UK Infrastructure Transitions Research Consortium

Providing the concepts, models and evidence to inform the analysis, planning and design of national infrastructure systems

ITRC

The national infrastructure challenge

Infrastructure, including energy, transportation, water, waste and digital communications, is essential for human well-being and economic productivity. Governments worldwide are increasingly looking to investments in infrastructure to enhance long-term economic competitiveness and quality of life. Societies need to build resilience to natural hazards and man-made shocks to infrastructure systems, which can propagate through society and the economy.

As infrastructure is largely made up of long-lived assets with high up-front costs, the wrong decisions during planning and design can 'lock in' unsustainable patterns of development. The pathways chosen for new and replacement capacity will dictate future infrastructure supply security, service quality and environmental impact. Now more than ever, it is essential that governments, utility providers, designers, investors and insurers have access to data and methods that enable the evaluation of the performance and impact of long-term plans and policy for infrastructure service provision in an uncertain future.

"Infrastructure forms the economic backbone of the UK. It is the fabric that defines us as a modern industrialised nation. The standard and resilience of infrastructure in the UK has a direct relationship to the growth and competitiveness of our economy, our quality of life and our ability to meet our climate change objectives and commitments."

HM Treasury: Strategy for National Infrastructure.

The UK Infrastructure Transitions Research Consortium

The UK Infrastructure Transitions Research Consortium is delivering research, models and decision support tools to enable analysis and planning of national infrastructure systems. The research addresses major challenges for the energy, transport, digital communications, flood protection, water and waste. We are providing the tools to analyse infrastructure policies, plans and investments in the long term with respect to major societal challenges such as demographic change, economic competitiveness and climate change. We have analysed the resilience of national infrastructure to help target investments to reduce vulnerability.

Our ambition is that through theoretical research and demonstration of a new generation of practical decision support tools, in concert with our government and industry partners, we will enable a revolution in the strategic analysis of national infrastructure in the UK, whilst at the same time becoming an international landmark programme recognised for novelty, research excellence and impact.

The ITRC has tackled four major challenges:

1. **How can infrastructure capacity and demand be balanced in an uncertain future?**

   ITRC has developed 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. These new infrastructure systems models and database provide the tools needed to develop and test long term strategies for national infrastructure provision.

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

   ITRC has analysed 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 is being used to identify ways of adapting infrastructure systems to reduce risks in future.

3. **How do infrastructure systems evolve and interact with society and the economy?**

   ITRC has examined the complex relationship between infrastructure, the economy and society. Empirical analysis has investigated the influence of infrastructure on business location. Meanwhile, theory about the role of infrastructure in the macro-economy is being extended. We have developed a spatial model of the relationship between infrastructure and regional growth in Great Britain.

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

   Working with government, utilities companies, regulators and their consultants, we are using our new methods to develop and test alternative strategies for Britain's national infrastructure. We are exploring the governance arrangements necessary to ensure that this transition is realisable in practice

The NISMOD family

The ITRC has developed the National Infrastructure System Model (NISMOD) family of models. NISMOD provides the datasets and tools needed to analyse national infrastructure performance, plans, vulnerabilities and risks in the long term. NISMOD contains four components:

NISMOD-LP: A national model of the **long-term performance** of interdependent infrastructure systems

NISMOD-RA: A national model of **risk and vulnerability** of national infrastructure systems

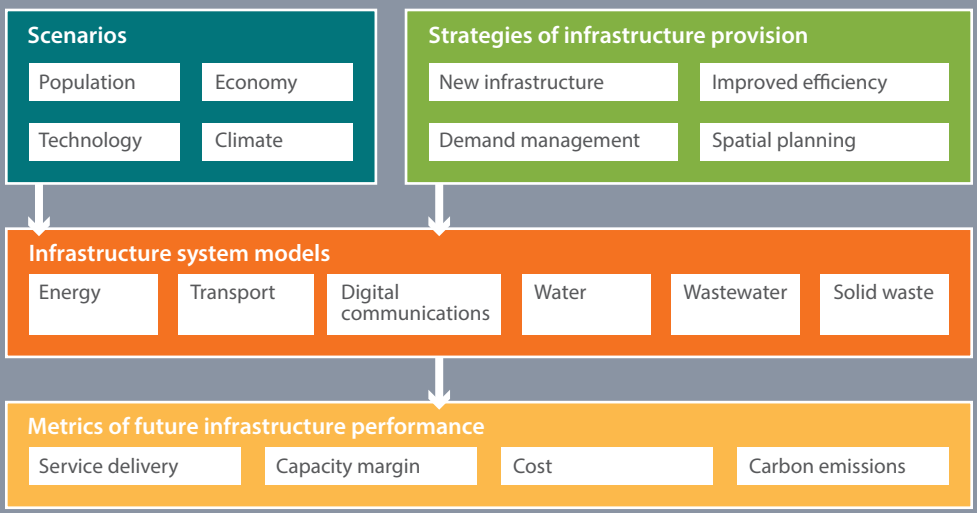
NISMOD-RD: A model of **regional development** and how it adapts to infrastructure provision

NISMOD-DB: A national **database** of infrastructure networks, demand and performance.

NISMOD-LP

NISMOD-LP analyses scenarios of the way in which demand for infrastructure services may change in future, the capacity of infrastructure networks, and the ways in which alternative strategies for investment in national infrastructure could enhance system performance. Like all of the ITRC research, NISMOD-LP takes a systems approach, quantifying how national infrastructure systems perform and interact with one-another.

NISMOD-LP starts with a consistent set of scenarios for how the factors that influence demand for infrastructure services (demography, the economy, prices, technology, climate) might change in future. These are combined with the decision options to be analysed – alternative strategies for infrastructure provision. Combinations of scenarios and strategies are input into the modules which compute demand for energy, transport, digital communications, water, wastewater and solid waste, now and in the future. NISMOD-LP outputs sets of metrics for how strategies for infrastructure investment could perform in future.

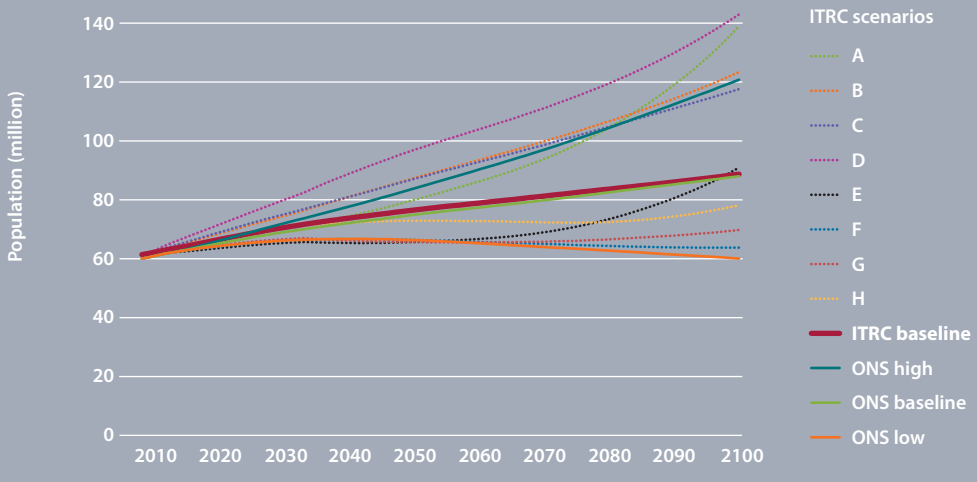


NISMOD-LP Scenarios of future needs for national infrastructure

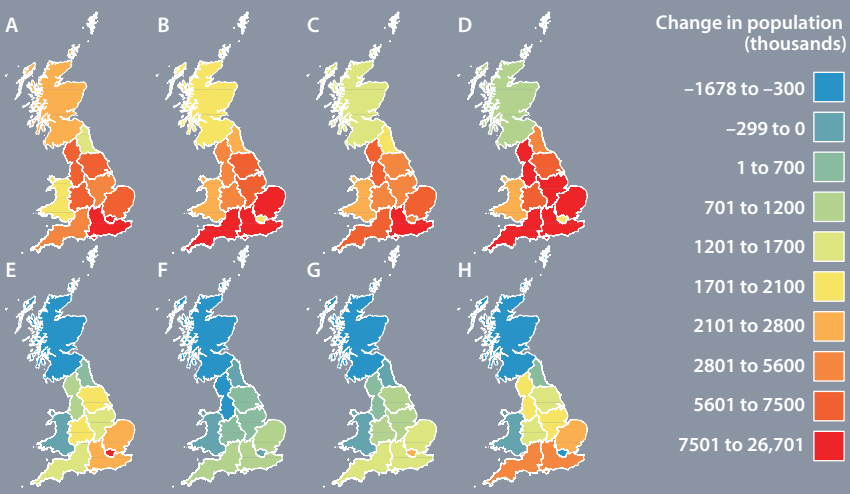
Future need for infrastructure services will be shaped by changes in population and the economy. ITRC has therefore developed a wide range of population scenarios for Great Britain, which span the Office of National Statistic's (ONS) scenarios and disaggregated them to the scale of 407 Local Authority Districts.

The patterns of population change in the Britain, and the distribution of ages, are as important for infrastructure provision as the total population, so we have explored eight different scenarios for regional change, with different patterns of growth.

The eight total population scenarios used in NISMOD-LP with comparison to ONS.



The eight scenarios of regional population change used in NISMOD.

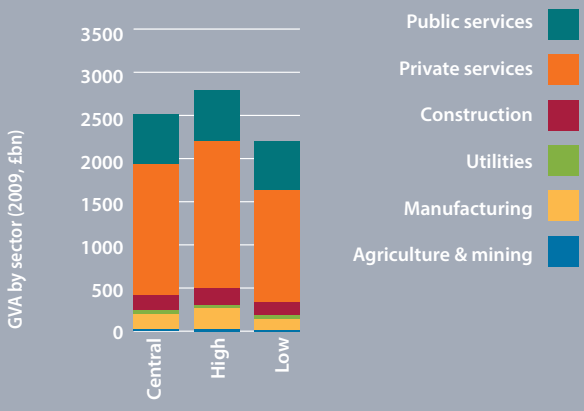


NISMOD-LP Scenarios of future needs for national infrastructure

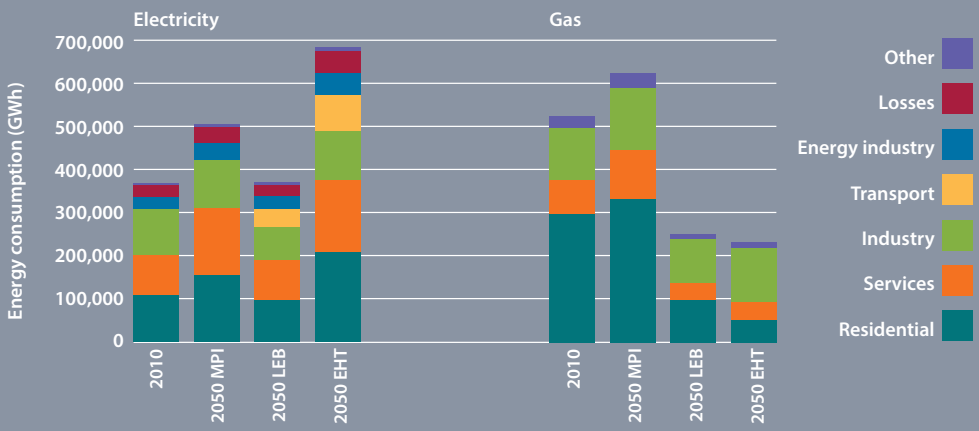
We have developed three scenarios for how the UK's economy might evolve through to the 2050s. These scenarios are based on central, high and low population projections, along with scenarios of global growth and energy prices.

The demographic and economic scenarios have been combined with per capita demand estimates and price elasticities to estimate demand for infrastructure services in future. Population and economic growth drives up demand for infrastructure services, like energy, but that is also shaped by changing patterns of demand e.g. the electrification of heating and transport.

The three economic scenarios for 2050 (Gross Value Added by sector).



Projections of energy demand in 2050 (compared with 2010, left hand column) for three different energy strategies: Minimum Policy Intervention (MPI), Local energy and biomass (LEB) and Electrification of Heat and Transport (EHT). Central population/economic scenario.



NISMOD-LP Energy systems modelling

ITRC has developed the CGEN+ model of Britain's energy supply and transmission system. We used CGEN+ to analyse the infrastructure investment needs associated with alternative strategies for energy supply, including least cost (MPI) strategies, with and without a carbon price, which involve an increasing proportion of gas generation. If there is a significant increase in electricity demand, including the effect of electrification of heat and transport, that could be achieved with a variety of supply technologies, including fossil fuel power plants with CCS, offshore wind with gas backup capacity, or nuclear power plants. These alternatives have very different implications for investment costs and carbon emissions.

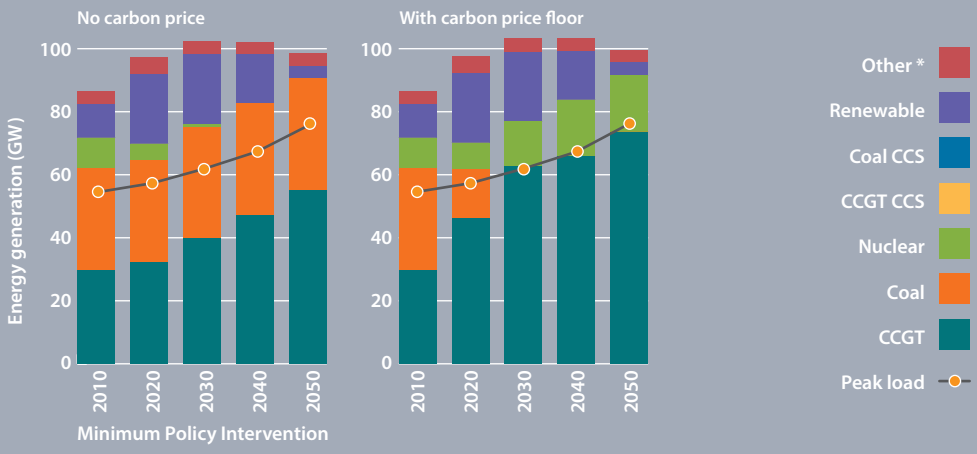
Making an impact

nationalgrid

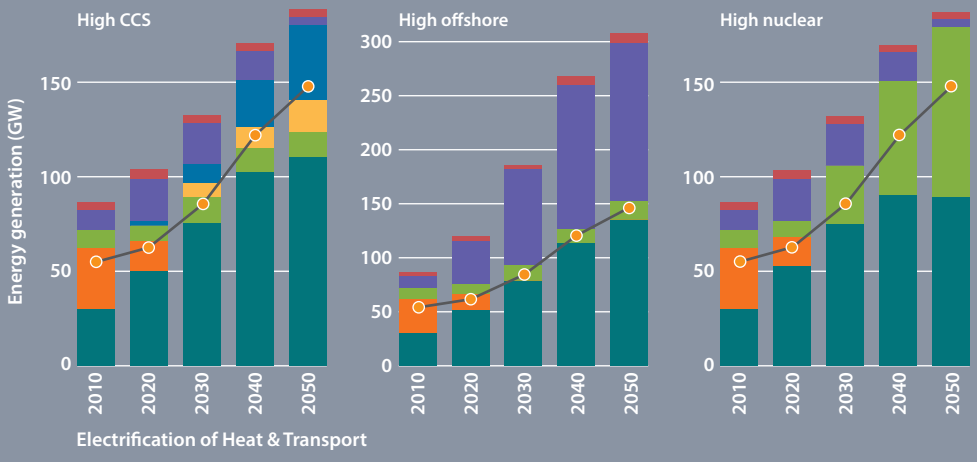
Two ITRC researchers were seconded to National Grid to develop new spatial modelling to analyse the potential effects of modelling of renewable technologies and embedded generation capacities on electricity demand. The secondment help National Grid to develop a needs analysis tool to:

- **integrate different data sources**
- **assign transmission and distribution level assets to key renewable technologies (such as solar, wind and photovoltaic installations)**
- **aggregate outputs from distribution regions to the grid.**

National Grid will incorporate the output into their own Future Energy Scenarios forecasting models to provide a demand allocation, by area, for different technologies and scenarios.



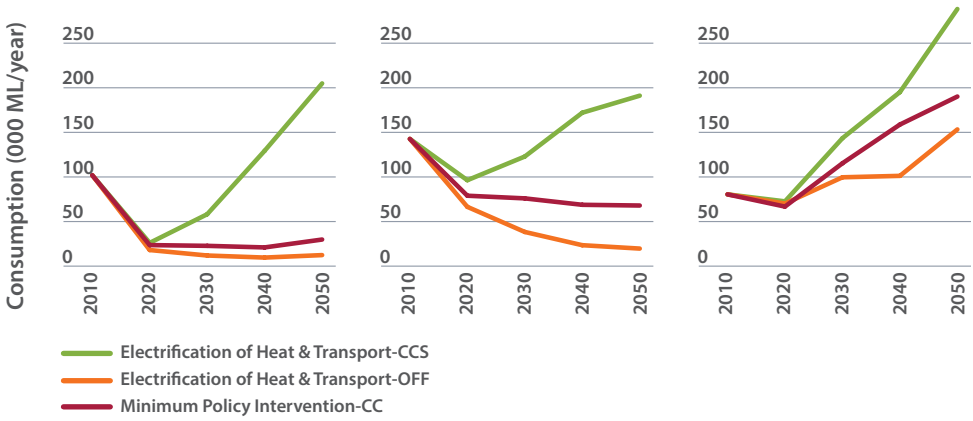
Evolution of energy supply mix for alternative energy infrastructure strategies.



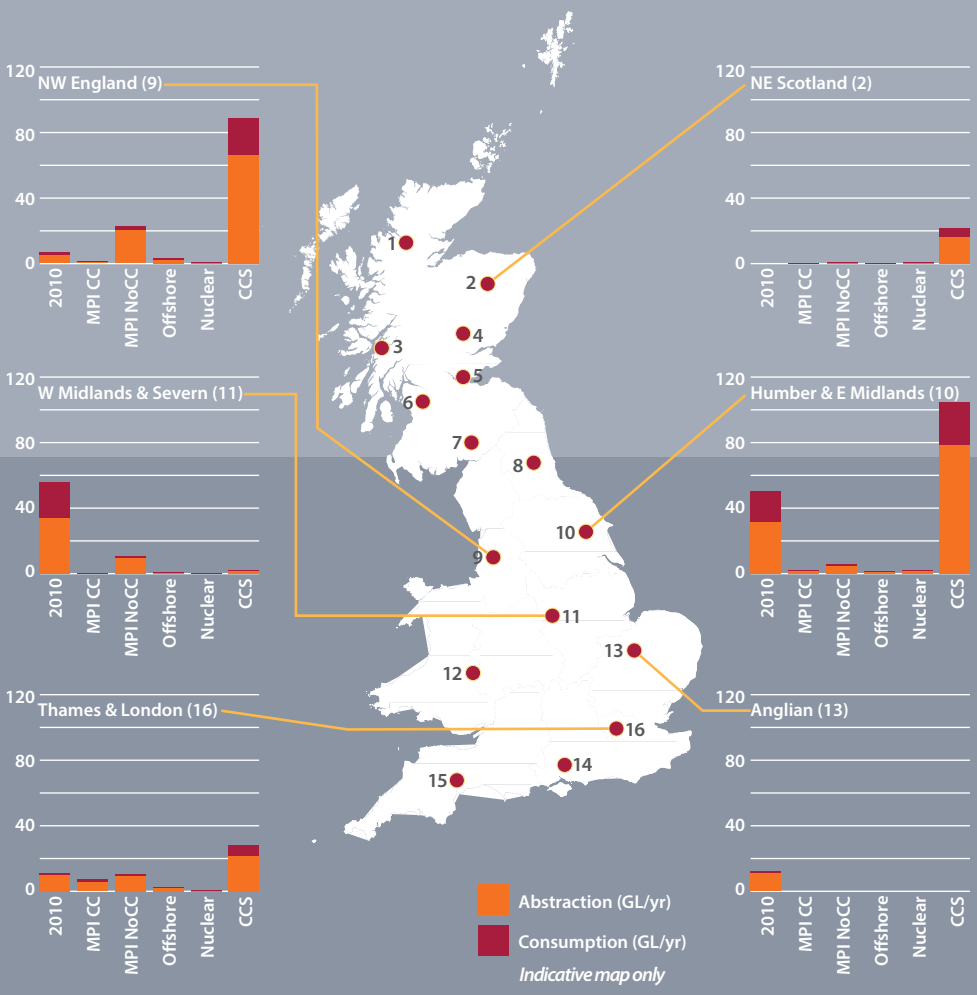
NISMOD-LP Cooling water demand from the energy system

Most of the strategies for energy generation that ITRC has analysed imply a reduction in freshwater abstractions, as a result of inland coal-fired plants being closed down and a transition to coastal plants fro cooling thermo-electric power plants (including nuclear) and an increasing proportion of wind and solar. However, large-scale uptake of carbon capture and storage (CCS) technologies at inland power plant sites could push that trend in the opposite direction, with a risk of insufficient cooling water.

Freshwater, tidal and seawater cooling water abstractions for three energy infrastructure strategies.



Regional freshwater abstraction (consumption is marked in red) for all three strategies in GL per year.

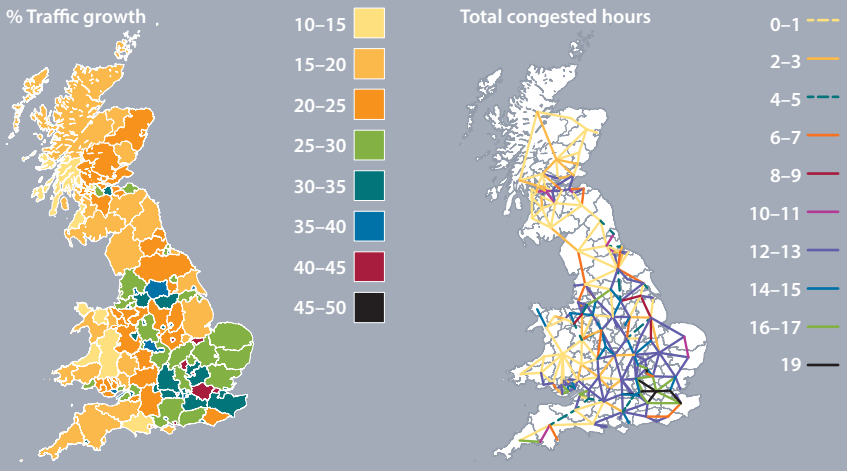


NISMOD-LP Transport systems modelling

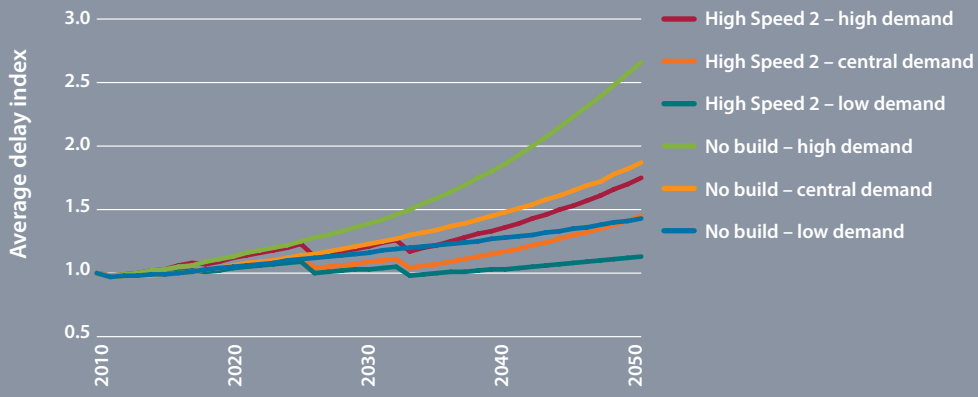
ITRC has developed a new strategic transport assessment model for Britain, which is modelled as 144 interconnected zones, with transport demand for road and rail being generated in each zone. Usage and average speeds are modelled for travel within and between zones. ITRC also examined demand for ports and airports over the next fifty years.

The research has demonstrated how the benefits of transport infrastructure investments are maximised if accompanied by smarter choices to manage demand.

Projections of road traffic growth and congestion.



Projections of the effect of High Speed 2 on delays (measured as average delay index) on the rail links that it affects most significantly.



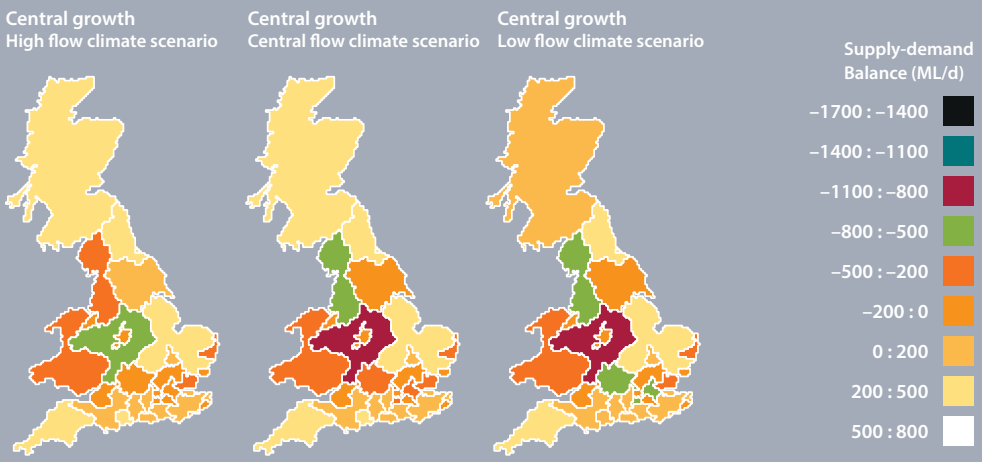
NISMOD-LP Water supply system modelling

ITRC has developed a national water resource system model, called GBWIM, which models water availability from surface and groundwater sources in a range of different climate change scenarios. Storage and transfer infrastructure is modelled at the scale of Water Resource Zones. The possibility of increased use of desalination and/or waste water reuse technologies is included in possible future infrastructure strategies. GBWIM models domestic and industrial demand for water based on the ITRC's population and economic projections, and identifies where further action to reduce demand and/or addition supply infrastructure might be needed. The current emphasis on demand reduction and fixing leaks is delaying the need for major new storage/transfer/reuse infrastructure, but further new investments in supply infrastructure will eventually be required.

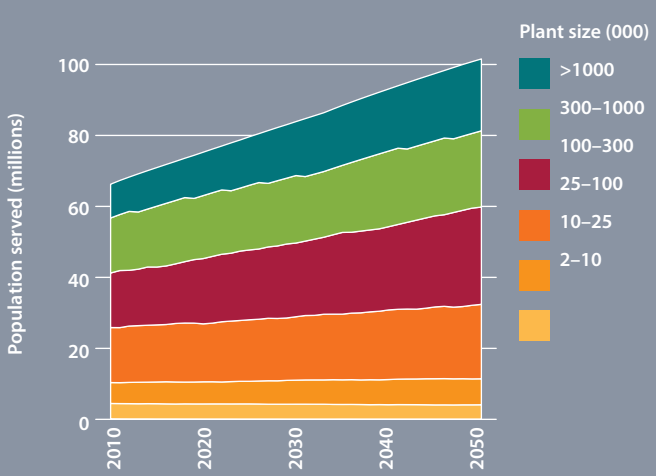
NISMOD-LP Waste water modelling

NISMOD-LP's model of the waste water system projects future demand for wastewater treatment based on the projected distribution of population. The life cycle of existing waste water plants is modelled and replacement costs are estimated. We anticipate that the trend over recent decades of centralising waste water treatment plants in urban areas will continue, because of economies of scale and the potential for increasingly efficient energy recovery.

Projections of water supply-demand balance in three climate change scenarios.



Projected changes in waste water treatment plant size and population served.



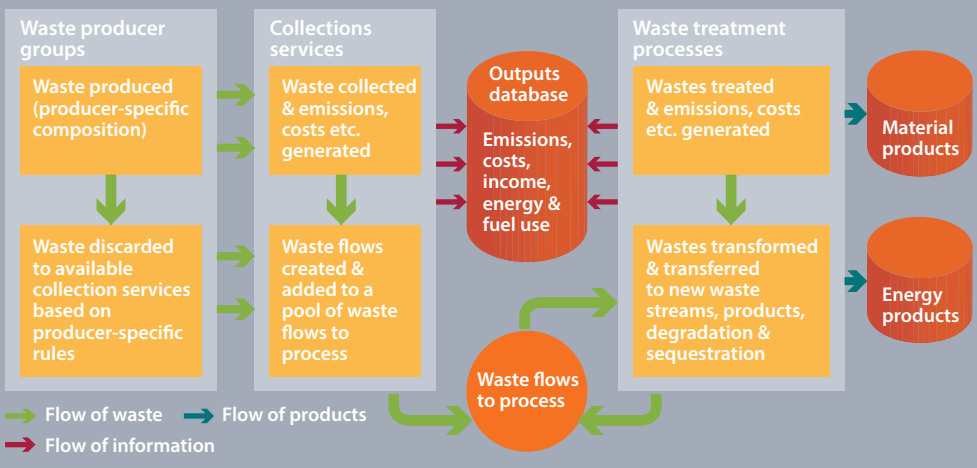
NISMOD-LP Solid waste modelling

ITRC has developed Britain's first national model of solid waste arising, collection, treatment and disposal. The model uses ITRC's simulations of population, and combines these with alternative scenarios for solid waste arising from municipal solid waste (MSW), commercial and industrial (C&I), construction and demolition (C&D) at a regional scale. The demand for solid waste infrastructure could vary enormously, depending on population/economic scenario and upon the approach taken to reducing waste. In our most ambitious demand reduction strategy, investment would only be needed to replace ageing plant, with a net reduction in the required capacity.

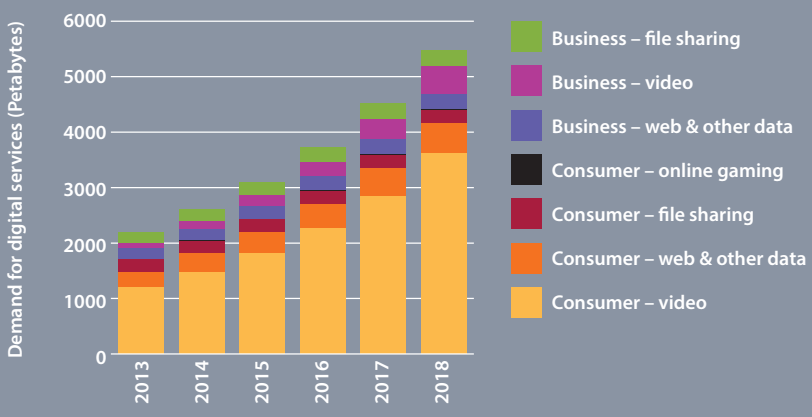
NISMOD-LP Digital communications modelling

Digital infrastructure (including cable and mobile communications) is a very rapidly evolving sector, with intense technological innovation and faster asset replacement rates that the other sectors that ITRC has considered. ICT is also fundamental to how infrastructure will be used and operated in future. The ITRC's analysis of digital infrastructure did not therefore look as far into the future as for other infrastructure sectors. We have analysed the rate of roll-out of digital infrastructure (at different speeds of connectivity) across Britain and the factors that are determining who gets what services.

Overview of NISMOD-LP's solid waste module.



Forecast future demand for broadband services.



Synthesising the results from NISMOD-LP

The NISMOD-LP system enables analysis of the performance of long term strategies for national infrastructure provision. In some infrastructure sectors, approaches to long term planning already exist, but before ITRC there was no methodology that stretched across sectors at a national scale, looking decades into the future.

ITRC has explored four contrasting strategies for national infrastructure provision:

Minimum Intervention (MI) seeks to minimise investment in national infrastructure systems. There is no long-term vision to reduce future demand or implement more stringent commitments to environmental policies.

Capacity Expansion (CE) focuses on increasing investment in infrastructure capacity. Priority is given to the expansion of physical capacity to alleviate pinch-points and bottlenecks.

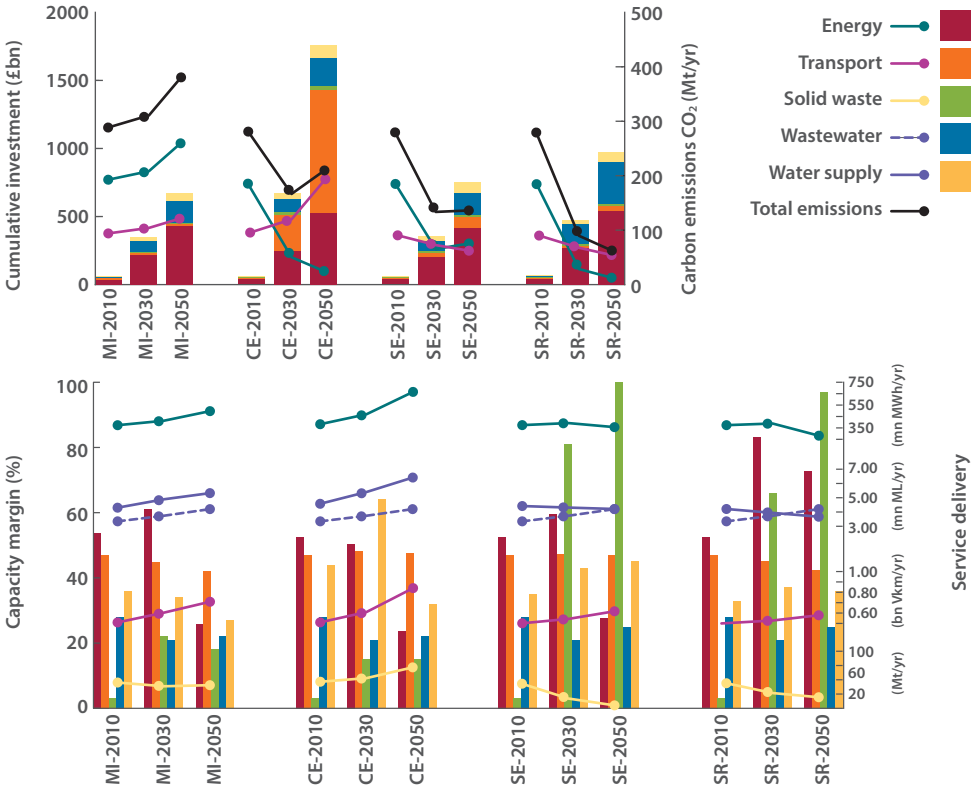
System Efficiency (SE) focuses on deploying the full range of technological and policy interventions to optimise the performance and efficiency of national infrastructure systems, targeting both supply and demand.

System Restructuring (SR) seeks to fundamentally restructuring and redesign the current modes of infrastructure service provision, deploying a combination of targeted centralisation and decentralisation approaches.

For each of these strategies we have computed a series of performance indicators, an a range of timescales:

- service delivery, measuring how much service is delivered by each infrastructure sector (e.g. measured in megawatt-hours, passenger kilometres or megalitres of water per day)
- capacity margin, which is a general metric of the margin between infrastructure use (i.e. service delivery) and the capacity of the system to deliver services
- investment cost, measuring both capital and operating costs
- carbon emissions.

Performance indicators for the ITRC's four national infrastructure strategies



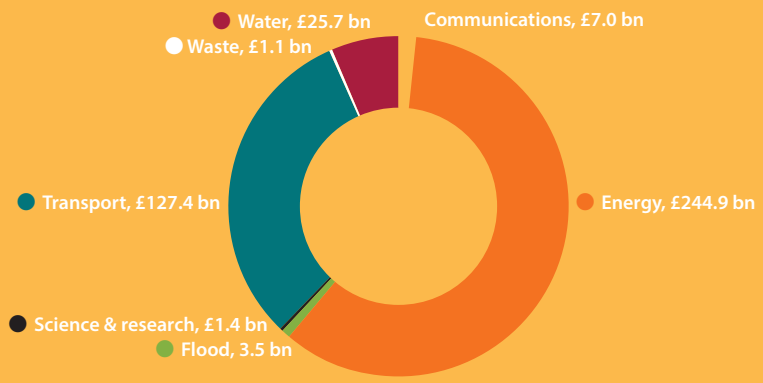
Making an impact

Infrastructure UK

Analysing the performance on the UK's National Infrastructure Pipeline

During a secondment to Infrastructure UK in the Treasury, ITRC staff have analysed the performance benefits that would be achieved by the £411 billion pipeline of infrastructure projects. Analysis with NISMOD compared the pipeline with a scenario in which these investments did not take place, and explored the potential effects of population and economic growth on system performance.

Infrastructure Pipeline £411 bn (2015–16 onwards)



NISMOD-RV: National analysis of the vulnerability of interdependent national infrastructures

National infrastructure systems are vulnerable to failure, due to natural hazards, security threats and accidental failures. Failure can propagate through networks and lead to major economic and societal disruptions. NISMOD's risk and vulnerability analysis system (NISMOD-RV) characterises Britain's infrastructure networks, the hazards to which they are exposed and the potential consequences of failure.

New statistical analysis enables us to simulate extreme hazards over all of Britain, accurately representing the spatial correlation of hazards, which is important for national infrastructure systems analysis.

Making an impact

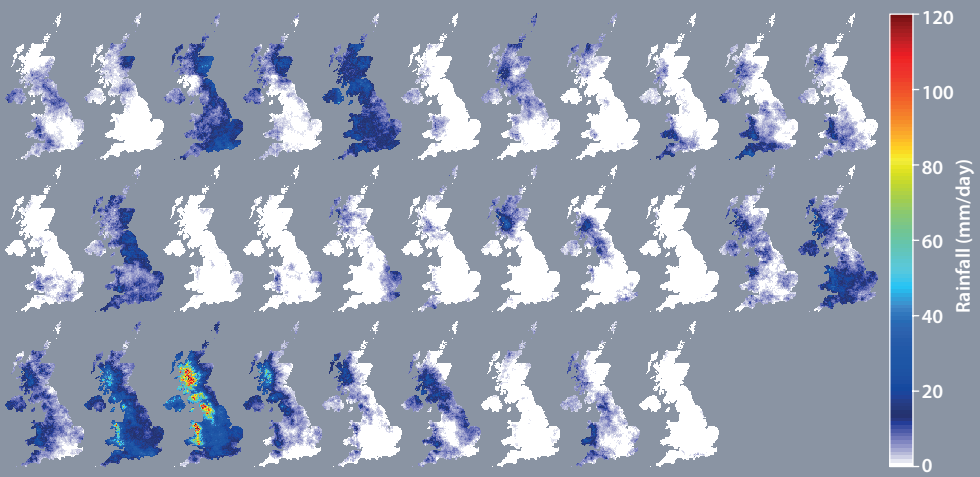
Geohazards to infrastructure

ITRC has examined the extent of geohazards to buried infrastructure and roads. Using Cranfield University's geohazard datasets and Lincolnshire County Council's road network and condition surveys, we assessed soil-related geohazards for Lincolnshire's highways department. We concluded that areas prone to clay-related subsidence, which is intensified in drought conditions, have a detrimental impact on road surface quality. Lincolnshire Highways Alliance has since used the research to allocate £600k of road maintenance fund.

Mark Heaton, Area Highways Manager, Lincolnshire County Council commented:

> **"This research has led to Lincolnshire County Council and myself as lead manager on this work prioritising the roads at risk and the treatment we are now using to overcome the issues and problems identified. This together with the site visit(s) undertaken [with the ITRC researcher] has helped me understand the soil-related hazards to our network, and as such we are now considering developing the re–tread [resurfacing] process further and looking at ways in which we can use our own arising's in conjunction with the re-tread programme to help improve the foundation to our road network where the [subsidence] issues are being found".**

Simulation of extreme rainfall events which could disrupt infrastructure networks across the UK.



NISMOD-RV: Infrastructure network analysis

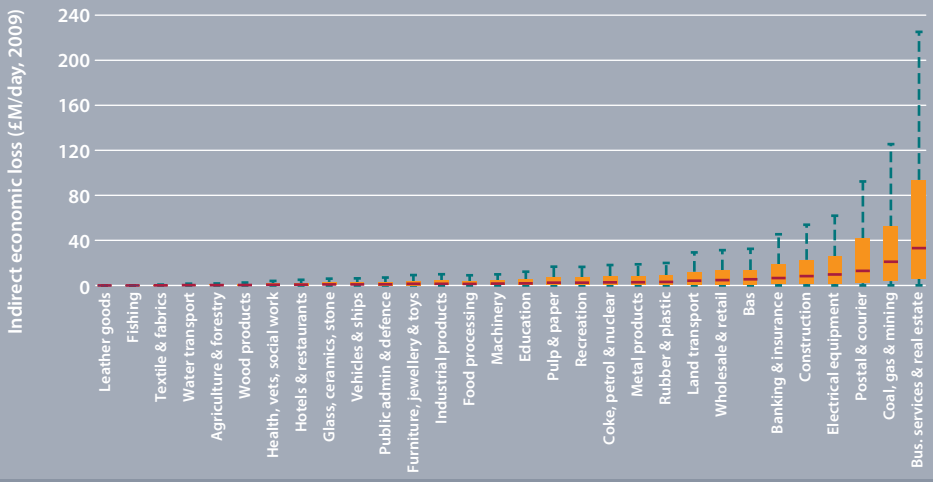
ITRC has assembled a unique dataset of national infrastructure assets, including:

- Electricity transmission & distribution
- Gas
- Liquid fuels
- Railways
- Roads
- Airports
- Ports
- Water towers
- Water pumping stations
- Sewage treatment works
- Solid waste facilities
- Telecom masts

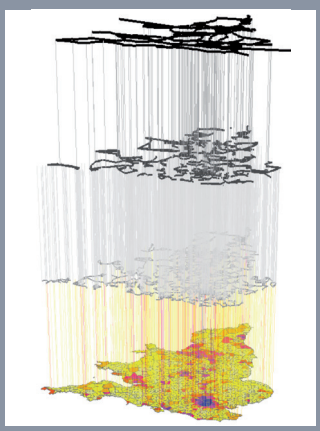
We have filled gaps in these networks and mapped their interdependencies.

ITRC has mapped the usage of infrastructure services, so we can estimate how many customers might be disrupted by failure of any infrastructure asset. Economic modelling has enabled us to estimate the scale of potential impact on the economy because of infrastructure disruptions to businesses and supply chains.

Potential scale of economic loss due to infrastructure disruption in a widespread flood event.



Mapping interdependent infrastructure networks (left). The national electricity network hierarchy and interdependent gas network (right).



NISMOD-RV Mapping the vulnerability of Britain's critical infrastructure

ITRC was asked by Infrastructure UK to identify critical infrastructure hotspots, which we define as location where there is a concentration of infrastructure assets whose failure could lead to large amounts of disruption.

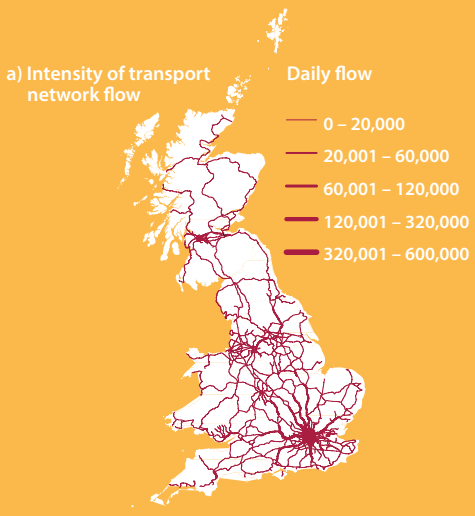
ITRC provided evidence to the Scientific Advisory Group in an Emergency which was convened by the Government Chief Scientific Advisor during the winter 2013/14 floods by identifying critical infrastructure assets and the scale of potential disruption due to failure of assets in the floodplain.

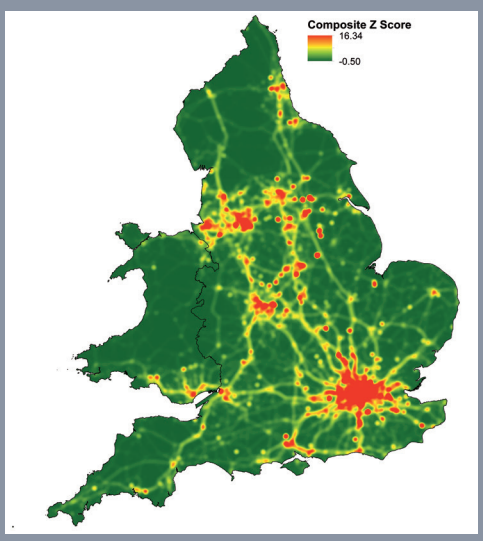
Making an impact

Identifying critical failure locations in Britain's transport network

Department for Transport

Following major disruption to Britain's transport network during the winter of 2013/14 the Department for Transport commissioned a review of the resilience of the transport network to extreme weather events (the Transport Resilience Review). One recommendation from that review was to identify critical vulnerabilities within the transport network. ITRC has therefore been helping DfT to assess vulnerability of the transport network by analysing how much traffic a transport link carries (a), whether there is potential to reroute traffic in the event of a failure and hence how serious a failure might be (b).



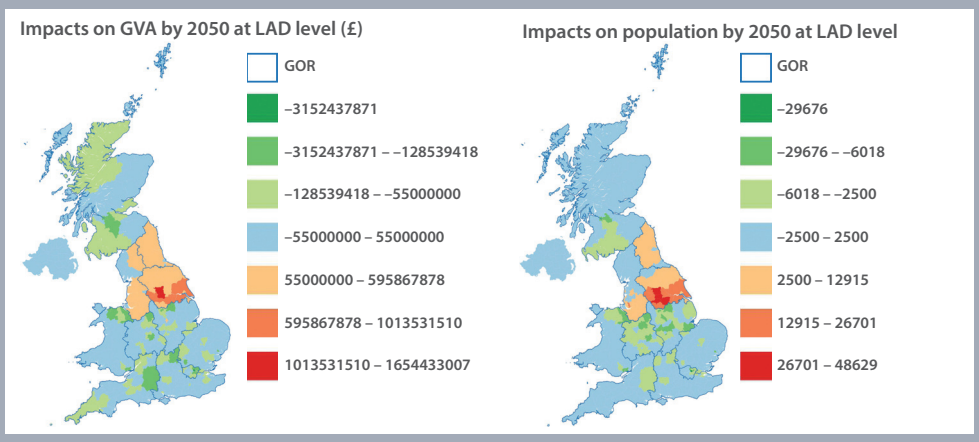


ITRC's critical infrastructure hotspots map.

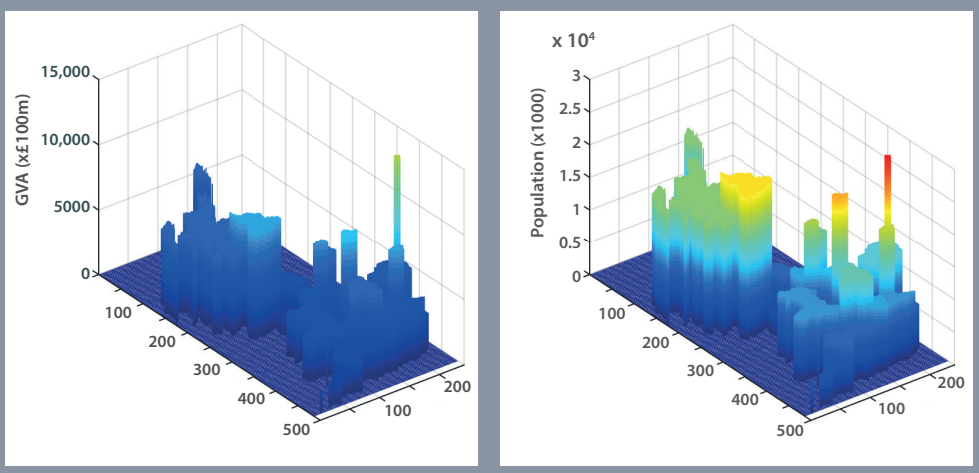
NISMOD-RD Understanding the relationship between infrastructure and economic growth

The relationship between infrastructure and economic growth is complex and not fully understood. Infrastructure is a factor of production, adding costs to production and meaning that production is constrained when infrastructure is not fully functioning. Transport and digital infrastructure enables trade in goods and services (at a cost), provides accessibility for the workforce and enable agglomeration and innovation. There is a feedback relationship between infrastructure and regional growth: infrastructure can enable growth, whilst at the same time growth in economic activity and population leads to the demand for more infrastructure. ITRC has sought to model these dynamics, using a spatial interaction model and a new economic geography model.

Projections of the effect of infrastructure investment in the north of England (the Northern Powerhouse) on economic activity and population.



Simulations of change in economic activity and population from 2015–2050 under the central growth scenario.

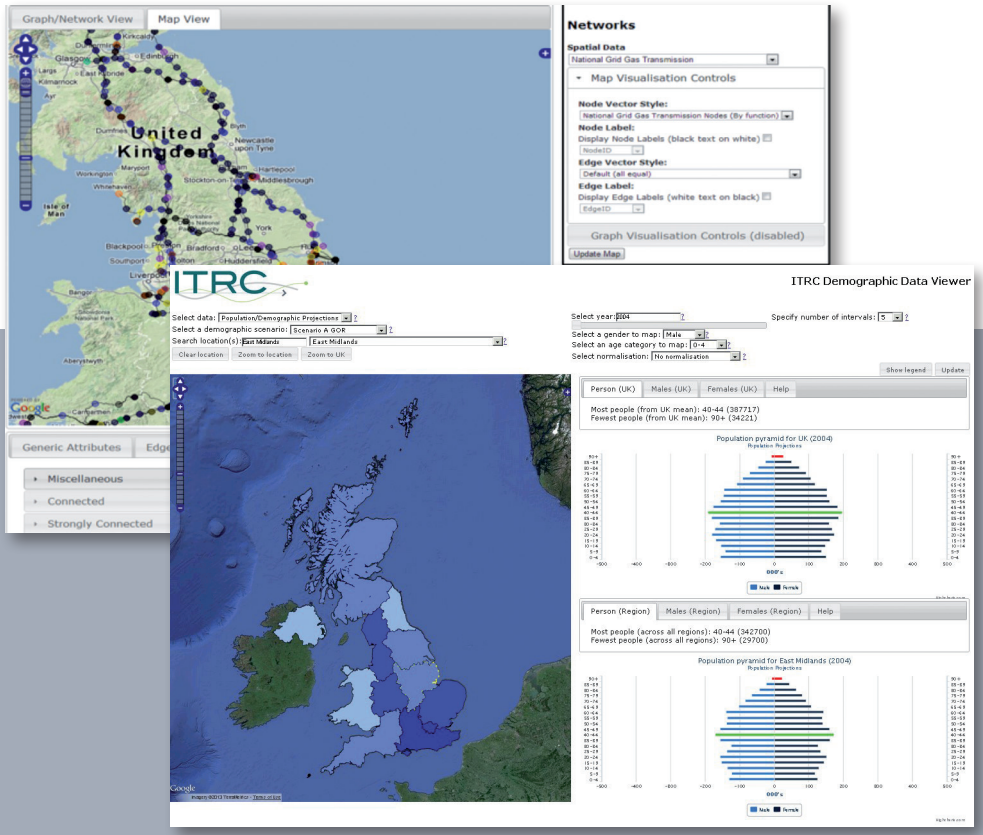


NISMOD-DB National infrastructure database

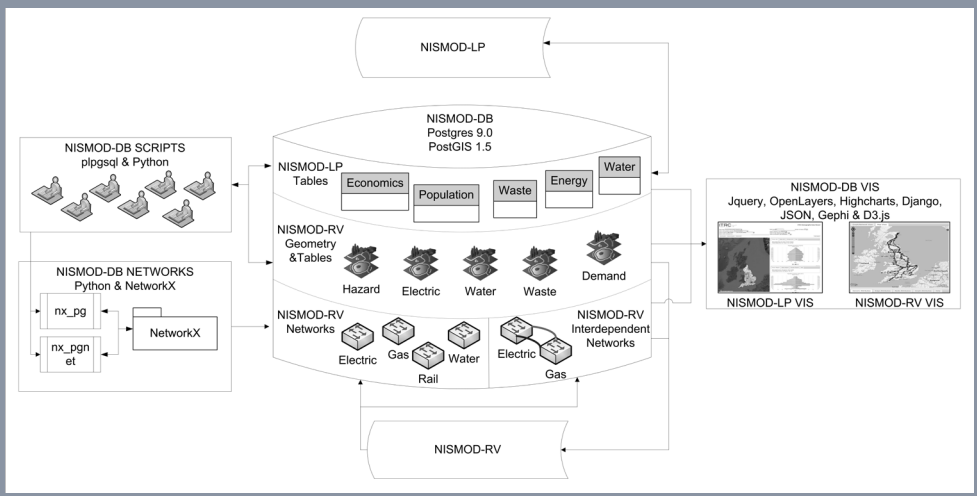
NISMOD-DB hosts 432 layers of infrastructure system data. It also hosts NISMOD's simulation model inputs and outputs. This means that all of our model analysis can be retained for scrutiny.

The reporting tools in NISMOD-DB are being used by Infrastructure UK to scrutinise ITRC's analysis of the National Infrastructure Pipeline.

NISMOD-DB network visualisation tool, and visualising ITRC's demographic projections.



Structure of NISMOD-DB.

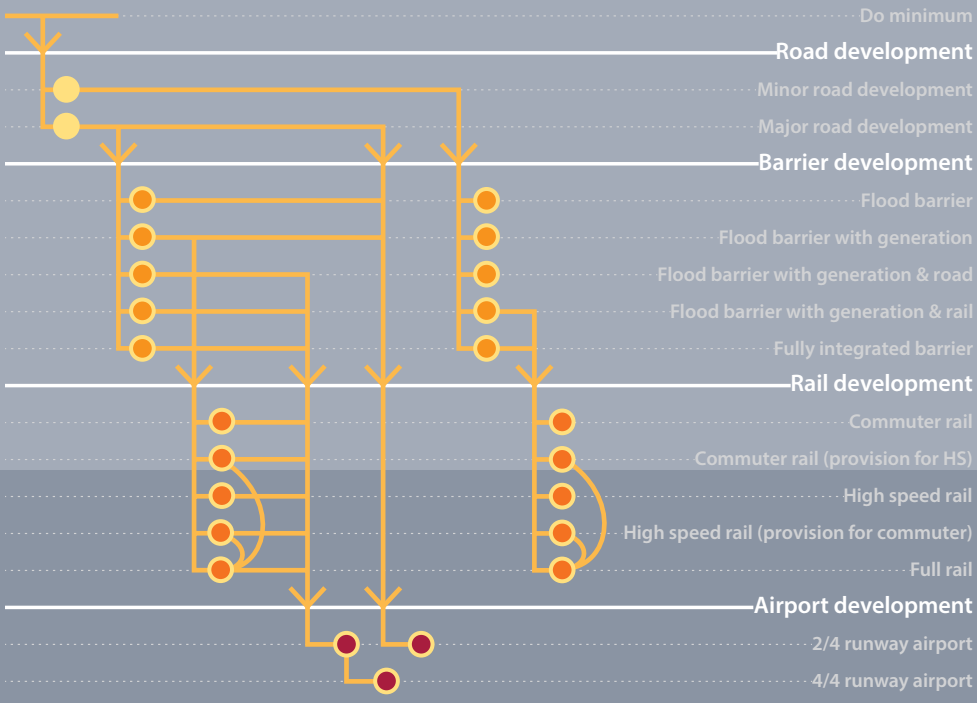


Governing interdependent infrastructure systems

During the twentieth century, the governance of most national infrastructure sectors has moved from a fragmented set of arrangements – with a mix of public and private provision – towards a national, market-led governance model. ITRC has examined modes of infrastructure governance, and the challenges for governance of the more systemic approach to infrastructure provision that our research has sought to illustrate and inform. Whilst national governments have an important role to play, developing more sustainable infrastructures will continue to require the involvement of multiple actors including government and public agencies at different levels (international, national and sub national), infrastructure providers as well as citizens.

ITRC has developed structured approaches to infrastructure investment decision making under uncertainty. We have demonstrated how accounting for network effects and interdependencies can have a significant impact on decision making. We have explore sequential 'pathway' approaches to investment decision making under uncertainty. Our approach is based upon demonstrating and, as far as possible, quantifying the multiple benefits, costs, impacts and trade-offs associated with infrastructure investment.

Adaptive infrastructure investment pathways for London's infrastructure.



About ITRC

The UK Infrastructure Transitions Research Consortium (ITRC) is funded by a £4.5million grant from EPSRC.

The ITRC is a partnership of seven of the UK's leading universities:

- University of Oxford
- Newcastle University
- University of Southampton
- Cardiff University
- University of Cambridge
- University of Leeds
- University of Sussex

with important additional research inputs from

- Cranfield University
- CEH Wallingford
- Cambridge Econometrics

The ITRC's national infrastructure assessment is described in:

Hall, J.W., Tran, M., Hickford, A.J. and Nicholls, R.J. (2016). *The future of national infrastructure: a system of systems approach*, Cambridge University Press.

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