America's Infrastructure estimated that \$3.6 trillion is needed for America's infrastructure by 2020. The ICE's State of the Nation Infrastructure assessment in 2014 gave Britain's infrastructure the following grades: energy C-, strategic transport B, local transport D-, flood management C-, water B and waste C+. The report cited evidence of lack of resilience to extreme events and weak commitment in the transition to low carbon infrastructure networks.

In recognition of these challenges, the UK has been developing a more systematic approach to national infrastructure. Infrastructure UK was created within HM Treasury in 2010, publishing annual

National Infrastructure Plans between 2011 and 2014. In 2013 Sir John Armitt led an independent review of long term infrastructure planning, recommending the creation of a National Infrastructure Commission, a proposal that was strongly supported by the ICE. The creation of the National Infrastructure Commission (NIC) was announced by the Chancellor of the Exchequer in 2015. The NIC is chaired by Lord Andrew Adonis and charged with carrying out a National Infrastructure Assessment by the end of the current parliament. To pave the way for the NIA, Sir John Armitt has launched a National Needs Assessment (NNA), which is developing an in-depth analysis of the future needs for infrastructure services and an independent vision for what the UK's infrastructure systems should look like decades in the future.

## **National infrastructure assessment**

Whilst there are well established investment planning methodologies in some infrastructure sectors, conducting cross-sectoral national infrastructure assessment (NIA) raises challenges that have only very recently been addressed by new methodology and 'system of systems' simulation models (Hall et al., 2016). The two most difficult challenges for NIA are (i) complexity and (ii) uncertainty. Complexity arises from the number of 'moving parts' in the national infrastructure system of systems, and the interdependency between different sectors. Dealing with complexity requires a rigorous conceptual framework and a common set of assumptions which can be applied across infrastructure sectors.

Uncertainty means that any deterministic masterplan for infrastructure investment would be vulnerable to unexpected future changes. Many of the factors that influence the future demand for infrastructure services, including population, economic growth and technology, are highly uncertain. An assessment framework should therefore be based around the development of adaptable strategies, whilst at the same time providing a clear sense of direction and confidence that long term targets, for example for carbon emissions, can be met.

The framework for NIA that we have developed (Hickford et al., 2015) (Figure 1) uses *scenarios* to explore uncertainty in a range of possible futures: the global and national economy; population/demography at national and local scales; climate change; technological development. These scenarios explore the possible range of contextual factors that are largely outside the control of decision makers responsible for national infrastructure. Of course there are feedbacks between the infrastructure system and these factors, notable in terms of regional economic development: provision of infrastructure can stimulate the economy, provide new employment opportunities and hence change where people live. These feedbacks are important to recognise but are also much more difficult to quantify (Venables et al., 2014) – attempting to model them would introduce additional complexity that for the time being we consider to be unwarranted. We prefer to explore the possible impacts of infrastructure investment on regional economies by using scenarios that test the possibility of additional growth being stimulated by infrastructure provision.

Alongside scenarios, our framework for NIA explores one or more infrastructure *strategies*. Strategies are sequences of infrastructure investments and policy/regulatory interventions that are intended to modify demand for, or provision of, infrastructure services. Strategies must be sufficiently adaptable to cope with uncertain scenarios, for example of population growth. On the other hand, a national infrastructure strategy must give a clear sense of direction about what

policies and investments need to be implemented, where and when. These are the big political choices. In the end these choices largely boil down to political judgements in three areas:

1. **How much are we prepared to invest in infrastructure?** For the time being, public and private investment in national infrastructure is 2.8% of GDP in the UK, compared to an OECD target of 3.5% of GDP (House of Commons, 2015). The cost of these investments has to be recovered sooner or later, via a combination of user tariffs and taxation. Infrastructure that is financed by borrowing will bequeath debt, as well as infrastructure assets, to future generations.
2. **How prepared are we to commit to policies to manage demand for infrastructure, such as road user charging, compulsory smart metering or building regulation?** Demand management strategies can improve the efficiency of infrastructure provision, often at a relatively low financial cost, but they can come at a high political price and may suppress economic activity.
3. **How do we wish to balance the different objectives for infrastructure?** For a given level of investment there are many trade-offs to be made (and potential synergies to be sought) concerning the quality, reliability and resilience of infrastructure services for the economy and society, alongside the environmental impacts of infrastructure (for example in terms of carbon emissions and pollution of air and water). Likewise, trade-offs have to be negotiated about the balance of provision between different regions.

Setting the overall vision for national infrastructure involves making political decisions on each of these dimensions. A high quality, low cost, environmentally friendly infrastructure system that doesn't involve unpalatable new regulation of demand unfortunately does not exist. Hard political choices have to be made. The NNA's vision for national infrastructure is that *"The UK will invest efficiently, affordably and sustainably in the provision of infrastructure assets and services to drive the economic growth necessary to enhance the UK's position in the global economy, support a high quality of life and shift towards a low carbon future."*

That overall vision implies a broad strategic direction for each infrastructure sector, however, a series of choices is needed to establish which combination of investments and policies should be implemented to deliver it. It is at this stage that quantified analysis is most needed to demonstrate that the proposed interventions will deliver the requisite performance in given scenarios. To quote the late David McKay's book on sustainable energy (McKay, 2008) "Make sure your policies include a plan that adds up!" Analysis of system performance needs to take place at a range of future timescales (years and decades ahead) and on appropriate spatial and temporal scales, e.g., distinguishing between 'peak' and 'off peak' demands in energy and transport to demonstrate the benefits of demand management and energy storage.

Analysis, supported by models, is also required to deal with cross-sectoral interdependencies. Though there are many interdependencies, from an infrastructure assessment and planning perspective, the interdependencies that matter most are when (i) demand for one infrastructure sector is highly correlated with demand for another (e.g. domestic demand for water and energy) and/or (ii) when one infrastructure sector can potentially consume a significant proportion of the capacity of another, notably in power generation, which is responsible for 40% of non-tidal surface water abstractions (Byers et al., 2014). Another instance of the latter type of interdependence would

become critical if there were to be largescale uptake of electric vehicles, which could eventually use more than 15% of electricity generation in 2050.

Appraisal of alternative strategies, in the context of given scenarios, is done based on projected values of a small set of relevant metrics, which include: the amount of infrastructure service the system could deliver; the margin between system capacity and projected system use, which gives a metric of reliability; the capital and operation costs of the system and; metrics of environmental impacts, including carbon emissions. These metrics provide the basis for choosing between alternative strategies. They will vary geographically and through time. They will also depend on the scenarios considered, so judgements will be required about the acceptable level of performance and the range of scenarios over which that performance is sought (Otto et al., 2014). The National Infrastructure Assessment cannot answer these questions, however it should appraise the possible performance of alternative strategies to enable informed decision making.

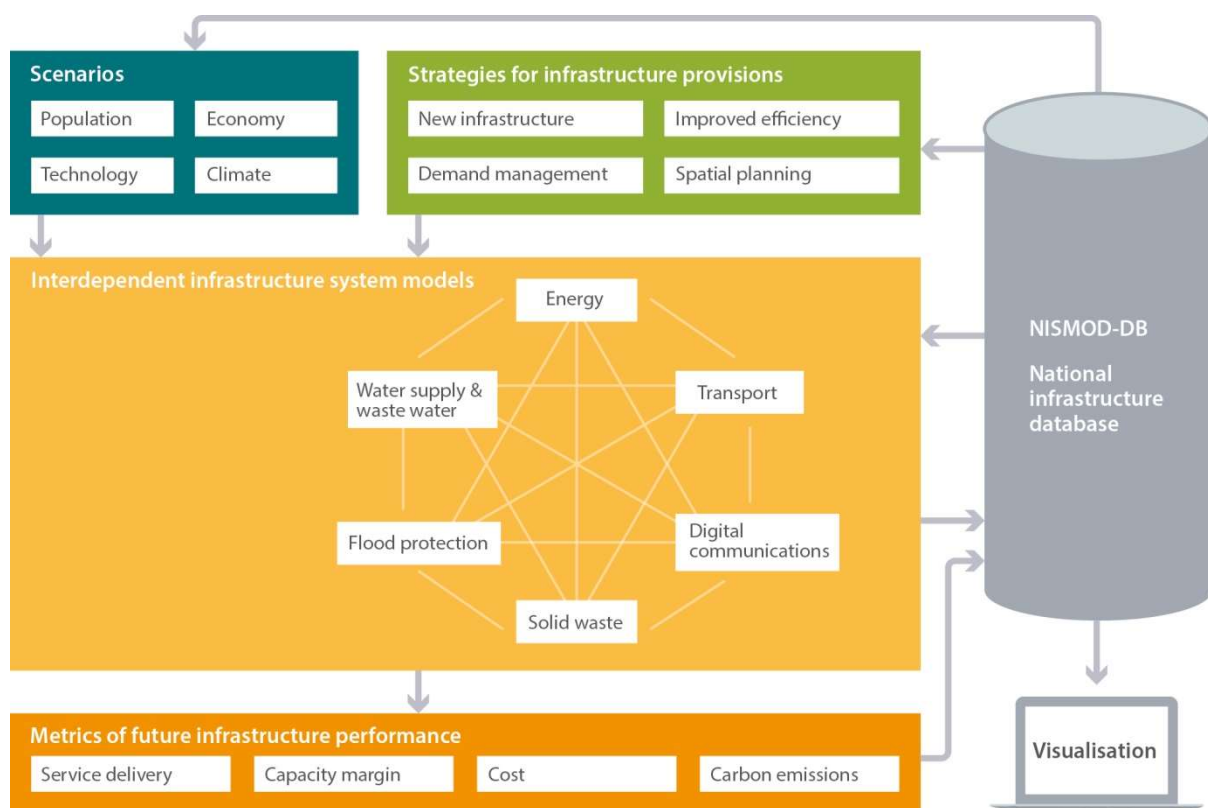


Figure 1 Schematic overview of the use of NISMOD for national infrastructure assessment

## NISMOD: National Infrastructure Systems Model

Whilst there have been many calls for a strategic approach to infrastructure provision, at present, a substantial, specific and forward looking cross-sectoral strategy has not yet been developed in any country worldwide. One reason for this lack of strategic analysis is the lack of methodology to develop long-term cross-sectoral strategies and the lack of models and tools to analyse infrastructure strategies. We believe that a national infrastructure assessment cannot be implemented without the benefit of some form of systems modelling to rigorously address the challenges of complexity and uncertainty.

The UK Infrastructure Transitions Research Consortium (ITRC) was launched in 2011 with the aim to develop and demonstrate a new generation of simulation models and methods to inform analysis, planning and design of national infrastructure systems. The ITRC was backed by £4.7 million of funding from the Engineering and Physical Sciences Research Council (EPSRC) and has recently been awarded a further £5.3 million to continue the research programme through to 2020.

During the first five years of research, the ITRC developed the National Infrastructure Systems Model (NISMOD), which was designed to provide the evidence to inform national infrastructure assessment (Hall et al., 2016). The structure of NISMOD is illustrated in Figure 1 and each component is briefly summarised in Table 1. Infrastructure and scenario data are held in a shared national infrastructure database, NISMOD-DB. That rigorous structure enables each combination of scenarios and strategies to be accessed and scrutinised. Visualisation functions enable presentation of maps, time series and other graphics. Additionally optimisation routines enable combinations of interventions to be developed that meet specified objectives or are subject to given constraints.

Table 1 Summary of the main module of NISMOD<sup>1,2</sup>

Module	Brief description	Interdependence represented in NISMOD-LP
Population projections	ONS population projections extended to Local Authority District scale	Consistent scenarios are used for all infrastructure sectors.
Economic projections	Cambridge Econometrics multi-sectoral model of the UK economy	
Climate projections	UKCP09 climate projections and Future Flows projections of GB river flows	
Technological projections	Factors for calculating infrastructure demand in each sector include the effects of technological and behavioural change.	
Strategies for infrastructure provision	Strategies can be programmed as (i) a pre-determined list of infrastructure investments and/or policy interventions (ii) a set of rules that implement investments/interventions subject to given criteria or (iii) an optimisation problem that maximises/minimises an objective function subject to constraints.	Coherent strategies are developed across infrastructure sectors.
Energy systems	Model GB electricity supply and transmission, coupled with model of gas storage and transmission	Electricity demand from electric vehicles, rail electrification and information/communications technologies
Transport systems	Road and rail passenger demand estimated at Local Authority District scale. Congestion estimated at inter- and intra- zone scale. Passenger and freight projections for ports and airports.	
Digital communications	Fixed and mobile connectivity analysed for Local Authority Districts, based upon population density, socio-economic status and topography (for mobile).	
Water supply	Demand for public and industrial water supply estimated for Water Resource Zones. Surface water availability from Future Flows; groundwater based on existing supplies. Simulation of storage, transfers and other sources (e.g. desalination)	Demand for cooling water from thermo-electric power generation
Waste water	Projection of domestic sewage based on population projections. Analysis of waste water treatment plant capacity.	
Flood protection	National analysis of risk from river and coastal flooding. Flood defence investments reduce flood risk.	
Solid waste	Projections of municipal solid waste arising calculated at the Local Authority District Scale and allocated to collection services and treatment, recycling and/or disposal infrastructure	Energy from waste (incineration and biogas)
Metrics of infrastructure performance	Capacity margin (infrastructure use / available capacity, averaged spatially), total service delivery, cost (capital operation) and greenhouse gas emissions calculated for each infrastructure sector; plus other sector-specific metrics.	Consistent metrics used across infrastructure sectors
Database	National infrastructure database containing all infrastructure asset data and simulation model inputs and outputs	
Visualisation	Maps, graphs and other statistical tools, coupled with the database.	

<sup>1</sup>See Figure 1 for colour coding<sup>2</sup>For further information see Hall et al. (2016). For flood protection see Environment Agency (2014) and Sayers et al. (2015)

## Populations and economic scenarios for Britain

Future needs for infrastructure services are driven in part by how population and the economy may change in future, so it is important to base infrastructure assessment on a common set of scenarios that spans the range of future possibilities. The population scenarios used in NISMOD are based on Office of National Statistics projections through the 21<sup>st</sup> Century, downscaled using NISMOD to Local Authority District scale (

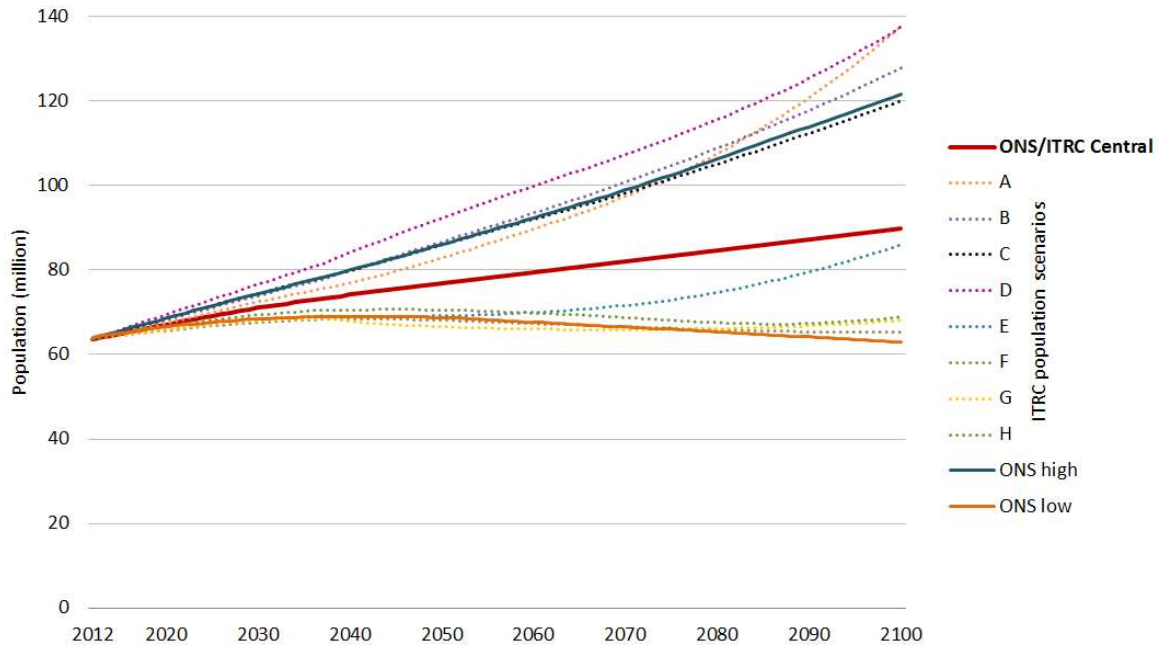


Figure 2), to enable projections of how the demand for infrastructure services could vary geographically. Figure 3 illustrates the range of regional variations in population that was chosen to stress test possible national infrastructure strategies. NISMOD's economic scenarios are based on Cambridge Econometrics' multi-sectoral model of the UK economy, which generates projections of industrial output, Gross Value Added and employment, thus helping to explore the range of possible economic demands for infrastructure services.

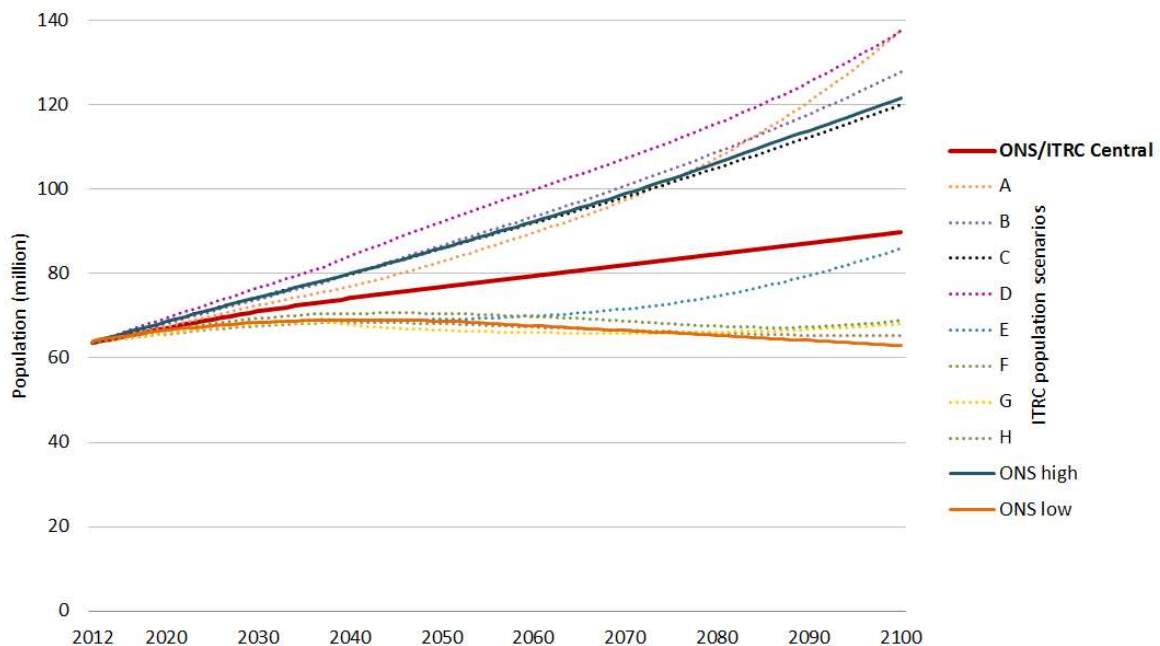


Figure 2 NISMOD scenarios of national population



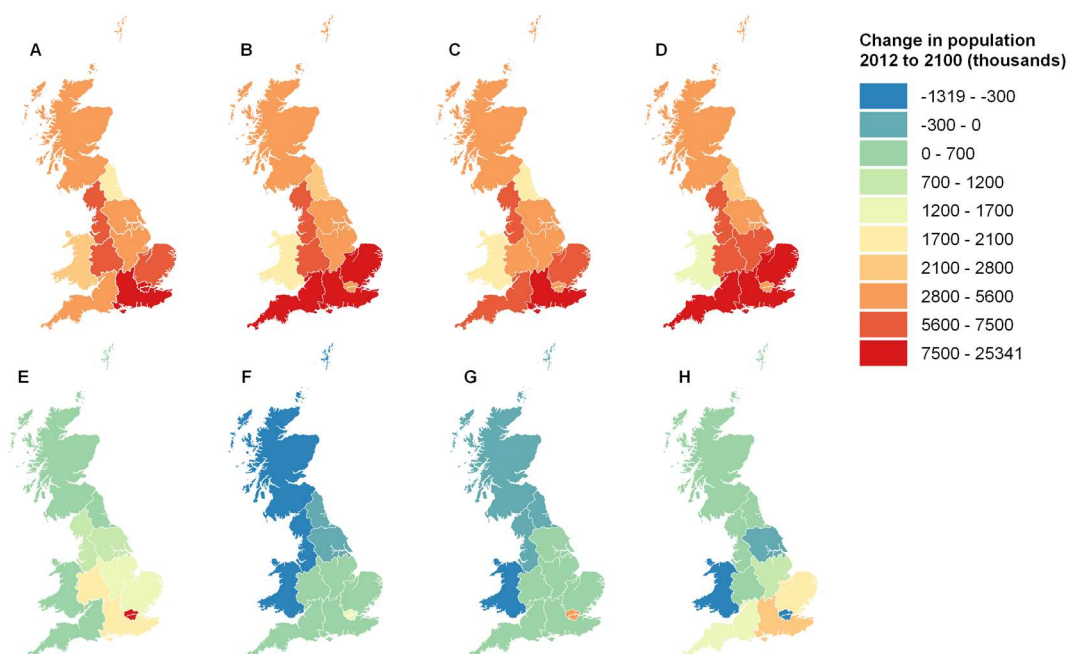


Figure 3 NISMOD scenarios of regional population change

## Sector strategies in the National Needs Assessment

NISMOD contains planning models for energy (electricity and gas), transport (road, rail, ports, airports), digital communications, water supply, flood defence, waste water and solid waste (Table 1), including interdependencies between these infrastructure sectors. Each of these planning models contains a module for estimating the demand for infrastructure services, given the population and economic scenarios and policy choices, which determine the demand elasticity in each infrastructure sector. Spatially resolved system models then simulate how those demands might be met for a given system configuration. This can involve iteration between demand and system simulation, as in the case of the road network, in which congestion feeds back to suppress demand, whilst provision of new road space can release latent demand.

The strategy for the energy sector in the NNA is based upon the UK meeting its carbon target of an 80% reduction in carbon emissions (relative to 1990 levels), which implies almost complete decarbonisation of the electricity system. Vigorous policies to reduce energy demand in buildings (notably for heating and lighting) are cost-beneficial (Frontier Economics, 2015) so are prioritised in the NNA. Innovative arrangements for heating, for example through local heat networks, will help to reduce demand for gas. Electrification of heat and transport, alongside projected population increases, could result in rising demand for electricity (Figure 4), so it is important that low carbon generation capacity is in place first. Distributed renewables (notably photo-voltaic panels) and distributed storage, both of which are rapidly falling in price, can help to mitigate peak demands upon the grid.

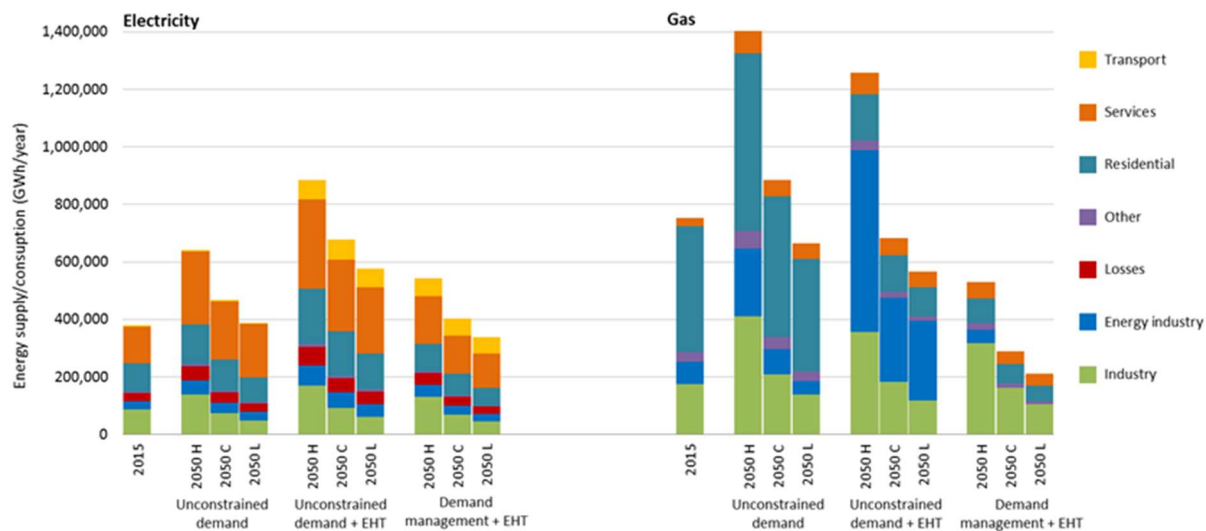


Figure 4 NISMOD projections of energy demand, for high (H), central (C) and low (L) population and economic growth scenarios. EHT is electrification of heat and transport.

Figure 5 illustrates possible low carbon electricity supply portfolios that will meet these demands. This implies rapid scaling up of offshore wind alongside a baseload component of nuclear supply. Combined cycle Gas turbines (CCGTs) fill the supply gap as a transitional fuel and provide backup for intermittent renewables. With North Sea gas reserves projected to run down and domestic shale gas unlikely to be extracted on a scale approaching Britain's needs, additional Liquefied Natural Gas (LNG) import and storage capacity will be required (Figure 6). To meet carbon targets, CCGTs will have to be fitted with carbon capture and storage (CCS), for which a UK system is urgently needed.

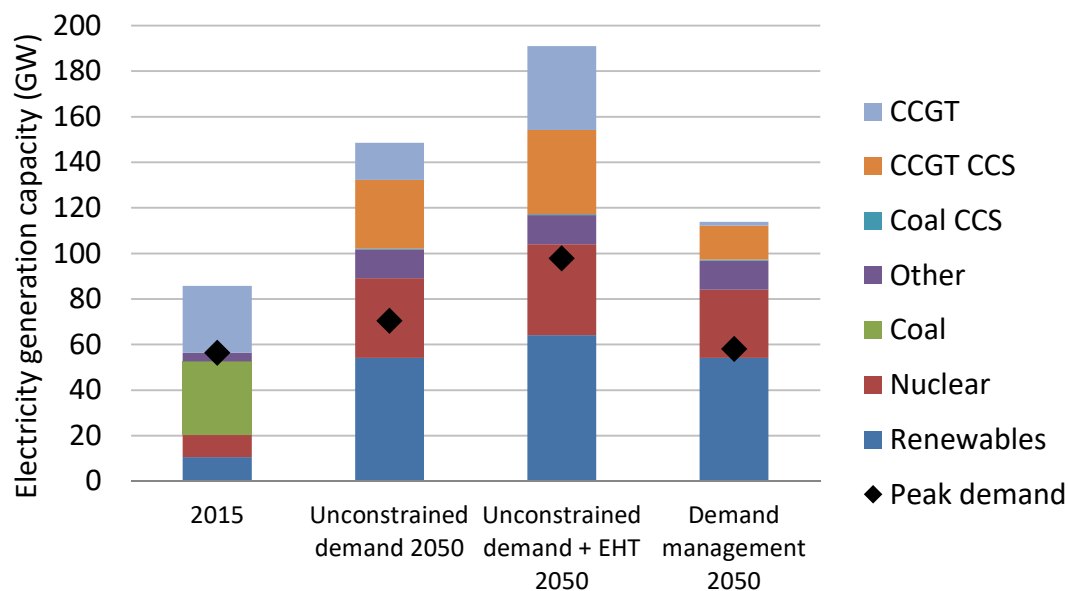


Figure 5 NISMOD analysis of the NNA strategy for electricity generation (central population and economic growth scenario)

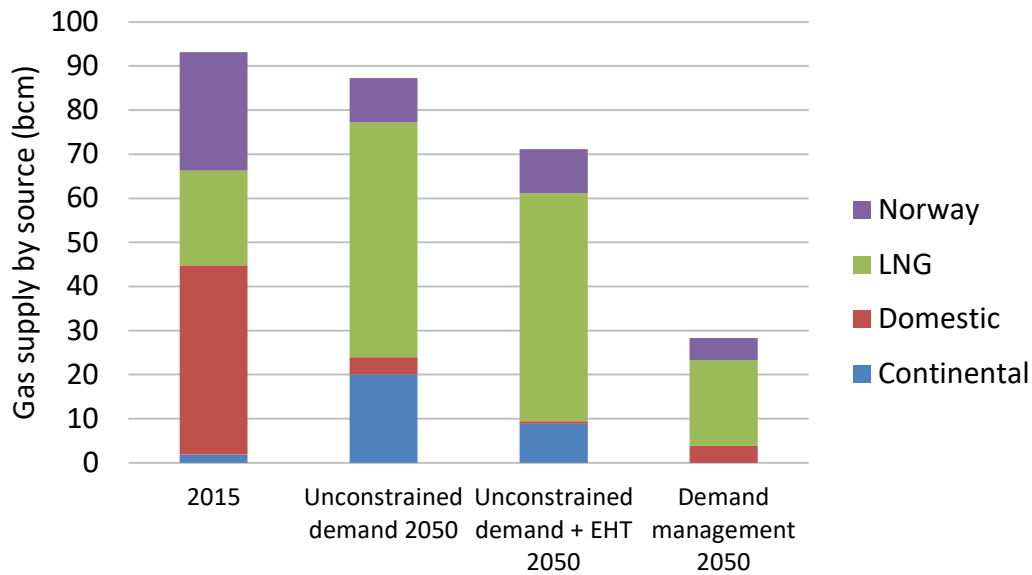


Figure 6 NISMOD analysis of the NNA strategy for gas supply (central population and economic growth scenario)

The strategy for transport in the NNA recognises that meeting unbounded demand for road transport by provision of additional (free) road space would be prohibitively costly and would further stimulate latent demand. Thus a programme of investments to improve capacity and efficiency of the highway network needs to be accompanied by more active intervention to manage demand. The possibility that car ownership and usage may be peaking ('peak car') and decoupling from economic growth (Metz, 2013) should be encouraged through incentives (road user charging) and technology (**Error! Reference source not found.**). The progressive shift from car ownership to purchase of mobility services is expected to render per-use charging more acceptable. In-vehicle technologies, notable autonomous vehicles, will enable more efficient use of the road network, though the scale of these efficiency improvements may be limited by the capacity of junctions and terminal points (Royal Academy of Engineering, 2015). Driverless vehicles may be particularly beneficial in the freight sector, enabling more efficient use of night-time capacity on the highway network.

Continued investment in capacity in the rail network will be essential (see **Error! Reference source not found.**), with the NNA aiming for 15% of all passenger trips to be by rail. This will require capacity improvements at pinch points in the rail network, continued electrification and rolling stock improvements and extension of High Speed 2 to Glasgow and Edinburgh by 2050.

The NNA has also examined urban transport, recognising the productivity returns to investment in connectivity in London (notably via CrossRail 1 and 2) and the relative deficiency of bus and rail provision in several of the UK's major cities, i.e. Birmingham, Manchester, Leeds, Nottingham, Bristol and Belfast. The NNA also recognises the importance of cycling and walking as local transport modes.

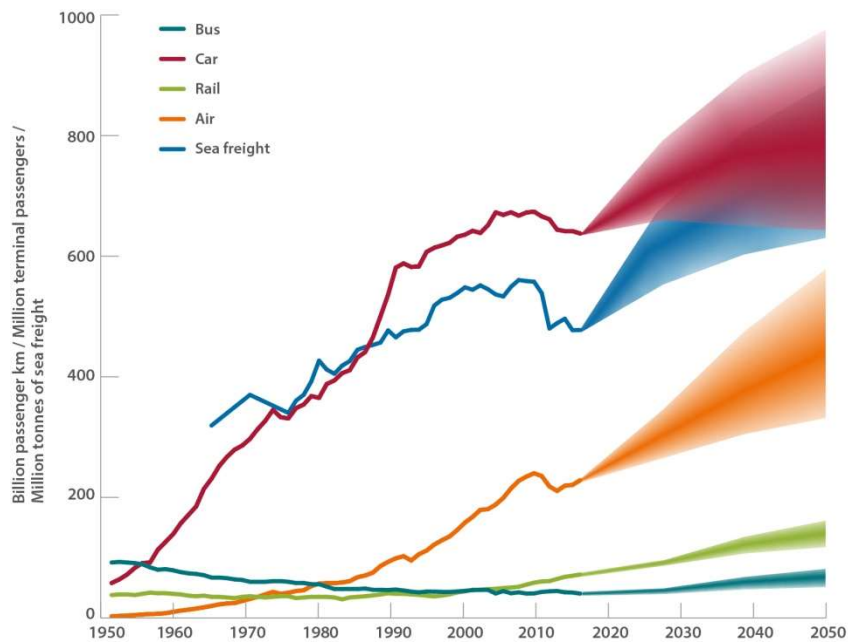


Figure 7 Historic trends and projections of transport usage for NNA transport strategy and central population/economic scenario. Car and air projections are based on DfT forecasts (Department for Transport, 2015, Department for Transport, 2013), but with more aggressive demand management and strong 'peak car' assumptions associated with the lower bound projections for cars

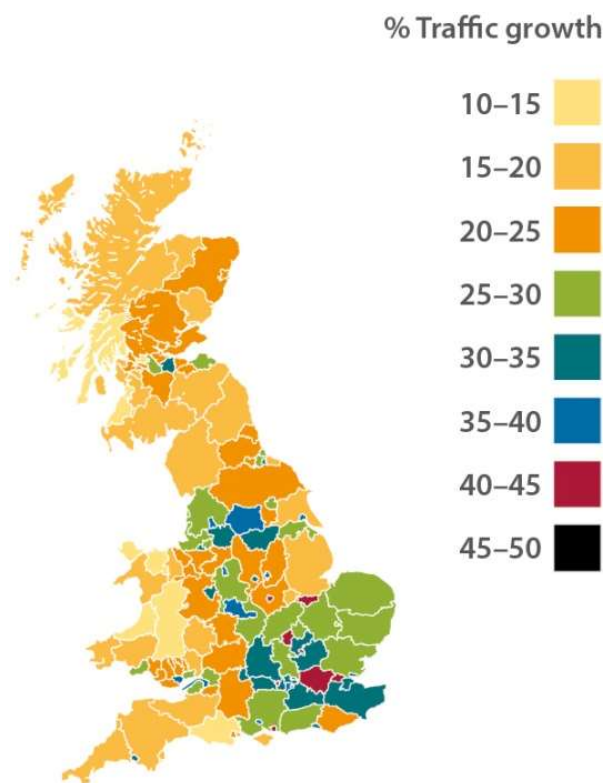
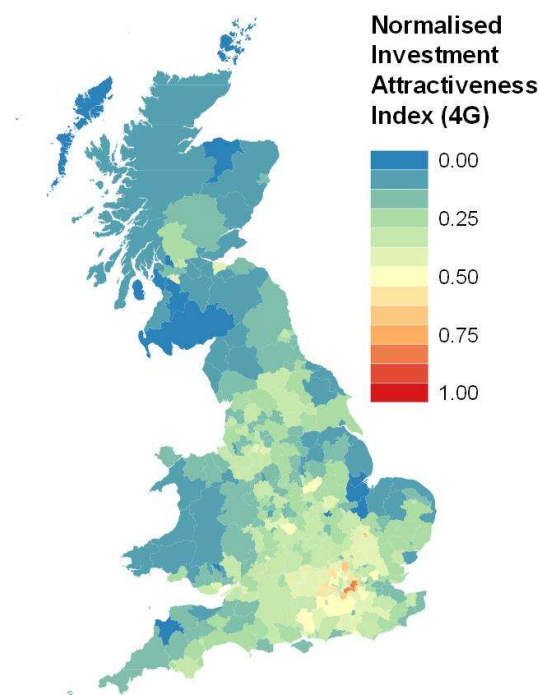


Figure 8 Road traffic growth by 2050 projected by NISMOD at Local Authority District scale for NNA transport strategy and central population/economic scenario

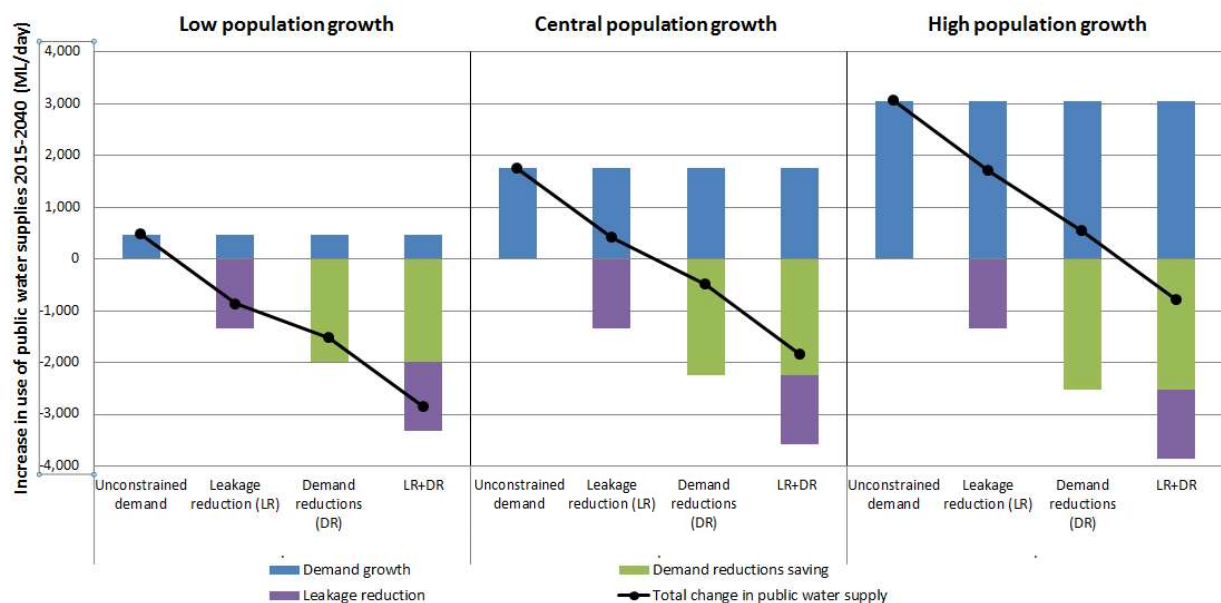
Digital communications systems, including fixed and mobile networks, switching stations and data centres, are providing very rapidly increasing capacity, which is a necessary requirement for the digital economy. Due to rapid innovation, increasing demand and changing structure of the

economy, the future of the digital communications infrastructure system cannot be predicted: We do not know exactly which technologies will be delivered to meet future connectivity needs, but there will almost certainly be a mix of fixed, mobile, wireless and satellite connectivity. The greater bandwidth and lower latency (i.e. shorter delays) that will be delivered by 5G technologies will be needed for new uses like virtual reality and digitally connected cars. . In remote areas where it is not profitable to invest in connectivity (Figure 9), regulatory intervention and state support is necessary to ensure coverage: The Universal Service Obligation (USO) that was announced in 2015 gives people everywhere in the UK the legal right to request a connection to broadband with speeds of 10 Mbps, which will meet needs for web browsing (0.5Mbit/s), video calling (1.5Mbit/s), catch-up TV (2Mbit/s) and High-Definition film streaming (6Mbit/s) (Ofcom, 2015). In the NNA we also examined the costs of Fibre to the Premises (FTTP) provision, which delivers speeds of up to 330 Mbit/s. Total coverage in urban areas would cost between £14.1 billion and £17 billion, depending on the technology, rising to £27.7-£32.8 billion for to also cover rural areas, split on average 80:20 between civil engineering costs and technology costs.



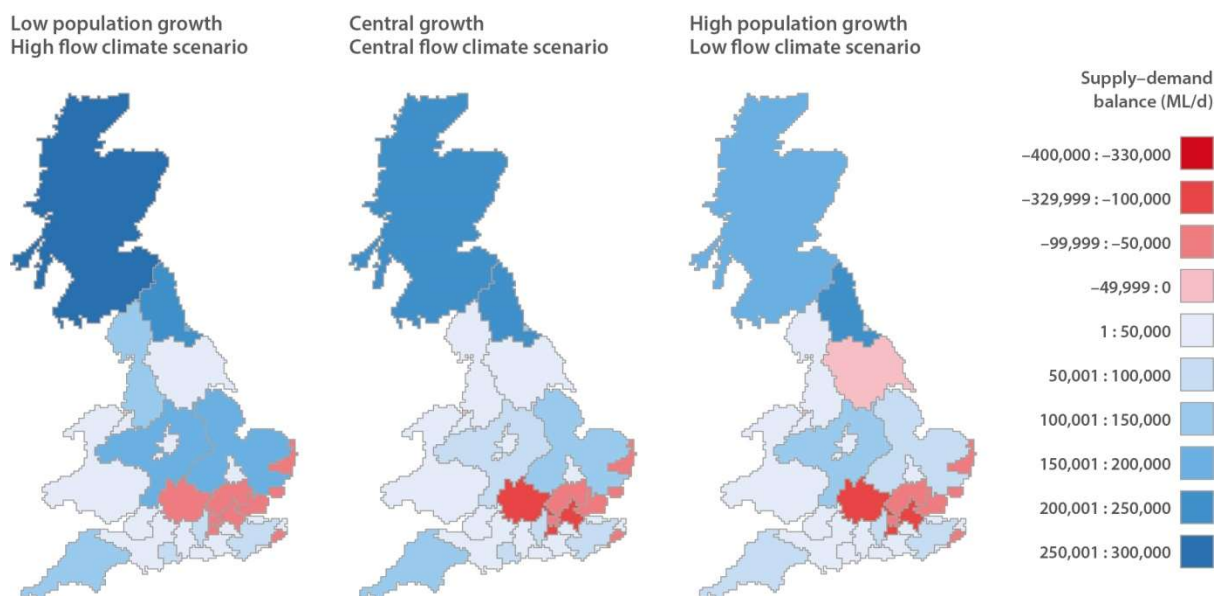
**Figure 9 Attractiveness of investment in 4G mobile communications infrastructure, based on population density, socio-economic status and ground elevation**

Like other infrastructure systems, water supply systems face challenges of increasing population, which will provide upward pressure on demand for public water supplies. There are relatively low cost steps that can be taken to reduce per capita demand to a certain extent. Further reductions in demand and leakage (Figure 10) will be more costly but will be necessary alongside strategic investments in water infrastructure. The NNA envisages leakage being reduced to 14%% of water supplied, compared to an average of 21% at present.



**Figure 10 Projections of changing use of public water supply and the effect of the NNA strategy for water demand management and leakage reduction**

The ambitious reductions in leakage and demand would be sufficient to compensate for the demand growth associated population growth (Figure 10), on average at a national scale. However, the projections vary geographically. Water withdrawals from some water bodies are already unsustainably high, so will be reduced to help preserve the aquatic environment. Climate change adds uncertainty to projections of future water availability. Figure 11 illustrates the projected water supply-demand balance, given the NNA strategy for reductions in per capita water demand and leakage. The NNA recommends increasing strategic transfers of water to address these deficits (which will typically have to be accompanied by storage reservoirs) along with exploitation of groundwater recharge schemes, effluent water reuse and desalination all help to build resilience in the water supply system.



**Figure 11 Projections of supply-demand balance for NNA demand management and leakage reduction strategy**



Waste water treatment systems have seen a wave of investment to improve effluent standards. There has been an ongoing process of centralisation of treatment facilities into larger more efficient plants, which will continue in future in all but the most isolated settlements. More could be achieved in reducing demands placed upon sewer networks by decreasing water use in buildings and reducing storm water discharges into sewers (for example, by installing sustainable drainage systems and separating storm water from sewage). Nonetheless, additional major investments in waste water infrastructure systems will be required to renew treatment facilities, provide services for an increasing population, meet improving standards of wastewater discharges and deal with surface water flooding.

Flood defence infrastructure will need to be extended and upgraded to deal with sea level rise on the coast and the uncertain effects of climate change on river flows. The Environment Agency's Long Term Investment Scenarios (Environment Agency, 2014) are based upon cost-benefit analysis of investment in flood defences in 3000 separate flood systems in England, producing an estimate of an optimal investment sequence costing around £860 million per year, which will see higher standards of protection in urban areas, along with decommissioning of defences in some locations to restore natural catchment and coastal processes. These infrastructure investments should be seen as part of a wider package of flood risk management measures to cease inappropriate development in floodplains (hence the relatively small effect of population in the projections of flood risk in Figure 12) and build resilience to flood events that exceed the standard for flood protection (the 'Extended whole system' approach in Figure 12).

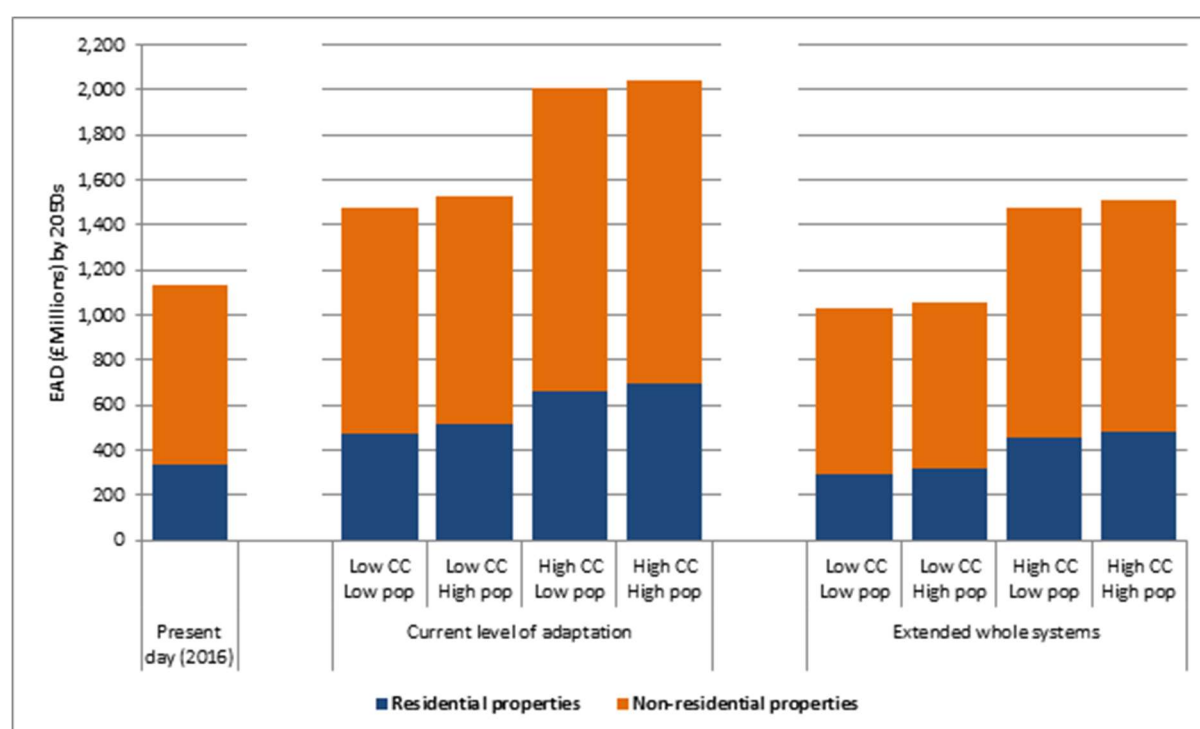


Figure 12 Economic impacts of flooding: present day, current level of expenditure, and an enhanced strategy which takes a 'whole systems' approach to managing flood risk in the most efficient way. "Low CC" and "High CC" denote low and high climate change, corresponding to 2°C and 4°C increases in global mean temperature by the end of the 21<sup>st</sup> Century, respectively (after (Sayers et al., 2015)).

The NNA foresees the circular economy of solid waste recovery and recycling into valuable resources. Additional action is required to ensure recycling of waste streams, so that household

recycling meets the EU target of 50% by 2020 (up from 44.9% in 2014). Increased resource recovery means that there will be some diminution of energy generation from waste at incineration plants, with an increasing proportion of waste being recycled. Meanwhile biological waste will provide a contribution to gas supplies. A potentially synergistic innovation is in mixing solid biological waste with sewage sludge, to increase the efficiency of anaerobic digestion. If waste production can be decoupled from economic growth (there is some evidence that this is already taking place (WRAP, 2012)) then there is already sufficient capacity in waste processing infrastructure and the only infrastructure requirement will be in treatment facility renewal.

## **Conclusions**

The civil engineering industry delivers society's needs for infrastructure. As a profession we need to understand how needs for infrastructure services might evolve in the future and, in response, develop innovative ways to delivering those needs. Analysis with NISMOD for the NNA has demonstrated the scale of demand for infrastructure services in future. Population and economic growth provide strong upward drivers of demand. There are some signs that demand for infrastructure services (e.g. energy, mobility, water, solid waste) may be decoupling from growth – but policies to manage demand will have to be more effective than at present for overall demand to be reduced or at least remain level. Meanwhile, technological innovation in information and communications technologies is driving up demand for digital bandwidth. Thus, investment in new capacity is required, in particular in the southeast of Britain where growth is strongest. The NNA also emphasises the contribution that new infrastructure can make to unlocking growth elsewhere in the UK, by providing improved transport and digital connectivity which enhances trade, improves access to labour markets and stimulates innovation.

Meanwhile, reliable energy, water, waste water, solid waste and flood protection services are essential to the smooth running of the economy and a sustainable environment. The ICE has long recognised the importance of improving the resilience of infrastructure to shocks, be they from natural hazards or man-made threats (ICE, 2009). The NISMOD-RV (Risk and Vulnerability) model, which has not been described here, analyses the risks of infrastructure failure, so can help make the case for investment in resilience (Thacker et al., in press).

The NISMOD national infrastructure systems model provides the capacity to rapidly analyse alternatives and compare them based on a consistent set of metrics. We foresee this process of national infrastructure assessment becoming progressively more open and inclusive, so that different stakeholders, including practicing civil engineers, can propose and analyse alternative infrastructure strategies. The shared modelling capability that we will develop in the new ITRC-MISTAL programme is particularly important in the context of devolution, in which the nations of the UK, regions and cities are taking responsibility for infrastructure. A shared systems view of the UK's infrastructure networks will enable devolved initiatives to be formulated in the context of a consistent overall strategy.

Finally, whilst NISMOD has been developed for Britain, the ITRC's new ITRC-MISTAL programme will be exploring the transferability of NISMOD to other countries, including: emerging economies where the pace of infrastructure development is fastest; least developed countries where the infrastructure deficit is greatest; post-disaster situations where there is a growing recognition of the need to 'build back better'; and post-conflict situations where infrastructure planning and



investment can provide a route to a peaceful and prosperous future. Many aspects of NISMOD need to be adapted to deal with the challenges of these different settings, making the most of new Earth observation datasets and global databases. The challenges are formidable, but we hope that the lessons from infrastructure systems analysis that have been learned over the last five years in Britain can be of value elsewhere in the world.

## Acknowledgements

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