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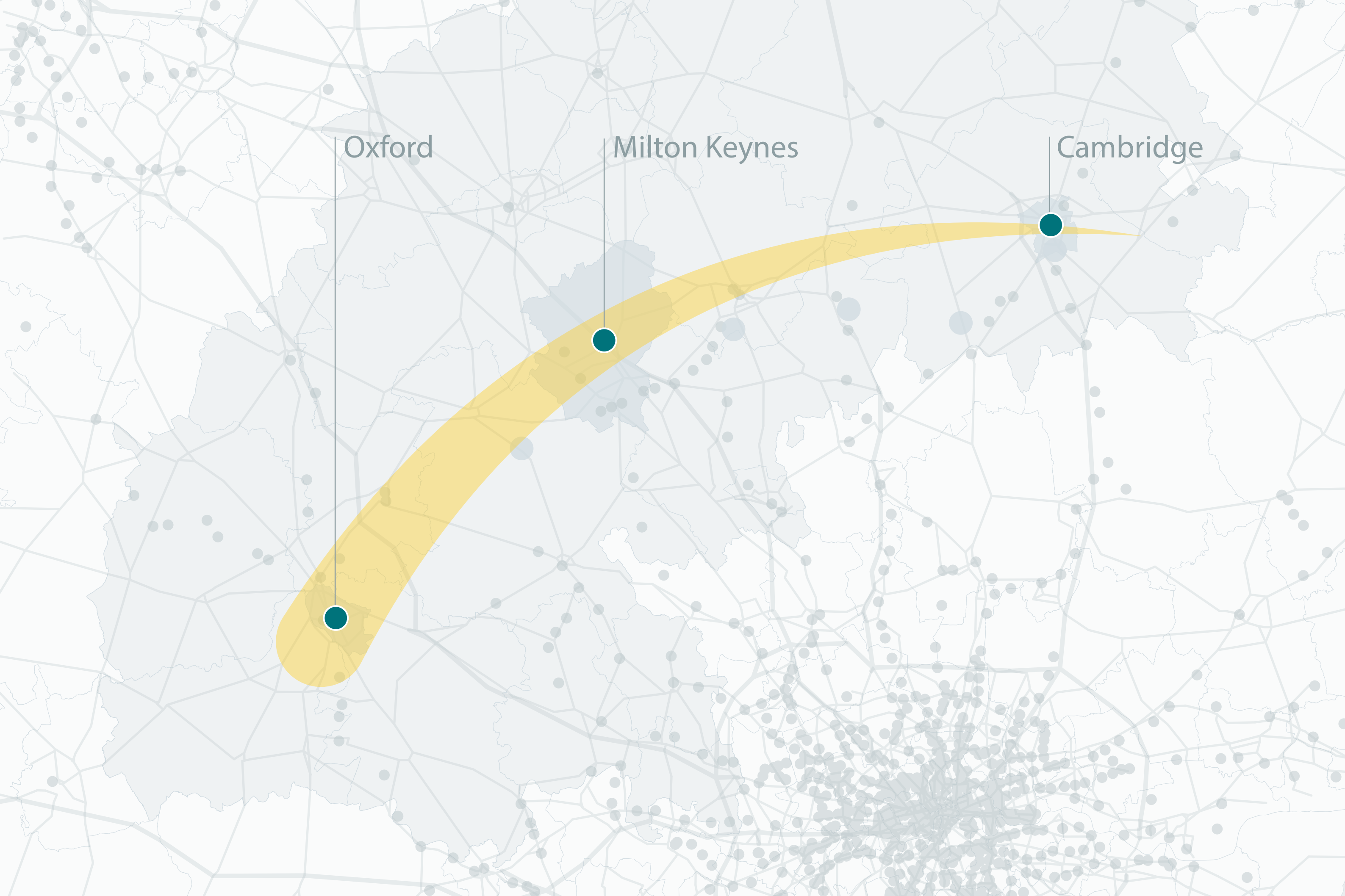


A sustainable Oxford-Cambridge corridor?

Spatial analysis of options and futures for the Arc

Summary

UKRI Engineering and Physical Sciences Research Council

1 Introduction

The Oxford-Cambridge Arc, bounded by two of the world's leading universities, contains some of the fastest growing and most productive towns and cities in the UK. Home to 3.7 million people, over 2 million jobs and contributing over £110 billion of annual Gross Value Added (GVA) to the UK economy per year, the Arc has been designated as a key economic priority by the Government, aiming to build on established strengths in knowledge-intensive sectors, science, technology, high-value manufacturing and innovation. Increased population, employment and productivity are key drivers of future economic growth and prosperity, enabled by increased accessibility to services and employment, and increased connectivity between urban centres.

The future vision for the region is one of continued growth, but this may be limited by a number of infrastructure constraints. The demand for housing throughout the Arc is high, and house prices in Oxford and Cambridge are twice the national average. The delivery of housing stock for future growth across the Arc is already insufficient, with the current average of around 15,000 new dwellings per year falling short of the estimated requirement of 20,000 dwellings per year.[1,2] There is limited transport infrastructure linking the major conurbations which adversely affects connectivity. For instance, the east-west transport routes are restricted as there is no major road or railway linking Oxford and Milton Keynes, which extends journey times and constrains flows across the Arc.

With these aims and constraints in mind, the National Infrastructure Commission (NIC) have identified four inter-related policy themes which are important to facilitate future growth throughout the Arc: (i) Productivity – ensuring businesses and skills are supported to maximise the Arc's economic prosperity; (ii) Place-making – delivering sufficient affordable, high-quality homes, workplaces and community places; (iii) Connectivity – improving infrastructure for transport, digital connectivity, and utilities; and (iv) Environment – protect and enhance the natural environment.

The Infrastructure Transitions Research Consortium (ITRC) has developed models, scenario analysis and geospatial design methodologies that can help to explore and inform choices about how the Arc will be developed. This report focuses on the Arc as a case study to demonstrate the ITRC MISTRAL (multi-scale infrastructure systems analytics) assessment methodology and the multiple capabilities of our infrastructure systems modelling suite. The analyses are based around three contrasting growth scenarios for new dwellings within the Arc, together with the development of the road and rail networks between Oxford and Cambridge.

This summary report provides a high-level overview of the modelling suite and methodology. More detailed information can be obtained from the ITRC website: **www.itrc.org.uk**

1 Savills (2016). The property market within the Cambridge – Milton Keynes – Oxford corridor.

2 5th Studio (2018). Cambridge, Milton Keynes and Oxford Future Planning Options Project: Final Report. Cambridge, UK.

2 The Oxford-Cambridge Arc

The Oxford-Cambridge Arc (or 'the Arc') is comprised of four county councils (Buckinghamshire, Cambridgeshire, Northamptonshire and Oxfordshire), 26 district councils and unitary authorities, and the combined authority of Cambridgeshire and Peterborough (see Figure 1). In addition, there are a variety of stakeholders, including four Local Enterprise Partnerships (LEPs),[3] England's Economic Heartland,[4] and many others. Of the 3.7 million people living in the Arc, 1.3 million live in one of the seven major urban centres of Oxford, Bedford, Luton, Milton Keynes, Northampton, Peterborough and Cambridge.

Figure 1: Outline of the Arc.

Proposals for the Arc have begun to take shape over recent years, culminating in the combined aims of central government and the local area to give a "commitment to providing new strategic infrastructure, matched with an ambition and commitment at a local level to deliver major housing growth and create places in which people want and can afford, to live and work".[5] This is reflected in the joint declaration between Government and local partners on future planning in the Arc.[6]

3 Oxfordshire Local Enterprise Partnership (OxLEP); Buckinghamshire Thames Valley Local Enterprise Partnership (BTVLEP); South East Midlands Local Enterprise Partnership (SEMLEP); The Business Board of the Cambridgeshire and Peterborough Combined Authority.

4 www.englandseconomicheartland.com

5 National Infrastructure Commission (2018) Partnering for Prosperity: A new deal for the Cambridge-Milton Keynes-Oxford Arc. London, UK.

6 MHCLG (2019). The Oxford-Cambridge Arc: Government ambition and joint declaration between Government and local partners. London, UK.

Central to this shared vision is the development of one million new homes across the Arc by 2050, the provision of an east-west Expressway road, and major improvements to the East-West rail routes connecting Oxford, Milton Keynes, Bedford and Cambridge. Whilst these proposals have been established, there are many remaining questions about how the Arc vision will be implemented in different places and whether goals of growth, prosperity and sustainability are achievable in practice.

Delivering such an ambitious growth plan across traditional boundaries is a significant challenge and requires a long-term, cross-cutting, integrated strategic plan with collaborative governance and investment mechanisms for planning and infrastructure. Such a plan should provide a clear vision for future change, with a pipeline of planned future investments and specific delivery milestones which are reviewed and adapted at regular intervals.

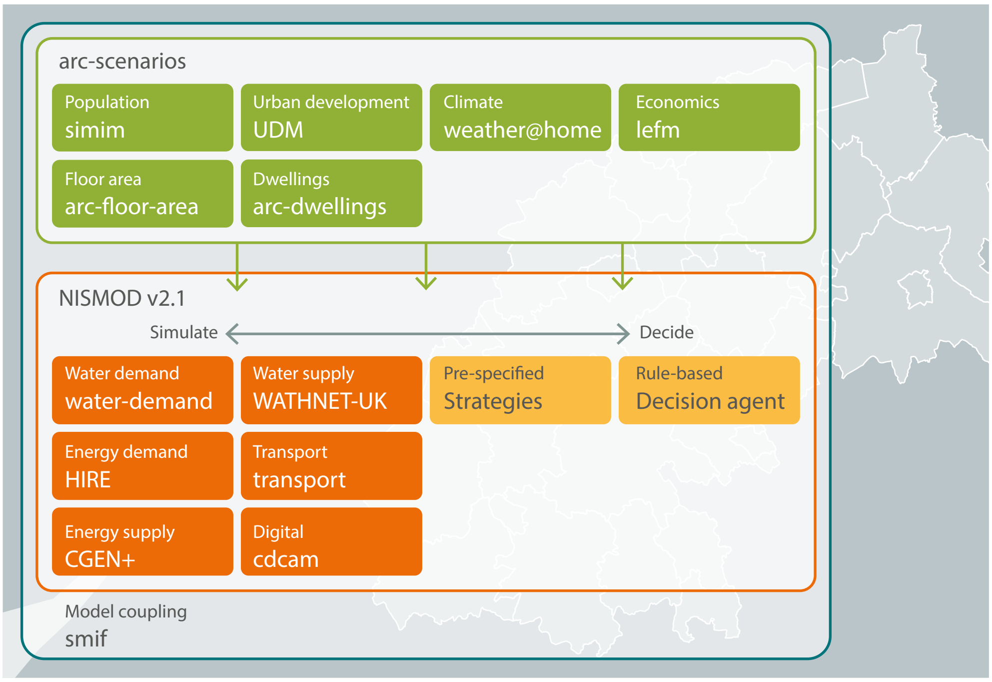
There is a need for a systematic and evidence-based approach to explore and analyse possible futures, assess the potential impacts of future decisions, and inform the development of a credible shared vision. The ITRC has conducted detailed spatial scenario analysis in order to explore these issues.

3 Applying the ITRC MISTRAL assessment methodology

The ITRC first developed the National Infrastructure Systems Model (NISMOD) to test and optimise long-term national plans for infrastructure provision, including energy, transport, digital, water and waste infrastructure.[7] The second phase of the ITRC research programme, MISTRAL, further developed NISMOD to examine sub-national infrastructure initiatives such as the Arc. NISMOD therefore now offers the capability to quantify the implications of changing local needs for infrastructure services, within the context of the national 'big picture' of population change, economic growth, technological innovation and climate change.

NISMOD is a system-of-systems model made up of simulation models of key infrastructure sectors (water, transport, energy and digital – see Box 1) and the interdependencies between them. NISMOD uses scenarios of population, economics, urban development, climate and hydrology to explore the ways in which needs for infrastructure services might evolve in future and options for how those needs could be met. This combination allows simulation and exploration of how infrastructure services may be provided, and how demand for infrastructure services may be managed in different possible futures (Figure 2). Related ITRC research provides strategic insights into urban development, natural capital and urban drainage. For more details on these aspects of our research, the main report accompanying this summary document is available at www.itrc.org.uk.

Figure 2: ITRC MISTRAL model components for the Arc assessment.



7 Hall, J. W., Tran, M., Hickford, A. J., & Nicholls, R. J. (2016). The future of national infrastructure: A system-of-systems approach. Cambridge University Press, Cambridge, UK.

Box 1: NISMOD – the ITRC MISTRAL key infrastructure modelling suite

Energy: Our energy supply model is a modified version of CGEN[8] and includes both transmission and distribution of electricity, natural gas, hydrogen and heat supply systems and their interactions. The new local 'energy hub' model developed during the MISTRAL programme enables exploration of options for local energy generation and storage, providing the capability to design and optimise a carbon neutral Arc.

Water: Our water resource system model simulates all major water supply assets in England and Wales (reservoirs, boreholes, transfers, water treatment works, pumped storage, desalination plants and river abstraction points) using Wathnet simulation software. Wathnet predicts whether water can be reliably supplied to the Arc, under a range of different water demand and climate change scenarios.

Transport: We have developed a national-scale model of the road and rail transport network. The model forecasts transport demand and congestion, providing predictions of travel times, travel costs and capacity utilisation.

Digital communications: We have developed models of the coverage and cost of providing a range of standards of fixed and mobile digital coverage in the Arc. Our 5G assessment model undertakes system-level evaluation of wireless networks, quantifying the capacity, coverage and cost of deployment strategies. The network capacity and coverage (and cost of investment in improvements) are estimated using cellular site density, spectrum usage, and technology generation (4G or 5G).

Further information on the modelling suite is available online at www.itrc.org.uk

The ITRC MISTRAL assessment is a systematic, integrated approach which takes contrasting illustrative scenarios of the large number of different possible development patterns and choices and examines the implications for infrastructure needs within the Arc and nationally. At this stage we have not yet investigated the wide range of detailed choices within the Arc. Rather, this study selects a few illustrative examples to explore the many possible combinations of future scenarios, and uses NISMOD to provide insights concerning these different choices. Infrastructure decisions are either (i) pre-specified as strategic plans for infrastructure interventions, where different strategies may be tested under various scenarios, or (ii) defined by a rule-based decision model, which is parameterised and used to generate actions in response to simulation outputs (for example, adding mobile cells in areas where demand is highest).

In this report, we focus on two of the NIC's policy themes which represent critical challenges for the Arc: (i) the impact of the predicted growth in population brought about by providing new housing, and (ii) the impact of new transport infrastructure (i.e. the Expressway and East West Rail) which allows greater connectivity within the Arc.

8 Chaudry, M., Jenkins, N., Qadrdan, M., & Wu, J. (2014). Combined gas and electricity network expansion planning. *Applied Energy*, **113**, 1171–1187.

4 Expressway and East West Rail: our assumptions

Improvements to the transport links between Oxford and Cambridge are a key aspect of the future vision for the Arc. The Expressway will comprise grade-separated dual carriageway between the A34 near Oxford and the A14 near Cambridge, including a proposed new road link between the M40 near Oxford and the M1 at Milton Keynes. East West Rail (EWR) will link Oxford and Cambridge via Bicester, Milton Keynes and Bedford, with opportunities for several new stations along the route.

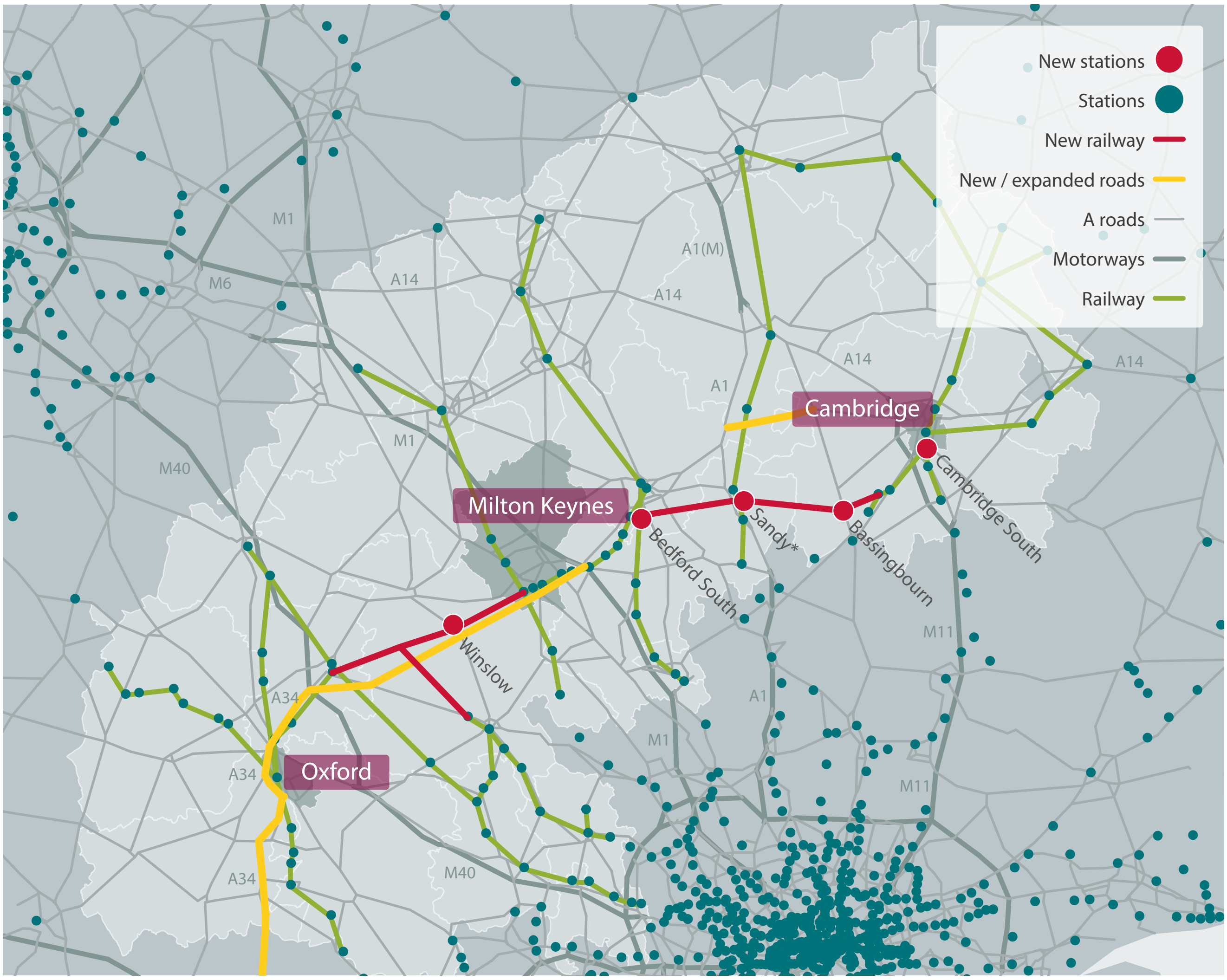


Figure 3: Expressway route B1 (marked in yellow) Oxford to Milton Keynes, and East West Rail route via Sandy and Bassingbourn (marked in red) selected for analysis.

There are important choices about these new transport routes which have yet to be finalised, and decisions about the location and density of new developments could result in a range of outcomes. At the time of writing, no decision has yet been made regarding the specific routes of the Expressway or East West Rail lines. We have selected the road and rail options shown below to include in our assessment. Other options are not considered in this study, but this does not imply those options are less likely to be chosen as the preferred routes. Any alternative option could be analysed within NISMOD.

Highways England propose several options for new road links and improvements around Oxford and between Oxford and Milton Keynes. Our assessment considers route B1, which goes to the west and north of Oxford, broadly via Bicester to Milton Keynes. A single corridor has already been identified for improvement between Milton Keynes and Cambridge (see Figure 3).

Network Rail propose options for rail stations and links towards the eastern end of the Arc, along the Bedford to Cambridge central section of East West Rail. Of the five options currently under discussion, we consider route A, which passes through Sandy and Bassingbourn (see Figure 3). The western section phase 1 between Oxford and Bicester is already operational, and the western section phase 2 is planned to reinstate and upgrade links to Milton Keynes, Bedford and Aylesbury.

We assume operational timings for each of the transport schemes: that the Expressway is operational by 2030, EWR Phase 2 is operational by 2025, and the Bedford-Cambridge ('Central') stretch by 2030 (see Figure 4).

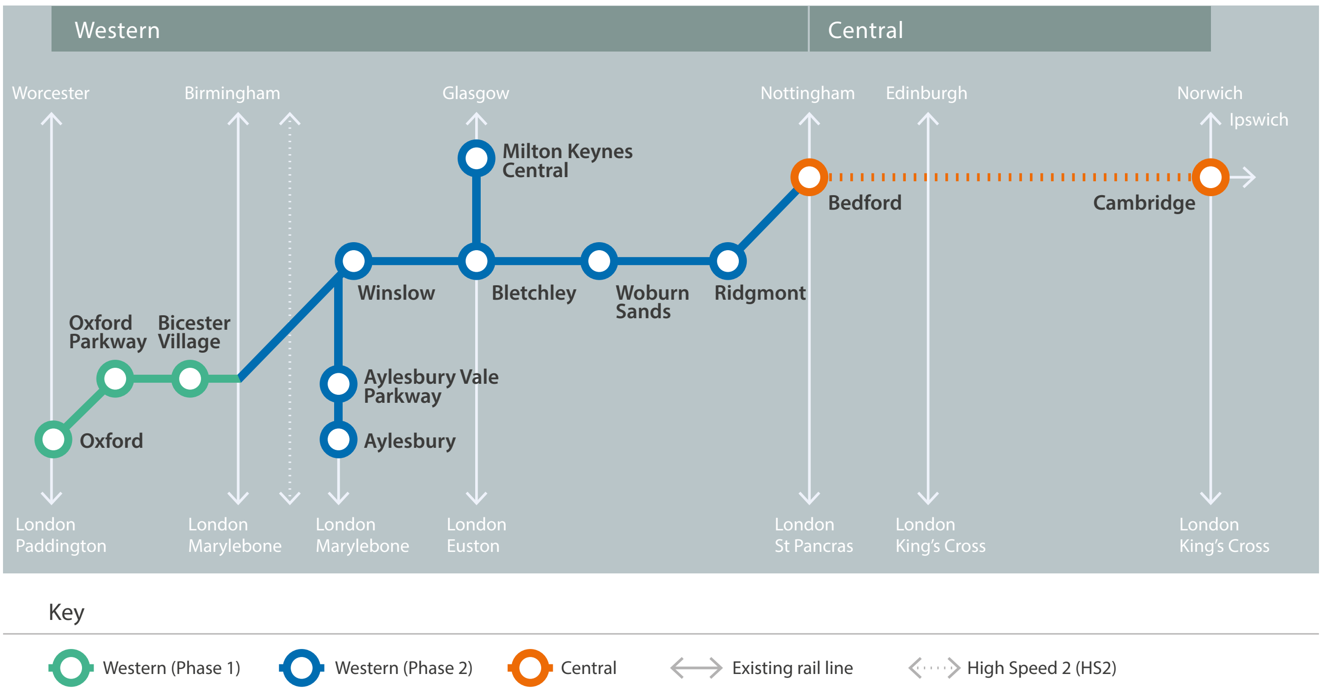


Figure 4: East West Rail planned connections (adapted from East West Rail https://eastwestrail.co.uk/the-project).

5 Scenarios of future development

As well as the transport options, there are many possible future development patterns and choices for the Arc. Scenarios of future needs for housing have been developed as part of the NIC consultation from 2016 to 2018. This projected a high growth scenario of 23,000 new dwellings per annum to meet needs within the Arc. This high growth scenario also projected an additional 7,000 dwellings per annum to relieve pressure from London and the South East. Our study adopts these same scenarios of higher developmental growth of both 23,000 and 30,000 new dwellings per annum. For a lower baseline scenario we assume 14,460 dwellings per annum, which is the average number of new dwellings completed in recent years.

The location and types of new dwellings are a key choice for the development of the Arc. There are many different ways in which a given number of new dwellings could be distributed across the Arc.[9] To illustrate contrasting possibilities, we have first analysed two spatial scenarios for new dwellings: (1) expansion of existing conurbations, and (2) the development of new settlements. NISMOD could be used to analyse many different variants of spatial development.

We consider 'Expansion' and 'New Settlements' for both 23,000 and 30,000 new dwellings per annum. We compare these planned growth scenarios with a baseline scenario based on recent average dwellings completions. We also consider an 'Unplanned' development scenario in which new housing development takes place at a rate of just under 19,000 new dwellings per annum, in response to the new transport infrastructure, but developments are allowed to occur on an ad hoc basis without an overall spatial vision. This range of spatial scenarios is summarised in Table 2.

For comparison, Figure 5 displays these levels of housing provision against the number of completions within the Arc since 2001.

For the Expansion scenarios, we have assumed that the new dwelling completions are divided among the major conurbations with Milton Keynes taking 30% of the new development, Luton and Bedford sharing 30% and the other 40% split between Oxford, Cambridge, Northampton and Peterborough. The implications of these choices are set out in Section 5.2.

9 5th Studio (2018). Cambridge, Milton Keynes and Oxford Future Planning Options Project: Final Report. Cambridge, UK.

For the New Settlements scenarios, we have assumed that there will be five new towns or cities situated near the new transport infrastructure, in locations which seem geographically appropriate for development (see Figure 8):

- Cherwell (North of Bicester)
- Aylesbury Vale (South of Winslow)
- Central Bedfordshire (North of Cranfield)
- Central Bedfordshire (East of Sandy)
- South Cambridgeshire (North of Bassingbourn)

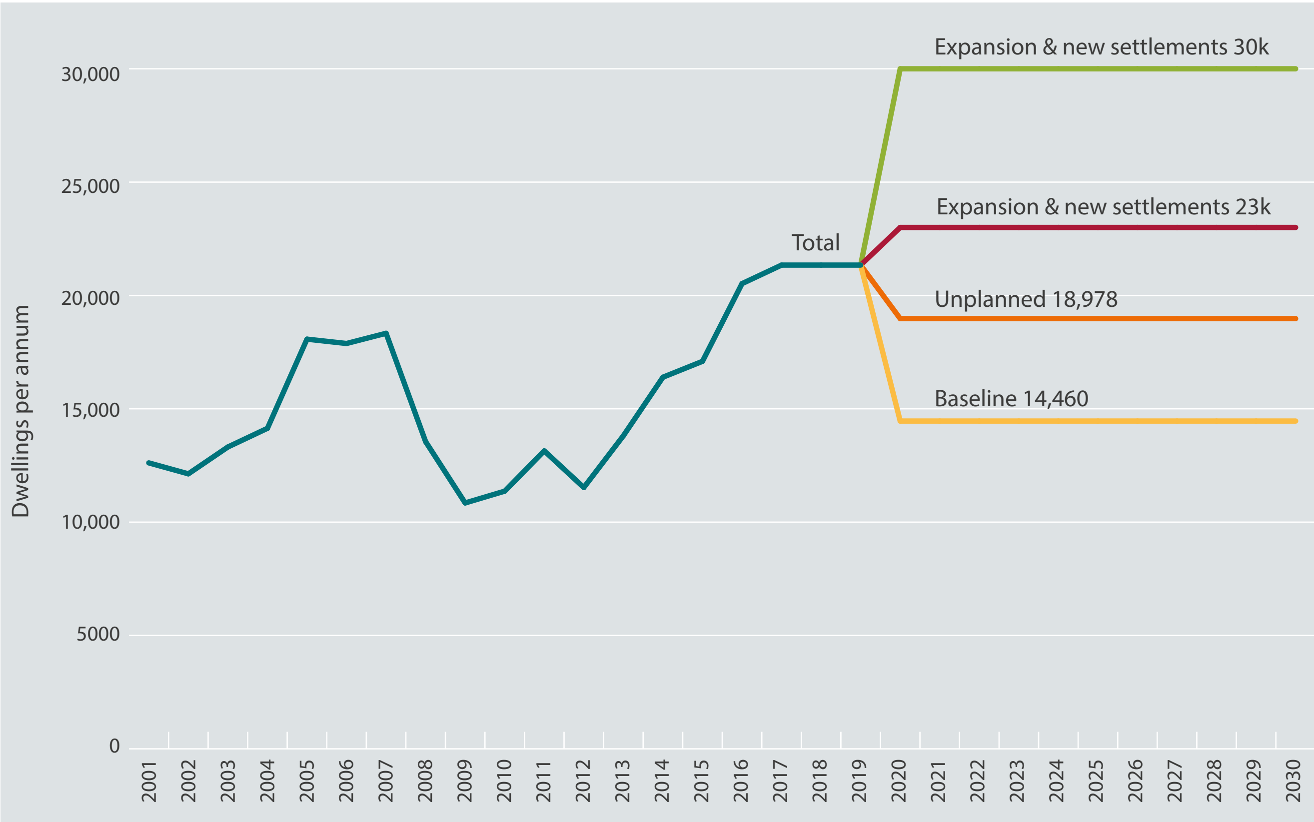


Figure 5: Recent rate of new housing provision in the Arc, compared with the future scenarios analysed in this study.

5.1 Economic scenarios

The NIC report laid out an ambition for an additional 350,000 knowledge sector jobs to be located within the Arc by 2050. This represents an increase of 50% over existing knowledge sector employment. Several significant economic changes are required to achieve this ambition, including the provision of space and premises for these new and expanded industries. If this new space for employment is to be provided, it will likely be achieved by a combination of urban densification, urban fringe developments, new hinterland locations, and at significant new developments based around prospective new stations along the planed EWR network. Our scenario of where the new employment could be located is illustrated in Figure 6.

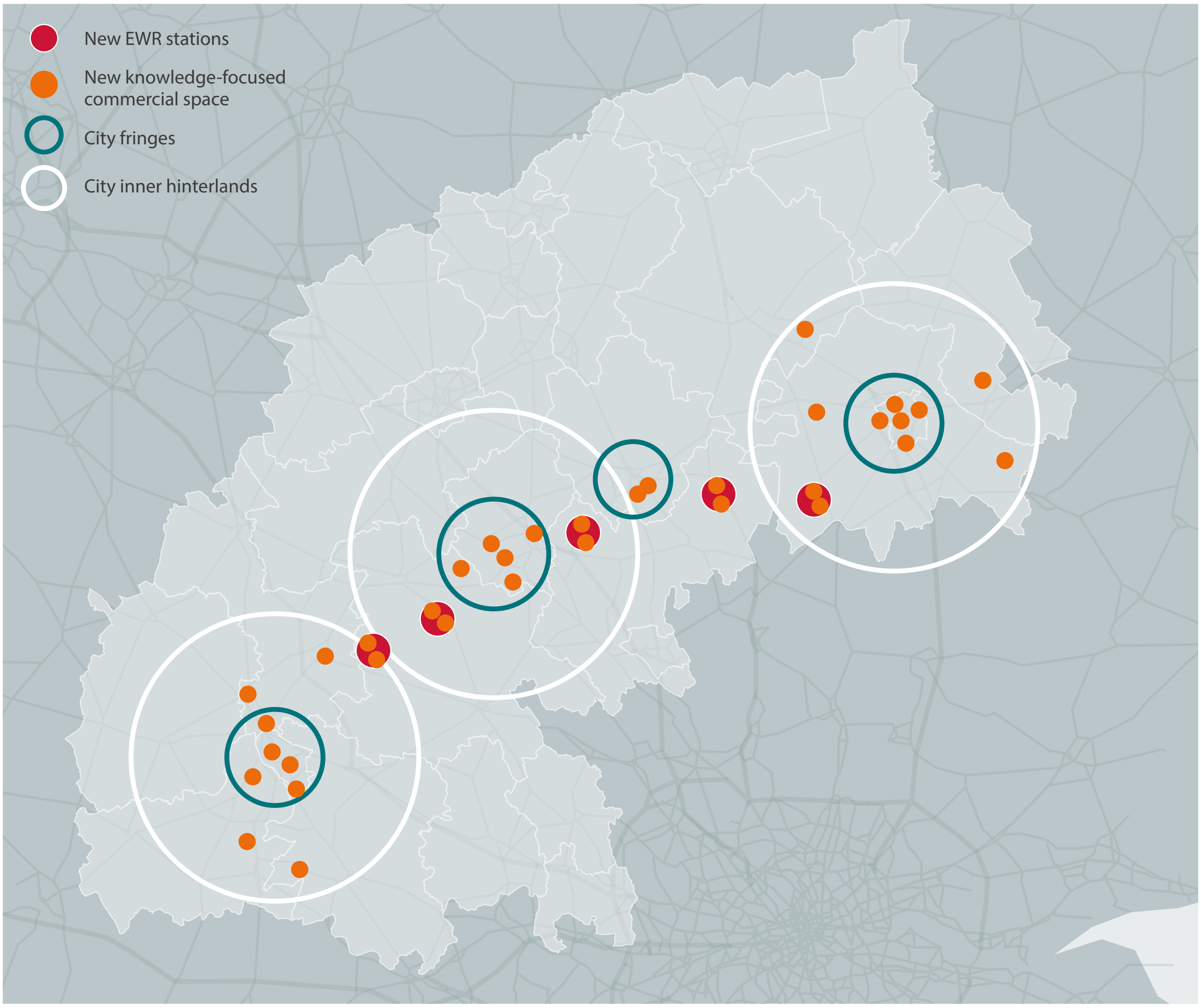


Figure 6: Indicative example showing potential new employment centres.

Table 1 shows the allocation of knowledge sector employment sites for use in the model.

Table 1: Knowledge sector employment allocation scenario	
Potential site	Additional knowledge sector jobs
Central Cambridge densification	20,000
Cambridge Fringe (<5km)	30,000
Cambridge Hinterland (>5km)	40,000
Central Oxford densification	20,000
Oxford Fringe (<5km)	30,000
Oxford Hinterland (>5km)	40,000
Central MK densification/expansion	20,000
MK Fringe (<5km)	30,000
Along EWR Route:	
New Station: North of Bicester	20,000
New Station: South of Winslow	20,000
New Station: North of Cranfield	20,000
New Station: South Bedford	20,000
New Station: East of Sandy	20,000
New Station: North of Bassingbourn	20,000
Total	350,000

In addition to the projected new knowledge-sector employment, there will be a corresponding increase in other non-tradable service sector jobs (e.g. retail and public sector). These jobs are assumed to be located in close proximity to the populations they serve.

5.2 Simulating new development scenarios

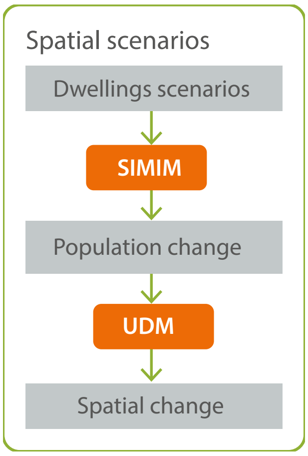


Figure 7: Generating spatial scenarios of population and development

The additional dwellings, people and jobs in the Arc region can be accommodated in a number of different ways depending on planning policies.

We use two related models to translate the dwellings scenarios into population change and to assign new development to appropriate land (Figure 7). SIMIM (Spatial Interaction Models of Internal Migration) determines the levels of population migration to and within the Arc, given the relative attractiveness of different locations. UDM (Urban Development Model) takes SIMIM outputs, and simulates the spatial patterns of new building development given land availability and other spatial constraints and attractors.

Several possible constraints on new developments are considered, including existing developments, greenbelt, flood plains and areas protected for environmental reasons. We considered different scenarios for the rigour with which these constraints are applied (Table 2). This does not mean that we advocate the existence or removal of constraints. It simply demonstrates NISMOD's capability to analyse policies that modify where land is made available for development

An example of the UDM outputs is shown in Figure 8. This highlights the different levels of development suitability and land availability given different attractors and constraints. For example, in New Settlements development of greenbelt is highly restricted, but such restrictions are not imposed for the Expansion scenario.

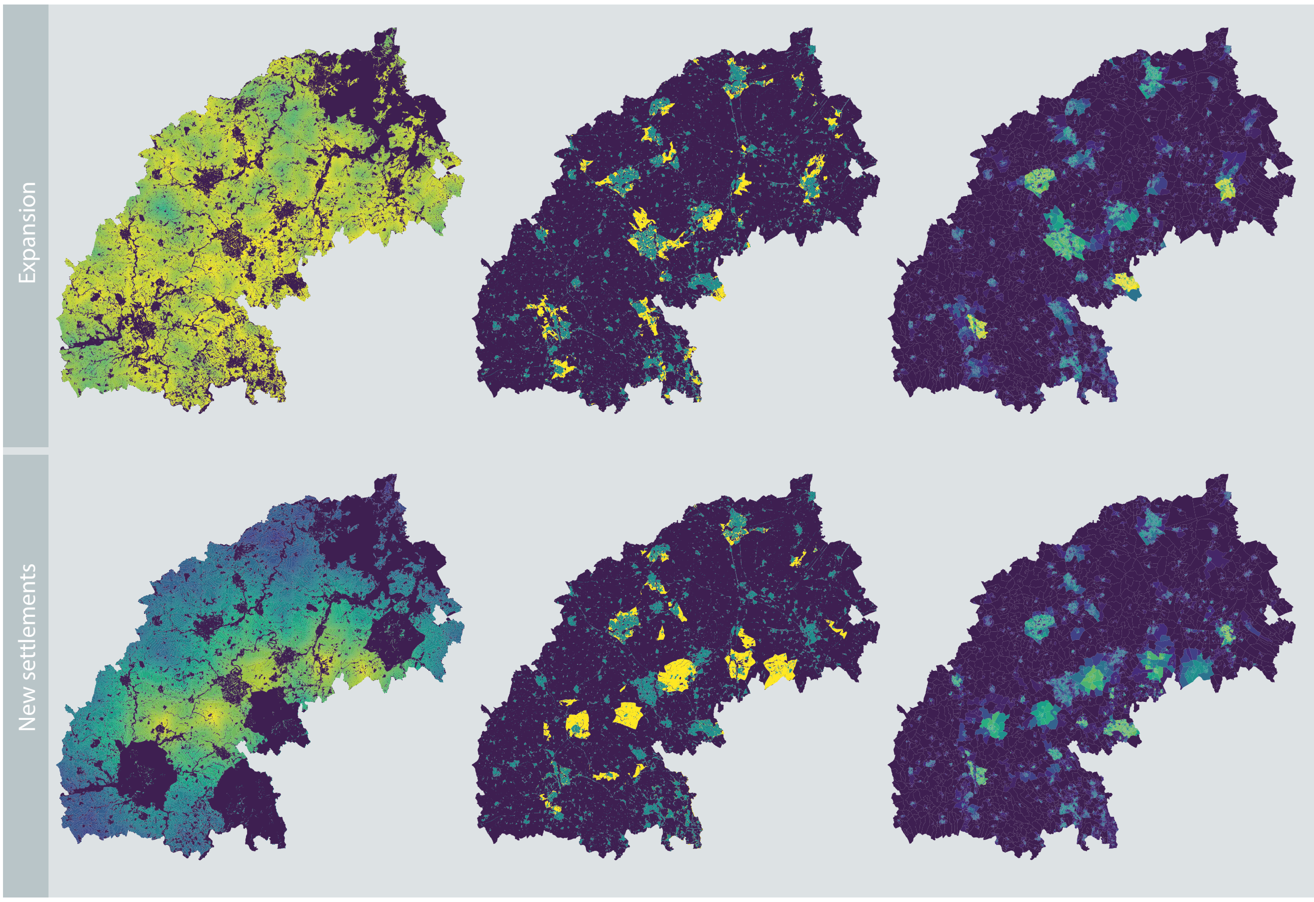
For the Expansion scenario, there are large increases in development and population density in areas around existing settlements, with currently-protected land including greenbelt surrounding Oxford and Cambridge being developed.

For the New Settlements scenario, each new conurbation implies a 180% increase (compared to baseline) in the amount of land development. However, there is significantly less sacrifice of the greenbelt than for the Expansion scenario, suggesting that careful planning could allow development, while still protecting greenbelt land and other important habitats in the Arc.

The use of a spatial development model also allows an assessment of the density that new development must achieve in order to accommodate the projected population increases across the Arc. In some cases planning constraints mean that very little land is available and thus densities are high. In the Expansion scenario, for example, the required population for new development in Oxford reaches 400 people/hectare compared to 50 people/hectare across that local authority area at present. This shows the tension between protecting valuable land and freeing up enough development space to allow construction at an acceptable density.

Table 2: Comparison of spatial scenarios for new dwellings				
Scenario	Dwellings per annum	Transport assumptions	Attractors	Development constraints[a]
Baseline Average 2007–2017 additional dwellings (Source: MHCLG)	c.14,500	No Expressway No East West Rail	Proximity to public transport, road network current development Accessibility to employment	All constraints in place **Greenbelt developed = 0 ha**
Unplanned development Slightly higher growth assumed along new transport corridors (Peak additions 2007–2017, Source: MHCLG)	c.19,000	Expressway by 2030 East West Rail Phase 2 by 2025 Bedford-Cambridge by 2030	Proximity to current development existing transport nodes and new stations, existing and new roads Accessibility to employment	Some greenbelt development allowed in LADs near new transport infrastructure Construction allowed on some protected habitats and higher flood risk **Greenbelt developed = 2160 ha**
New settlements Major growth in five new urban conurbations	23,000 and 30,000	Expressway by 2030 East West Rail Phase 2 by 2025 Bedford-Cambridge by 2030	Proximity to new development locations, existing transport nodes and new stations, existing and new roads Accessibility to employment	Construction allowed on some protected habitats near new settlement locations **Greenbelt developed = 475 ha**
Expansion Major growth around existing urban centres	23,000 and 30,000	Expressway by 2030 East West Rail Phase 2 by 2025 Bedford-Cambridge by 2030	Proximity to current development, existing transport nodes and new stations, existing and new roads Accessibility to employment	Construction allowed on greenbelt **Greenbelt developed = 12480 ha**

a The constraints considered are as follows: Greenbelt areas, Battlefields, Scheduled Ancient Monuments, SSSI, Protected Habitats, Local Nature Reserves, National Nature Reserves, World Heritage Sites, EA Flood Zone 3, Currently developed areas, Water bodies.



Key

Suitability

0		0.75	
0.25		1	
0.5			

Development

- Undeveloped
- Developed
- Future development

Density
(dwellings / ha by output area)

0–6	16–27
6–9	27–40
9–16	> 40

Figure 8: Example UDM outputs for New Settlements 30k and Expansion 30k scenarios for 2050.

Box 2: Impact on natural capital – developing a 'Green Arc' vision

'Natural capital' encompasses those elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as the natural processes and functions that link these components and sustain life. Healthy stocks of natural capital underpin the delivery of essential services for human health and wellbeing. These 'ecosystem services' include provision of food, fresh water, clean air, natural flood management, carbon storage, crop pollination, green space for recreation, and opportunities for interacting with and learning from nature.

Preserving the environment is one of the government's key themes in future developments, with a "commitment to embed 'natural capital' thinking throughout our approach to the Arc, so that we create sustainable places for people and wildlife, and ensure that we leave the environment in a better state for future generations".[10] Thus, for the Arc region, there is a need to develop a 'Green Arc' vision, with carefully planned development that preserves and integrates existing natural capital assets, and creates new green corridors for people and wildlife.

To help develop this vision, MISTRAL researchers have mapped existing high value natural capital assets as well as potential future strategic networks of 'Green Infrastructure', to inform decisions before sites are allocated for development. In the Arc, food production is a major service but the dominance of intensively farmed agricultural land means that the semi-natural habitats providing other essential ecosystem services are sparse and fragmented. Particularly in the Unplanned scenario, where development is unconstrained, there are risks of further depletion and fragmentation of important natural habitats. This threatens undermining quality of life for current and future residents, and fails to exploit opportunities such as cost-effective flood protection, carbon storage, active travel routes and health benefits.

Even with a 'Green Arc' vision in place, there will be difficult decisions to balance environmental sustainability and future developments. One key aspect of the future vision could be to minimise land take, keeping developments compact but building in enough multifunctional green space and green corridors to maintain ecological integrity and provide services for people.

This aspect of the study is on-going and will be reported further in the future.

10 MHCLG (2019). The Oxford-Cambridge Arc: Government ambition and joint declaration between Government and local partners. London, UK.

6 Results

The population and spatial development scenarios were input to NISMOD's infrastructure system models, and some of the key results are highlighted below.

6.1 Road transport

- **The Expressway offers time savings for some longer journeys, for example between Cambridge and Oxford the journey time by road is expected to decrease by 15-20 minutes on average.**
- **High population growth scenarios result in increased congestion levels throughout the road network, especially on the existing trunk roads and motorways that traverse the Arc.**
- **Planned road expansions and developments may initially generate some travel time savings, but are insufficient to prevent travel time increases in the longer term, unless steps are taken to manage demand for road travel (e.g. via shifts to rail) and reduce congestion.**
- **Conversion to electric vehicles would result in a sharp decrease in carbon emissions and other air pollutants by 2050, but would lead to substantial new electricity demand from the transport sector.**

New roads and Arc connectivity

Our strategic road transport model demonstrates that the Expressway provides a new fastest route between Oxford and Cambridge, as traffic no longer has to negotiate roads in and around Milton Keynes. Travel times are reduced by 15–20 minutes compared with baseline journeys. However, for journeys between central Milton Keynes and Oxford, there are several existing routes which provide similar or faster travel times (see Figure 9). Locally, the new road link will, for example, be beneficial to the inhabitants of Winslow (or any new cities built in that area), for improving their commute to Oxford or Milton Keynes.

Increasing congestion and travel times

Road expansion interventions on the A428 (between Cambridge and Milton Keynes), and around Oxford (in B1 variant) are predicted to initially reduce congestion, but are not sufficient to deal with major population increases that are expected by 2050, when there are many congested areas present in all scenarios in the absence of strong action to reduce demand, such as road user charging designed to incentivise shifts to rail and active travel.

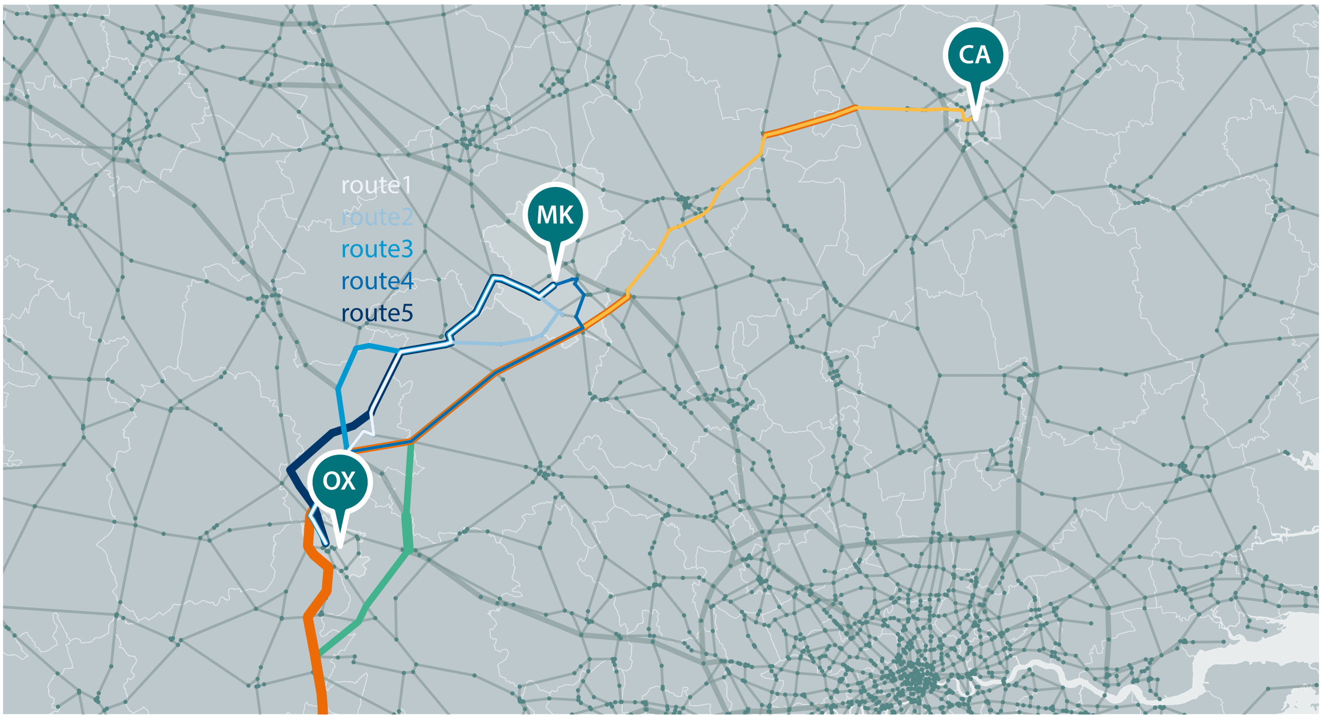


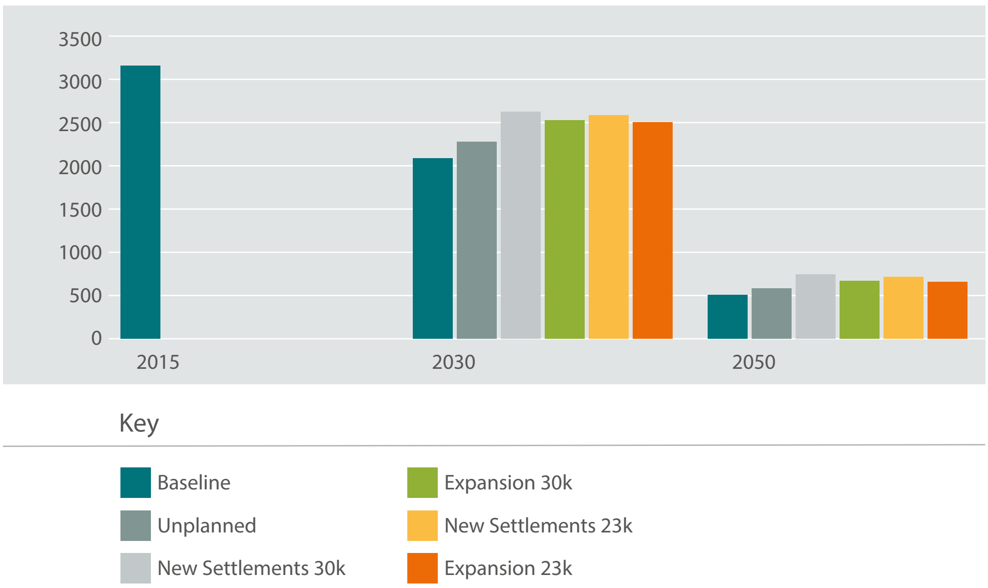
Figure 9: Route sets for fastest trips between the centres of Milton Keynes and Oxford (blue) and Cambridge and Oxford (yellow).

High increases in car-dependent population will soon require even more interventions to address the capacity pinch points, whether in the form of additional road construction or demand management measures and the provision of alternative travel options.

Vehicle electrification and carbon footprint

Despite the population growth, a substantial decline in CO_2 emissions can be expected as a direct result of vehicle electrification (see Figure 10). In 2050, CO_2 emissions from car trips are expected to drop to about 20% of the base-year emission. Spatial analysis across the scenarios suggests that in 2050 there will be more CO_2 emissions in New Settlements and Expansion scenarios compared to the Baseline and Unplanned scenarios, consistent with their population projections. CO_2 levels also increase in LADs through which the Expressway passes.

Figure 10: Yearly CO_2 emission for car trips in the Arc.



6.2 Energy supply

- **There are different ways in which the goal of a carbon-neutral Arc (for energy supply and buildings) can be achieved.**
- **Consistent with the UK's current energy policies, we assume that electricity supplied by the national electricity transmission system will be near zero carbon by the 2030s.**
- **Coordinating the connection of electric vehicles (EV) to the grid could generate up to 25% of the Arc's electricity needs by 2050.**
- **Local renewables have the potential to contribute up to 15% of the Arc's electricity needs in 2050, primarily from photo-voltaic (PV) panels.**
- **EVs, local renewables and combined heat and power (CHP) units connected to heat networks could supply up to two-thirds of the Arc's electricity requirements in 2050.**
- **The national electricity transmission system would still be required to provide backup. In 2050, from 60% of overall electricity supplies in electric-based Arc strategies to 30% where heat networks are prevalent.**
- **Gas use decreases by at least 90% in 2050 compared with 2015 in heat electrification strategies across all scenarios.**
- **Eliminating carbon emissions from heating systems will be much more disruptive than decarbonising existing electricity supplies, which can be more or less 'invisible' to the consumer. Nonetheless, electrification of heating in the Arc region by utilising heat pumps, resistive heating and electric boilers, and running these on decarbonised electricity can cost-effectively reduce residential and commercial emissions to near zero.**
- **An electric heating strategy and rapid uptake of electric vehicles is projected to double the annual and peak electricity demand in 2050 (compared to 2015), requiring significant additional generating and electrical network capacity.**
- **Demand for electricity (including for heating) could be reduced by 7% relative to a 'business as usual' building scenario through the adoption of energy efficiency and insulation solutions.**
- **Implementation of Demand Side Management (DSM) solutions illustrates the possibility of shifting up to 1GW peak electricity demand to off-peak periods.**

Meeting the net zero carbon emissions target by 2050 is likely to require a power system that is largely decarbonised and heat related emissions from buildings substantially reduced. These are formidable objectives and will require laying the foundations for these emission reductions by the late 2020s.

Planning and preparation for decarbonising the energy system needs to commence in order to pave the way for emission reductions in a cost-effective manner whilst meeting end user requirements. National energy system decisions and polices have a direct impact on the options available locally. As an example, the rate of decarbonisation of the national power system influences the carbon emissions footprint of energy consumed locally.

NISMOD's energy systems model was used to assess the how different strategies for energy supply, from zero carbon electricity to use of 'green' gases or local heat networks, could affordably reduce or eliminate carbon emissions from the Arc's energy system. A summary of these strategies is illustrated in Table 3.

A summary of key modelling metrics such as emissions, energy demand and supply, and costs over Arc scenarios and strategies are shown in Figure 11, and discussed further below.

Table 3: Summary of heat supply system strategies (2050)

<table>
<tr><th rowspan="2"></th><th colspan="4">Energy strategy</th></tr>
<tr><th>Electric</th><th>Heat networks</th><th>Green gas</th><th>Unconstrained</th></tr>
<tr><td>Heat supply</td><td>Heat supply driven completely by electricity: Heat pumps, resistive heating and electric boilers.</td><td>Heat supply is mainly from CHP units utilising natural gas, biomass and solid waste.

Availability of biomass and solid waste is restricted.

Gas boilers are used to back-up CHP units during peak periods.</td><td>Use of dedicated hydrogen boilers for heating.

Gas boilers remain to produce heat (as green gas is injected into the gas mix).

Biomass/Biogas CHP units are installed.</td><td>Full availability of technologies.

Availability of resources such as biomass and waste.</td></tr>
<tr><td>Electricity supply</td><td colspan="4">Distributed wind and solar (PV).

CHP units are installed as they produce heat (Heat driven CHP operation) and power.</td></tr>
<tr><td>Gas supply</td><td colspan="2">Transmission grid supplies are available with limited gas storage facilities within the region.</td><td>Hydrogen and biogas injection into the gas grid limited to 20% by volume.

Large scale hydrogen production via SMR, CCS, and small-scale electrolysis deployments.

Hydrogen is supplied via new hydrogen pipelines and re-purposed gas distribution pipes.</td><td>Transmission grid supplies are available with limited gas storage facilities within the region.</td></tr>
</table>

Figure 11 shows a comparison of the business-as-usual (BaU) 2015 case with key modelling metrics in 2050, shown under each strategy investigated – Electric, Heat Networks, Green Gas and Unconstrained. Each row describes a different metric, as follows: (1) annual heating demand and the share of heat supply by different technologies; (2) the share of electricity supply by technology, the largest electricity peak demand (in this case Expansion 30k scenario) and a comparison of annual electricity demand between BaU and Expansion scenarios; (3) the change in annual natural gas supply across strategies, shown as the lowest and the highest annual gas supply among Arc scenarios; (4) annual emissions (ktCO_2) in 2050 for BaU and the change in emissions for other Arc scenarios with respect to Baseline; (5) cumulative annual costs per household to implement the strategy up to 2050, comparing BaU and the lowest Arc scenario (Expansion 30k in this case).

Energy demand

Scenarios with higher population growth rates (30k variants) have the highest annual demand (70TWh average across strategies) in 2050. This is an additional 10TWh demand compared to BaU. 'Electric' heating strategies have a lower overall demand for energy in 2050 than BaU (2015), mainly due to highly efficient heat pumps. This is in contrast with the 'heat network', and to a lesser degree 'green gas' strategies which predominantly use CHP units. Whilst being efficient, these do not provide the performance offered by heat pumps. Thus, for 'heat networks', final energy demand in 2050 is nearly double that for the 'electric' strategy.

Electricity supply and demand

In 'electric' based strategies across the 30k scenario variants, the combination of EV charging and electrification of heat more than doubles both electricity peak (~11GW) and annual demand (~54TWh) in 2050 compared with 2015. Of this, EV charging accounts for approximately 4GW of peak electricity and 15TWh of annual demand.

Some electricity demand in 2050 can be met by supplies from within the Arc (e.g. 34% in an 'electric' strategy, 66% in the 'heat networks' strategy where co-generation units are employed). Electricity supplies from EV utilisation of vehicle to grid services provide approximately 25% of the electrical demand, with other renewables accounting for 15%. Additional generation in 'heat networks' and 'green gas' strategies is from gas, biomass or waste CHP units.

The national electricity transmission system maintains a prominent role in balancing electricity supply and demand within the Arc, with more than 50% of electricity demand in 'electric', 'green gas' and 'unconstrained' strategies being met by supplies from the electricity transmission system.

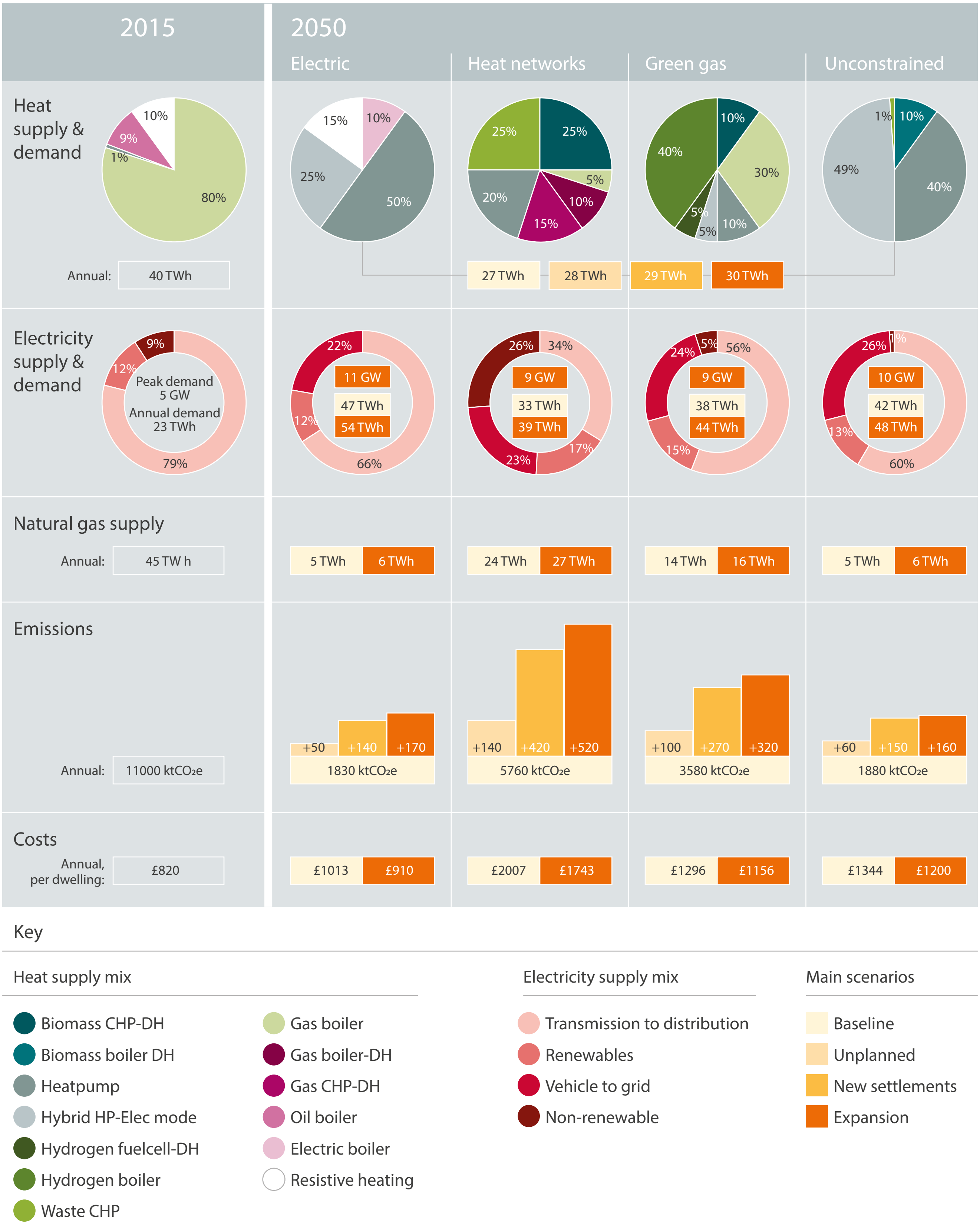


Figure 11: Summary of key output metrics.

Gas demand

Annual demand for natural gas drops significantly across the Arc scenarios by 2050, to less than half of that in 2015 (~45TWh). In the 'electric' and 'unconstrained' heating strategies in 2050, the gas demand declines even further to 5TWh/year (90% lower). As natural gas has no significant role in these electric heating strategies, the variation in population and dwellings across the Arc scenarios has little or no impact on the gas demand. The use of natural gas is highest (~12TWh) in the 'heat networks' strategy in 2050 as it is mainly used to produce heat via district heating CHP units and boilers. In the 'green gas' heating strategy natural gas demand declines to 8TWh as biomethane and hydrogen are blended into the gas network.

Options for decarbonising heat, emissions and overall implementation costs

The overall demand for heating declines by 2050 across all scenarios due to ambitious 25% savings from improved insulation, thermal comfort in the building stock and a 100% smart meter rollout across the region. The Expansion 30k scenario has the highest heating demand of ~30TWh, which is an additional 4TWh of demand compared to BaU.

The heat supply strategy options illustrate ways of meeting the demand for heating up to 2050 across Arc scenarios. The heat options, emissions and implementation costs (energy system in the Arc region) are described as follows:

Electrification of heat

Decarbonisation of heat can be achieved by switching from a system with predominately gas boilers to one that is built to accommodate heat pumps (dwelling level), resistive heating and storage, and running these on decarbonised electricity. The model outputs for the 'electric' strategy across all Arc scenarios show that this would require significant additional generating and electrical network capacity. The overall costs per dwelling of applying this strategy across the scenarios are approximately £130 per annum greater than BaU (2015). Given this and the near zero emissions in the residential and commercial sectors, this strategy performs strongest across all key metrics when compared with others.

In scenarios where retrofitting of existing buildings is required the implementation of an 'electric' strategy would entail the requirement of radical change in infrastructure at the end user level, such as each household either acquiring a heat pump, resistive heating system or electric boiler. It becomes a great deal easier to incorporate this change on new dwellings proposed in the scenarios (especially in 'New Settlements' and 'Expansion').

Decarbonisation of the gas distribution system

The UK has an extensive gas transmission and distribution system. Although the use of natural gas will reduce over time, the modelling suggests a residual role for gas by 2050 to help meet peaks in heat demand in all scenarios including those based exclusively on electricity heating strategies.

The gas network could still be utilised in several ways, for instance by mixing natural gas with hydrogen (up to 20% by volume) or biomethane for partial decarbonisation. This has the advantage that minimal changes would be required for end use appliances such as gas cookers and boilers. A side benefit of the Iron Mains Replacement Programme (IMRP), which since 2002 has been decommissioning cast iron mains near existing properties, is that new polyethylene pipes are suitable for full hydrogen flows. This implies the possibility of near zero carbon emissions with relatively low network repurposing costs. The challenge of producing hydrogen at such scale and to do so commercially and carbon free is articulated within the 'green gas' strategy for the Arc scenarios.

Hydrogen production in the 'green gas' simulation is expected to be from steam methane reforming (SMR) with carbon capture and storage (CCS), hoped to be technically and commercially viable in the 2030s, and to a lesser degree through electrolysis (powered by mainly renewables and other low carbon sources). The overall costs per household for implementation of the 'green gas' strategy across the scenarios are on average around £400 per annum greater than BaU 2015 case. In this strategy, emissions by 2050 are about 70% lower than in 2015.

Heat networks

The 'heat networks' strategy focuses primarily on combined heat and power (CHP) based heating technologies. The heating source for heat networks can be changed without excessive disruption. For instance, biomass CHPs can be replaced by gas fuelled units or alternatively by large heat pumps. Implementation of this strategy results in the largest costs per household across all strategies and scenarios of approximately £1,180 per annum greater than BaU, whilst emission reductions are not as impressive (around 50% reduction from 2015 levels). With the 'New Settlements 30k' and 'Expansion 30k' scenarios, given higher demand (for heat) densities and possible synergies during the construction of heat networks and new dwellings, potential reductions in annual costs of approximately £300 per dwelling are feasible.

There are several areas where progress needs to be made to fully realise the benefits offered by district heating systems. These include economic issues which are mainly centred around digging and laying of hot water pipes and high capital costs of CHP based technologies. Heat network systems also suffer from perceived technological shortcomings, which can partly be countered by demonstrations and exemplars. Lastly, complexity of 'business models' which can range from a lack of understanding around ownership issues such as who owns the network, who operates it and what the grievance procedures are. Some of these issues may well be addressed by future regulation of the heat supply and network sector.

Additional measures

A Demand Side Management (DSM) scheme across all strategies was evaluated in 2050. It assumed a maximum shifting capability of 10% electricity demand at peak to off peak periods. The DSM scheme, either via electric vehicles or appliances and smart meters within dwellings reduced peak electricity demand by an average of 1GW across all strategies. This is translated into cost savings with minimal negative impact on emissions, despite the use of non-renewable based generation technologies.

The impact of a further 10% reduction in overall heating and non-heating demand in 2050 due to better insulation and efficiency improvements in dwellings was assessed across all strategies. This showed a reduction of annual heating demand of ~8TWh in both 'green gas' and 'heat network' strategies. In electric dominant strategies the annual energy demand was reduced by 4.5TWh. These results demonstrate the vital impact of demand reduction especially for heat strategies that are predominately CHP based.

Summary

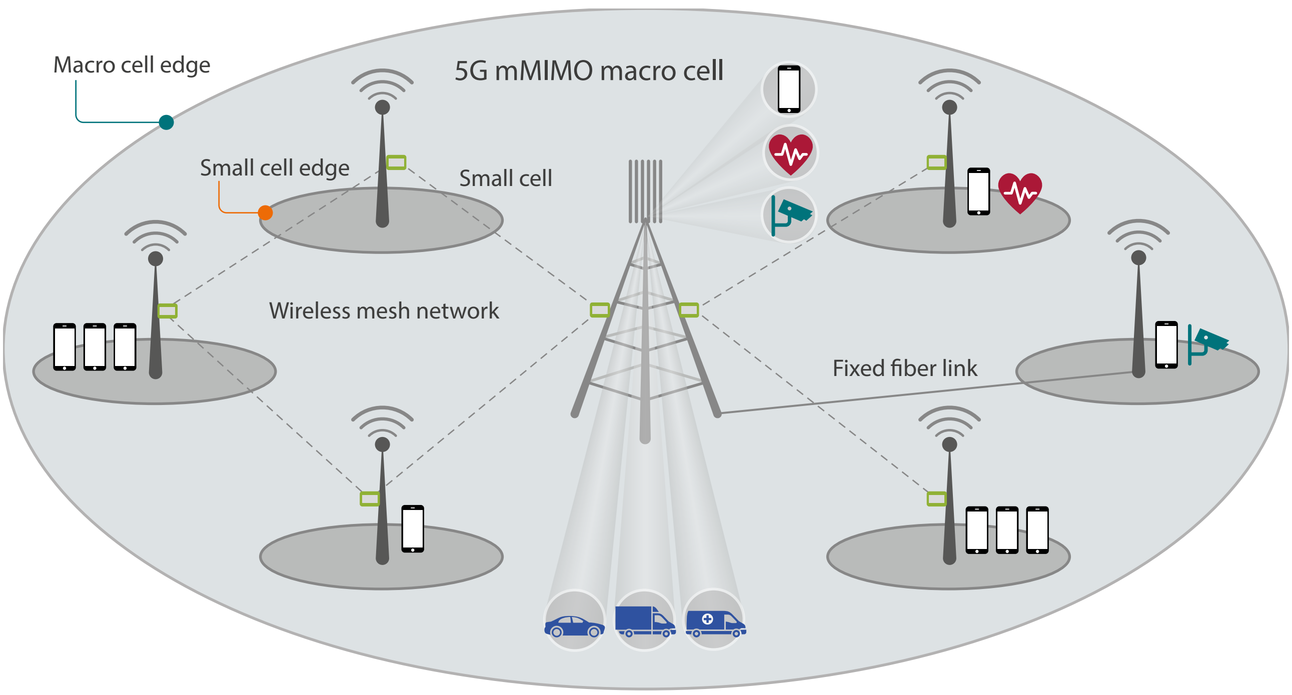
Electrification of heating in the Arc region was shown to be the most cost-effective way to meet emission targets across all scenarios despite requiring significant additional generating and electrical network capacity. For existing dwellings this will entail radical change in infrastructure at the end user level such as installation of heat pumps and will be disruptive to householders. Before contemplating expensive energy infrastructure, insulation and energy efficiency solutions should be considered. Most low-carbon heat technologies across the scenarios and strategies analysed have high upfront capital costs in comparison with incumbent technologies and networks, such as gas distribution networks and boilers. This is a barrier for early deployment, but the UK must make a stand on this and absorb these early costs so that technological learning (costs and efficiencies) can be made and the workforce can be sufficiently trained to allow a relatively smooth transition to one of these low-carbon pathways.

6.3 Digital communications

- **5G strategies that meet data demand were assessed for 2020–2030.**
- **Population change has minimal impact on demand for 5G infrastructure.**
- **Baseline growth can be met using brownfield Macro Cell sites and new 5G spectrum.**
- **Greenfield Small Cells should only be deployed in the densest urban areas.**
- **Digital infrastructure needs to be considered at the greenfield planning stage, particularly when planning new transportation corridors.**
- **Mobile data demand to 2030 can be met throughout the Arc using 5G for £160 million per operator.**
- **Full fibre broadband can be delivered for between £1.59–2.34 billion depending on the scenario and deployment strategy.**

The fifth generation of cellular technology (5G) will provide significant improvements over the previous generation (4G), by providing enhanced capacity, as well as reduced latency. Mobile Network Operators around the world have begun to roll-out new 5G infrastructure.

Figure 12: Feature of 5G infrastructure.



While many 5G use cases are proposed, the main current use is enhanced mobile broadband. Significant supply-side changes are expected in how mobile networks deliver data services, including the deployment of new spectrum bands utilising more efficient 5G technologies and increased network densification via the deployment of Small Cells, as illustrated in Figure 12. Such changes should provide considerably enhanced capacity for users.

However, much excitement is associated with the potential demand-side impacts resulting from digital transformation in vertical industrial sectors such as utilities, manufacturing, health and automotive.

From our analysis, different scenarios of population change have only a minimal impact on the demand for 5G infrastructure, as the main factor driving demand is the increase in per user data consumption, driven predominantly by on-demand video.

We also find an approach that re-uses brownfield Macro Cell sites is satisfactory in meeting baseline data demand over the study period. This results from the availability of new 5G spectrum bands and the increased efficiency of 5G technologies, as well as existing 4G being sufficient to meet demand in some places. The cost for upgrading existing brownfield Macro Cell sites with 5G technology by 2030 is estimated to be approximately £160 million per operator for the Arc. In contrast, the deployment of Small Cells proved to be most suited to dense urban areas, because while Small Cells provided significant capacity enhancement, they were much more expensive to deploy, especially in lower population densities, as illustrated in Figure 13.

However, there is long-term value in exploring the deployment of Small Cells in the densest urban areas, as this future-proofs capacity, and provides the highly reliable, low latency connectivity required for upcoming 5G use cases.

Planners need to consider how the delivery of digital infrastructure can be incorporated into the cycle of building and maintaining other infrastructure sectors. As just one example produced for the NIC,[11] the capital expenditure cost for UK-wide full Fibre-To-The-Premises was estimated to be £28 billion, compared to £20 billion if existing ducting and overhead pole infrastructure is re-used. Hence, re-using existing assets can help to reduce capital expenditure by up to one third. Similar cost savings will be achievable in 5G deployment.

11 Tactis & Prism (2017) Costs for digital communications infrastructures. A cost analysis of the UK's digital communications infrastructure options 2017–2050.

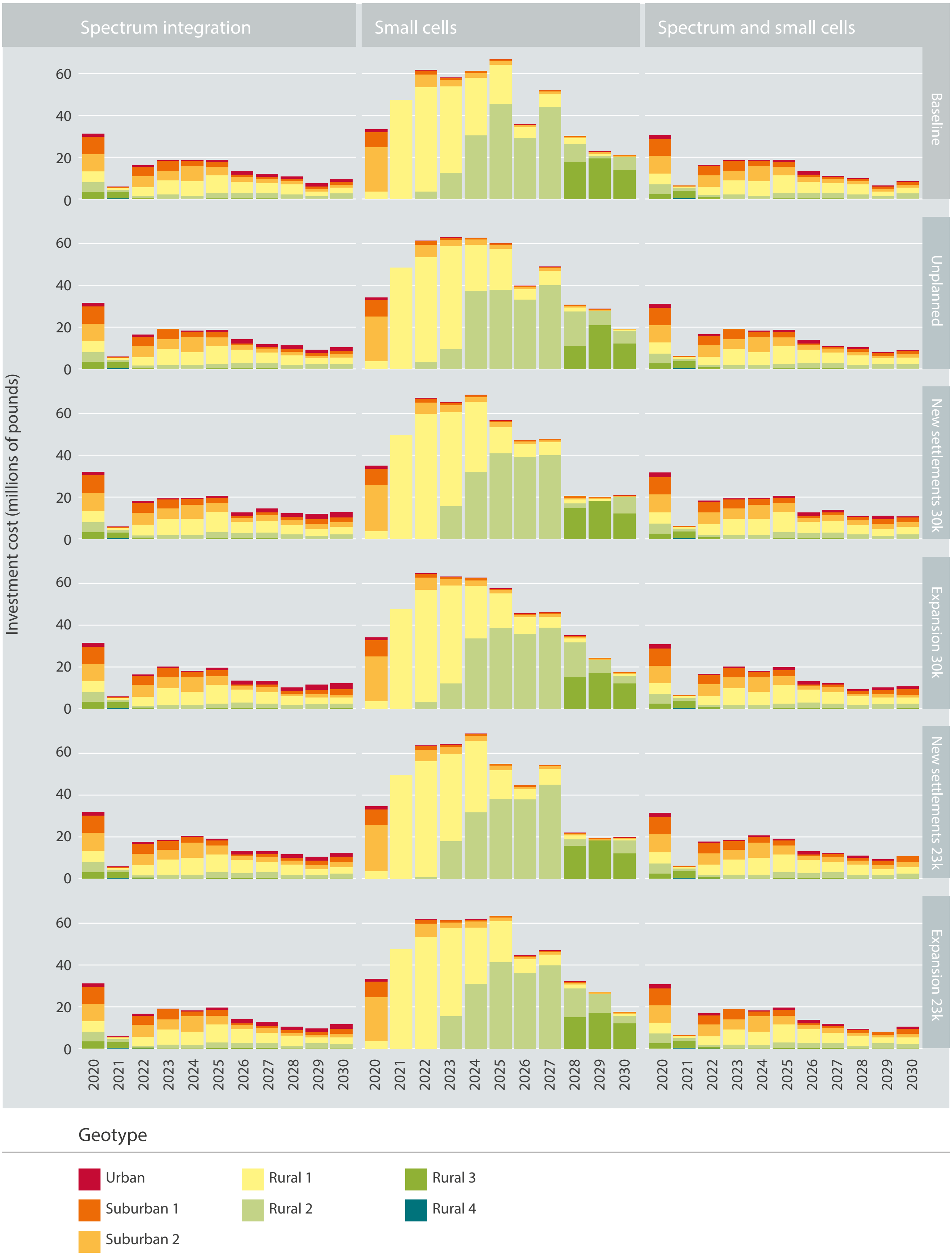


Figure 13: Investment broken down by settlement type.

The cost of delivering full Fibre-To-The-Premises broadband in the Arc by 2050 ranges from £1.59-2.34 billion depending on the Arc scenario and strategy. Costs are lower if existing underground ducting and overhead poles are re-used as shown in Table 4. Ofcom has been taking measures to ensure existing infrastructure is open for fibre deployment, therefore the likelihood is that re-use will take place in most circumstances, and lead to lower costs.

Table 4: Estimated costs of delivering FTTP broadband in the Arc (for all premises built by 2050)

	Baseline	Unplanned	Expansion	New Settlements
Costs of 100% FTTP with infrastructure re-use	**£1.59 billion**	**£1.66 billion**	**£1.85 billion**	**£1.87 billion**
Costs of 100% FTTP with no infrastructure re-use	**£2.05 billion**	**£2.12 billion**	**£2.33 billion**	**£2.34 billion**

The findings have large ramifications for public policy, as local, regional and national governmental decision makers can grant access to publicly owned assets to help expedite the roll-out of 5G digital infrastructure. While this could also bring new sources of revenue, decision makers need to be aware that (i) charging high rents may lead to decreased infrastructure investment, and therefore detract from delivering the reliable and consistent connectivity which the digital economy needs, and (ii) the more expensive it is to cover urban and suburban areas, the fewer resources mobile operators have to fund digital infrastructure in otherwise non-viable areas (e.g. rural areas).

6.4 Water

- **Long-term national water demand is expected to decrease if water companies' future demand management measures are met.**
- **However, long-term water demand in the Arc increases for New Settlements, as the effects of high population growth exceed the expected reductions in demand.**
- **At the eastern end of the Arc, the New Settlements scenario could result in a doubling of the annual risk of water shortages.**
- **Growth in water demand in the Arc can best be mitigated by water companies investing in reducing leakage and applying vigorous demand management measures.**
- **New water supply infrastructure can also bring the risk of water shortages to acceptable levels, including new reservoirs (Abingdon Reservoir, South Lincolnshire Reservoir), water transfers (Trent to Rutland, Severn to Thames) and effluent re-use schemes (Beckton).**

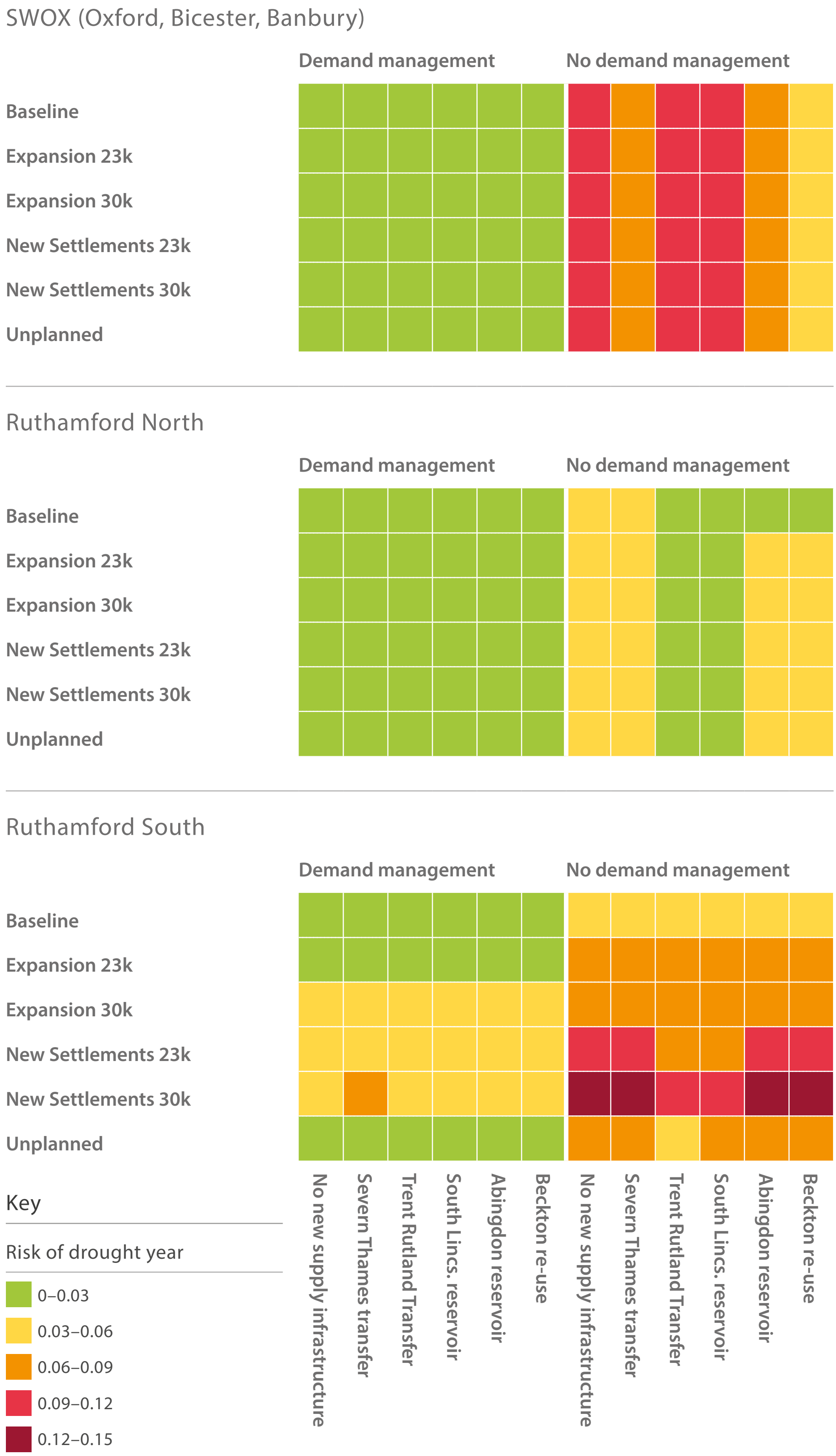
The Arc is served by four water companies (Thames Water, Anglian Water, Cambridge Water and Affinity Water). For this assessment, we focus on the three key water resource zones (WRZ) in the Arc: SWOX (Oxford, Bicester, Banbury), Ruthamford North (Northampton, Peterborough, Wellingborough), and Ruthamford South (Bedford, Milton Keynes, Huntingdon). Cambridge is not explicitly included in these analyses.

We analysed changing demand for water in the Arc and the impacts of climate change on water availability. Population growth will increase demand for water (which may be offset by reductions in per capita demand), whilst climate change is making the Arc region warmer (on average) and is making rainfall less predictable. Our analysis examined the strategic water supply infrastructure options being considered by water companies. The results are presented in terms of the annual probability of water shortages.[12]

Figure 14 shows the annual risk of water shortages for each WRZ in the 2030s. The results are given for each of our scenarios, with two levels of actions around demand management and leakage reduction (either current levels of demand and leakage, or the more ambitious levels that water companies are now planning for) and for a range of water supply infrastructure options.

12 We consider the more severe Level 3 and Level 4 restrictions on water use.

Figure 14: Risk of water shortages in the 2030s for different Arc scenarios, levels of demand management and water supply infrastructure options.



All large infrastructure options under consideration in this region have some impact in reducing risk. The Thames Water options (Severn Thames transfers, Abingdon reservoir, Beckton re-use) benefit the SWOX WRZ, while the Anglian Water options (Trent-Rutland transfer, South Lincolnshire reservoir) mainly benefit Ruthamford North, with Ruthamford South achieving some gains.

In general, reservoirs are more effective than transfers, since during droughts when the transfer is needed, the transfer source is also likely to be under stress and have less water available. There are significant environmental impacts of both transfers and reservoirs. While more expensive, the Beckton effluent re-use scheme (Thames Water) is the most effective option at reducing risk.

Figure 14 suggests that the best approach may be to focus on demand management and leakage reduction, options which have very few unintended consequences (environmentally or otherwise) and prove to be the most effective means at reducing risk of water use restrictions. The proposed levels of leakage reduction and demand management are already incorporated in water companies' future plans, but it is difficult to predict how effective these will be in practice.

The different dwelling/population scenarios for the Arc impact the risk of restrictions to varying degrees. The western area (SWOX) is much more sensitive to water demand changes in London (not examined here) than it is to any of the Arc scenarios. Ruthamford North has increased in risk under all scenarios, but 'Expansion' in particular. Ruthamford South has increased in risk under all scenarios, but 'New Settlements' in particular. The 'Unplanned' scenario has the lowest increase in risk relative to the baseline because population growth is lower overall and is spread across the Arc rather than being concentrated in any particular centre(s).

Thames Water manage the risk of water shortages for any Arc scenario by either fulfilling their plans for leakage reduction and demand management, or by extensive water re-use at Beckton (a 300Ml/d project), which would be one of the largest schemes of its kind in the world. Anglian Water's plans can manage the risk of water shortages for any Arc scenario other than the 'New Settlements' scenario, which would increase the risk of water shortages. The South Lincolnshire reservoir is highly effective at mitigating risk in the Ruthamford North WRZ, but Ruthamford South would still be subject to increasing risk if the Arc goes ahead. If, for example, a transfer from the reservoir to Ruthamford South were to be implemented, then the 'New Settlements' scenario may become viable.

Box 3: Urban drainage

New conurbations require an effective urban and wastewater drainage strategy, allowing cost-effective and efficient use of sewer networks and Waste Water Treatment Plants (WWTPs). Conventional urban drainage design in the UK has traditionally relied on urban runoff being conveyed through the sewerage network mixed with wastewater. That results in unnecessary treatment of large volumes of storm water at WWTPs and the widely recognised problem of sewer overflows during storms.

This ITRC-MISTRAL research applies a flexible and powerful methodology for defining an urban configuration and then modelling its drainage, allowing a range of realistic representations of surface drainage to be assessed. We consider the economic and physical impacts of alternative drainage strategies, primarily separation of the networks (clean and foul) and use of Blue Green Infrastructure. This work assesses these strategies using new simulation methodologies for (a) generating realistic urban and drainage layouts at the full town scale and (b) estimating the cost and performance of drainage solutions.

As a proof of concept, a typical single urban area was chosen from the 'New Settlements' scenario for the Arc region, using outputs from the Urban Development Model (UDM) to generate a detailed spatial mapping of possible land development patterns and associated residential densities, represented by a set of one-hectare tiles.[13] Buildings, green and impermeable spaces are all represented in the CityCAT flow modelling system, and a design storm applied to the model resulting in flooded areas which can be mapped and flood risk estimated.

Examples of the flood depth resulting from the different models are shown in Figure 15. These results show that surface flows are primarily governed by the natural topography, but are heavily modified by the road network acting as channels. The introduction of a sewer network at standard drain spacing has a major benefit in reducing flooding, further improved by introducing a higher density network.

This work is ongoing. The next steps are to extend the idealised drainage system to include the sewer pipe network. Simple costing methods will then be applied to estimate: (a) costs of pipe network and inlet drains for different levels of service; (b) costs and benefits of multiple decentralised WWTPs relative to single WWTP and associated pumping; and (c) costs of Blue Green Infrastructure solutions to achieve same levels of service.

13 This work makes use of 16 tile types, four in each housing category of Detached (D), Semi-detached (S), Terraced (T) and Flats (F) with specified density of dwellings and proportion of impervious and green areas. See Hargreaves, A.J. (2015). Representing the dwelling stock as 3D generic tiles estimated from average residential density. *Computers, environment and urban systems*, **54**: 280–300.

a) No sewer network

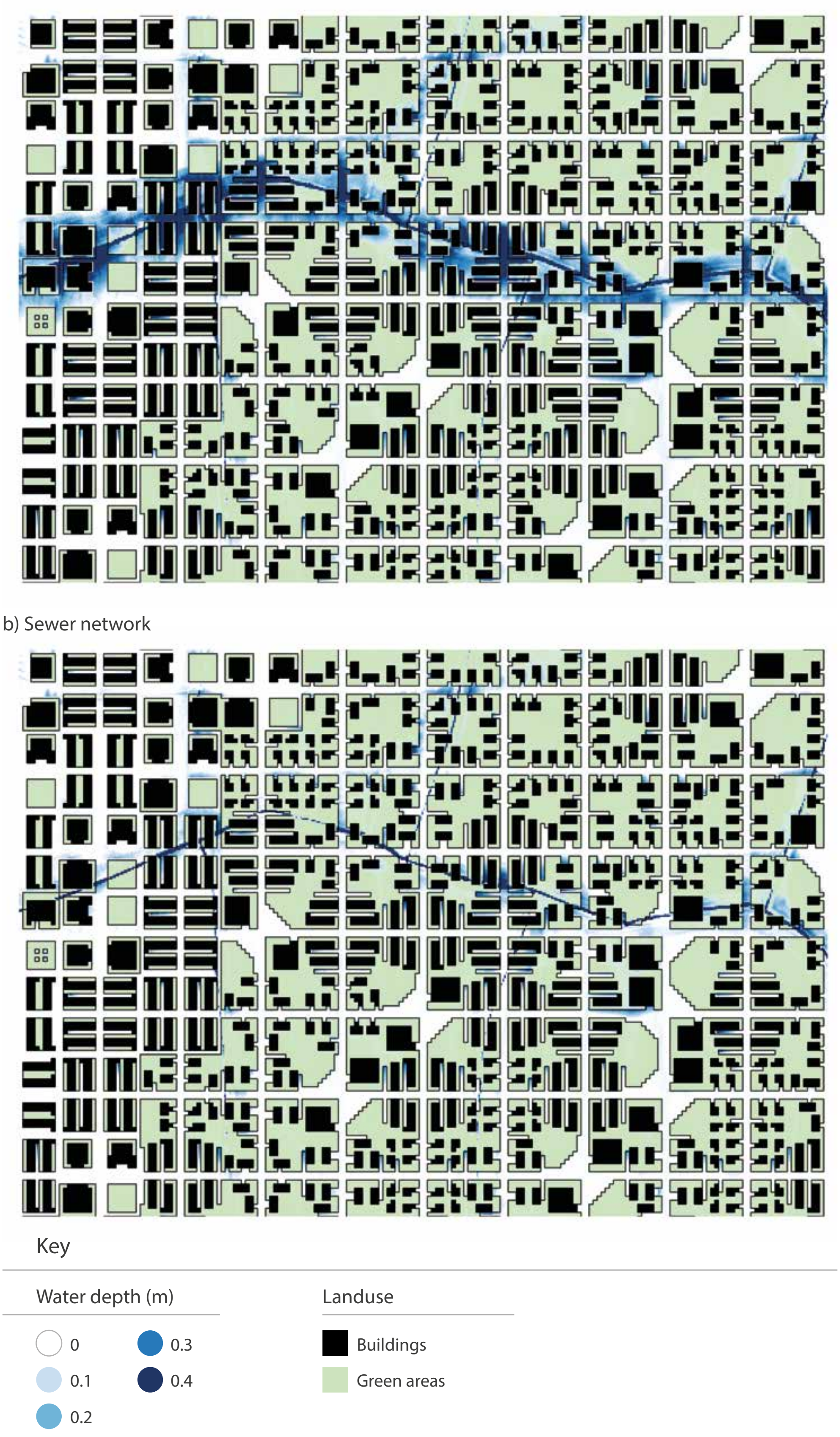


Figure 15: Flood depth maps for a 100-year design storm showing the effects of (a) inset roads (b) conventional drainage density.

7 Conclusion

The Oxford-Cambridge Arc is an important region for future growth, building on established strengths in knowledge-intensive sectors. Increased population, employment and productivity are key drivers of future economic growth and prosperity, enabled by increased accessibility to services and employment, and increased connectivity between urban centres.

This report demonstrates how the ITRC-MISTRAL modelling suite NISMOD can provide independent systems-based analysis of the implications of future change, and provide new insights into the implications of the major policy themes related to population change and new transport infrastructure. The analyses are based around the development of the road and rail networks between Oxford and Cambridge, and three contrasting growth scenarios for new dwellings within the Arc. The future of the Arc is likely to be a combination of different types of development, but for ease of comparison we have examined the cases whereby development is focused either on (i) Expansion of existing settlements; (ii) in New Settlements; or (iii) is Unplanned so happens in a haphazard way across the Arc.

The allocation of new dwellings and population for each Arc scenario is modelled by assessing development suitability using a set of constraints and attractors, with future employment demand met by a combination of urban densification, urban fringe developments, new hinterland locations, and at significant new developments based around prospective transport hubs. While Expansion of existing conurbations is likely to impact on protected greenbelt areas, careful planning could allow development of New Settlements, while still protecting greenbelt land and other important habitats in the Arc.

The Expressway initially delivers some time savings for longer road journeys, such as between Oxford and Cambridge, but the fastest route choices more locally tend to remain on existing roads, depending on the origin and destination. For all growth scenarios, higher population implies higher levels of congestion, and while the planned road expansions and developments initially generate time travel savings, congestion levels and travel times will increase in the longer term if steps are not taken to manage demand for road transport and transfer passengers onto other modes of transport including rail and 'active travel' (walking and cycling).

Notwithstanding high population growth, uptake of electric vehicles would result in a sharp decrease in carbon emissions and local air pollution in the longer term, although electrification will substantially increase electricity demand.

The vision of a carbon neutral Arc is achievable, given the current trends in generating increasing amounts of electricity from renewable sources and the potential for increased uptake of renewables within the Arc. The greatest challenge to achieving a carbon neutral Arc is how to heat new and existing buildings without using fossil fuels. We have examined a 'multi-vector' energy solution, which incorporates local heat networks, green gas and widespread use of electric heating. This enhances resiliency and operational flexibility compared to a heating solution that relies entirely on electricity; however, it is hindered by increased systems complexity, and high capital costs. The most cost-effective route to decarbonisation of heating may be transitioning to heat pumps, resistive heating and electric boilers, and running these on decarbonised electricity. However, there are barriers to such a future, such as the potential disruption to households during retrofitted installation, relatively high capital costs of low-carbon heat technologies, and potential gaps in engineering training and human capacity. A campaign to raise awareness of such technologies may help increase public confidence and uptake. It will be much more cost-effective to incorporate these technologies from the outset in the new buildings within the Arc, but developers should also consider improvements to energy efficiency and insulation to reduce the energy requirements of heating.

Population change only has a minor impact on demand for 5G infrastructure, which is largely driven by the changing nature of per user data consumption, particularly for on-demand video. Significant supply-side changes are expected in how mobile networks deliver data services, and a combination of deploying new spectrum bands utilising 5G technologies and increased network densification through Small Cells may be the most cost-effective and reliable means of delivery in dense urban areas. There are further cost efficiencies to be gained through coordinated planning of both fixed and mobile digital communications, particularly when building and maintaining other infrastructure sectors.

The Arc is served by four water companies, and if these companies are able to deliver on their plans for demand management and leakage reduction, future per capita demand for water will decrease, but population growth in the Arc is projected to increase total water use in the long-term. Without new infrastructure to improve supply, the risk of restrictions on water use doubles by 2050. These risks can be somewhat mitigated through new reservoirs (as proposed by Anglian Water) and effluent re-use schemes (as proposed by Thames Water at Beckton in East London).

The scenarios considered are transformative. Baseline population growth takes the Arc from 3.7 million people in 2015 to 4.4 million in 2050; the higher growth Expansion and New Settlements scenarios consider up to 5.4 and 6.1 million people respectively by 2050. Strategies to significantly reduce the carbon emissions from heat and transport require sweeping technology transitions. Population growth drives increases in water demand despite per capita reductions while the generally drier near-future climate scenarios contribute to increased risk of water use restrictions. Full-fibre and 5G broadband must prioritise coverage if they are to meet future expectations of digital connectivity.

The Arc region is not isolated. Population change, economic growth and their implications for infrastructure services in the Arc have wider impacts on a regional and national context. Some of the housing pressure within the Arc comes from demand in London and the South-East. Part of the motivation for the road and rail improvements comes from the need to move freight more effectively between the East of England, South West England and South Wales. North-south transport flows also affect congestion on the major roads in the Arc. Resilience to drought in the SWOX water resource zone is linked to the Thames system and London. Transmission-connected electricity generation across the country affects the cost, reliability and carbon intensity of electricity consumed within the Arc.

Changes in one sector have effects in others. Rapid vehicle electrification would reduce transport emissions and increase electricity demand from transport, while demand-side management (including from grid-connected vehicle batteries) is effective in reducing peak demand. Existing urban areas have opportunities for densification and challenges to upgrade, adopt or retrofit technologies. New developments present opportunities to build to the highest standards of energy efficiency, introduce heat networks, lay ducts for fibre and design sustainable drainage, but also challenges to preserve green corridors, design liveable places and build urban environments that can adapt and last.

In conclusion, this analysis of the Arc shows the benefits of an integrated analysis of infrastructure development, including sectoral interaction. The development and analysis of consistent scenarios including a range of possible urban forms illustrates the diverse ways the Arc may develop. Key interactions between sectors such as growing electricity demand for transport are also apparent as well as wider consequences of the Arc development such as in water supply.

This report has shown how ITRC-MISTRAL modelling capabilities can be applied in a regional context. All this new information and these insights can inform the ongoing debate about how the Arc will proceed and the key policy decisions and actions that need to follow. The ITRC-MISTRAL modelling suite NISMOD is continuing to be developed for national and regional application within the UK and around the world.

ITRC MISTRAL

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