CESER
Centre for Earth Systems Engineering Research

Civil Engineering and Geosciences

Tyndall Centre for Climate Change Research

Newcastle University

Integrated Assessment of Long-term Change in Cities: A London Example

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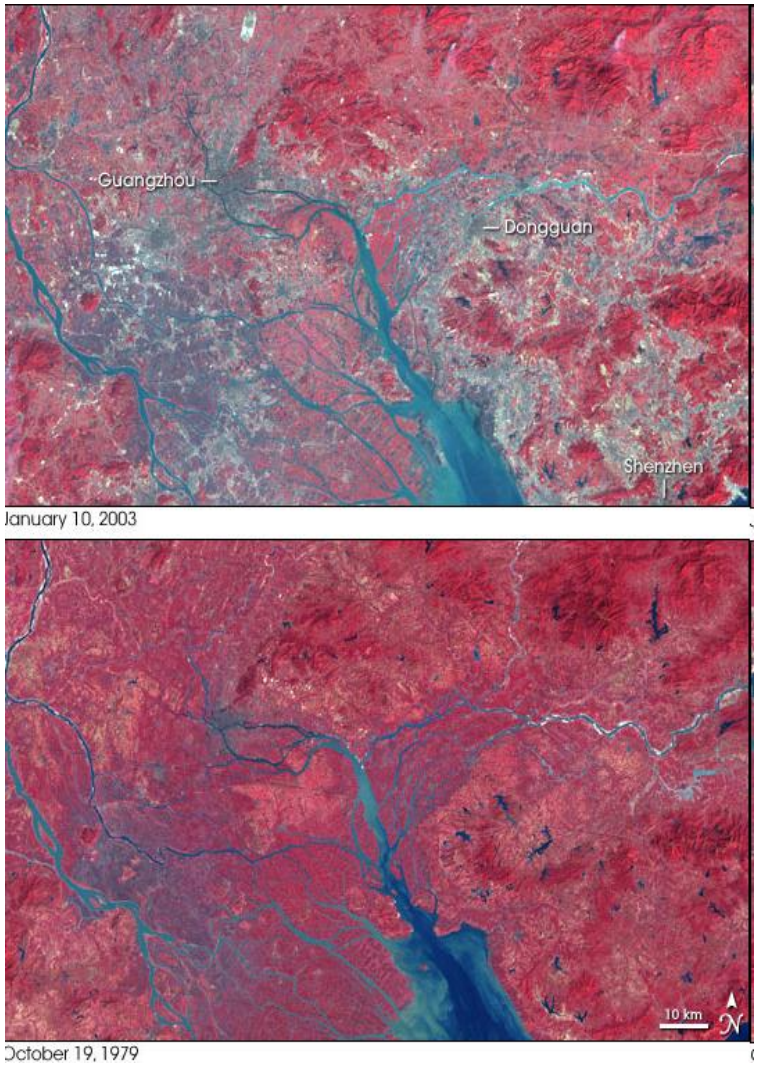
Cities on the front line

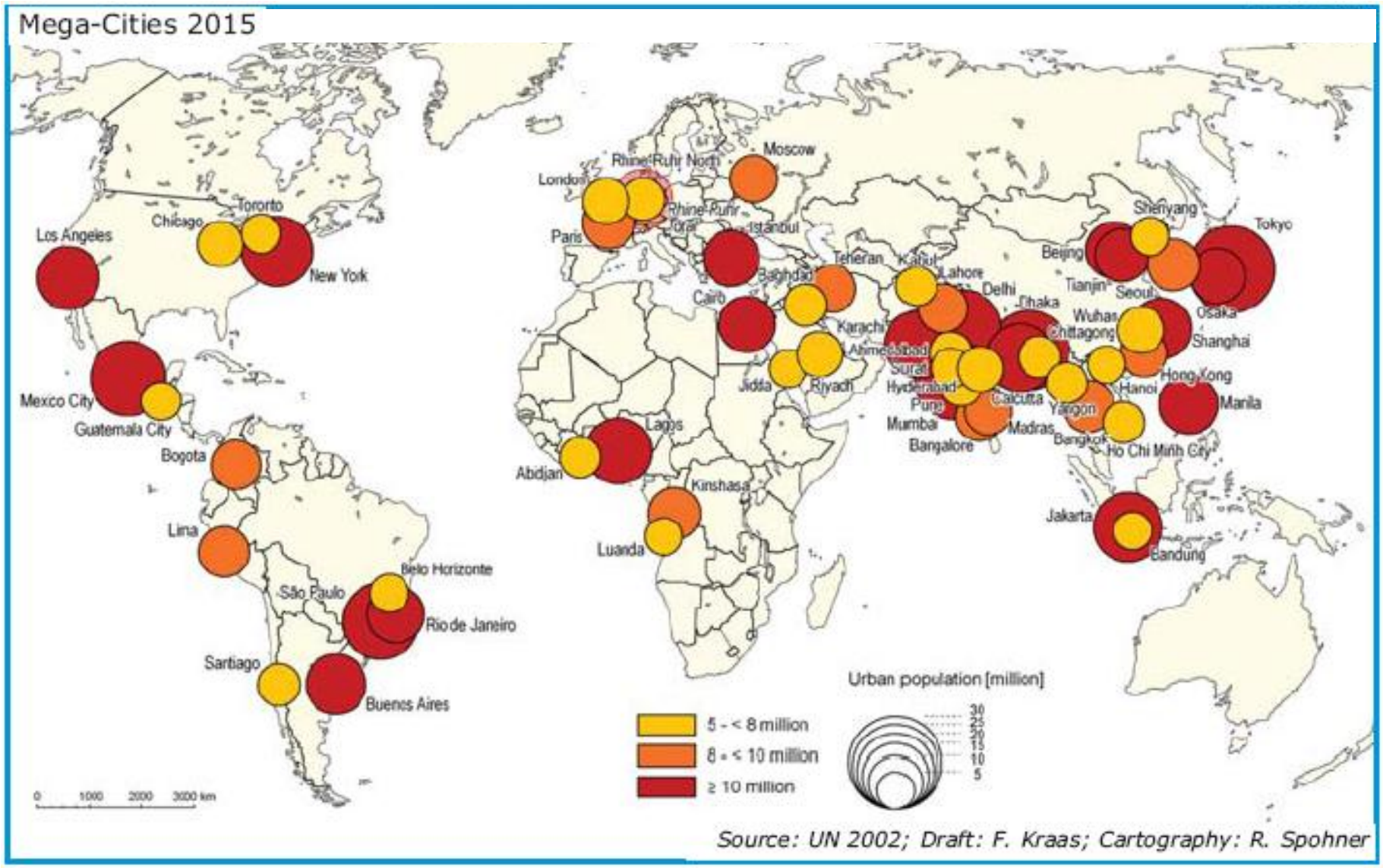
- **Urbanisation is one of the most powerful and visible anthropogenic forces on Earth**

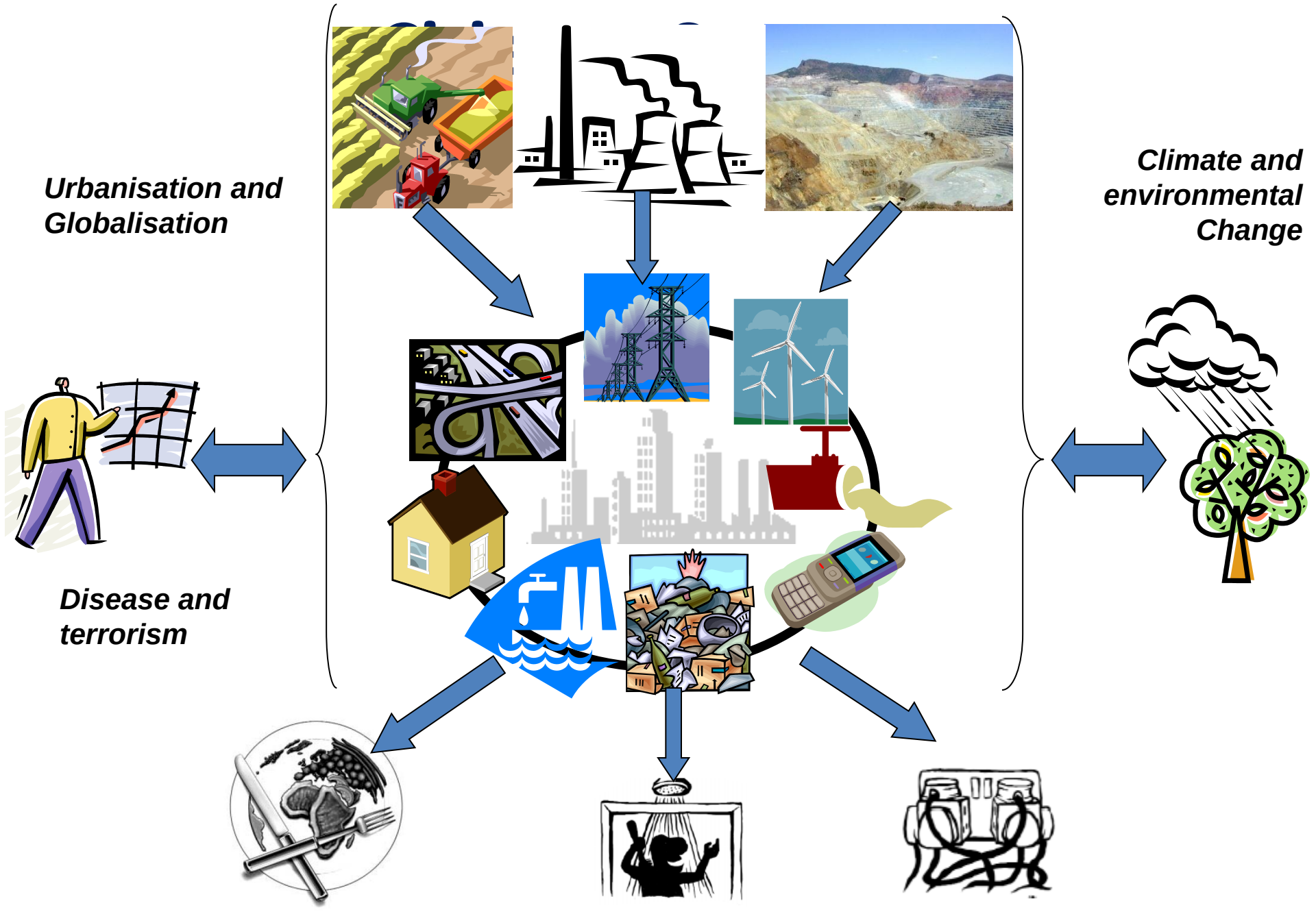
- **Urban areas are concentrations of climate vulnerability as well as being major greenhouse gas emitters**
  - 19 MegaCities (>10million people): Mainly developing world & coastal
  - <3% Earth's land surface urban
  - 50% global population
  - 60-80% global GHG emissions
  - ~75% global resources
  - BUT this makes them our greatest opportunity!

- **Today's decisions will alter our vulnerability to climate change and our emissions profiles for many years to come**



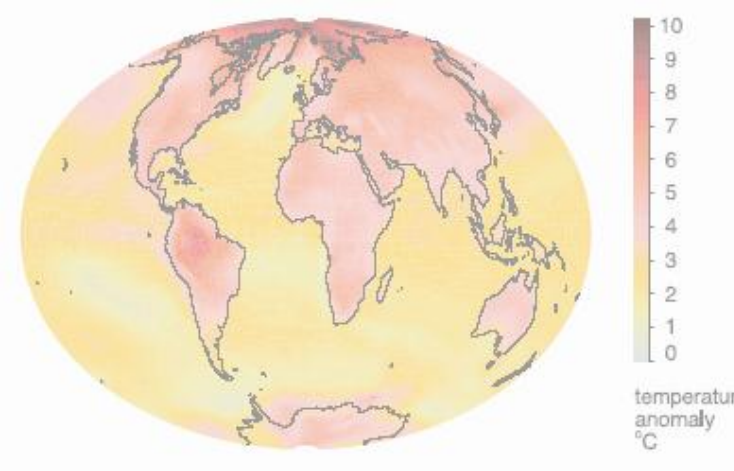
Mega-Cities


Mega-Cities 2015
Los Angeles
Chicago
Tororto
New York
Mexco City
Guatemala City
Bogota
Lima
Belo Horizonte
São Paulo
Rio de Janeiro
Santiago
Buenos Aires
London
Rhine-Ruhr North
Rhine-Ruhr
Paris
Moscow
Istanbul
Cairo
Baghdad
Teheran
Kabul
Lahore
Delhi
Dhaka
Karachi
Ahmedabad
Surat
Hyderabad
Pune
Mumbai
Bangalore
Calcutta
Madras
Jidda
Riyadh
Lagos
Abidjan
Kinshasa
Luanda
Shenyang
Beijing
Tianjin
Seoul
Tokyo
Osaka
Wuhan
Chittagong
Shanghai
Hong Kong
Hanoi
Manila
Yangon
Bangkok
Ho Chi Minh City
Jakarta
Bandung
0 1000 2000 3000 km
Urban population [million]
5 - < 8 million
8 - < 10 million
≥ 10 million
30
25
20
15
10
5
Source: UN 2002; Draft: F. Kraas; Cartography: R. Spohner


Urbanisation and Globalisation
Climate and environmental Change
Disease and terrorism

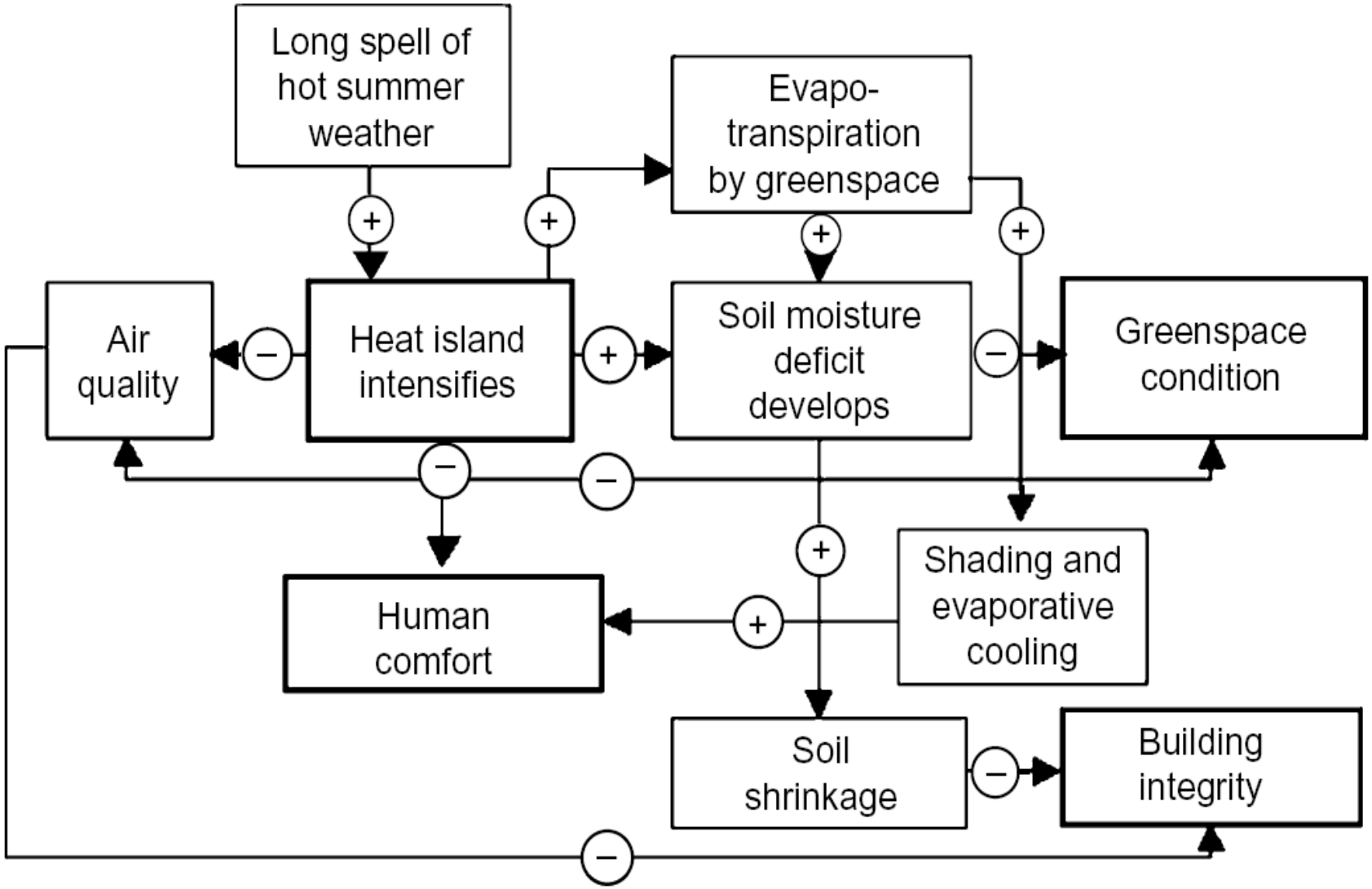
Cities on the front line

- Flooding
  - Storm surges, rivers, urban drainage
- Building and infrastructure
  - Subsidence, landslides, wind
- Water resources
  - Quality (implications for health and ecosystems)
  - Availability for human consumption, industry and neighbouring agricultural areas
- Heat, air quality, and health
  - Changing profile of heat vs. cold related deaths
- Resources (including agriculture, fisheries, waste management, ecology, wildlife, biodiversity and fires)
- Disease (changing profile of vector and water-borne diseases)



Vulnerability is NOT just a function of assets

Complex Dynamics



Vulnerability

- Vulnerability is NOT just a function of assets:
  - Economic well-being and stability (*e.g*. standard of living; rate of urbanisation)
  - Demographic structure of population
  - Institutional stability (*e.g*. institutional 'memory'; corruption)
  - Strength of and reliance on public infrastructure (*e.g*. health expenditure; communication infrastructure; financial, transport, corporate and systems; degree of centralisation)
  - Global interconnectivity (*e.g*. trade balance; tourism)
  - Natural resource dependence and regenerative ability of ecosystems

- Vulnerability reduction:
  - Diversification of ecological and economic systems and building inclusive governance structures
  - A portfolio approach to minimising risks across society in the broadest sense

Complicities and Trade Offs

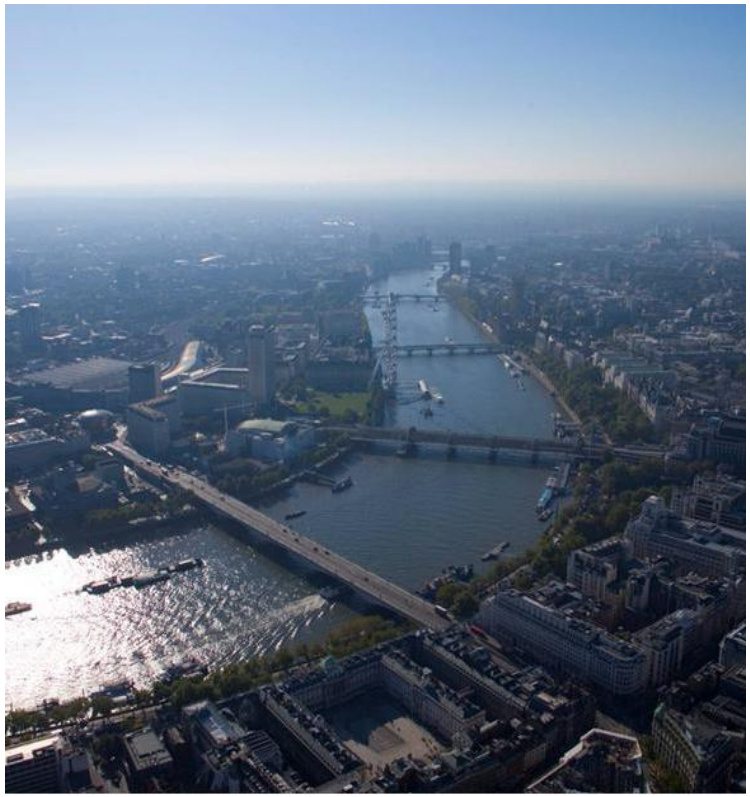
Response	Potential benefit	Potential negative impact
Air conditioning	Reduce heat stress	Increase energy needs and emissions
Densification of cities	Reduce public transport emissions	Increase urban heat island intensity and exposure to grater noise pollution
Desalination plants	Secure water supply	Increase greenhouse gas emissions
Irrigation	Supplying water for food	Salinisation of soil, degradation of wetlands,
Biofuels for transport and energy	Reduce GHG emissions	Encourage deforestation; replace food crops raising food prices; can increase local air quality pollutants such as NO_x
Cavity wall insulation	Reduce GHG emissions	Increase damages from a flood event
Raise flood defence	Reduce flood frequency	Encourage more development (positive feedbacks)
Insurance/disaster relief	Spread the risk from high-impact events	Reduce longer term incentive to adapt
Traffic bypasses or radial routes	Displaces traffic from city centre, improving air quality and reducing noise	Can increase congestion and journey times (consequently overall greenhouse gas emissions)
Vehicle user charging	Discourage vehicle use to reduce greenhouse gas emissions	Lead to greater social inequality

Viewing cities as systems helps avoid conflicts between different objectives by representing the different urban functions and linking climate change issues to broader policies such as spatial planning.

Engineering Cities Programme

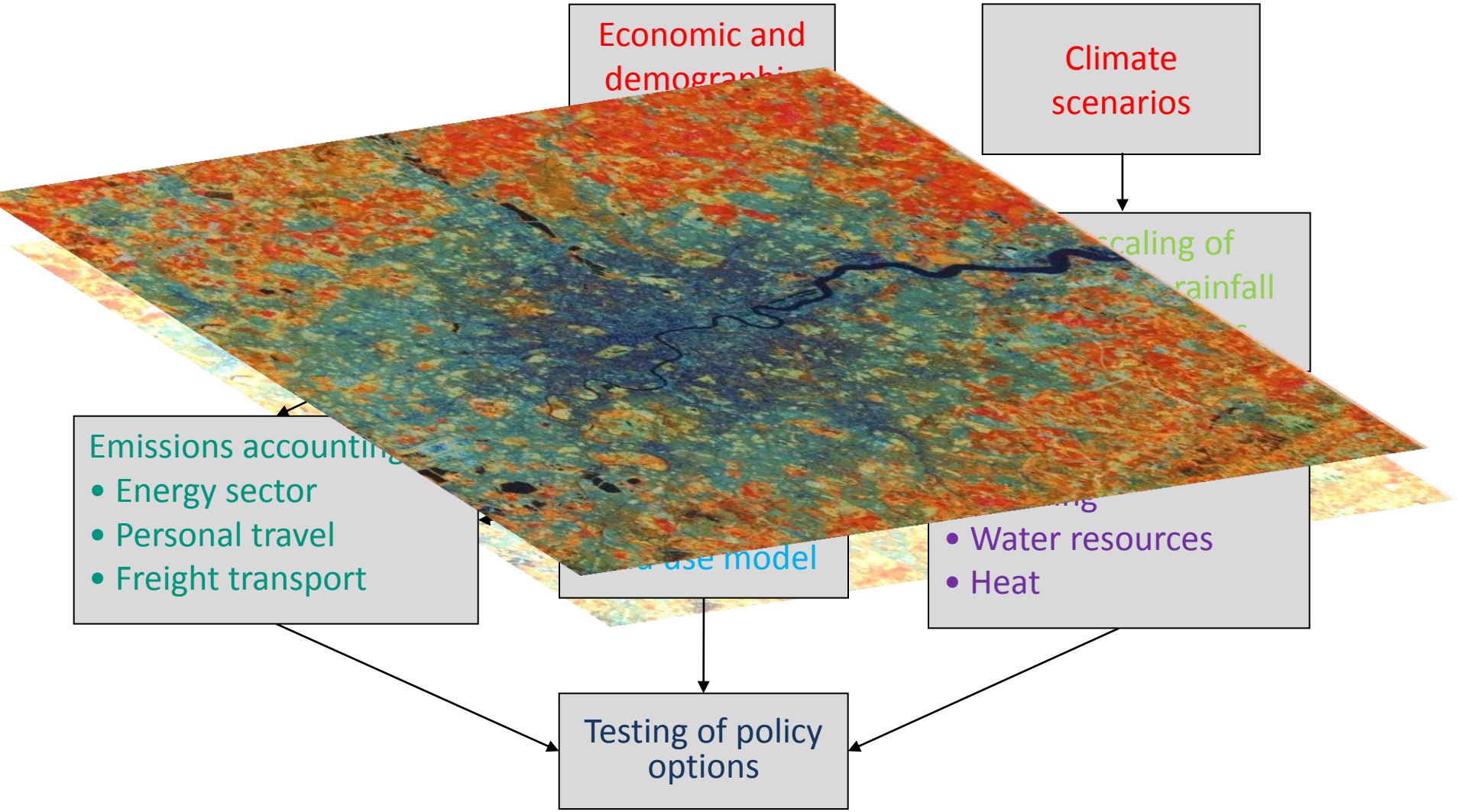
How can cities grow whilst reducing emissions and vulnerability?

Tyndall Centre for Climate Change Research



Coherent national and regional economic, demographic and climate scenarios that incorporate spatially explicit simulations of land use and infrastructure to understand key vulnerabilities – flooding, heat and drought and the effects of spatial planning decisions.

Integrated Assessment Concept



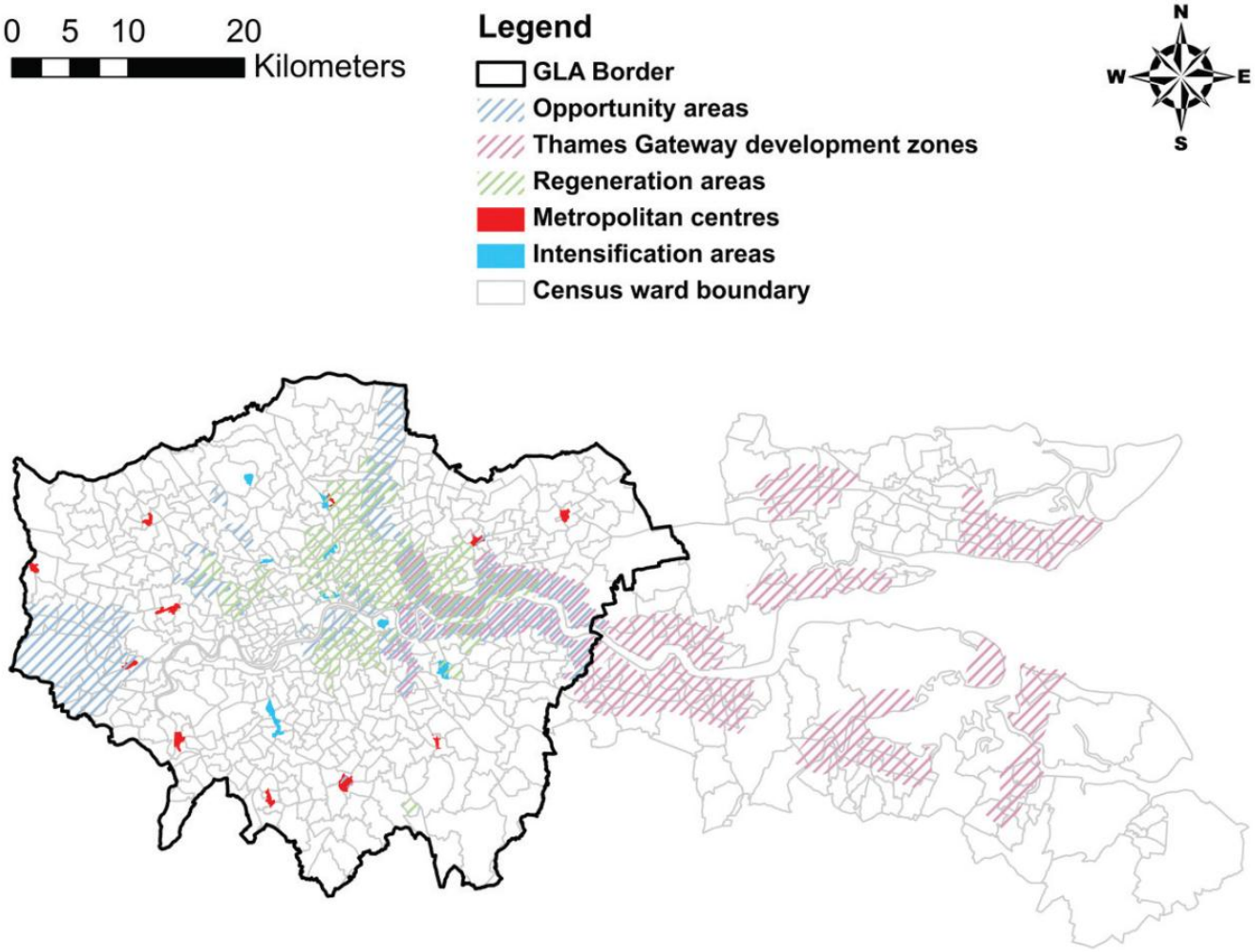
London

- Most populous and one of largest urban areas in the European Union: 1,584km^2
- Population in decline between 1939-89, but ‘resurging’ and now ~7.4million
- Governed by the Greater London Authority (est. 2000) – promote economic and social development and environmental improvement of Greater London. Reducing CO_2 emissions.
- Predicted growth for next 20 years:
  - Population increase of 1.4m
  - 600,000 more households
  - 700,000 more jobs

Climate Governance

- Greater London Authority (GLA)
- London Climate Change Agency (LCCA) - abolished
- Government for London (GOL) - abolished
- London Climate Change Partnership (LCCP)

Development Pressures



THE LONDON PLAN

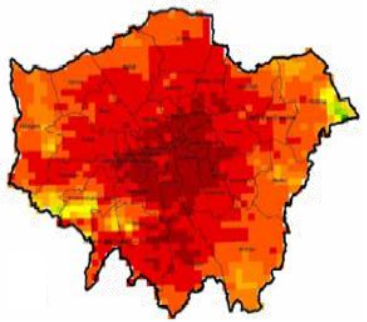
SPATIAL DEVELOPMENT STRATEGY FOR GREATER LONDON
JULY 2011

MAYOR OF LONDON

Changing Climate

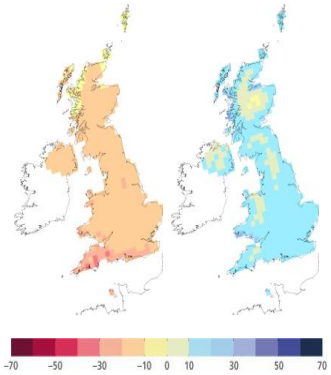
Temperature

- Warmer summers and winters
- Increased variability in extremes
- Potential for intensification of urban heat island



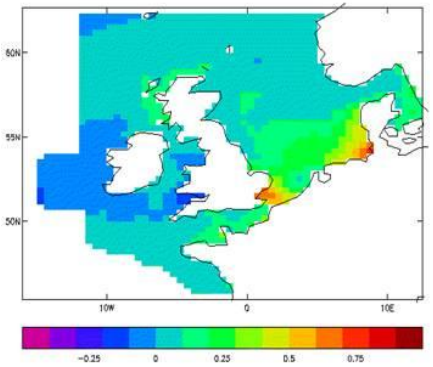
Precipitation

- Increased winter rainfall
- Decreased summer rainfall
- Increased variability in extremes



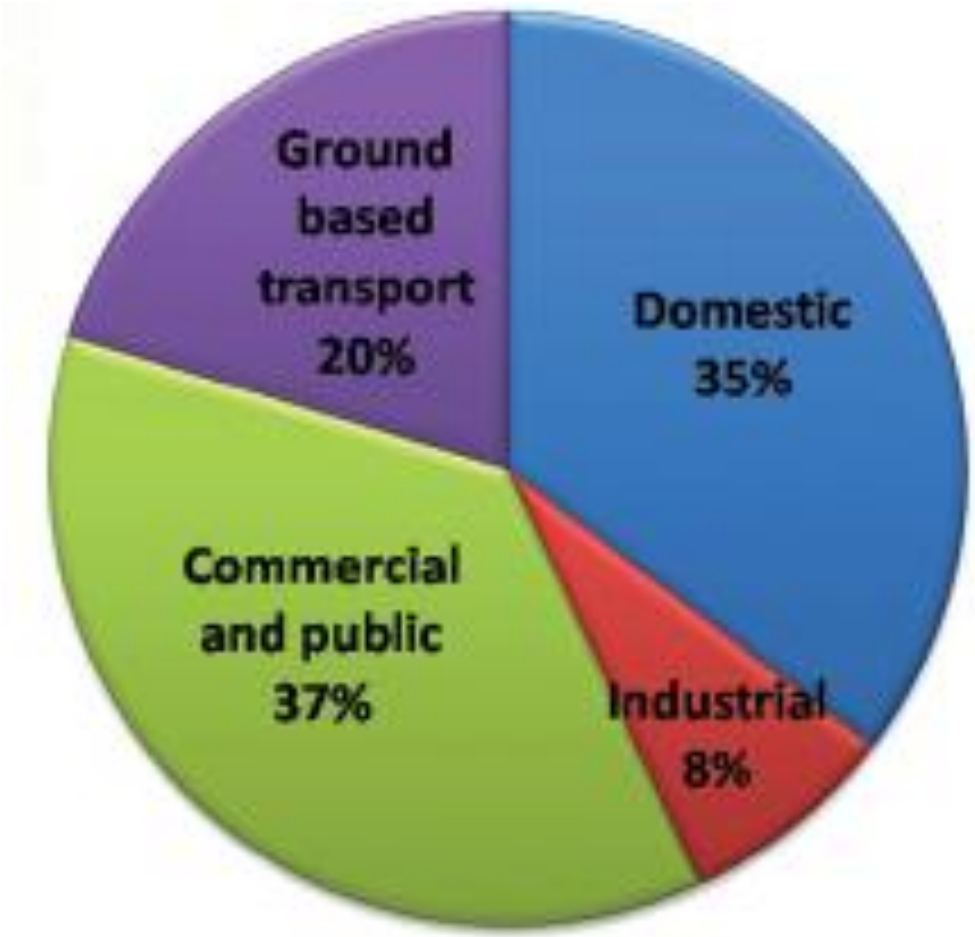
Sea level rise

- Estimates range 0.5-1.6m, with extreme polar melt scenarios of ~3m
- Increased winter wind speeds and storminess



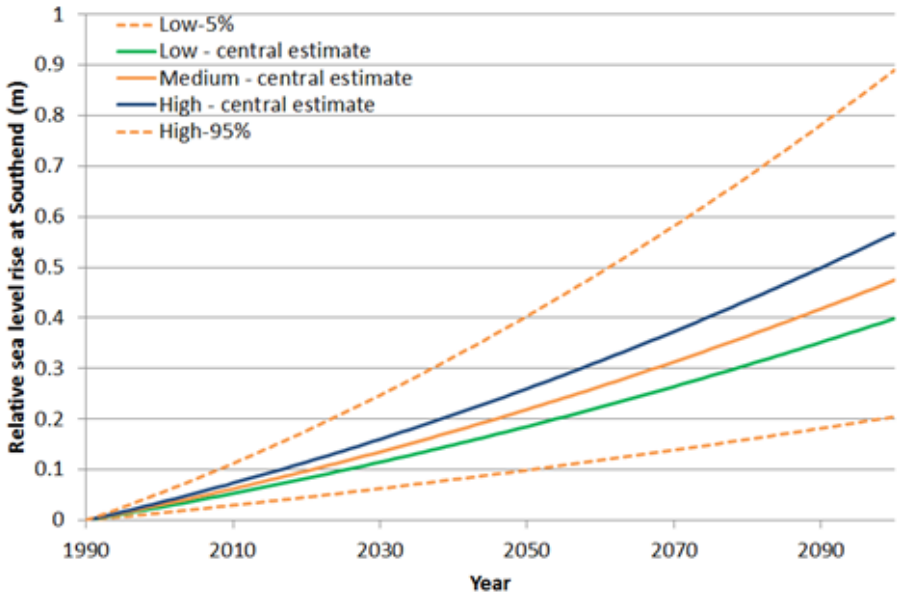
CO_2 Emissions

- 2009:
  - 42.4Mt CO_2 emissions
  - 9.3% of the UK total
  - 15% increase in CO_2 by 2030 emissions if we continue BAU
  - Target to reduce by 60% by 2025!



Climate Scenarios

- UKCP09 Low - IPCC SRES B1 emissions scenario
- UKCP09 Medium - IPCC SRES A1B emissions scenario
- UKCP09 High - IPCC SRES A1FI emissions scenario
- HadRM3 parameterised using surface scheme to allow of sub-grid scale variations at land surface to capture UHI effect.
- Weather Generator – downscaled 100 realisations – 100 year hourly time series of rainfall, temperature and evapotranspiration on 5 x 5 km grid.



Relative sea level rise projections at Southend for the low, medium and high UKCP09 scenarios.

Economic Scenarios

- Multi-sectoral, regional energy-environment-economic model.
- Predicts output from and employment in 42 different industrial sectors. Aggregated to 8 sector groups.
- Inputs: baseline projections of long term national GDP growth and population, awa input-output data of relationships between different industrial sectors.
- 3 GDP scenarios, baseline, low growth and high growth
- Output tables:
  - Economic activity with regional and industrial disaggregation (GVA)
  - Employment with regional and industrial disaggregation (FTEs)
  - Energy demand at national level with industrial disaggregation (thousands of tonnes of oil equivalent by different fuel type)

Economic Scenarios

Baseline scenario:

- UK GDP growth rate steadily decreases to an annual rate of 1.5% per year in 2100.
- In London the growth rate is 2.5-3% up to 2060, which decreases steadily at the level of 1.4% in year 2100.

Low Growth Scenario:

- UK GDP growth rate at national + regional level is 0.3% less than baseline , decreasing to 1.2% per year in 2100.

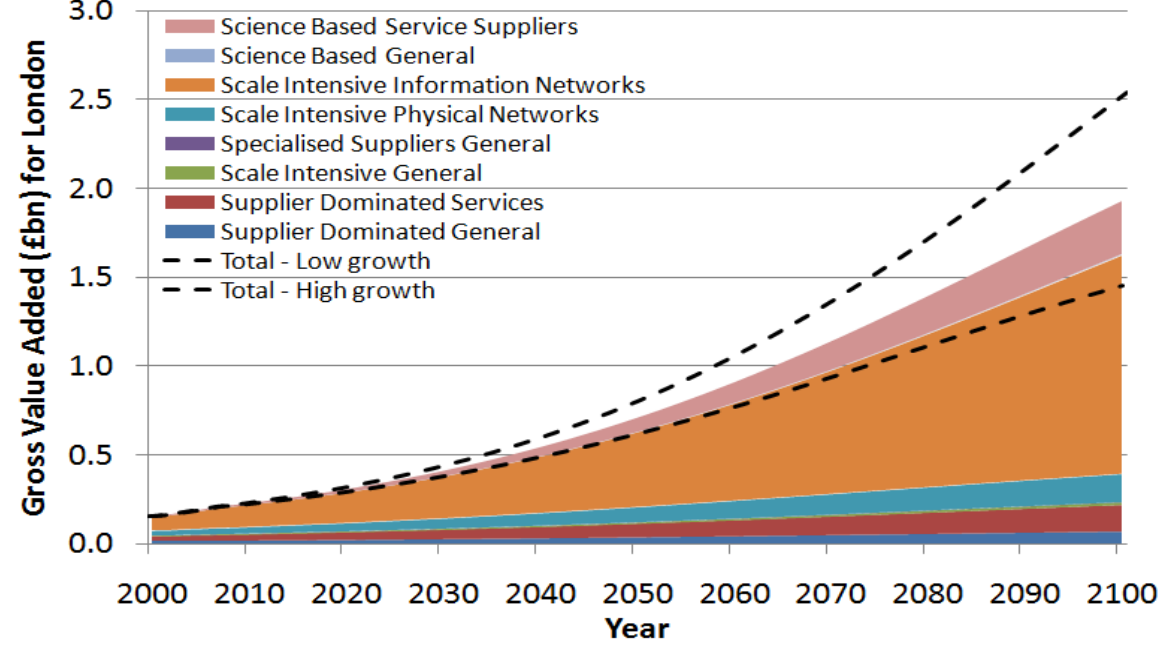
High Growth Scenario:

- UK GDP growth rate at national + regional level is 0.3% higher than baseline, steadily decreasing to 1.8% per year in 2100.

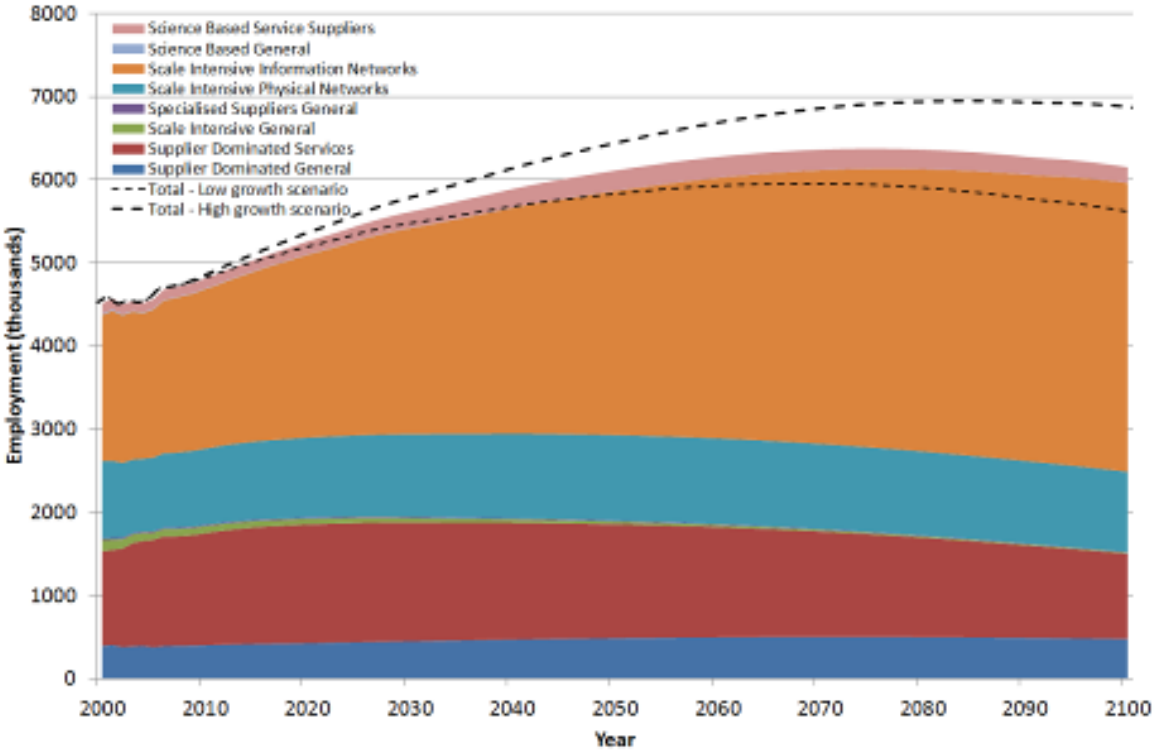
Industrial Categories

Based on their technological characteristics and on the likely effects of 3 pervasive technologies – IT, biotech, nanotech

Aggregate sector	MDM Economic model sectors
Supplier Dominated General Manufacturing	Agriculture; Coal; Oil & Gas; Other Mining; Printing & Publishing; Necessities; Electricity; Gas Supply; Water Supply; Construction
Supplier Dominated Services	Textiles, Clothing & Leather; Hotels & Catering; Public Administration; Education; Health & Social Work
Specialised Suppliers General	Mechanical Engineering; Other Transport Equipment
Scale Intensive Physical Networks	Distribution; Retailing; Land Transport; Air Transport; Water Transport
Scale Intensive Information Networks	Communications; Banking & Finance; Insurance; Professional Services; Other Business Services; Miscellaneous Services
Science Based Service Suppliers	Computing Services
Scale Intensive General	Food, Drink & Tobacco; Wood & Paper; Manufactured Fuels; Chemicals; Rubber & Plastics; Non-Metallic Mineral Products; Basic Metals; Metal Goods; Electrical Engineering & Instruments; Motor Vehicles
Science Based General	Pharmaceuticals; Electronics



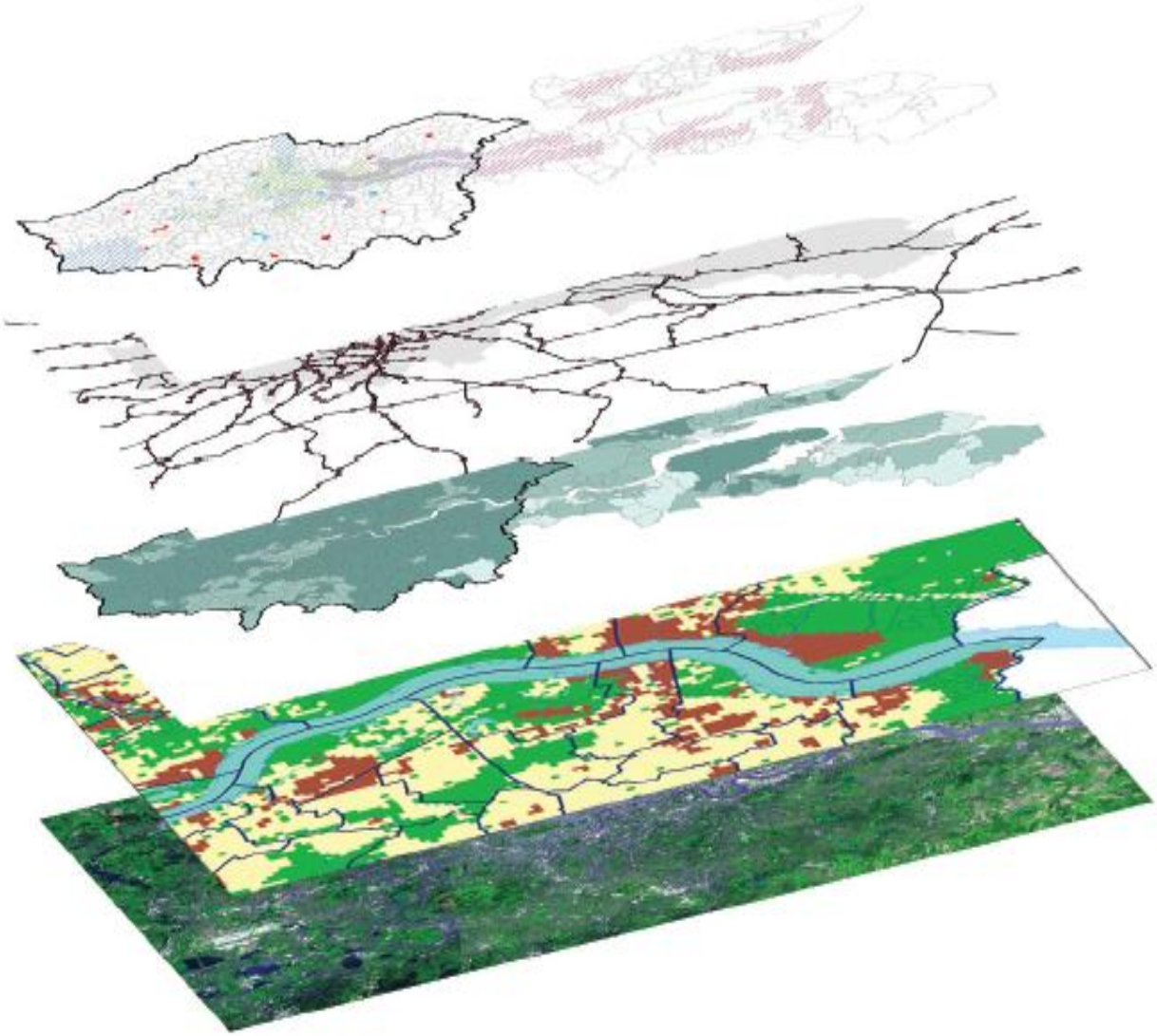
Scale Intensive Information Networks (banking, finance, communications) projected to dominate.



Science Base Service Suppliers become second largest by 2060.

Both projected to require high productivity personnel, which explains lower growth rate in employment.

Land Use Modelling



Planning policy:
Attractors, constraints etc

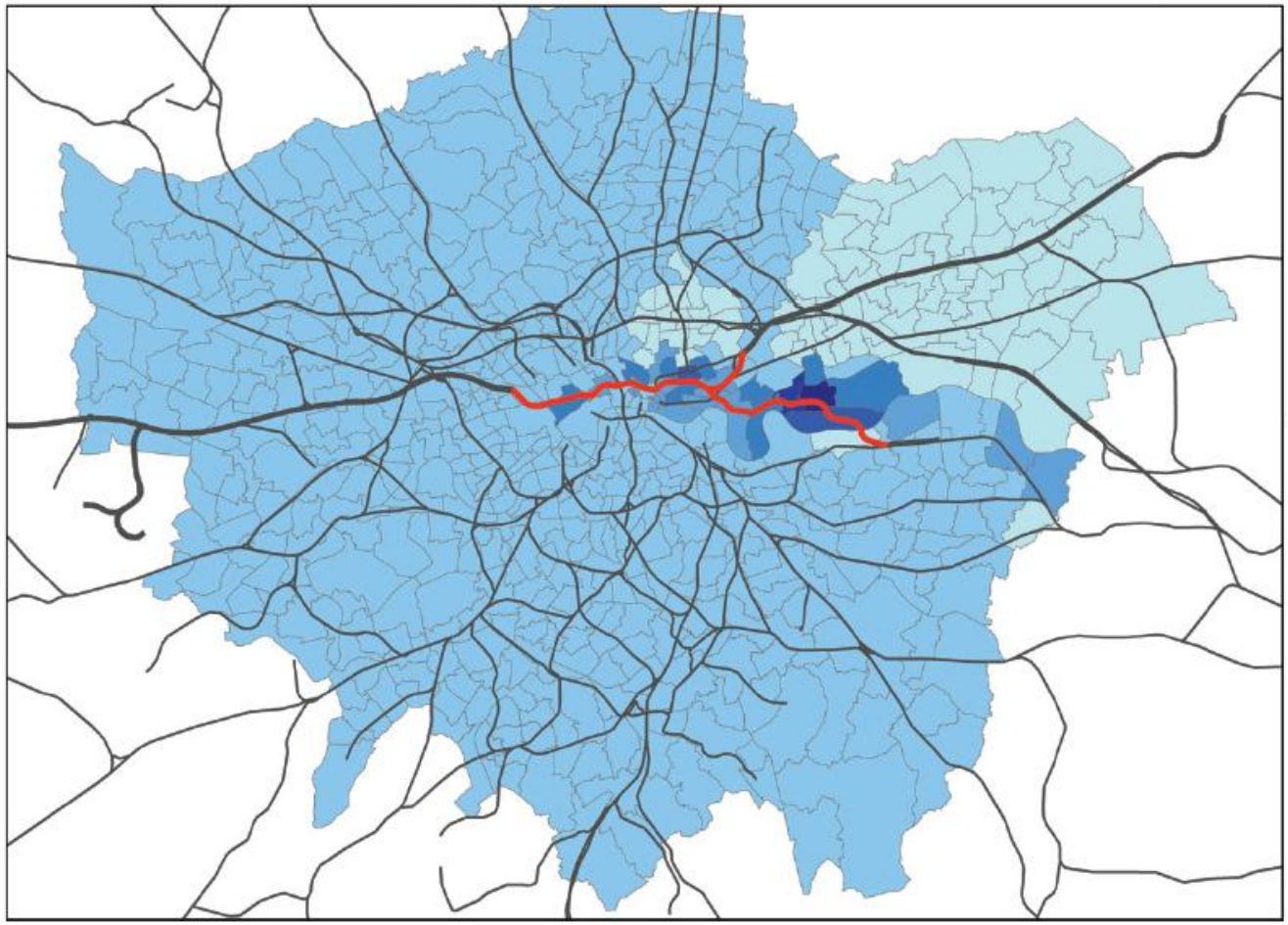
Transport network and generalised cost of travel

Spatial allocation of population and employment

High resolution downscaling of development

The real world

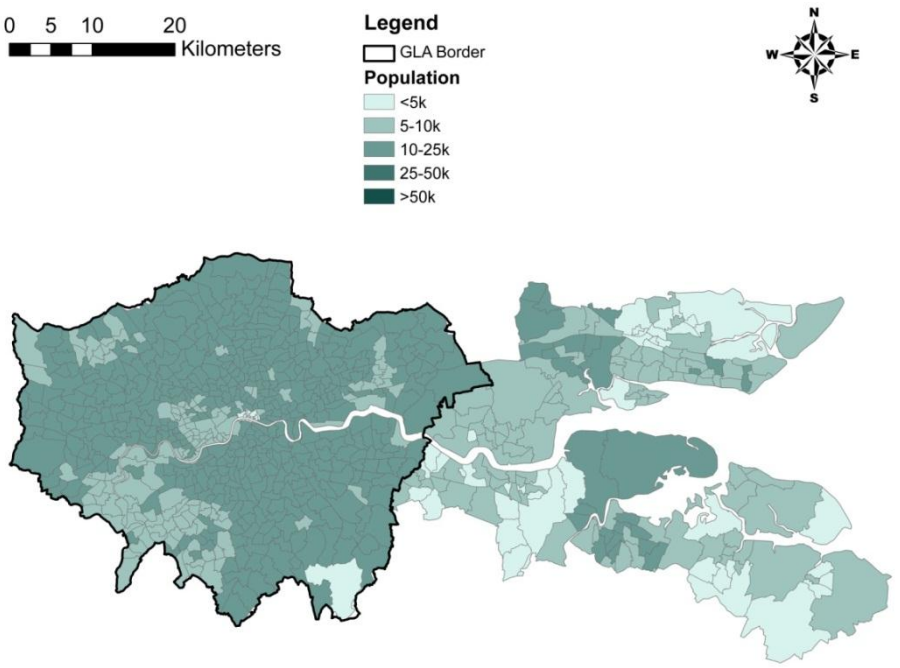
Travel Accessibility-Generalised Cost



Reduction in travel times from Heathrow to all other census wards within the GLA boundary by rail after the construction of CrossRail.

Spatial Interaction Model

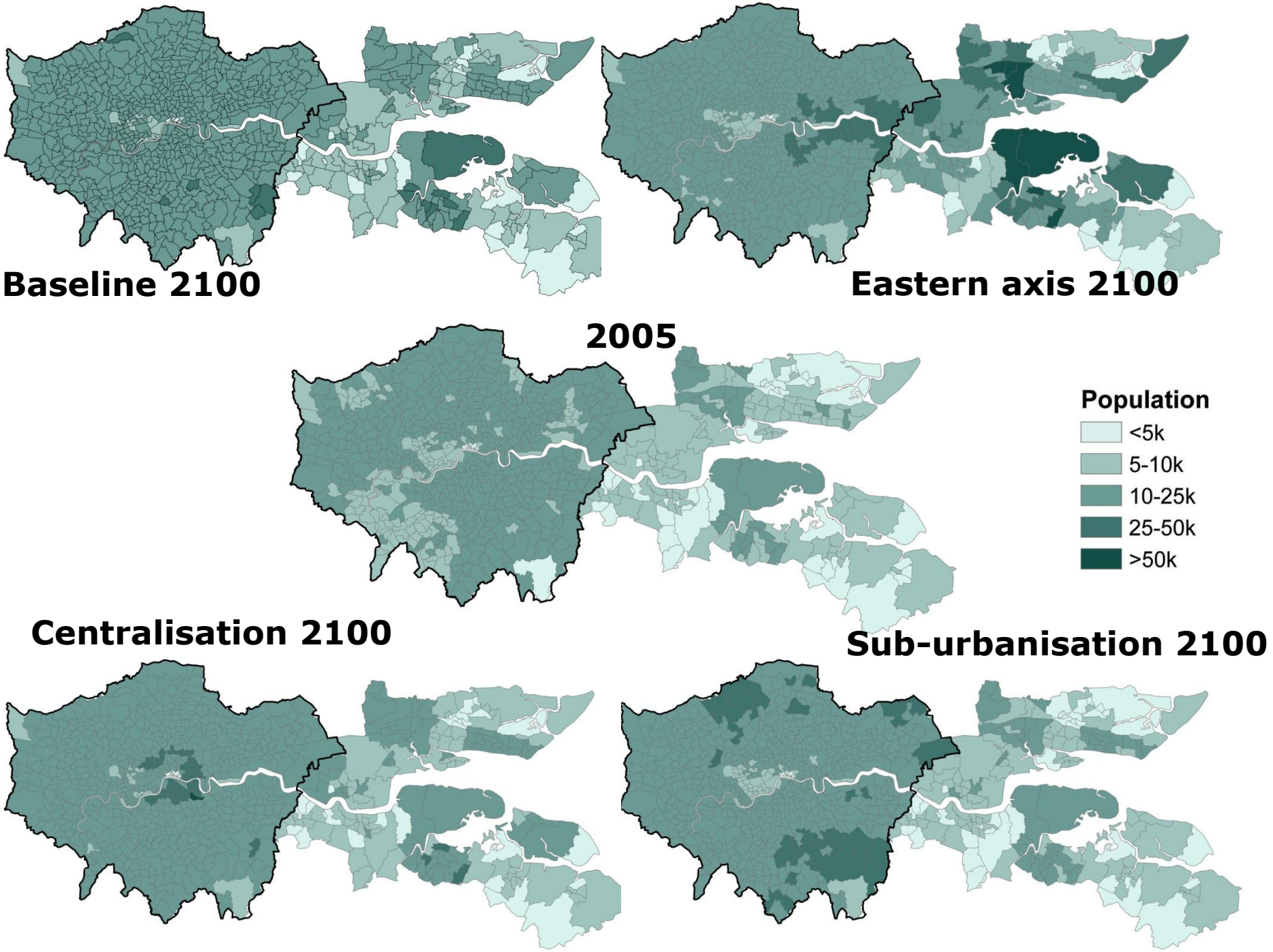
- Projections of employment sectors from economic model are allocated to census wards according to existing patterns modified by policy initiatives and planning constraints, whilst remaining consistent with regional economic scenarios.
- Population is then allocated to wards according to relative accessibility to different types of employment, planning policy and desirability.
- Calibrated to existing pattern of travel movements.
- Parameters obtained are used along with future employment predictions to generate future population estimates for each ward.
- Test different employment scenarios, planning policy initiatives and changes in the modal split of future travel.



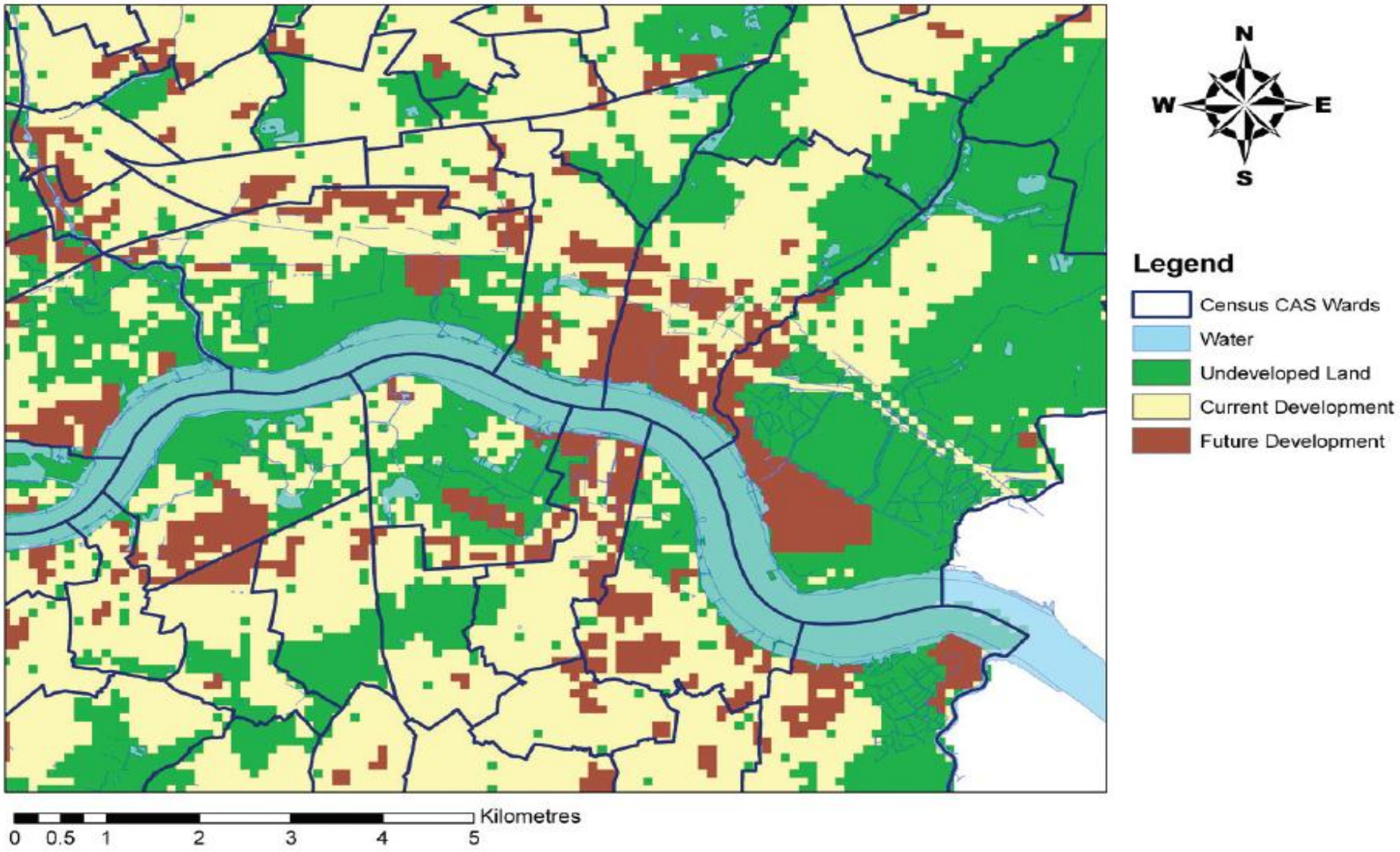
Constraints and Attractors

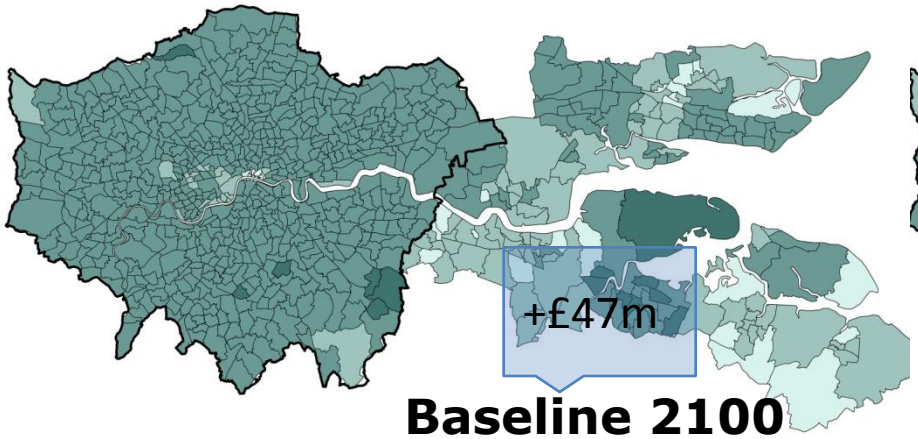
Constraints – reduce attractiveness of development in an area	Attractors – drive land use change by stimulating development in one area
Current development: buildings, infrastructure	Employment
Current water courses and lakes	London Plan designations: opportunity areas, regeneration areas, intensification areas
Environmental areas: SSSIs, nature reserves, greenbelt	Proximity to public transport
Constraints used in the London Plan	Proximity to amenity
Floodplain zones	Quality of schooling (Index of Multiple Deprivation)

Output – transition to 4 different land use 'paradigms' was simulated using a selection of weighted constraints and attractors to achieve desired land use objectives, allowing exploration of implications of contrasting development trajectories.

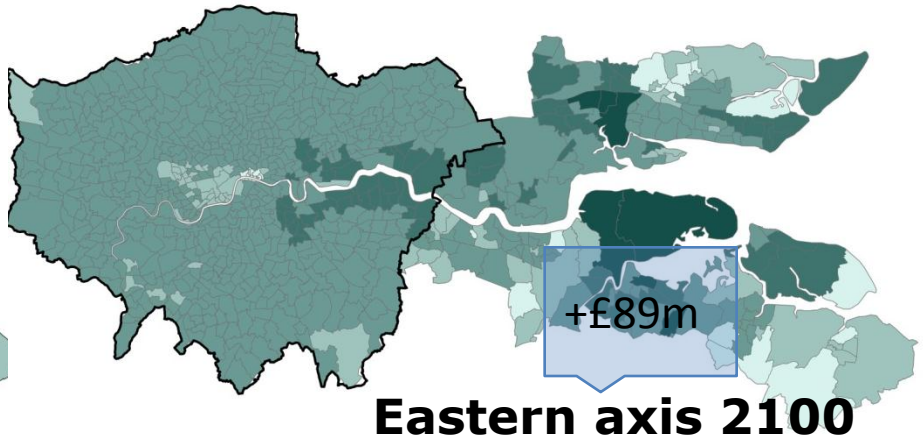

Baseline 2100
Eastern axis 2100
2005
Population
<5k
5-10k
10-25k
25-50k
>50k
Centralisation 2100
Sub-urbanisation 2100

Urban Development Model

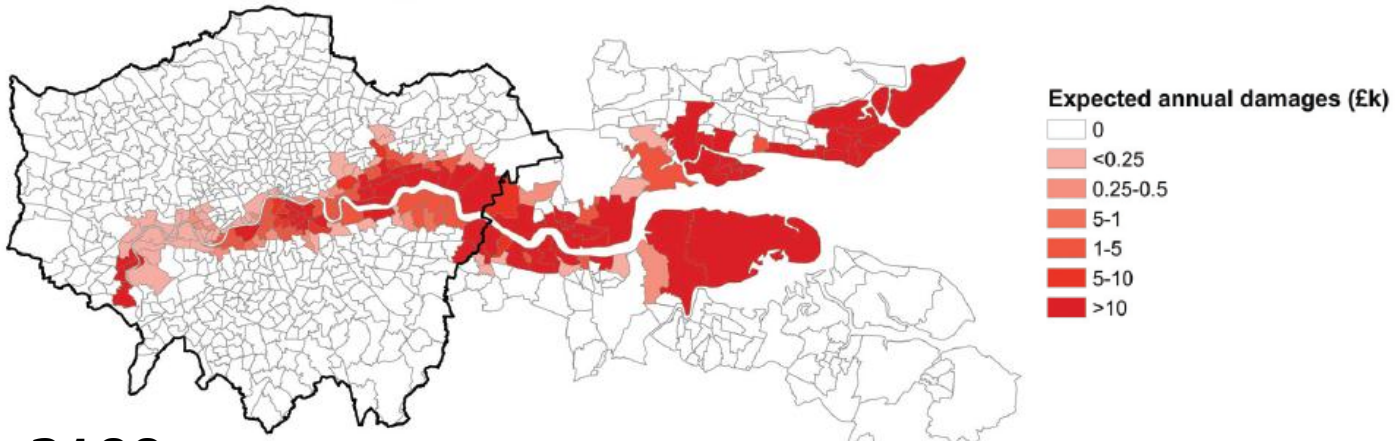




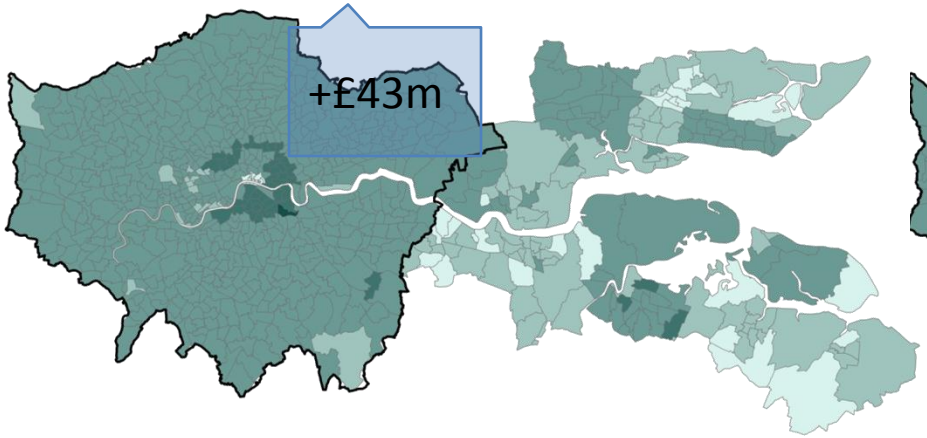
Baseline 2100



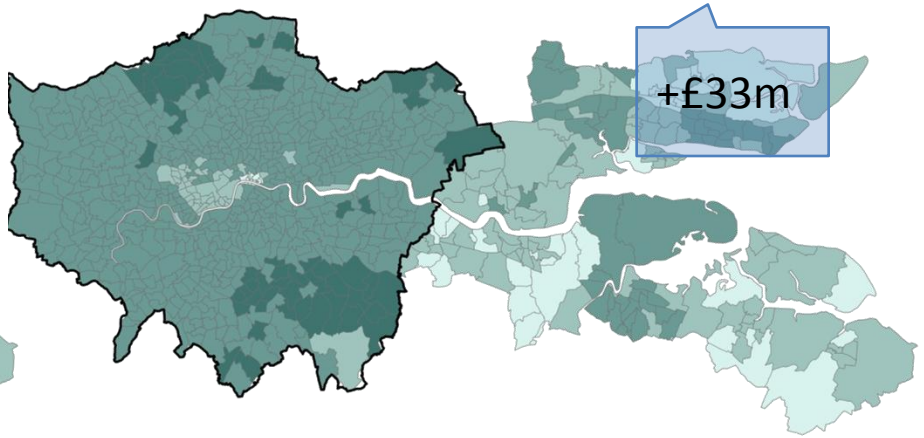
Eastern axis 2100



Centralisation 2100

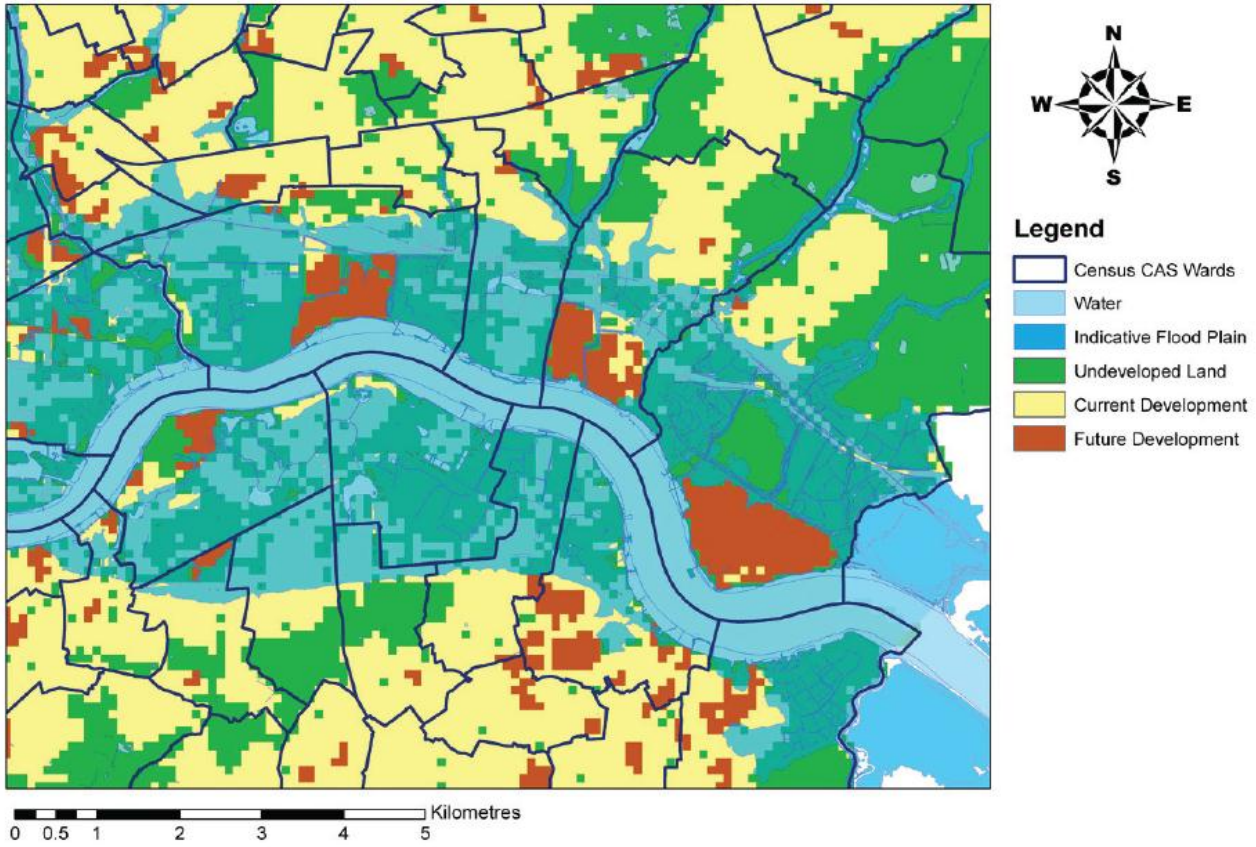


Sub-urbanisation 2100



Expected Damages – Adaptation

Higher Resolution



Ward scale – strategic city-wide planning of infrastructure

Finer scale – planning decisions

100 x 100 m grid

Water Availability

Pressures:

- Long term precipitation – 690mm/yr
- More vulnerable to changes in surface water regime which provides 80% of city's water (UK 30%).
- Population increases including 25% increase in single occupancy households.
- 163 litres per head per day – 30 litres more than UK average.
- Development pressures.
- Leakage - nearly half of the 31,000km of water mains are over 100 years old.

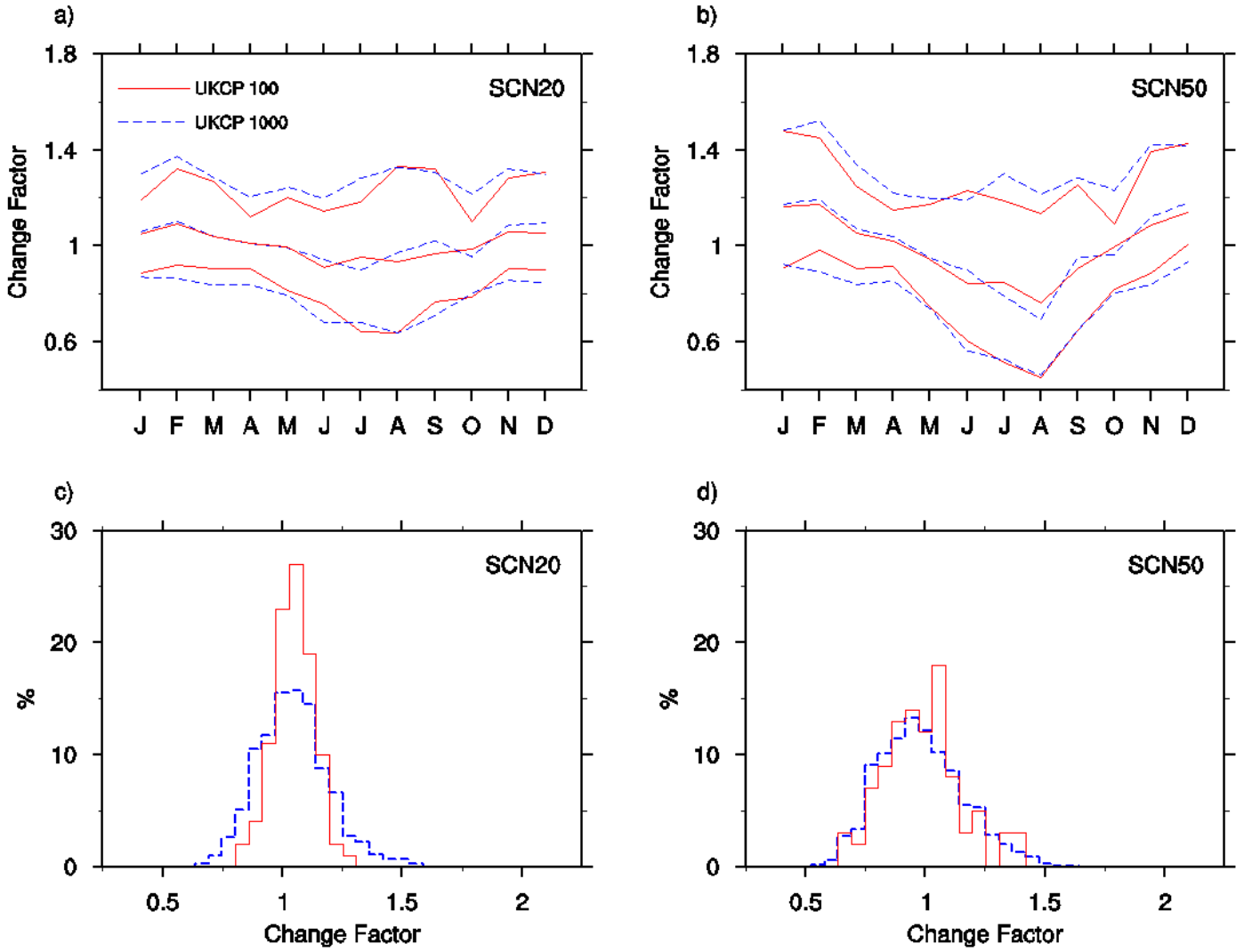
Water Resources

Rainfall series are generated using a rainfall model applying climate projections for the 2020s and 2050s from UKCP09. Associated series of potential evapotranspiration (PET) are also generated.

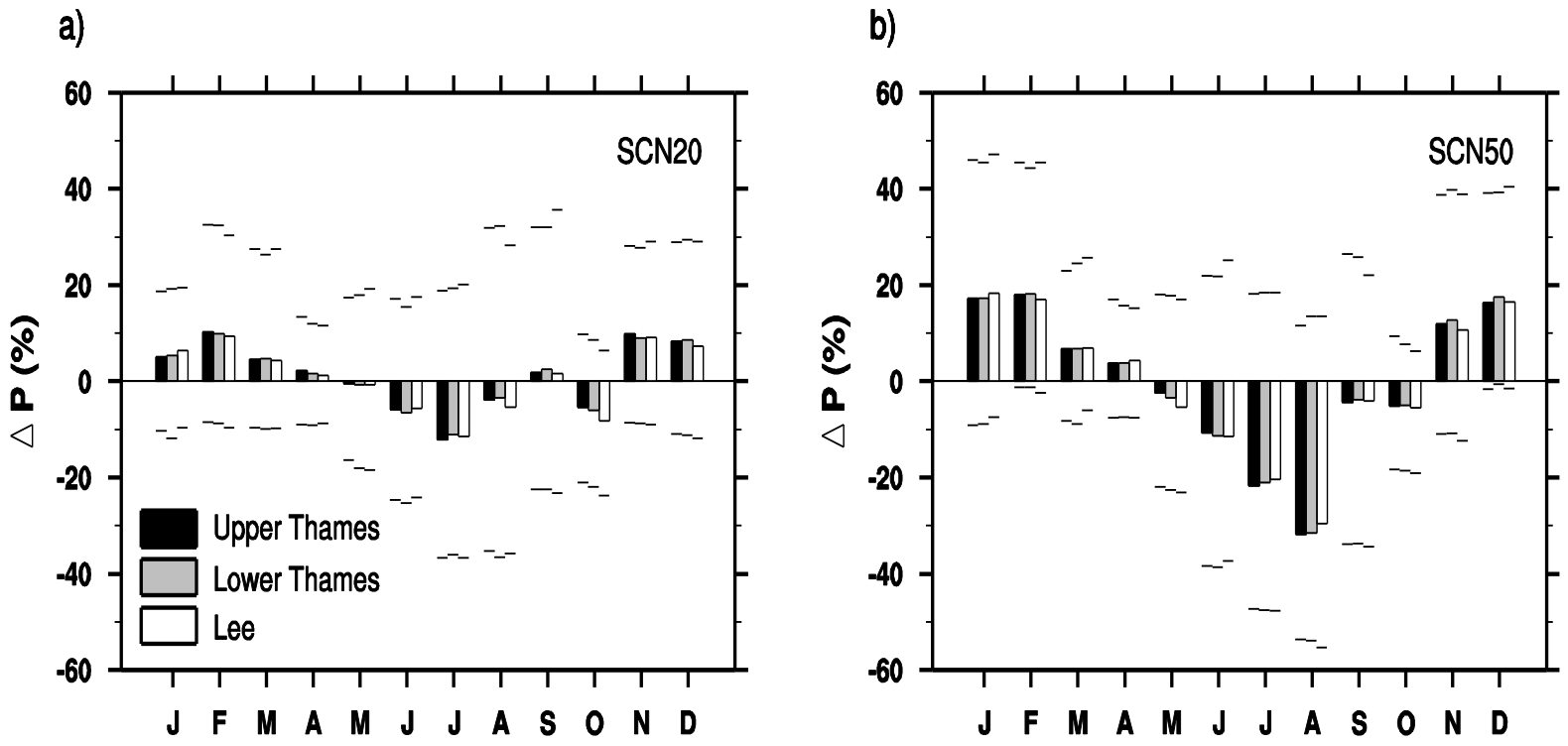
River flows are generated using a catchment rainfall-runoff model – CATCHMOD.

The generated flow series are the primary input to the Environment Agency's London Water Resource Zone model (AQUATOR).

Change Factors

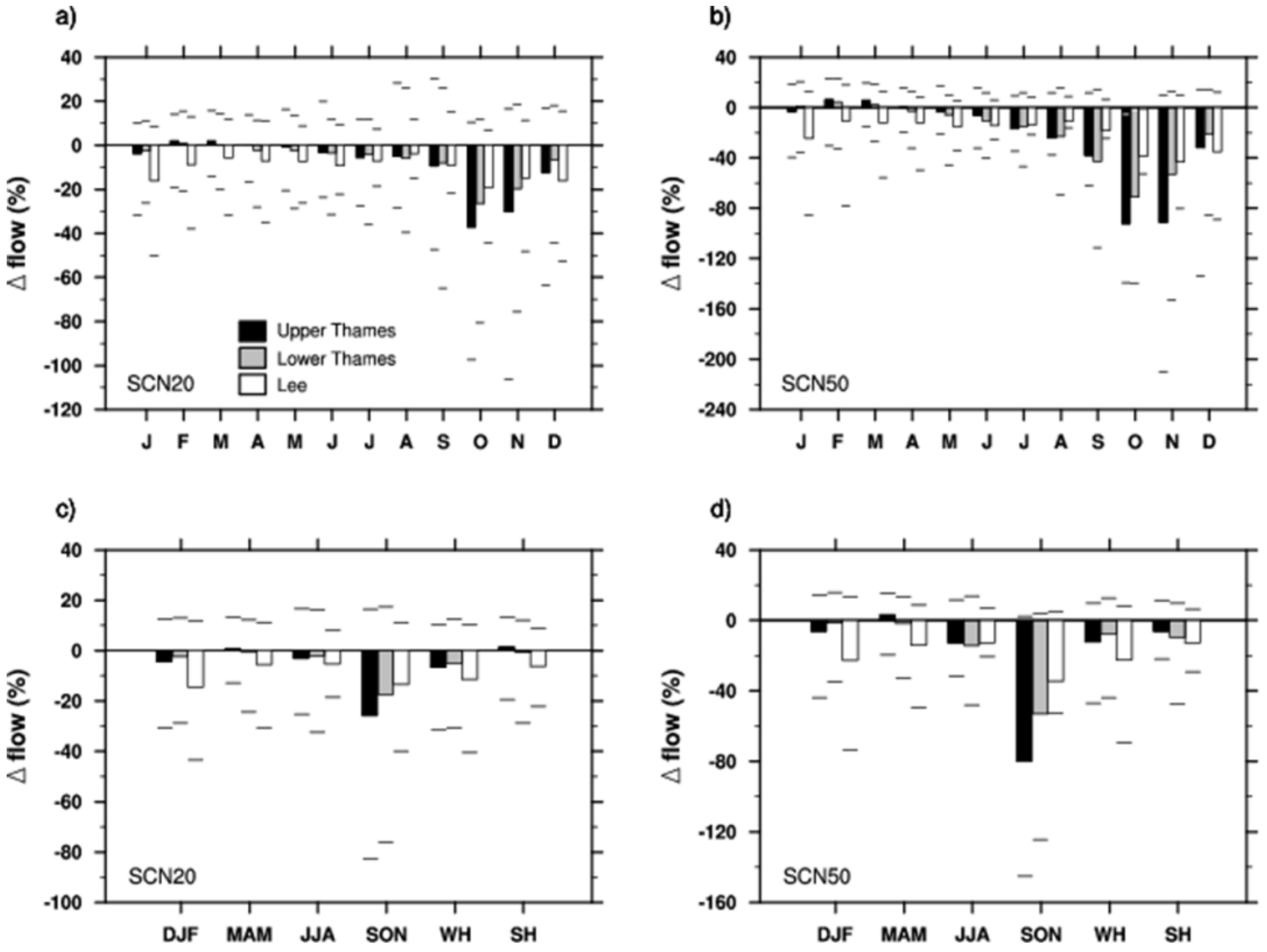


Precipitation



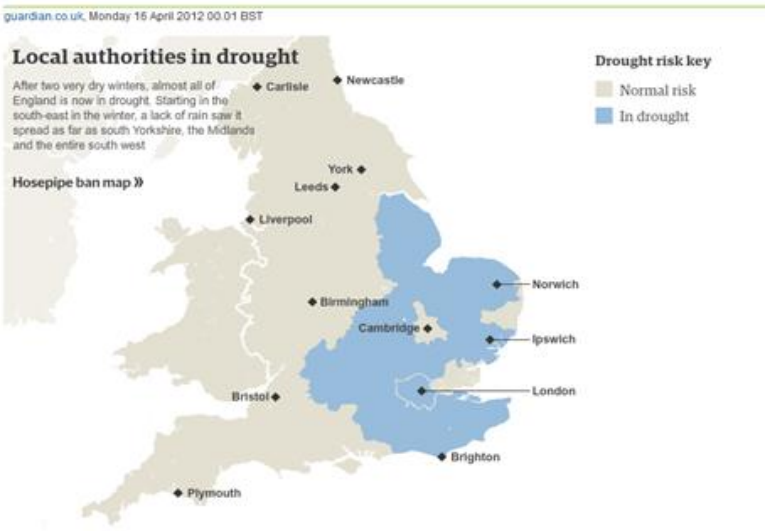
Percentage change in precipitation for a) 2020 and b) 2050. The bars denote the median change from the 100 member ensemble, the upper and lower horizontal lines indicate the ensemble 90th and 10th percentiles respectively.

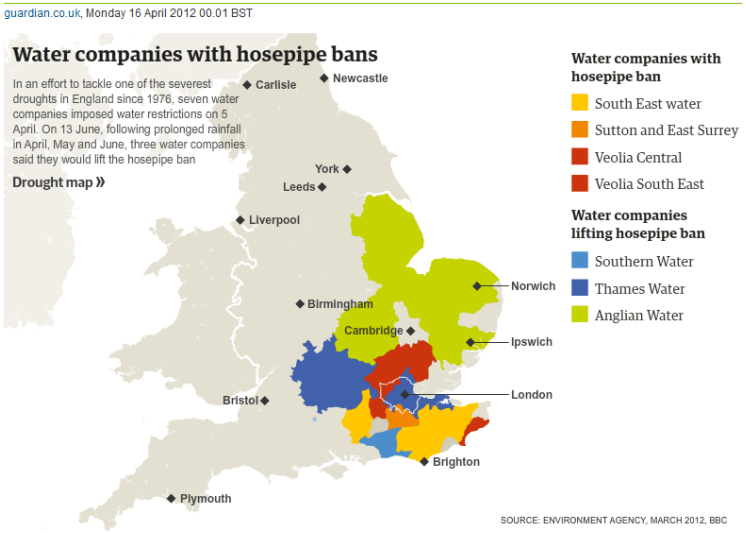
Changes in Flows



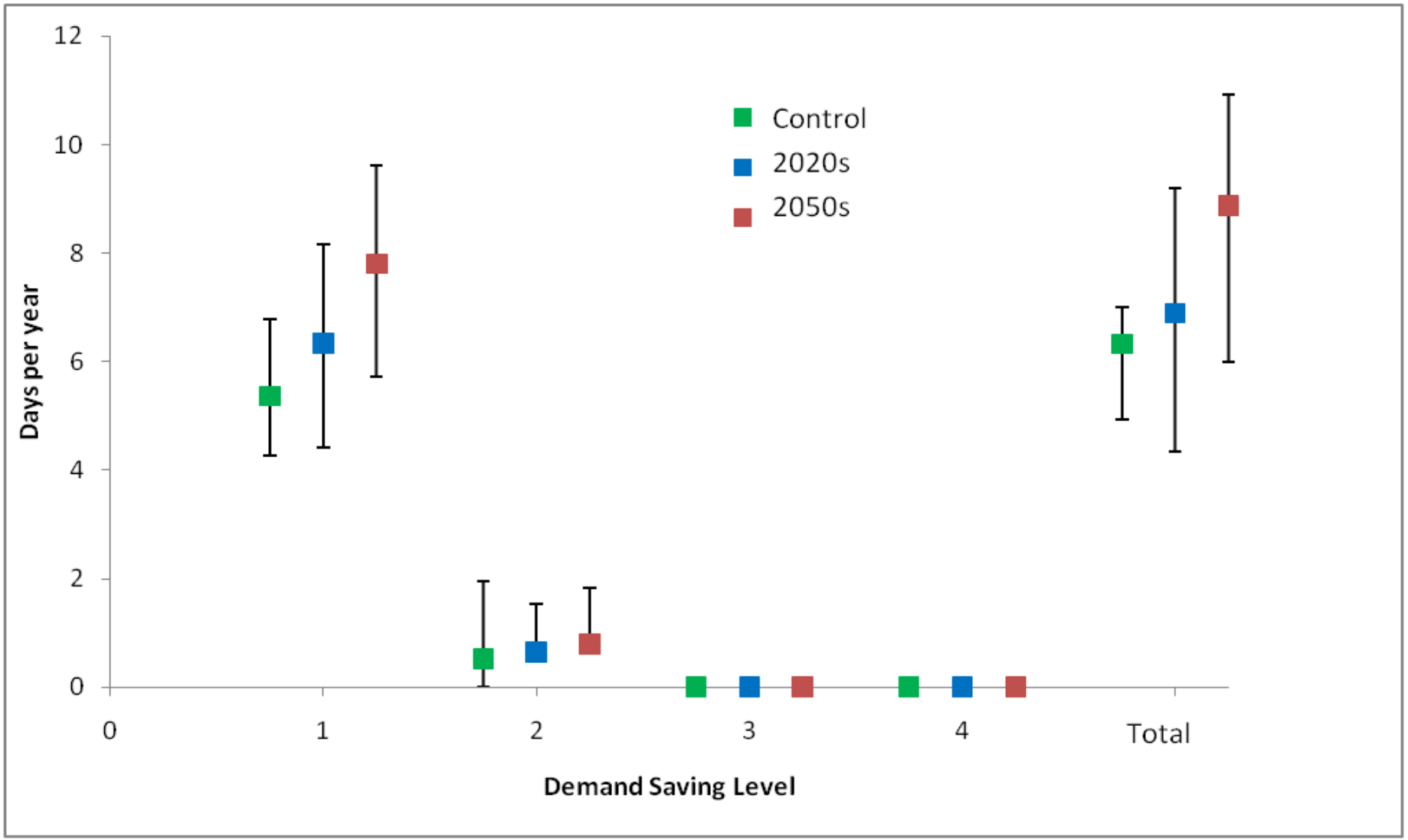
Demand Saving Measures

- Level 1: Media campaigns, additional water efficiency activities, enhanced activity and restrictions to reduce risk to water supply;
- Level 2: Enhanced media campaign, customer choice/voluntary constraint, sprinkler ban;
- Level 3: Hosepipe ban, non-essential use ban, drought order;
- Level 4: Severe water rationing e.g. rota cuts, stand pipes.

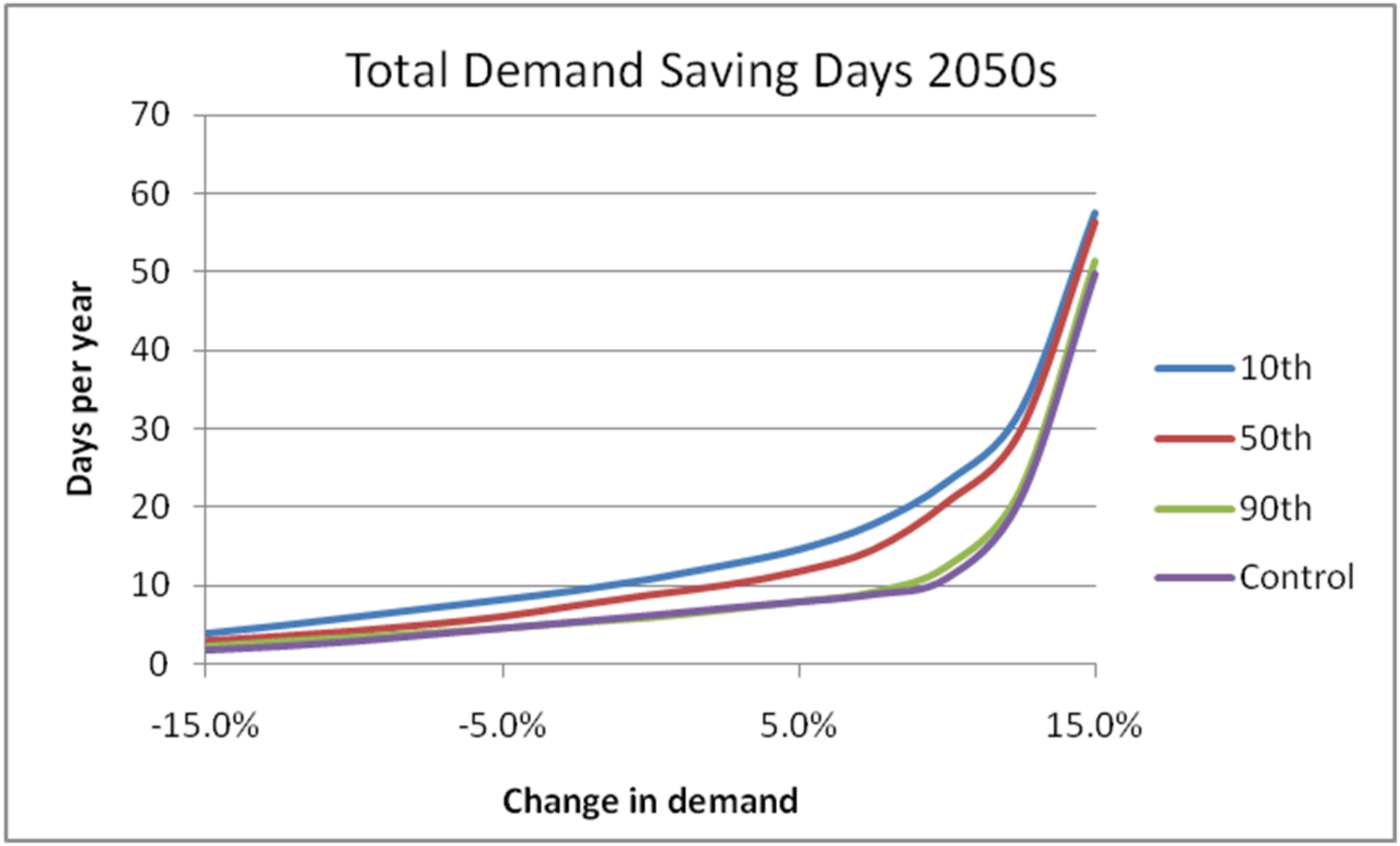




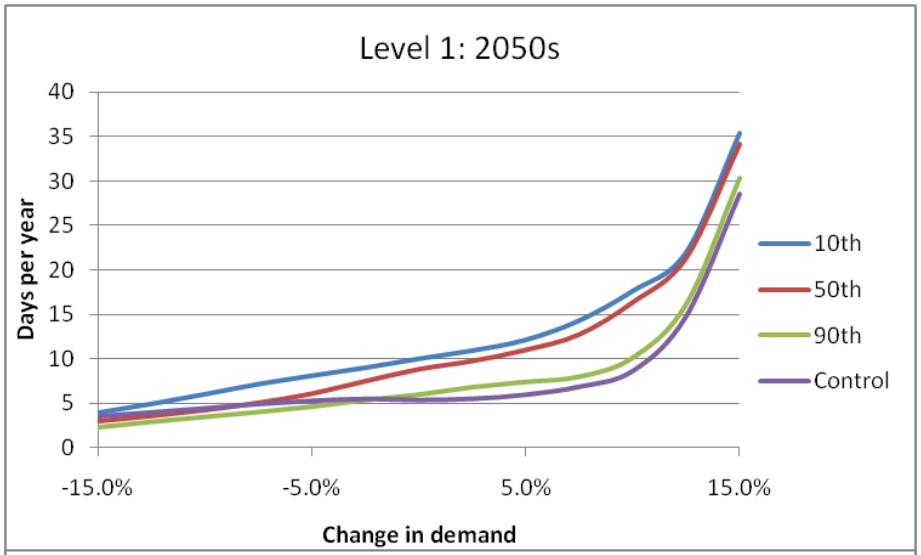
Demand Saving: Climate Only

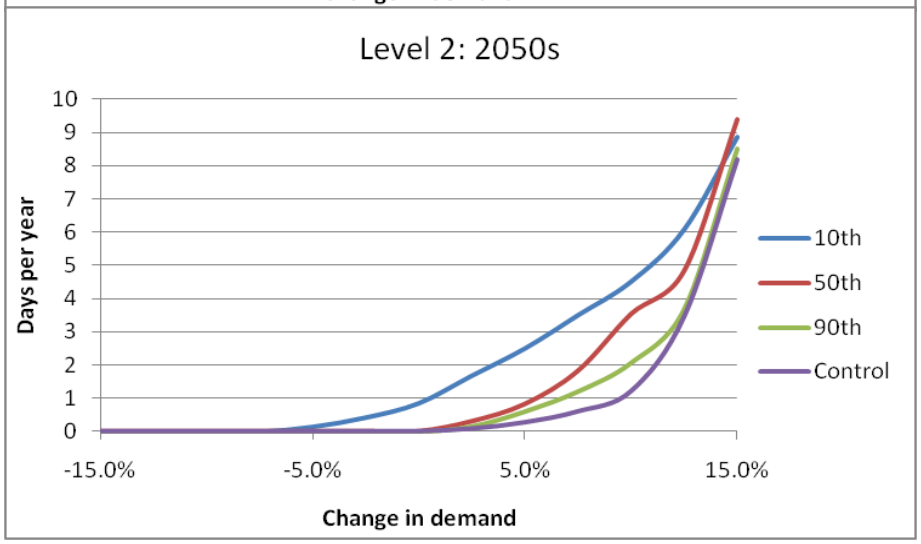


Demand Saving: Climate and Demand



Demand Saving: Climate and Demand

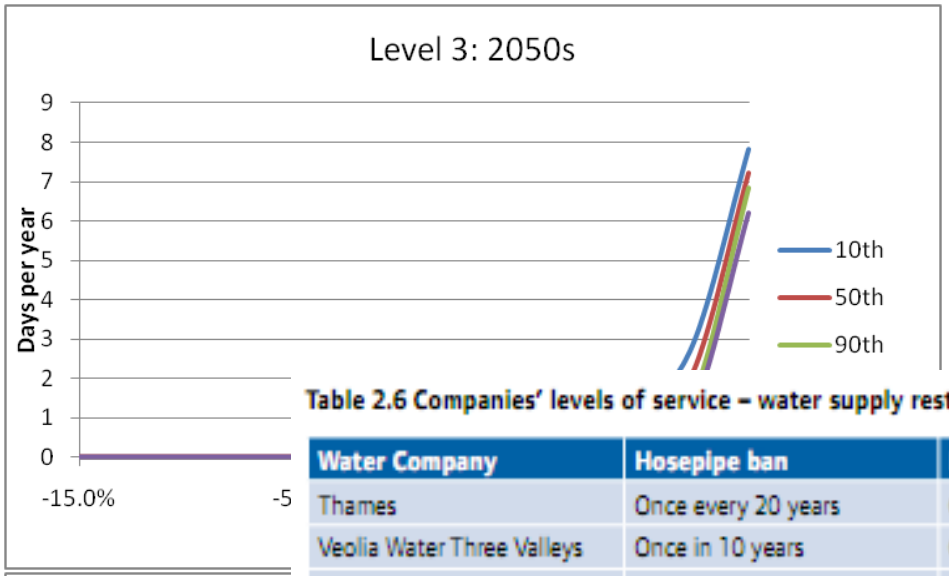




Level 1: Media campaigns, additional water efficiency activities, enhanced activity and restrictions to reduce risk to water supply.

Level 2: Enhanced media campaign, customer choice/voluntary constraint, sprinkler ban.

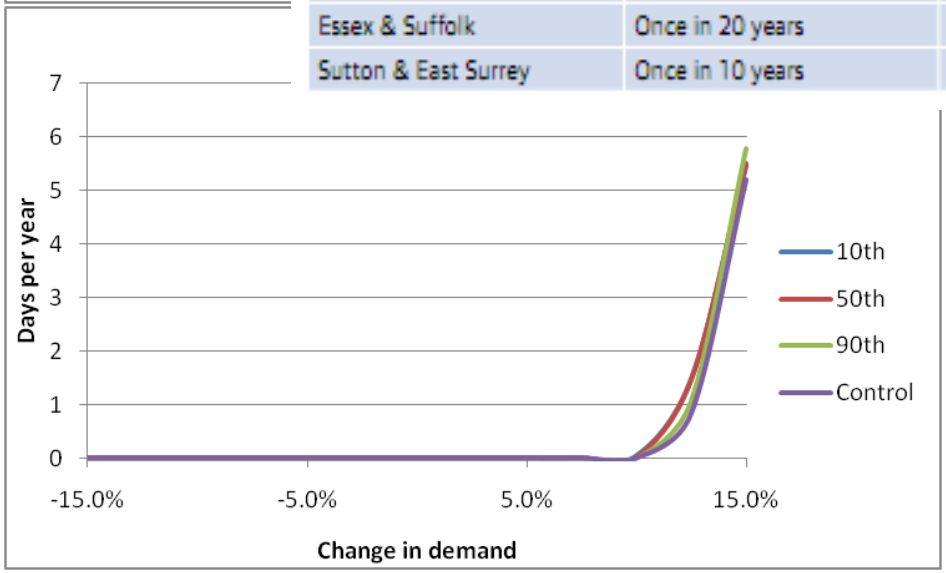
Demand Saving: Climate and Demand



Level 3: Hosepipe ban, non-essential use ban, drought order.

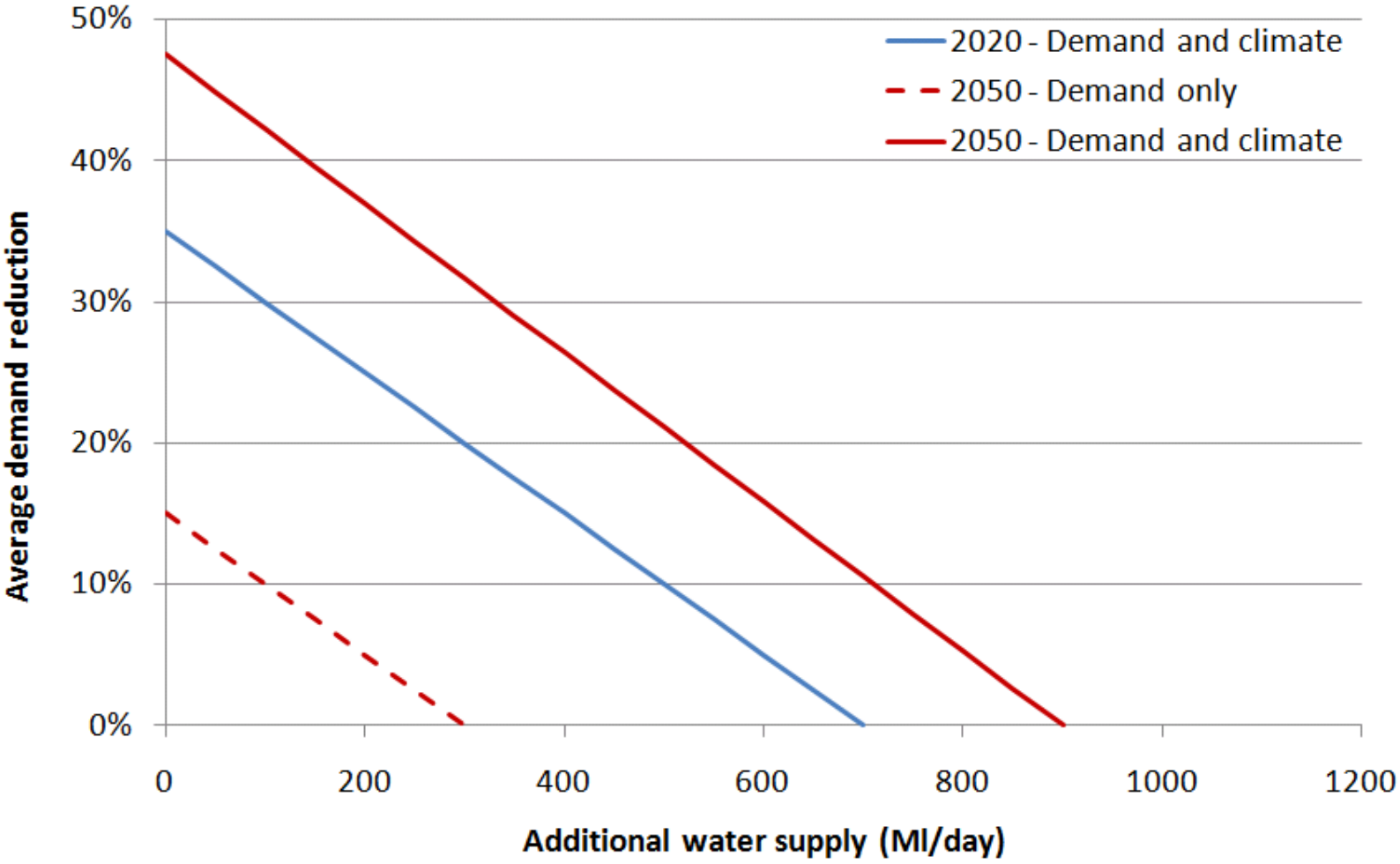
Table 2.6 Companies' levels of service – water supply restrictions

Water Company	Hosepipe ban	Drought order/permit	Rota cuts/standpipes
Thames	Once every 20 years	Once every 20 years	Never
Veolia Water Three Valleys	Once in 10 years	Once in 20 years	Unacceptable
Essex & Suffolk	Once in 20 years	Once in 50 years	Never
Sutton & East Surrey	Once in 10 years	Once in 20 years	Once in 100 years



Level 4: Severe water rationing e.g. rota cuts, stand pipes.

Supply and Demand Trade Offs



Emissions

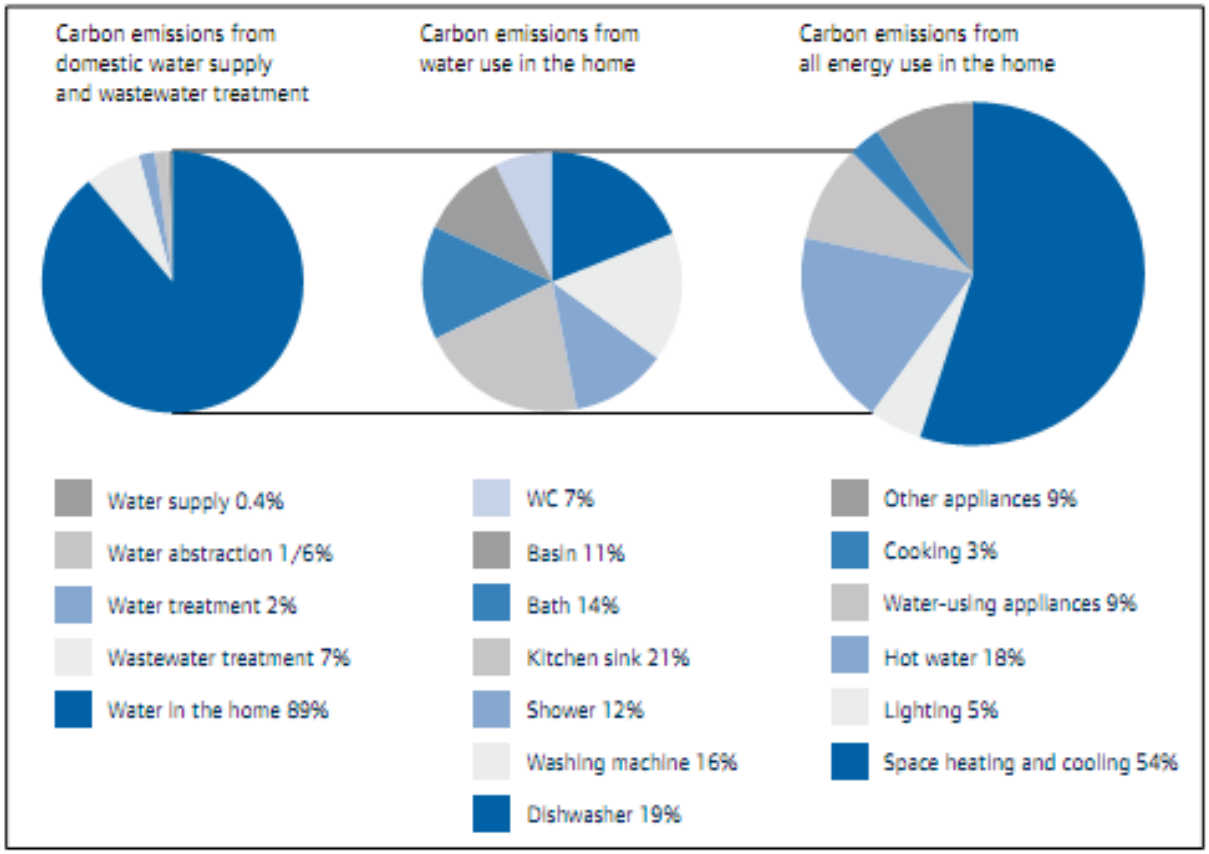
Desalination Plant

1000ML/day

2kWh/m^3

1.7Mt/CO_2/year

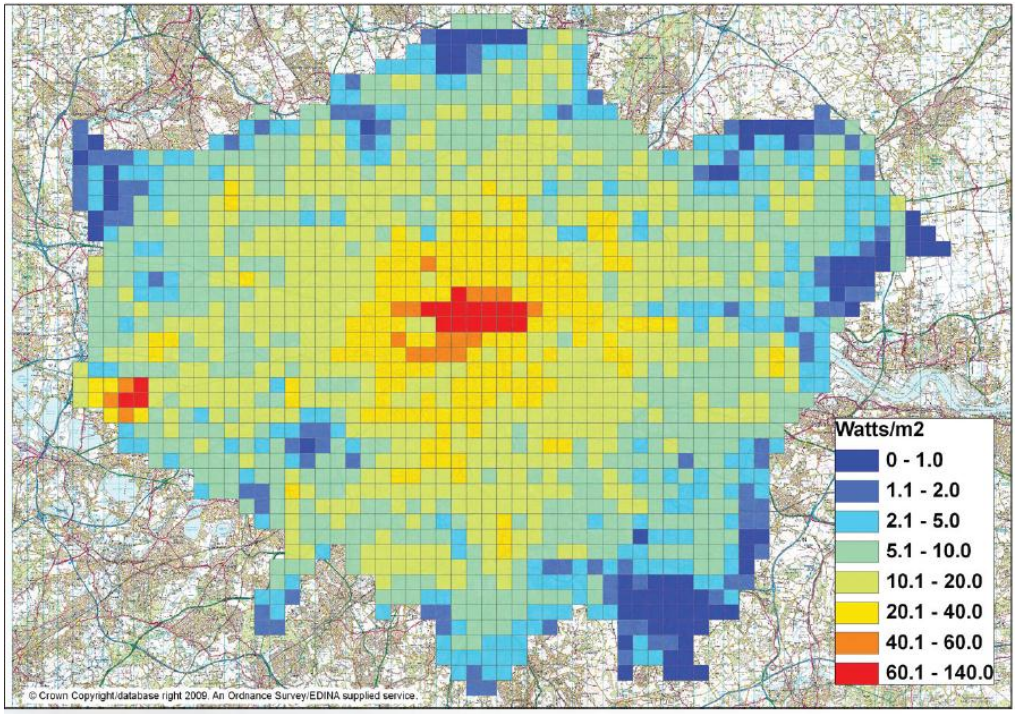
Figure 3.2 Carbon emissions resulting from water supply, use and wastewater treatment



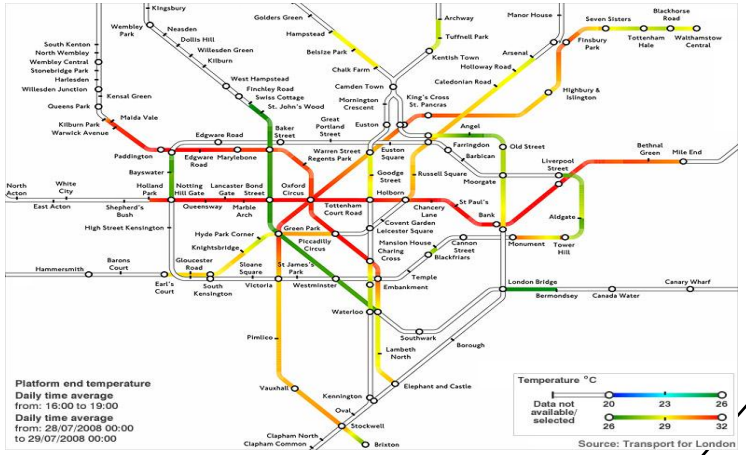
Sources: Environment Agency[41] (left chart) Energy Saving Trust (centre chart)

Heat Adaptation vs. Mitigation

Average current anthropogenic heat emissions estimated from energy use statistics



Social and Economic Effects



Extreme T, UHI, Anthropogenic Heat Release

Heat Event

Thermal Discomfort

Residential

Commercial

Transport

Mortality

Direct damage to infrastructure

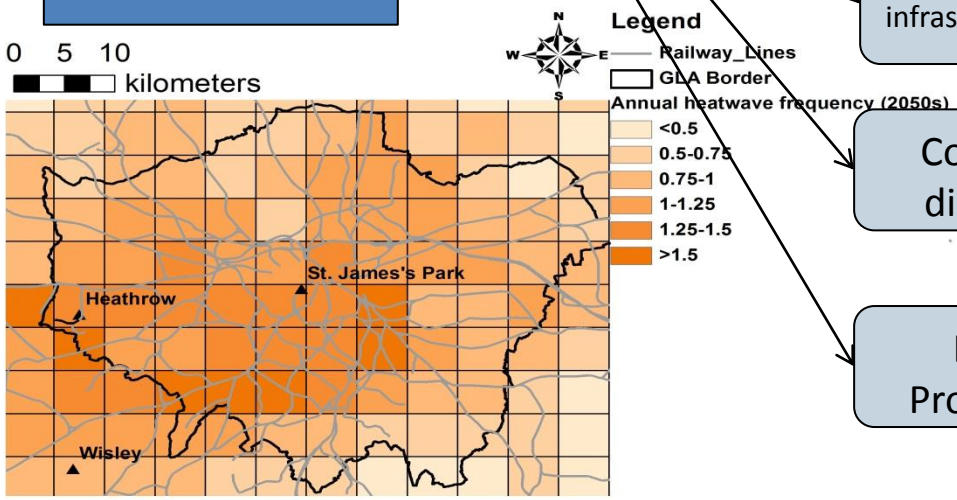
Rail Buckles

Commuter disruption

Speed Restrictions

Labour Productivity

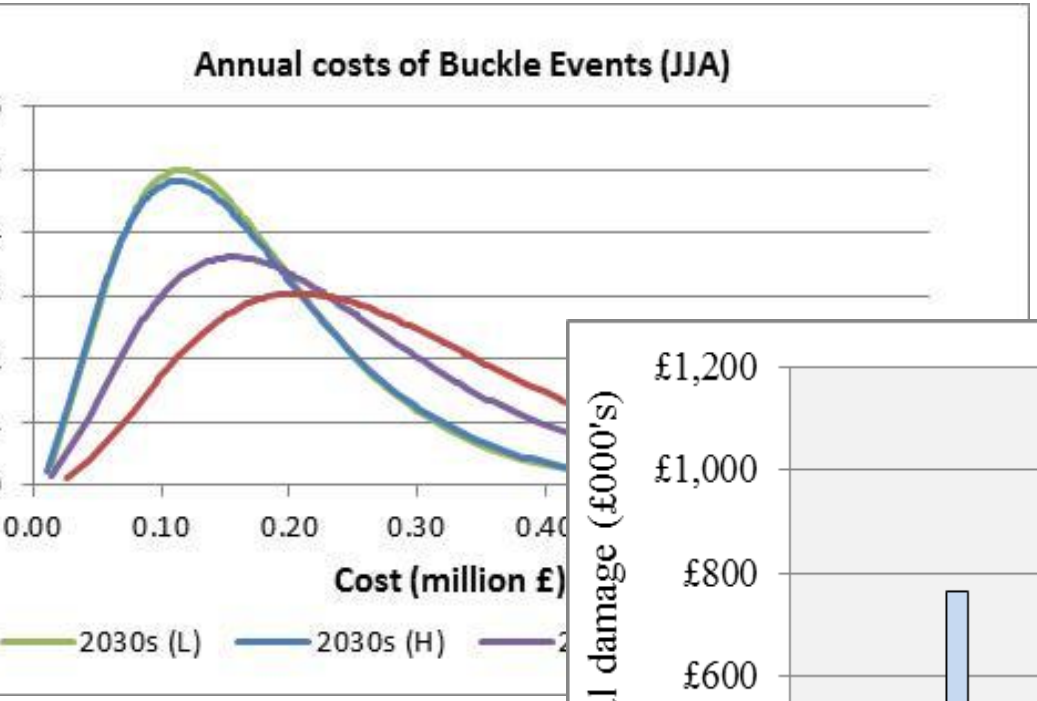
ARCADIA I-O model (Labour and Capital) Indirect



Underground

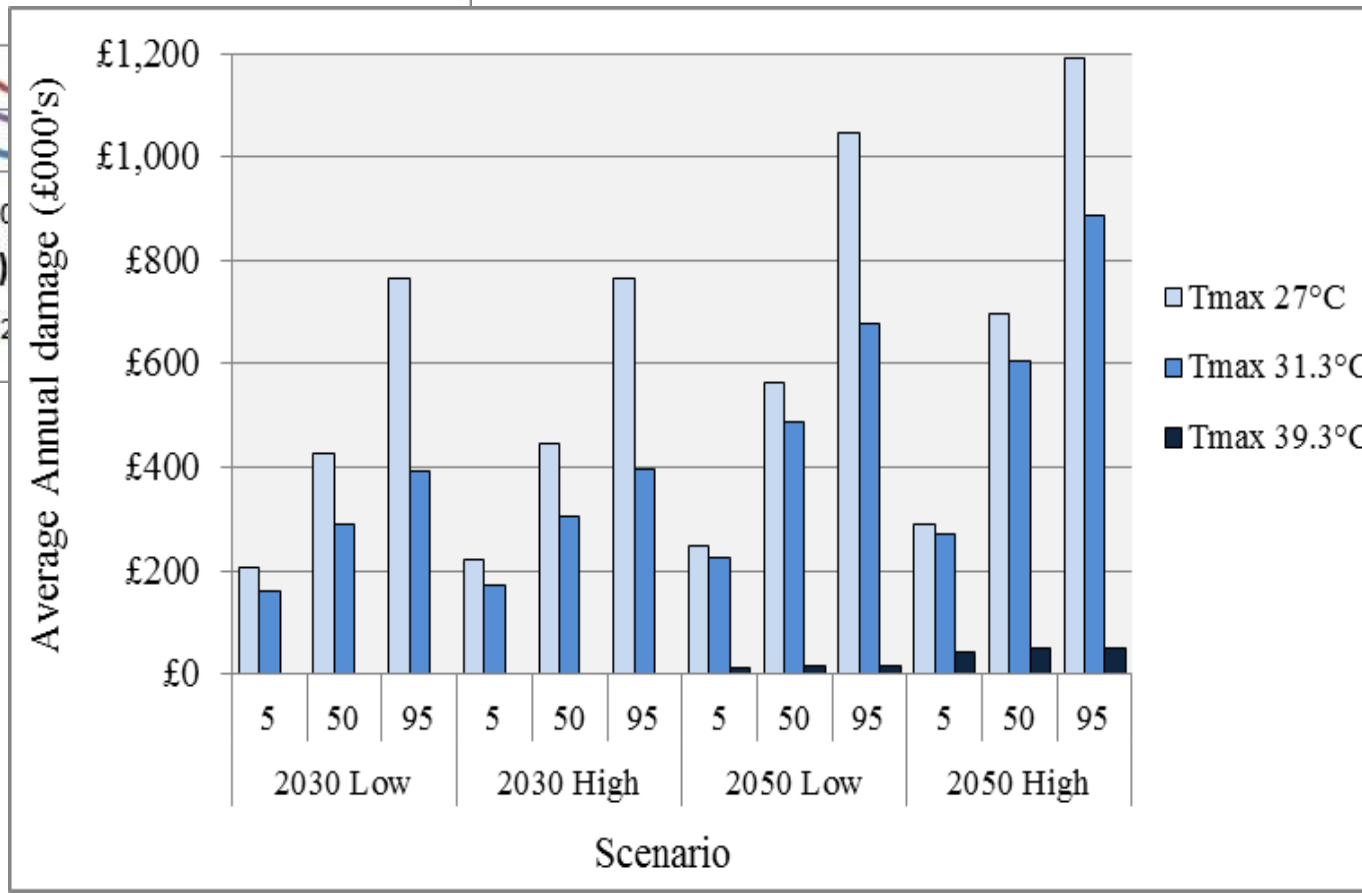
Variation in average track and train temperatures for the London Underground on the 28th July 2008

Rail Buckles

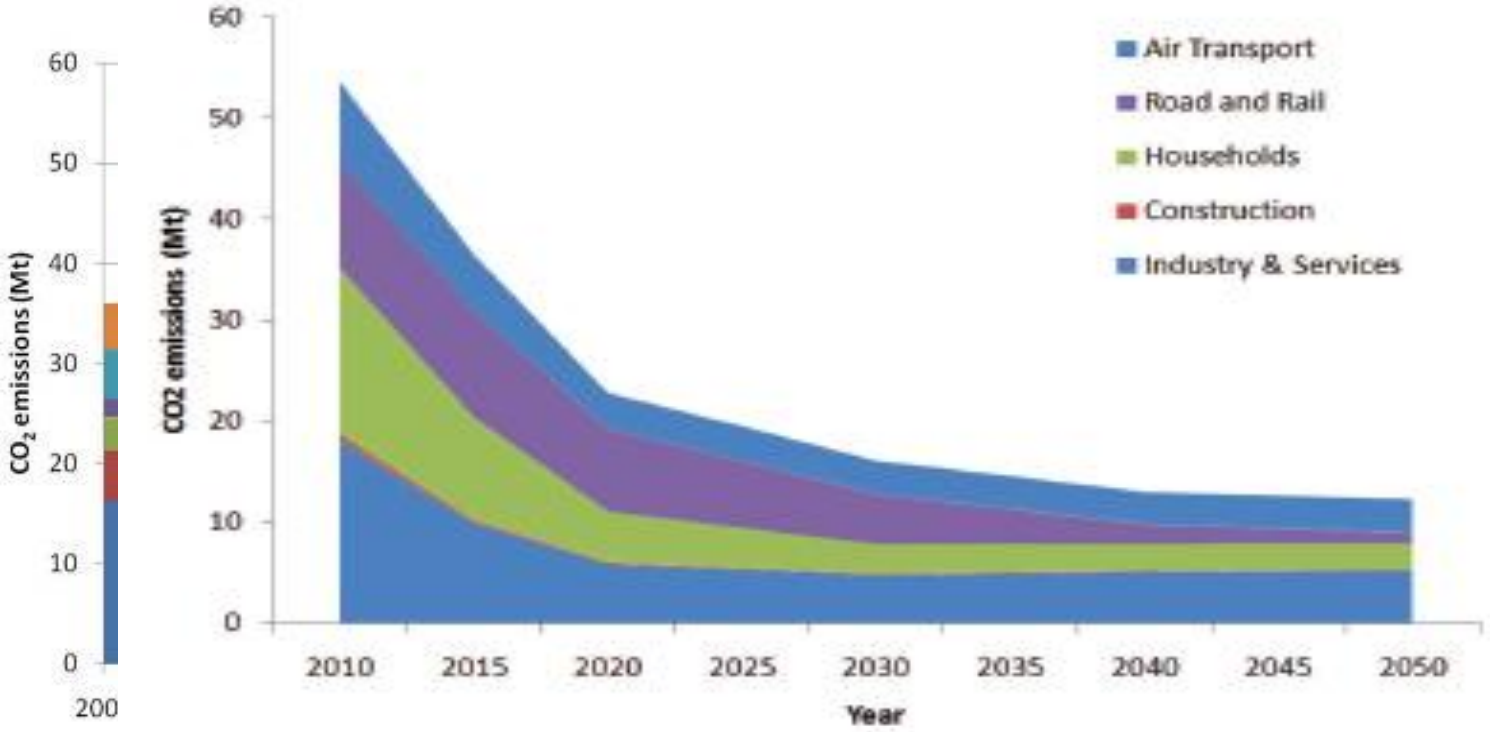


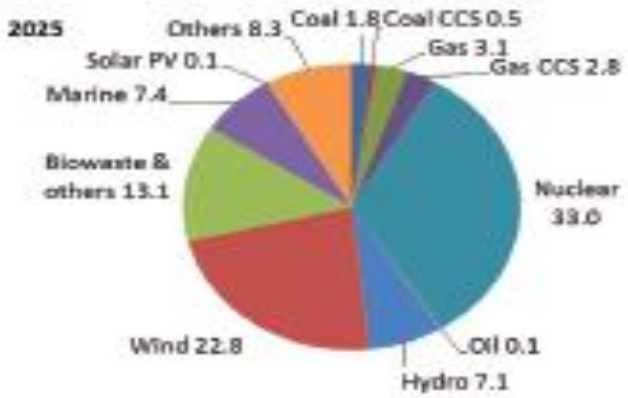
Annual costs of rail buckle events in JJA.

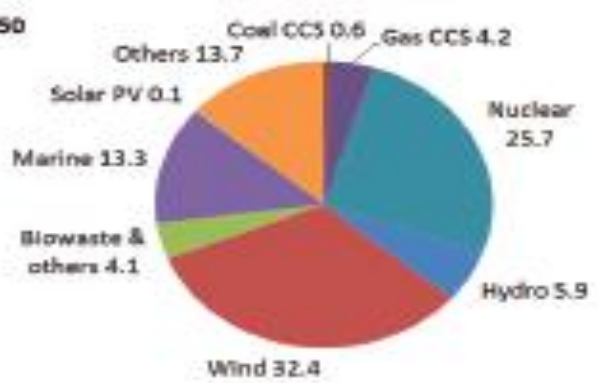
Probability of damages from rail buckle events in June, July, August, for various time-periods and emission scenarios.



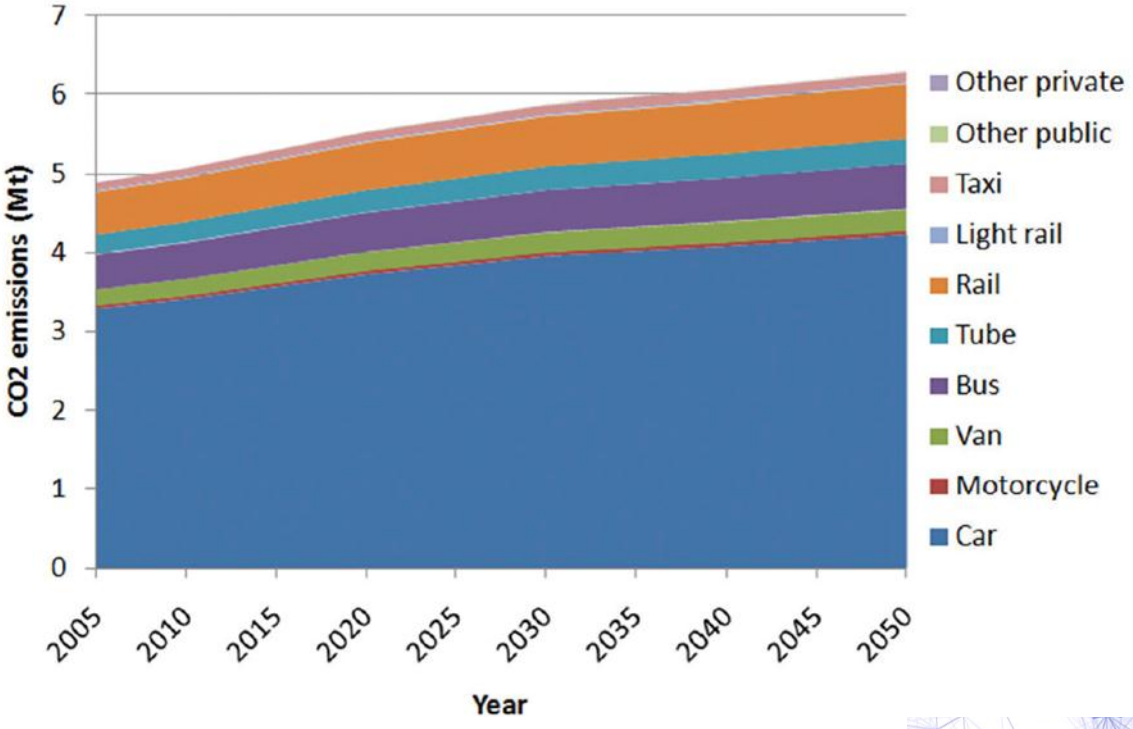
Mitigating Carbon Emissions



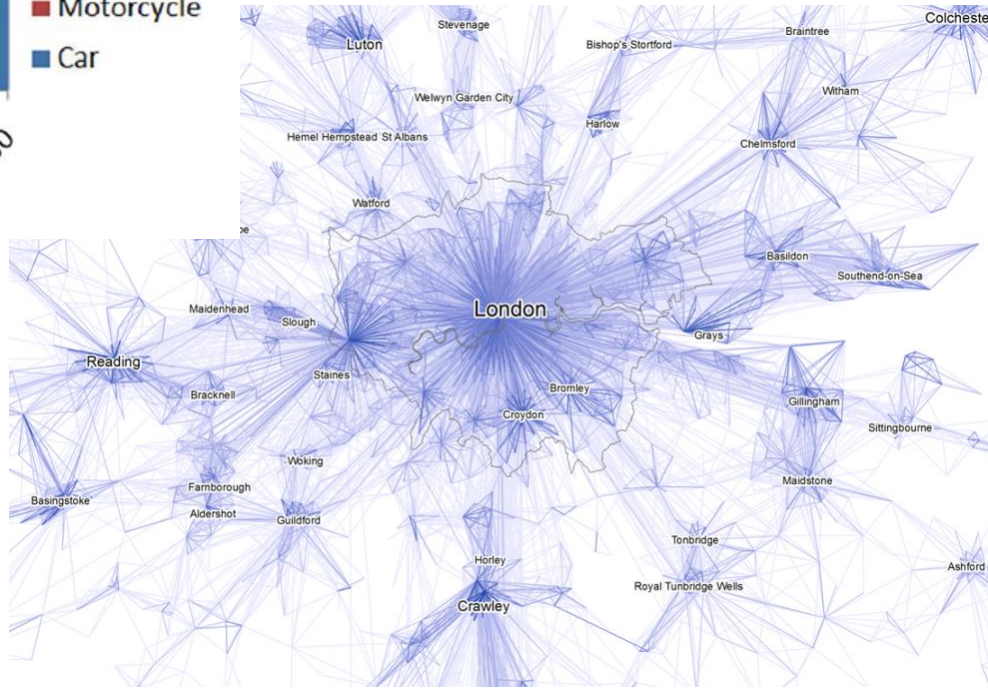




Personal Transport Emissions



Emitters' area of residence:
50% from Outer London residents
25% from inner Londoners
12% from southeast region
9% from east region
4% from rest of the UK



Transport CO2 emissions could increase by 1.5Mt by 2050 if no mitigation action is taken, assuming same per capita use remains the same.

Personal Transport Policy Options

Policy 1: Implementation of the London Mayor's Climate Change Action Plan by 2025:

Increased operational efficiency – 20%
Eco-driving – 10%
Improved infrastructure and vehicles – 35%
Lower carbon fuels – 15%

~12% reduction by 2025 (relative to base line)

Policy 2: as policy 1 plus:

25% zero emissions vehicles
40% zero carbon rail, tube and light rail
30% zero emissions buses;
40% hybrid buses

~23% reduction by 2025 (relative to base line)

Policy 3: as policy 2 plus:

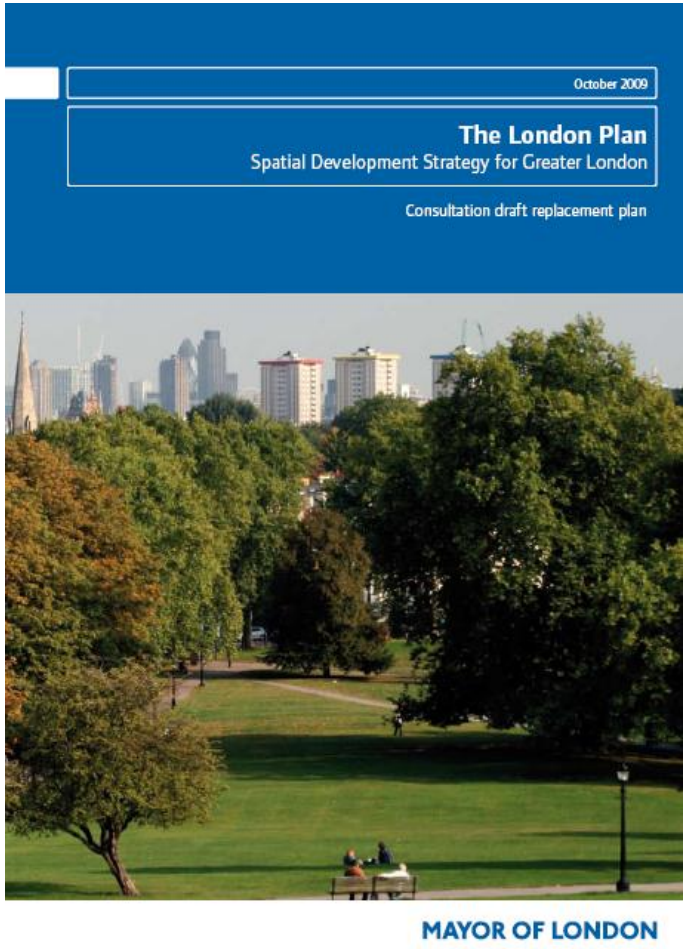
43% zero emissions vehicles
90% zero carbon rail
45% zero emissions buses;
55% hybrid buses

~25% reduction by 2025 (relative to base line)

Policy 4: as policy 3 but with a substantial modal shift to walking and cycling, supported by the appropriate infrastructure, giving a 60% mode share.

~37% reduction by 2025 (relative to base line)

Working with the GLA



- Revision of London Plan
- What does the Tyndall Cities work bring?
  - Quantifying impacts and adaptation benefits
  - Testing multiple population/ employment scenarios
  - Testing land use/ adaptation/ mitigation policies
  - City scale overview that integrates across sectors traditionally analysed independently
  - Systems view, so sometimes more detailed models required for specific issues
- London Plan is very broad - can't inform it all!
- Challenge of timing of engaging with plan process

Value of UIAF

- Main processes of long term change at the city scale
  - Flexibility to test wide range of mitigation and adaptation policies by incorporating diverse evidence, representing a number of urban processes and interactions.
- Adaptation pathways
  - Climate risks driven by growing population and changes to the economy, set to increase.
  - Portfolio of measures – existing technologies, manageable scales
- Adaptation/Mitigation Conflicts
  - Consequences of maladaptations to be quantified.
  - E.g. desalination plant to provide 10% of London's current demand could contribute a further 0.7% to CO2 emissions. Its relative importance would depend on changes to water and energy demand, awa energy generation mix.

Value of UIAF

- Sustainability Objectives
  - Relationship between urban density and quality of life is complex.
  - Decisions set in motion development trajectories for future climate risks and constrain development options for future generations.
- Decision Making
  - Internally consistent framework for analysis of long term drivers to test both adaptation and mitigation policies in cities.
  - Principles and overarching systems framework provides a platform for additional issues.
  - Projected risks and growth can be managed by existing approaches and technologies – fundamental building blocks are already in place.
  - Other cities face greater challenges than London, and portfolios will vary by city, but opportunities to minimise future risks and climate policies will be greater in faster growing cities.

So…can cities grow while reducing their vulnerabilities and emissions

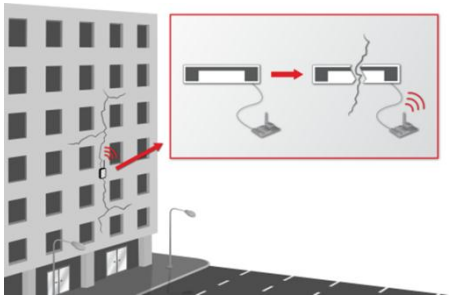
- Today's decisions will alter vulnerability and emissions for years
- Innovative approaches to adaptation and mitigation can be developed by evidence-based integrated assessment of urban systems
  - Develop a collective understanding of policies concerning
  - Multiple hazards
  - Involving wide range stakeholders
  - Delivering individual urban functions.
- Local Gov rarely have powers to address all these issues but cities are centres of innovations and where many are best addressed
- London can address challenges through existing technologies
  - Opportunities for new build limited compared to other cities
  - No magic bullet, and potential for conflicts:
    - Socio-economic *vs*. climate change
    - Demand reduction *vs*. supply increase
    - Trade-offs between mitigation, adaptation, living density etc.
- Spatial planning plays a central role in mediating vulnerability and emissions

Limitations

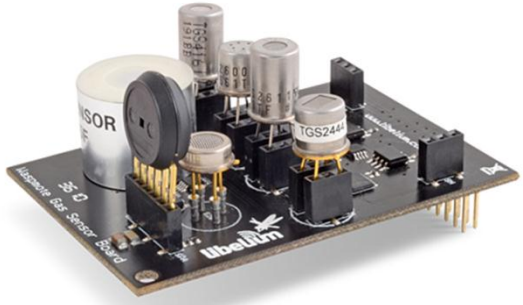
- Simplifying assumptions about processes and interactions.
- Aggregated approach for estimating CO2 emissions – more complete approach would examine explicitly energy demands, supply, networks and flows in urban areas e.g. in relation to water, waste, materials.
- Tested adaptation and mitigation policies, but the next crucial step is to develop integrated portfolios and strategies for implementation. More rigorous examination of uncertainties should then form the basis for development of robust portfolios.
- No examination of qualitative aspects – important to consider how evidence can be related to city governance of mitigation and adaptation.
- Footprints – is city-region more appropriate?

Decision Theatre

Long Term Monitoring



Building condition will be monitored using accelerometers and crack gauges (*Libelium, 2012).*

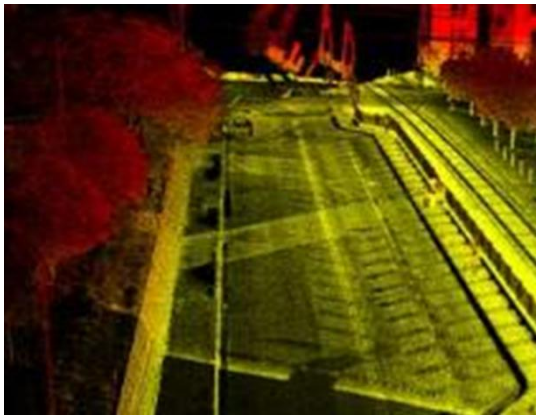


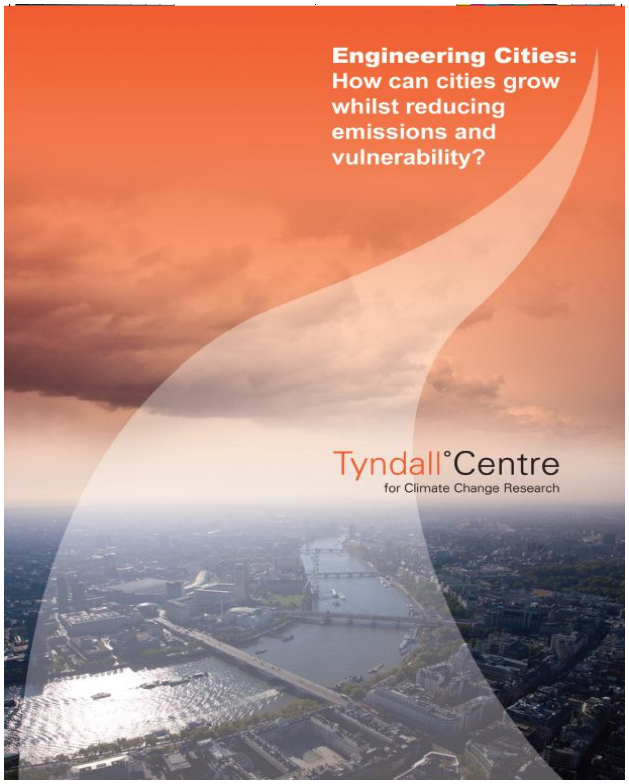
High density weather monitoring will be achieved through a network of over 20 weather stations.

Proximity sensors will be able to anonymously monitor building activity, the same platforms will also house temperature and air quality sensors.

Ground temperature, soil pore water pressure and slope instability will be measured using piezometers, thermistors and tensiometers .

Rapid laser scanning will be used to provide high resolution data on the built environment





http://www.ncl.ac.uk/ceser

"We have come to recognise how integrated modelling of the type delivered by the Tyndall Centre Cities programme can help to bring different stakeholders together to develop common understanding of processes and consequences of long term change.

That collective understanding is essential if we are to manage change rather than become its victims."

GLA