Critical infrastructure vulnerabilities and adaptation priorities

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Workshop on:
A SYSTEM OF SYSTEMS PERSPECTIVE ON CRITICAL INFRASTRUCTURE MANAGEMENT IN RESPONSE TO CLIMATE CHANGE AND SEA LEVEL RISE
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University of Virginia

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EPSRC
Engineering and Physical Sciences Research Council

Acknowledgements

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  - JBA
  - Infrastructure UK
  - Network Rail
  - Department for Transport
- Adaptation Sub-Committee (ASC) of the Committee on Climate Change

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Infrastructure failures

Castle Meads electricity substation flooded in 2007 leaving 42,000 people without power

Railway workers inspect the main Exeter to Plymouth railway line at Dawlish (2014).

December 2015 55000 homes left without power after a substation in Lancaster flooded

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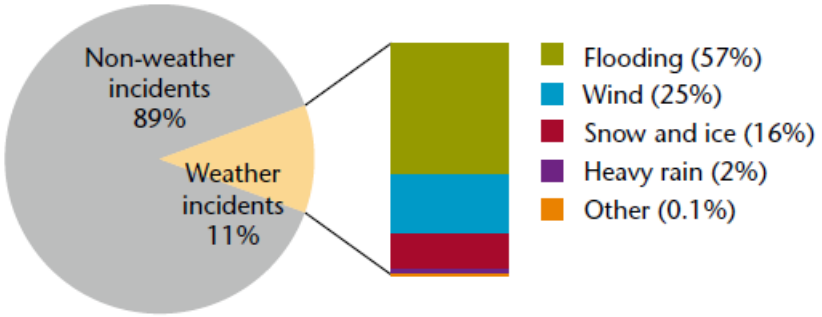
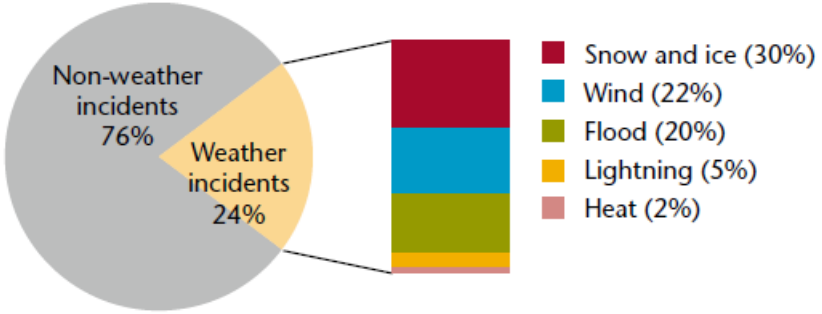
Disruptions to UK infrastructure

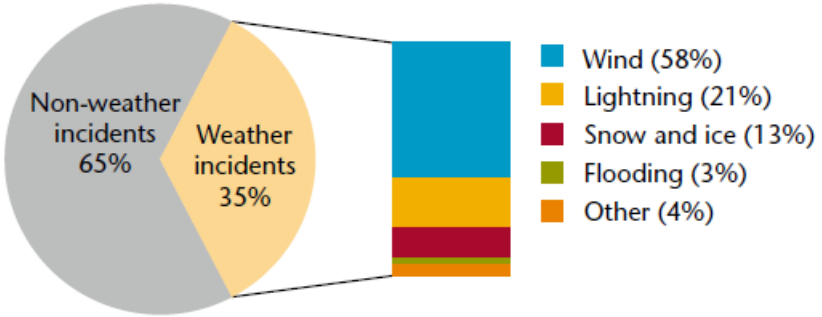
Roads (2006-2014)
Total average annual disruption (England):
2.2 million customer minutes



Rail (2006-2013)
Total average annual disruption (England and Wales):
7.1 million customer minutes



Electricity distribution high voltage network (1995-2011)
Total average annual disruption (UK):
1.3 million customer minutes



Water supply (2012-13)
Number of properties affected by unplanned interruptions of more than 3 hours: 921,114
(4% of all connected properties)

Source: ASC, 2014

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ASC assessment of progress with adaptation

Overview of progress			
Adaptation priorities	Is there a plan?	Are actions taking place?	Is progress being made in managing vulnerability?
1. Design and location of new infrastructure	Green	Green	Amber
2. Resilience of infrastructure services	Green	Green	Amber
(a) Energy	Green	Green	Green
(b) Public water supply	Green	Green	Amber
(c) Ports and airports	Amber	Amber	Grey
(d) Roads and rail network	Green	Green	Amber
(e) Digital infrastructure	Amber	Grey	Grey
3. Infrastructure interdependencies	Amber	Green	Amber

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Key questions

- What are the key vulnerabilities in the national infrastructure network?
- What are the hazard scenarios?
- What is the probability of failure?
- What are the economic consequences of failure?
- How should adaptations be prioritised?

Network vulnerability

Network mapping

Multiple infrastructure types:

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

Database of 200,000 assets (nodes & edges) for GB

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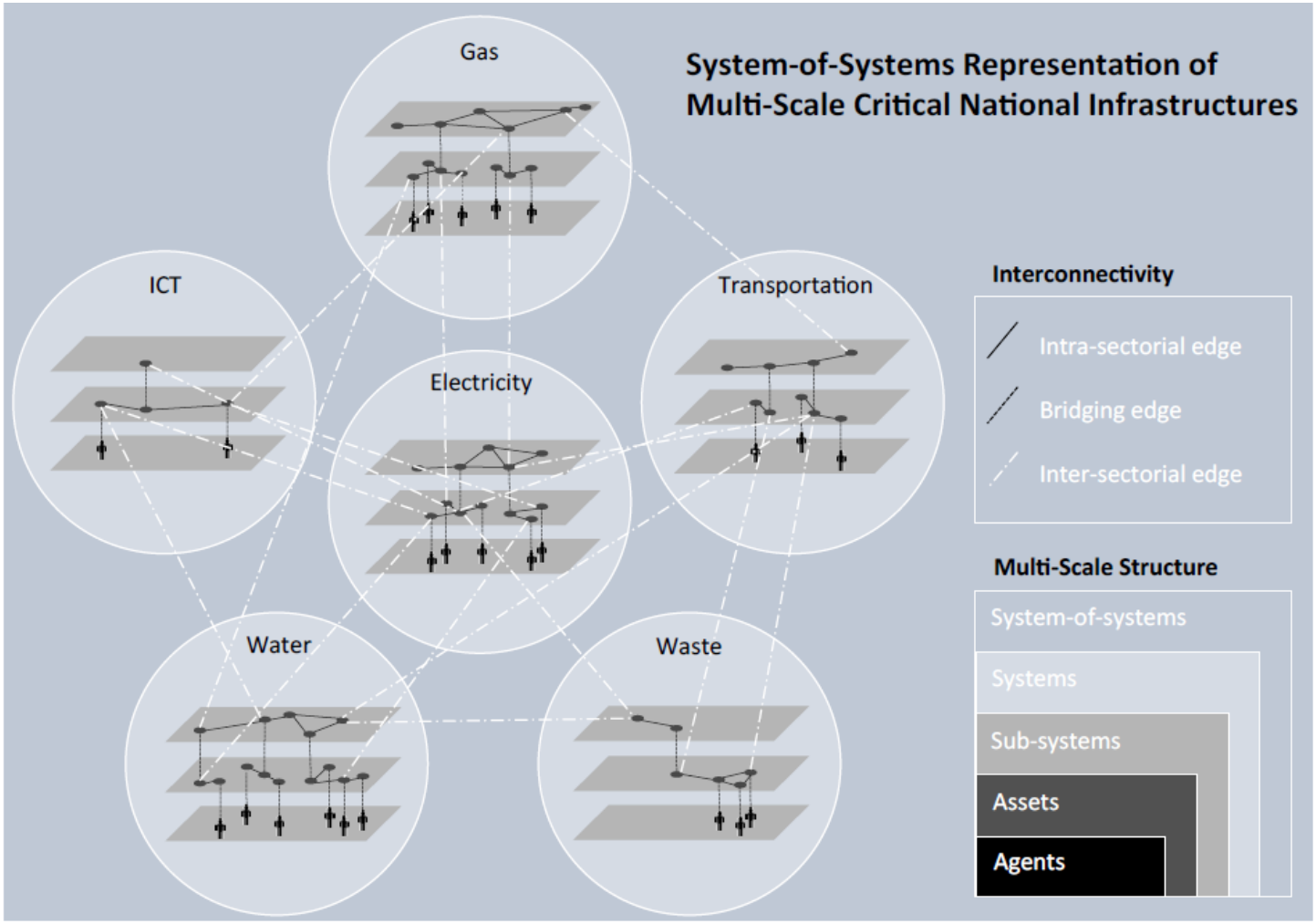
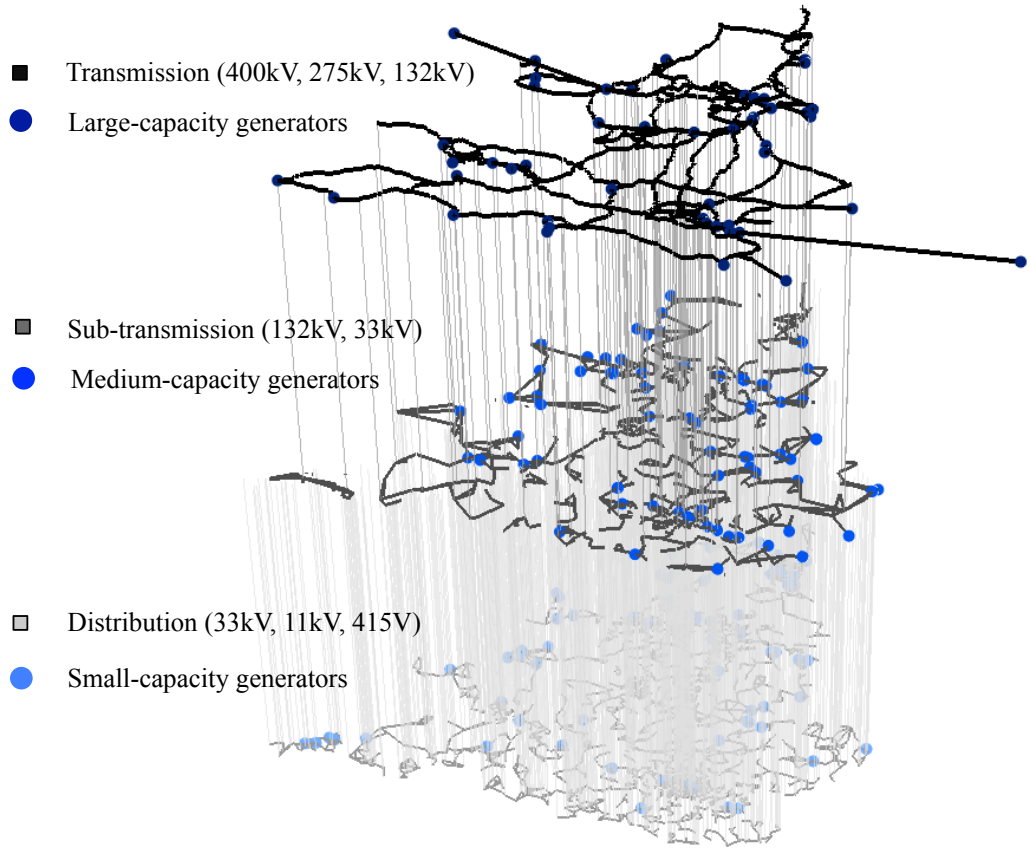
Network interdependencies



Mapping interdependencies

Integrated electricity network



Infrastructures dependent on electricity for their operation

33kV connections

- Ports
- Airports
- Railway stations

11kV connections

- Water towers
- Waste water treatment
- Telecom masts

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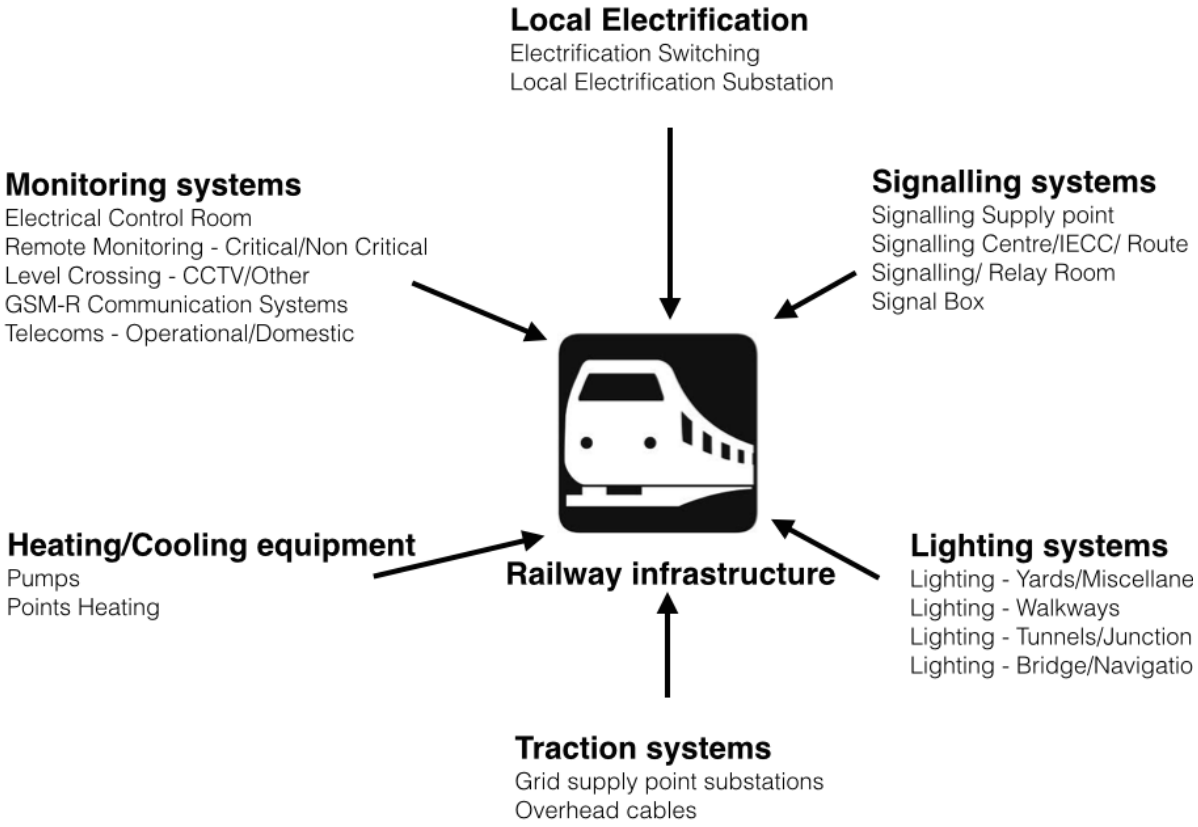
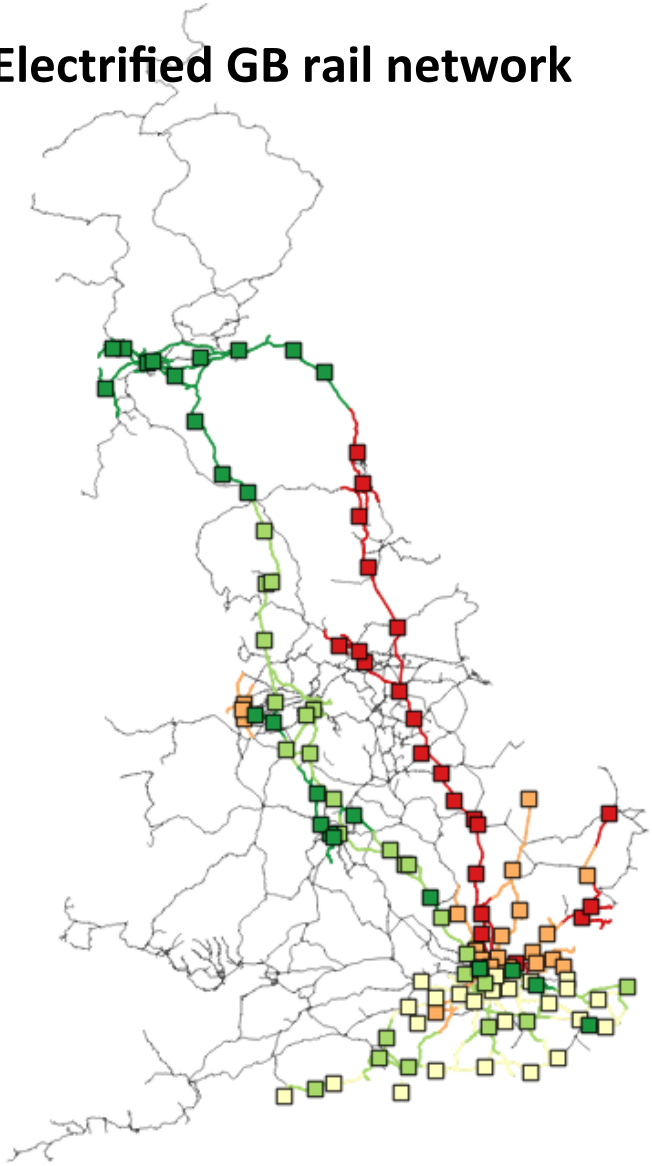
Mapping infrastructure interdependence

Example: Railway



Electrified GB rail network



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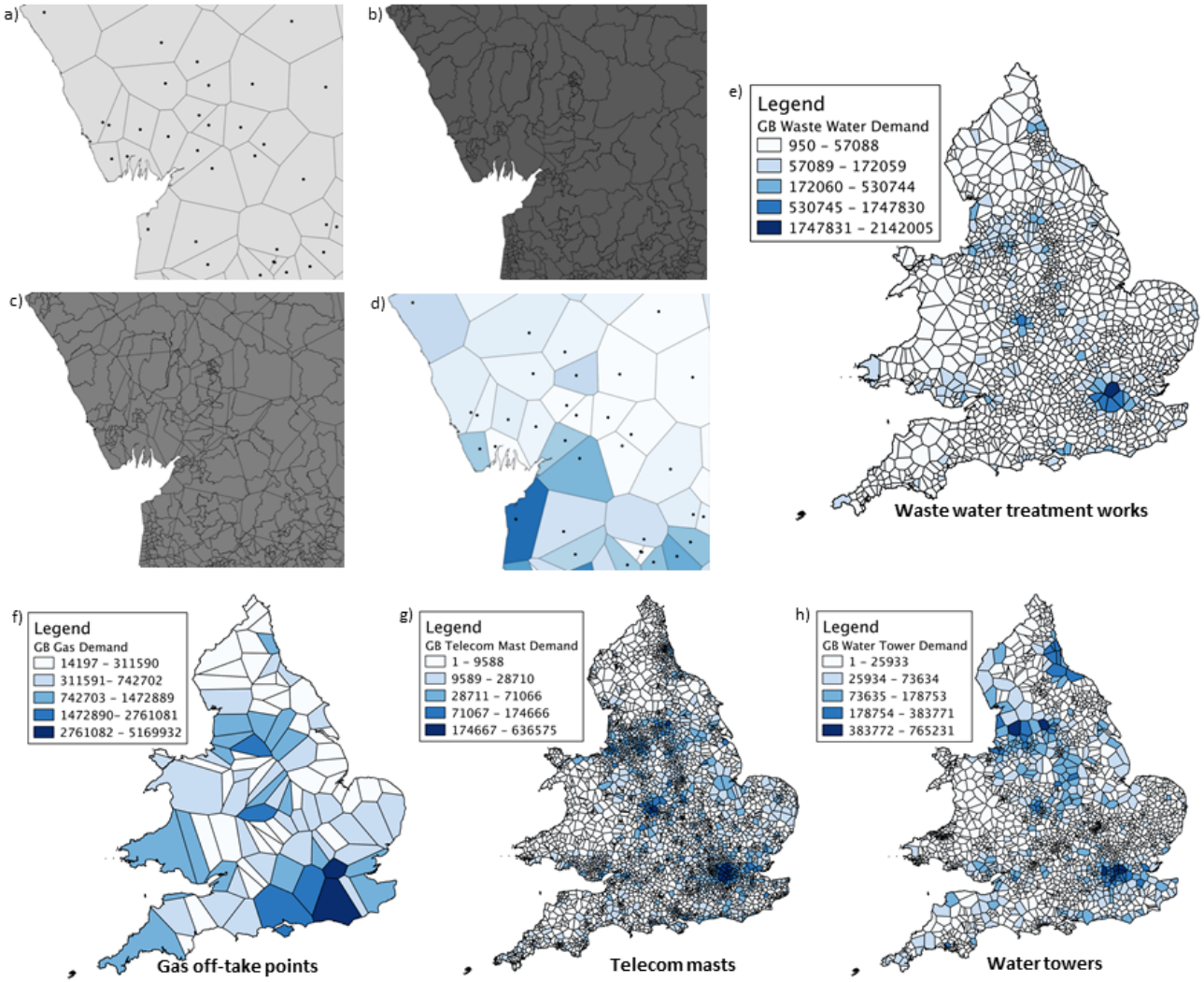
Mapping customer demands



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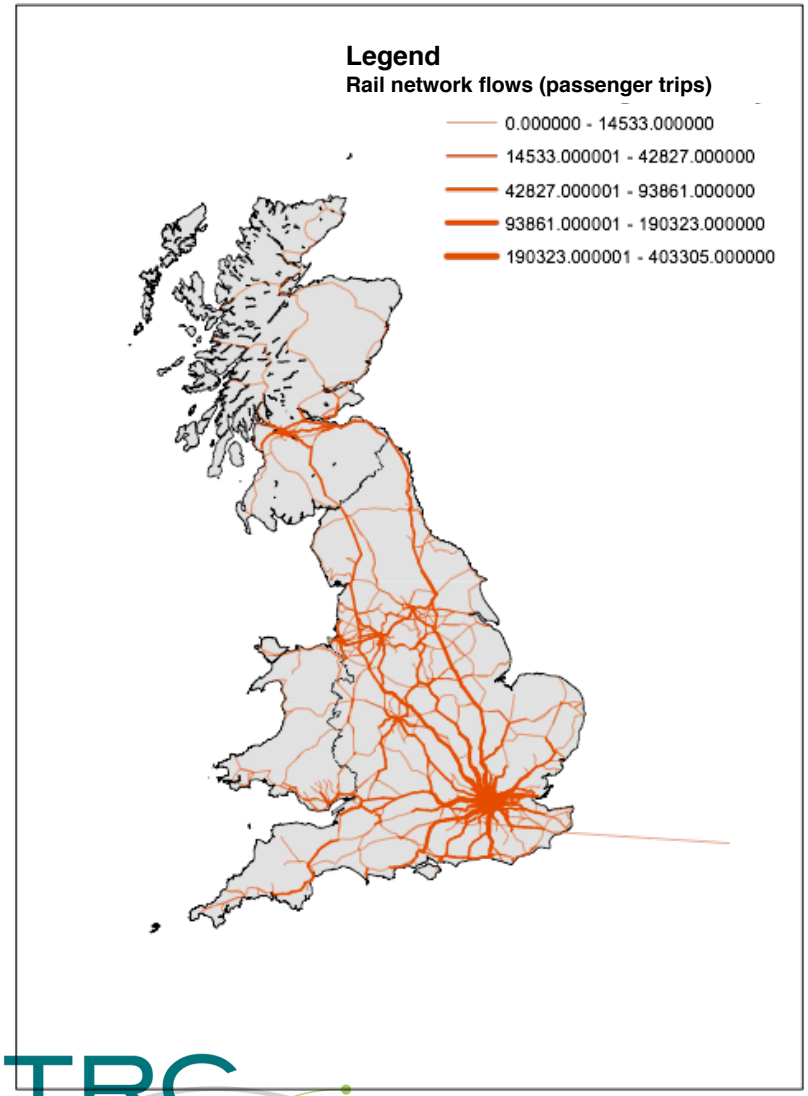
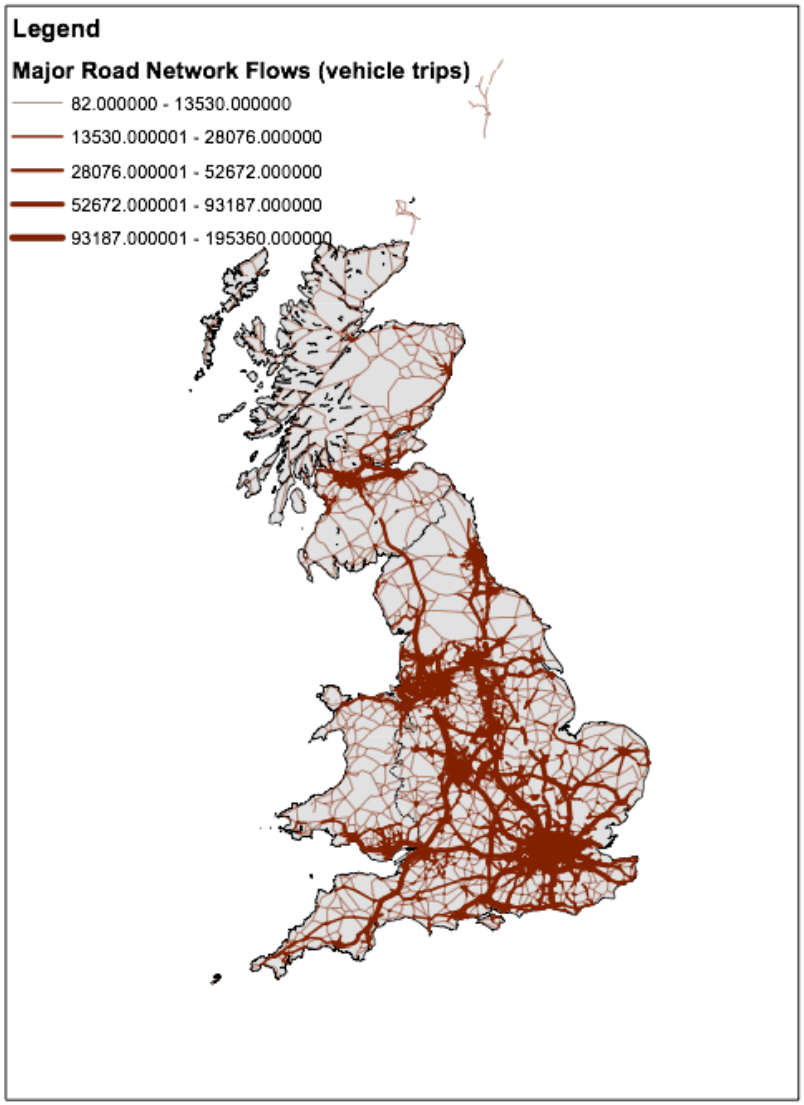
Infrastructure demands: Transport sector

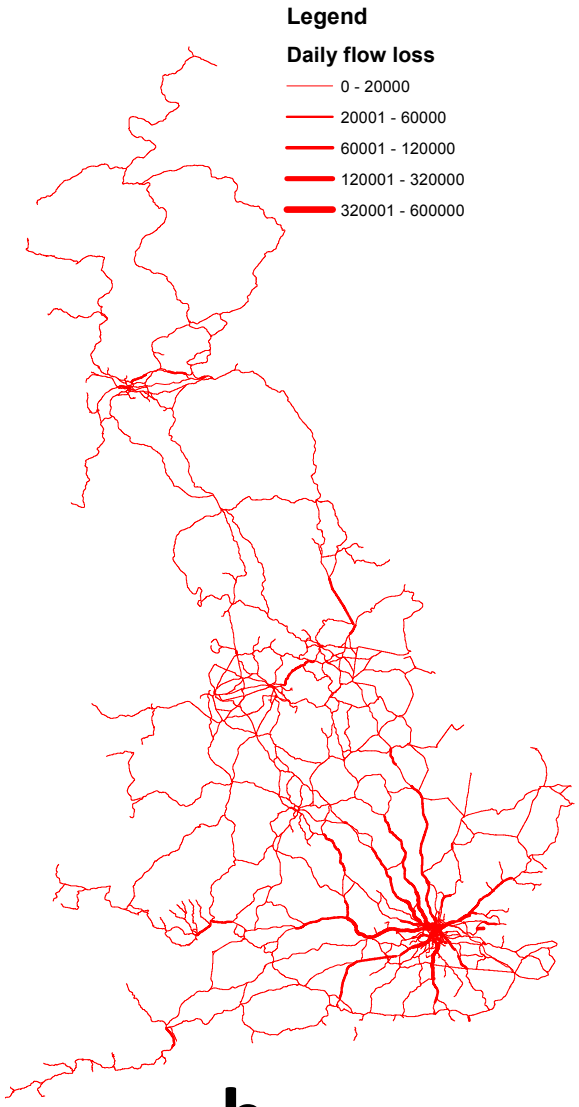
Daily network flow data: Rail and Road networks



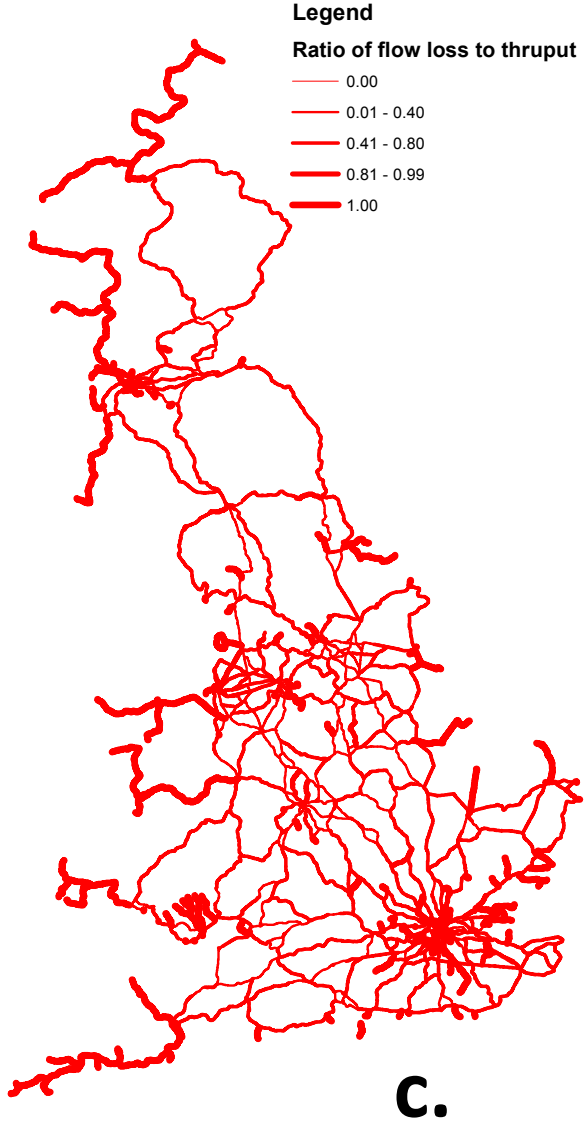


Criticality example - Railway Network

a.

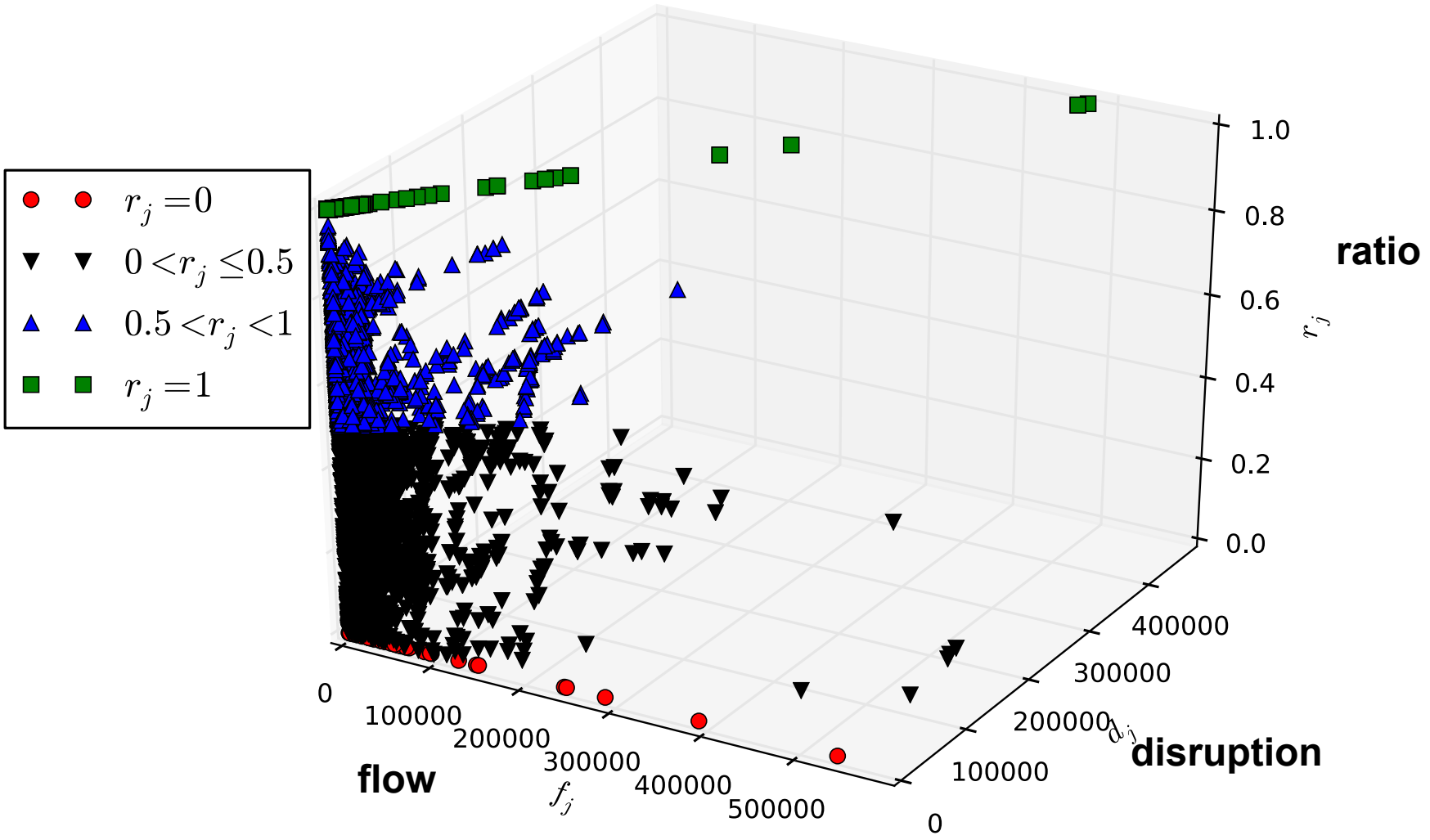


b.



c.

Multi-dimensional criticality



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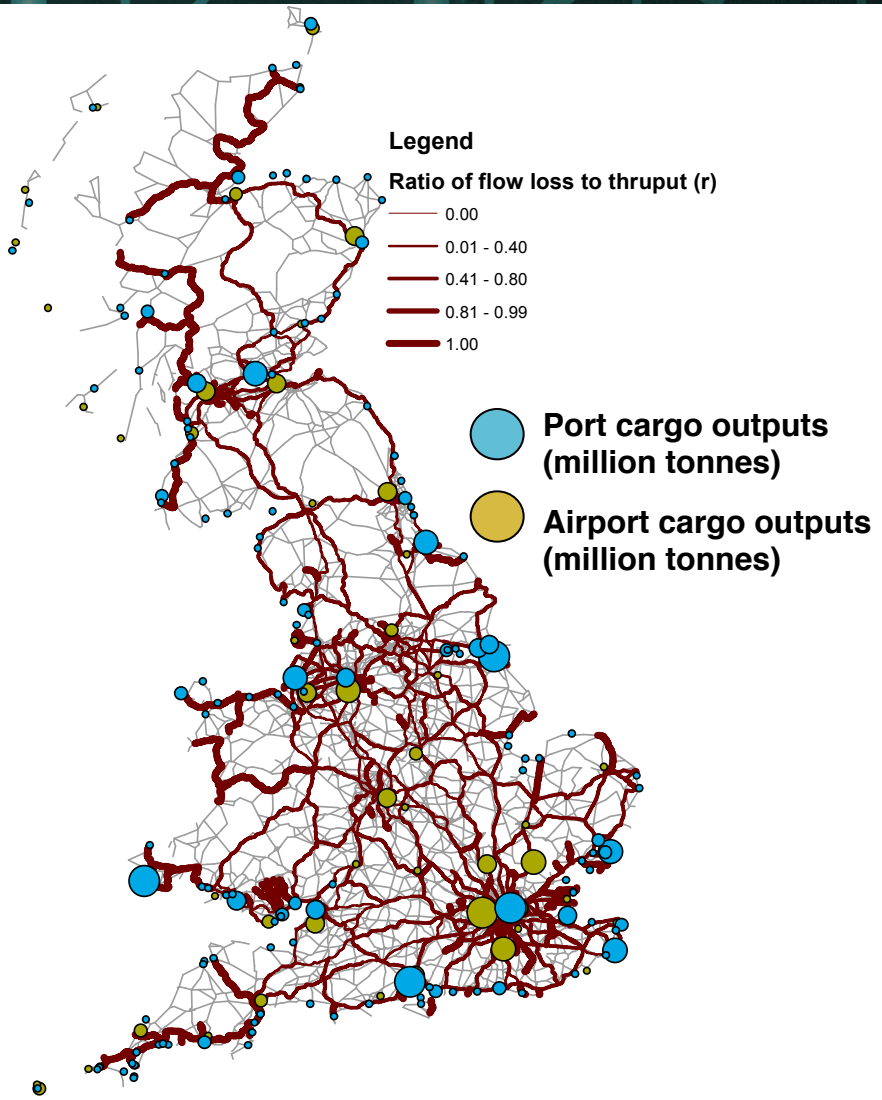
Multi-modal criticality

Understanding and informing:

- **Key locations of systemic criticalities**
- **Risks and opportunities for strengthening assets and resilience planning**



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Criticality hotspot analysis

An infrastructure criticality hotspot is a geographical location where there is a concentration of critical infrastructure, measured according to number of customers directly or indirectly dependent on the infrastructures in that location

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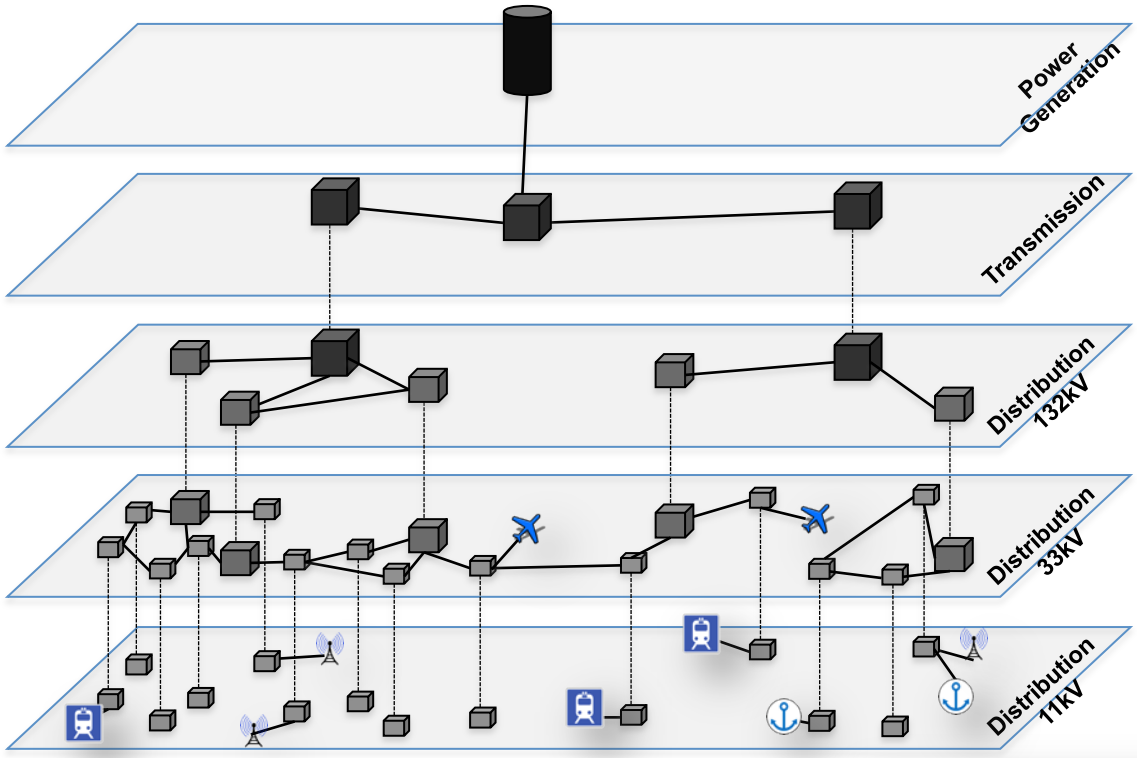
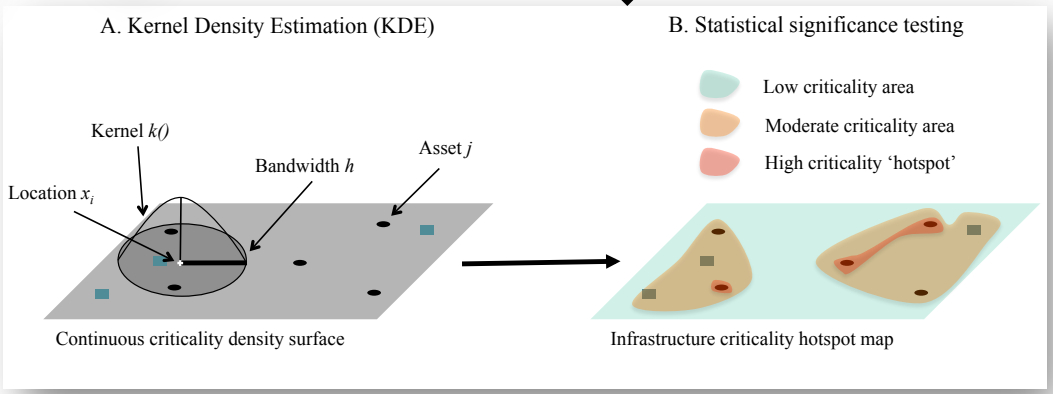
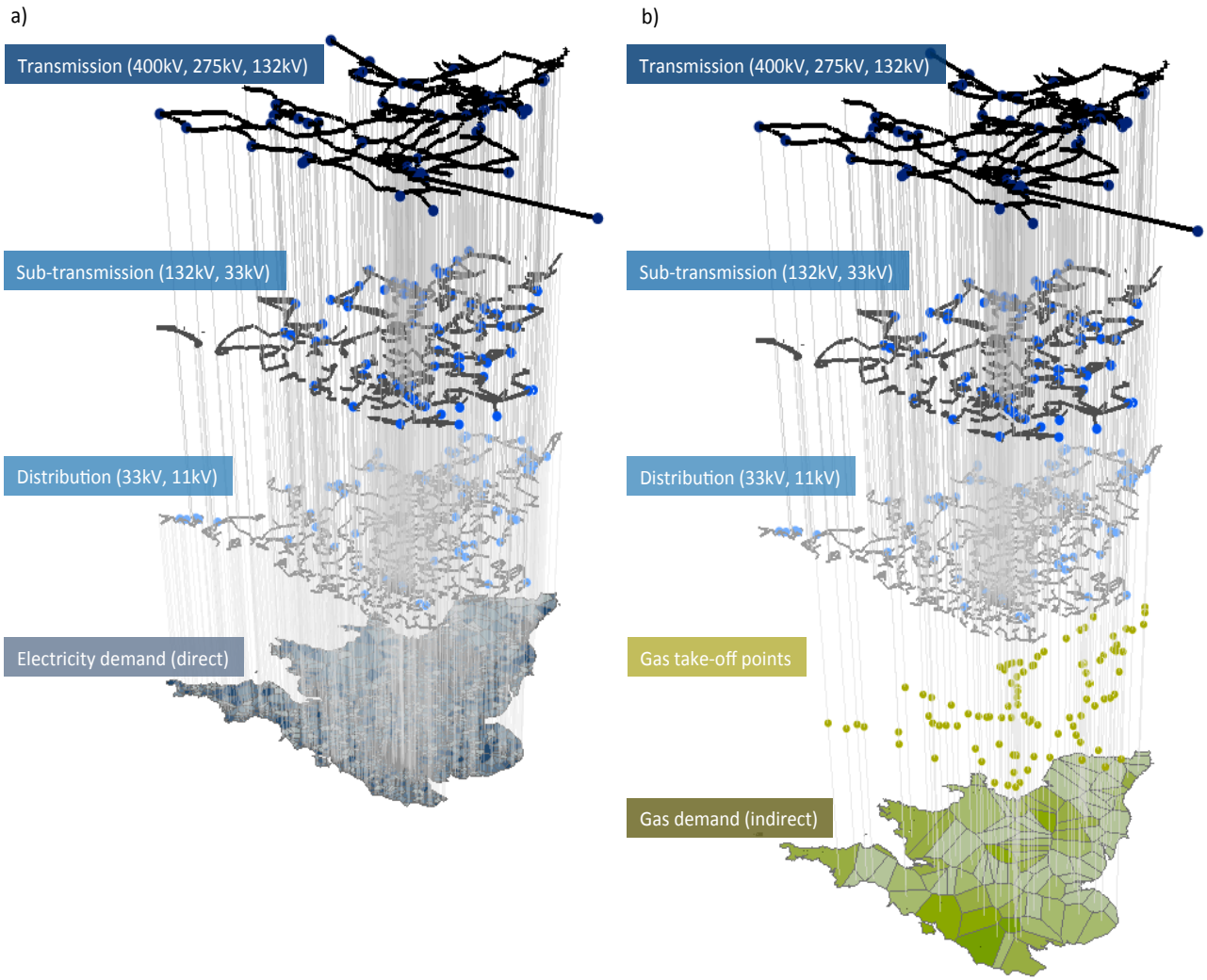
Hotspot analysis overview



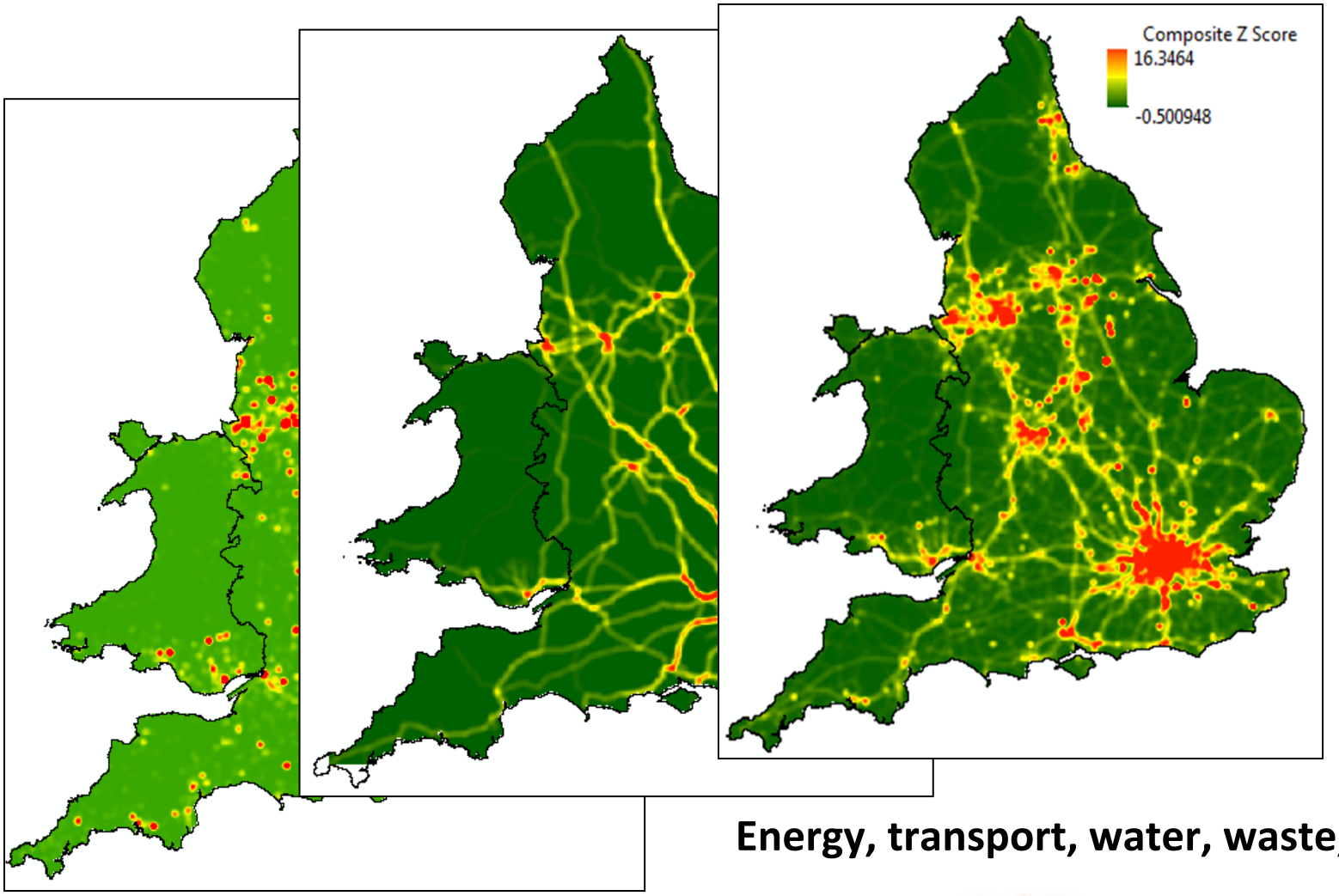
Unique national infrastructure network models and database ~ 200,000 assets



Interdependent network assembly



Critical hotspot analysis



Energy, transport, water, waste, ICT

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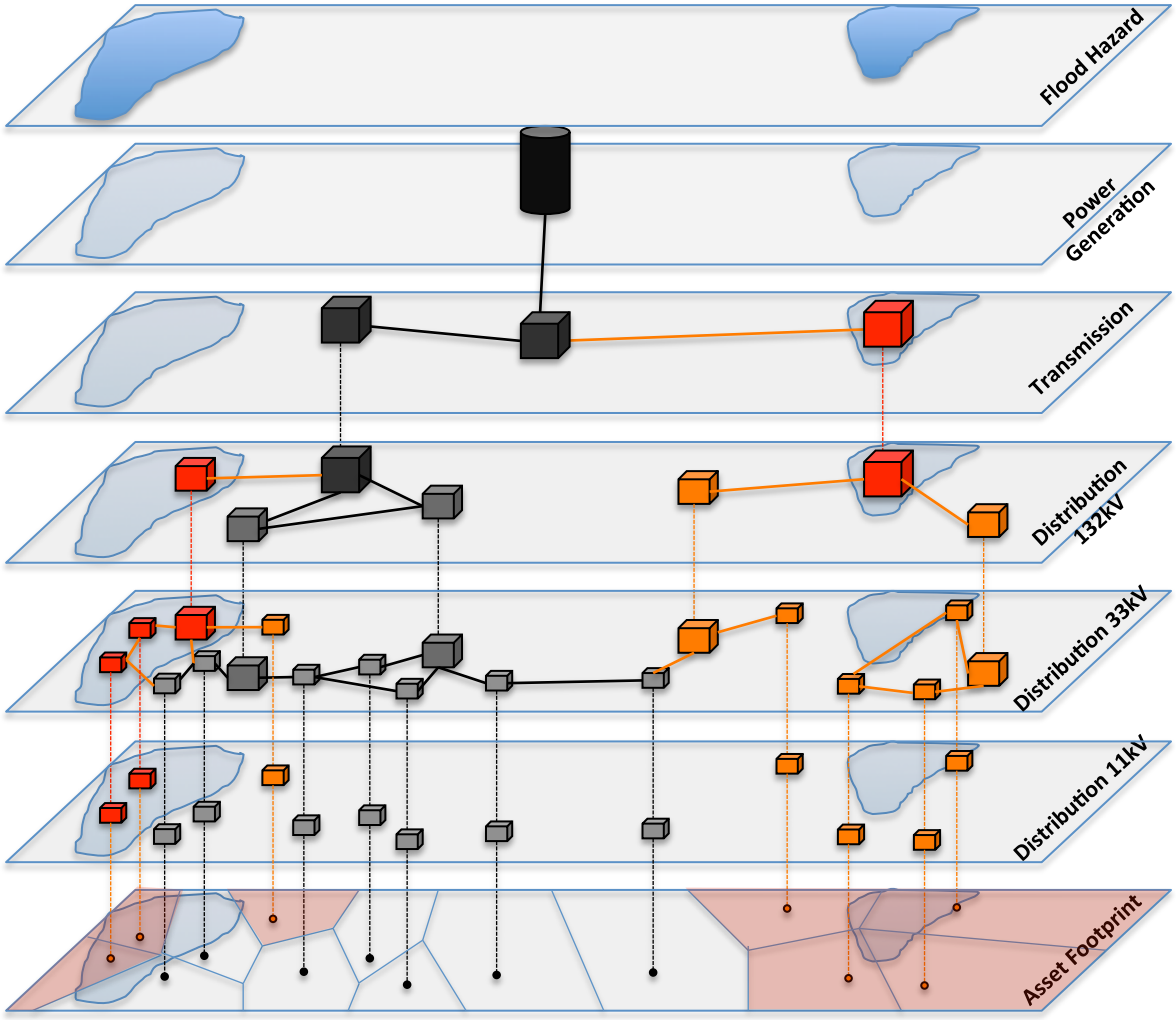
Infrastructure UK

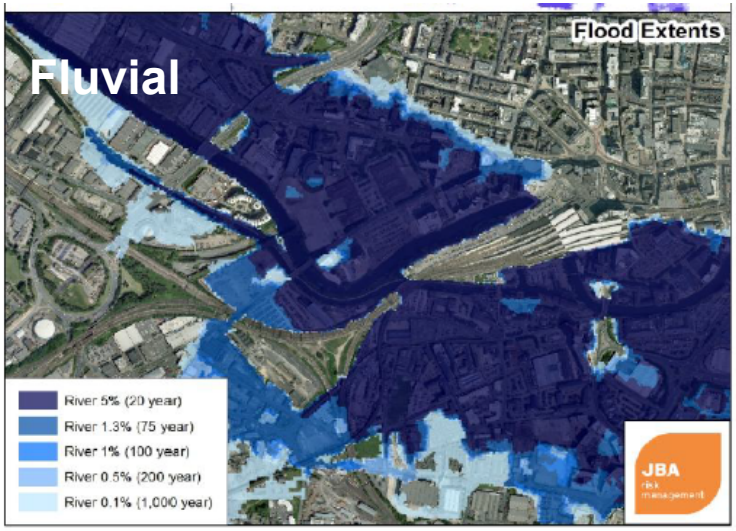
Super-imposing hazards

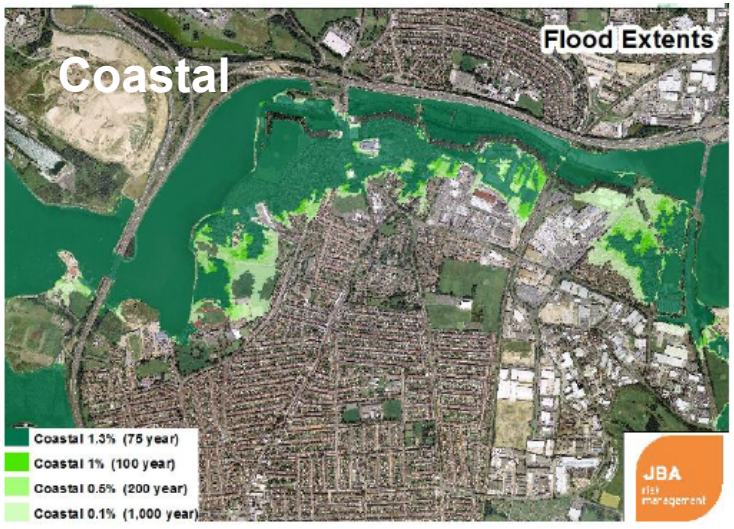
Superimposing hazard maps



- Asset – Direct failure
- Asset – Indirect (network) failure

Hazard assessment - Flooding





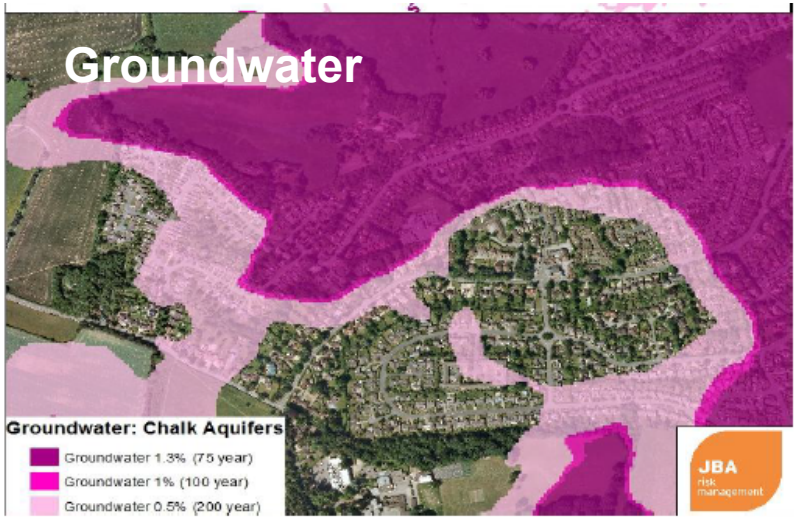
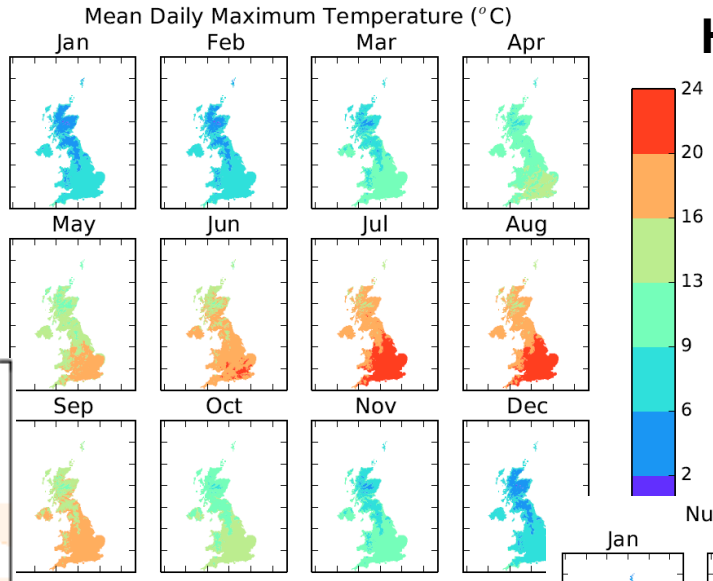


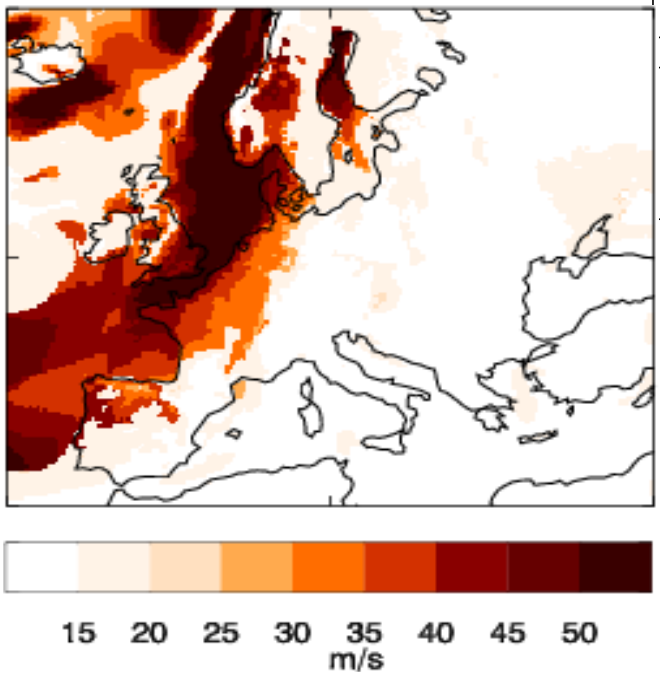
Figure 12: Example of groundwater output (aerial imagery © GeoPerspectives)

Wind, Heat, Cold hazards

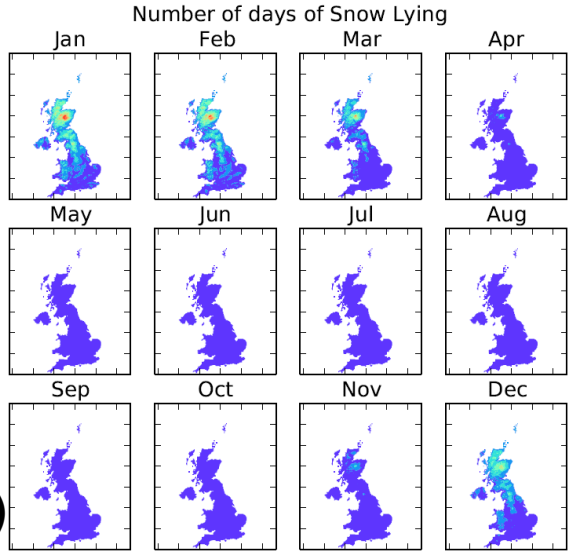
Heat (Met Office)



Wind (XWS Catalogue)



Ice (Met Office)



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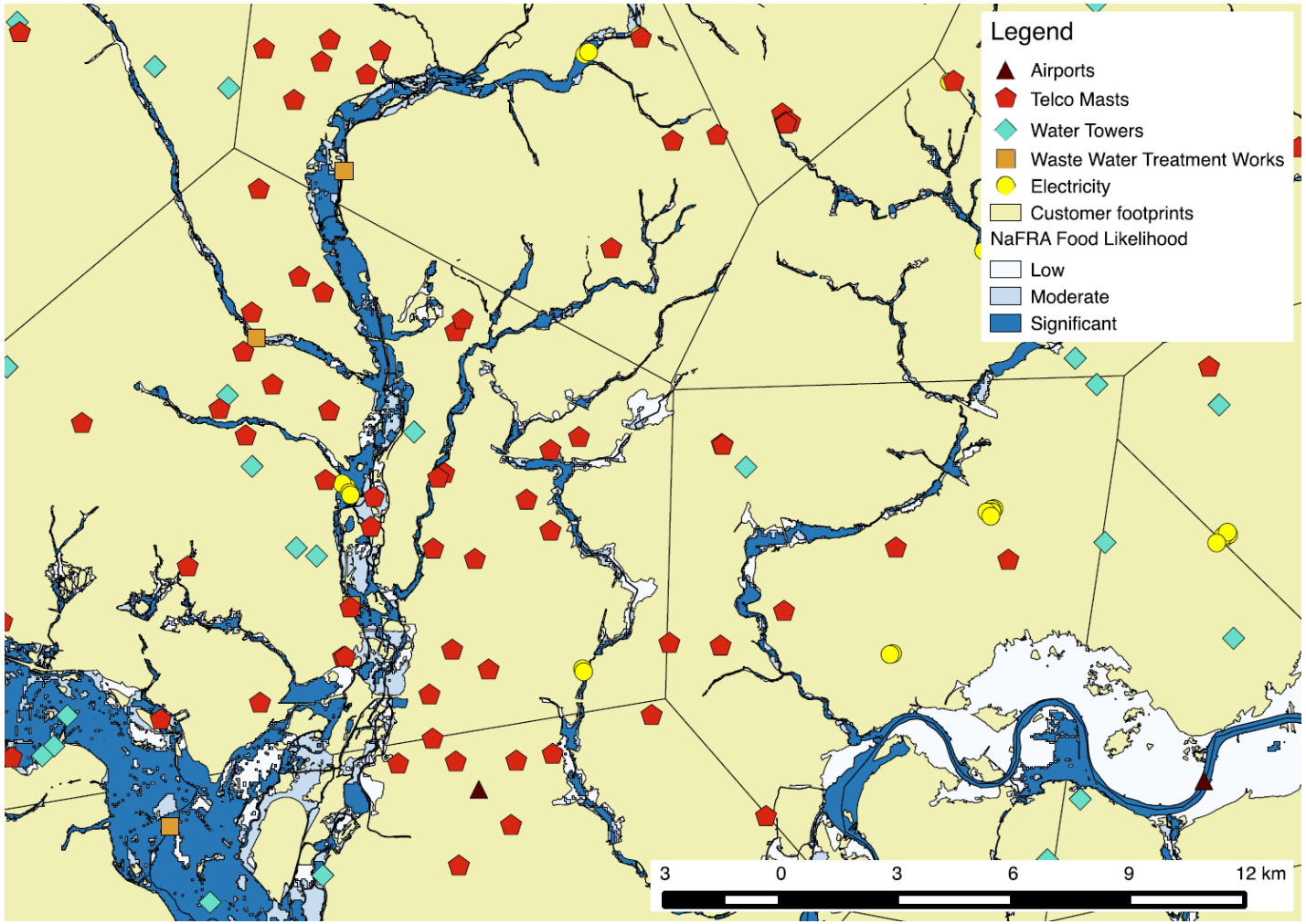
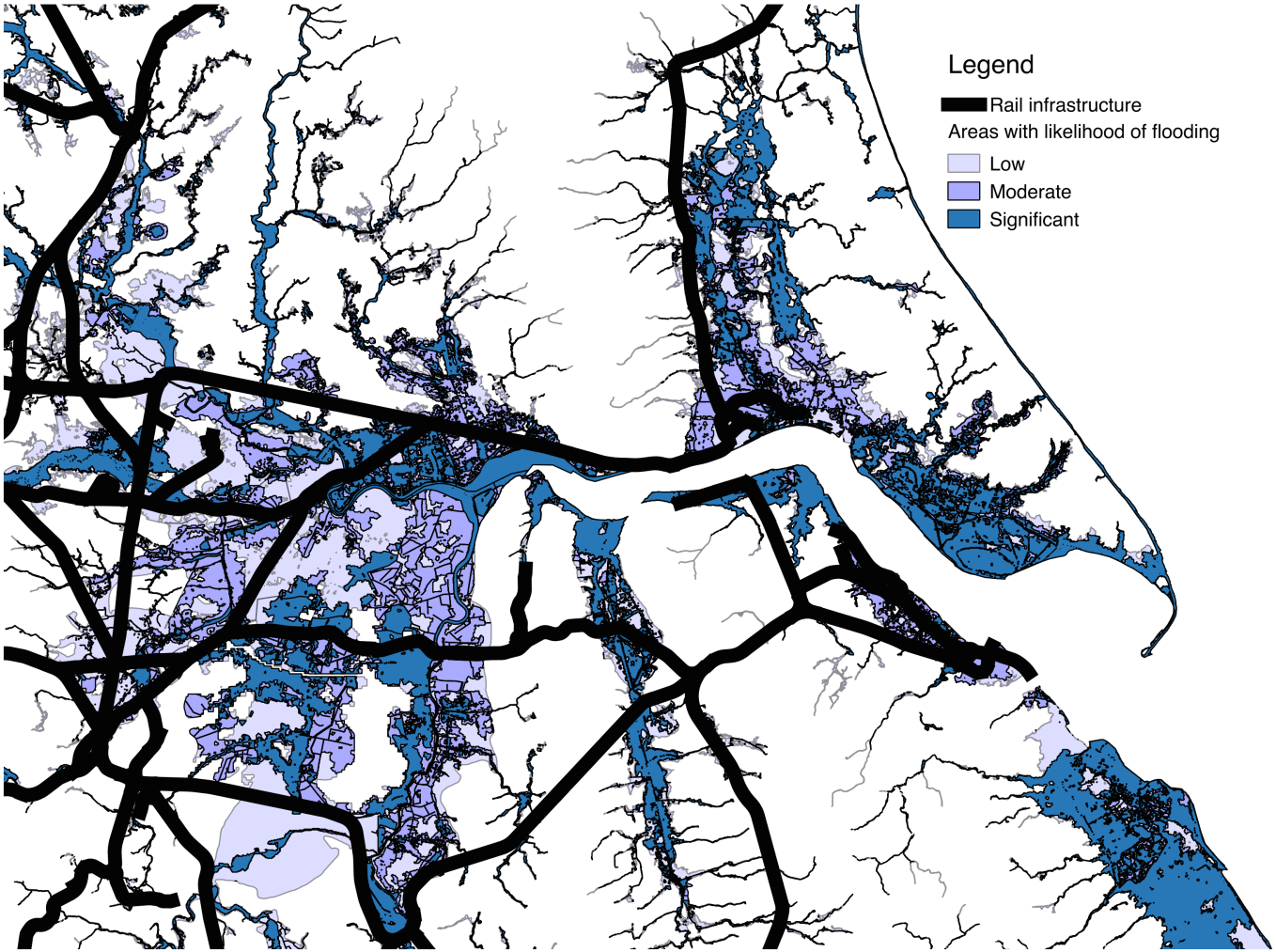
Super-imposing hazards



Railway vulnerability analysis



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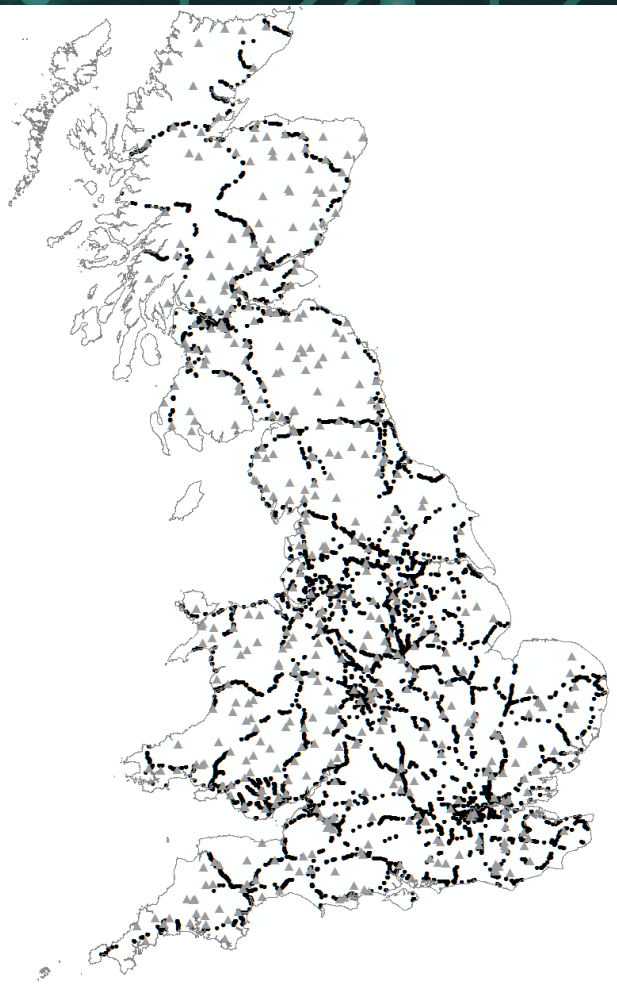
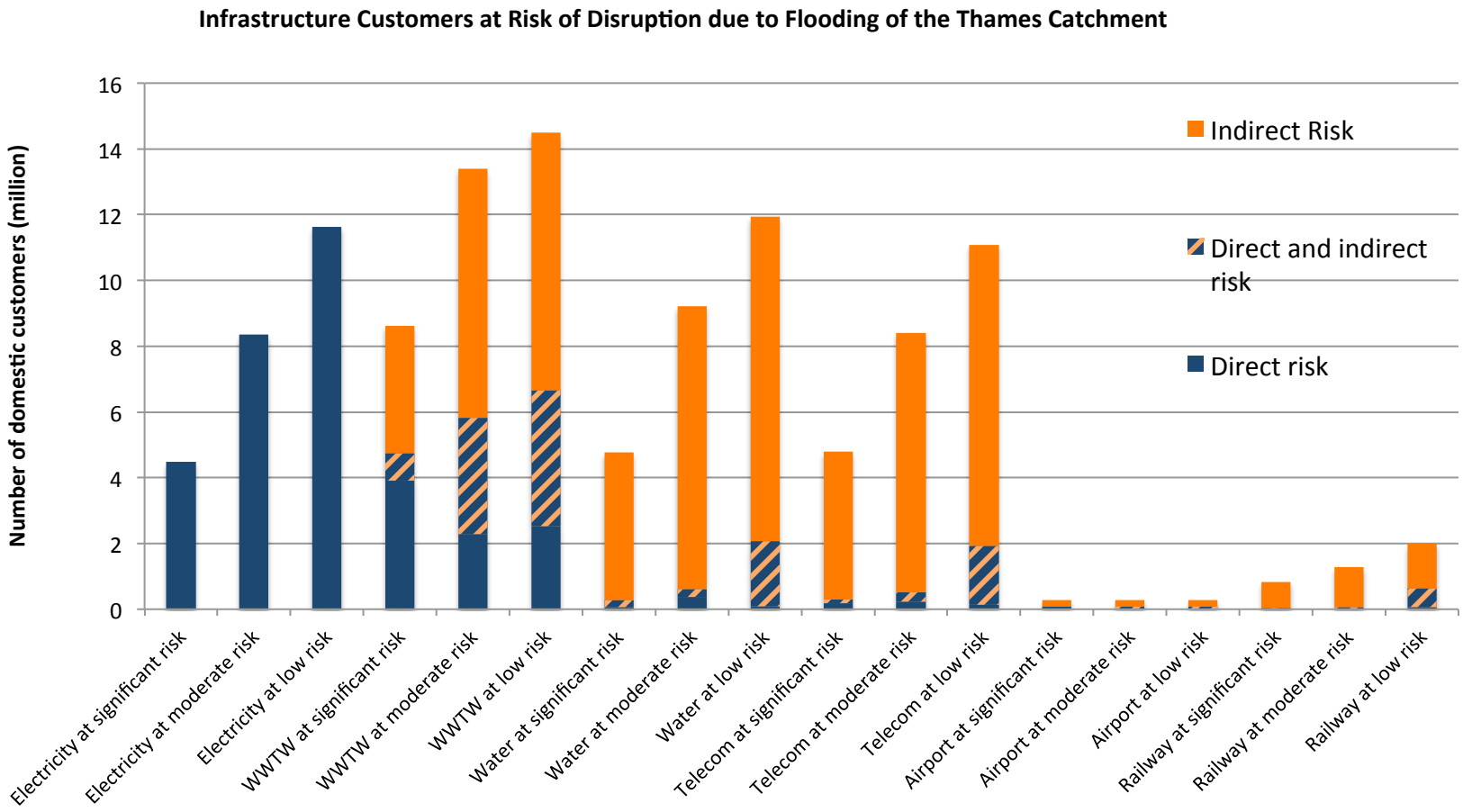
Network Rail

Rail bridges over rivers



Location of rail bridges over rivers and their floodplains (floodplain defined as areas potentially at risk of flooding with a 1/1000 annual probability or more, not accounting for flood defences), shown as dots. River gauges shown as grey triangles.

Impacts of flooding: Thames

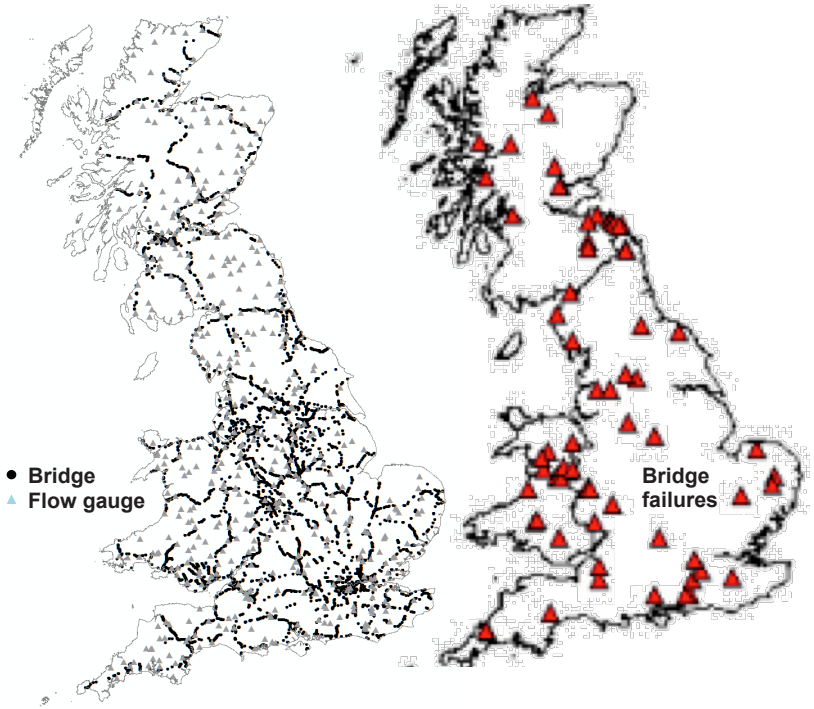


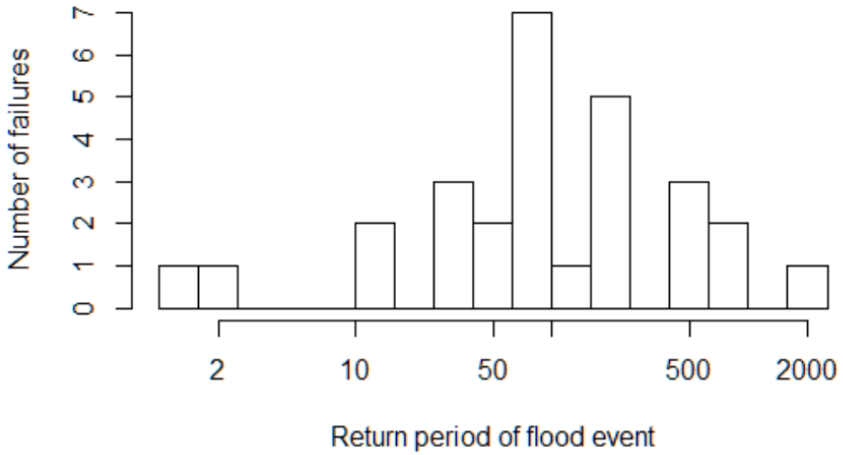
Estimating fragility

Bridge scour fragility

Historical scour-related bridge failures

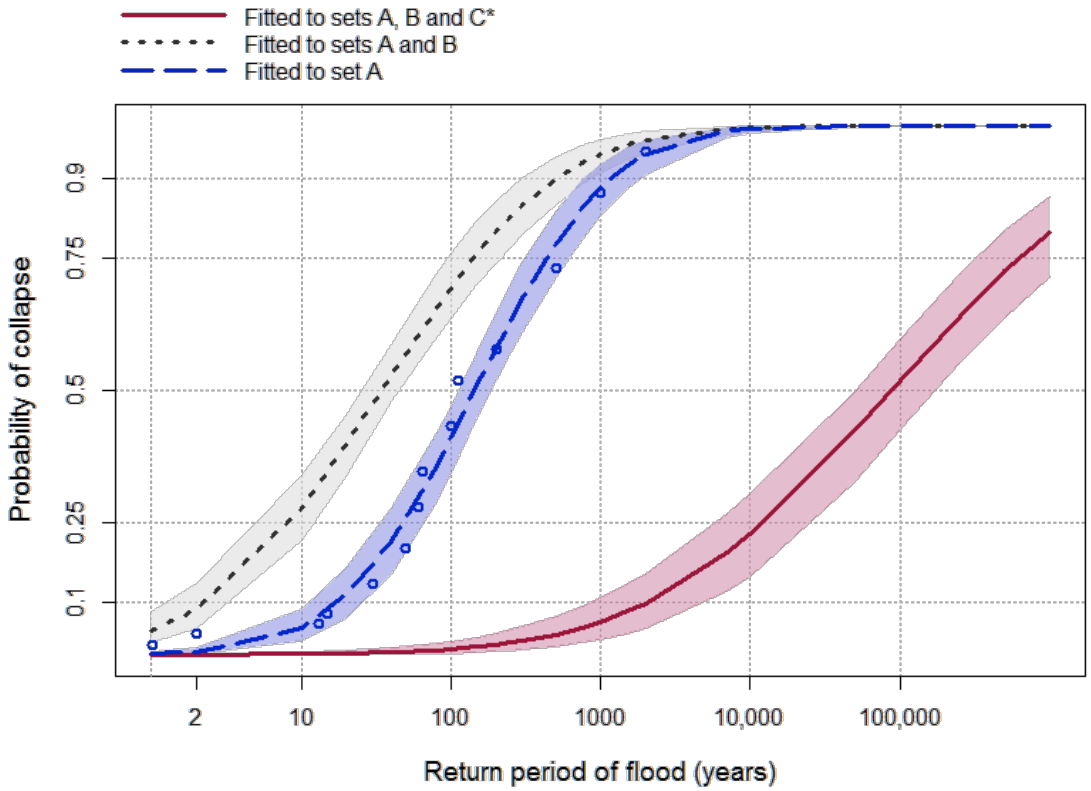
- Unique data: 100 rail bridge failures since 1846
- Flood events reconstructed from observations





On average 1.9 structures failed per flood

Bridge scour fragility



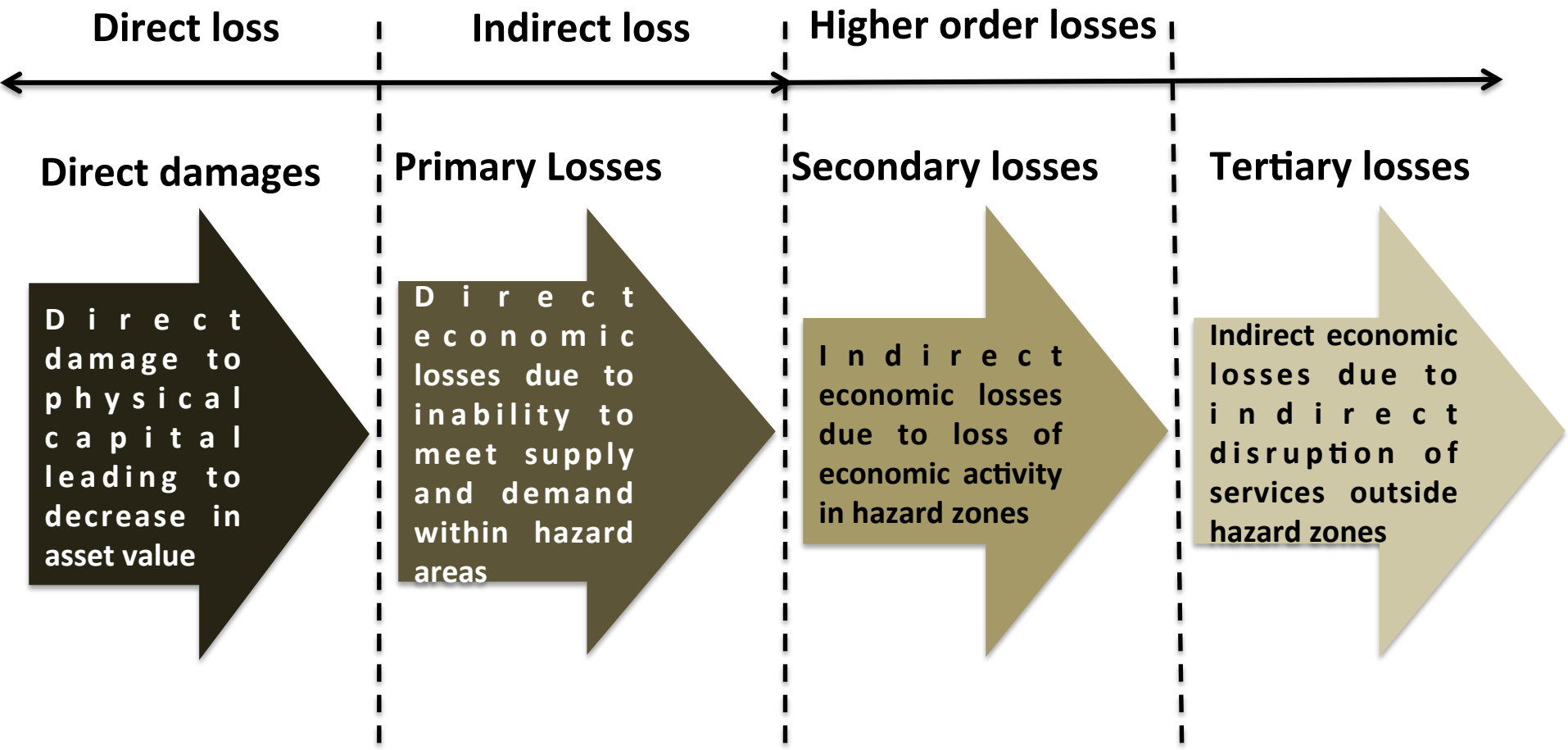
Set A Historical bridge failures with associated flood event return periods, which are regarded as known values for the loading condition at failure.

Set B Historical bridge failures associated with an unknown flood return period are incorporated as a form of left-censored data

Set C Bridges that are assumed not to have failed (“survivors”)

Economic loss calculation

Economic impacts of disruptions



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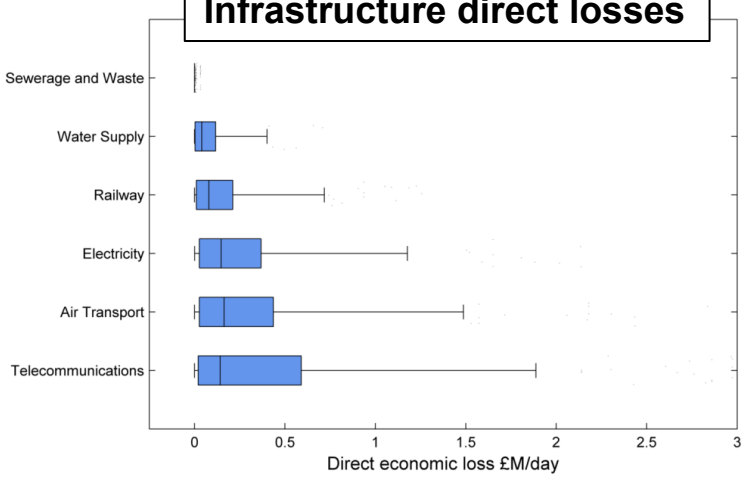
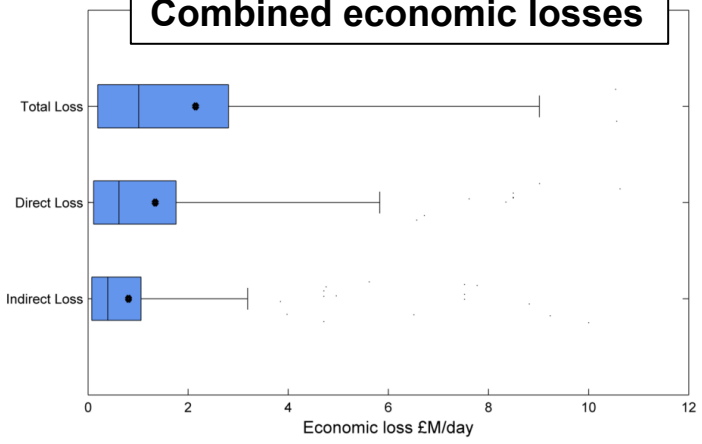
Quantifying economic disruption

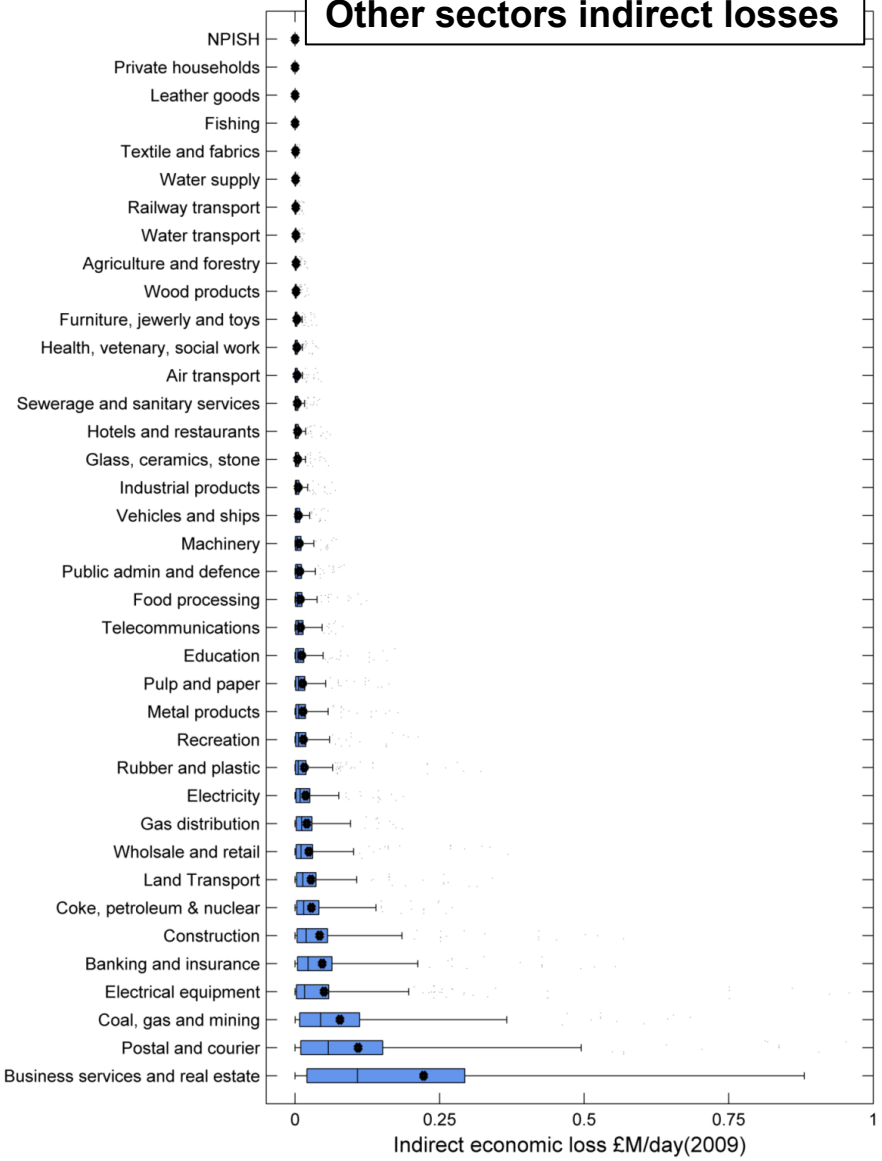
Infrastructure direct losses



Combined economic losses



Other sectors indirect losses



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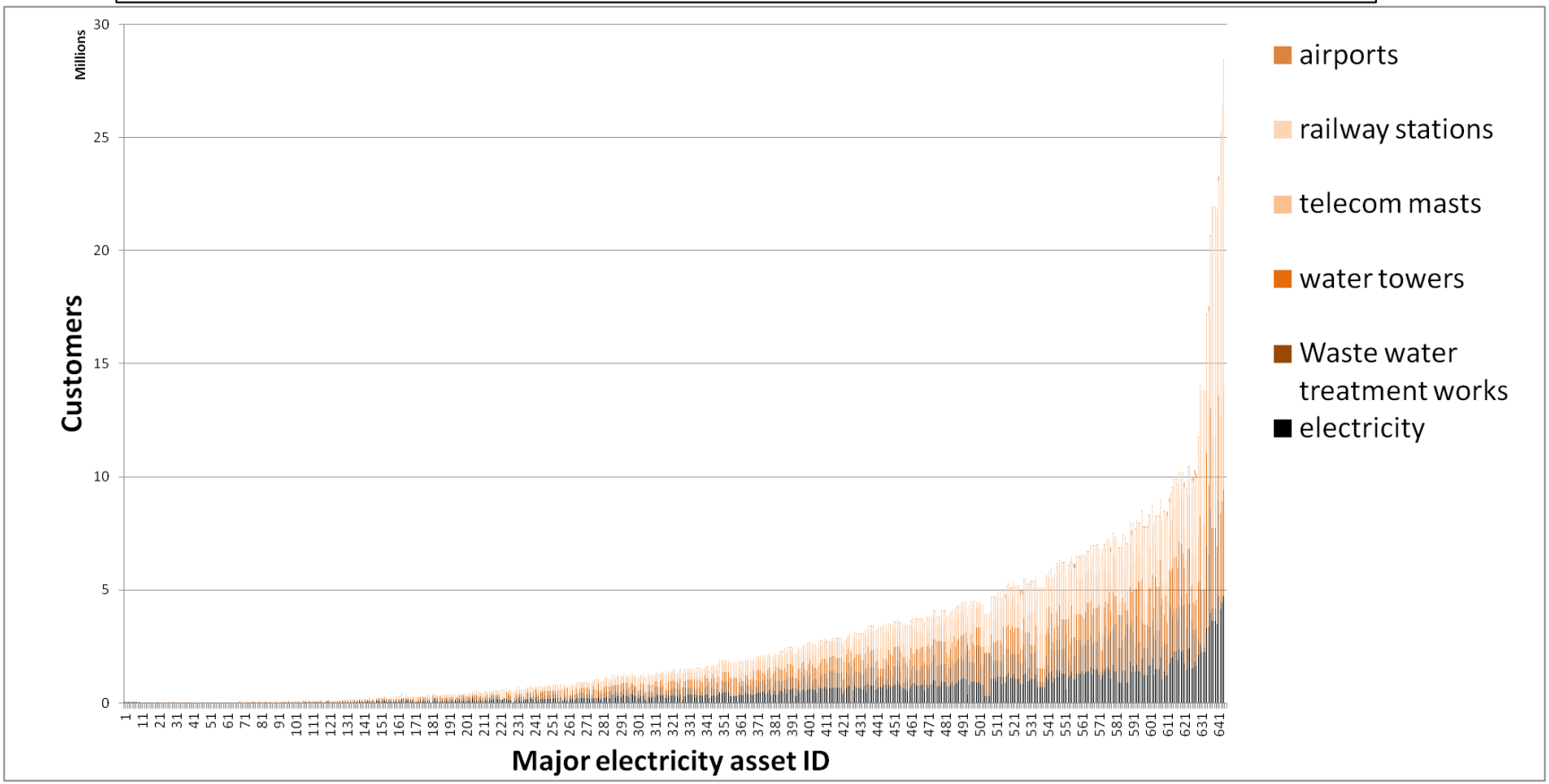
Prioritizing adaptation interventions

The most important electricity assets

Direct and Indirect customers impacts due to electricity transmission assets



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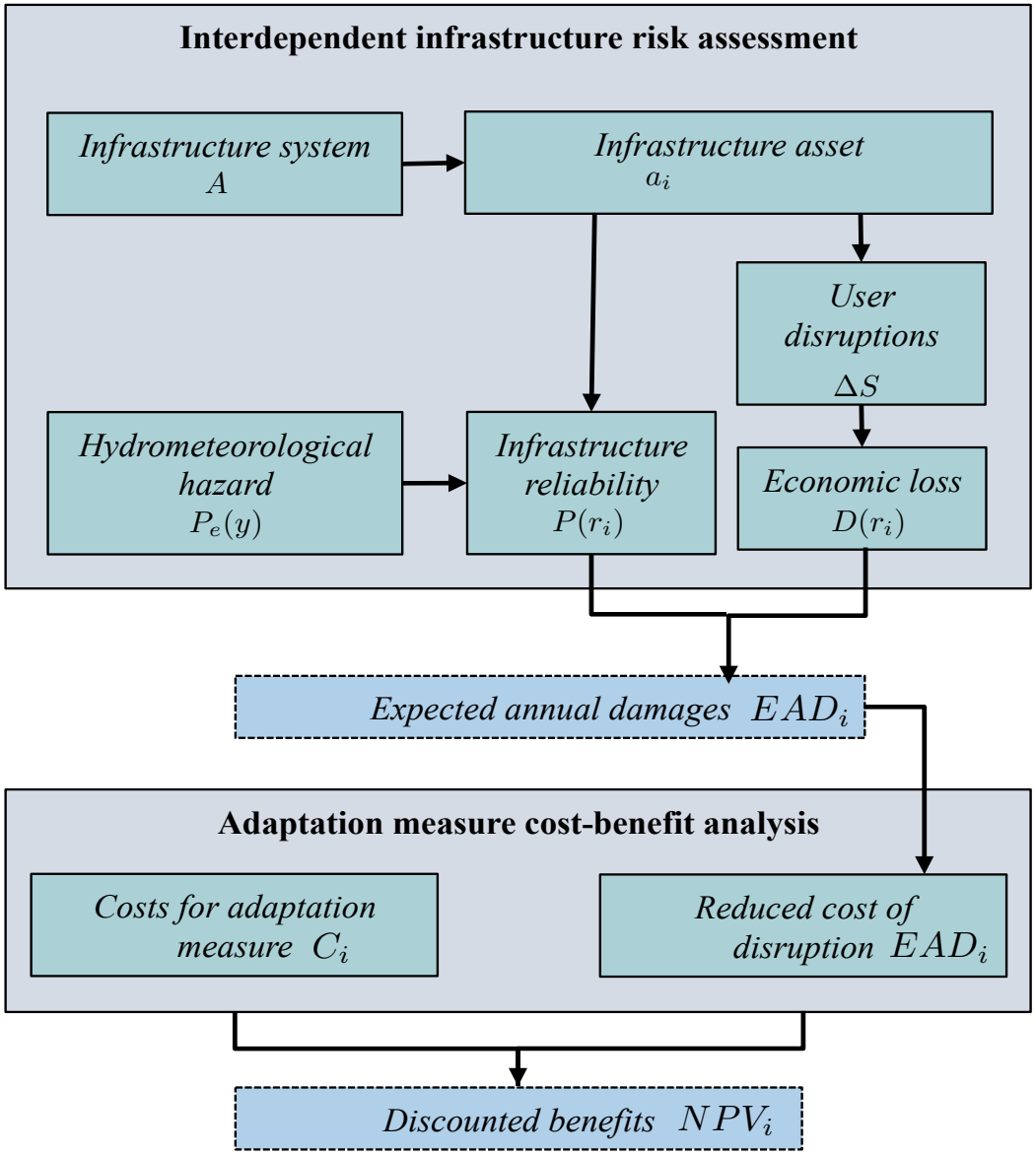
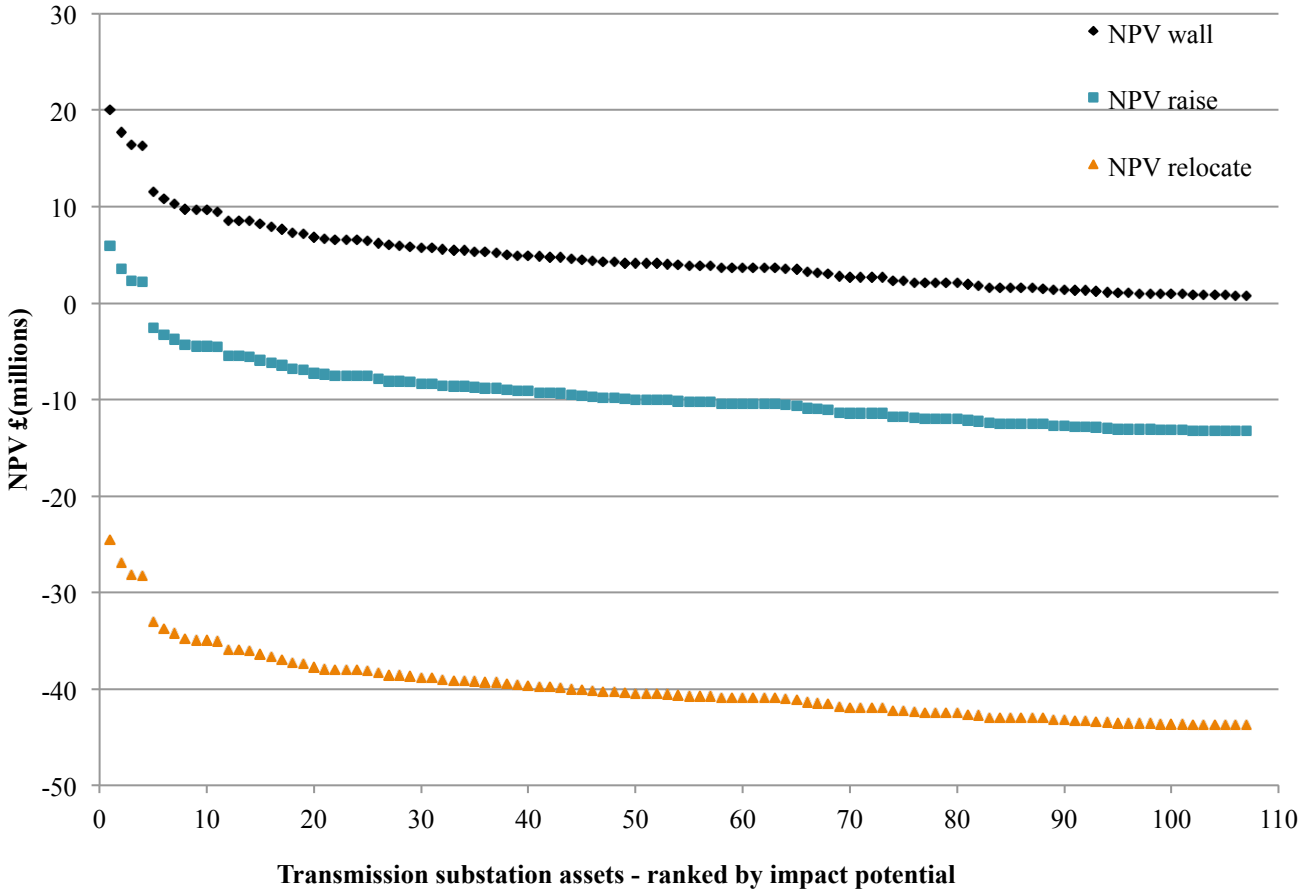
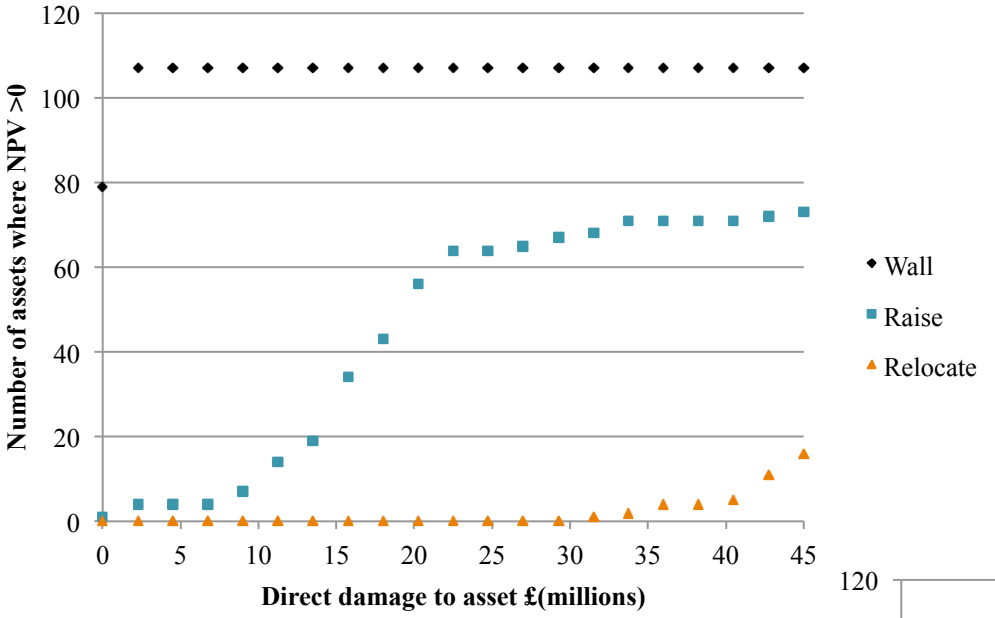
Cost-benefit framework

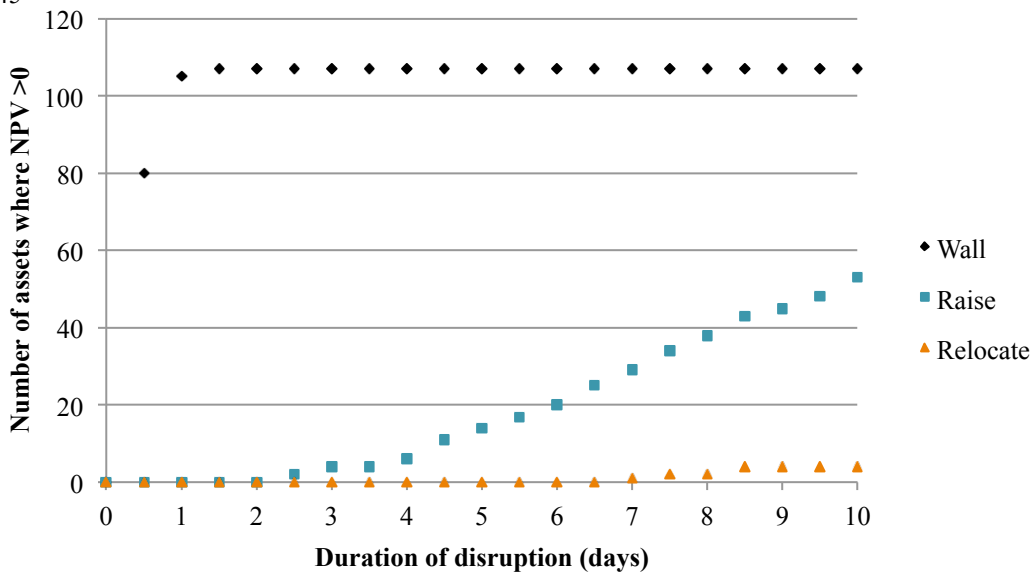


Economic benefit of alternative adaptations



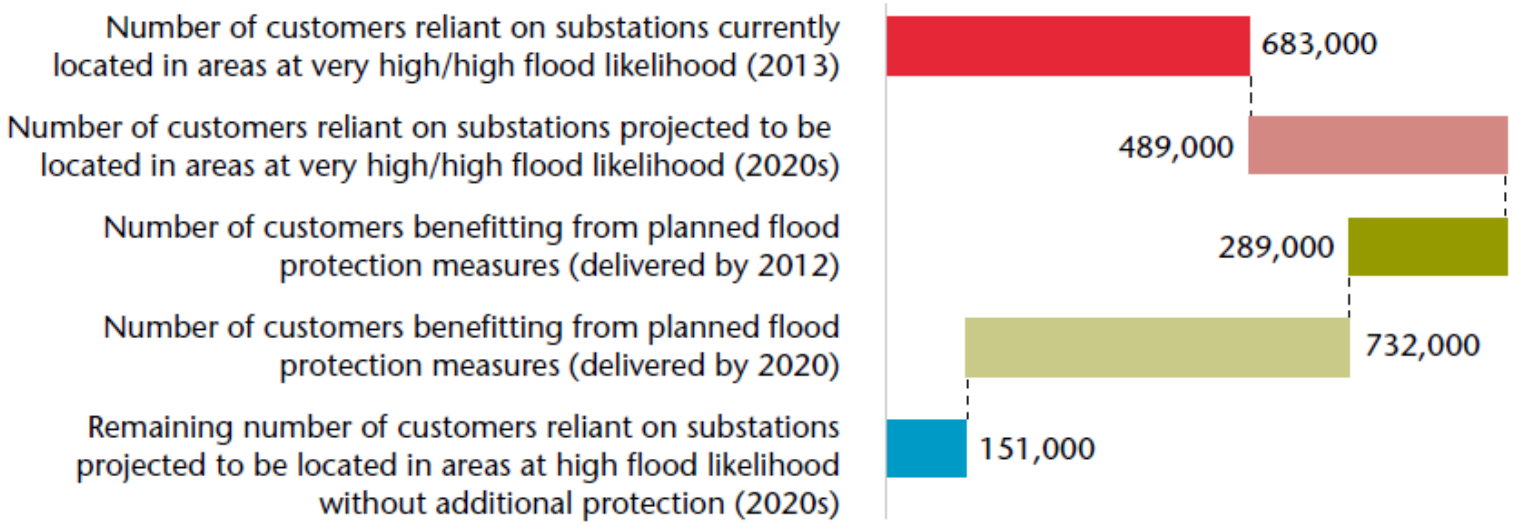
Sensitivity to impact





Progress with adaptation

Risk	Number of sites	Completed works	Remaining
1:100	11	7	4
1:200	26	0	26
1:1000	65	0	65



Towards a comprehensive framework

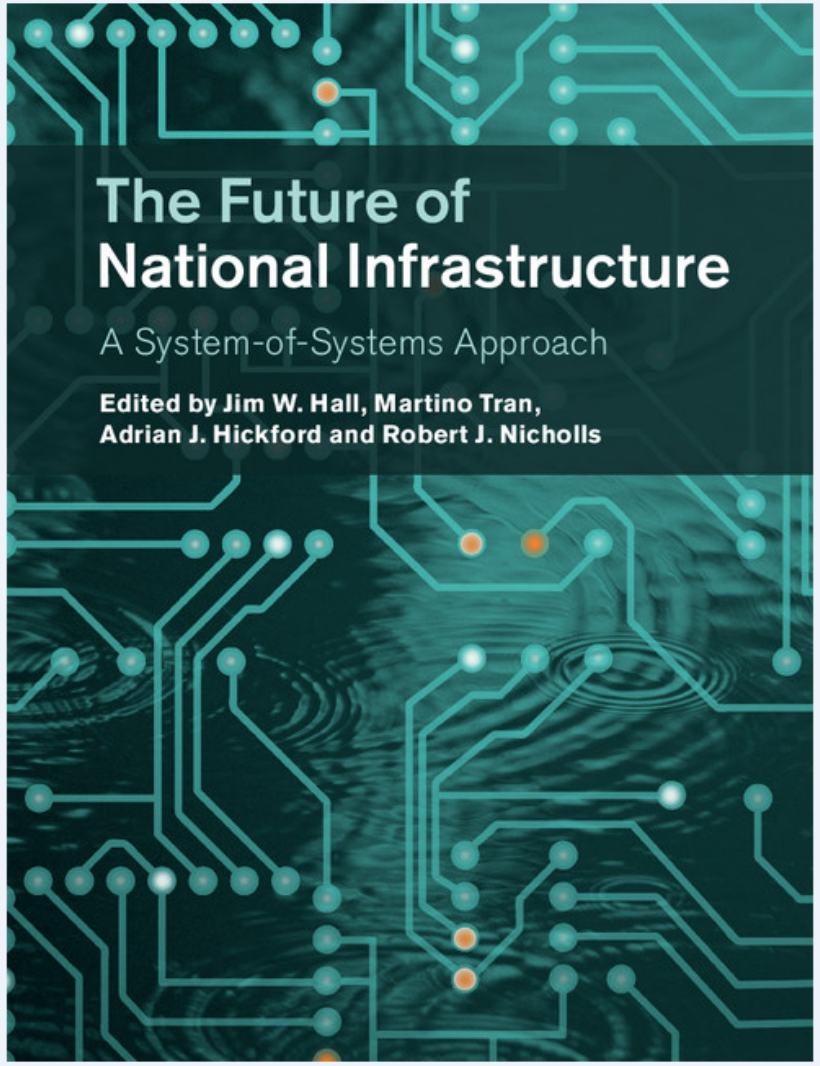
- Risk assessment:
  - Hazard
  - Exposure
  - Vulnerability
- Cost-benefit analysis
- Uncertainty analysis
- Learning from failures
- Monitoring of progress with adaptation

Further Information:

ITRC website: www.itrc.org.uk

Contact:

jim.hall@eci.ox.ac.uk



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