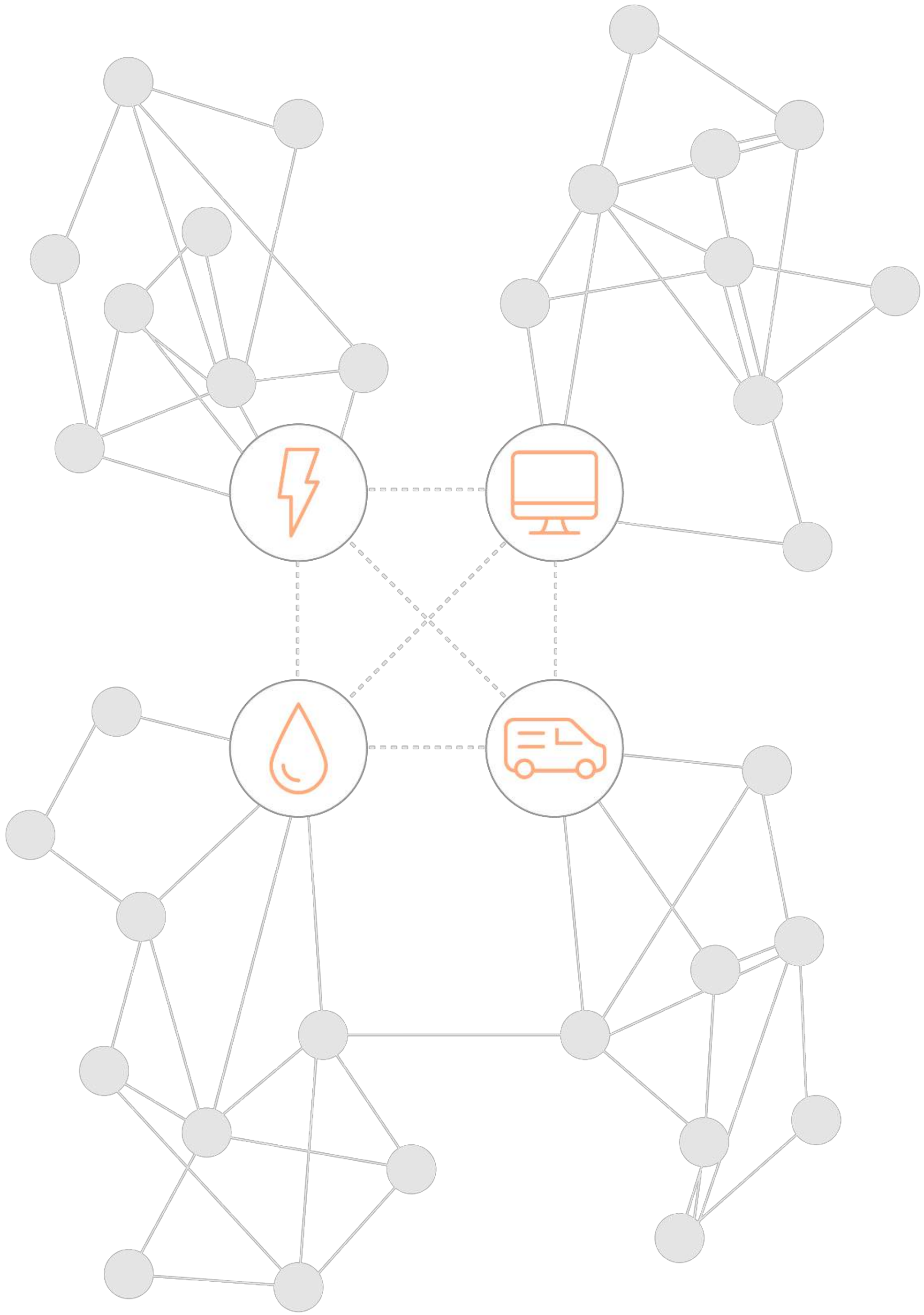
National Infrastructure Commission

System Mapping for UK Infrastructure Systems Decision Making



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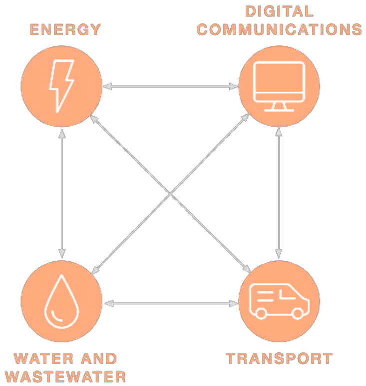
This report was produced to inform the National Infrastructure Commission's Resilience Study. The views expressed and recommendations set out in this report are the authors' own and do not necessarily reflect the position of the National Infrastructure Commission.

Executive Summary

Study Scope

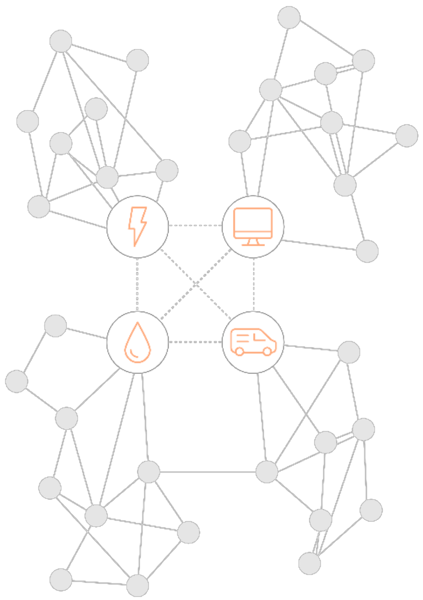
As part of the National Infrastructure Commission's Resilience Study, Arup was commissioned to understand which national-level decisions (such as policies, incentives, markets and other factors) influence UK infrastructure Levels of Service.

The study focused on the four main economic infrastructures in the UK.



This study considers two scenarios, that are:

- **Current scenario** of national-level decision making factors, and how they impact the Level of Service that is delivered across the UK's infrastructure sectors and;
- **Future scenario** considering how national-level decision making may look in 2050 with the implementation of some of the recommendations set out in the 2018 National Infrastructure Assessment.



Systems Mapping for UK Infrastructure Decision Making

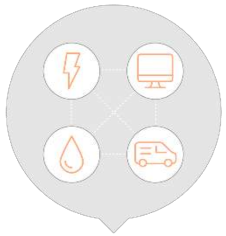
This study took a systems mapping approach to the problem. Systems mapping provides an ability to map and explore complex systems to identify knowledge gaps, intervention points, and insights.

Through qualitative methods, including a stakeholder workshop, subject matter expert interviews and a desk study, a systems diagram of the national level decision making factors for the two scenarios and four infrastructure sectors was produced.

Reliability was identified as the most relevant Level of Service to the study and was used as the focus of the system diagram.

Current Scenario

This systems diagram revealed the following key insights for current national level decision making in UK infrastructure:



01 SILOED INFRASTRUCTURE SECTORS

02 FRAGMENTED GOVERNANCE

03 REGULATORY INFLUENCE

04 VARYING APPROACHES TO LONG-TERM PLANNING

05 SHORT-TERM ECONOMIC BUSINESS PLANNING

06 VARYING ROLE OF MARKETS AND CUSTOMERS

07 CONSIDERATION OF EMERGENCY FACTORS

NATIONWIDE FULL-FIBRE BROADBAND BY 2033

HALF OF UK'S POWER PROVIDED BY RENEWABLES BY 2030

PREPARING FOR 100 PER CENT ELECTRIC VEHICLE SALES BY 2030

Future Scenario

For the 2050 scenario, incorporating the three recommendations outlined above, the systems diagram showed a greater likely degree of interconnectedness between the sectors. This highlights the need for a whole-systems view of UK infrastructure decision making, rather than current sector specific policy and decision making.

The future environment is likely to be very dynamic and uncertain, and the systems diagrams show that recommendations can create tensions between sectors. Policy and regulation will be needed to reflect this and explicit infrastructure multi-sector resilience by design is vital going forward.

1. Introduction

The National Infrastructure Commission (referred to as the 'Commission') is examining the resilience of the UK's economic infrastructure to understand what changes might be needed to ensure that infrastructure can cope with future challenges.

As part of the Commission's Resilience Study[1], Arup was commissioned to develop a systems diagram, using a systems mapping approach, of the national-level decision making factors that have an impact on the Level of Service delivered by UK infrastructure sectors.

Decisions and policies that may intentionally or inadvertently influence the resilience of the UK's economic infrastructure systems are made by individual organisations, government departments or regulators. However, there is limited high-level view of how these decisions impact the resilience of the service delivered to customers and the system overall.

Level of Service and Resilience

Currently, approaches to define levels of service in the UK are very output-focused (e.g. punctuality of trains) and tend to be for 'business as usual' rather than extreme or unexpected scenarios (Arup, 2018)[2]. The Arup (2018) study also argued that Levels of Service are not measured consistently across sectors. Furthermore, they only apply to individual sub-sectors and therefore do not directly consider cross-sector interdependencies.

While Levels of Service are a useful proxy for functionality (e.g. providing water supply), the fact that they don't consider the inherent resilient qualities of a system to be identified or improved on means that they only present a partial view of resilience. Where appropriate, our analysis has drawn out considerations around resilience. Nonetheless, the Level of Service has provided a useful starting point for this study.

Infrastructure systems have multiple interdependencies. As illustrated by Figure 1, key economic infrastructure such as transport, water, digital communications and energy are the foundation on which socio-economic infrastructure such as government, education, healthcare, food and manufacturing relies on to function. Society as a whole depends on the services provided by our infrastructure systems, and conversely, infrastructure systems are tightly coupled to the communities who use them, thus creating a highly interconnected system of systems that includes social, environmental and technical elements.

Study Objective

An ability to articulate, through system mapping and analysis, how national-level decisions (such as policies, incentives, markets and other factors) influence UK infrastructure Levels of Service will help the Commission to ensure that their recommendations will enhance the long-term resilience of our infrastructure systems.

This study provides the Commission with insights into the relative influence of, and connections between national decision making factors that are most important in ensuring the resilience of UK infrastructure.

This study considers two scenarios, that are:

- **Current scenario** of national-level decision making factors, and how they impact the Level of Service that is delivered across the UK's infrastructure sectors and;
- **Future scenario** considering how national-level decision making may look in 2050 with the implementation of some of the recommendations set out in the 2018 National Infrastructure Assessment[3].

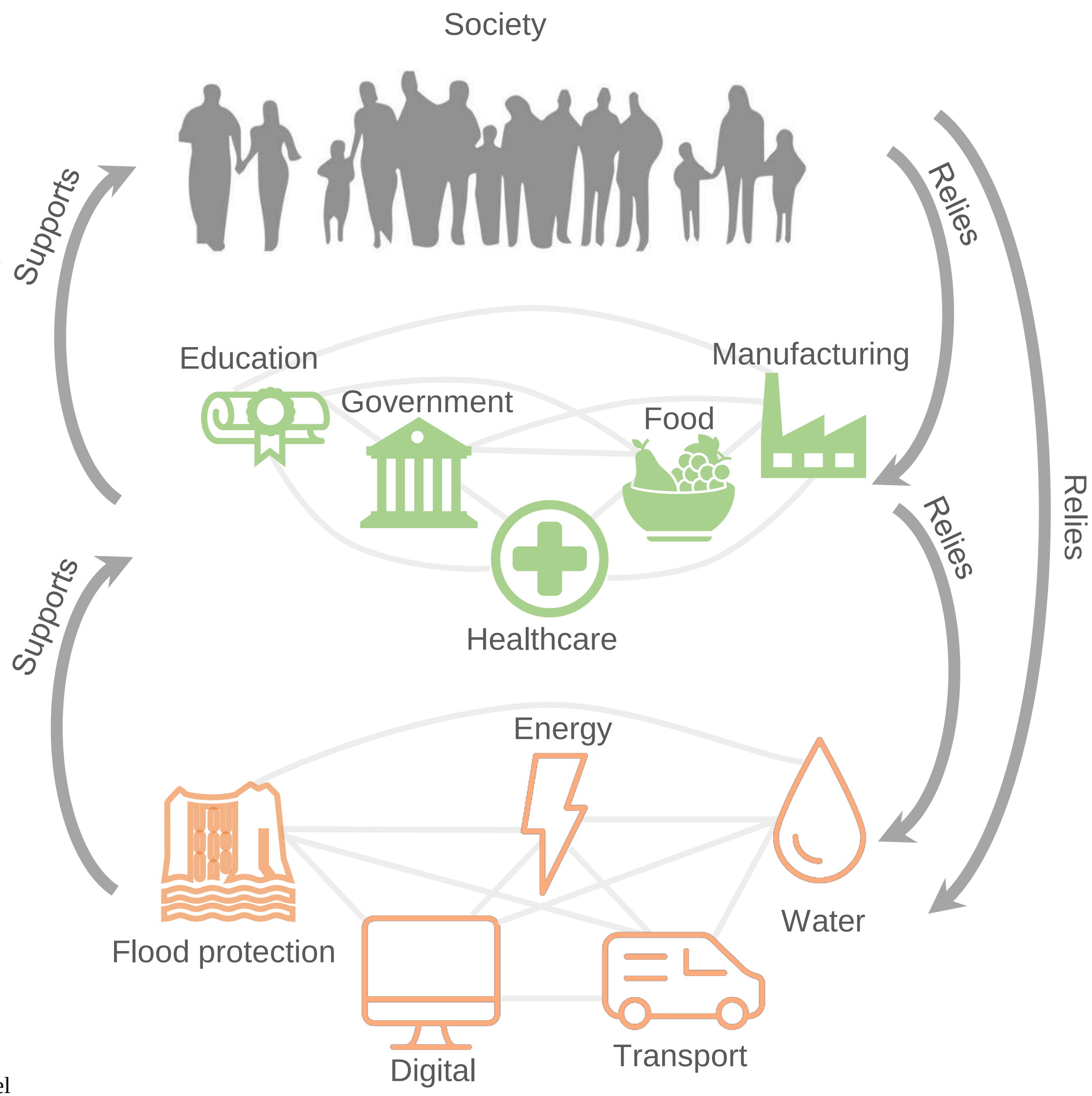


Figure 1: Some key elements of our economic and socio-economic infrastructure systems © Arup

[1] https://www.nic.org.uk/our-work/resilience/
[2] https://www.nic.org.uk/wp-content/uploads/Review-of-UK-levels-of-infrastructure-service.pdf
[3] https://www.nic.org.uk/publications/national-infrastructure-assessment-2018/

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2. Study Scope

Table 1 sets out the infrastructure sectors that were considered in the scope of this project.

Our analysis has considered the following recommendations from the 2018 National Infrastructure Assessment[1], that inform the future ‘2050’ scenario:

- *Nationwide full-fibre broadband by 2033*
- *Half of the UK’s power provided by renewables by 2030*
- *Preparing for 100 per cent electric vehicle sales by 2030.*

Study Limitations

The focus of this study has been on the national-level decision making system for UK infrastructure. It has not considered detailed physical interactions between infrastructure networks. Nor has it considered the role of individual actors or organisations including decision making at the level of the devolved authorities.

Furthermore, it has not considered external impacts on the decision making system, including[3]:

- Foreign ownership
- Specific critical national infrastructure assets
- Industrial relations
- National and cyber security concerns
- The security of supply chains.
- UK withdrawal from the European Union.

This study is also carried out at a fixed point in time for a highly dynamic environment, therefore it is likely that elements of the system map will change or become obsolete over time.

Table 1: Infrastructure sectors considered in this study.

Infrastructure System	**Infrastructure Subsystem**	
Digital	Mobile Communications	
	Fixed-line communications[2]	
	Broadband	
Energy	Electricity	Generation
		Transmission
		Distribution
	Gas	Storage
		Transmission
		Distribution
Transport	Highways	Strategic Roads
		Local Authority Roads
	Rail	
Water	Storage (including abstraction)	
	Treatment	
	Distribution	
Wastewater	Collection	
	Treatment	

[1]https://www.nic.org.uk/publications/national-infrastructure-assessment-2018/
[2]Fixed line communications are defined as the high capacity and highly resilient core network plus the access network which runs from the exchanges to tens of millions of individual customer premises (Arup, 2019)
[3]Refer to the Commission’s Resilience Study terms of reference, available here: https://www.nic.org.uk/wp-content/uploads/CX_letter_resillience_study_and_terms_or_reference_29102018-002_final-digi.pdf

3. Systems Mapping for UK Infrastructure Decision Making

Our approach

What is Systems Mapping?

A systems map (or diagram) shows the components and boundary of a system at a point in time. Systems mapping provides the user with an ability to explore complex systems, communicate understanding, and allow for the identification of knowledge gaps, intervention points, and insights.

Role of Systems Mapping for UK Infrastructure Decision Making

Infrastructure is becoming increasingly tightly-coupled and complex (see Figure 2). It is a complex, adaptive system with many known and unknown interdependencies. These interdependencies range from physical, information, and geographic to organisational[1]. This study focuses on organisational interdependence, defined by HM Treasury as:

- **Organisational Interdependence**[1] – *Shared ownership, governance or oversight* links infrastructure together; *Financial mechanisms* link components together.

The objective is to develop an illustrative systems diagram that provides the Commission with new insights, supported by evidence-based diagrams. This provides understanding of the relative influence of national-level decision making on the overall Level of Service and resilience of key infrastructure sectors.

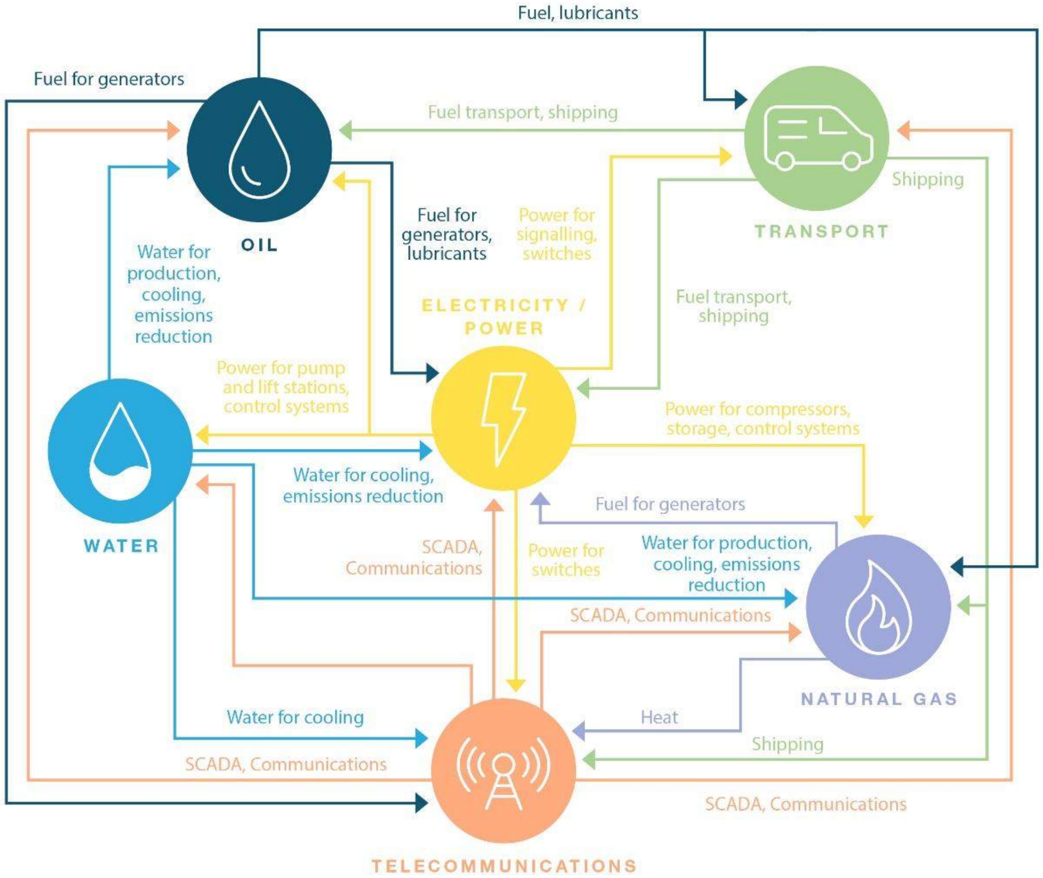

Figure 2: Example of physical infrastructure interdependencies (after Rinaldi et al, 2001)[2]

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/417822/PU1798_Valuing_Infrastructure_Spend_-_lastest_draft.pdf
[2] https://pdfs.semanticscholar.org/b1b7/d1e0bb39badc3592373427840a4039d9717d.pdf

3. Systems Mapping for UK Infrastructure Decision Making

Our approach

Development of Systems Diagrams

The first iteration of the systems diagrams was produced using a qualitative approach. This has involved consultation with a range of subject matter experts, supplemented by a desk-based review.

On 8th November, 2019 the Commission and Arup held a half-day workshop with over 30 attendees from a range of UK infrastructure sectors (see Appendix A for workshop report) to review methodology and initial systems diagrams. A separate meeting with the Committee on Climate Change and Ofcom was also held to review the maps. The systems diagrams were peer reviewed by Professor Brian Collins of UCL.

Software Selection

Following a review of available systems mapping software, [Kumu](#) was selected as this capable of addressing the requirements of the project and has a user friendly and interactive interface.

Stage 1 - Detailed Sector Specific

The detailed sector specific maps that emerged from the initial research plus workshop findings, whilst comprehensive, primarily confirmed the "wickedness" of the problem, i.e. one that is inherently resistant to a clear definition and an agreed solution[1]. This was reinforced during the workshop, where they were generally seen to be comprehensive but too complex for integration or useful analysis. Therefore, it was decided that simplified diagrams were necessary to provide the insight required. The sector-specific diagrams presented at the workshop are given in Appendix B.

Stage 2 - Simplified

The simplified systems diagrams are intended as valuable tools for understanding the complexities of aspects of the UK's infrastructure systems and the impact of decision making on the Level of Service. The diagrams deal with a range of issues affecting the UK's infrastructure. Some have specific reference within the report, and the aim is that all of the diagrams will help offer a clearer understanding of interactions between various components which ultimately influence the Level of Service and the resilience provided by UK infrastructure.

Specifically, it is hoped that these diagrams will add value to both decision making within and across UK infrastructure sectors, and the Commission's resilience study through:

- Showing the 'bigger picture'
- Integrating specialist knowledge
- Communicating complex information
- Stimulating stakeholder engagement

Outputs from the project include the maps which are available at these links, a database of all the elements and connections and this report.

Figure 3: Example of an annotated systems map following the stakeholder workshop

[1]https://www.apsc.gov.au/tackling-wicked-problems-public-policy-perspective

3. Systems Mapping for UK Infrastructure Decision Making

Connections between Levels of Service

The diagram in Figure 4 was developed in the Workshop (Appendix A). It represents the results of an exercise focusing on how levels of service from one sector are linked to another.

Defining Level of Service

Level of Service is defined as "what the organisation intends to deliver", and these were broken down into components, based on the work by Arup (2018)[1]. See section 1 of this report for further detail on why levels of service were used.

Service areas are specific to each sector, but commonly include **reliability** and **availability**.

For example, in the roads sector, **reliability** of roads relates to the proportion of journeys completed on time and **reliability** of electricity supply is related to the number of disruptions and the time taken to restore. Whereas **availability** of electricity supply is indicated by the total time per year where there is no power.

The participants, in groups were asked to draw lines and explain the links on post-its at their table. The combined results of this are presented in Figure 4, with the size of each circle proportionate to the number of connections made to that element, and the line thickness also proportionate to the number of connections.

Figure 4 illustrates the extent to which the levels of service in all other sectors depend on a reliable energy supply. The web of lines within the figure show clearly how a reduction in Level of Service in one sector will directly impact a number of other levels of service, and hence indirectly impact even more. However, this exercise does not provide insights into the scale of the expected impacts.

Reliability of service across all sectors came out as high importance, with water quality a close second in that sector. These findings were used as the basis of the systems diagrams in later stages of the project. Reliability was selected as a single Level of Service for each sector, in order to develop system diagrams that were not overly complex. However, it is noted that all Levels of Service are important.

Clark-Ginsberg argued that resilience can be a compromise and necessary component of reliability but that reliability is the ultimate end goal of an infrastructure system[2]. Considering an energy system, reliability would be focused on 'keeping the lights on' whereas resilience would be the ability of the system to rapidly recover from multiple shocks and stresses (e.g. extreme weather), while taking a systemic view of the potential impacts.

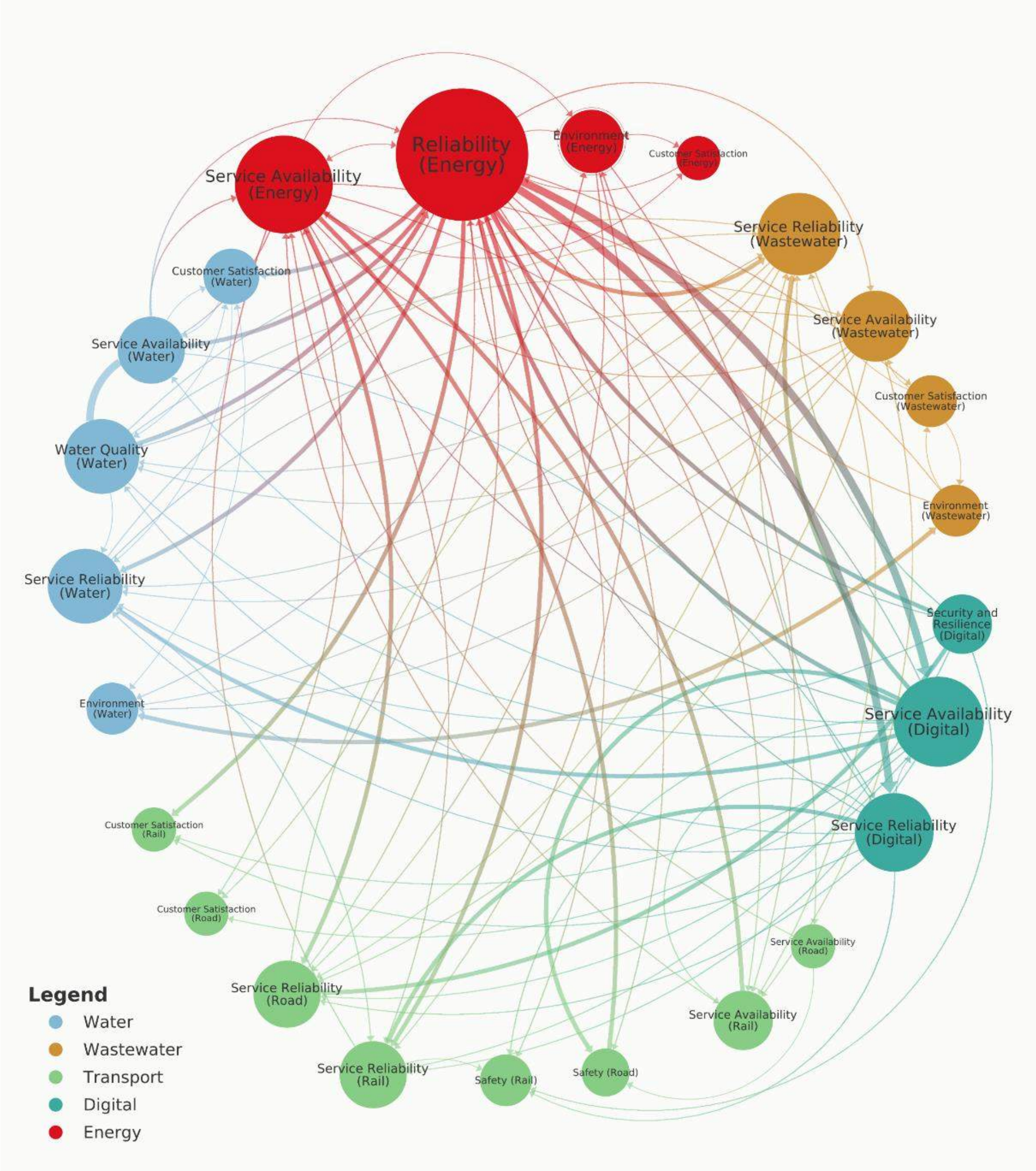

Figure 4: Results from workshop exercise on how levels of service from one sector are linked to another.

[1]https://www.nic.org.uk/wp-content/uploads/Review-of-UK-levels-of-infrastructure-service.pdf
[2]https://www.researchgate.net/profile/Aaron_Clark-Ginsberg/publication/320456274_What's_the_Difference_between_Reliability_and_Resilience/links/59e651230f7e9b13aca3c2ba/Whats-the-Difference-between-Reliability-and-Resilience.pdf

3. Systems Mapping for UK Infrastructure Decision Making
Decision making Factors

Figure 5 contains the main components that are key to the basic functioning of infrastructure and relevant to service delivery, as well as their relationships to each other. Decision making factors can consist of a wide variety of elements.

For this work, factors have been categorised as follows:

- Policy e.g. Government sets strategic policy statement for water
- Regulatory Action e.g. price review processes
- Markets e.g. Wholesale and retail markets
- Service Provision e.g. Operation and maintenance activities
- Emergency Service Provision e.g. Planning for major incidents
- Customers e.g. Energy customers
- Level of Service e.g. Reliability (Transport)

This categorisation has aided interpretation of the maps. Each of the elements has information behind it that can be accessed online, e.g. the element 'Network Rail set 5-year delivery plan' which can be accessed by clicking on Figure 6. Clicking on the map will open the interactive version on www.kumu.io.

Factors and connections that might influence the 'qualities' of a resilient infrastructure system were considered in addition to factors that solely influence the Level of Service. For example, any factors that may reduce incentives for redundancy in the system. More information on resilience qualities is presented in Section 7.

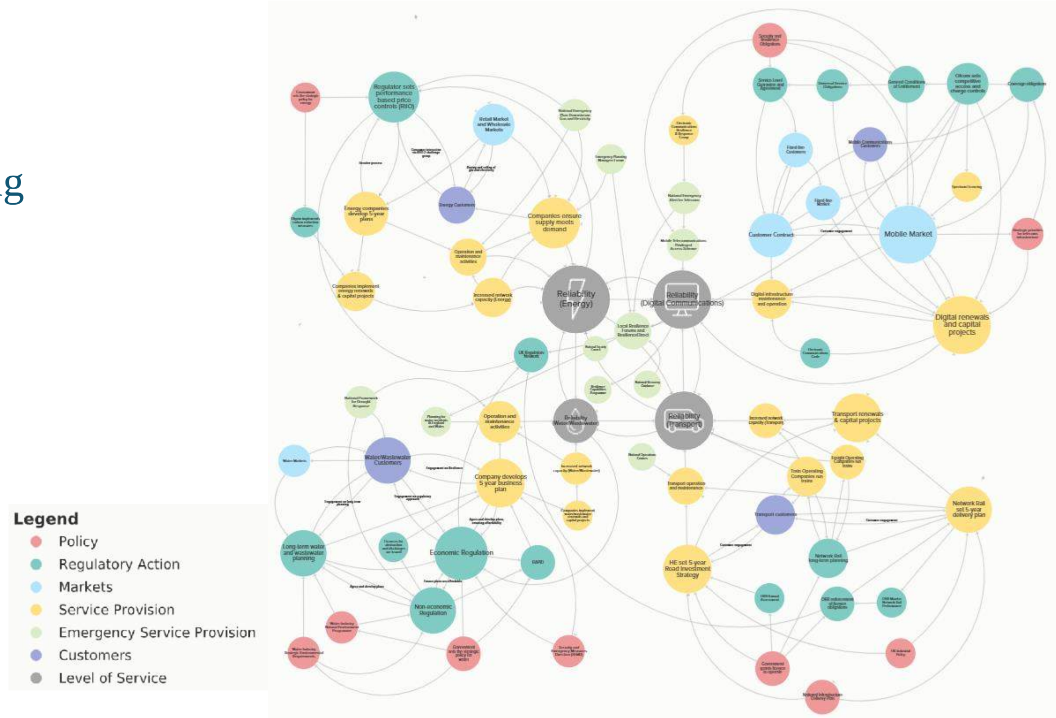

Figure 5: Overview of the systems map in Kumu showing 'factors' (click on image for interactive version)

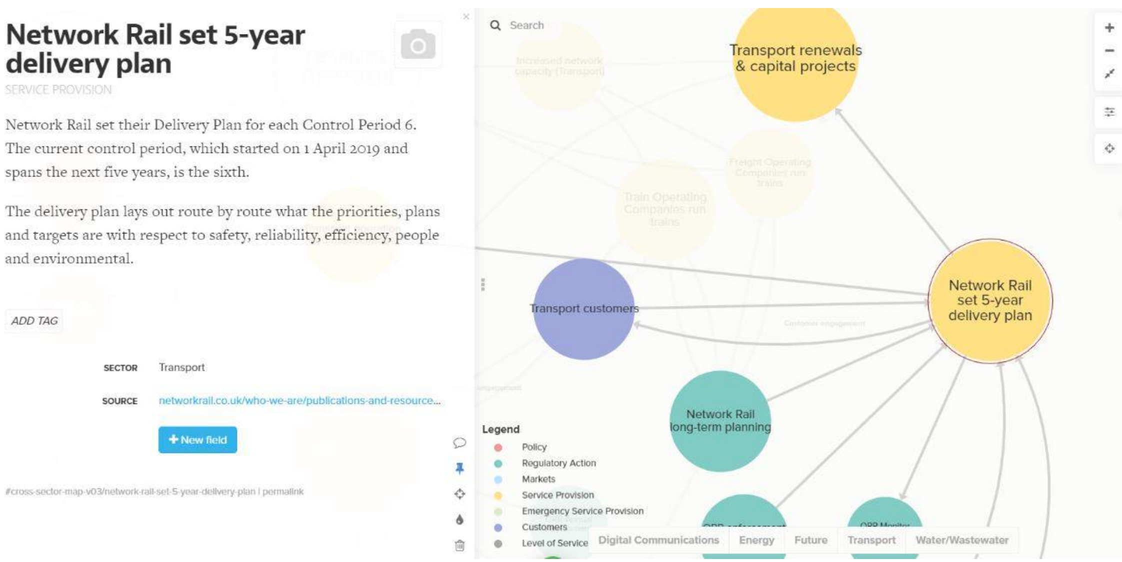

Figure 6: Overview of the systems map in Kumu showing details behind the elements (click on image for interactive version)

3. Systems Mapping for UK Infrastructure Decision Making
Connections

The systems diagrams (Figure 7 and 8) show the same elements as that on the previous page, but here the connections are highlighted.

The connections are categorised in terms of their influence and coloured green or red to represent a very positive, positive or negative influence from one factor to the other (depending on the connection arrow direction); very negative has not been used as we did not find any connection with that attribute. There are also several grey coloured connections where the influence is contingent, which could have either a positive or negative influence. As with the other connections, where this occurs an explanation is available behind the connection in Kumu, which can be accessed by clicking on it (e.g. Figure 8).

The strength of the influence was determined by desk top review, feedback in the workshop, and independent review by subject matter experts. Where a source was available this evidence is linked in the information in the online systems diagram.

Throughout this report, system diagrams are presented either with a focus on the elements (as in Figures 5 and 6) or on the connections (as in Figures 7 and 8) depending on the emphasis of the supporting commentary. However, the connections and their influence on the infrastructure decision making system was a key focus of this study.

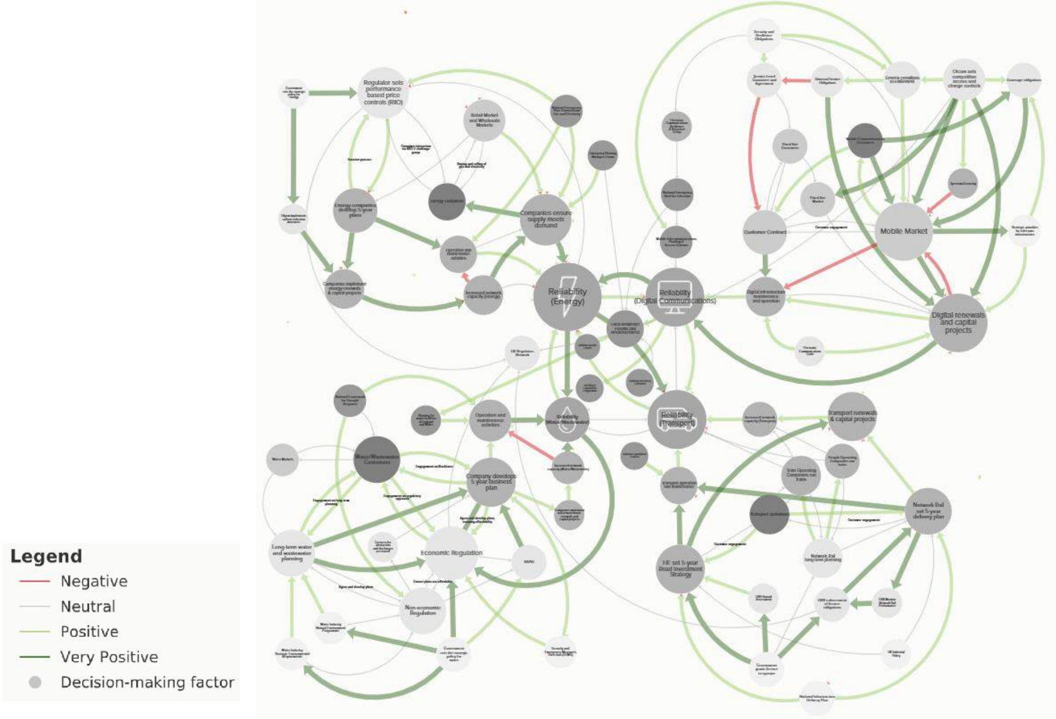

Figure 7: Overview of the systems map in Kumu showing 'factors' (click on image for interactive version)

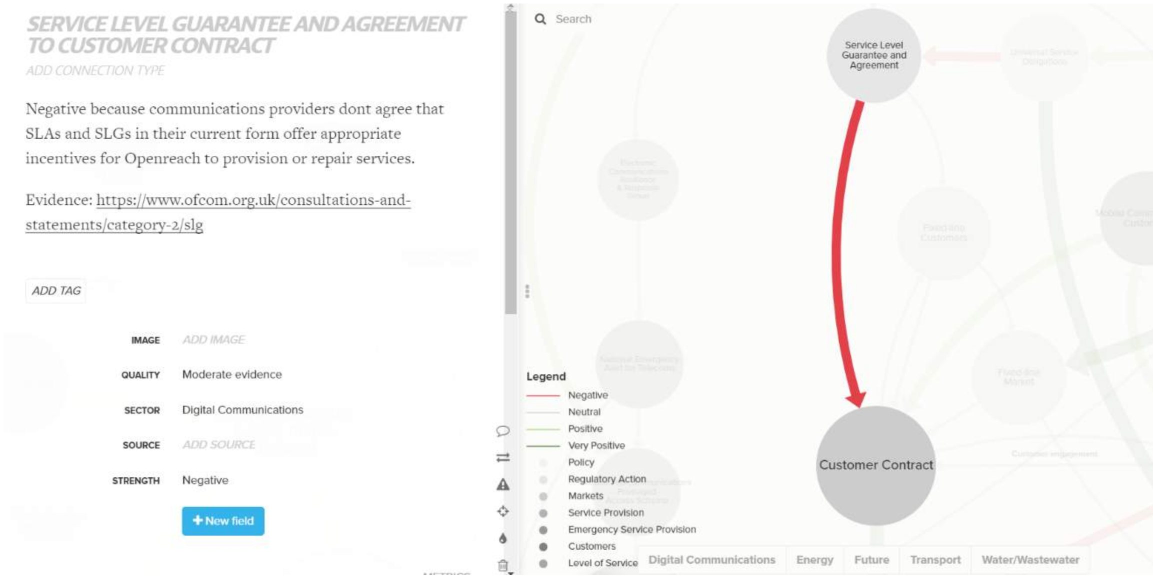

Figure 8: Overview of the systems map in Kumu showing strengths of 'connections' (click on image for interactive version)

4. Decision Making within UK Infrastructure Systems

Overview – Factors

Overview

This sections provides a narrative of the key findings that have emerged from the systems diagrams for the current scenario.

A systems diagram has been developed that shows the relative influence of the identified national-level decision making factors on the Level of Service delivered by UK infrastructure in 'present day' operating situations.

Figure 9 shows the entirety of the UK infrastructure system considered in this study, coloured by the type of factor. This comprises digital communications, energy, transport (rail and road) and water and wastewater.

The size of individual factors on the diagram (Figure 9) has been scaled depending on the number of connections that they have.

Click on the map to open the interactive version online.

Key findings are presented on the following pages.

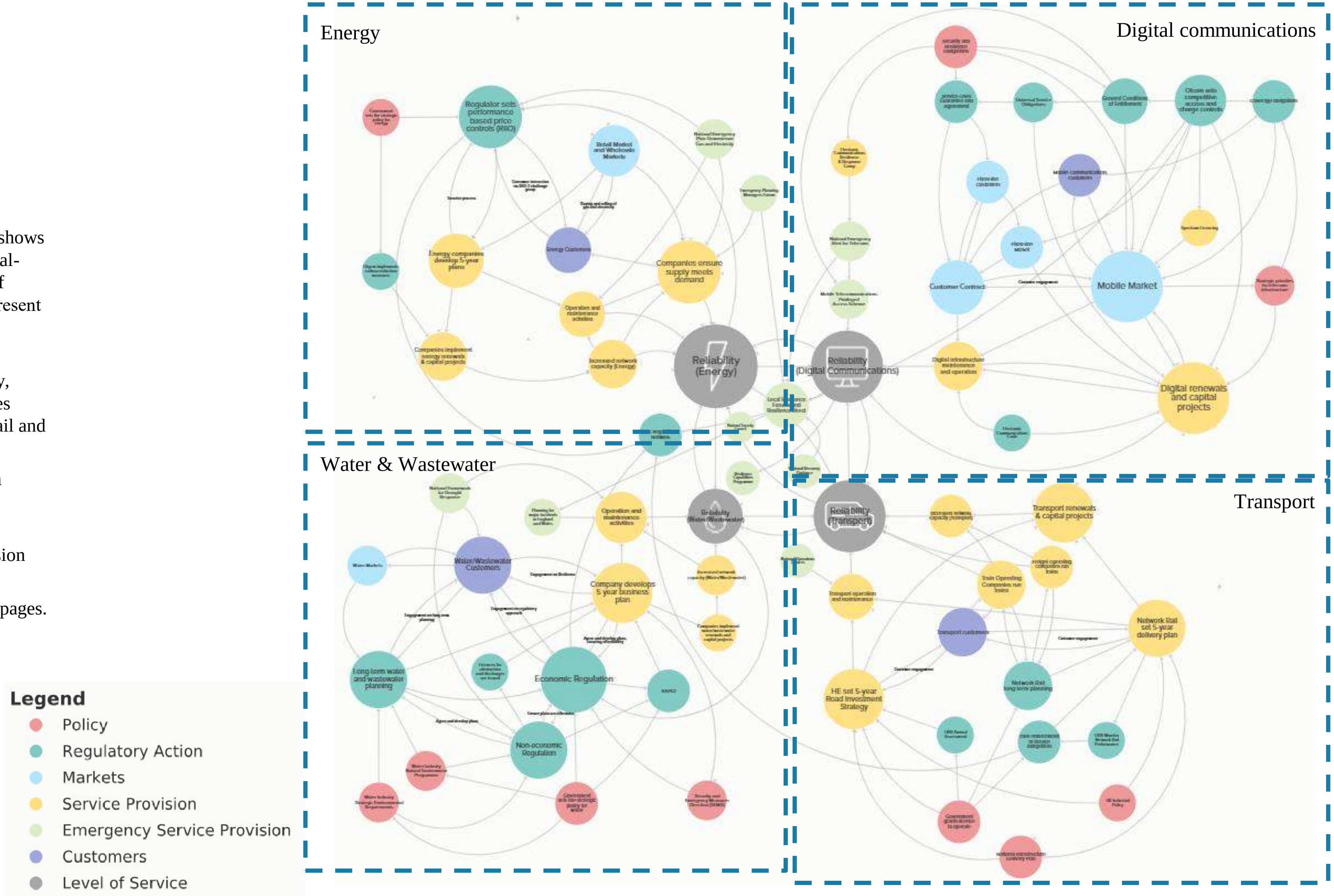

Figure 9: Systems diagram showing each sector by type of factor (sectors have been highlighted by dashed boxes) (click on image for interactive version)

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4. Decision Making within UK Infrastructure Systems

Overview – Connections

Overview

The diagram in Figure 10 shows the same elements as identified on the previous page (Figure 9). However, this systems diagram highlights the strength of influence of the links between the factors.

Defining whether a link has a positive or negative influence is particularly important for comparing the current and future (see Section 5) scenarios. It also helps the user to understand where there may be opportunities for making improvements in decision making. This could also then have the impact of increasing the resilience of the system.

Click on the map to open the interactive version online.

Key findings are presented on the following pages.

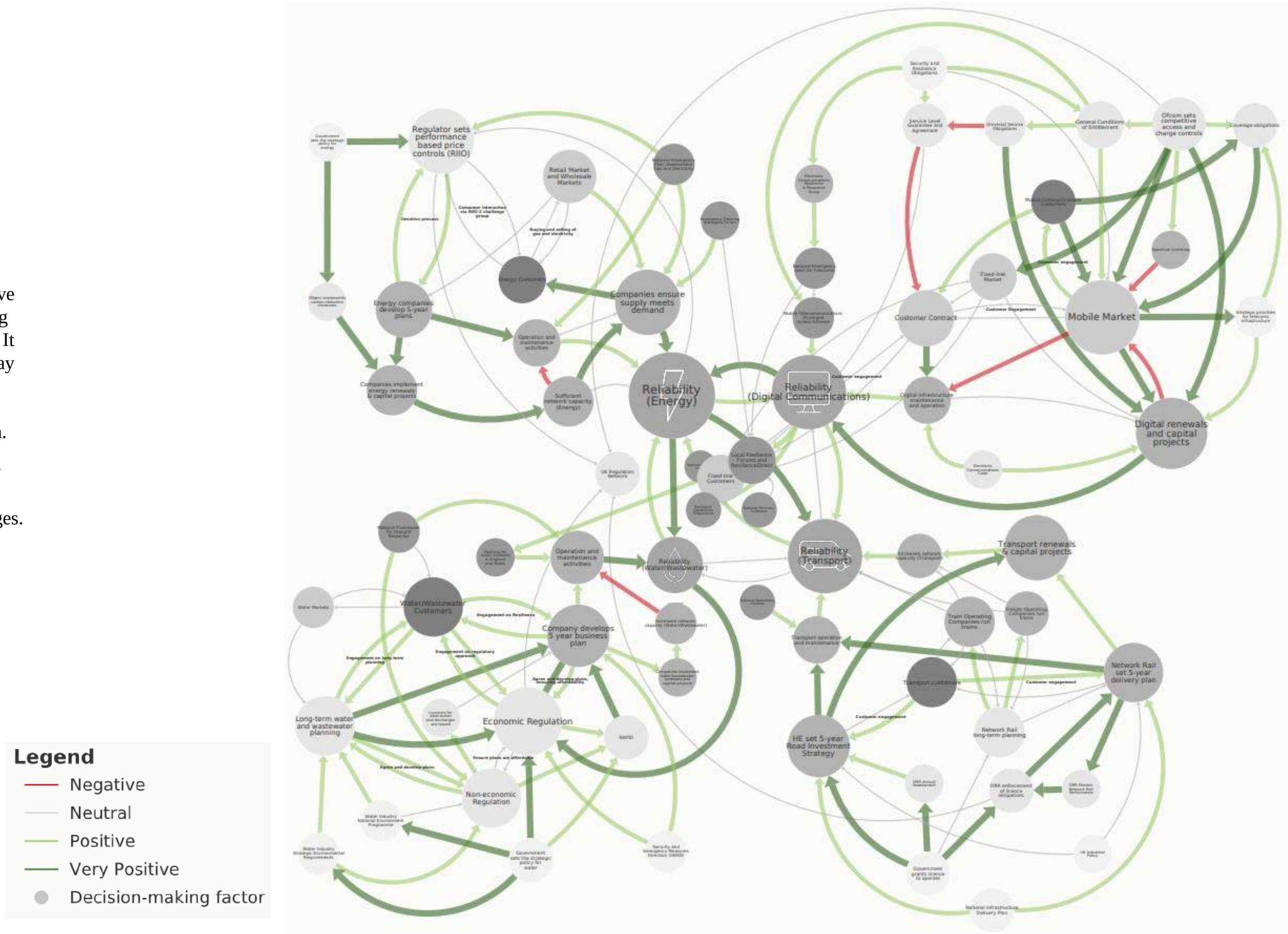


Figure 10: Systems diagram showing each sector by influence between the factors (click on image for interactive version)

4. Decision Making within UK Infrastructure Systems
Current Scenario: Digital Communications

Overview

Figures 11 and 12 provide an overview of the Digital Communications sector, based on factor type and link influence respectively.

The digital communications sector is separated into mobile and fixed-line networks. The markets for each respective sector drive decision making, with significant influence from customer requirements.

The role of Ofcom (the regulator) is primarily to incentivise and ensure access to these markets at a fair price to customers. Ofcom and operators have also jointly agreed *coverage obligations* for mobile and broadband technologies within the UK, driven largely by customer pressure, which is improving reliability through capital projects.

For fixed-line communications, Ofcom has provided access to Openreach infrastructure through the *electronic communications code*. However, shared access can result in a negative impact where third party providers are reliant on Openreach to maintain the network through the *Service Level Agreement*. The *Universal Service Obligation* ensures that basic fixed line services are available to all customers within the UK.

An issue for the mobile and wireless networks is the availability of the spectrum, which could represent a long-term risk to the mobile market, shown by the negative connection between spectrum licencing and the mobile market in Figure 12.

Other key findings that have emerged from this systems diagram are presented on the following pages.

Figure 11: Systems diagram of the digital communications sector showing the factors

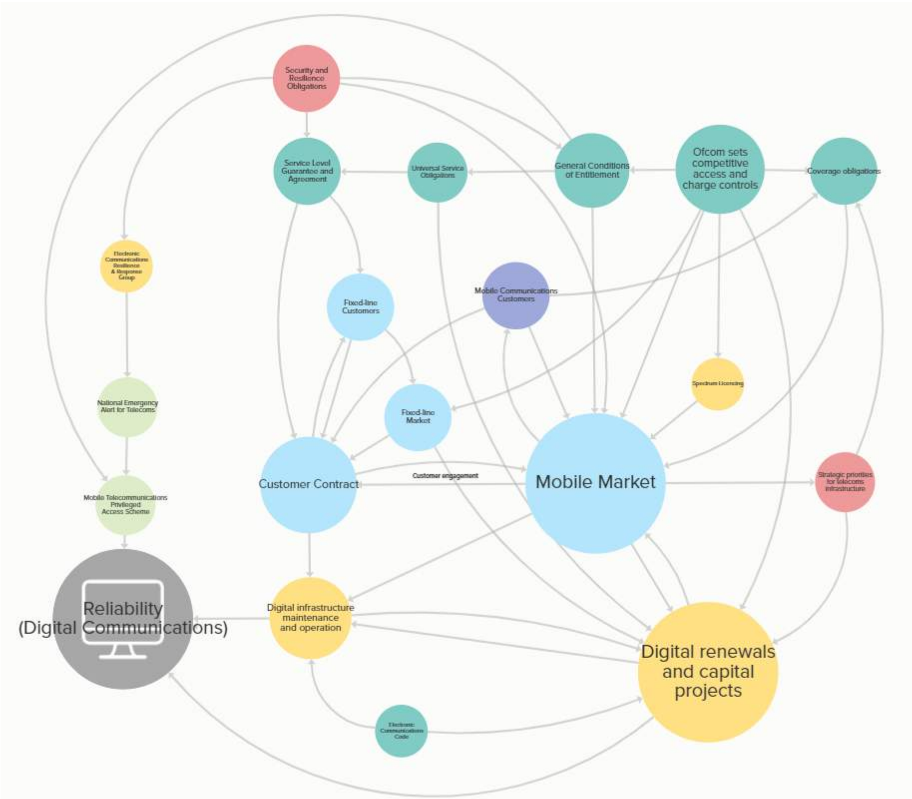
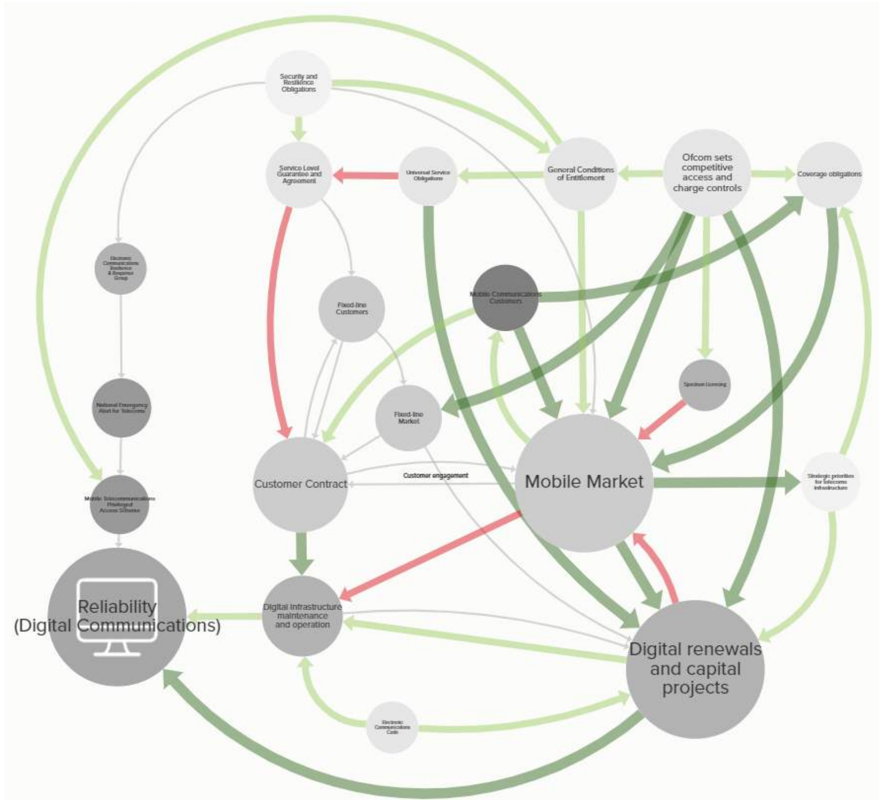


Figure 12: Systems diagram of the digital communications sector showing the relative influence between factors (click on image for interactive version)



4. Decision Making within UK Infrastructure Systems
Current Scenario: Energy

Overview

Figures 13 and 14 provides an overview of the energy sector, based on factor type and link influence respectively.

The energy sector currently provides both gas and electricity across the UK. The main drivers in this sector are the retail and wholesale markets (full competition was introduced in the 1990s), and the regulator Ofgem's performance based price controls, which ultimately stem from government strategic policy. This includes extensive customer engagement for developing Ofgem's RIIO approach and developing individual companies plans.

These both have an impact on the energy companies' 5-year plans, which lay out plans for operating, maintaining and developing the networks. Ofgem is currently in the process of moving from 8 to 5 year business planning cycles.

Development of the networks is usually aimed at ensuring there is sufficient capacity which in turn lead to an increased requirement for operation and maintenance activities, shown via the only red arrow on the diagram.

In addition, the means by which companies ensure supply meets demand differ from gas to electricity. Gas can be stored much more easily than electricity through line-packing. For gas and electricity ensuring supply meets demand involves metering, settlement and constraint management, whereas for electricity only it includes the capacity market, use of interconnectors and frequency response, due to the second-by-second nature of electricity balancing.

Figure 13: Systems diagram of the energy sector showing the factors

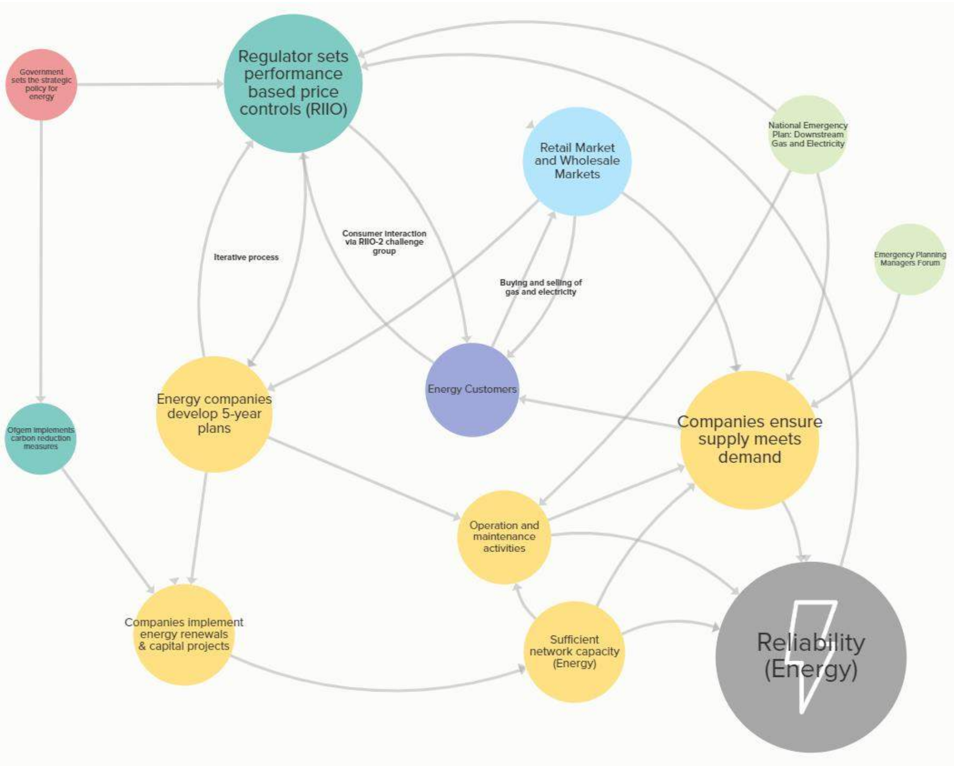
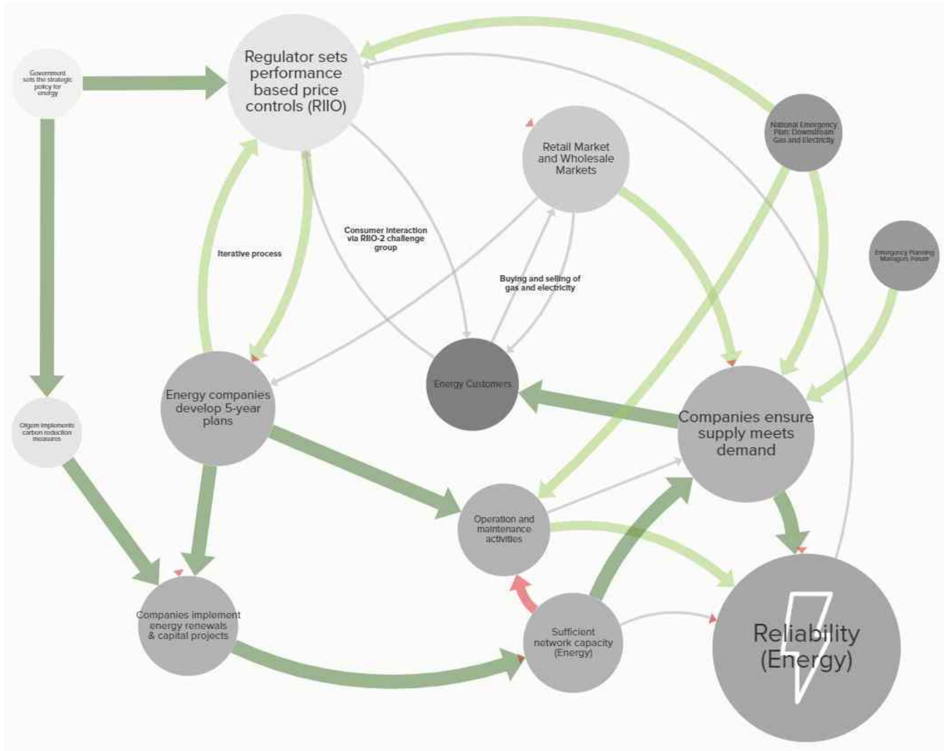


Figure 14: Systems diagram of the energy sector showing the relative influence between factors (click on image for interactive version)



4. Decision Making within UK Infrastructure Systems
Current Scenario: Transport

Overview

Figures 15 and 16 provide an overview of the Transport sector, based on factor type and link influence respectively.

Within the transport sector, the licence requirements have a positive impact on how infrastructure operators maintain and operate their networks. The 5 year delivery and investment strategies represent the most significant decision making factor of the system. These then dictate what renewals and capital projects are undertaken.

The Office of Road and Rail have an impact on how those licence requirements are adhered to.

Also represented on the map are train and freight operating companies (TOCs and FOCs). These have a key role in the rail sector.

Other than the oversight provided to both sectors by ORR, road and rail planning and operations in the UK are typically operated separately.

Other key findings that have emerged from this systems diagram are presented on the following pages.

Figure 15: Systems diagram of the transport sector showing the factors

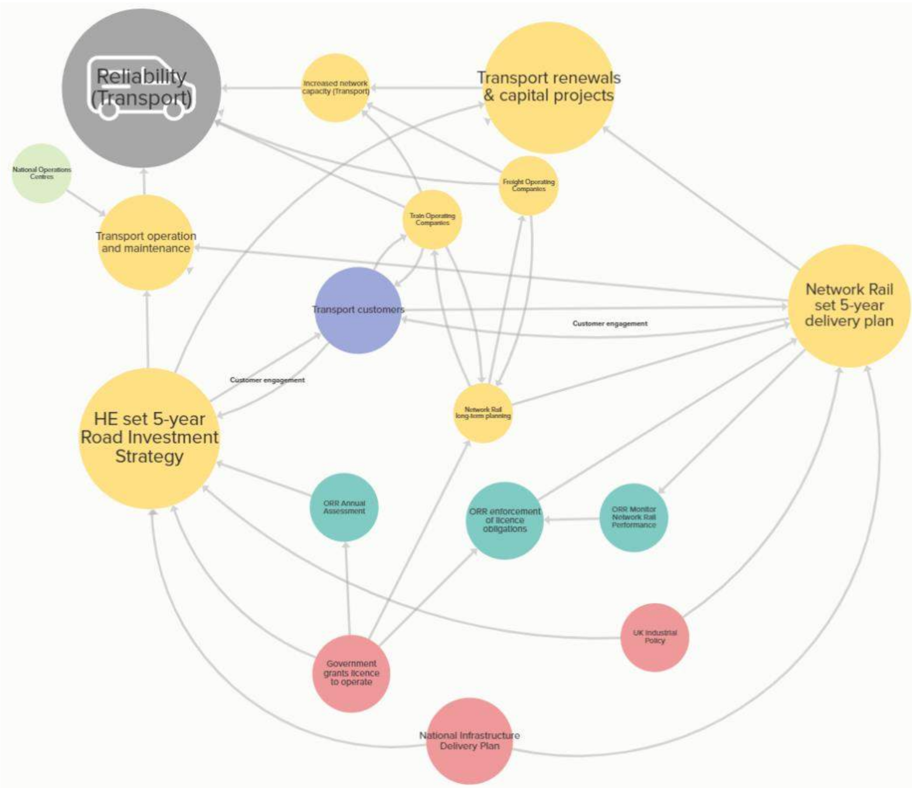
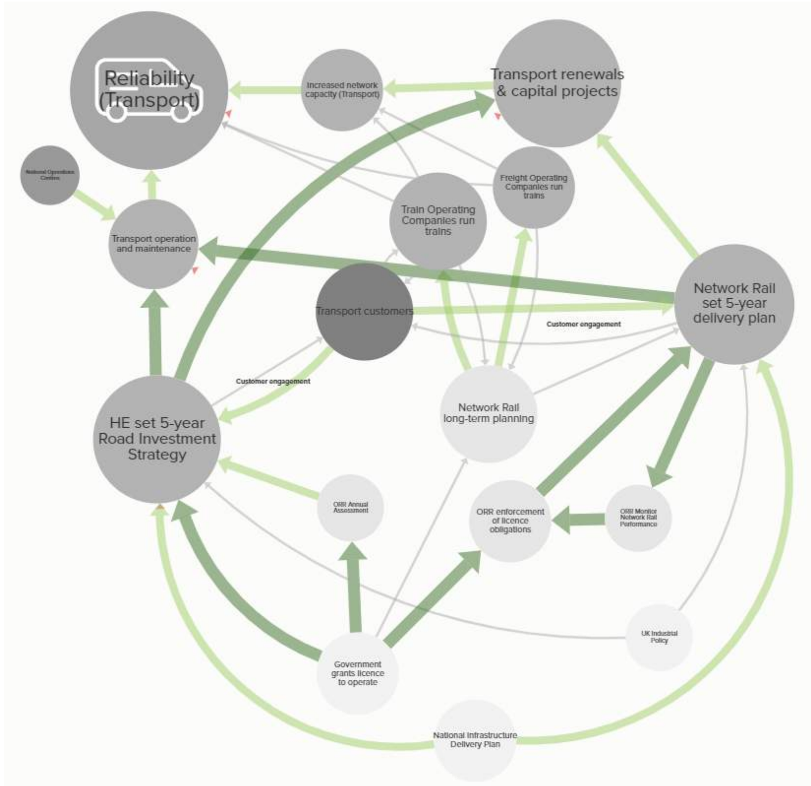


Figure 16: Systems diagram of the transport sector showing the relative influence between factors (click on image for interactive version)



4. Decision Making within UK Infrastructure Systems
Current Scenario: Water and Wastewater

Overview

Figures 17 and 18 provides an overview of the Water and Wastewater sector, based on factor type and link influence respectively.

Regulation of the water and wastewater sector has a complex governance structure. This comprises economic (i.e. Ofwat) and non-economic (Defra, Environment Agency and Drinking Water Inspectorate) regulatory bodies. RAPID (Regulators Alliance for Progressing Infrastructure Development)[1] in the water sector has been developed to bring together the economic and non-economic regulators.

This sector is more advanced in terms of its formal integration of long-term planning, which is represented by the '*Long-term water and wastewater planning*' factor shown in the figures below. Regulators play a role in reviewing and agreeing business plans. Moreover, two-way engagement with customers is important in this sector, and water companies are mandated to engage with their customers to co-develop 5 year investment plans.

Figure 17: Systems diagram of the water & wastewater sector showing the factors

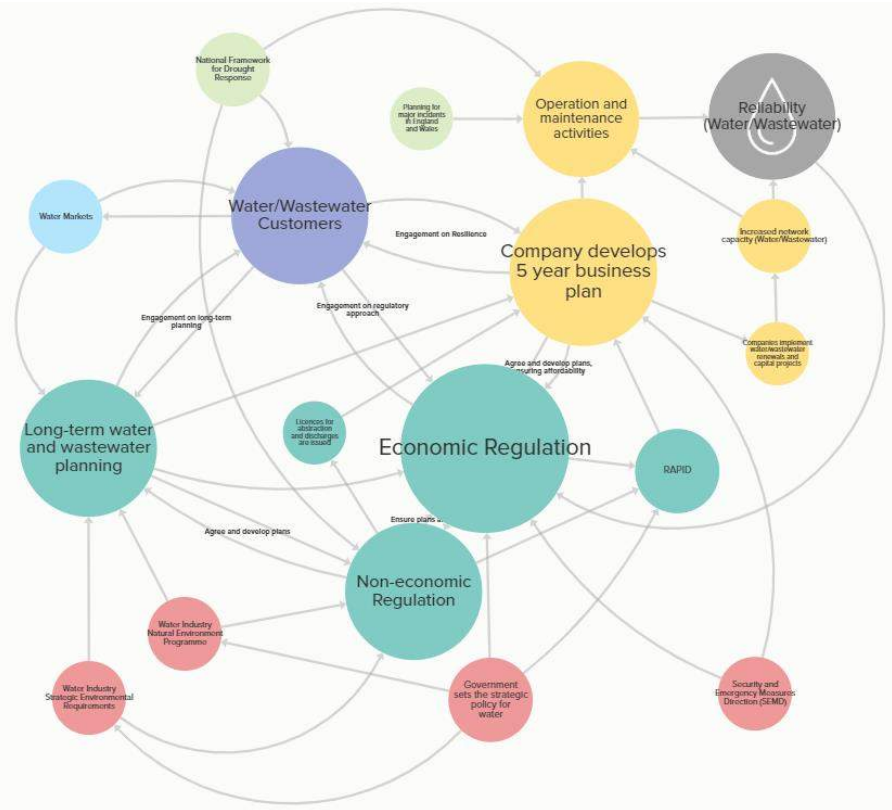
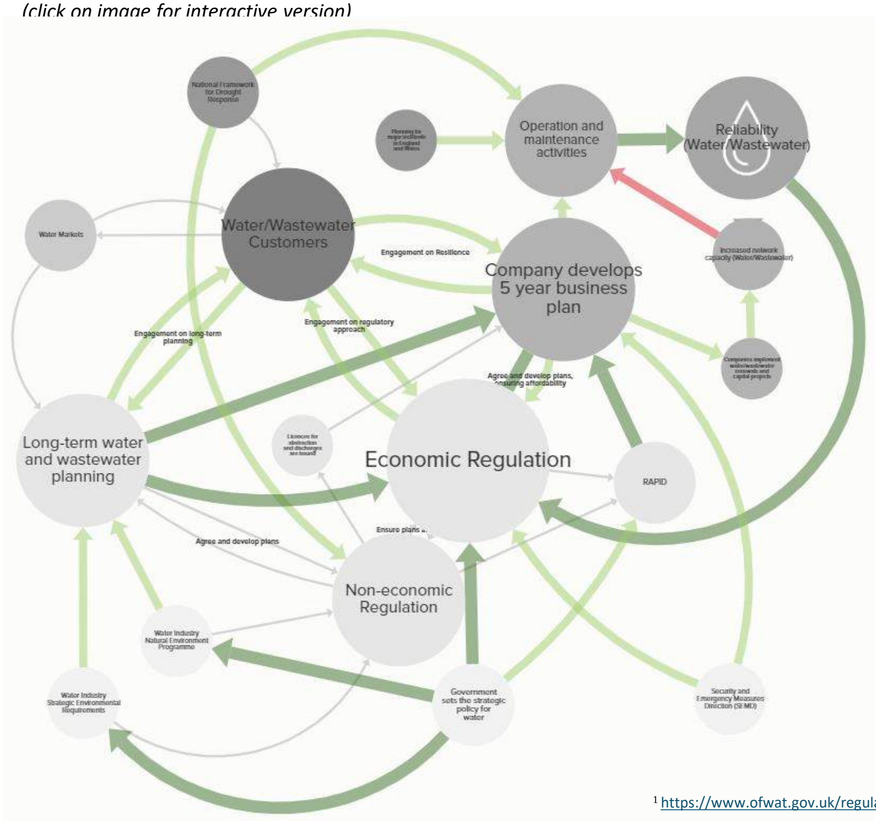


Figure 18: Systems diagram of the water & wastewater sector showing the relative influence between factors (click on image for interactive version)



[1] https://www.ofwat.gov.uk/regulated-companies/rapid/

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4. Decision Making within UK Infrastructure Systems

Current Scenario

01 SILOED INFRASTRUCTURE SECTORS

Key Insight 1: Siloed Infrastructure Sectors

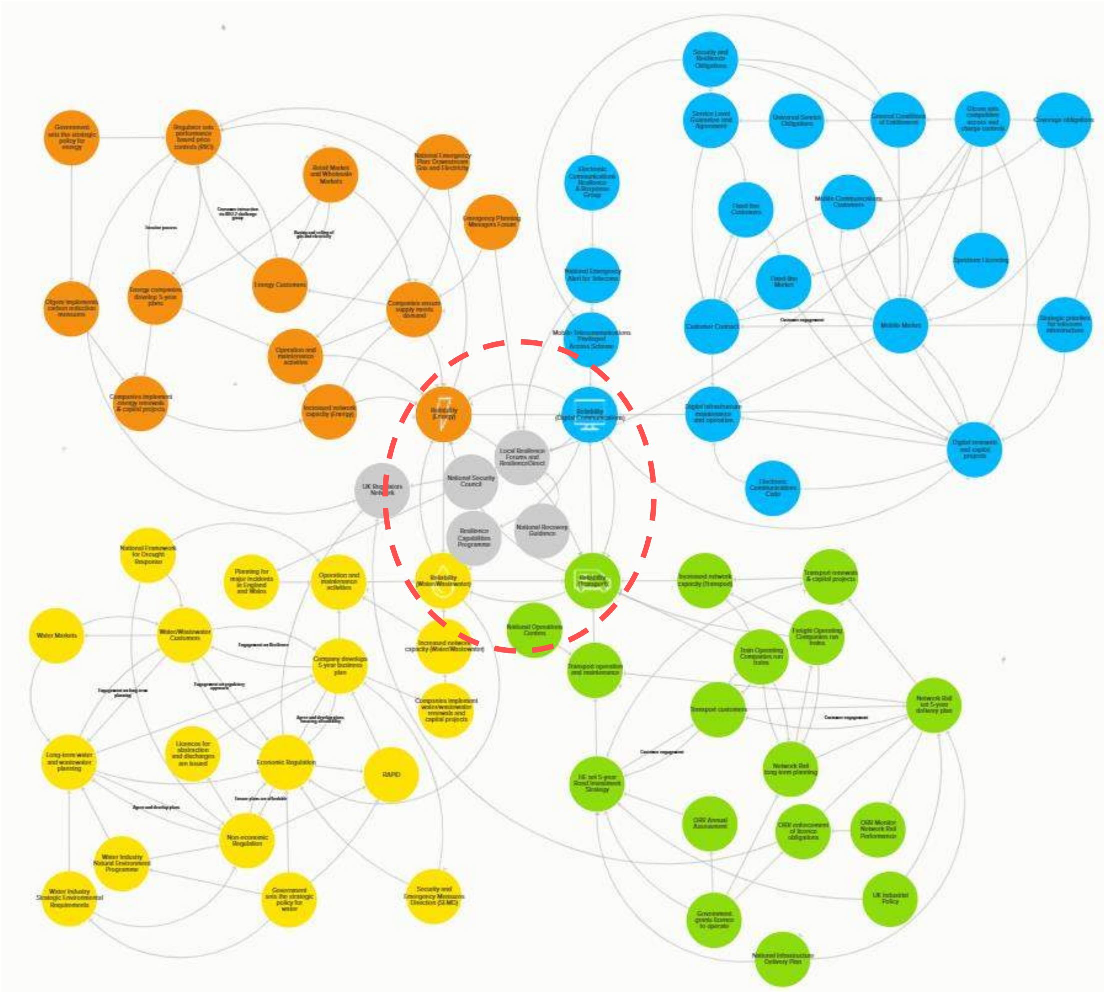
Decision-makers are aware of the importance of interdependencies, particularly in ensuring the resilience of a service, as supported during our consultations. The only key connections between the sectors are in the centre of the diagram, between the Levels of Service (red dashed circle).

The recent 9th August, 2019 power failure[1] and the 2015 Lancaster flooding[2] are reminders of how failure in one system (e.g. energy) can significantly impact others (e.g. transport). The National Policy Statement for National Networks[4], although not considered in the systems diagram is focused on the road and rail networks and **does not explicitly consider interdependencies as part of the planning process**. However, supplementary guidance to the green book[5] and the National Infrastructure Delivery Plan[6] identify some initiatives (e.g. Ebbsfleet case study[6]) where interdependencies are considered.

An **ability to understand cross sector implications is especially important for resilience**. The red dashed circle on Figure 19 draws attention to the key interdependencies between the Levels of Service of different sectors. However, the **interdependencies represented in the diagram, although increasingly acknowledged, are currently not part of decision making processes**. Instead, they represent the physical dependencies between each network, to help understand the impact of decision making within each sector on the others.

A recent report by the UKRN[7] has shown that **data sharing is essential for decision making** and "*although challenging, individual and cross sector collaboration is required to continue improving behaviours and fully enable digital transformation*". National Grid's Future Energy Scenarios[3] has also argued that a "*whole system view across electricity, gas, heat and transport underpins a sustainable energy transformation*".

Overall, Figure 19 clearly shows that when it comes to policy and decision making, there is very **little that explicitly considers cross-sectoral interdependencies**.



Legend
- Digital Communications
- Water/Wastewater
- Transport
- Energy

Figure 19: Systems diagram, showing factors coloured by sector (grey factors are not associated with individual sector; red dashed circle represents a need for cross-sector collaboration; click on image for interactive version)

[1]https://www.ofgem.gov.uk/publications-and-updates/investigation-9-august-2019-power-outage
[2]https://www.raeng.org.uk/publications/reports/living-without-electricity
[3]http://fes.nationalgrid.com/media/1409/fes-2019.pdf
[4]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/387222/npsnn-print.pdf
[5]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/417822/PU1798_Valuing_Infrastructure_Spend_-_lastest_draft.pdf
[6]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/520086/2904569_nidp_deliveryplan.pdf
[7]https://www.ukrn.org.uk/wp-content/uploads/2019/09/UKRN-Infrastructure-Data-Sharing-0919.pdf

4. Decision Making within UK Infrastructure Systems
Current Scenario

02 FRAGMENTED GOVERNANCE

Key Insight 2: Fragmented Governance

The systems diagrams (e.g. Figure 19) show that the **UK's infrastructure has a complex governance structure**. Across the sectors there is **varied influence between regulators, markets and customers**. This is shown by the relevant size of the factors in Figure 10.

Rail, for example, has many stakeholders involved with service delivery (see Figure 20). Network Rail operate and maintain the infrastructure, and TOCs and FOCs provide passenger and freight services. The recent example of the East Coast Rail Franchise (see Box 1) and Northern Rail[4] can be seen as an example of how this **complex governance structure, and a lack of join up in it, can result in impacts that can affect the Level of Service** provided. However, the current rail franchising model is being reviewed as part of The William's Rail Review[7].

In digital communications, service providers are concerned that the current Service Level Guarantees are not being met by Openreach. The system diagram extract in Figure 20 shows how this can impact third party service providers (i.e. companies that provide a communications service using BT and Openreach networks). This is particularly important where the provider has a customer contract to provide digital communications for another infrastructure sector.

In the energy sector, governance is also complex, with generation, transmission and distribution operators, in gas and electricity needing to work together to ensure the Level of Service. Ofgem's report into the August 9th power failure (see Box 4) stated that the issue was exacerbated by a **lack of communication** between the ESO (Electricity System Operator) and the DNOs (Distribution Network Operators). Moreover, retail and wholesale markets also add to this complexity of governance, and the failure of some energy suppliers in the UK has led **Ofgem to develop stricter rules for companies to enter the market**[5].

There appears to be a **lack of coordination between Lead Government Departments** in decision making for ensuring the Level of Service is maintained across sectors. This has been emphasised by a recent Institute for Government report[6].

Many sectors are also going through significant changes in the way that they operate. For example, digital communications has seen the introduction of wireless and 5G technology; energy with an increase in renewables and moving towards a distributed energy generation and; transport with the introduction of electric vehicles. These **new technologies are adding to the complex governance structure** through the development of emerging markets and associated players in this. In comparison, the water sector is not undergoing such fundamental change, although it is adapting to reduced water resource availability.

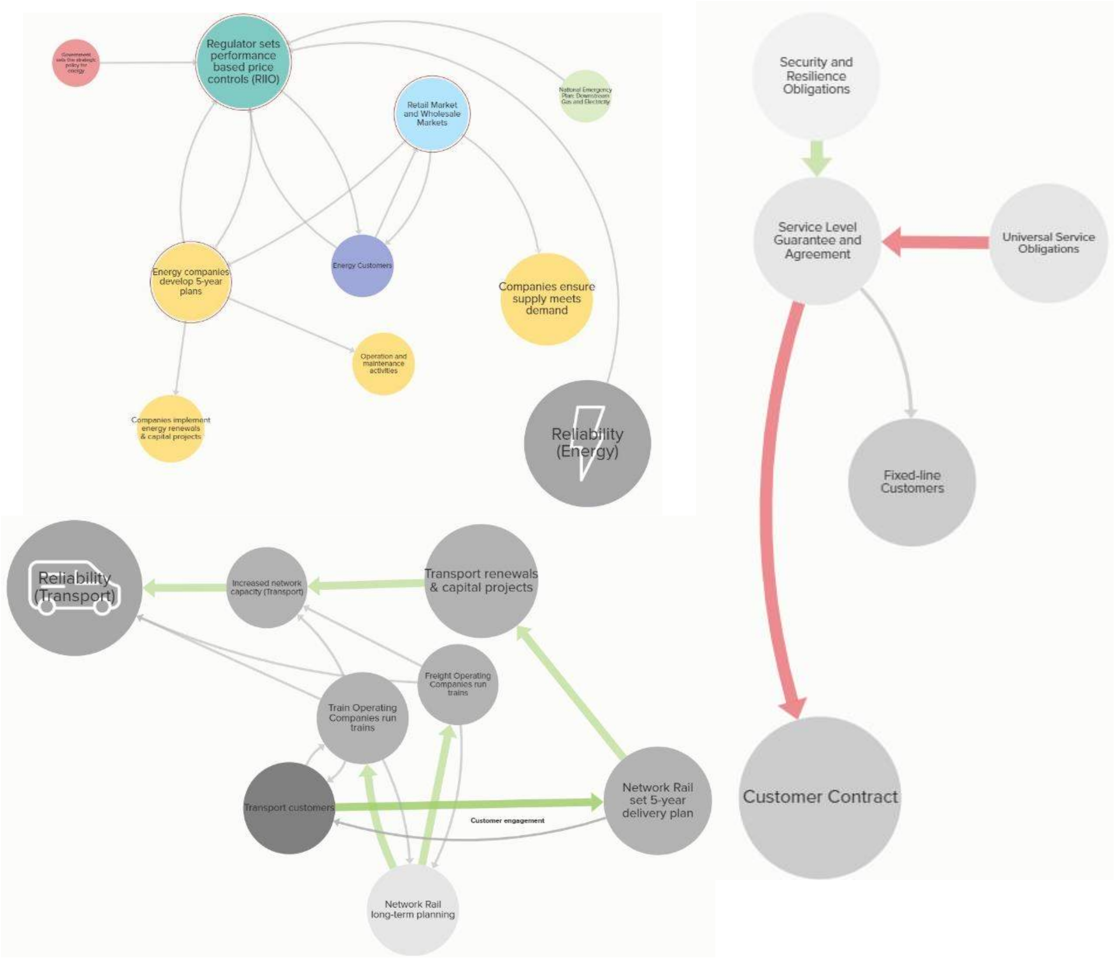


Figure 20: Extracts of the systems diagrams showing the impact of fragmented governance.

Box 1: East Coast Rail franchise[2]

In November, the Department for Transport said Virgin and Stagecoach could withdraw from running the London to Edinburgh service three years early. Virgin and Stagecoach claimed they had been affected by delays to upgrade the rail infrastructure to facilitate the mandated (by DfT) running of electric trains on the network. A parliamentary committee[3] concluded that the Department for Transport were responsible for confusion around what infrastructure enhancements on the East Coast mainline were going to be delivered and when. They recommended that *"much closer alignment between the invitation to tender in the franchise agreement and Network Rail's planned enhancements"*.

[1] https://www.ofwat.gov.uk/regulated-companies/rapid/
[2] https://www.bbc.co.uk/news/business-42851274
[3] https://publications.parliament.uk/pa/cm201719/cmselect/cmtrans/891/89109.htm
[4] https://www.economist.com/britain/2020/02/01/britains-government-renationalises-northern-rail
[5] https://www.ft.com/content/1c2c8b10-f49b-11e9-b018-3ef8794b17c6
[6] https://www.instituteforgovernment.org.uk/executive-summary-how-design-infrastructure-strategy-uk
[7] https://www.gov.uk/government/news/rail-review-chair-says-franchising-cannot-continue-in-its-current-form

4. Decision Making within UK Infrastructure Systems
Current Scenario

03 REGULATORY INFLUENCE

Key Insight 3: Regulatory Influence

Regulatory influence varies across the sectors. Our systems diagrams shows that the **regulator has a bigger role in the water and energy sectors** for ensuring the Level of Service provided (Figure 21).

Each regulator currently has a different focus. For example, Ofwat is particularly concerned with long-term water resources management, which they have focused on in their *Resilience in the Round*[2] review. In contrast, the energy regulator, Ofgem is focused on decarbonisation (in addition to reliability and price). The digital communication sector is facing significant technological changes, and managing the emerging markets in this area (e.g. 5G communications).

Figure 21 highlights the **absence of an overarching, cross-sectoral regulatory approach to resilience**. However, there **are some coordinated efforts by the UK Government** around resilience. For example, the establishment of the UK Regulators Network[1] (UKRN) was designed to develop a culture of collaboration and learning.

There are **many regulatory requirements**, which are becoming increasingly complex. For example, the water sector is regulated by the Environment Agency (Environment), Drinking Water Inspectorate (Water Quality) and Ofwat (Economic) (Figure 21). The recent formation of RAPID[3] in the water sector is bringing together the economic and non-economic regulators, enabling the planning of strategic schemes to improve the future resilience of water supplies; which should have a positive influence on the Level of Service.

The current regulatory regime, and business planning approach also makes the development and construction of large-scale infrastructure projects problematic. This is something that has been addressed in the Commission's recent Regulation Study[4], that suggests large-scale projects should be managed separately to regular capital and operational expenditure budgets.

A UKRN report[5] on cross-sector resilience identified that **none of the UK regulators has specific cross-sector resilience duties** and the extent to which they can address this aspect under their general resilience work varies. Moreover, the Commission's Regulatory Study[6] emphasises that regulator's "do not have consistent duties on resilience".

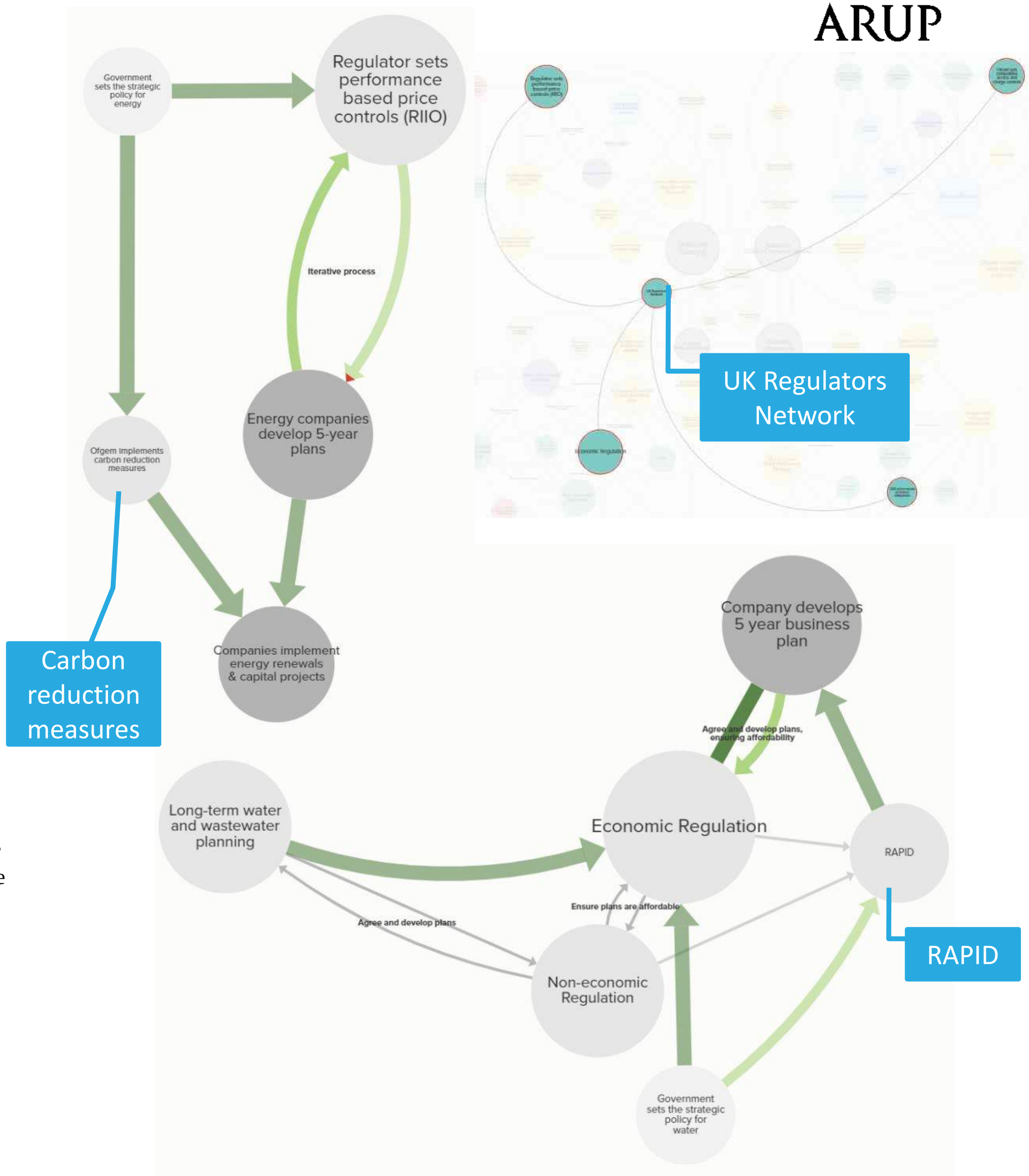


Figure 21: Extracts of the systems diagrams showing regulatory influence.

[1] https://www.ukrn.org.uk/
[2] https://www.ofwat.gov.uk/publication/resilience-in-the-round/
[3] https://www.ofwat.gov.uk/regulated-companies/rapid/
[4] https://www.nic.org.uk/our-work/regulation/
[5] https://www.ukrn.org.uk/wp-content/uploads/2018/06/2016FebCSR-Phase2Report.pdf
[6] https://www.nic.org.uk/publications/strategic-investment-and-public-confidence/

4. Decision Making within UK Infrastructure Systems
Current Scenario

04 VARYING APPROACHES TO LONG-TERM PLANNING

Key Insight 4: Varying role of markets and customers

The systems diagrams (Figure 22) show the **importance of markets for the energy and digital communications sectors**. They are the primary drivers for investment, which can impact the reliability and resilience of the respective networks. However, this can add to the complex governance as previously described.

In contrast, **transport is primarily driven by national government priorities and funding**, with more limited influence from its customers.

There **needs to be incentives for markets to work together** to develop more resilient and reliable networks. However, this can be problematic. For example, the Shared Rural Network Program (see Box 2) which represents an agreement to share network equipment has seen the mobile network operator EE reportedly charging significant amounts for sharing of its equipment that it has invested in. Other Mobile Network Operators have warned that this could reduce investment in 4G technology across rural areas of the UK.

In the water and wastewater sector, **Ofwat has put more onus on companies to engage with their customers**, as part of 2019 price review process. This is important, as reducing the demand for water is part of the 'twin-track' approach for increasing the resilience of the UK's water infrastructure[1]. Furthermore, it also provides an understanding of customers' resilience expectations and at what level of impact to their bills.

In the energy sector, Ofgem has created a Customer Engagement Group and User Group[4], who advise on the business planning process for the respective parts of the sector (e.g. transmission and distribution). This is shown in Figure 22.

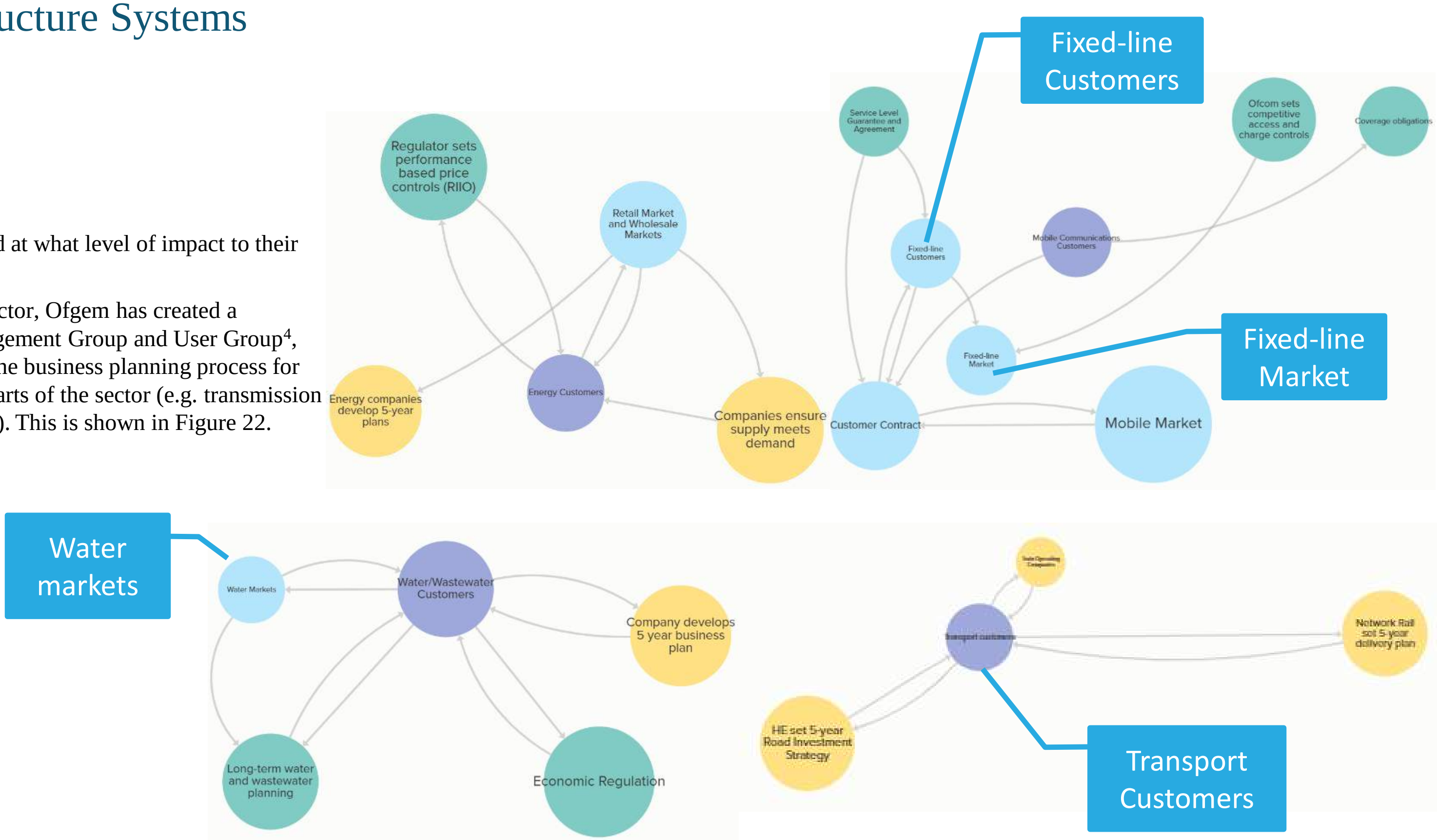


Figure 22: Extracts of the systems diagrams showing the influence of markets and customers.

Box 2: Shared Rural Network[2]

The Shared Rural Network agreement was introduced in October 2018, as a joint venture between the four Mobile Network Operators (MNOs) and the Government. It aims to provide a mechanism to increase 4G coverage to rural parts of the United Kingdom through sharing masts and networks. However, in January 2020 it was reported[3] that BT-Owned EE's costs for sharing equipment were significantly higher than expected, which has met opposition from other MNOs and could impact improvements to rural mobile coverage.

[1] https://www.nic.org.uk/publications/preparing-for-a-drier-future-englands-water-infrastructure-needs/
[2] https://www.mobileuk.org/shared-rural-network
[3] https://www.bbc.co.uk/news/technology-51372017
[4] https://www.ofgem.gov.uk/publications-and-updates/reports-ofgem-riio-2-independent-customer-engagement-groups-and-user-group-energy-network-company-business-plans-riio-2

4. Decision Making within UK infrastructure systems
Current Scenario

05 SHORT-TERM ECONOMIC BUSINESS PLANNING

Key Insight 5: Short-term economic business planning

The current regulatory approach in the water, energy and transport sectors dictates that they **undertake periodic reviews and develop business plans every 5 years**. Benefits of the current regulatory approach have been increased investment since privatisation, and a regulatory model that has avoided economic extremes.

An example of the energy sector business planning approach is shown in Figure 23. The energy sector had been operating to an 8 year business plan, but from 2021 is moving back to a 5-year business plan approach.

In digital communications, Ofcom undertakes a strategic review of the market; the most recent review[1] taking a 2021-2026 outlook.

Although not reflected in the system diagrams, **each sector has different business planning cycles**, including:

- Water and wastewater – 2020-2025
- Rail (Network Rail Control Periods)– 2019-2024[2]
- Highways (Road Investment Strategy[3]) – 2020-2025
- Energy – 2021-2026[4]

These short timescales highlight the potential for **conflicting priorities between delivering for shareholders and customers**. Current business planning is typically focused on functional/performance monitoring information that contributes towards economic targets and short-term profitability. This can make it **difficult for the sector to invest in measures that could improve longer-term resilience**. For example, it is understood that the energy sector does not have a regulatory requirement for companies to reinvest their profits in grid reinforcement. Whereas Ofwat in the latest price review (2019) has **made companies ringfence finances for the regulated business**[5]. Moreover, Ofwat's *Resilience in the Round* (see case study box) approach is an example of where long-term resilience thinking can be built into the 5-year business planning process.

In the Transport sector, the public ownership of the infrastructure networks means that the **Secretary of State is able to put forward additional investment cases** within a business planning period. Moreover, the **Train Operating Companies franchise agreements will also go beyond a 5 year planning cycle**, that are typically not aligned with Network Rail Control Periods.

The ability to tackle strategic long-term issues when sectors are subject to short-term price controls has also been a focus for the Commission's recent Regulation Study[6]. The National Infrastructure Delivery Plan[8] also takes a 5 year outlook to major infrastructure planning. However, it does **consider interdependencies and wider resilience as part of the scheme evaluation process**.

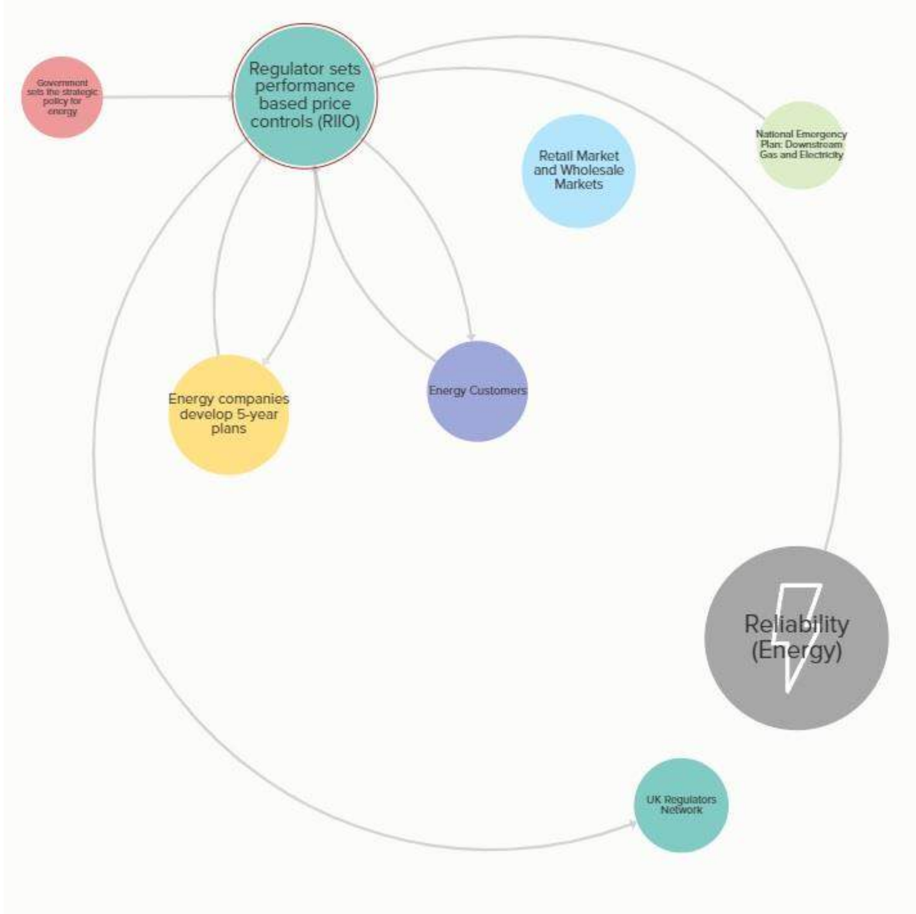


Figure 23: Extracts of the systems diagrams showing the influence of short-term business planning.

Box 3: Ofwat – Resilience in the Round[7]

Resilience has been a core concept for Ofwat in its 2019 Price Review. Their 'Resilience in the Round' publication has provided a toolkit for water companies to help them consider their corporate, financial and operational resilience and the impact on customers. Importantly, the report recognised that "*it will be vital for companies to have a better understanding of the interrelationships and interdependencies across the systems underpinning their service delivery*".

1 https://www.ofcom.org.uk/__data/assets/pdf_file/0037/188956/wftmr-volume-1-overview.pdf
2 https://orr.gov.uk/rail/economic-regulation/regulation-of-network-rail/price-controls/periodic-review-2018
3 https://www.gov.uk/government/collections/road-investment-strategy
4 https://www.ofgem.gov.uk/publications-and-updates/riio-2-sector-specific-methodology-decision
5 https://www.ofwat.gov.uk/publication/delivering-water-2020-final-methodology-2019-price-review/
6 https://www.nic.org.uk/our-work/regulation/
7 https://www.ofwat.gov.uk/publication/resilience-in-the-round/
8 https://www.gov.uk/government/publications/national-infrastructure-delivery-plan-2016-to-2021

4. Decision Making within UK infrastructure systems
Current Scenario

06 VARYING ROLE OF MARKETS AND CUSTOMERS

Key Insight 6: Varying approaches to long-term planning

Despite economic business plans having a short-term approach, the systems diagrams (Figure 24) show that **several infrastructure sectors do undertake long-term planning and forecasts**.

Evidence of long-term planning includes:

- **Water and wastewater** - Ofwat has placed a responsibility on water companies to consider the long-term impact of water resources and wastewater management. Companies are mandated to produce 25-year water resource management plans[1] and there are plans to introduce the same approach for wastewater management plans. The impact of this long-term planning is shown in the systems diagrams.
- **Rail Transport** - Network Rail's Long-term Planning Process considers the long-term capability of the network up to 30 years into the future[2]. This is to understand efficient use of network capability and capacity.

Long term planning in the water sector is more embedded and therefore has a larger impact on the system than in the rail sector. This is evident through the relative sizes of the elements in Figure 24, which are proportional to the number of other elements they interact with.

There are some examples of long-term planning in other sectors, but they are not represented in the diagrams due to their peripheral impact on the current functioning of the system and that they are not mandated as part of licence requirements. Some examples include:

- **Highways Transport** - Highways England's long-term planning for the strategic road network looks to understand how it may need to change to reflect this potential future up to 2050[3].
- **Energy** - as electricity system operator, the National Grid produce a report on 'Future Energy Scenarios'[4]. This is intended to identify a range of credible scenarios across the gas and electricity in Great Britain.

Digital communications does not undertake any mandated long-term planning, which is likely a factor of the fast-pace of technology within the sector. However, it will be important for other sectors to understand the future direction of the digital communications sector, to ensure aligned long-term resilience planning.

Despite this evidence of long-term thinking and planning within the sectors, what the system diagram shows is a **lack of central coordination** for how this planning impacts the UK infrastructure system as a whole (Figure 24). Understanding of how these plans and plausible futures could impact on each sector could be important for cross-sector resilience.

(Section continued on next page)

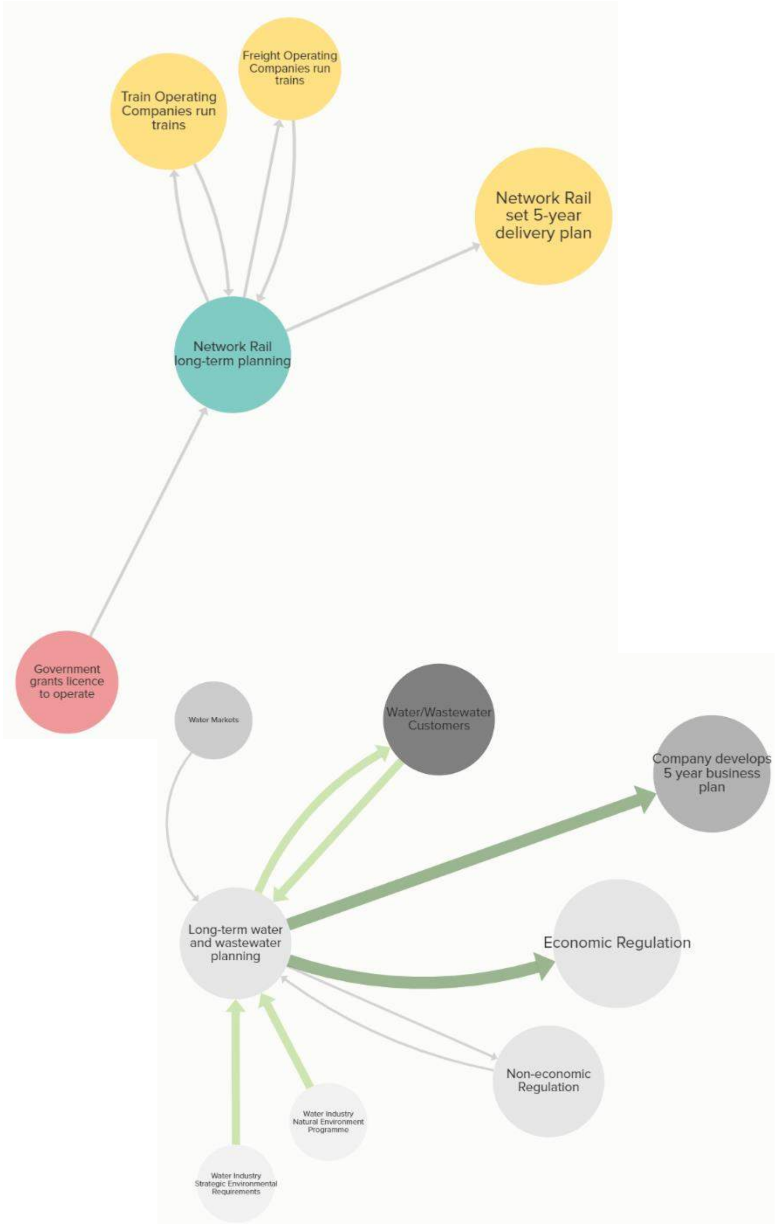


Figure 24: Extracts of the systems diagrams showing the influence of long-term business planning.

[1] https://www.ofwat.gov.uk/regulated-companies/resilience-2/water-resource-planning/
[2] https://www.networkrail.co.uk/running-the-railway/long-term-planning
[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/666876/Connecting_the_country_Planning_for_the_long_term.pdf
[4] http://fes.nationalgrid.com/

4. Decision Making within UK infrastructure systems
Current Scenario

06 VARYING ROLE OF MARKETS AND CUSTOMERS

Key Insight 6: Varying approaches to long-term planning (continued)

Although not shown explicitly in the systems diagrams, the impact **of climate change legislation[1] has been the main driver for undertaking long-term reviews** (e.g. the energy and water sectors).

Energy is considering climate change from a decarbonisation view. That although is having a positive impact on the energy sector, focus is more on mitigation. In respect that they need to reduce carbon outputs and so are implementing renewable energy technology, rather than adapting to a 'no fossil fuel' environment. Whereas the water sector is being required to adapt as a result of water resource availability due to longer-term climate change and environmental impacts of water extraction.

Infrastructure sectors must adapt their systems to cope with the impacts of climate change and also population growth. However, the development of robust adaptation strategies remains a challenge due to the **deep uncertainty surrounding future conditions**. This can be exacerbated by long lead times for infrastructure, due to current planning regulations. Although flood defence and coastal protection is not included in this study, the Environment Agency has taken an innovative adaptive pathways approach (see Figure 25) to deal with the impact of climate change on flood risk in their 100 year Thames Estuary Plan[4].

The 2017 UK Climate Change Risk Assessment Evidence Report[2] supports the findings presented in our systems diagrams that "*Understanding of these [interdependencies and interconnectivities] is less comprehensive, and current governance arrangements mean that responsibilities for assessing and managing risks from interdependencies are unclear".* However, like Network Rail's Route Weather Resilience and Climate Change Adaptation Plans, although there **is awareness of interdependencies, there is typically no cross-sector action plan** to address these. The diagrams show that interdependence are there by design from the outset, and therefore there is need for explicit infrastructure multi-sector resilience by design.

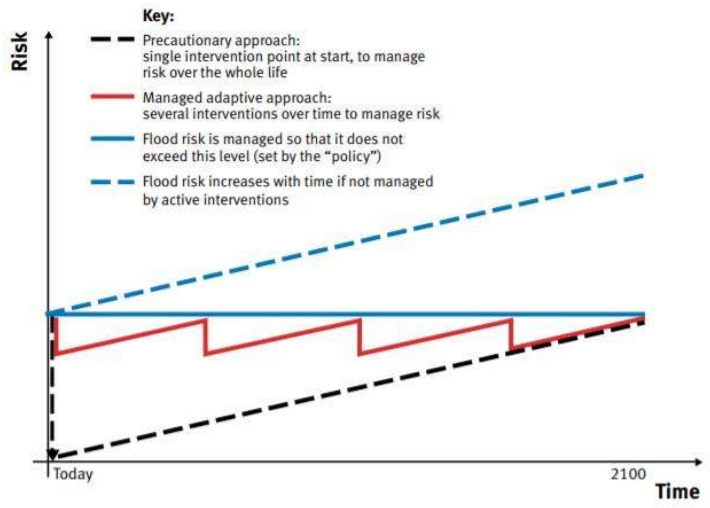


Figure 25: Example of the adaptive pathways approach taken by the Environment Agency[4]

[1] i.e. Climate Change Act (2008)
[2] https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/ccra-chapters/infrastructure/
[3] e.g. https://cdn.networkrail.co.uk/wp-content/uploads/2019/10/South-East-CP6-WRCCA-Plan.pdf
[4] https://www.gov.uk/government/publications/thames-estuary-2100-te2100

4. Decision Making within UK infrastructure systems
Current Scenario

07 CONSIDERATION OF EMERGENCY FACTORS

Key Insight 7: Consideration of Emergency Factors

Figure 26 shows the emergency factors that are in place across the UK infrastructure sectors.

During an emergency scenario, there are connections between sectors that **are not otherwise visible in the planning and day-to-day operations that become active**. These connections demonstrates the relationship between sector-specific plans and the Local Resilience Forums as shown in Figure 26. The Local Resilience Forums emerged from the Civil Contingencies Act 2004. However, these **cross-sector factors focus on the recovery and response** and not on the decision making that would prevent the cascading failures in the first place.

Sectors typically develops plans for responding to an emergency scenario, which have the primary function of restoring the Level of Service for the particular sector. These emergency factors are shown in Figure 26. For example, the water sector has a National Framework for Drought Response to enable a response to drought conditions. Energy has also developed a *National Emergency Plan: Downstream Gas and Electricity*'[2] (Figure 26), describing the national arrangements for management of gas or electricity supply emergencies.

Despite this sector specific planning, emergency planning **does not address the implications of loss of the Level of Service on the reliability of other systems.** This is a result of the siloed nature of UK infrastructure (see Key Insight 1). For example, the energy National Emergency Plan does not explicitly consider the impact on other infrastructure sectors. The recent power failure on the 9th August 2019 has highlighted how energy failures can impact the resilience of other sectors and cause cascading failures during emergency scenarios (see Box 4). Moreover, in the digital communications sector, the current 'Security and Resilience Obligations'[3] primarily focus on security and do not cover how the service could impact the reliability or resilience of other sectors who depend on digital infrastructure.

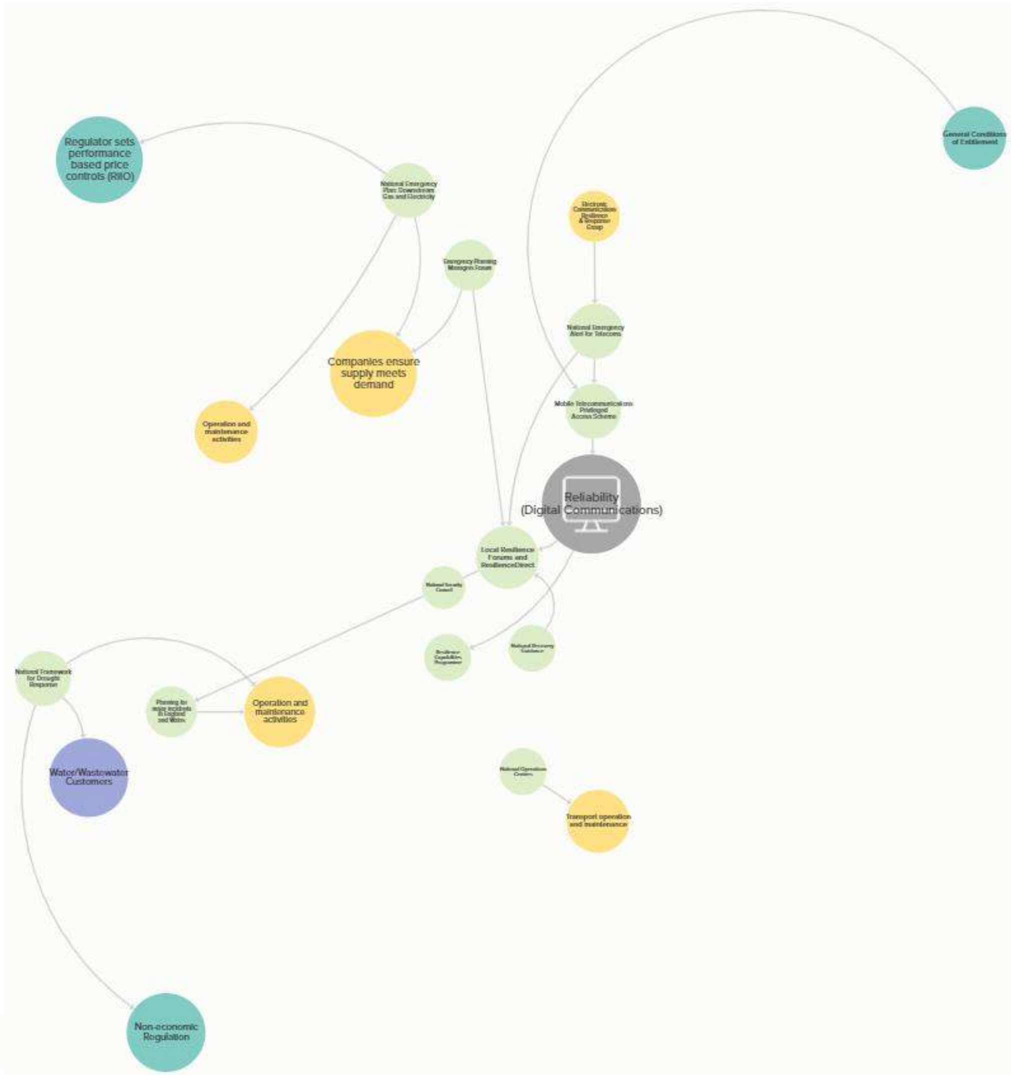


Figure 26: Extracts of the systems diagrams showing the influence of emergency factors.

Box 4: 9th August UK Power Failure[1]

The failure of the energy grid in the UK on the 9th August, 2019 resulted in multiple impacts to the UK's transport sector. For example, the rail network, due to its increasing reliance on electrification was impacted for several days as trains were not able to cope with sudden changes in voltage and frequency during an emergency situation, activating safety systems. This led to a failure of several passenger trains, which required technicians to attend before trains could run again.

[1]https://www.gov.uk/government/publications/great-britain-power-system-disruption-review
[2]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/844931/national-emergency-plan-downstream-gas-electricity.pdf
[3]https://www.ofcom.org.uk/__data/assets/pdf_file/0021/51474/ofcom-guidance.pdf
[4]https://www.ofgem.gov.uk/system/files/docs/2020/01/9_august_2019_power_outage_report.pdf

5. Decision Making within UK infrastructure systems

Future Scenarios

Overview

This section considers the future scenario that includes all three recommendations set out in the Commission's 2018 National Infrastructure Assessment[1] (Figure 27). These recommendations include:

- *Nationwide full-fibre broadband by 2033*
- *Half of the UK's power provided by renewables by 2030*
- *Preparing for 100 per cent electric vehicle sales by 2030.*

We have taken the system diagram in Figure 27 to include all three of the recommendations set out above, rather than focus on these in isolation. The following pages discuss the implications of each of these recommendations on decision making.

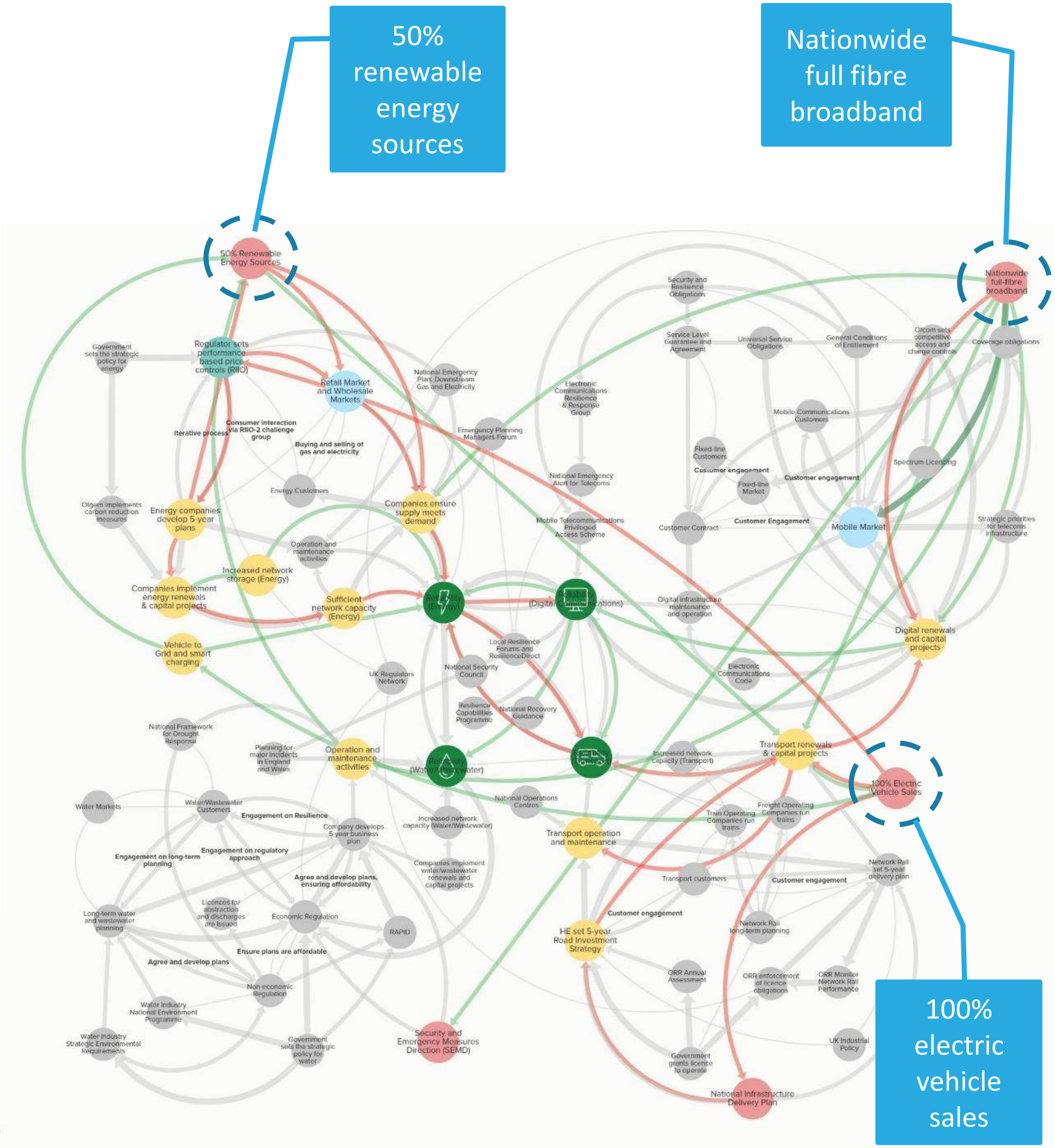
Based on the approach taken for the current scenarios, the following diagrams consider how the relative impacts of the different factors on the Level of Service could be impacted.

Certain elements of the systems diagram (Figure 27) are greyed out. This is because they are considered not to be directly impacted by the implementation of the future recommendation. This therefore allows a clear visual representation of the recommendations impact on the UK infrastructure system.

However, it is acknowledged that the recommendations may be implemented at different timescales and speeds that could create tensions. So while we have identified high level interdependencies, and the influence between them, these may change in relatively short timescales.

Overall, the systems diagram in Figure 27 shows a **greater likely degree of interconnectedness between the sectors**. Each sector has specific challenges to delivering reliability, and therefore the current siloed approach to infrastructure policy becomes even more pertinent, and highlights the **benefits of a whole-systems view of UK infrastructure decision making**.

Although not considered explicitly in the systems diagrams, it will also **be important to consider 'transition risks' that could emerge** as changes are made to the current UK infrastructure system. More information on how to approach this is provided in CISL (2019)[2].



Legend
- Policy
- Markets
- Service Provision
- Level of Service
- Negative
- Neutral
- Positive
- Very Positive
- Elements without colour unaffected by future scenario

Figure 27: Systems diagram showing the impact of the Commission's National Infrastructure Assessment recommendations on the UK infrastructure decision making (click on image for interactive version). Recommendations are highlighted by a blue dashed circle.

[1] https://www.nic.org.uk/publications/national-infrastructure-assessment-2018/
[2] https://www.cisl.cam.ac.uk/resources/sustainable-finance-publications/transition-risk-framework-managing-the-impacts-of-the-low-carbon-transition-on-infrastructure-investments

5. Decision Making within UK infrastructure systems
Future Scenario

Impact of 'Nationwide full-fibre broadband by 2033'

The systems diagram (Figure 28) shows the impact of full-fibre broadband on the reliability of other sectors, which is described further below.

The introduction of fibre will mean a **bigger requirement for energy reliability**, compared to legacy copper cable which doesn't require external sources of electricity to operate. Back up batteries are now mandated by Ofcom in certain circumstances.

The deployment of full fibre networks will **support the delivery of other communications services**, such as the roll out of 5G mobile and fixed wireless access networks[4]. However, the increased roll-out of 5G technology may also **reduce market incentives** for full-fibre rollout (Figure 28).

Digitally-connected infrastructure

The infrastructure sectors in this study are all moving towards a **higher degree of digital connectivity**. A topic that has been explored for the Commission by Arup[1] alongside the ICE and Pinsent Masons[2] report on '*InfraTech*'. For example, the use of smart metering and real-time monitoring of supply/demand balance for energy networks, digital connectivity required by connected and autonomous vehicles and sensors used to operate and maintain assets (applicable to all sectors). The negative link in Figure 28 between '*Transport renewals and capital projects*' and '*Digital renewals and capital projects*' represents an increased reliance on digital for electric vehicle charging points.

Data on infrastructure systems, derived from sensors, consumers and suppliers will allow for better investment strategies, alongside improved scenario modelling capabilities. This will improve confidence in investment plans and reduce costs of capital investments. It could also lead to **improved resilience through quicker anticipation and response to emergency events** that might otherwise have caused widespread disruption[3].

Although digitally-connected infrastructure may seem explicitly associated with mobile and wireless networks, full-fibre broadband will be required to **ensure user requirements for mobile networks are met**[5].

Spectrum Availability

A particular impact of digitally-connected infrastructure and increasing customer needs will be spectrum availability. The Department for Culture, Media and Sport states that "*the number of machines 'talking' to each other will soon outstrip the number of people on the planet, and while each individual communication may use only a small amount of spectrum, the cumulative effect may be significant in terms of demand for spectrum and increased economic and social benefits*". The OECD[5] state that if all the access demands placed on fixed networks were transferred to mobile networks, the **physical limitations on available spectrum would severely reduce the efficiency of mobile services**. This means that the rollout of full-fibre broadband will be increasingly important.

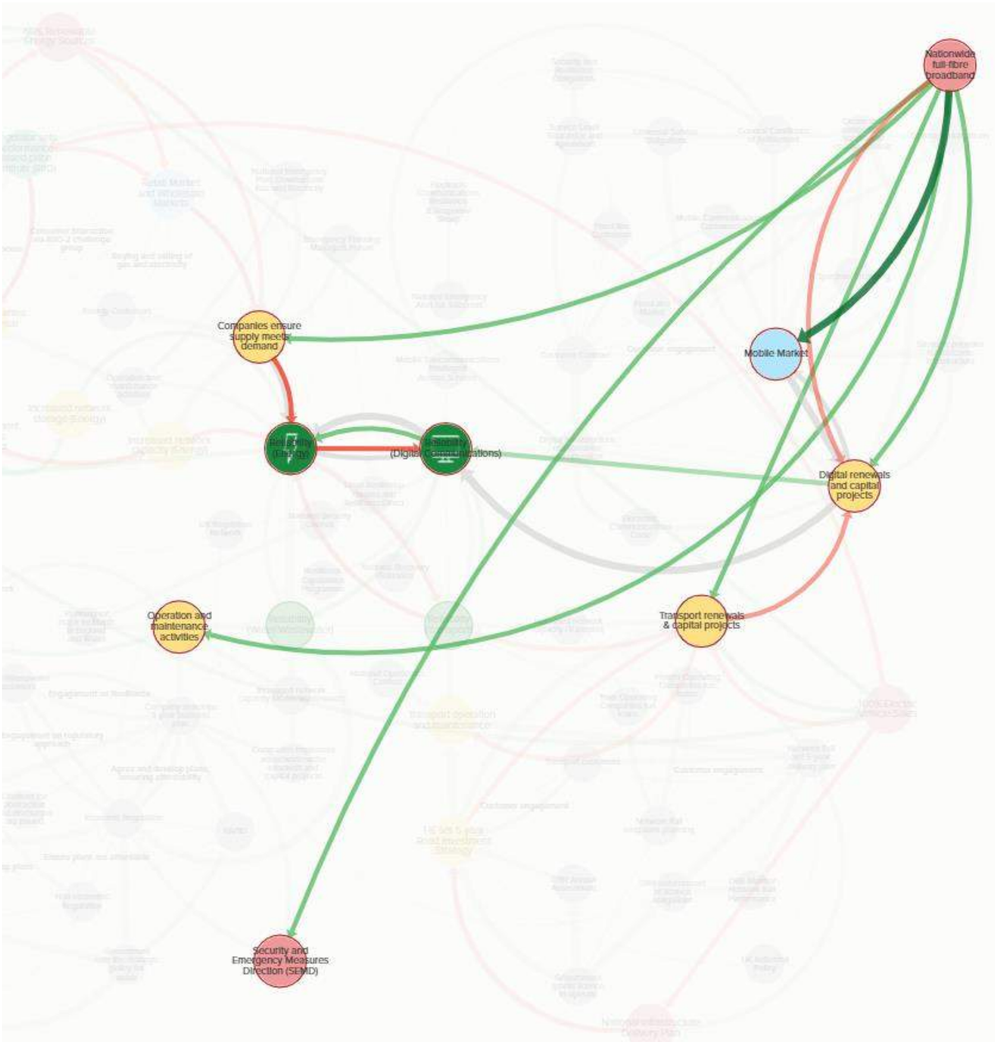


Figure 28: Extract of systems diagram showing the influence of Nationwide full-fibre broadband by 2033 on other infrastructure sectors.

[1] https://www.nic.org.uk/publications/resilience-digitally-connected-infrastructure-systems/
[2] https://www.ice.org.uk/news-and-insight/the-infrastructure-blog/october-2017/infrastructure-and-technology-explained
[3] https://www.nic.org.uk/wp-content/uploads/Data-for-the-Public-Good-NIC-Report.pdf
[4] https://www.ofcom.org.uk/__data/assets/pdf_file/0037/188956/wftmr-volume-1-overview.pdf
[5] https://www.oecd-ilibrary.org/docserver/5k91d4jwzg7b-en.pdf?expires=1582560182&id=id&accname=guest&checksum=C073F9C174D52500FBFE108CE523ABEA

5. Decision Making within UK infrastructure systems

Future Scenario

Impact of 'Half of the UK's power provided by renewables by 2030'

The National Grid's Future Energy Scenario[1] report has emphasised that "*a whole system view across electricity, gas, heat and transport underpins a sustainable energy transformation*". Widespread digitalisation and sharing of data is fundamental to harnessing the interactions between these changing systems. Figure 29 emphasises the need for this in the future due to the **greater number of interconnections between energy and other sectors**.

The systems diagram in Figure 29 shows an **increased reliance on digital networks**. This is because the balancing of the grid will need to be managed in real time. This will require a bigger safety net for managing supply/demand balance, which will come at an increased cost to the consumer[2].

A bigger percentage of renewable energy will also **impact on the wholesale electricity market** (see Figure 29). There will be an increased potential for **more periods of negative pricing** resulting from the intermittent nature of renewable energy sources (see Box 5)[3]. Energy storage facilities will be required to manage these market fluctuations; for example, vehicle to grid technology (more information is provided on following page).

Assuming that Ofgem's current 5 year business planning approach will remain, there may be a **risk of 'lock-in' regarding certain technologies** (e.g. renewables and gas). Currently, there is ongoing work to understand how hydrogen could be used in existing gas infrastructure[4]; the role of hydrogen has not been considered in the systems diagrams as this was out of scope. Incorporating this uncertainty into policy and regulation should be considered.

Although not adequately captured in the systems diagrams, it has been emphasised that moving to renewables will reduce the **inertia from traditional electricity generation that helps maintain stability** and frequency within the required range across sectors[5].

Energy from Waste

Energy from Waste, although not strictly a renewable form of energy, is emerging in the current scenario, and is already bringing significant benefits. For example, Thames Water is using energy from waste to partially run its sewage works, reducing their own carbon emissions[6], contributing the decarbonisation of the energy grid. Energy from waste generation is therefore likely to become a bigger contributor to the energy grid by 2050. However, deriving income from bioenergy generation may not be possible if the electricity sector or the regulator has no incentive to promote the use, purchase, and/or transportation of energy generated from biogas[7].

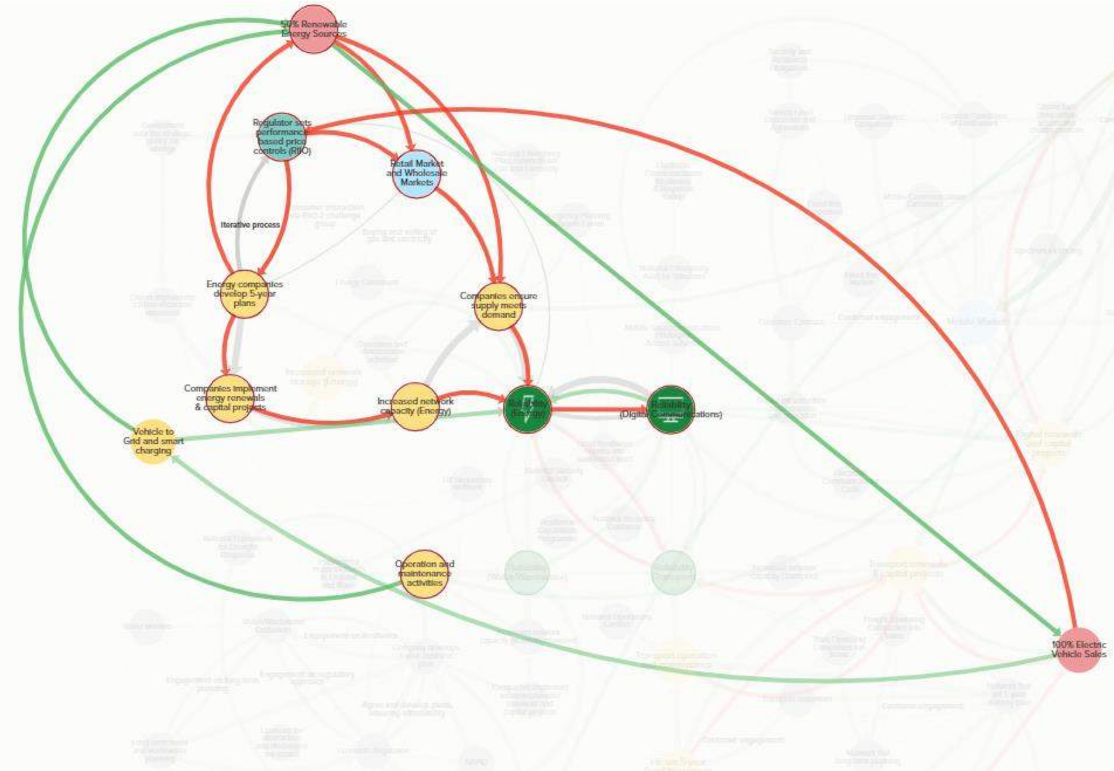
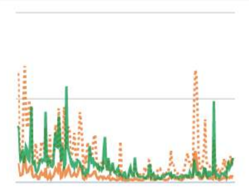


Figure 29: Systems diagram showing the influence on the system of half of the UK's power provided by renewables by 2030.

Box 5: Wholesale negative energy prices[3]

A greater proportion of renewable energy sources, particularly solar and wind, can lead to negative wholesale prices in the electricity market. This can occur when there are high winds and low demand. An example of this was on Sunday 26 May 2019 when there was 9 hours of negative pricing.



[1]http://fes.nationalgrid.com/
[2]https://www.lowcvp.org.uk/projects/electric-vehicle-energy-taskforce.htm
[3]https://www.current-news.co.uk/news/uk-negative-power-pricing-record-smashed-and-balancing-costs-spike-during-extraordinary-weekend
[4]http://erpuk.org/project/hydrogen/
[5]https://www.renewableenergyworld.com/2019/10/25/grid-inertia-why-it-matters-in-a-renewable-world/#gref
[6]https://corporate.thameswater.co.uk/Media/News-releases/Sewage-works-running-on-50-per-cent-poo-power
[7]http://blogs.worldbank.org/water/wastewater-treatment-critical-component-circular-economy?cid=WAT_TT_Water_EN_EXT/?cid=EXT_WBBlogTweetableShare_D_EXT

5. Decision Making within UK infrastructure systems

Future Scenario

Preparing for 100 per cent electric vehicle sales by 2030.

The future system diagram (Figure 30) shows that moving towards 100% electric vehicle sales by 2030 will put an **increased demand on the energy grid**. The Electric Vehicle Energy Taskforce (EVET) state that this increase could be as much as 30% by 2050[1], with the National Grid predicting there will be 35m electric vehicles by 2050[2]. This impact could be **compounded by the electrification of heat** in domestic and commercial properties, but has not been considered in this study.

Investment will be required to reinforce the grid to cope with demand, which is being considered in Ofgem's Decarbonisation Plan[3].

Vehicle to Grid (V2G) and smart charging technology has been included in the systems diagram (Figure 30) as this will be required to manage the energy supply/demand balance, by allowing electric vehicles to provide energy storage. The demand for electric vehicles could support increased renewable generation through **energy storage and smart charging of electric vehicles**. Moreover, investment in renewable energy infrastructure to support increasing numbers of electric vehicles indirectly benefits all energy consumers through lower prices and lower carbon generation intensity[2].

The introduction of smart charging will also put an **increased requirement on digital networks to facilitate smart monitoring**, in real time, of the demand/balance of energy networks. The reliability and latency of digital networks will therefore become increasingly important. Especially where energy is produced by generators or supplied from storage devices, the grid must exactly **balance the energy demand on a second-by-second basis**.

The National Grid has suggested that "*A smart flexible system will need new business models and services to match system needs with vehicle charging requirements and consumer preferences*"[2]. Moreover, this will create a **more distributed grid generation**, compared with the traditional centralised generation. This will therefore **require regulatory and governmental coordination** across highways, digital communications and energy sectors.

Additionally, Figure 30 identifies that **markets will be needed to encourage EV smart charging**, and to ensure a level of coordination so as not to present a risk to managing the demand balance of the network. Currently, these markets are not in place but Ofgem[3] has recently announced an action to address this: "*We will identify and tackle regulatory barriers, removing obstacles to new business models, products and services such as EV users selling flexibility services*".

The EVET[1] states that a charge point operator, electricity supplier or aggregator could have control over very large numbers of charge points which could present a potential risk to the energy network through **mismanagement of significant numbers of charge points**. Safety margins could be increased for managing supply/demand balance, however this would result in additional cost to consumers.

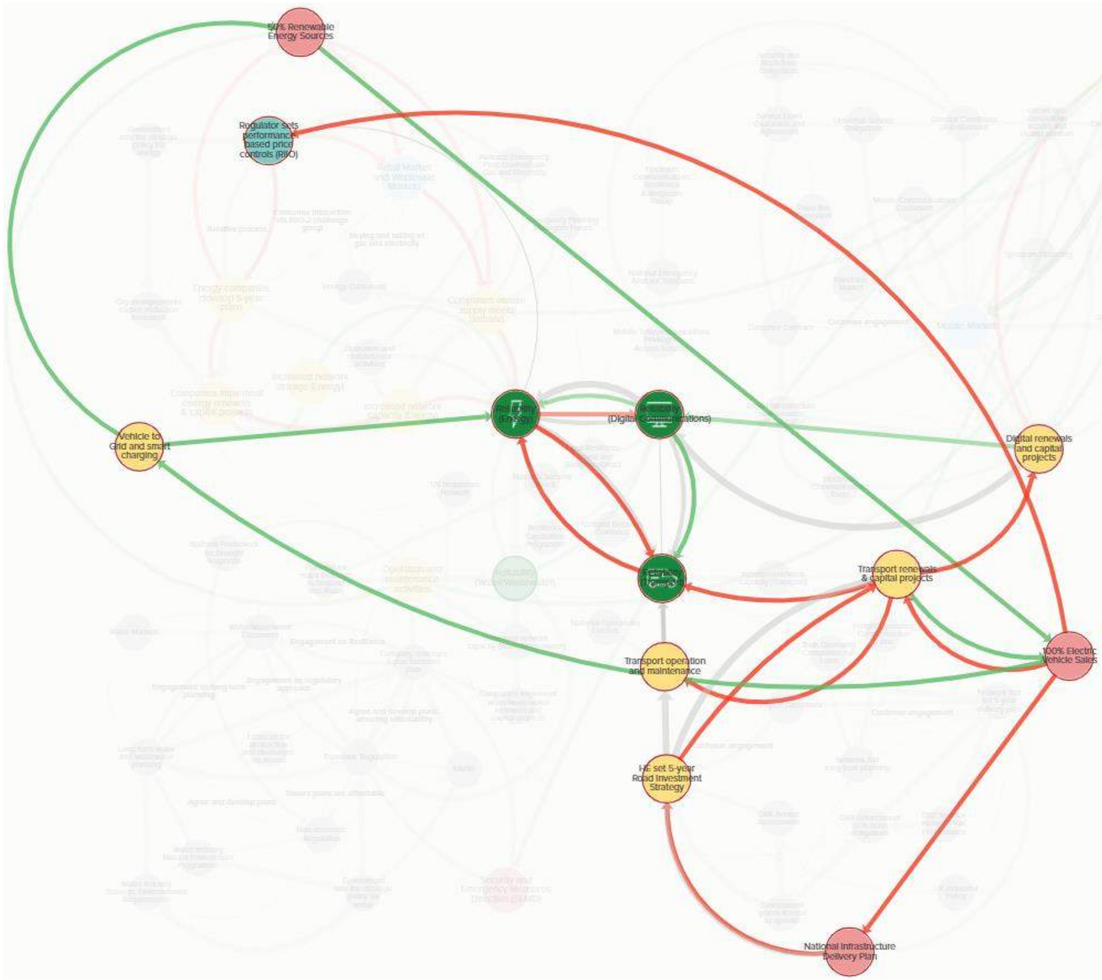


Figure 30: Systems diagram showing the influence on the system of preparing for 100% electric vehicle sales by 2030.

[1]https://www.lowcvp.org.uk/projects/electric-vehicle-energy-taskforce.htm
[2]http://fes.nationalgrid.com/media/1409/fes-2019.pdf
[3]https://www.ofgem.gov.uk/publications-and-updates/ofgem-s-decarbonisation-action-plan

6. Summary of Findings

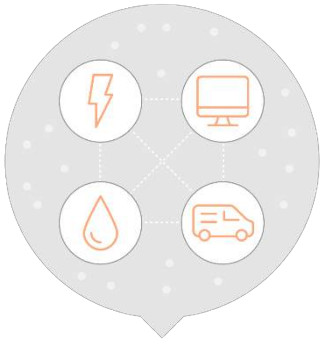
The development of the systems diagrams presented in this report has provided the Commission with a more informed view of the national-level decision making landscape for the UK infrastructure sectors of energy, digital communications, transport and water & wastewater.

The detail of the systems diagram is in the interactive Kumu viewer (see these links), and should be viewed alongside this report. An understanding of the relative influence of different factors and connections has also provided insights into where to focus policy interventions or incentives.

The high-level summary of the study findings are presented below for the 'current' scenario, with 'future' scenario findings presented on the next page.

Current Scenario

A systems diagram has been developed that shows the relative influence of the identified national-level decision making factors on the Level of Service delivered by UK infrastructure in 'present day' operating situations. The key insights from this study are summarised below.



01 SILOED INFRASTRUCTURE SECTORS

- Decision makers are increasingly aware of interdependencies, however this is currently not a fundamental part of decision making.
- An ability to understand cross-sector implications of reduced Level of Service is important for resilience.
- Data sharing within and between sectors is currently limited, and is needed to improve understanding of interdependencies.

02 FRAGMENTED GOVERNANCE

- The governance of UK Infrastructure decision making is complex and can lead to lack of coordination and communication at all levels.
- Digital communications, energy and transport sectors are going through significant technological change, introducing emerging markets and exacerbating governance complexity.

03 REGULATORY INFLUENCE

- Each regulator has a different focus on how it delivers its Level of Service.
- Regulation has a bigger role in the water and energy sectors.
- Regulators have resilience duties, but there is an absence of an overarching cross-sector regulatory approach to resilience.

04 VARYING APPROACHES TO LONG-TERM PLANNING

- Markets have a significant influence in the digital communications and energy sectors, compared with other sectors.
- Transport sector decision making is primarily driven by national government priorities and funding.
- Incentives are needed to ensure that markets work together effectively to deliver a Level of Service.
- More emphasis is placed by the regulator for customer engagement in the water and energy sectors.

05 SHORT-TERM ECONOMIC BUSINESS PLANNING

- Each infrastructure sector has different 5 year business planning cycles.
- Short term planning cycles can cause conflict between delivering value for shareholders and ensuring a Level of Service for customers.
- Short-term profitability considerations makes it difficult for companies to invest in long-term measures to improve Level of Service and Resilience.
- National Infrastructure Delivery Plan does not consider interdependencies and wider resilience as part of the scheme evaluation process.

06 VARYING ROLE OF MARKETS AND CUSTOMERS

- Climate change legislation and impacts are the main driver for undertaking long-term planning. However, there is deep uncertainty surrounding future conditions that UK infrastructure will operate within.
- Most infrastructure sectors undertake long-term planning, however this is more embedded within the water sector.
- The digital communications sector does not undertake any mandated long-term planning.
- Although, specific plans highlight an awareness of interdependencies, there is a lack of central coordination to long-term planning across UK infrastructure sectors.

07 CONSIDERATION OF EMERGENCY FACTORS

- Sector specific plans are developed for response to emergency situations.
- Emergency planning within a sector is siloed and does not explicitly address the impact on the Level of Service of another sector.
- During emergency scenarios, connections appear across systems which are not typically visible in planning and day-to-day operations.
- Emergency planning focuses on response and recovery, rather than preparation.

6. Summary of Findings

Future Scenario

The systems diagram was used to consider separately, the potential impacts of three of the recommendations set out in the Commission’s 2018 National Infrastructure Assessment on national level decision making.

Overall, this showed a greater likely degree of interconnectedness between the sectors in future. This highlights the need for a whole-systems view of UK infrastructure decision making, rather than current sector specific policy and decision making.

The future environment is likely to be very dynamic and uncertain, and the systems diagrams show that recommendations can create tensions between sectors. Policy and regulation will be needed to reflect this.

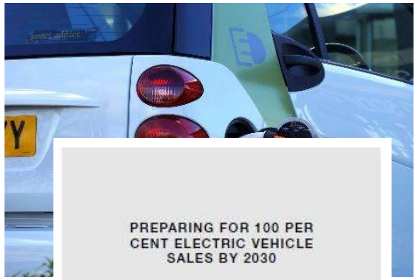
Key insights around each recommendation are presented here.

NATIONWIDE FULL-FIBRE BROADBAND BY 2033

- Compared to traditional copper networks, full-fibre broadband will mean an increased reliance on a reliable energy supply.
- Full-fibre broadband will support the delivery of other communications services (i.e. mobile and wireless), ensuring user requirements are met.
- There will be a higher degree of digitally-connected infrastructure, that will require improved digital communications services.
- A prevalence of digitally-connected infrastructure, facilitated by full-fibre broadband, will improve resilience through quicker anticipation and response to emergency events.
- Full-fibre broadband can help mitigate the risk of physical limitations on available mobile spectrum that would severely reduce the efficiency of mobile services.

HALF OF UK'S POWER PROVIDED BY RENEWABLES BY 2030

- There will be an increased number of interconnections between energy and all other sectors.
- There will be increased reliance on the digital communications network to manage the energy network in real time.
- More renewable energy will mean more potential for periods of negative pricing in wholesale energy markets.
- There is a risk of locking in certain renewable and low carbon technologies. For example, the UK is currently considering the potential to move to hydrogen.
- Renewable energy may not be able to supply the inertia to maintain stability and frequency of energy supply, that is provided by traditional energy generation.



PREPARING FOR 100 PER CENT ELECTRIC VEHICLE SALES BY 2030

- Moving to 100% electric vehicle sales will place an increased demand on the energy grid, that could be compounded by the electrification of heat.
- Electric vehicle demand could increase energy storage and smart charging capabilities, subsequently supporting renewable energy generation.
- There will be an increased requirement on digital communications networks to facilitate electric vehicle charging smart monitoring, helping to balance energy demand in real time.
- The energy grid will become more distributed as a result of electric vehicle storage capabilities.
- Markets will be required to encourage electric vehicle smart charging to better manage energy networks.
- Potential for the mismanagement of significant numbers of electric vehicle charge points, and associated emerging market, that could present a risk to the energy system.

Images sourced from www.pexesls.com

7. Implications for the Resilience Study

This study has focused on national-level decision making and how it impacts Level of Service for UK infrastructure. This has been a good starting point for developing the systems diagrams, but has limitations.

Level of Service is sector specific, and is focused on short-term economic factors. Moreover, Level of Service, and in this context reliability, does not account for how the system responds, recovers or adapts during or after emergency events. This is where consideration of resilience is important.

The systems diagram reinforces the importance of the need to take a whole-systems view of UK infrastructure and demonstrates that interdependence is there 'by design' from the outset. Therefore, explicit infrastructure multi-sector resilience by design will be important to consider going forward.

Approaches to resilience cannot however take the same approach across all sectors. This is because, as the systems diagram has shown, decision making operates in different ways, with varying influence from markets and regulators. A range of policy instruments (ranging from incentives to regulations) will be needed, depending on what works for each sector; see McCann et al. (2019)[2] for further information.

Current focus for UK infrastructure sectors is on resistance and redundancy, and the 4Rs approach (Resistance, Reliability, Redundancy, Response and Recovery) developed by the Cabinet Office[3]. However, there are other qualities to consider in developing resilience across the UK's infrastructure systems. Some examples of moving towards the resilient qualities are provided below:

- **Reflective:** August 9th 2019 power failure – sector specific reports[4,5] on the failure shows reflectiveness, but to what extent is this shared across sectors and within the sector? Should there have been a cross-sector report that puts resilience actions on those affected?
- **Integrated (or coordinated):** the systems diagram has shown that sector policy and decisions are siloed, and that a systems view is required going forward. The UKRN has also stated that although all the regulators have resilience duties, no one is responsible for a cross-sector, integrated approach to managing resilience issues.
- **Flexible:** If we take hydrogen replacing natural gas for example, the design of a flexible system that allows for uncertainty in technology is ideally required, rather than short-term planning that locks-in a specific technology or approach.

These actions will all require improved data and knowledge sharing within and across sectors. This will require the support and duties of regulators and markets.

Figure 31: Resilience Qualities (Arup)

[1] https://www.nic.org.uk/publications/national-infrastructure-assessment-2018/
[2] https://www.resilienceshift.org/publication/role-of-public-policy/
[3] https://www.gov.uk/government/publications/keeping-the-country-running-natural-hazards-and-infrastructure
[4] https://www.ofgem.gov.uk/publications-and-updates/investigation-9-august-2019-power-outage
[5] https://orr.gov.uk/__data/assets/pdf_file/0017/42164/railway-power-disruption-on-2019-08-09-report.pdf

Appendix A
Workshop Report

National Infrastructure Commission

System Mapping Workshop
Factual Report

November 2018

NATIONAL INFRASTRUCTURE COMMISSION

ARUP

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Appendix B: Presentation Slides

Appendix C: List of Interdependencies

Workshop Overview

Over 30 attendees across many infrastructure sectors convened for a half-day workshop, held in Arup's London office on the 8th November 2019. This workshop explored the national-level decision-making factors that contribute to the level of service across UK infrastructure sectors. We sought to identify decision-making policies, incentives and markets, alongside any externalities, that could impact on the level of service delivered.

The sectors that are subject of this study are ***digital communications***, ***energy***, ***transport*** and, ***water*** and ***wastewater***. We examined how these decision-making factors interact with each other, both in 'normal times' of operation and during emergencies.

The event was opened by Tom Hughes, Senior Policy Adviser at the National Infrastructure Commission (NIC), who spoke about the NIC's resilience study. Tom also introduced the systems mapping project. This was followed by an introduction and review of the project objectives from Juliet Mian, Associate Director at Arup and Technical Lead for the NIC system mapping project.

The first exercise was a discussion about how the level of service of one sector affects another. Four sub-groups containing representatives across all sectors discussed the interdependencies.

Following this Oliver Pritchard, Senior Consultant at Arup, presented on decision making factors, and the taxonomy of factors that are in the system maps. He also gave a brief introduction to system mapping, including some examples.

Following lunch people were split into four sector specific groupings to review maps of each of the sectors. The final exercise involved specific sector groups analysing each sector map in turn, highlighting interdependencies with their own sector. The results of these discussions are summarised in this report.

Agenda

Welcome and scene setting

Presentation from National Infrastructure Commission introducing the wider context of the Resilience Study

Introduction to the System mapping project

Objectives of the workshop

Exercise #1 Cross-sector discussion

How does the level of service of one sector affect another?

Presentation by Arup on decision making factors

Lunch

Exercise #2 Review of sector maps

What are the decision making factors (policies, incentives, markets) that affect the level of service in water, energy, transport and communications?

Exercise #3 Interdependencies

What are the interdependencies between sectors, and which are the key decision making factors from one sector that affect another?

Close

Context

The National Infrastructure Commission is examining the resilience of the UK's economic infrastructure to understand what changes might be needed to ensure that infrastructure can cope with future challenges. As part of this study, the NIC has commissioned Arup to undertake an analysis of the national-level decision making factors that could have an impact on the level of service delivered by UK infrastructure sectors. For further detail on the resilience study, see Tom Hughes' presentation slides in Appendix B.

The key questions that are being used to frame the issues are:

1. What are the systemic issues that make infrastructure vulnerable to current shocks and future changes and how could they be addressed?
2. What does the public expect of infrastructure services and how should their views be considered in decisions about resilience?
3. What changes to governance and decision making could improve current levels of resilience and ensure future challenges are addressed?

The systems mapping project is a key piece of analysis to support answering these questions. The aim is to develop a model to identify the national-level policies, incentives, markets, decisions and other factors that have the most impact on the level of service delivered by infrastructure, both during '*normal times*' and in emergencies.

The project is looking at:

- How decision-making and governance influence resilience.
- The relationship between different factors.
- Their relative importance in determining what levels of service are delivered.
- Whether there are any gaps or vulnerabilities created by the way decisions are made at the moment, or by the current approach to governance around resilience more generally.
- Whether decisions involve the right stakeholders.
- Whether decisions take dependencies and interdependencies into account as much as they should; and
- Whether there is a consistent approach across infrastructure system and in individual sectors.

To do this we are looking at national level decision-making factors – not individual assets or local decisions/priorities – and we want to focus on how the system currently works, based on current approaches and policies.

Exercise 1 - Cross-sector discussion

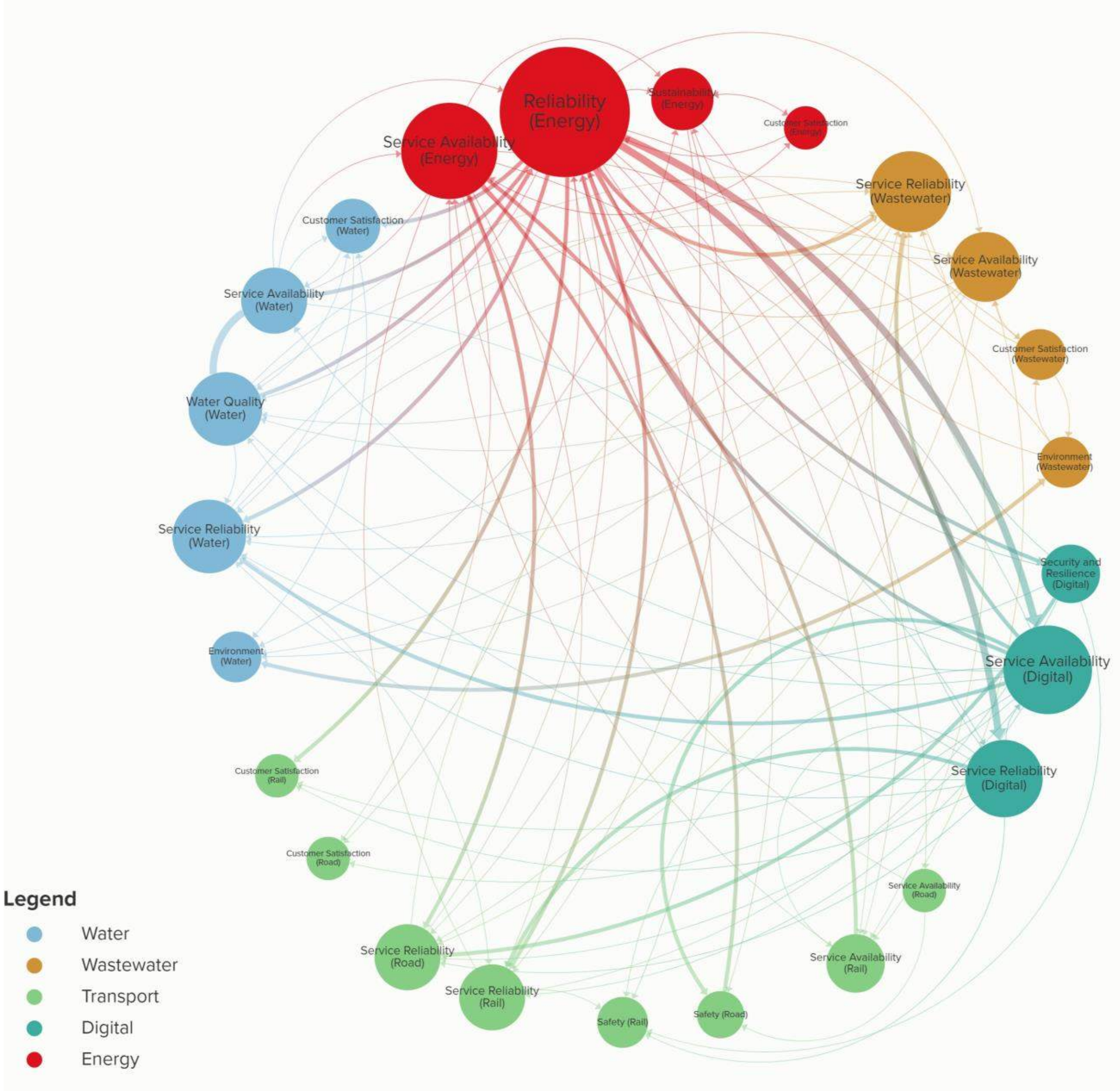
The first exercise focused on how levels of service from one sector are linked to another. We defined level of service to be *what the organisation intends to deliver*[1], based on [previous work](), and these were broken down into components.

Components are specific to each sector, but commonly include reliability and availability. Availability is, for example, having a road network that is available to traffic (e.g. open lanes). Whereas reliability is related to the average delay, and how long the journey might take[2].

The participants, in groups made up of different sector representatives, were asked to draw lines and explain the links on post-its at their table.

The combined results of this are presented in the figure to the right, with the number of connections made proportionate to line thickness, and component size proportionate to the total number of connections to that element.

Initial results show that energy reliability has the most interdependencies with other levels of service. Reliability across all sectors came out as high importance, with water quality a close second in that sector. These findings will be used to prioritise mapping in later stages of the project.



1. International Infrastructure Management Manual: International Edition 2015, Institute of Public Works Engineering Australasia
2. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/775149/Operational_Metrics_Manual.pdf

A key workshop objective was to obtain feedback on the draft systems maps that Arup has created for digital communications, energy, transport, water and wastewater sectors. An introduction to systems mapping approaches was presented to provide context to this work (see Appendix B).

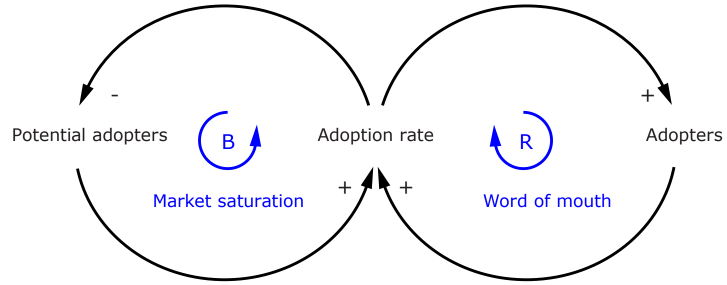
A simple[1] (top right) and more complex[2] (bottom right) examples of a systems map is presented here, which represent causal loop diagrams[1].

Fundamentally, systems maps are made up of a series of components with associated interactions. Within the interactions there can be:

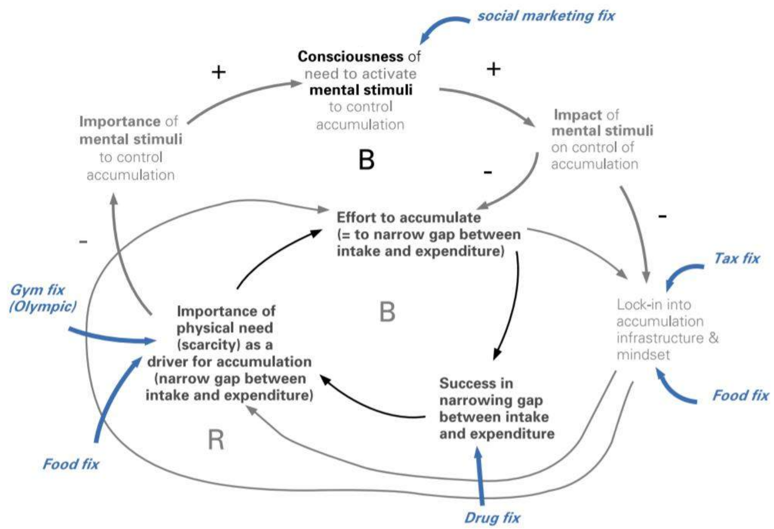
- **Positive reinforcement** (labelled R) loops – for example, the simple systems map indicates that the more people have already adopted the new product, the stronger the word-of-mouth impact. There will be more references to the product, more demonstrations, and more reviews. This positive feedback should generate increased adoption and sales that continue to grow.
- **Balancing** (labelled B) loops – for example, the complex systems map that is taken from the Government Office for Science mapping of the obesity system[2], shows a physical need for energy replenishment triggers a process of energy accumulation in the form of food in order to narrow the gap between energy expenditure and intake.

Systems maps also allow the user to understand the impact of interventions in the system. For example, in the more complex map, the potential interventions are highlighted in blue.

The complexity of these systems is evident. However, an infrastructure system is many times more complex again. Therefore simplification is required. Draft infrastructure systems maps with simplifications were presented in this workshop.



Source: By Adoption_CLD.gif: Original uploader was Apdevries CC BY-SA 3.0[1]



Source: Foresight Tackling Obesities: Future Choices – Building the Obesity System Map (Government Office for Science)[2]

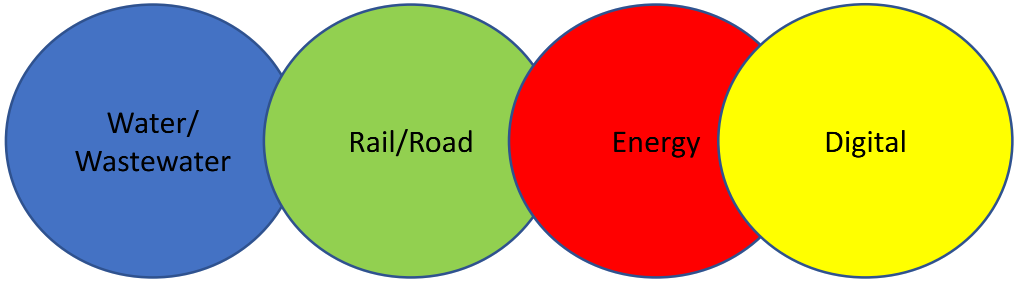
1. https://en.wikipedia.org/wiki/System_dynamics
2. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/295154/07-1179-obesity-building-system-map.pdf

Exercise 2 - Review of sector system maps

A draft system map was presented for each infrastructure sector: digital communications, energy, transport, water and wastewater. Attendees were split into four groups based on the sector they are a part of or interact with most.

Each group examined the map of their sector with the aim to critique the maps, identify clusters, missing levels, links between factors and any missing elements that would help understand the decision paths. It was also an opportunity to test/critique the strawman taxonomy.

All groups discussed how each policy/incentive/market factor influences Level of Service. They explored whether we could explain better on the map what does legislation put in place e.g. enforcement powers, processes or regulatory model.



Exercise 3 - Interdependencies

The workshop's final exercise involved the four sector groups exploring the draft systems maps that have been developed for other infrastructure sectors. The aim for this exercise was to ask attendees to highlight interdependencies between their sector and others.

Sector groups were given 15 minutes to consider each system map, with post-its used to capture thoughts on key interdependencies.

The output of this exercise is presented in Appendix C.

Overall, this task identified numerous interdependencies between the sectors considered. However, dependencies on the energy and digital sectors were most common. It was identified that there is a changing nature of dependencies with, for example, considerably more reliance on digital systems across all sectors.

Next Steps

Participants agreed that this is an important study. This was reflected by the level of interaction and engagement during the workshop, which has provided valuable cross-sector insights. Our initial findings reinforced the view that the UK's infrastructure networks are complex, and that there are many national level decision-making factors that contribute to the level of service provided in both normal and emergency scenarios.

Cross-sector interdependencies were identified, providing an understanding of how national level decision-making factors can impact resilience within and between the infrastructure systems being mapped.

Next steps, based on the findings of this workshop, will be to:

- Update sector systems maps, and list of national level decision-making factors, to reflect the additional findings that emerged in the workshop.
- Review and refine the proposed taxonomy approach.
- Subsequently, further engagement with workshop attendees to validate systems maps.

The systems mapping project is due to conclude in February 2020. This will inform the NIC's Resilience Study that is due to produce a final report later in spring 2020. For more information about this project, or the wider resilience study please contact Resilience@nic.gov.uk.

Appendix A

List of organisations in attendance

List of organisations in attendance

Organisation
National Infrastructure Commission
BEIS
Highways England
Arup
University College London
Network Rail
Defra
UKCRIC
Energy Networks Association
Environment Agency
National Grid
University of Bristol
Civil Contingencies Secretariat
Ofgem
Department for Culture, Media and Sport
Northern Ireland Executive
Rail Delivery Group
Infrastructure Projects Authority

Appendix B

Presentation slides

NATIONAL
INFRASTRUCTURE
COMMISSION

Resilience Study Workshop

8 November 2019

Today's workshop

11:00 **Welcome and scene setting**

Presentation from National Infrastructure Commission introducing the wider context of the Resilience Study

Introduction to the System mapping project

Objectives of the workshop

Breakout exercise #1 Cross-sector discussion

How does the level of service of one sector affect another?

Presentation by Arup on decision making factors

12.30 **Lunch**

13:00 **Breakout exercise #2 Review of sector maps**

What are the decision making factors (policies, incentives, markets) that affect the level of service in water, energy, transport and communications?

Breakout exercise #3 Interdependencies

What are the interdependencies between sectors, and which are the key decision making factors from one sector that affect another?

15.30 **Close**

NATIONAL INFRASTRUCTURE COMMISSION

What are we expecting to produce from the resilience study?

The final report should deliver an analytical approach that can be used to better understand resilience and suggest improvements, as well as practical changes.

The key outputs are expected to be:

1. A framework to consider resilience across economic infrastructure, primarily for application during future National Infrastructure Assessments, but which can also evolve over time as knowledge improves.
2. Policy recommendations on resilience, including changes needed in the short term (e.g. changes in governance or decision making) and more strategic recommendations about the research, tools and data that will be needed to improve resilience in the medium term.

We are not expecting to answer every question about resilience. It's complicated(!) and this is the first step in a longer-term process.

The second National Infrastructure Assessment is expected to include recommendations in the context of resilience, informed by the output of this project.

The ToR asked us to:

a) Review UK and international knowledge and approaches

b) Develop an understanding of **public expectations and responses**

c) Develop an analytical approach that can be used to better understand resilience, and the costs and benefits of measures to improve this

d) Undertake **pilot analysis** of infrastructure systems to identify actions to improve resilience

e) Make **recommendations** to government

The NIC's approach to resilience

Rather than limiting ourselves to a specific definition, we will apply a broad understanding of resilience for this study. However, there are some key characteristics of resilience and resilient systems that we think are important:

- Thinking about resilience encourages **a dynamic and holistic approach**; one that looks at the system as a whole over time and the service that it delivers, rather than focussing on the risks to individual assets.
- Effective risk management is critical, but a truly resilient system is also able to **respond effectively to as-yet-unknown, or difficult to predict challenges**.
- Having **the right processes in place** matters.
- It requires having:
  - **an understanding of vulnerabilities, interconnections and interdependencies;** and
  - **the capability to adapt to the combination of pressures and uncertainty that infrastructure systems face.**

Some of the terms most commonly used to define resilience in infrastructure systems are:

- **resist** – the ability to withstand possible hazards
- **absorb** – the capacity of the system to limit the damage incurred during an event
- **recover** – the ability for the system to return to its original state following an event
- **adapt** – the system's ability to change to maintain its function in a new environment

Our analysis so far suggests more needs to be done

- Resilience is generally thought about largely within individual sectors (often with a security focus)
- It is difficult to find examples of holistic, or cross-sector approaches and cross-cutting challenges are not being sufficiently addressed
- There is no understanding of the resilience and vulnerabilities of UK economic infrastructure as a whole
- The public has limited awareness of the growing challenges facing the UK's economic infrastructure and are not necessarily prepared for the deterioration in service that may occur.

"There is currently a lack of collaboration and co-sharing of data and flexibilities in relation to key infrastructure, which is hampering long-term resilience planning and delivery of collaborative projects. This lack of data sharing between sectors is often due to security issues."
(Consultation response)

No detailed assessment of infrastructure cross-sector dependencies exists today, nor any assessment of how these may change with future trends in respective infrastructure sectors."
(Consultation response)

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We’re trying to address these issues over the rest of the study

This has informed the 3 key questions we’re using to frame our work for the rest of the study:

1. **What are the *systemic* issues that make infrastructure vulnerable to current shocks and future changes and how could they be addressed?**
2. **What does the public expect of infrastructure services and how should their views be considered in decisions about resilience?**
3. **What changes to governance and decision making could improve current levels of resilience and ensure future challenges are addressed?**

These were drawn from work with UCL to develop a number of hypotheses (shown on the right).

Theme 1: Systemic issues that make infrastructure vulnerable to current shocks and future changes

Infrastructure services are vulnerable to cross-system problems, which are not yet known and may be exacerbated by future changes

Future changes to infrastructure may compromise resilience

Uncertainty in future risks and system’s changes will impact on the ability to manage infrastructure resilience

Theme 2: Public acceptability of infrastructure services

Current levels of disruption to infrastructure services do not meet the need or expectations of “customers” (public, businesses and emergency responders).

Theme 3: Resilience governance and decision making

Investment to improve infrastructure resilience is more cost effective when interventions are considered at a system level, improve multiple aspects of resilience and consider potential vulnerabilities

The resources don't exist to identify interventions to improve infrastructure resilience

There is a lack of appropriate investment in the resilience of infrastructure services.

Resilience is undervalued in many investment decisions.

There is a lack of coordination of interventions to improve the resilience of infrastructure services

Incentives for resilience investment are inadequate

The systems mapping project is a key piece of analysis to support answering these questions

Aim: to develop a model to identify the national-level policies, incentives, markets, decisions and other factors that have the most impact on the level of service delivered by infrastructure, both during "normal times" and in emergencies.

We want to find out:

- How decision-making and governance influence resilience
- The relationship between different factors
- Their relative importance in determining what levels of service are delivered
- Whether there are any gaps or vulnerabilities created by the way decisions are made at the moment, or by the current approach to governance around resilience more generally.
- Whether decisions involve the right stakeholders and
- Whether decisions take dependencies and interdependencies into account as much as they should
- Whether there is a consistent approach across infrastructure system and in individual sectors

Scope

In Scope:

- ***Energy, transport, digital, water and wastewater***
- ***Hazard agnostic / all hazards approach***
- ***Malicious threats, skills and the financial stability of infrastructure operators were limited to this first phase***

Out of scope:

Issues relating to…

- ***foreign ownership***
- ***specific critical national infrastructure assets***
- ***industrial relations***
- ***National and cyber security concerns***
- ***the security of supply chains***
- ***the UK's withdrawal from the EU***

- We are looking at **national level factors** – not individual assets or local decisions/priorities
- We want to focus on **how the system currently works**, based on the current approach and policy

Objectives of the workshop

Juliet Mian, Arup

Our take on the project

- What approaches and actions should be taken to ensure the resilience of the UK's infrastructure?
- Decisions that influence resilience are made by individual organisations
- Decisions made within sectors (not about resilience) affect resilience of other sectors
- No high-level view of how these decisions impact the resilience of the overall service and the system
- Articulation of the influence of national-level decisions will help the NIC make recommendations that will enhance resilience
- System mapping and analysis is the means by which we will do this – not the answer

Objectives for today

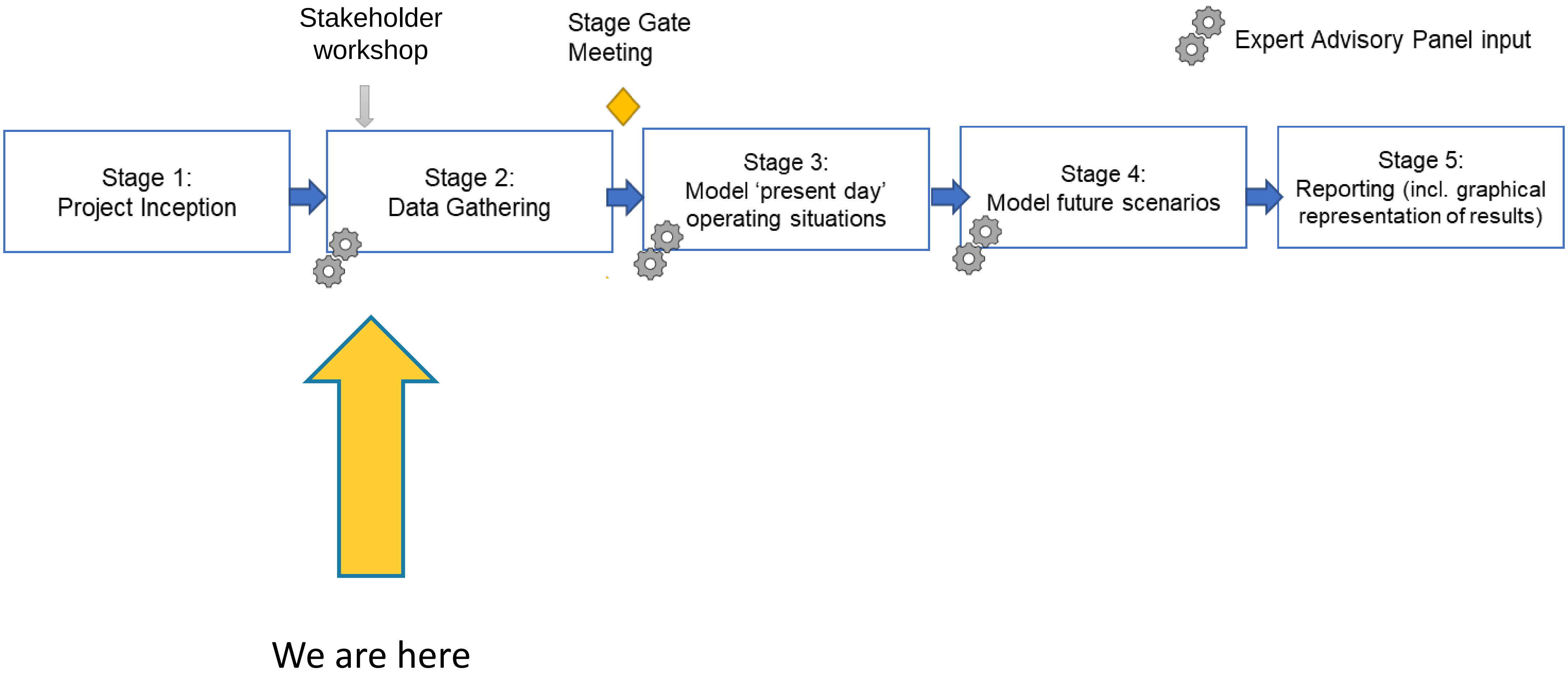
- Get your input to these decision-making factors

- Get your input to cross-sector factors and interdependencies

Setting the scene

- This work is complex
- “**Cognitive fluency**” - we identify with only those trends we understand
- “**Confirmation bias**” - look for evidence that underpin our assumptions
- Be aware of the former and try to embrace complex systems

Project timeline



Workshop exercise #1

Savina Carluccio, Arup

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ARUP

Workshop exercise #1: Cross-sector discussion

- Working in cross-sector groups
- 20 minutes to talk through how levels of service from one sector are linked to another
- Level of service = What the organisation intends to deliver broken down into components
- Please draw lines and explain the link on post-its

Decision Making Factors

Oliver Pritchard, Arup

Decision making factors

- What is the decision? A decision that has an impact on the service delivered by UK infrastructure

- Policies, incentives, markets and others

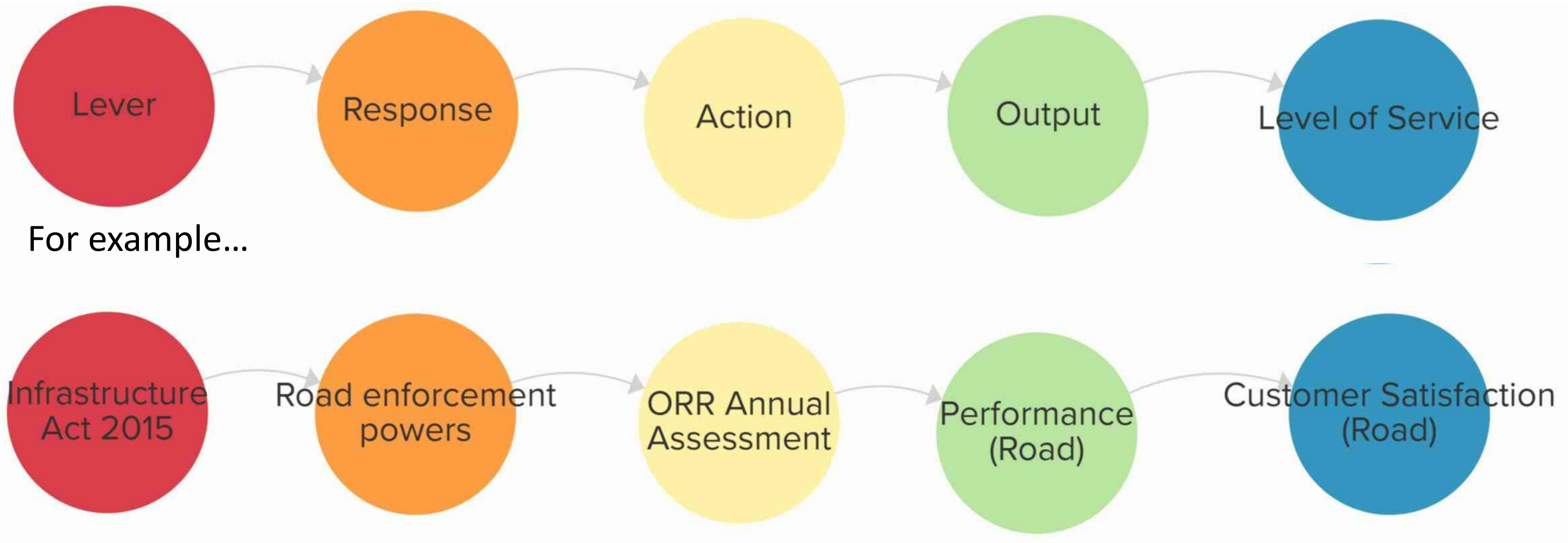
Decision making factors

Regulatory factors e.g.	Economic factors e.g.	Coordination & convening factors e.g.	Information factors e.g.	Voluntary factors e.g.
• Legislation • Executive orders • Zoning and planning • Mandatory standards	• Taxes or reliefs • User charges • Fines and penalties • Market-based instruments • Government subsidies	• Emergency response • Coordination meetings	• Public information and advertising • Consultation • Capacity-building • Research	• Voluntary standards • Codes of practice

Decision making factors

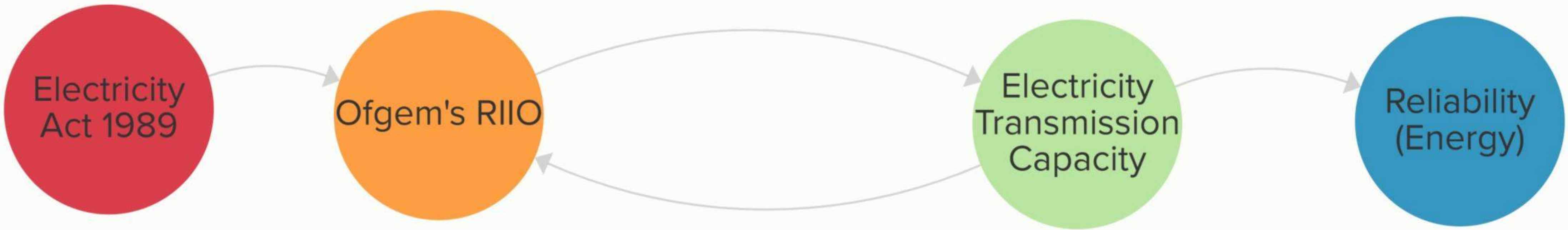
Regulatory factors e.g.	Economic factors e.g.	Coordination & convening factors e.g.	Information factors e.g.	Voluntary factors e.g.
• Legislation • Executive orders • Zoning and planning • Mandatory standards	• Taxes or reliefs • User charges • Fines and penalties • Market-based instruments • Government subsidies	• Emergency response • Coordination meetings	• Public information and advertising • Consultation • Capacity-building • Research	• Voluntary standards • Codes of practice

Proposed taxonomy of factors

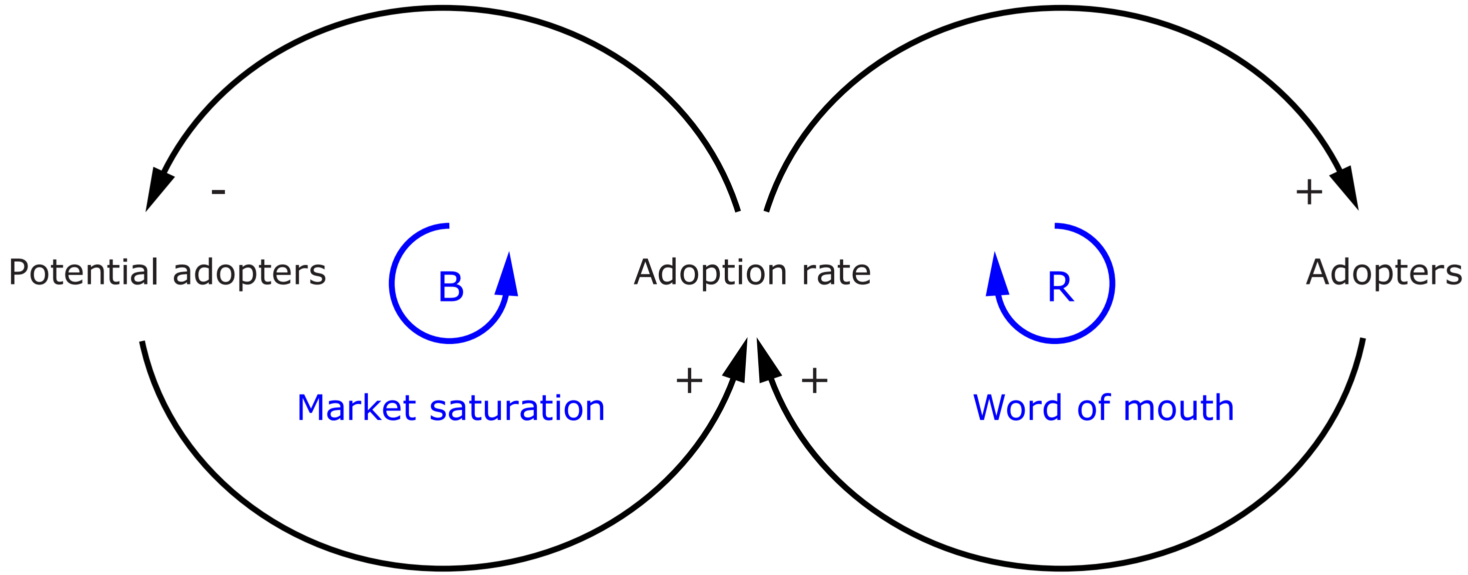


Proposed taxonomy of factors

For example…

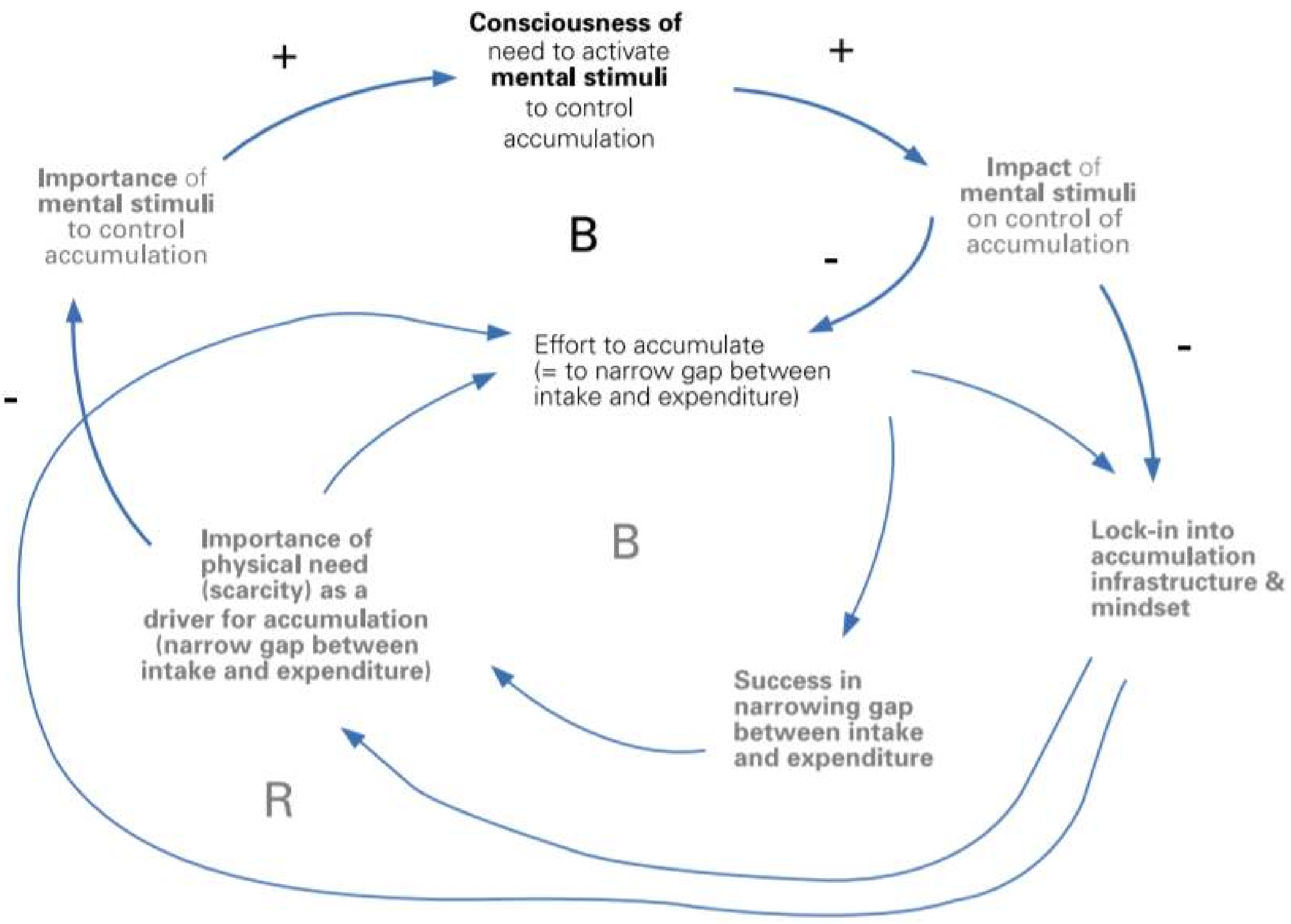


Simple System Map

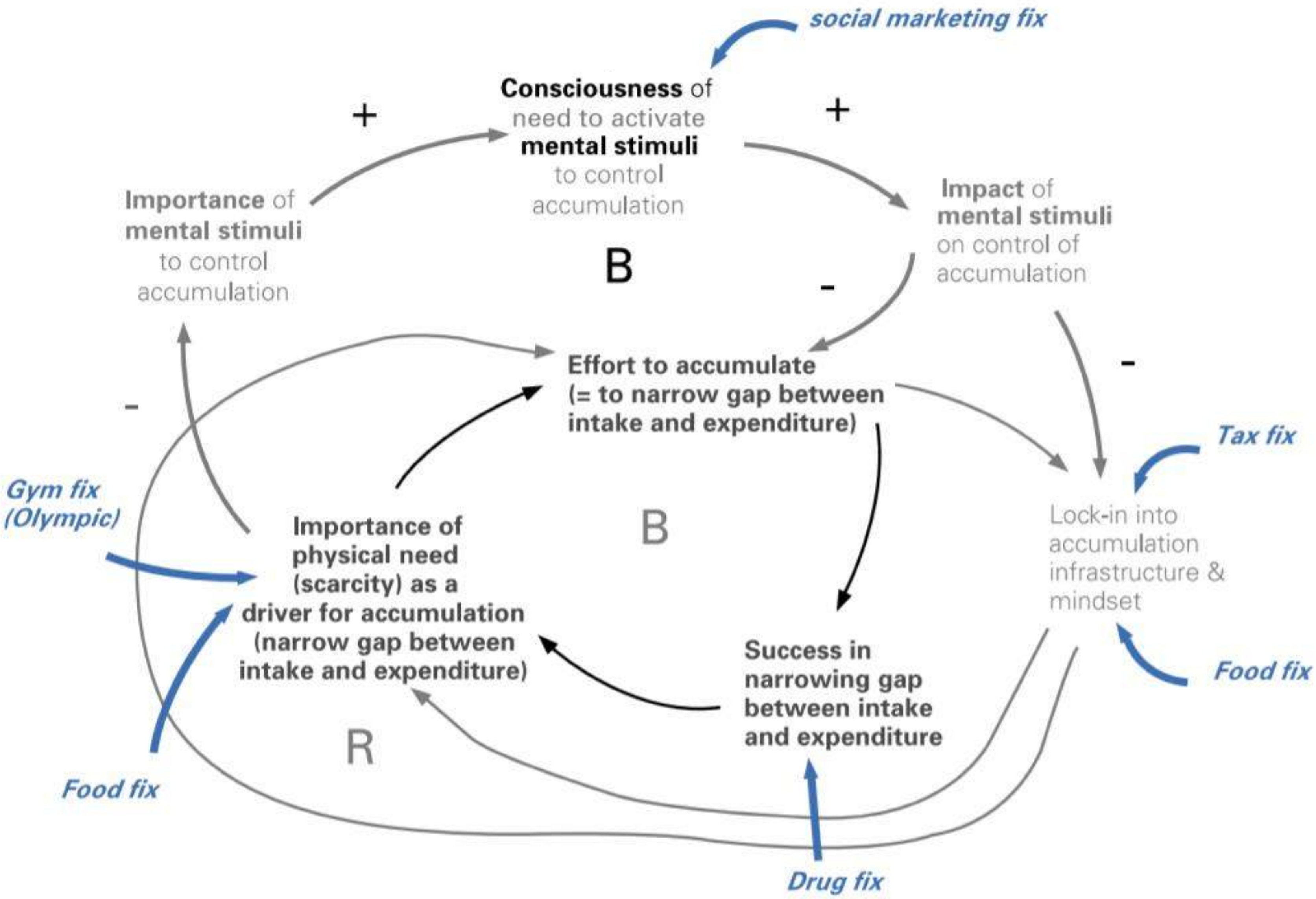


By Adoption_CLD.gif: Original uploader was Apdevries CC BY-SA 3.0

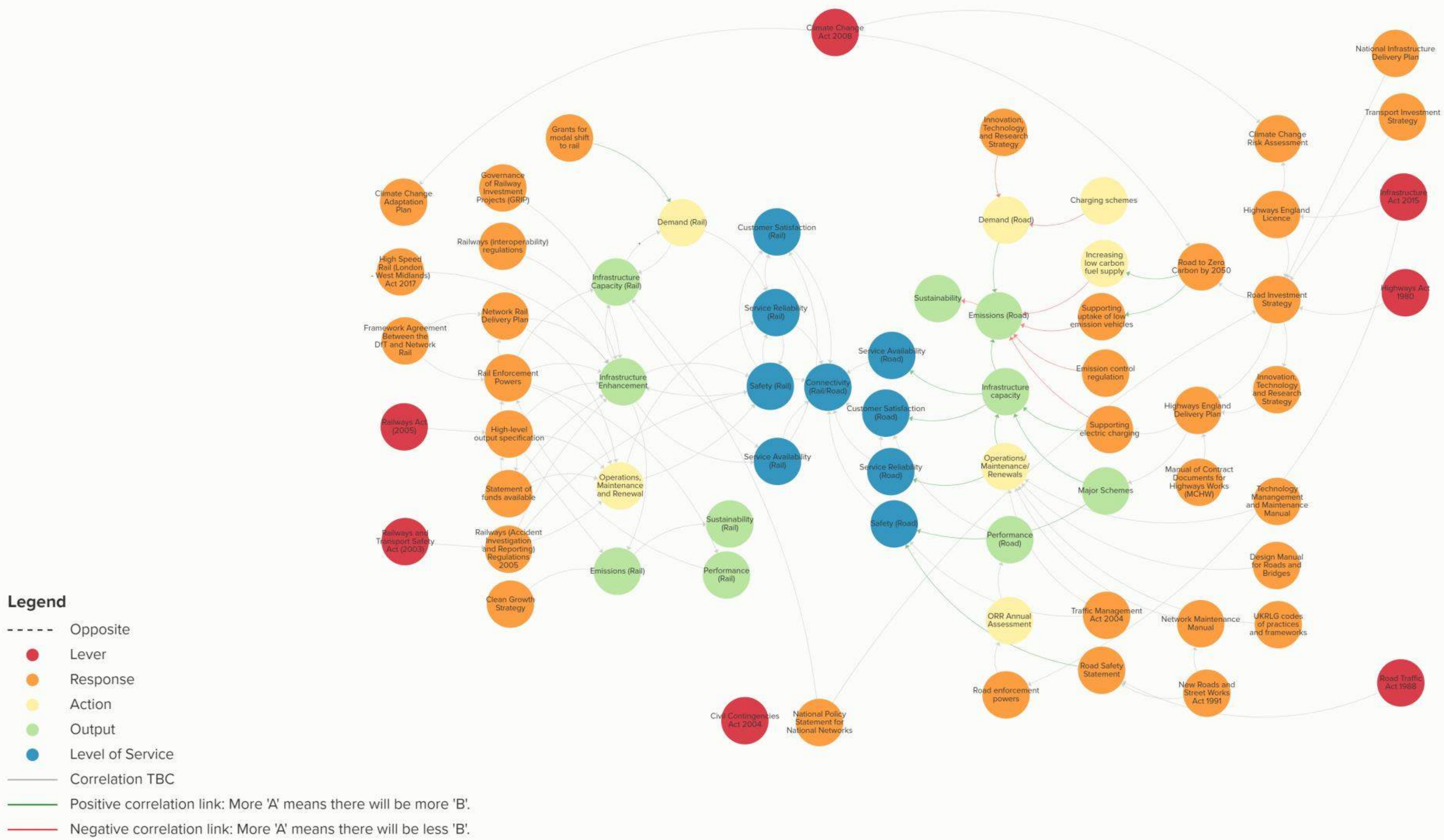
Causal Loop for Obesity System



Causal Loop for Obesity System with interventions



Transport system map



Sectors

Infrastructure System	Infrastructure Subsystem	
Digital	Mobile Communications	
	Fixed-line communications	
	Broadband	
Energy	Electricity	Generation
		Transmission
		Distribution
	Gas	Storage
		Transmission
		Distribution
	Petroleum (e.g. oil)	Storage
		Transmission
Transport	Highways	Strategic Roads
		Local Authority Roads
	Rail	
Water	Storage (including abstraction)	
	Treatment	
	Distribution	
Wastewater	Collection	
	Treatment	

Workshop exercise #2: Review of sector maps

- Sector groups will examine the map of their sector for 60 minutes
- How does each policy/incentive/market factor influence Level of Service?
- Can we explain it a bit better: what does this legislation put in place e.g. enforcement powers, processes or regulatory model?

Workshop exercise #3: Interdependencies World Café

- Identify and discuss cross-sector aspects of the map
- Sector groups will visit different tables for 15 mins
- Water and wastewater travel together

Sector Interdependencies: poll

Go to www.menti.com and use the code 30 92 79

Closing comments

- Thank you for your input!
- Please get in touch if you have further insights or ideas to share
- Factual report will be distributed

Appendix C

List of interdependencies

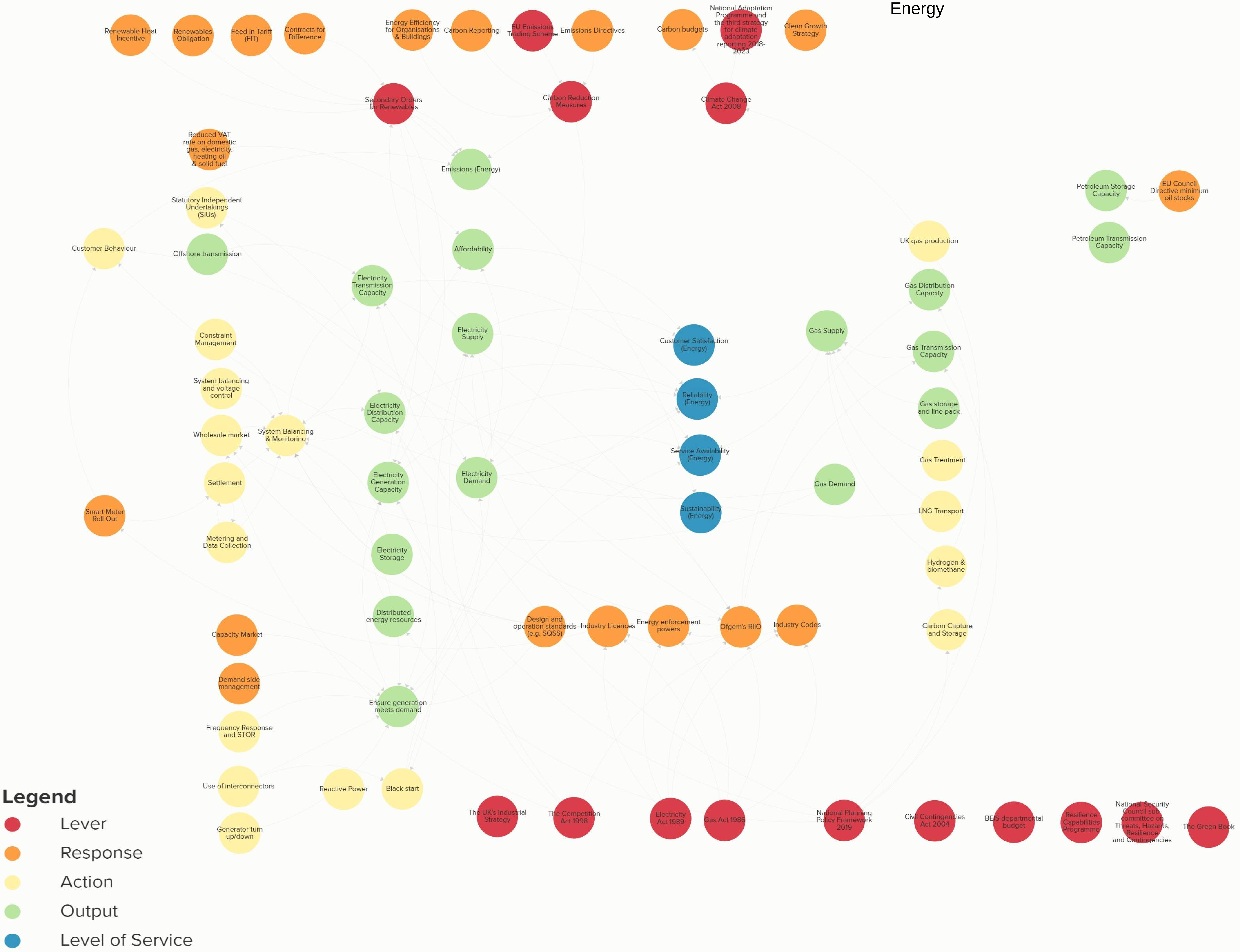
Primary Sector	Secondary Sector	Interdependencies Identifed											
Energy	*Water/Wastewater*	Shared data network for smart metering.	Water and energy companies can work together to increase household efficiency, in future energy use of a home will increasingly be from water use.	Energy is one of the top 3 operational costs for water companies.	Barrier to energy and water partnerships.	Price control differences across water and energy could mean resilience measures (i.e. Cost-bebnefit analysis) do not stack up on their own.	Resillence to specific hazards not same across sectors (e.g. drought).	Conflict between carbon net zero drive and need to pump water as a response to drought.	Petroleum refineries need clean water to operate.	Move to hydrogen economy for transport will result in high water demand.	Bioresources from waste water treatment provides methane bio-gas.	Water availablity can constrain ability to build and operate new generating plant.	Watersource heat pumps as renewable heating (in a domestic and commercial setting).
	Digital	Command and control of energy systems (i.e. operational technology). Decision support systems	Access to drivers / exchanges (comms) run on diesel generator back ups.	National grid has its own independent fibre network.	Facilitates contact with energy supplier.	High Integrity Telecommunications System (HITS)	Energy provides power to the Emergency Services Network (ESN).	Digital allows for workforce communication.	Telecoms is reliant upon electricity supply (throughout network).	Data Centres.	Security of communications (e.g. hack into smart meters)	Blackstart events	Comms are key in balancing energy system across entities.
	Transport	Energy required for railway control centres and signalling.	Renewable generation on railway feeding into grid e.g. Riding sunbeams (solar power on railways) which is identifying opportunites to install renewable generation	Specific transport services for energy sites (e.g. train service for Sellafield staff). If transport service stops sellafield impacted.	Energy required to get fuel out of ground to power transport.	Fuel needed to for transport modes and freight.	Technology required for safety critical functions depend on electricity.	Rail network electrification creates further demands on energy grid.	Energy required for the transport of nuclear material.	Energy required for space heating at rail depots.	Non-traction electricity.	Traction electricity, rail	Bi-directional at substations
Water	*Energy*		Using renewable energy to move water around in regional pipes.	Reduction in water would lead to a reduction in energy production.	Water pumping reliance on energy	Energy from waste (i.e. sludge) providing loss of mains protection (e.g. Thames Water generating 1/5th energy needs).	Demand side contracts Short term low frequency demand (scenario > source of resilience to energy sector)	Mutual reliance on natural water sources (e.g rivers).	Sludge as feedstock for power stations is creating a market.	Nuclear power station need for water.	Hydroelectric > water storage association with meterological conditions		
	Digital	Reliance on digital to provide emergency forecasts (e.g. EA Flood alerts) and emergency alerts.	Reservoir control systems.	Work force communications.	Digital required to keep customers informed during an incident. Leads to improved customer satisfaction.	Contact with supplier (day to day).	Digital offers transformative analytics to predict and forecast demand.	Digital provides command and control for water networks.	Emergency communications.	Facilitates implementation of smart meters.	Capex for better communications - ofwat priority		
	Transport	Water run-off from road and rail networks can impact water quality.	De-watering of tunnels, glasgow subway/ CTRL /Mersey tunnel	Water and drainage assets co-located with transport, impact of bursts etc.	Water treatment chemicals transported by road.								
Transport	*Water/Wastewater*	Bridges have water infrastructure services running across them.	Tankering chemical, water, supplies etc	Transport embankments are used for flood defence. Impact of flood run-off.	Dewatering for tunnels etc. that can impact on water environment (i.e. groundwater).	Transport enviroment fund to improve water quality.	Water is required to build transport infrastructure.	Pollution in run-off from road and rail infrastructure.	Cars end up in water courses > batteries from ev impacting polution	Current project by Environment Agency and Network Rail considering water quality issues.	Differing draiange standards across sectors. For example, Environment Agency want to slow down water, whereas Highways England/Network Rail standards want to speed up water.	Link between Sustainable Drainage Systems (SuDS) and wastewater management.	No septic tanks are allowed which has implications for railway stations being connected to the sewerage network.
	Energy	Banning or restricting diesel might impact Transport for London's emergency supply in greenwich LUL increases resilience opposite effect if taken out	Reliance on energy for smart motorway and signal control.	Smart charging locations impact demand	If there is an extensive power cut then people leave cities, impacting transport network.	During power outages and frequency disruptions, tolerance of electric trains is challenged.	Diversity of supply to signalling /comms etc 3 different systems	Opposite interaction, rail accident causing impact on electricity (takes out power supply) impact of other trains on track or other owners	Operation of train rolling stock.	Energy required to refine petroleum products for transportation.	Energy required to distribute petroleum products to consumers.		
	Digital	Losing of social interaction	Workforce communications.	Emergency communications (e.g. Emergency Services Network)	Mobile and wifi coverage on rail lines / poor coverage in the rail corridor.	Transport bridges with co-located digital services.	Digital networks for command and control of transport infrastructure.	Shared infrastructure corridors.	GPS needed for transport systems.	Safety of life dependency on rail/road connected.	Digital required for enforcement and monitoring of tolls and emmission zones.	Railway signalling and contact systems	Rail signalling systems reliance on digital technology.
Digital	*Transport*	Importance of fibre optics & other digital infrastructure in transport.	Data collection at macro level about customers travel routes and locations.	Rail passenger information apps (on delays) that provide situational awareness e.g. in emergencies	General safety regulation LCAVS	Security of BIM							
	Water/Wastewater	Sharing data on vulnerable customers in Digital econonmy ACT	Control & Monitoring of assests and demand	Rapid water travelling relies on digital infrastructure	Sector becoming more digitilised which creates resilience risks	Use of digital infrastructure for precision agriculture, leading to more efficient water use.	Digital communication underpin ability to respond to or report incidents .	Could water sector become more intergrated with availability of digital software.	Negative connection to service bundling (phone and broadband and energy/water) for business retail.				
	Energy	Distributed Energy Resources (Energy/Reforce) Dispatch	Telecommunications equipment has energy demand. Smart operation & resilience also has energy demand.	Digital communications resillence.	Digital communication underpin ability to respond to or report incidents.	Ongoing study into dedicated spectrum for utilities (future).							

Primary Sector	Secondary Sector													
Energy	*Water/Wastewater*	Water bills relatively small compared to energy. Water production responsible for ~10% all energy costs.	Hydroelectric storage schemes and thermal energy needs a lot of water.	Energy required for operation of water & wastewater treatment works.	Hydro a component of Distributed Energy Resources - Enviromental regulation applies.									
	Digital	Electric vehicle demand will affect distribution of network.	GPS Network for navigation and network (via digital).											
	Transport	Cost of Fuel for driving (taxes) (Global Prices).	Energy required for ticket machine and payment systems.	Co-location of buried infrastructure can lead to disruption during maintence. Transport shares utilities corridor with energy	Energy loss can lead to disabled transport system. Resulting in stranded commuters and therefore low customer satisfaction .	Vegetation removed from transport networks could be sold for bio-fuel as part of sustationable land use programme.	Rail Services e.g lights, cctv, catering.	Biofuels used for transport fuel.	Regulatory consultation by Ofgem to move to half hourly pricing for industrial customers.	60% of trains are metered.	Supply fee electric freight to different scale to Electric Vehicles.	Energy required for traffic lights and road signals.	Safety of commuters in over crowded stations during power outage (e.g. tunnels).	Energy required for freight transport of fuel/ biofuel (e.g. nuclear fuel/wood).
Water	*Energy*													
	Digital													
	Transport													
Transport	*Water/Wastewater*	Water needed for welfare/ catering/bathrooms and washing trains.	Abstraction licence and permits required with transport (e.g. in summer can't wash trains).											
	Energy													
	Digital	New projects provide economic benefits for introducing digital infrastructure.	Traffic light for roads	Remote sensing capabilities that provide real time forecasting for transport infrastructure.	Mobile reception on train + wifi & stations	Digital railways (signal/comms on trains rather than lineside (current programme)	Smart motorways Control systems for highways england	Smart ticketing	NIS regulations (cover both transport and digital (on cyber secruity)	Buried infrastructure, repair or maintenance. (geographic interdependanc e)	Navigation / GPS Sat Navs/ Auto vechicles	Cyber interdependen ce. Any functioning of transport system that needs digital		
Digital	*Transport*													
	Water/Wastewater													
	Energy													

Appendix B
Individual Sector Maps

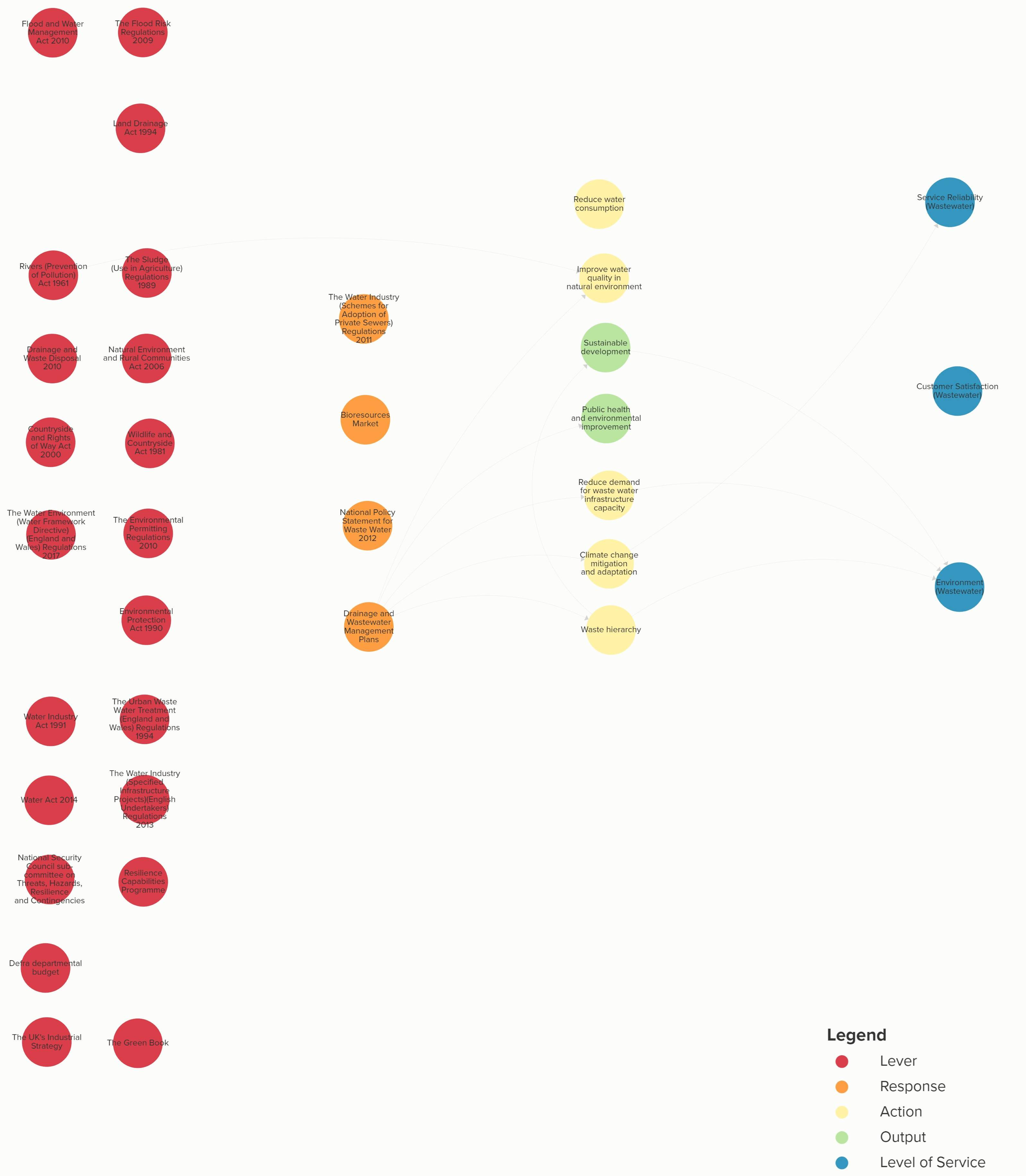
Digital Communications

Energy


Renewable Heat Incentive
Renewables Obligation
Feed in Tariff (FIT)
Contracts for Difference
Energy Efficiency for Organisations & Buildings
Carbon Reporting
EU Emissions Trading Scheme
Emissions Directives
Carbon budgets
National Adaptation Programme and the third strategy for climate adaptation reporting 2018-2023
Clean Growth Strategy
Secondary Orders for Renewables
Carbon Reduction Measures
Climate Change Act 2008
Reduced VAT rate on domestic gas, electricity, heating oil & solid fuel
Emissions (Energy)
Statutory Independent Undertakings (SIUs)
Customer Behaviour
Offshore transmission
Affordability
Petroleum Storage Capacity
EU Council Directive minimum oil stocks
Petroleum Transmission Capacity
UK gas production
Gas Distribution Capacity
Electricity Transmission Capacity
Electricity Supply
Customer Satisfaction (Energy)
Gas Supply
Gas Transmission Capacity
Constraint Management
System balancing and voltage control
Electricity Distribution Capacity
Reliability (Energy)
Gas storage and line pack
Wholesale market
System Balancing & Monitoring
Service Availability (Energy)
Settlement
Electricity Generation Capacity
Electricity Demand
Gas Treatment
Gas Demand
Smart Meter Roll Out
Sustainability (Energy)
LNG Transport
Metering and Data Collection
Electricity Storage
Hydrogen & biomethane
Distributed energy resources
Design and operation standards (e.g. SQSS)
Industry Licences
Energy enforcement powers
Ofgem's RIIO
Industry Codes
Carbon Capture and Storage
Capacity Market
Demand side management
Ensure generation meets demand
Frequency Response and STOR
Use of interconnectors
Reactive Power
Black start
The UK's Industrial Strategy
The Competition Act 1998
Electricity Act 1989
Gas Act 1986
National Planning Policy Framework 2019
Civil Contingencies Act 2004
BEIS departmental budget
Resilience Capabilities Programme
National Security Council sub-committee on Threats, Hazards, Resilience and Contingencies
The Green Book
Generator turn up/down
Legend
Lever
Response
Action
Output
Level of Service

Transport
Climate Change Act 2008
National Infrastructure Delivery Plan
Transport Investment Strategy
The UK's Industrial Strategy
Climate Change Risk Assessment
Innovation, Technology and Research Strategy
Grants for modal shift to rail
Governance of Railway Investment Projects (GRIP)
Climate Change Adaptation Plan
Demand (Rail)
Customer Satisfaction (Rail)
Demand (Road)
Charging schemes
Highways England Licence
Infrastructure Act 2015
Railways (interoperability) regulations
High Speed Rail (London - West Midlands) Act 2017
Infrastructure Capacity (Rail)
Increasing low carbon fuel supply
Road to Zero Carbon by 2050
Service Reliability (Rail)
Sustainability
Emissions (Road)
Supporting uptake of low emission vehicles
Road Investment Strategy
Highways Act 1980
Network Rail Delivery Plan
Framework Agreement Between the DfT and Network Rail
Service Availability (Road)
Rail Enforcement Powers
Infrastructure Enhancement
Safety (Rail)
Connectivity (Rail/Road)
Infrastructure capacity
Emission control regulation
Innovation, Technology and Research Strategy
Railways Act (2005)
High-level output specification
Customer Satisfaction (Road)
Highways England Delivery Plan
Supporting electric charging
Service Availability (Rail)
Operations/ Maintenance/ Renewals
Manual of Contract Documents for Highways Works (MCHW)
Statement of funds available
Operations, Maintenance and Renewal
Service Reliability (Road)
Major Schemes
Technology Manangement and Maintenance Manual
Railways and Transport Safety Act (2003)
Railways (Accident Investigation and Reporting) Regulations 2005
Sustainability (Rail)
Safety (Road)
Performance (Road)
Design Manual for Roads and Bridges
Emissions (Rail)
Performance (Rail)
Clean Growth Strategy
ORR Annual Assessment
Traffic Management Act 2004
Network Maintenance Manual
UKRLG codes of practices and frameworks
Civil Contingencies Act 2004
National Policy Statement for National Networks
DfT departmental budget
Road enforcement powers
Road Safety Statement
New Roads and Street Works Act 1991
Road Traffic Act 1988
Legend
Lever
Response
Action
Output
Level of Service
The Green Book
National Security Council sub-committee on Threats, Hazards, Resilience and Contingencies
Resilience Capabilities Programme
webTAG guidance

Wastewater



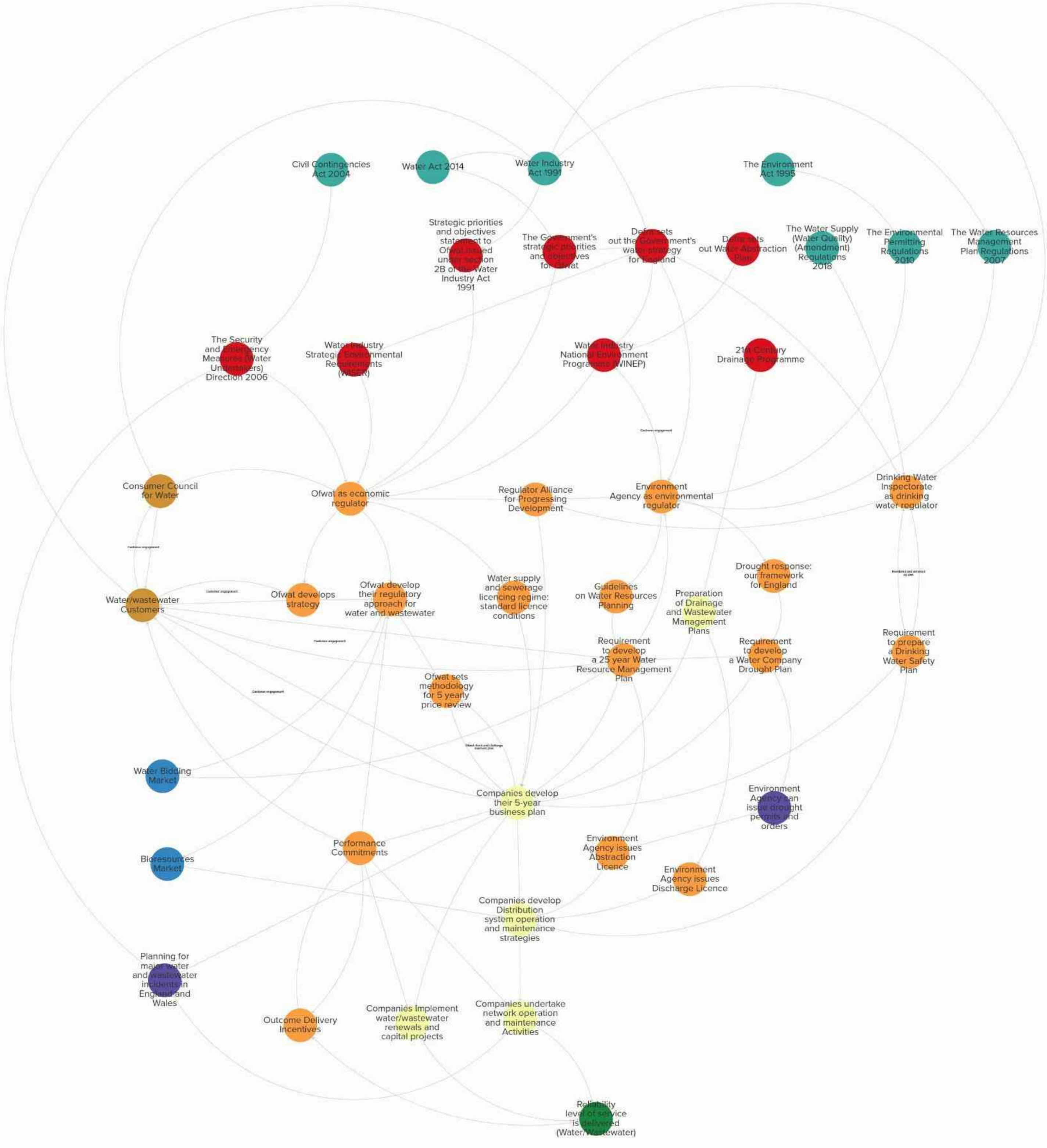
Flood and Water Management Act 2010
The Flood Risk Regulations 2009
Land Drainage Act 1994
Rivers (Prevention of Pollution) Act 1961
The Sludge (Use in Agriculture) Regulations 1989
Drainage and Waste Disposal 2010
Natural Environment and Rural Communities Act 2006
Countryside and Rights of Way Act 2000
Wildlife and Countryside Act 1981
The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017
The Environmental Permitting Regulations 2010
Environmental Protection Act 1990
Water Industry Act 1991
The Urban Waste Water Treatment (England and Wales) Regulations 1994
Water Act 2014
The Water Industry (Specified Infrastructure Projects)(English Undertakers) Regulations 2013
National Security Council sub-committee on Threats, Hazards, Resilience and Contingencies
Resilience Capabilities Programme
Defra departmental budget
The UK's Industrial Strategy
The Green Book
The Water Industry (Schemes for Adoption of Private Sewers) Regulations 2011
Bioresources Market
National Policy Statement for Waste Water 2012
Drainage and Wastewater Management Plans
Reduce water consumption
Improve water quality in natural environment
Sustainable development
Public health and environmental improvement
Reduce demand for waste water infrastructure capacity
Climate change mitigation and adaptation
Waste hierarchy
Service Reliability (Wastewater)
Customer Satisfaction (Wastewater)
Environment (Wastewater)
Legend
Lever
Response
Action
Output
Level of Service

Water

Drinking Water Directive 1998
The Water Supply (Water Quality) (Amendment) Regulations 2018
Water Supply (Water Fittings) Regulations 1999
The Water Quality and Supply (Fees) Order 2016
The Private Water Supplies (England) (Amendment)(Regulations 2018
National Security Council sub-committee on Threats, Hazards, Resilience and Contingencies
Resilience Capabilities Programme
Civil Contingencies Act 2004
Water 2020
The Security and Emergency Measures (Water and Sewerage) Direction 1998
Delivering Water 2020: Our final methodology for the 2019 price review (2017)
Maintained drinking water quality
The Security and Emergency Measures (Water Undertakers) Direction 2006
Time to act, together: Ofwat's strategy
Customer Satisfaction (Water)
Water Act 2014
Water Industry (Financial Assistance) Act 2012
The Water Industry (Specified Infrastructure Projects)(English Undertakers) Regulations 2013
Outcome Delivery Incentives
Infrastructure Capacity (Water)
Water Industry Act 1991
Competition and Service Act (Utilities Act) 1998
National Planning Policy Framework 2019
Service Availability (Water)
The Environment, Food and Rural Affairs (Miscellaneous amendments etc) Regulations 2019
The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017
National Adaptation Programme and the third strategy for climate adaptation reporting 2018-2023
Improved Governance and Collaboration
Climate Change Act 2008
Improved Water Environment
Service Reliability (Water)
The Environment Act 1995
Flood & Water Management Act 2010
Climate Change Policy Statement 2008
Water Resources Act 1991
WRMP Statutory requirement 2007
Demand Reduction
Draft Environment Bill 2018
25 year Environment Plan 2018
Environment (Water)
Reservoirs Act 1975
Drought Direction 2011
Water Quality (Water)
Defra departmental budget
Maintain and Improve Infrastructure (Water)
The UK's Industrial Strategy
The Green Book
Carbon Reduction (Water)
WRMP Statutory requirement 2007
New Appointments and Variations
Increase Access to Competition and Markets (Water)
25 year Environment Plan 2018
Connections Market
Business Retail Market
Legend
Lever
Response
Action
Output
Level of Service

Water and Wastewater Systems Diagram

Example of simplified diagram, updated following the workshop event.



Legend

- Legislation
- Policy
- Regulatory Action
- Markets
- Service Provision
- Emergency Service Provision
- Customers
- Level of Service

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