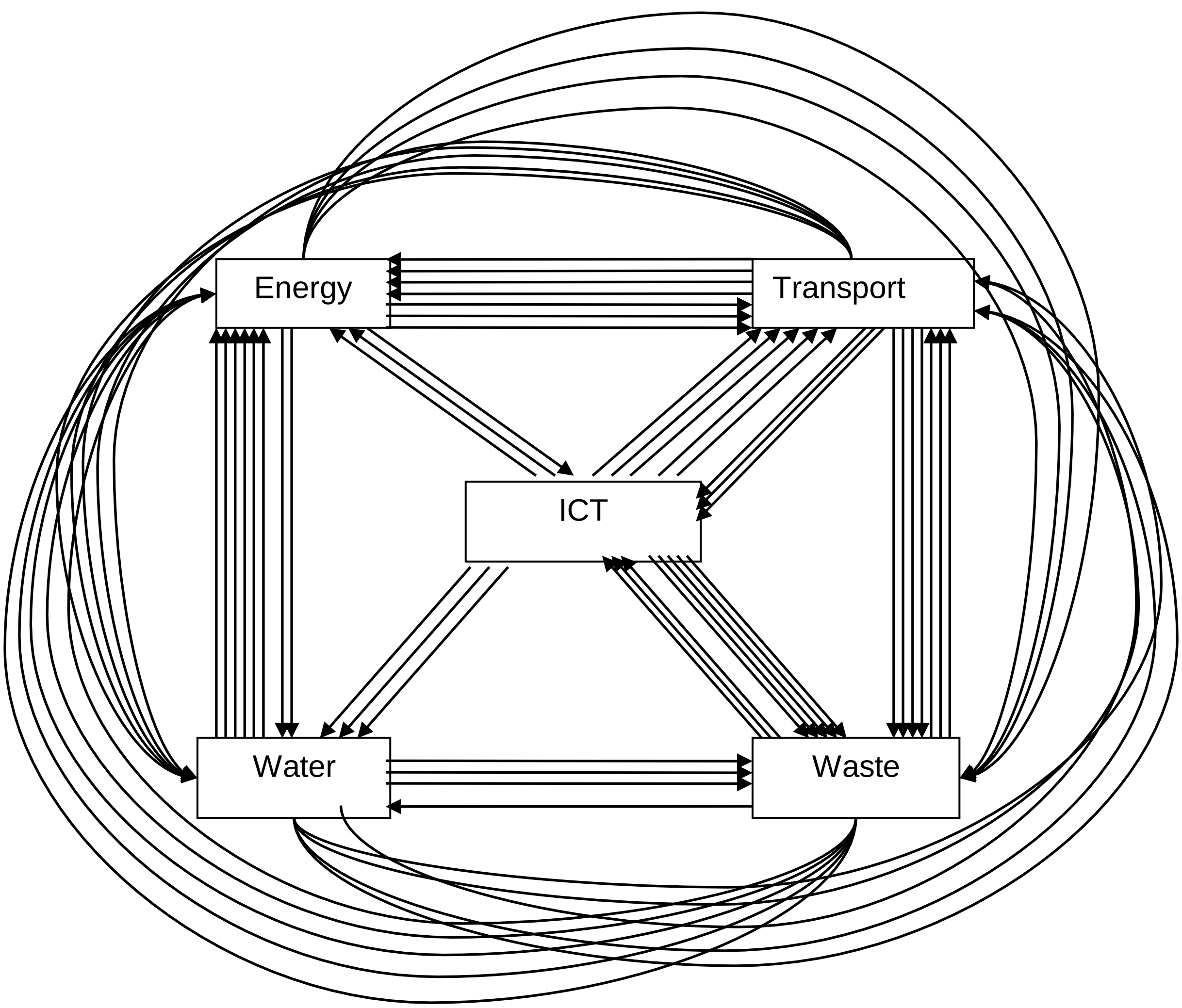
# An Overview of Systemic Interdependencies of the UK National Infrastructure

# Draft





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# Contents:



**Front cover:**

This shows a systemic overview of all critical interdependencies between the five infrastructure elements. The map reveals a richly interconnected system and highlights the co-dependency of the sectors upon each other.


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# Executive Summary

The Chief Scientific Advisor to DfT, BERR and DECC is engaged on a project to explore how to develop a strategy for the modernisation of the National Infrastructure of the UK. In order to gain the highest-level view of the landscape of UK National Infrastructure and to inform further thinking in this area, AEA were engaged to develop a systems map of the major infrastructure components and sub-components.

This project considered five elements of the UK national infrastructure:

- Energy
- ICT
- Transport
- Waste
- Water

The approach was based on an iterative systems mapping, with workshops in which sector experts developed and documented the basic structural components for each sector, from which higher-level maps were developed to reveal key interconnections between components.

The primary theme concerned current and future resilience of the national infrastructure in delivering national demand. The analysis extended beyond the individual components and focussed on interdependencies between the components. The effects of major environmental change, i.e. climate change, on the interdependencies were also considered, as were possible future trends in resilience and the urgency for improvement.

In addition to risks, opportunities presented by the potential renewal of infrastructure were reviewed. This included improvements for better operational efficiencies, for example through better use of ICT, as well as opportunities to respond to potential for mitigation of, and adaptation to, climate change and for supporting the provision of ‘green jobs’.

Clearly the process was qualitative. However, it provided useful initial insights and revealed even richer complexity in the interdependencies than perhaps is already acknowledged. This offers both concerns for vulnerabilities and opportunities for building resilience. The maps could be used to consider other potential large-scale trends such as changing demographics, availability of raw materials, and conflict or terrorism.

This initial brief was a first step in further understanding infrastructure interdependencies. The outputs will help guide and prioritise subsequent analyses, which will require more detailed and quantitative modelling and assessment techniques.

However, some initial key findings from the detail and insights recorded in Sections 5,6 and Appendix 2 are:


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1. The elements of the National Infrastructure considered are even more richly interdependent than may already be recognised. Consequently, the risks and vulnerabilities associated with the interdependencies are likely to be poorly understood.

2. There is and absolute dependence on Energy and ICT, as they underpin operations across all of the other sectors.

3. Stress, failure, growth or significant change in any one element will create interdependences that may be different in nature from the better-understood ‘business as usual’ interdependencies. Single Points of Failure can become more important and pronounced in times of stress.

4. The likely ‘business as usual’ trends in these interdependencies, i.e. whether they are on a trajectory to change for the better or for worse, vary for specific types of interdependence within specific infrastructure pairs.

5. Governance emerges as a key issue. Governance responsibilities and oversight are shared and split in a number of ways, for example:

    - Various elements of infrastructure are regulated at a national level by different regulators with their own specific responsibilities, aims, and priorities. There can be institutionalised conflict between the actions of a regulator of one element with actions of another.

    - Governance of a given sector is sometimes shared between public regulators and planners, and private sector businesses. For example, the resilience of a sector may be dependent on a mixture of a business’s own ICT system and national ICT systems. This means that, firstly, decisions and developments affecting the long-term resilience of each may not be co-ordinated, or even recognised. Secondly, priorities of the private sector may be focused on efficiency and short-term value within that sector/business, rather than maximising the contribution to wider and national objectives.

    In a highly interdependent system this will not lead to optimised risk management.

6. A particularly important aspect of governance is data ownership, which can often be split between different parties. This means that decisions are not, and indeed cannot, be made based on comprehensive information.

7. The five infrastructure elements are not fit for purpose in the context of the expected impacts of climate change. They may not be able to support the operations of UK plc during periods of stress, such as extreme weather events, which may occur more frequently over the coming decades.

8. Rather than just being an issue of risk management, appropriate development of future infrastructure, and in particular better cross-sectoral planning, offers significant opportunities for improved efficiency, effectiveness, and added value. However some legacy systems will need upgrading before full advantage of such thinking (e.g. more advanced use of ICT) can be realised.


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9. While it is recognised that all sectors require enhancement of the skills and knowledge base, which supports them, there is also a need to develop multi-sectoral knowledge, training, and operational research skills.

10. Renewal of national infrastructure should be a key component of planning and action of any national investment to stimulate job creation and economic recovery.

11. Responding to the challenge of infrastructure renewal in a coordinated and timely fashion will require development of efficient policy and planning regimes. A fundamental requirement is therefore a roadmap defining priorities over the next forty to fifty years to support such coordinated decisions on planning, financial investment, development of the appropriate skills base and deployment of new technologies.


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# 1 Acknowledgements

We are grateful for wider contributions to the outcome of this study received from:

Professor Brian Collins, Chief Scientific Advisor to BERR, DfT and DECC

Elizabeth Hogben, Assistant Chief Scientific Advisor, BERR

Jessica Moore, Council for Science and Technology Secretariat

Gordon Cole, Assistant Director, Cross-Whitehall Strategic
Relationships on Infrastructure, BERR

Robert Bell, CTO, AEA

Their comments, thoughts and reflections have informed and guided the thinking of the core team.


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# 2 Brief

The Chief Scientific Advisor to DfT, BERR and DECC is engaged on a project to explore how to develop a strategy for the modernisation of the National Infrastructure of the UK. In order to gain the highest-level view of the landscape of UK National Infrastructure and to inform further thinking in this area, AEA were engaged to develop a systems map of the major infrastructure components and sub-components. The map was also required to illustrate the relationships and inter-dependencies between the components, to identify any systemic weaknesses and to set out at the appropriate level, further relationships, commonalities, differences and dependencies between sub-components. During the mapping process, it was expected that insights would also be generated into timing and prioritisation of any actions, which would address the most urgent or important weaknesses. The project considered the energy, water, transport, Information Communication Technology (ICT) and waste sectors.

As stated, this work was undertaken as a first key stage in understanding and interpreting the relationships between the five infrastructure elements. It was agreed that the insights included herein would be deliberately and consciously not based on a fully researched and traditionally scientific approach, but generated as a part of the rich dialogue that took place between all the contributors. The insights draw on the synthesis of their collective knowledge and experience in the fields of concern with the interdependencies identified and the associated opportunities and risks.

It is proposed in the conclusions that the next phase of this work includes analysis to quantify risks and impacts of the interdependencies identified here in order to provide the basis for risk assessment and decision-making.


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# 3 Key Findings

1. The elements of the National Infrastructure considered are even more richly interdependent than may already be recognised. Consequently, the risks and vulnerabilities associated with the interdependencies are likely to be poorly understood.

2. There is and absolute dependence on Energy and ICT, as they underpin operations across all of the other sectors.

3. Stress, failure, growth or significant change in any one element will create interdependences that may be different in nature from the better-understood 'business as usual' interdependencies. Single Points of Failure can become more important and pronounced in times of stress.

4. The likely 'business as usual' trends in these interdependencies, i.e. whether they are on a trajectory to change for the better or for worse, vary for specific types of interdependence within specific infrastructure pairs.

5. Governance emerges as a key issue. Governance responsibilities and oversight are shared and split in a number of ways, for example:

    - Various elements of infrastructure are regulated at a national level by different regulators with their own specific responsibilities, aims, and priorities. There can be institutionalised conflict between the actions of a regulator of one element with actions of another.

    - Governance of a given sector is sometimes shared between public regulators and planners, and private sector businesses. For example, the resilience of a sector may be dependent on a mixture of a business's own ICT system and national ICT systems. This means that, firstly, decisions and developments affecting the long-term resilience of each may not be co-ordinated, or even recognised. Secondly, priorities of the private sector may be focused on efficiency and short-term value within that sector/business, rather than maximising the contribution to wider and national objectives.

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9. While it is recognised that all sectors require enhancement of the skills and knowledge base, which supports them, there is also a need to develop multi-sectoral knowledge, training, and operational research skills.

10. Renewal of national infrastructure should be a key component of planning and action of any national investment to stimulate job creation and economic recovery.

11. Responding to the challenge of infrastructure renewal in a coordinated and timely fashion will require development of efficient policy and planning regimes. A fundamental requirement is therefore a roadmap defining priorities over the next forty to fifty years to support such coordinated decisions on planning, financial investment, development of the appropriate skills base and deployment of new technologies.


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# 4 Approach and Outputs

## 4.1 Approach

This project was carried out using an inter-disciplinary, systemic approach. The requirement for a focus on interactions between elements and the consequences of those interactions demanded the adoption of a workshop-based, collaborative process.

This involved:

- assembly of a team with expertise in the key areas of enquiry including systems thinking
- creation of a systemic enquiry process using an iterative, learning process to re-inform the 'question' during each cycle
- adoption of a mapping method based on Forrester (1961)[1] coupled to thinking informed by Weiner (1948)[2] and Beer (1959)[3].

The core team was:

| | |
|---|---|
| Gill Hall | Director of Marketing and Sales, AEA |
| Geoff Dollard | Knowledge Leader Air Quality, AEA |
| Chris Fry | Practice Director, Energy, Climate Change and Risk, AEA |
| Heather Haydock | Knowledge Leader Energy and Climate Change, AEA. |
| Adam Read | Knowledge Leader Waste and Resource Efficiency, AEA |
| Sujith Kollamthodi | Knowledge Leader, Transport, AEA |
| Iarla Kilbane-Dawe | Proposition Manager, AEA |
| John Beckford | Professor of Information Science, Systems Scientist |

An iterative process was adopted based on four core team workshops with periods between for completion of interim outputs, discussion, reflection and adaptation. The interim outputs, and reflections were used to inform discussion and reflection with Professor Brian Collins as Project Sponsor as well as members of his support staff. The outputs of these reflections were then fed back into the subsequent core team event. Thus, after each core team event there was a meta-level reflection on the output, which steered the content of the next event. This cybernetic or adaptive process enabled steering of the enquiry and enabled rapid learning and sharing.

[1] Jay Wright Forrester, (1961). "Industrial Dynamics"; Pegasus Communications, USA.
[2] Norbert Wiener (1948), "Cybernetics, or Control and Communication in the Animal and the Machine". Cambridge MIT Press, 2000 (1st edit. 1948).
[3] Beer, S., (1949) "Cybernetics and Management". English Universities Press, London.


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## 4.2 Outputs

Breaking this down, the outputs were arrived at, and fit together, as follows:

***Level 3 (Base) Analysis: Key Components Maps (see Appendix 3)***

The initial step was to develop and map a broad outline of the key components of each of the elements of infrastructure under consideration (ICT, Waste, Energy, Transport, Water) – the Base or Level 3 analysis. The mapping was framed to include governance and regulatory structures, the physical components of the infrastructure as well as the demand environment of the industry being considered.

The thinking, working and outputs for each sector generated during this first step are summarised in the diagrams in Appendix 3. The influences and interconnections between the sectoral elements of these maps were detailed and 'cross-sectoral' entities and elements identified for further consideration. This Base (Level 3) Mapping was then used to inform a Level 2 Analysis.

***Level 2 Analysis: Detailed Interdependencies (see Appendix 2)***

A Level 2 Analysis then constructs the interdependencies for the issues identified at Level 3 for specific relationships between infrastructure components. The text and figures in Appendix 2 expose and explain these relationships so that their impacts and dependencies can be understood.

The Level 2 Analysis considers each of the 10 infrastructure pairs (e.g. Transport-ICT, Water-Energy, etc). For a given pair, the key interdependencies are then identified and scored against 5 criteria:

- Governance
- Living with Environmental Change
- Timescales
- Resilience
- GHG Emission Reduction

Each criterion is given a score for the present situation and the likely future situation (to show the likely improvement or degradation assuming a 'business as usual' future)

Thus, although the process was qualitative and not based on detailed analysis, the Level 2 Analysis gives quite a lot of food for thought on:

- the richness of the interactions;
- the current state of the interactions (positive or negative), and their possible future development;
- priorities for further analysis.

***Level 1 Analysis: Systemic Overview (see Section 5)***

The third step, drawing on the expertise of the industry and sector experts, was to consider the extent of the interdependencies between sectors and their effects.


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Particular consideration was given to any interactions that had the possibility of creating a significant opportunity or causing a system failure.

These high level interdependencies are considered in Section 5, ‘Level 1 – Systemic Overview’. This Level 1 Analysis represents the whole system of interest (the 5 elements) and their interactions. There is deliberately little detail at this level. It is an overview, which enabled the contributors to understand the richness of interaction between the elements and the existence of key relationships.

***Initial Insights (see Section 6)***

In addition to recording the detail from the Key Component Maps, and from the Level 1 and 2 Analyses, this report records some initial insights gleaned from those who took part in the workshops and discussions. They are not exhaustive, but indicate the type of the deductions that could be made by more thorough examination of the interactions in future. They are given in Section 6.


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# 5 Level 1 Analysis: Systemic Overview

This Level 1 view is based upon the detailed Level 2 Analysis given in Appendix 2. Many examples of interdependencies are given in the Appendix with reflection on the current and future status of the interdependence - both negative and positive.

## 5.1 Overview

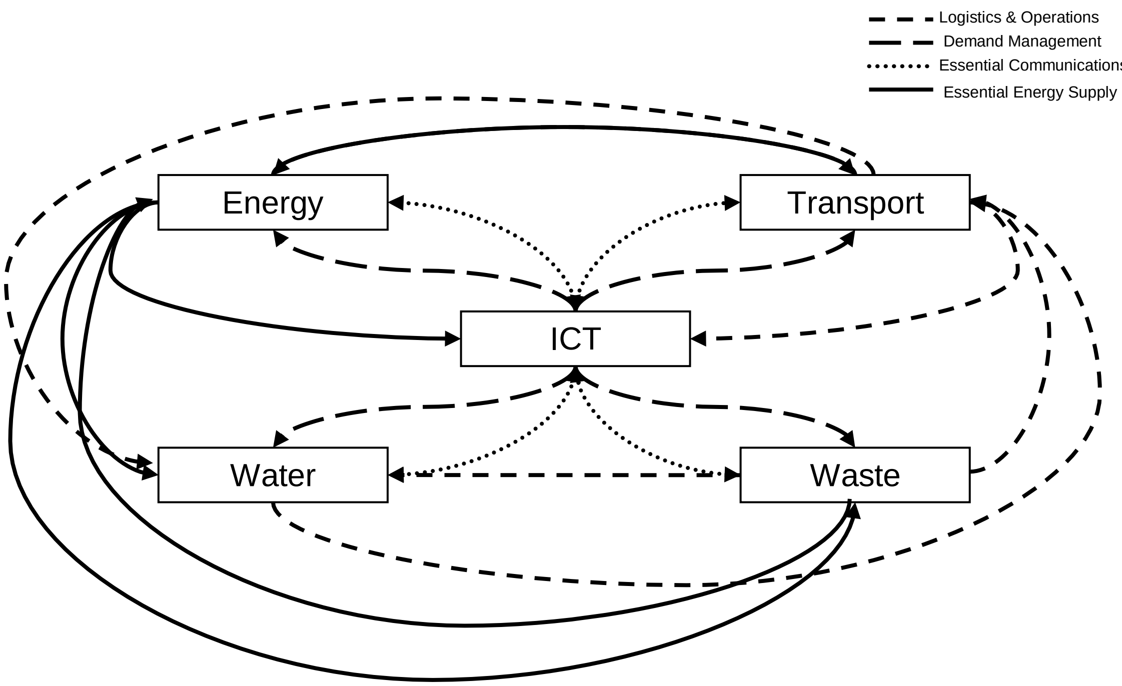


**Figure 5.1 Systemic Overview of Critical Interdependencies**

This mapping, summarised in Figure 5.1, presents an overview of all the critical interdependencies identified between the 5 infrastructure elements considered during Key Component Mapping and the Level 2 Analysis (see Appendices 3 and 2 respectively). The richness of interconnectedness between the elements highlights the co-dependency of these sectors on each other. In total the project identified 67 interactions between the 5 elements suggesting a high level of overall interdependency. The data are presented in tabular form in Appendix 1.

For this report the relationships are expressed primarily in terms of the existence of the interaction; some qualitative commentary is made below in relation to the nature, strength and weakness of the Interdependency.

In further work it would be possible to express this in terms of the volume and frequency of interactions and the degree of dependence although some have been identified


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already as absolute and continuous. The identified interdependencies have been classified as reflecting:

Logistics and Operations
Demand Management
Essential Communications
Essential Energy Supply

The industry with the highest number of interdependencies (reliance on other industries) is energy, having 17 interactions whilst transport and waste have 16. ICT has the least reliance with 7, while water has 6. Again, the importance of the interdependency has not been assessed, but it is clear to a casual observer that the dependence of ICT on energy is, currently, absolute.

By contrast, transport is the most frequently depended on industry with 16 interactions, whilst ICT is second with 15. While there are 14 dependencies on water and 12 on waste, energy only has 10 dependencies but it should be clear that the dependencies on energy are both absolute and continuous in nature, i.e. the industry cannot function without that interaction. It will be important in extending this study to properly evaluate the importance of the identified interactions although some thoughts on this are provided in Section 6 of this report (Initial Insights).

This initial ‘count’ of interdependencies, effectively providing a volume based ranking, provides a first insight to the degree of resilience needed in each sectoral component, energy clearly being the one which must not fail. Prioritisation of actions to increase resilience might be informed by this initial ranking but also by assessment against a more rigorous evaluation framework.

Opportunities to improve infrastructure performance arise from several of the sectoral interdependencies. However, the value or benefit of an opportunity in any one sector may only be fully realised when it is accrued in the context of values or benefits in one or more other sectors. The volume/frequency of interactions leads to consideration that, for example, significant systemic benefits may be derived from the co-location of infrastructure facilities. Examples might include co-location of waste treatment, water treatment and power-generation facilities. However, this may have negative effects on resilience in some circumstances.

Potential failures similarly interact; thus failure in any one will impact on each of the others – the key variable being the time to impact – a domino effect. For example, a failure in the ‘waste’ area can be tolerated for quite a lengthy period (waste will accumulate at the point of origin), whilst total failure in the energy supply might stop everything very rapidly. A particularly powerful lesson was the extent to which several of the other sectors have developed a critical dependency on the ICT sector, both for operational ‘Demand Management’ information and for ‘Essential Communications’ – those which are fundamental to safe operation of the other sectors. Currently the waste sector has a relatively low direct dependency on ICT but one that is likely to grow giving rise to a future potential failure linked to ICT.

The ICT Sector provides a privately owned, communications network (wired and wireless) upon which every other sector relies. Perhaps the key contribution, under normal circumstances, is that ICT provides the capability for demand and flow


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management which is the key to capacity utilisation in each other sector, e.g. road, rail and air traffic control systems, response to demand fluctuations in electricity supply and so on. Whilst there is substantial adoption of ICT in the transport industry in general, much of this is ageing and has suffered a lack of both substantial research and development of the potential and, in consequence, a lack of substantial investment. Knowledge of the rail sector in particular indicates that while such systems exist, capacity management and utilisation is not drawing on state of the art applications of ICT. That industry is lagging well behind what is possible and currently proposed developments are not fully coherent or likely to fully resolve this. In times of crisis in other sectors, the ICT industry is critical as the basis of communications and it in turn has an absolute reliance on energy for its continued operation.

Each of the key, Level 1, Interdependencies will now be considered.

## 5.2 Logistics and Operations

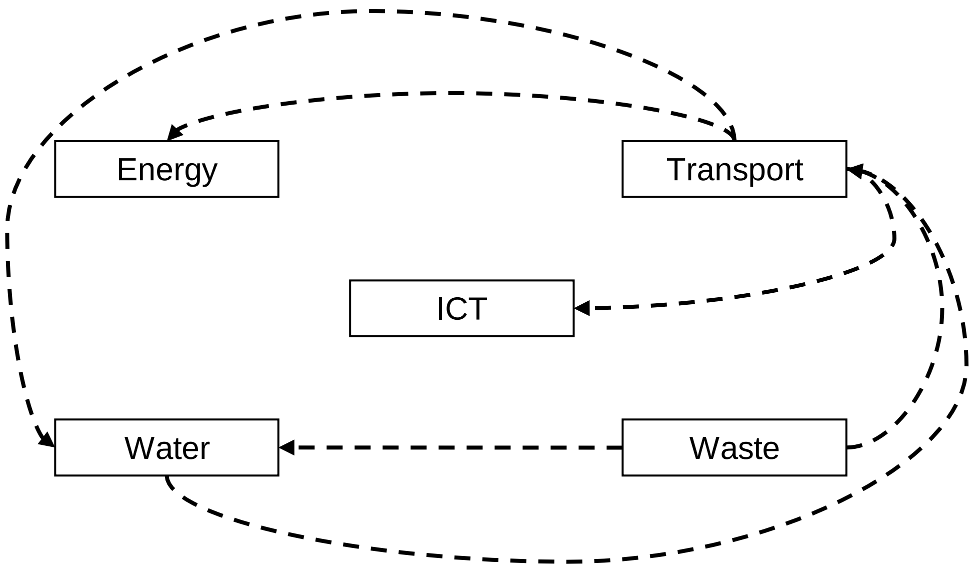


**Figure 5.2 Dependencies for Logistics and Operations**

Abstracting only the logistics and operations interdependencies reveals that energy, water and ICT have logistical dependency on transport, while waste depends on water operationally and transport depends on water for shipping.

Transport relies on the availability of energy in a variety of forms in order to function. It is the case that, whilst energy cannot function without transport (raw materials supply), transport cannot function without energy (oil based fuels and lubricants, electricity).

Taken together, these sectors enable the continued operation of UK plc. The interdependencies are both absolute and continuous and the failure of any one, but particularly the energy-transport co-dependencies, would have catastrophic potential.


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Supply chains for energy raw materials, oil for transport and food are short, tightly managed and largely operated on a ‘just-in-time’ basis. This suggests they will have high-vulnerability to disruptive shocks with significant and rapid implications for the population as a whole.

## 5.3 Demand Management

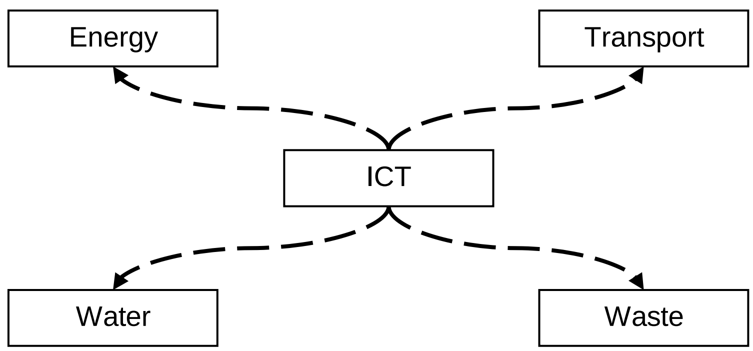


**Figure 5.3 Dependencies for Demand Management**

ICT is a core dependency for all forms of demand management. Some of this ICT will be embedded in the infrastructure of the particular industry e.g. rail signalling, metering on pumps for water supply, logic control units in power stations but much of the data is not visible outside individual businesses – or even outside individual units within such businesses. Data transfer outside the industry or across it relies largely on communications infrastructure which is neither owned nor operated by the industry of concern; nor does it have any meaningful priority against other data traffic on shared communications facilities.

The quality of decision support data derived by the various industries through the communications infrastructure is known to be very variable with some excellent systems for demand management and some poor.

Much of the communication is largely held within each industry - partly for reasons of commercial constraint - and little or nothing is believed to exist which considers or reflects the interdependency of the industries. Similarly, metering and demand


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management is largely a one-way process in most cases with little opportunity with existing metering and data capture devices for more intelligent system and interaction management.

Some of these limitations simply reflect that this question has not previously been addressed; others might more accurately reflect ownership and/or skill issues. The know how to create a systemic infrastructure for intelligent demand management is unlikely to be embedded in any of the individual industries of concern and the owners of businesses in those sectors do not necessarily have a commercial interest in addressing the issue.

Continuation of the existing approaches embeds vulnerability and inhibits the development of higher-order ICT systems, which could enable optimisation of performance against multiple criteria at a national rather than organisational level.

## 5.4 Essential Communications

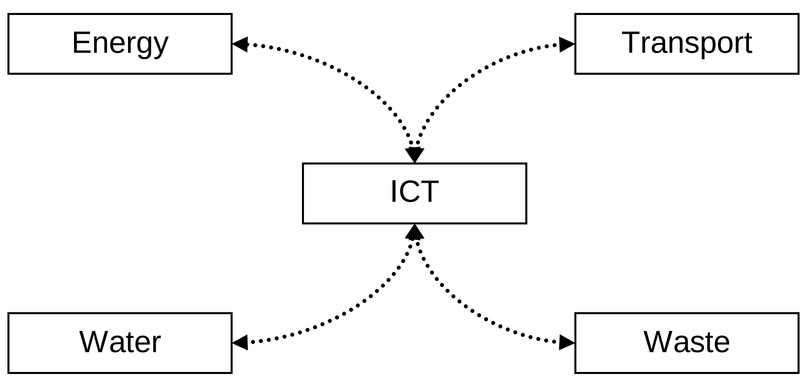


**Figure 5.4 Dependencies for Critical Communications**

Whilst under business as usual conditions the demand management systems already flagged handle the continuing flows of data, under stressed or critical conditions, the reliance on the ICT sector is substantially amplified. For example, under normal conditions, the rail signalling system (signals, junction boxes, train describers and so on) inform the various control rooms of the status of each service and its location. If one or several of these parts fail, or as in some parts of the country are non-existent (e.g. train


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describers on parts of the rail network in the north of England), then the safe and efficient operation of the railway draws on the telecommunications part of the ICT infrastructure (drivers and signalmen with mobile phones, or as fitted on some rail vehicles, GPS locators using satellite technology).

Hence the ICT infrastructure needs to sustain a level of resilience and diversity capable of maintaining service under highly stressed conditions.
Individuals and most businesses are not concerned with the infrastructure itself – we simply use it. Telecommunications businesses are primarily concerned with capacity and bandwidth issues for ‘business as usual’ and the prime role of the regulators (where the services are regulated at all and much of the ICT industry is not) is concerned with licence pricing, bandwidth allocation and competition. The current position is that the performance of critical communications under stressed conditions, at a national level, appears to be nobody’s responsibility.

## 5.5 Essential Energy Supply

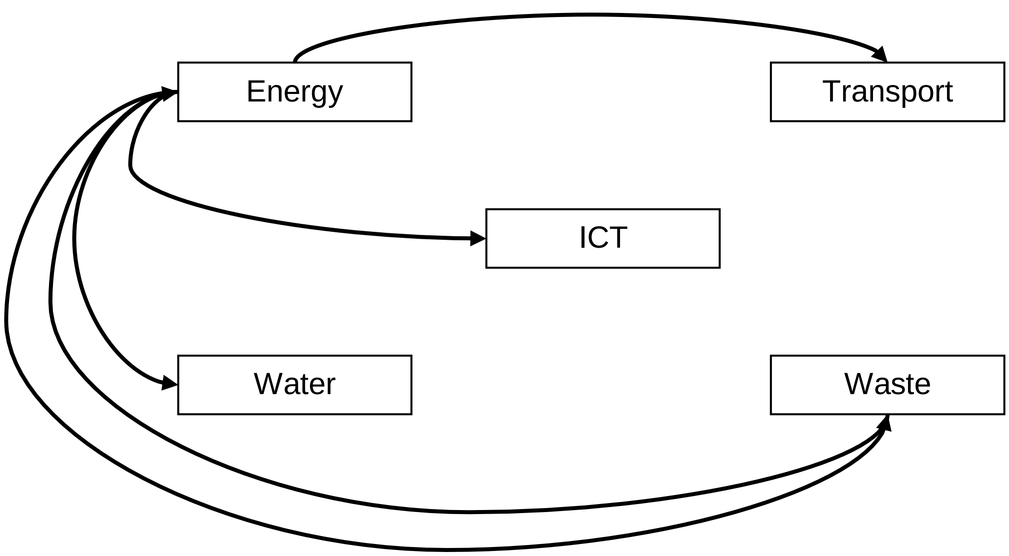


**Figure 5.5 Dependencies for Energy Supply**

Very simply, if the energy supply fails or is inadequate to the increased demand placed upon it, each of the other sectors progressively fails. Whilst reserves of raw materials e.g. vehicle fuel or gas provide a level of resilience in the event of supply failure, this resilience is limited to a relatively short time period. Of equal importance is the ability of the energy supply industry to convert raw materials to useable forms of energy (e.g. fuel


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oils, electricity) and to distribute that energy to the relevant users. Unlike the ICT sector, the energy sector does not appear to have as web-like an architecture to support this conversion and distribution process, reducing its resilience and increasing the potential for single points of failure.

The centrality of the energy supply to the operation of the whole country is self-evident. Whilst spare electricity generating capacity currently exists, this is very dependent on continuity of supply of raw materials (gas and coal) which events in 2008 highlighted are very vulnerable (e.g. the closure of the gas pipeline through Eastern Europe). With a shift towards low carbon and renewable energy sources (wind, solar, hydro), there may be a concurrent reduction in reliance on coal (especially closure of established coal fired power stations) and loss of resilience in the energy supply – with negative consequences for every other infrastructure element.


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# 6 Initial Insights

This section of the report brings together a number of high-level insights, which arose from the mapping workshops and subsequent reflections during plenary sessions on the possible opportunities and consequences of the interdependencies identified. The insights are essentially synopses of the thinking of each group as they followed key common themes shaped by the systemic analysis of interactions in the national infrastructure. Each contains examples raised and discussed by the groups. These are not presented as scientific analysis and do not contain quantitative data to support the ideas described. They draw on the knowledge, insight and experience of the contributors and are not supported by detailed evidence. They may not be complete.

## 6.1 Resilience

Resilience is the measure of the ability of the five elements of the infrastructure to continue to provide service under both stable and stressed conditions. Our work in this project built on a consideration of the resilience of the individual infrastructure elements to facilitate a focus on their resilience in interaction.

The infrastructure elements have for the most part been developed independently of each other – each industry seeking to achieve optimum performance for itself with reference to the business model, or models, which drive it. These models generally tend towards a measure of internal efficiency relative to normal market demand with sufficient redundant capacity to meet anticipated peaks in demand and long-term trends in renewal and growth rates.

As each industry aims towards achieving greater internal efficiency, its ability to absorb additional demands becomes more limited and potential single points of failure (SPOF) become exposed, e.g. the power transmission lines into the City of London. When there is interaction between the demands of two or more sectors, occurrence of a failure in one can easily impact on a second. For example, failure of the power transmission grid into London could not only impact on the built environment (offices, shops and factories) but would have immediate impact on the transport network (e.g. electricity for underground and overground trains) and ICT (electricity for all forms of communication both fixed and mobile).

A further example is the current, unconfirmed, proposal by major ICT mobile network providers to share base stations and masts in remote geographical areas – increasing their own efficiency but reducing the resilience of the network – in effect deliberately creating a potential single point of failure. Whilst this may be unimportant for the normal service provision to their customers, the reduction in resilience may have impacts for other sectors. Train operating companies (TOCs) are currently considering on-train installation of data capture and transmission devices to monitor rail vehicle positions in real time in order to improve their own performance. These will rely on the capacity of the mobile networks to transmit the data to control rooms and use ‘multi-sim’ devices operating on multiple networks to guarantee continuity of transmission – a core safety requirement for the TOCs. If the base stations, unbeknownst to the TOCs, are shared then this becomes a SPOF for both the ICT network and the TOC.


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Changes now widely anticipated in the environment contain significant potential for systemic failure arising from a SPOF. For example, whilst average sea levels are not expected to rise during the time period under consideration to the extent that all coastal areas will become uninhabitable, the likelihood and probably frequency of extreme weather events are expected to increase. Thus whilst the infrastructure may continue to cope with the average change in water levels, any one element may not cope with an extreme weather event e.g. a spring tide in conjunction with a storm, with consequential impact on the others.

Resilience of the national infrastructure components is influenced by age, timing of renewal and stresses from demand levels beyond the original design specification, and more recently from environmental change. A rise in temperature, flooding caused by sea level rise or changing rainfall patterns and possible subsidence due to soil drying through drought may progressively increase stress on our infrastructure over the next decades. Scientists now confirm that we should expect an increase in extreme weather events causing acute impacts. In the waste industry, for example, a developing Mediterranean-like climate in the UK may require removal of waste from domestic and commercial operations on a daily basis for reasons of public hygiene. This will create stress in an industry geared to weekly collections and will have further impacts on transportation as more vehicles fill the roads and reduce the capacity for everyday traffic to circulate.

A further challenge to resilience also comes from malicious actions where – intentionally or not - such actions may take out critical structures or systems out of operation. The ICT industry is a good example of this. The ICT sector has resilience in the context of the internet but its dependence on vulnerable PC software creates a critical weakness. Increasing dependence on technology may also reduce resilience. A growing trend for the utilisation of data on, e.g. stock levels of goods at exact geographic locations to inform logistics in order to satisfy demand in a more operationally efficient manner introduces a dependency on GPS technology. This technology is reasonably secure but the logistically more efficient approach may reduce resilience due to greater dependence on ‘just in time transport’ as well as through reduced stocking. It is interesting to note that the current waste sector infrastructure could be classified as having good resilience – largely because it has relatively low technology and a capacity to stockpile. A continuing drive to improve data collection for better operations and logistics could ‘flip’ waste to lower resilience - due to a greater dependence on ICT and transport operations.

Diversity of fuel types and sources for energy production enhances resilience. In this context, greater distributed power production through growth in micro-generation creates a positive impact. In the electricity, gas and water industries, additional storage is a means of increasing resilience. Such additional capacity is probably under pressure in terms of cost benefits assessment by the responsible organisation for which benefits to the national infrastructure will not accrue directly.


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## 6.2 Opportunities

Many opportunities for improvements in design and delivery across the national infrastructure emerged during the workshops and several have already been identified in this report; a short, further commentary is provided here. Across all infrastructures, addressing problems and seeking solutions adopting a holistic approach will create greater synergies, benefits and cost savings as well as improving reliance and thereby reducing risk.

### 6.2.1 Waste Management

This section looks at the wider opportunities that exist for the future design and delivery of the UK waste infrastructure, which in many respects is less regulated and less operationally sophisticated than the other infrastructure areas.

The first significant opportunity with positive benefits across all sectors is the adoption of co-location policies that actively promote the development of waste treatment facilities on the same sites as industrial users of materials e.g. processing and manufacturing plants configured to consume the energy and heat generated. This could include warehouses, distribution centres and logistics parks from which waste is currently collected and transported. This approach would not only reduce transport time and impacts but would also enable more joined up delivery in terms of feed stocks, stock control, processing etc, which would create an altogether more efficient and effective solution. This could be considered as a ‘waste management value chain’ reflecting the ‘materials management value chain’ of the producers of waste.

This approach of co-location would directly benefit a central appreciation of waste as materials streams. Currently we identify waste by origin or source and the regulatory and economic structure is focused around municipal, commercial or agricultural sources. However, all waste streams are an amalgamation of materials. Focusing, for example, on the paper content or organic fraction of commercial and municipal waste would allow more economically appropriate facilities to be developed in the right location to suit the ‘hinterland’. This would also allow reprocessing industries to co-locate near to sorting facilities that have a high throughput of their target materials. This would also reduce transport costs and impacts. Under certain circumstances a concentration of infrastructure could weaken resilience.

The other area of immediate opportunity and benefit is joint policy setting, regulation and enforcement. There is a current debate about what level of Energy from Waste (EfW) is appropriate with caps in place for Municipal Solid Waste in Wales, Scotland and England. However this limiting of the use of thermal treatment technologies to boost recycling - which is a more carbon friendly solution - may cause a problem for the energy sector which may want to develop waste fuel systems to improve the resilience of their sector. Clearly a more holistic approach to industrial processing is needed in these times of great change and transition. This could also prove a limit on the development of co-treatment for sewage sludge and municipal organic materials which are currently regulated separately even though co-mingling of these materials makes technical sense and could prove more cost-effective.


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Another key opportunity area for the waste industry is with skills and knowledge transfer. Currently, many of the technologies being developed and employed in the waste sector are inherited or borrowed from water, ICT and transport. Sharing resources across sectors is a critical opportunity for development. With the right engineers and technicians, the waste sector could make fast and significant progress to modernise.

### 6.2.2 Energy

Provision of reliable energy supply is critical to the continued operation of each of the other elements of the national infrastructure. A number of interacting opportunities arise in this area.

The relocation of power stations to sites with port access and where there is a ready supply of cooling water (they tend to be sited near coal mines for historical reasons); co-location with demand for heat would also be helpful. Extracting the maximum benefit from power generation suggests that optimising the whole supply chain would involve developing power generation locations where water, raw materials, waste management and heat consumption could all be optimised. This would necessitate an approach to infrastructure development that is multi-sectoral.

Within the energy sector there is an opportunity to achieve better supply-demand management through the use of smart meters and associated ICT infrastructure; the planned full role out of smart meters across the UK by 2020 will facilitate this. A major challenge for electricity provision from renewable sources, such as wind, wave and tidal, is that the peaks in availability of power and peaks in demand will not be matched. There is a requirement to store and manage electricity to make it available at times of peak demand. The present metering infrastructure is predominantly one-way – it measures flow of electricity to consumers. ICT in conjunction with smart-metering systems would provide the potential for distributing the storage-and-demand problem across the grid. For example, a smart meter could be used to control various devices in a factory or home, switching them off in order to cater for a peak in demand for which there is no spare capacity. In the longer term and with improvement in battery technology there is the potential for electric vehicles to be used as load-levelling devices for the electricity system such that vehicles plugged in to the grid could make electricity available to meet short-term peaks in demand. Two-way metering, as exists in some homes equipped with power generation systems, would enable the management not only of the flows of electricity but also the costs and benefits.

### 6.2.3 ICT

The UK can be considered as world leading in the provision of a generally robust telecommunications infrastructure by a highly competitive industry. Whilst the pursuit of business efficiency and the desire for profitability means that service provision can be marginal in areas of low population, there is nonetheless very extensive telecommunications coverage across the UK mainland. This telecommunications architecture is relied upon very heavily by each of the other infrastructure elements.

The opportunity for the infrastructure businesses lays, not so much in extending the use of the ICT infrastructure, as in the systems in use internally and the messages they


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communicate. It is probably fair to say that other industries do not explicitly realise the extent to which they rely on the ICT infrastructure – it is, in effect, invisible to them except when it doesn't work. Its importance is almost certainly not understood – and its potential is unrealised.

ICT infrastructure has the potential to carry useful information between sectors, e.g. energy and transport enabling more informed, more effective decision-making. However, the legacy systems upon which much of the transport infrastructure continues to operate can make this very difficult to achieve. Coupled to this is some difficulty associated with the ownership of the data – for example in the rail industry, legislation demands that certain databases (operated by suppliers external to the Train Operating Companies - (TOCs)) are used for safety-critical information. The TOCs are obliged to provide data to this system and then the external supplier charges them for access to the data they supplied. This structure does not encourage effective data sharing and imposes significant cost on potential improvements. In effect the TOCs are discouraged from investing in future information systems by the cost of maintaining the legacy systems.

The somewhat cumbersome nature of the systems also means that the skills of many individuals are focused on the utilisation of what exists already leaving limited capacity for thinking about or developing future solutions.

Because the value of information is not adequately understood within most of the businesses concerned, they remain focused on the cost of information provision. There is an urgent need and opportunity to invest in the development of a range of skills in the information area. These skills particularly need to include inter-disciplinary subjects such as Operational Research and Analysis, Systems Thinking and Systems Problem-Solving.

Our analysis suggests a major role for the synergistic collection of data from the operational elements of many infrastructures. This is congruent with the general trend towards telemetry and automated data collection, but seeks to add value through the interconnection and correlation of multiple spatial datasets. A possible methodology for the development of such a system is the development of a Spatial Data Infrastructure for the UK, an activity that is already effectively a requirement of the INSPIRE Directive (2007/2/EC).

## 6.3 Cross Cutting Issues

### 6.3.1 Severe climate change impacts by 2050

Here we envisage a scenario where global greenhouse gas emissions continue to rise over the coming decades leading to severe climate change impacts by 2050. A 4°C rise in average, global temperature by 2050 is well within the range of possibilities predicted by climate models. In the UK this could translate to higher summer and winter temperatures, average sea level rise of up to 1 metre, and more extreme weather events (e.g. heat waves and storms, high winds and more flooding incidents). There would be more frequent and longer-lasting drought conditions in parts of the UK, e.g. South East England and more deaths from heat and air pollution, balanced by fewer deaths from cold weather events.


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This is likely to change the pattern of demand for energy with less heating in winter and more air conditioning in summer. This peak in demand in summer may coincide with outages in inland power stations reliant on cooling water from aquifers. Water shortages could also be heightened by increased leakage rates through pipework damage caused by weather-induced subsidence.

For those power stations and oil refineries close to the sea, the rise in sea level and greater incidence of tidal surge could cause localised flooding. For example, Fawley refinery and Marchwood power station are co-located next to Southampton Water. The extent to which this would have a knock-on effect on electricity supply and transport provision would depend on the excess capacity in UK electricity supply and refinery operations at that time. Currently Marchwood is a relatively small power station and there is sufficient spare capacity on the system above peak demand, but this may not be the case in 2050. The current power station at Marchwood may have been replaced with something larger and there could be significantly less spare capacity on the network. This is currently due to lack of incentives to build spare capacity (see discussion below on regulatory issues) as well as factors such as the ageing of coal and nuclear power plants, intermittency of renewable energy sources and lack of transmission and storage capacity.

Under this scenario there would be direct and indirect effects on the transport infrastructure. Direct effects could include flooding of ports, rail buckling and/or more frequent and extensive maintenance, melting of road surfaces and flooding of road and rail networks. There could be a feedback effect from ports and rail unavailability into power station operation as many power stations may be reliant on imported coal delivered by rail. Indirect effects might include lack of electricity supply for electric vehicles and rail transport or lack of transport fuels due to refinery constraints. For example, the Fawley refinery is currently the main supplier of aviation fuel to Heathrow. Failures in the transport network could then lead to knock-on effects on logistics and operations putting further stress on medical services and preventing waste collection and waste treatment.

### 6.3.2 Skills

One observation that arose from the workshop process is that there may be a current gap in the skills required to support the ongoing development of the UK's key national infrastructure elements, both now and for the future. In particular, there is a distinct lack of UK engineering expertise required to design, deploy, operate and maintain important parts of the country's infrastructure. Approaching half of the UK's registered, professional engineers are due to retire within the next ten years, leaving a significant skills gap. Additionally, there may be a lack of scientific skills and expertise although it is thought that the needs in this area are probably less pressing with respect to national infrastructure development, than the needs with respect to engineering expertise.

Taking the example of the energy sector, there is a pressing need to deploy more renewable energy infrastructure in order to meet forthcoming targets for renewable energy. Offshore wind is particularly suited to the UK's geography but the deployment of this technology is being hampered by the fact that other countries have developed capabilities and skills in this area and have used these skills to build business


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opportunities in this area. Similarly, there are plans to develop new nuclear energy power stations in the UK over the next ten to fifteen years but the UK currently lacks the requisite nuclear engineering expertise to be able to develop and deploy these new power stations without resorting to non-UK skills and resources.

In theory, the lack of home-grown engineering skills might not be viewed as a problem if it is assumed that these skills can be imported from other countries. This is a trend that has been observed over the last several years. However, there are a number of potential problems with this approach. Firstly, such engineering skills are likely to be in great demand across the whole of Europe and more widely in the coming years due to the global need to improve infrastructure to meet GHG emissions reductions targets. By not developing our own engineering skills in these areas, the global pool of resources is likely to become highly sought after pushing up the prices that the UK pays for these resources and capabilities. This may mean that in future years, the costs of developing and deploying new infrastructure technologies may increase and consequently the costs to the UK as a whole of complying with future national and international regulation are likely to increase.

Additionally, by not developing home-grown skills in engineering and science the UK is not able to:

- effectively innovate and develop new technologies that could be used to leverage our position internationally and potentially develop new industries;

- rapidly take advantage of new technologies that may have been developed elsewhere but that could play a key role in strengthening the UK's national infrastructure and the whole economy.

The engineering skills gap observed in the UK is a particularly British phenomenon; the same type of skills gaps is not seen in other major economies such as the USA, Japan, Germany, or France. It is thought that one of the key reasons for this difference is due to cultural perception issues around the nature of engineering jobs. In most countries, engineering is viewed as a very highly skilled and valued profession on a par with doctors and lawyers. By contrast, in the UK engineering is generally viewed as a low-status profession. The only way to address this problem is through root-and-branch revisions to the education system taking into account all stages from primary education through to the university sector.

### 6.3.3 Regulation, Governance and Ownership

Analysis of the regulatory regimes for the national infrastructure indicates that:

- Regulatory regimes imposed on the privatised and deregulated industries have largely developed in silos for each industry or infrastructure
- Alignment of priorities across regulatory sectors is on an ad-hoc basis and does not reflect national or central policies and priorities
- Significant opportunities exist to bring the regulatory regimes into greater alignment.


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Some examples follow.

#### *6.3.3.1 Water issues*

Within the water sector, a significant conflict exists between the maintenance and operation of urban drainage systems that prevent flooding and the ownership of that infrastructure. The infrastructure is owned by the water and sewage companies, whose prime regulatory objectives are to provide water and sewage services - not prevent flooding. Responsibility for flood prevention and management in practice lies with the Environment Agency as the head agency with an extremely diverse and disconnected set of responsibilities further down the chain of governance.

There is substantial potential for energy capture or generation by off-gas capture during anaerobic digestion of sewage, and this has been identified as an opportunity for development in the UK Water Strategy. Such energy generation would dramatically reduce the carbon footprint of the UK water industry, which accounts for 1% of UK GHG emissions. However, governance of water companies by Ofwat does not prioritise renewable energy generation, but rather water provision.

Of the water abstracted from natural supplies in the UK, 29% is taken by the electricity generators and 59% is taken by the water companies for domestic and commercial supply. However, abstraction licenses are granted by the Environment Agency without meterage, so there is no incentive for abstractors to reduce their consumption. This is a particular problem in Central and SE England, where there is often strong competition for water between the two major abstractors in times of drought.

Water companies need a lot of power both to pump water and to treat fresh water and sewage; the stringency of these water quality regimes may encourage more energy consumption than is optimal.

#### *6.3.3.2 Waste Issues*

Within the waste sector, no incentives exist to encourage co-collection of waste from municipal and commercial sources, so waste collection can be inefficient. Similarly, waste processing systems are planned to address only a single stream – whether municipal or commercial – as a result of which economies of scale are not being achieved.

Current legislation requires that no more than 25% of the waste stream be incinerated. As a diversified and decarbonised energy supply is a UK Government priority, this seems out of line as considerably more energy could be generated from incineration of waste.

#### *6.3.3.3 Transport issues*

Within the transport sector, and number of regulatory conflicts exist which contradict national priorities. For example, rail franchises do not prioritise passenger capacity growth or modal switch. While all forecasts indicate dramatic growth in demand for rail


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services over coming decades, the rail franchise contracts simply require achievement of a minimum capacity criterion, and no incentives are provided to encourage an increase in rail capacity or a modal switch from road transport. This is at odds with our national objectives on greenhouse emissions reduction.


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# 7 Recommendations

The objective of this project was to produce high-level mapping of the interdependencies of the identified five elements of the national infrastructure and thereby to gain insight into potential vulnerabilities and opportunities for improvement in relation to their continued operation over the next 40 years or so. This is based on an assessment drawing on the knowledge and experience of the contributors rather than formal quantification of either risk or opportunities.

Any follow up work from this project will require further analysis and quantification and here we make recommendations for further study. At this first stage it is evident that there are several priority actions that should be considered for timely implementation; these are given below with other recommendations for further research.

Priority actions:

- Establish a national database containing baseline, digitised maps of all key infrastructure elements
- Raise awareness of the extent of interdependencies identified among stakeholders associated with the infrastructure elements
- Investigate those vulnerabilities, risks and opportunities identified through this project where the situation is perceived to be deteriorating in relation to one or more aspects of their future performance
- Develop a policy and regulatory model to support alignment to national priorities across relevant sectors
- Undertake formal evaluation of the present and future skills and knowledge bases required to support these infrastructure elements; leading to review of educational/developmental funding streams
- Identify and resolve situations where national and industry priorities may be in conflict.

Further research:

- To develop a deeper, systemic and systematic/scientific understanding of the initial relationships in order to fully understand the interdependencies, potential opportunities and emergent threats under changing economic and environmental conditions and to help establish a prioritised framework for action.

- To quantify interdependencies and risks through development of a predictive/forecasting systematic computer modelling of the national infrastructure, using public information sources, in order to:

    - comprehend the stress and potential failure points caused by changes in industry capacity and weather patterns;
    - explore leveraging opportunities across sectors;
    - identify critical interaction and/or confluence points.


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- To review the current and future availability of relevant skills and determine a strategy (in conjunction with higher education and professional bodies) to overcome likely shortfalls in skills;


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# Appendix 1 Table of Interdependencies

The table is split left and right to clarify the perspectives: ‘depending on’ and ‘depended on by’.

| **That** | **depends on** | **This** | **Count** | **Sum** | | **This** | **depends on** | **That** | **Count** | **Sum** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Transport | depends on | Waste | 3 | | | Transport | depends on | ICT | 5 | |
| Transport | depends on | Water | 5 | | | Energy | depends on | ICT | 2 | |
| Transport | depends on | ICT | 5 | | | Water | depends on | ICT | 3 | |
| Transport | depends on | Energy | 3 | 16 | | Waste | depends on | ICT | 5 | 15 |
| | | | | | | | | | | |
| Energy | depends on | Transport | 4 | | | Transport | depends on | Waste | 3 | |
| Energy | depends on | Waste | 5 | | | Energy | depends on | Waste | 5 | |
| Energy | depends on | Water | 6 | | | ICT | depends on | Waste | 3 | |
| Energy | depends on | ICT | 2 | 17 | | Water | depends on | Waste | 1 | 12 |
| | | | | | | | | | | |
| ICT | depends on | Transport | 3 | | | Transport | depends on | Water | 5 | |
| ICT | depends on | Waste | 3 | | | Energy | depends on | Water | 6 | |
| ICT | depends on | Water | 0 | | | ICT | depends on | Water | 0 | |
| ICT | depends on | Energy | 1 | 7 | | Waste | depends on | Water | 3 | 14 |
| | | | | | | | | | | |
| Water | depends on | Transport | 5 | | | Transport | depends on | Energy | 3 | |
| Water | depends on | Waste | 1 | | | ICT | depends on | Energy | 1 | |
| Water | depends on | ICT | 3 | | | Water | depends on | Energy | 2 | |
| Water | depends on | Energy | 2 | 11 | | Waste | depends on | Energy | 4 | 10 |
| | | | | | | | | | | |
| Waste | depends on | Transport | 4 | | | Energy | depends on | Transport | 4 | |
| Waste | depends on | ICT | 5 | | | ICT | depends on | Transport | 3 | |
| Waste | depends on | Energy | 4 | | | Water | depends on | Transport | 5 | |
| Waste | depends on | Water | 3 | 16 | | Waste | depends on | Transport | 4 | 16 |


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# Appendix 2 Level 2 Analysis: Detailed Interdependencies

The Level 2 Mapping considered interactions between the five infrastructure areas and identified their key interdependencies. A key dependency is one, which would result in reduced capacity to operate if one of the infrastructure pairs ceased or was limited in capacity. This led to the second level maps shown below for each of ten pairings. A dependency is indicated by a connecting arrow that always points to the dependent component; in most maps there is a mutual dependence between sectors.

Each connecting arrow has a title describing the nature of the interaction. Several of the connecting arrows have been qualified in terms of the 'key issues' outlined below in table A2.1 with further comment on the present day condition (current score) and likely future condition (future score - in approximately 40 years time or by 2050) of the issue. Thus: A = 'good', B = 'ok' and C = 'poor'. The right angle bracket (>) indicates the change in this view over the next 40 years or so. Thus, 1A > 1C indicates the effectiveness of governance is likely to become poor and likely to reduce efficiency in the future if not improved. This process is by necessity very qualitative and the issues presented are limited in number and depth. Those presented represent the views at the workshops of the most important issues and which could be qualified in order to help give an impression of how matters may change in time.

For issue 1 - Governance, 1A indicates present day governance is good - without major constraint on the infrastructure operation; 1C indicates poor governance and a negative impact of governance on operation. In the case of issue 5, Timescales the scoring represents the degree of urgency for action. Thus 5A indicates no urgency; B represents some concerns for action and C indicates urgency for action.

Table A2.1 Key issues for Level 2 Interdependency Maps.

| **Issue number** | **Description** | **Influence** |
|---|---|---|
| 1 | Governance | Positive or negative impacts |
| 2 | *Impact of ICT* | *N/a cross cutting* |
| 3 | Living with environmental Change | Positive or negative in terms of environmental pressures |
| 4 | *Skills* | *N/a cross cutting* |
| 5 | Timescales | Degree of urgency for attention |
| 6 | Resilience | Measure of the robustness of the established interactions |
| 7 | GHG emission mitigation | Potential to support or hinder achievement of Greenhouse gas emission reductions |

Summary commentary on each of the identified interdependencies is given below in sections A2.1 to A2.10.


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The number of commentaries is not equivalent to the number of interactions as some have been clustered for comment and others have no further comment. Each section follows the same structure with presentation of the interdependency map followed by commentary on the key interactions shown on the map.

# A2.1 Transport - ICT

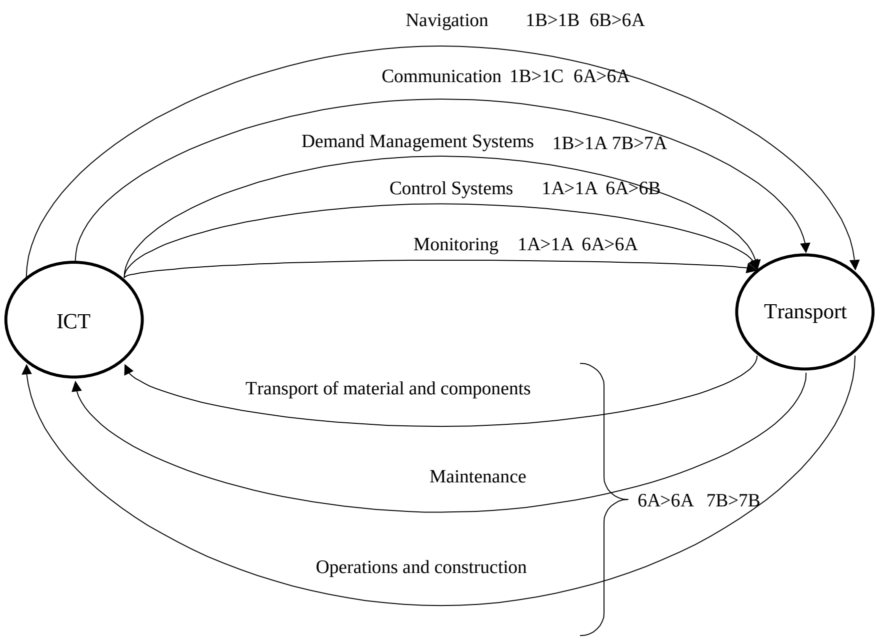


**Figure A2.1. Level 2 Transport-ICT interdependencies**

Figure A2.1 above summarises the key interactions between the ICT and transport sectors. Considering first the dependence of transport upon ICT systems:

## A2.1.1 Navigation

Governance (1) Current score: B Future score: B

Navigation systems are critical for the aviation sector and for the shipping sector. They are becoming increasingly important for the road transport sector as well. Governance issues are generally well controlled for aviation and shipping, but the use of navigation systems in the road transport sector currently relies on the US GPS network – it may be necessary to improve governance once competing systems are available.

Resilience (6) Current score: B Future score: A

Navigation that currently relies on GPS generally does not have any major resilience issues but is currently wholly dependent on a US satellite system. If for some reason this satellite system failed all GPS navigation across the world would also fail. In thirty


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years time, other competing systems may be in operation including the European, Gallileo system - thereby improving resilience.

### A2.1.2 Communications systems

Governance (1) Current score: B Future score: C

The communications systems used by the transport sector are well regulated and there are no significant problems associated with them. In the future it is considered that strengthened governance relating to data collection for demand management will be required in order to avoid, for example, congestion.

Resilience (6) Current score: A Future score: A

The transport sector is heavily reliant on communications systems; the rail network, the aviation sector, and the shipping sector all require communications to co-ordinate the movements of trains, aircraft, and ships respectively. Communications systems are also heavily used in the road transport sector (e.g. telecommunications for the emergency services, freight operators, armed forces etc). There are no significant resilience problems with the current systems and there are not anticipated to be any significant problems in 40 years time.

### A2.1.3 Demand management systems

Governance (1) Current score: B Future score: A

The use of ICT to facilitate demand management in the transport sector is still at a relatively early stage of development. There are a number of systems in use including various forms of intelligent transport systems (ITS); these work relatively well but there is scope for improving the effectiveness of such systems. In the future, it is anticipated that such systems will be much more sophisticated including automated vehicle control systems that may necessitate improvements in governance and regulation.

GHG mitigation (7) Current score: B Future score: A

ICT-based demand management systems can be used as a method for controlling GHG emissions from the transport sector, although to date they have had only limited impacts. The more sophisticated systems likely to be available in the next 40 years are likely to play a more significant role in reducing transport emissions.

### A2.1.4 Control systems

Governance (1) Current score: A Future score: A

The transport sector relies on a wide variety of ICT-based control systems, including traffic light controls for road transport, signalling for the railways, and air traffic control for the aviation sector. These systems are tightly regulated due to their importance in ensuring safety across the different transport networks. It is not anticipated that there


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will be any significant changes over the next 40 years that would reduce the effectiveness of the governance systems in place for these control systems.

Resilience (6) Current score: A Future score: B

We see no current, major problems in the resilience of control systems. However, additional demand for aviation in future years could compromise the resilience of air traffic control systems.

### A2.1.5 Monitoring and enforcement systems

Governance (1) Current score: A Future score: A

ICT is used to control monitoring and enforcement systems including cameras on the road network, safety systems (e.g. Train Protection and Warning System (TPWS) on the rail network) as well as systems for the aviation and shipping sectors. These systems are currently well regulated and it is not envisaged that there would be any degradation in the effectiveness of governance in the future.

Resilience (6) Current score: A Future score: A

Our view is that there are no current major problems in the resilience of control systems, and none are expected over the next 40 years.

Considering now the dependence of the ICT sector upon the transport sector.

### A2.1.6 Operations and construction: transport of staff and materials to construct, operate and maintain ICT infrastructure

Resilience (6) Current score: A Future score: A

There are no current transport network resilience problems with transporting the people necessary to construct, operate and maintain ICT infrastructure. Most people carrying out these roles are likely to travel by road transport. It is not anticipated that there will be any resilience problems with the transport networks that would cause any significant future problems.

GHG mitigation (7) Current score: B Future score: B

The transport of people and materials by road in order to construct, operate and maintain ICT infrastructure releases GHG emissions, but these emissions are low as a proportion of UK total transport emissions. These emissions are expected to remain low in 40 years time.


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# A2.2 Transport-Energy

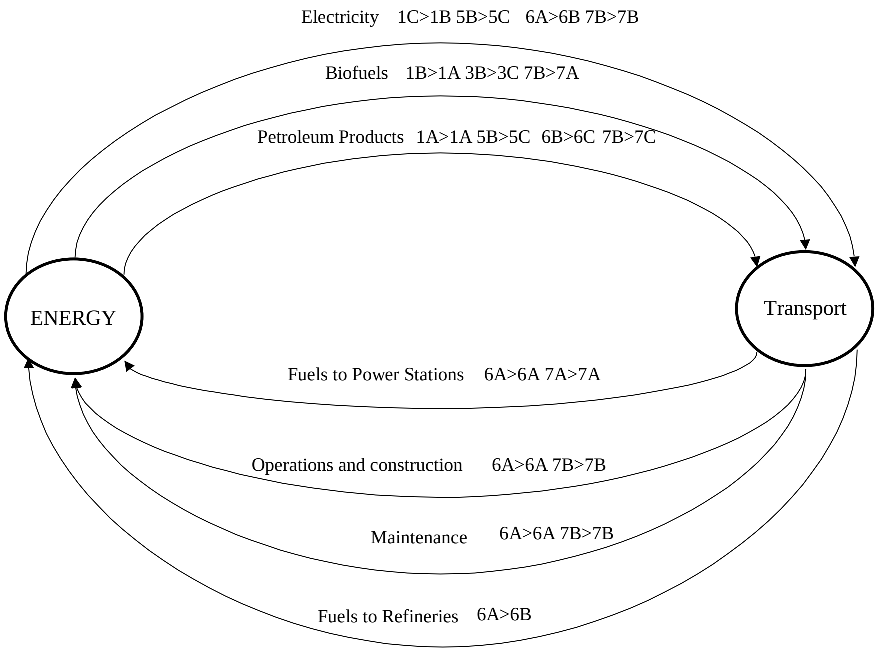


**Figure A2.2. Level 2 Transport – Energy interdependencies**

## A2.2.1 Petroleum products

Governance issues (1) Current score: A Future score: A

The distribution of petroleum-based fuels for the transport sector is currently, well regulated as these are the dominant fuels used by most forms of transport (used in road transport, rail, aviation, and shipping). It is not expected that there will be any degradation in governance issues over the next 40 years.

Timescales (5) Current score: B Future score: C

Petroleum products are limited resources and there are already some concerns about the limited global availability of these products – high levels of demand and concerns for over supply in 2008 caused prices to increase to unprecedented levels. In the future the impacts of growing demand in newly-industrialised countries will mean that there will be increasing urgency to reduce consumption of fossil fuels and switch to alternatives.

Resilience (6) Current score: B Future score: C

The supply of petroleum products from refineries is relatively resilient, but previous experience has shown that severe disruption to the distribution network can occur in a very short period of time (e.g. fuel protests in 2000). Over the next 40 years, potential


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reductions in the global availability of fossil fuels may make the supply and distribution system less resilient than it is now.

GHG mitigation (7) Current score: B Future score: C

The transport sector's use of fossil fuels is already recognised as a significant contributor to GHG emissions (currently approximately 21% of total GHG emissions in the UK). Projected growth in demand for transport services over the next 40 years means that without action to either reduce demand for transport or to shift to alternative energy sources, the transport sector's contribution to UK and global GHG emissions is projected to grow significantly.

### A2.2.2 Biofuels

Governance (1) Current score: B Future score: A

Biofuels are a relatively new form of transport fuel and consequently, the regulations concerning their use are still in the process of being developed. Issues surrounding the wider sustainability impacts of biofuels have only recently been identified and EU legislation is currently being developed, taking regard of these issues. Knowledge and understanding regarding the production and use of biofuels are still evolving, but it is anticipated that in 40 years time there will be a much better developed regulatory framework for these fuels.

Environmental change (3) Current score: B Future score: C

In certain areas of the world, the production of some types of biofuels leads to direct and indirect land use change, including deforestation. There are significant environmental impacts associated with such deforestation, not least of which is the destruction of important carbon sinks; deforestation of this nature is likely to accelerate the rate at which the effects of dangerous climate change are felt around the world.

GHG mitigation (7) Current score: B Future score: A

One of the main reasons for pursuing the use of biofuels for the transport sector in Europe and the UK is the potential reduction in transport GHG emissions that can be achieved through their usage. However, current first generation fuels offer relatively limited net emissions benefits. In 40 years time, most if not all biofuels may be so-called second generation or third generation fuels that are expected to be much more efficient in terms of reducing GHG emissions.

### A2.2.3 Electricity

Governance (1) Current score: C Future score: B

Currently, electricity for transport is only used in any significant proportion by the rail sector, and the governance issues are well-resolved in this area. However, there is now an emerging market for electricity to provide power for road transport applications, and the Governance issues in this area are not yet resolved (e.g. standards, provision of


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public recharging points, etc). In 40 years time, there is likely to be a much greater proportion of road vehicles that use electricity and it is anticipated that most of the governance issues will have been resolved.

Timescales (5) Current score: B Future score: C

Given the current need to start rapidly decarbonising the road transport sector by switching to alternative fuels, there is a pressing need to ramp up the process of using electricity to power light duty vehicles and some types of heavy-duty vehicles. This is dependent on both the provision of recharging infrastructure and the development and commercialisation of electric vehicles. In 40 years time, it is anticipated that there could be significant uptake of electric vehicles, but it is likely that there will still be some conventional fossil fuel powered vehicles on the road.

Resilience (6) Current score: A Future score: B

At the moment, there are no real resilience issues associated with the provision of electricity for transport services. Only the rail sector currently makes significant use of electricity for providing motive power, and even in this sector, electric trains account for less than 50% of current rolling stock. In 40 years time, should there be a more widespread shift to using electricity for transport, then any problems with electricity supply from the national grid would cause more severe problems than today.

GHG mitigation (7) Current score: B Future score: B

GHG emissions related to electricity use in the transport sector are currently very low in absolute terms (due to the current low levels of demand for electricity in this sector), but it would be possible for emissions to be even lower if a different mix of energy sources was used to generate the UK's electricity. Over the next 40 years there is likely to be action to significantly decarbonise electricity generation, which would reduce GHG emissions per kilometre travelled. However, if the mass electrification of the road transport sector occurs over the same time period, then overall GHG emissions associated with transport's use of electricity are likely to increase (but there would be a reduction in total transport sector emissions compared to the business as usual scenario of continuing to use fossil fuels).

Considering now the dependence of the energy sector on the transport sector.

### A2.2.4 Transport of fuels (e.g. coal, gas, oil, etc) to power stations

Resilience (6) Current score: A Future score: A

There are no current problems with transporting the raw materials (fuels) necessary to operate power stations in the UK – these fuels are transported by road, rail, and sea with little or no problems. It is not anticipated that there will be any resilience problems with the transport networks in 40 years that would cause future problems.

GHG mitigation (7) Current score: A Future score: A


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The transport of goods releases GHG emissions, and the provision of raw materials to power stations is no exception. However, these emissions as a proportion of total UK transport emissions are low and are likely to remain low in 40 years time, especially if a greater proportion of UK electricity is generated from renewable sources (e.g. wind, tidal) by that time.

### A2.2.5 Transport of staff to construct and operate power stations

Resilience (6) Current score: A Future score: A

There are no current transport network resilience problems with transporting the people necessary to construct and operate power stations (most are likely to travel by road transport, or possibly rail). It is not anticipated that there will be any resilience problems with the transport networks in 40 years that would cause future problems.

GHG mitigation (7) Current score: B Future score: B

The transport of people by road and rail in order to operate and/or construct power stations releases GHG emissions, but these emissions are low as a proportion of UK total transport emissions. These emissions are expected to remain low in 40 years time.

### A2.2.6 Transport of staff to maintain power stations and related infrastructure

Resilience (6) Current score: A Future score: A

There are no current transport network resilience problems with transporting the people necessary to maintain power stations and any related infrastructure (e.g. electricity substations, gas pipelines, etc). Most people carrying out these roles are likely to travel by road transport. It is not anticipated that there will be any resilience problems with the transport networks in 40 years that would cause any significant future problems.

GHG mitigation (7) Current score: B Future score: B

The transport of people by road in order to maintain power stations and supporting energy infrastructure releases GHG emissions, but these emissions are low as a proportion of UK total transport emissions. These emissions are expected to remain low in 40 years time.

### A2.2.7 Transport of fuels to refineries

Resilience (6) Current score: A Future score: B

There are no current significant problems with transporting unrefined crude oil to UK refineries. These fuels are transported by road, rail, and sea with little or no problems. It is possible that increased global demand for oil in future years may lead to some problems in being able to ensure security of supply in future years.


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# A2.3 Energy – ICT

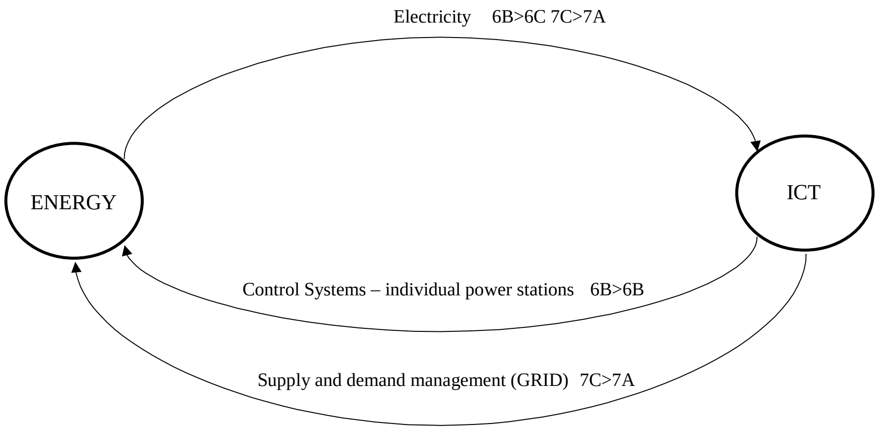


**Figure A2.3. Level 2 Energy-ICT interdependencies**

## A2.3.1 Electricity to power ICT systems

Resilience (6) Current score = B Future score = C

The resilience of the UK's electricity supply is currently reasonable with sufficient generation capacity to meet peak demand throughout the year (the margin between capacity and peak demand was 28% in 2008). There have been incidents where supplies have been affected by storm damage and flooding in local regions, and one power station came close to flooding in Gloucestershire in 2008. However the overall reliability of supply for the GB Transmission System during 2007-08 was 99.9995% according to National Grid statistics.

There are increasing concerns about resilience in the next 10-15 years due to (1) the need to close many of the existing coal and nuclear power stations as they reach the end of their lives or because they fail to meet the requirements of the EU Large Combustion Plant Directive (2) increased renewably generated electricity on the grid, mainly from wind energy, which supplies intermittently (30-40% of electricity from renewables targeted by 2020) and (3) energy security concerns as the UK relies more on imported oil and gas, much of it from politically unstable countries. Additional energy storage capacity could be added to make the system more resilient.


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GHG mitigation (7) Current score = C Future score = A

Technology analysts estimate that the manufacture, use and disposal of ICT equipment contribute around 2% of global emissions of carbon dioxide, which is about the same as aviation. This could rise to 3% by 2020. In the UK, the energy consumption associated with non-residential ICT use has grown from about 5 TWh in 1995 to nearly 20 TWh today, with a further 10T Wh used by servers and data-centres. 30 TWh represents about 9% of total UK electricity consumption. Electricity consumption associated with personal computers and other ICT equipment in the home is also increasing.

There is potential to significantly reduce electricity use in the ICT sector, and to use low carbon electricity sources such as renewable energy or nuclear. In the shorter term there is considerable potential to reduce the electricity consumption of ICT equipment, e.g. using power management techniques that cut the power supply when equipment is idle. If the UK follows the recommendations of the Committee on Climate Change (CCC) then it will significantly decarbonise its electricity supply in the medium- to long-term. According to the CCC, each kWh of electricity currently produces 500 grams of $CO_2$ and this figure could be down to 300 grams by 2020, to below 100 grams by 2030 and to well below 50 grams by 2050.

Considering now the dependence of the energy sector upon ICT.

### A2.3.2 Control Systems – individual power stations

Resilience (6) Current score = B Future score = B

Control systems for individual power stations appear to work reliably; we have been unable to find statistics on control system failures or overall plant availabilities.
New generation nuclear and fossil fuelled power plant are likely to use more sophisticated control systems than the current generation of plant, which should improve reliability and resilience. Conversely, control systems for distributed generation systems, including renewable energy generators, may be less advanced and less reliable than those used in large centralised power stations.

### A2.3.3 Supply and demand management (grid)

GHG mitigation (7) Current score = C Future score = A

There is thought to be considerable potential for using ICT technologies to reduce the demand for energy. In concept, smart meters can allow energy suppliers to monitor how electricity is being used in the home or office, and control demand either by providing information or by direct remote control of appliances. For example, if there was a peak in electricity demand forecast then the supplier could turn off the power to freezers for an hour or two. This sort of control will be particularly important if and when electric vehicles are introduced in significant numbers (a link with the transport sector). At present there are ongoing small-scale trials of smart meters to raise householder and business awareness of their energy use but these are not yet linked with active demand management measures. As recently highlighted by the National Audit Office, better


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information on how energy is used in the home could also be valuable in defining and implementing effective energy efficiency policies.

# A2.4 Water-ICT

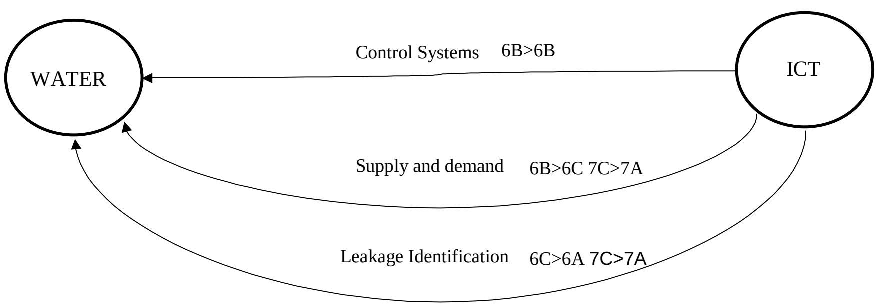


**Figure A2.4. Level 2 Water-ICT interdependencies**

## A2.4.1 Control Systems

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = B |

Water related services – including fresh water supply, sewage removal and flood control, are strongly dependent on ICT control and operations systems embedded in the equipment. This equipment is undergoing regular renewal and requires no urgent upgrades. However, water service systems are dominated by a single software operating system family, so all water services are vulnerable to a sustained attack from computer viruses or hackers. Service supply is also vulnerable to unusual natural events that could disrupt general ICT services, such as large solar flares.

## A2.4.2 Supply and demand

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = C |
| GHG mitigation (7) | Current score = C | Future score = A |


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Domestic demand for water has risen consistently since 1945 in accordance with trends in hygiene and washing, and is strongly linked to knowledge of consumption rates and cost, with demand typically falling by 10% where water meters are introduced. Meters are in place in about a third of homes, but there is no plan in place to complete the metered network, though there are regular calls for this from both OFWAT and the Environment Agency. A rapid installation of meters in all homes in drought prone areas of the UK (i.e. most of England South and East of Chester) would reduce demand for additional infrastructure, in particular potential infrastructure to pipe water from less drought prone areas of the UK.

An option to increase the efficacy of such meters would be integration with domestic energy metering systems, and telemetry of continuous meter counts. Such integrated metering systems could both improve domestic resource management and help to identify leaks in the domestic supply, which account for 6% of current demand for fresh water. This would also lead to improved resilience and reduction in GHG emissions

Thus an opportunity exists both to reduce demand for water by 10%-16% and so improve resilience, through a planned programme to rapidly install water or environment meters in homes in the drought prone parts of England. This would also reduce the UK's greenhouse gas emissions, as water supply accounts for 6% of emissions.

### A2.4.3 Leakage identification

| | | |
|---|---|---|
| Resilience (6) | Current score = C | Future score = A |
| GHG mitigation (7) | Current score = C | Future score = A |

District metering with telemetry is used as part of the freshwater distribution network in order to help identify and manage losses due to leakage in the network, and an extension of district metering would help reduce losses in the network. If taken in conjunction with improved domestic metering, this would give even better knowledge of state of the network, and could lead to a significant reduction in leakage, which currently accounts for 17% of demand.


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## A2.5 Water - Energy

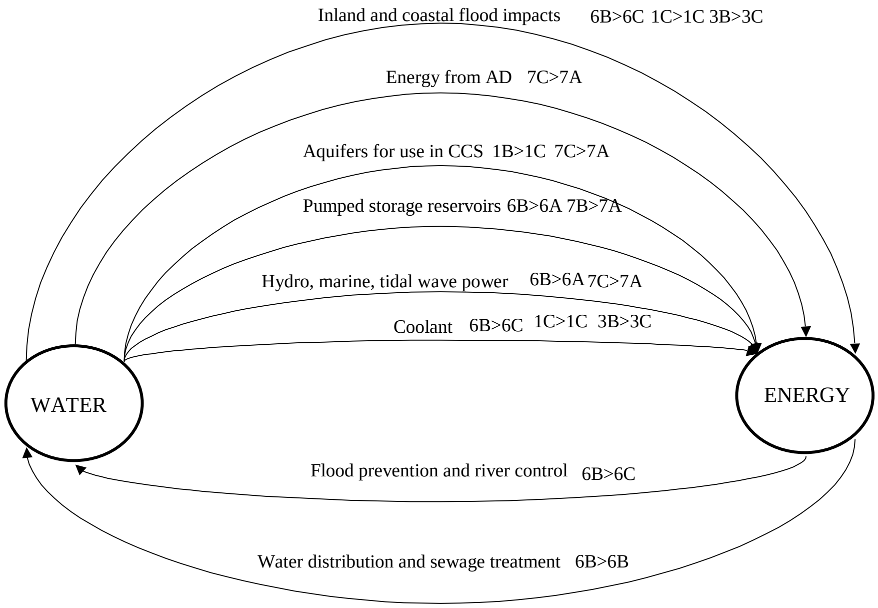


**Figure A2.5. Level 2 Water – Energy interdependencies**

### A2.5.1 Inland and coastal flood impacts

| | | |
|---|---|---|
| Governance (1) | Current score = C | Future score = C |
| Environmental Change (3) | Current score = B | Future score = C |
| Resilience (6) | Current score = B | Future score = C |

A significant proportion of UK energy generation and supply infrastructure is located close to the coast or significant water supplies. While most are not directly vulnerable to flooding, the supply chains of these power stations, oil refineries and gas storage depots, whether for fuel or labour, may be vulnerable to flooding. We recommend that the supply chains of these critical infrastructures be studied for vulnerability to flooding.

### A2.5. Energy from anaerobic digestion of sewerage and other compostables

| | | |
|---|---|---|
| GHG mitigation (7) | Current score = C | Future score = A |

Anaerobic digestion (AD) is the standard method of treatment of domestic sewerage and results in the production of methane. If captured and processed, this methane could be used to power turbines to generate electricity, power combined heat and power plants or to generate biomethane. The use of anaerobic digestion for energy is already included in the UK Water Strategy, but investment in this technology at sewerage plants would both


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allow the water industry to become energy neutral and reduce the UK's greenhouse gas emissions from sewerage treatment and potentially fresh water supply.

As the water industry emits 6% of the UK's GHG emissions and is capable of generating over 1% of UK energy demand, investment in this technology represents a significant opportunity to increase sustainable energy supply and reduce UK greenhouse gas emissions.

### A2.5.3 Aquifers for use in Carbon Capture and Storage

| | | |
|---|---|---|
| Governance (1) | Current score = B | Future score = C |
| GHG mitigation (7) | Current score = C | Future score = A |

Some aquifers are suitable for the storage of carbon dioxide and an opportunity exists to invest in this technology so that emissions of carbon dioxide from major energy consumers can be sequestered in aquifers. Development of this technology is already advanced in a number of competitor nations.

### A2.5.4 Pumped storage reservoirs

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = A |
| GHG mitigation (7) | Current score = B | Future score = A |

The ability to store energy confers a substantial increase in the effectiveness and resilience of the energy supply network, both using current technologies when demand is low at night and in future technologies when wind, solar or wave energy production may be intermittent. Storage of electricity by pumping water into uphill reservoirs is a very well established technology, in use since the 1930s, but investment in such reservoirs now will permit an increase in the efficiency of both current and future energy supplies.

### A2.5.5 Hydro, marine, tidal and wave power

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = A |
| GHG mitigation (7) | Current score = C | Future score = A |

Energy may be generated using these technologies, some very mature, and development of these services and technologies are currently the subject of extensive work. Investment in these technologies would help to diversify the supply of electricity in the UK and thus improve the resilience of the national energy supply. These technologies are also based on renewable resources and thus effectively zero GHG after construction.


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### A2.5.6 Water abstraction for the supply of coolant for power stations

| | | |
|---|---|---|
| Governance (1) | Current score = C | Future score = C |
| Environmental Change (3) | Current score = B | Future score = C |
| Resilience (6) | Current score = B | Future score = C |

Some 29% of water abstracted from surface and ground sources in the UK is used as coolant in power stations, a significant proportion of which is from the drought prone areas of the UK. During periods of drought or increased demand for water in future warmer weather scenarios, competition for water between domestic demand and coolant for electricity production could lead either to water shortages in the domestic supply or to the unplanned shutting down of a power station, leading to interruptions to electricity supplies.

In addition, an issue of governance exists as abstraction of water is managed by the Environment Agency, while demand for water is managed through OFWAT, and organisations directly abstracting water do not pay per mega-litre extracted, so there is no incentive to reduce demand.

Considering now the dependence of the water sector upon the energy sector.

### A2.5.7 Flood prevention and river control

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = C |

Many flood prevention systems, such as the Thames Barrier, depend on electricity to operate. In the event of a failure of energy supply, these systems would be unable to operate and protect their catchments. With possible impacts on rainfall, sea level rise and storminess expected to increase the current resilience of this infrastructure will come under increased challenge. The energy supply to major flood prevention infrastructures should come from generation systems that are not vulnerable to co-located threats.

### A2.5.8 Water distribution and sewage treatment

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = B |

Both the distribution of freshwater and the management of sewerage depend on the electricity supply, and loss of power would result in the immediate loss of fresh water distribution and sewerage removal. Where feasible water supply should be made resilient to energy generation, and this may be facilitated by energy generation from anaerobic digestion.


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# A2.6 Water –Transport

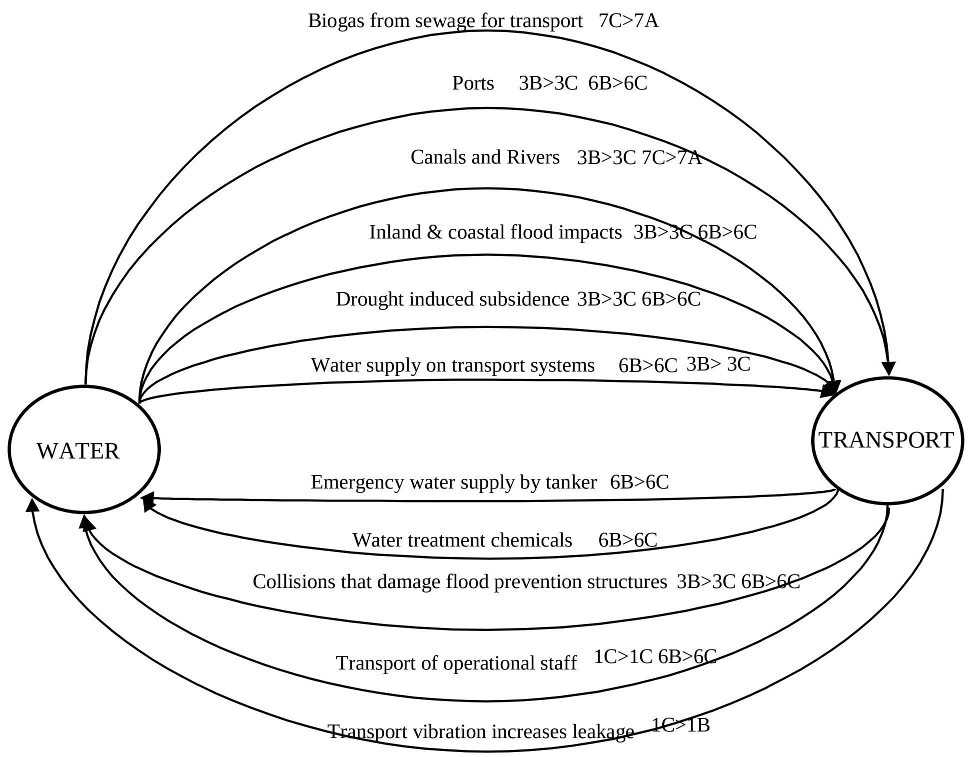


**Figure A2.6. Level 2 Water-Transport interdependencies**

### A2.6.1 Biogas from sewage for transport

Greenhouse gases (7) Current Score = C Future score = A

Anaerobic digestion of sewage produces as a by-product, methane which is a greenhouse gas. The technology for the capture of this by-product and its use as a fuel is well established, and one potential application of this fuel is in the transport system. This has the advantage of reducing the emissions of methane, increasing UK energy diversity and independence, increasing revenue for water companies and reducing the emissions of some regulated air pollutants, a four-way co-benefit. While the use of this fuel for electricity generation is emphasised in the Water Strategy, the use for transport is less so and this aspect of the fuel's use deserves greater attention, not least in transitional arrangement for air quality improvement.


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### A2.6.2 Ports

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Resilience (6) | Current Score = B | Future score = C |

A rise of even a couple of meters in sea levels would have dramatic effects on the UK coastline and would render a number of our ports obsolete. In the event that scientific evidence points strongly towards a rise in sea levels, it will be necessary to abandon some UK ports and invest in increasing the resilience of others to rising waters.

### A2.6.3 Canals & Rivers

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Greenhouse gases (7) | Current Score = C | Future score = A |

The UK has a substantial canal and river network and already makes good use of the Thames to transport non-urgent and bulky items, such as waste for incineration or landfill. There is scope for greater use of this resource as a low carbon method of transporting bulk items. However, these waterways can be expected to change significantly over the coming decades, and plans for their expansion and uptake should take account of these expected changes.

### A2.6.4 Impacts of inland and coastal floods, droughts and heatwaves

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Resilience (6) | Current Score = B | Future score = C |

Our transport infrastructure is designed to resist the effects of flooding, droughts and heatwaves that have occurred historically at certain locations and with certain frequencies. These locations and frequencies may change substantially with climate change, but the multi-decadal planning timescales for transport infrastructures mean that many planned roads and railways will experience different levels of flood or heatwaves when they are completed. Our plans for these structures should reflect the expected conditions on completion, rather than historic patterns.

### A2.6.5 Drought induced subsidence

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Resilience (6) | Current Score = B | Future score = C |

Prolonged drought leads to subsidence of land under geological conditions found widely in the UK, and such droughts are expected to increase in frequency over coming years. The consequence of this in the past has been to undermine roads and railways and this


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can be expected to increase in years to come. The UK should prepare a risk map for the effects of future drought induced subsidence on transport networks, to help identify locations of maximum impact and target infrastructures for improvement.

### A2.6.6 Water supply on transport systems during hot weather

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Resilience (6) | Current Score = B | Future score = C |

Hot weather can lead to transport failures, whether by subsidence, tar melting or rail buckling, and it is well documented that such failures can lead to passengers being stranded for significant periods in very hot conditions. This can be a great risk to health. When prolonged hot spells are expected we can increase the resilience of our services by storage of bottled water supplies on the underground and surface trains on lines that are most prone to signal failure or subsidence, and close to major roads that are most vulnerable to fine weather congestion or tar-melt.

Considering now the dependence of water upon the transport infrastructure.

### A2.6.7 Emergency water supply by tanker

| | | |
|---|---|---|
| Resilience (6) | Current Score = B | Future score = C |

During the most severe flooding or drought events, water supply by tanker may be required, and the frequency of such events is expected to increase in years to come. Current demand for such tankers is met by supply; demand is expected to increase in the future. Risk mapping of floods and droughts can be used to estimate the potential demand for such tankers in the event of a prolonged or serious extreme weather event, and ensure that sufficient vehicles are available to meet demand.

### A2.6.8 Water Treatment Chemicals

| | | |
|---|---|---|
| Resilience (6) | Current Score = B | Future score = C |

The fresh water supply depends on the availability of certain chemicals with which the water is treated. Certain extreme weather events have the potential to close off roads to water treatment plants in flood risk zones and their frequency is expected to increase over coming decades. To mitigate the potential impacts of such events, a reserve supply of these chemicals could be kept at the water treatment plants.

### A2.6.9 Collisions that damage flood prevention structures

| | | |
|---|---|---|
| Environmental Change (3) | Current Score = B | Future score = C |
| Resilience (6) | Current Score = B | Future score = C |

A number of flood prevention structures, in particular the Thames Barrier, are vulnerable to collisions from shipping or other transport related accidents that could temporarily


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reduce their effectiveness. If such an accident took place during or immediately before a high tide or storm surge event, there's a risk the floodplain behind the barrier could be affected. As the likelihood of such storm tides and flooding incidents is expected to increase over coming years, modifications should be made to traffic controls near such installations so as to reduce the risk of disabling incidents during periods of high risk.

### A2.6.10 Transport of Operational Staff

Resilience (6) Current Score = B Future score = C

Water supply depends on staff having adequate access to non-automatic treatment plants, and access for staff to plants needs to be considered in resilience planning.

### A2.6.11 Transport vibration effects on water leakage

Governance (1) Current Score = C Future score = B

Vibration from vehicles has the effect of increasing damage to water pipes, particularly in older ceramic mains. An opportunity exists at local level to prolong the life of water mains and reduce leakage by diverting the heaviest vehicles from roads that such water mains lie under. As water supplies dwindle over coming decades this may become a significant factor in the conservation of water.

## A2.7 Waste –Transport

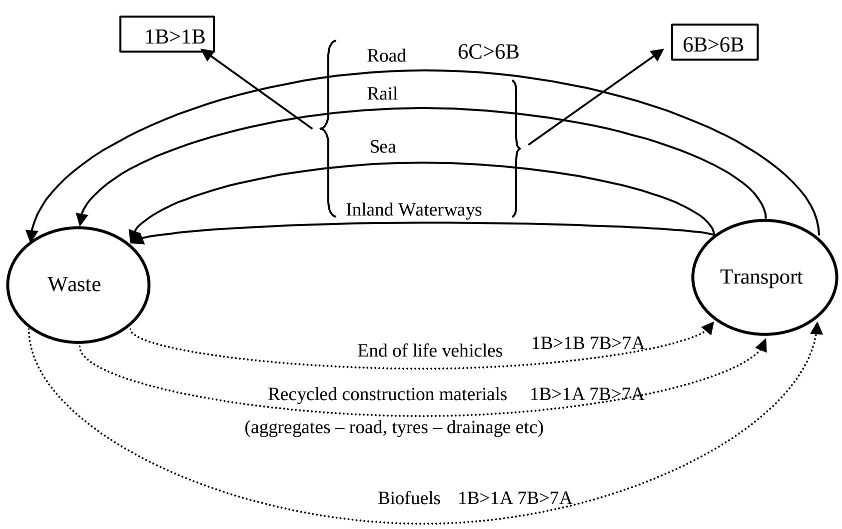


**Figure A2.7. Level 2 Waste-Transport interdependencies**


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### A2.7.1 Roads, Rail, Sea and Inland Waterways to Transport Waste

Governance (1) Current Score = B Future score = B

There is currently reasonably strong governance over the transportation of waste. The governance surrounding waste is unlikely to change to any great degree and should not change if waste flows are to continue to be monitored and waste data collection is going to improve. However, as initiatives such as the Waste Quality Protocols and Publicly Available Specifications (PAS's) continue to be rolled out, more recycled materials will be labelled as products as opposed to waste and will therefore be subject to a certain degree of deregulation.

### A2.7.2 Roads to Transport Waste

Resilience (6) Current score = C Future score = B

Most waste is currently transported by road and in most cases there is currently no alternative to this. Kerbside collection of MSW (Municipal Solid Waste) is particularly vulnerable to any issues with road transport as waste is collected by road, door to door. Going forward, the carbon agenda is likely to drive a move towards other transport modes (rail, sea and inland waterways), which would mean that any significant problems with the road infrastructure would be less catastrophic for the continued waste operations. Whereas this will help the collection of waste once it has been bulked, the system is still vulnerable due to the requirement to collect from households and individual premises.

### A2.7.3 Rail, Sea and Inland Waterways to Transport Waste

Resilience (6) Current score = B Future score = B

There is some flexibility inherent between these modes of transport. If one of road, sea or inland waterway transport modes are no longer available, it is possible for waste to be re-routed elsewhere. This will continue to be the case going forward unless too much reliance is placed on rail, sea or inland waterways; this is the case with roads presently.

Considering now dependence of the transport sector upon the waste sector.


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### A2.7.4 End of Life Vehicles (ELVs), which are disposed of to the Waste Sector

| | | |
|---|---|---|
| Governance (1) | Current Score = B | Future Score = B |
| GHG mitigation (7) | Current Score = B | Future Score = A |

This has been assigned a dotted line as although it is recognised that the transport sector is dependent on the waste sector to safely dispose of its waste in an environmentally responsible manner it is also recognised that the transport system would continue should this link be removed. Therefore this is a very weak dependency. There is sufficient effective governance in place surrounding ELVs. There is no anticipated change to this we must continue to ensure that vehicles are disposed of in a responsible manner. Currently the ELV legislation is helping drive GHG savings. It is likely that this dependency will continue to be encouraged promoting further GHG savings.

### A2.7.5 Recycled Construction Materials used by the Transport Sector in Construction of Transport Links

Again this has been assigned a dotted line as although it is recognised that the transport sector currently has some dependency on the waste sector for recycled construction material for roads, rail and other infrastructure it is recognised that this construction would continue without these materials. Therefore this is a very weak dependency.

| | | |
|---|---|---|
| Governance (1) | Current Score = B | Future Score = A |
| GHG mitigation (7) | Current Score = B | Future Score = A |

There is a significant amount of legislation in place to ensure that these materials are used appropriately and in a responsible manner. The governance surrounding the use of these materials is set to continue to improve to encourage the use of recycled, reused and recovered materials in construction as opposed to virgin raw materials. Currently the use of waste materials in construction is promoting GHG savings when compared with using raw materials. It is likely that this dependency will be encouraged promoting further GHG savings.

### A2.7.6 Biofuels derived from waste materials used to power vehicles

A dashed line represents this dependency because, although the transport sector is currently partially reliant on the waste sector for these fuel sources, it would not fail without them – it would use alternate sources.

| | | |
|---|---|---|
| Governance (1) | Current Score = B | Future Score = A |
| GHG mitigation (7) | Current Score = B | Future Score = A |

Currently the climate change agenda and national waste policy are driving a move towards the use of biofuels to fuel waste vehicles promoting close loop systems within waste management. This is set against the backdrop of strong climate change and waste governance. With a drive towards increased use of anaerobic digestion, GHG


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savings and cost efficiencies the governance surrounding the use of biofuels is likely to increase. Currently the use of biofuels is promoting GHG savings when compared with using fossil fuels. It is likely that this dependency will be encouraged, promoting further GHG savings.

# A2.8 Waste-Energy

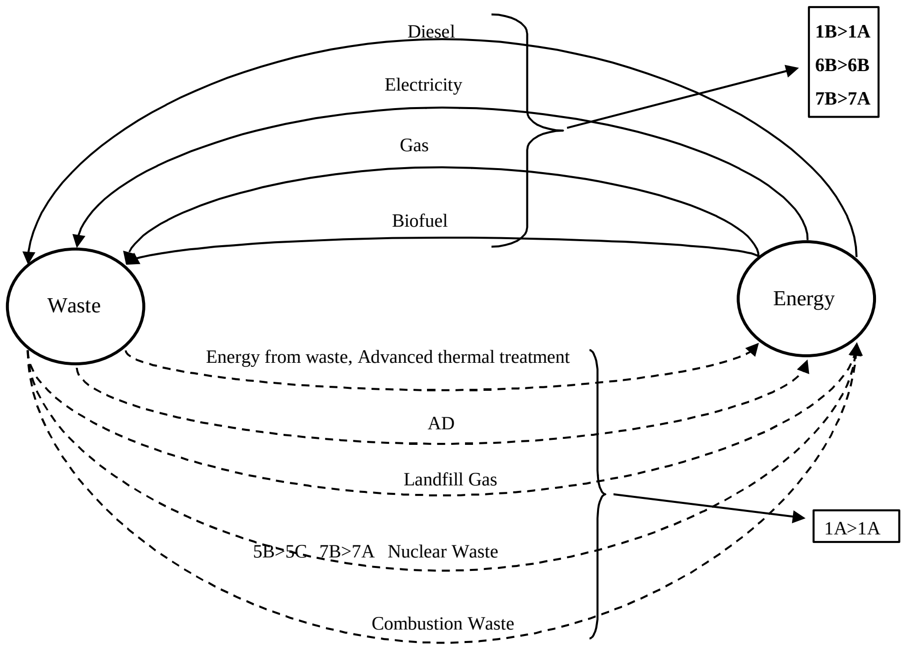


**Figure A2.8. Level 2 Waste-Energy interdependencies**

## A2.8.1 Energy to power waste systems and services

| | | |
|---|---|---|
| Governance (1) | Current Score = B | Future Score = A |
| Resilience (6) | Current Score = B | Future Score = B |
| GHG mitigation (7) | Current Score = B | Future Score = A |

There is governance in place that is shifting the emphasis from an over-reliance on a single energy source towards renewable energy or closed looped scenarios. This trend is set to continue. Due to the diversity of energy sources there is some resilience in the system. Diesel is perhaps the least resilient in terms of vehicles collecting waste. The resilience of the fuel supply for waste collection vehicles is likely to remain sufficient as there will be continued, if not increased efforts to move towards more renewable or closed loop systems. The waste sector is already making moves to become more sustainable using biofuels derived from wastes to power vehicles and energy from waste to power facilities. This trend is set to continue which will have a continued positive effect on GHG emissions.


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Considering now dependence of the energy sector upon the waste sector.

### A2.8.2 Energy from Waste, Advanced Thermal Treatment, Anaerobic Digestion, and Landfill Gas – providing sources of energy from waste materials.

A dashed line represents this dependency because, although the energy sector is currently partially reliant on the waste sector for these fuel sources, it would not fail without them – it would use alternate sources.

Governance (1) Current Score = A Future Score = A

There is a great deal of governance surrounding these technologies that derive energy from waste – disproportionately so when compared with other sources of energy production. Due to the controversy surrounding waste treatment and disposal facilities this is likely to continue to be the case.

### A2.8.3 Combustion Waste, disposed of to the waste sector

These have been assigned a dotted line as although it is recognised that the energy sector is dependent on the waste sector to safely dispose of its nuclear and combustion waste in an environmentally responsible manner it is also recognised that the energy sector would continue should this link be removed. Therefore this is a very weak dependency.

Governance (1) Current Score = A Future Score = A

There is a great deal of governance surrounding the disposal of these wastes. Due to the controversy surrounding these waste streams this is set to continue.

### A2.8.4 Nuclear Waste, disposed of to the waste sector

| | | |
|---|---|---|
| Timescales (5) | Current Score = B | Future Score = C |
| GHG mitigation (7) | Current Score = B | Future Score = A |

There is need to identify safe and responsible methods and locations for disposing of this material. As time progresses the urgency to identify these methods and locations will continue to increase, particularly if a new tranche of facilities is constructed. Nuclear energy represents a low GHG emission energy source. Continuing to use this - safe disposal of the waste has been a consideration in this decision – will enable continued and increased reductions in GHG emissions.


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# A2.9 Waste-ICT

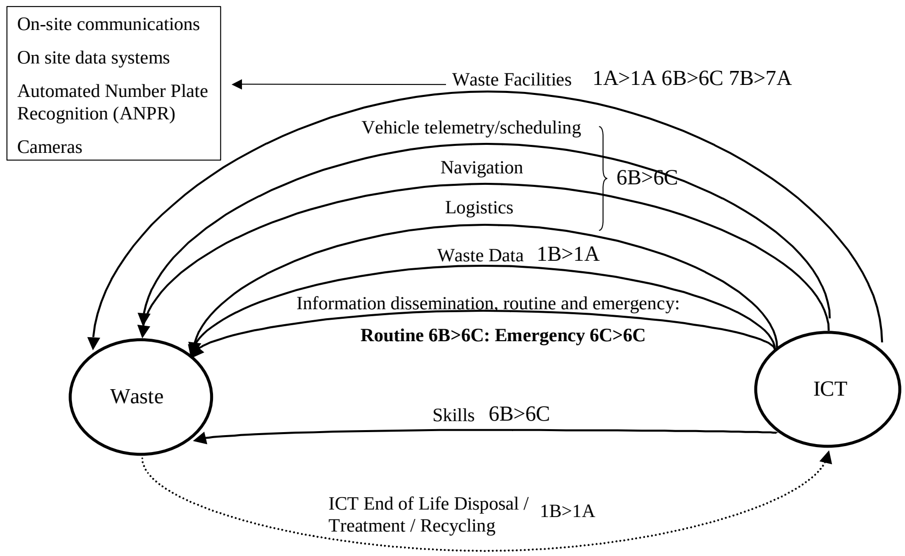


**Figure A2.9. Level 2 Waste-ICT interdependencies**

### A2.9.1 Waste Facilities, Vehicles, Navigation, Logistics, Waste Data reliance on ICT systems

| | | |
|---|---|---|
| Resilience (6) | Current score = B | Future score = C |
| Governance (1) | Current Score = A | Future Score = A |
| GHG mitigation (7) | Current Score = B | Future Score = A |

A combination of the underdevelopment of ICT in waste management industry and the traditional (pre ICT) know how within the industry means that an ICT failure would be less catastrophic than in other sectors. As dependency on ICT increases and traditional (pre ICT skills) diminish the waste sector will be less resilient to ICT failure.

There are very strong ICT systems in place at waste facilities in terms of operations and emission controls. The ICT controlling waste facilities will continue to improve and develop due to the controversial nature of these sites. There are good ICT control systems currently in place to monitor and control GHG emissions. These are likely to continue to improve due to the controversy over emissions at waste facilities.


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### A2.9.2 Waste Data reliance on ICT systems

Governance (1) Current Score = B Future Score = A

There is currently good use of ICT in monitoring Municipal Solid Waste (MSW) arisings and waste flows. However, the use of ICT is poor in the other waste sectors. This assumes the required need for greater collation of data from other waste sectors leads to this infrastructure being put in place.

### A2.9.3 Information dissemination, routine and emergency

Resilience (6) Current Score = B Future Score C (Routine)
Current Score = C Future Score C (Emergency)

There are other methods such as door-stepping and use of visiting organisations as well as businesses available to disseminate information, if there were an ICT failure currently. However, this would not be sufficient in an emergency situation where other ICT dependent communication methods would be more effective – TV and radio announcements and internet / e-mail. Greater reliance on ICT will make information less resilient to ICT failure in the future.

### A2.9.4 Skills

Resilience (6) Current Score = B Future Score = C

Currently there is a growing demand for ICT support for the waste sector with the drive for better quantification of waste flows and management of more sophisticated plant. Any future shortage of trained staff able to operate and manage new plant will increase vulnerability.

Considering now dependence of the ICT sector upon the waste sector.

### A2.9.5 ICT End of Life Disposal, Treatment and Recycling

This has been assigned a dotted line because, although it is recognised that the ICT sector is dependent on the waste sector to safely dispose of its waste in an environmentally responsible manner it is also recognised that the ICT system would continue should this link be removed.

Governance (1) Current Score = B Future Score = A

The Waste Electrical and Electronic Equipment (WEEE) Regulations provide a governance framework for the recycling, treatment and disposal of WEEE products. As ICT becomes more and more intrinsic to the national infrastructure the continued safe and responsible disposal of the waste from this sector will need to be implemented and the governance will need to support this.


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# A2.10 Waste-Water

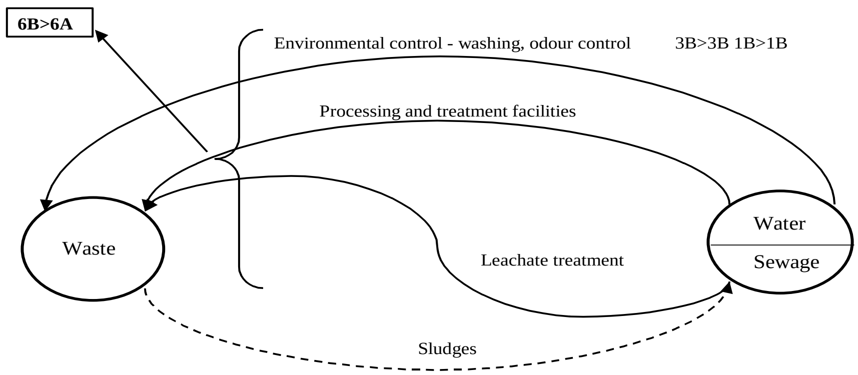


**Figure A2.10. Level 2 Waste – Water interdependencies**

## A2.10.1 Waste sector dependence on the water sector to maintain environmental permitting e.g. washing and odour scrubbing

| | | |
|---|---|---|
| Governance (1) | Current Score = B | Future Score = B |
| Environmental Change (3) | Current Score = B | Future Score = B |
| Resilience (6) | Current Score = B | Future Score = A |

Waste permitting and planning provide a rigid governance framework for the use of water in terms of mitigating potential environmental issues. The controversial nature of waste facilities will require this framework to remain in place. A drought may produce issues associated with water as if there is no wash down water this could present odour, vermin and other environmental issues. This risk would remain the same going forward.

## A2.10.2 The waste sector dependence on the water sector to operate waste facilities and undertake leachate treatment

| | | |
|---|---|---|
| Resilience (6) | Current Score = B | Future Score = A |

Currently waste facilities are dependent on the water sector operationally and for environmental control making them vulnerable if there is a failure in the water sector. Co-locating and a more sustainable approach to water management on site could reduce the dependency on water at these facilities


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# Appendix 3 Level 3 (Base) Analysis: Key Component Maps

The maps in this section were generated during the early workshops sessions and cover the influences on the five infrastructure elements. They capture the initial thinking on the issues relating to governance, infrastructure linkages and demand for services or supply from the public and commercial sectors. Because they represent the evolving thinking of the groups at the time, the contents have not been edited for uniformity. The thinking and mapping represented in the maps subsequently informed development of the Level 2 Detailed Interdpendencies given in Appendix 2 of this report.

The map structure for each sector utilises a common “3-layer” model (the first diagram) with a layer to represent each of: governance, infrastructure elements and demand. The final layout for each map varies and reflects the thinking at the time of the working groups on how best to represent the key elements and influences for each sector.

During the early mapping, entities (or elements of infrastructure) were represented in ovals; where these are coloured yellow this indicated a link to another sector, red ovals indicated a virtual entity. In the diagrams relationships between entities are shown simply, using connecting arrows. For some relationships, further qualification emerged in the workshops; thus, some of the arrows have been colour coded - green arrows indicate an amplifying influence and blue arrows a damping influence. On some figures straight bold arrows appear; they represented ‘areas of connectivity’ between levels.


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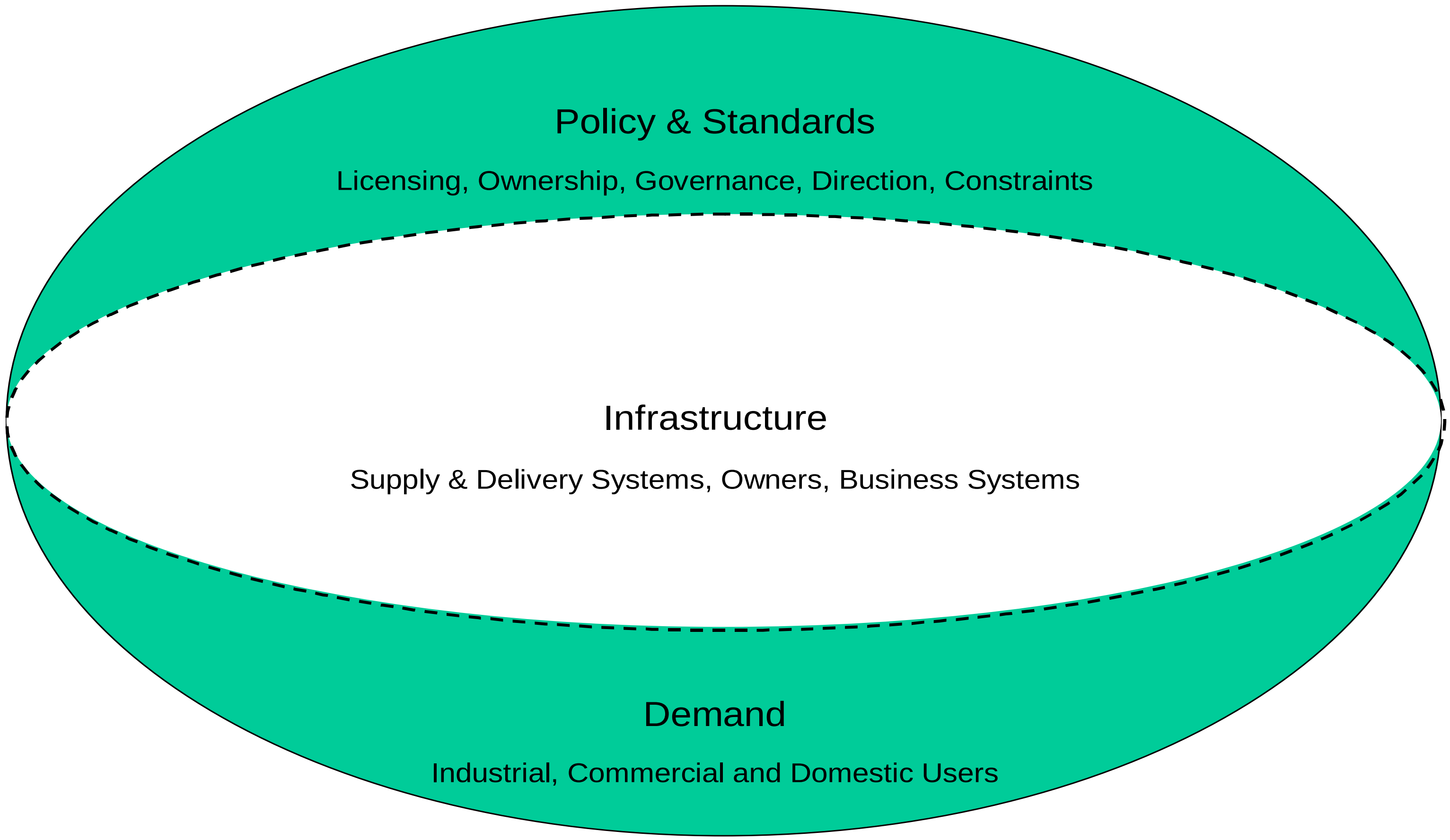
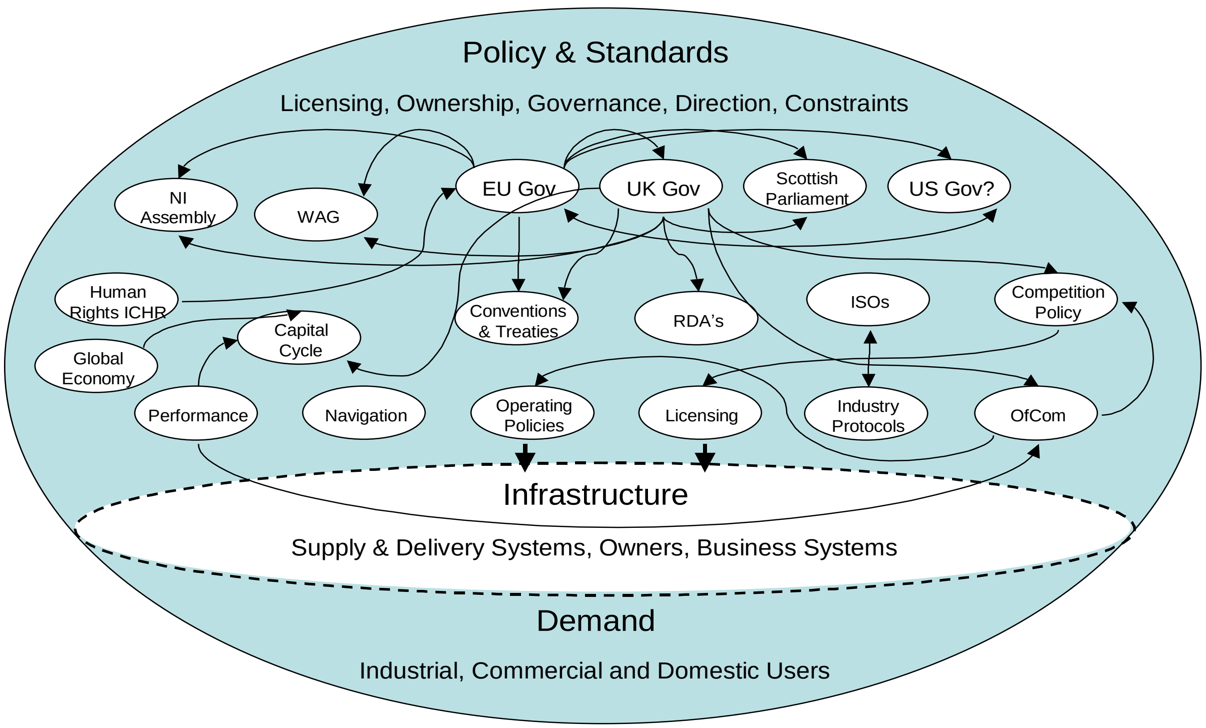
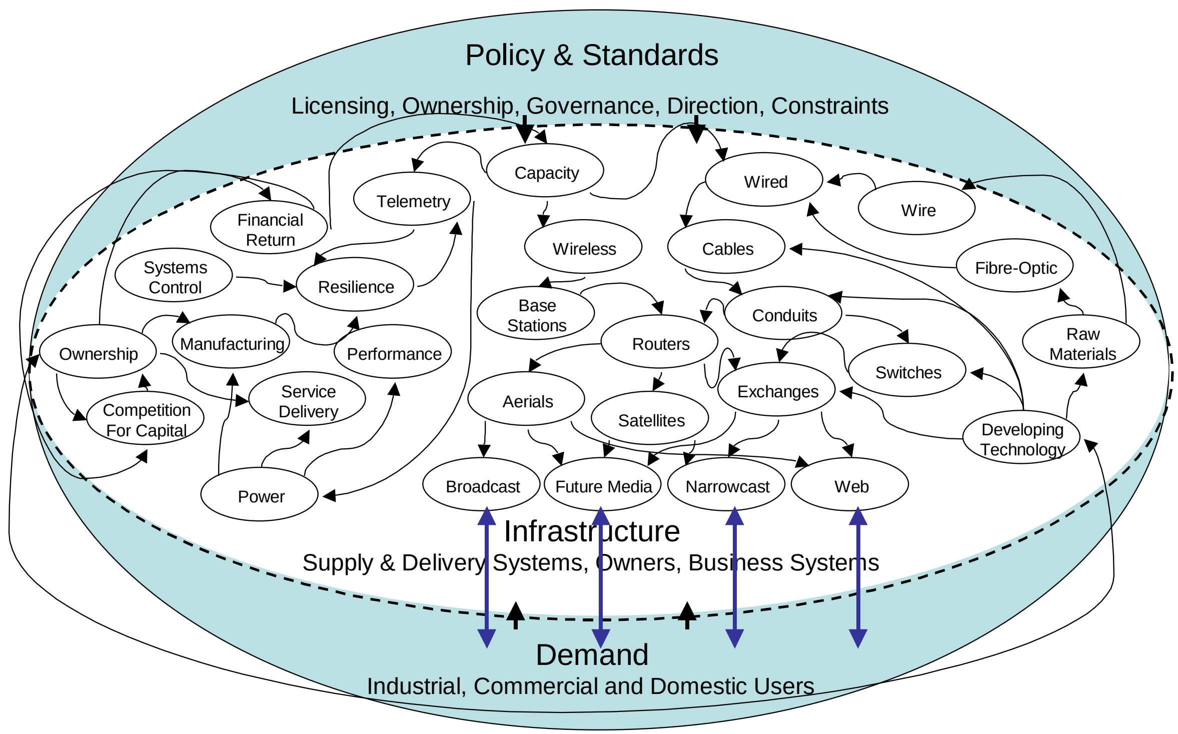
# The Levels


Policy & Standards
Licensing, Ownership, Governance, Direction, Constraints
Infrastructure
Supply & Delivery Systems, Owners, Business Systems
Demand
Industrial, Commercial and Domestic Users

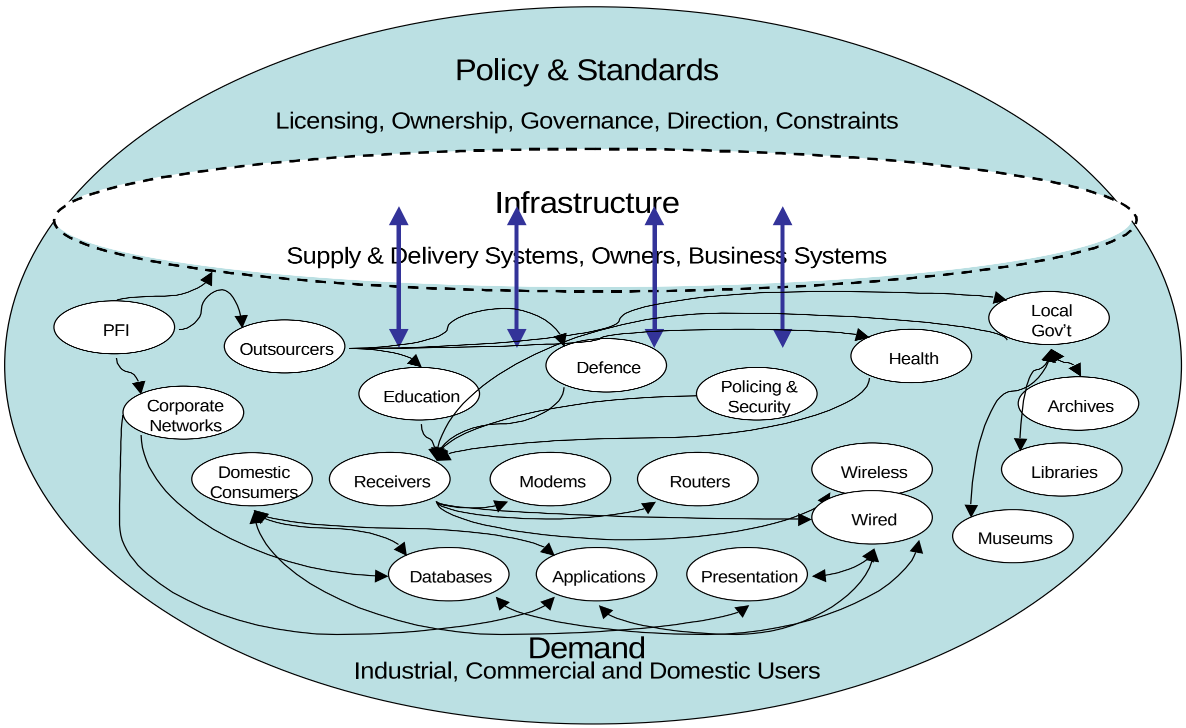
# ICT - Policy and Standards



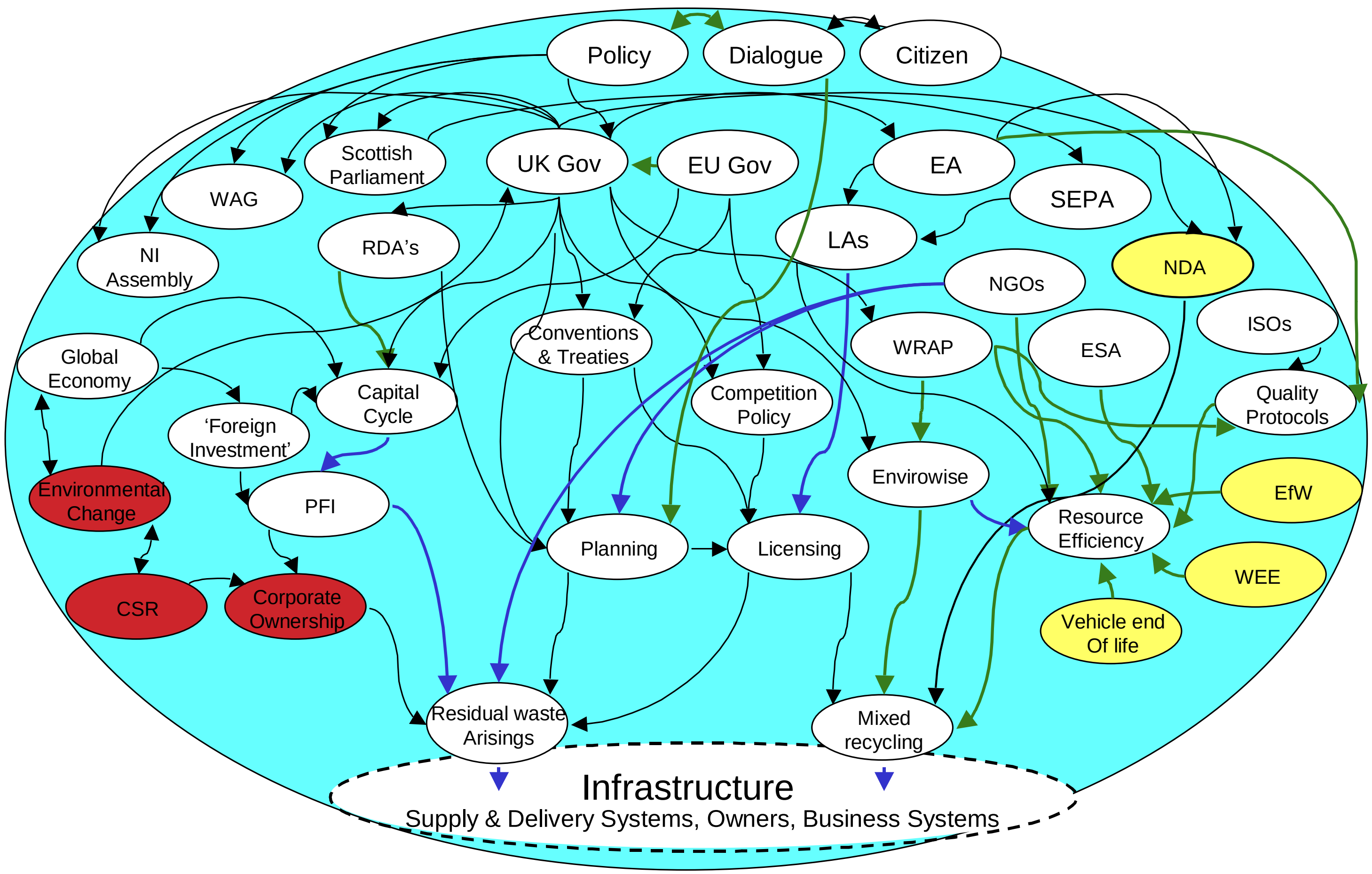
# ICT -Infrastructure



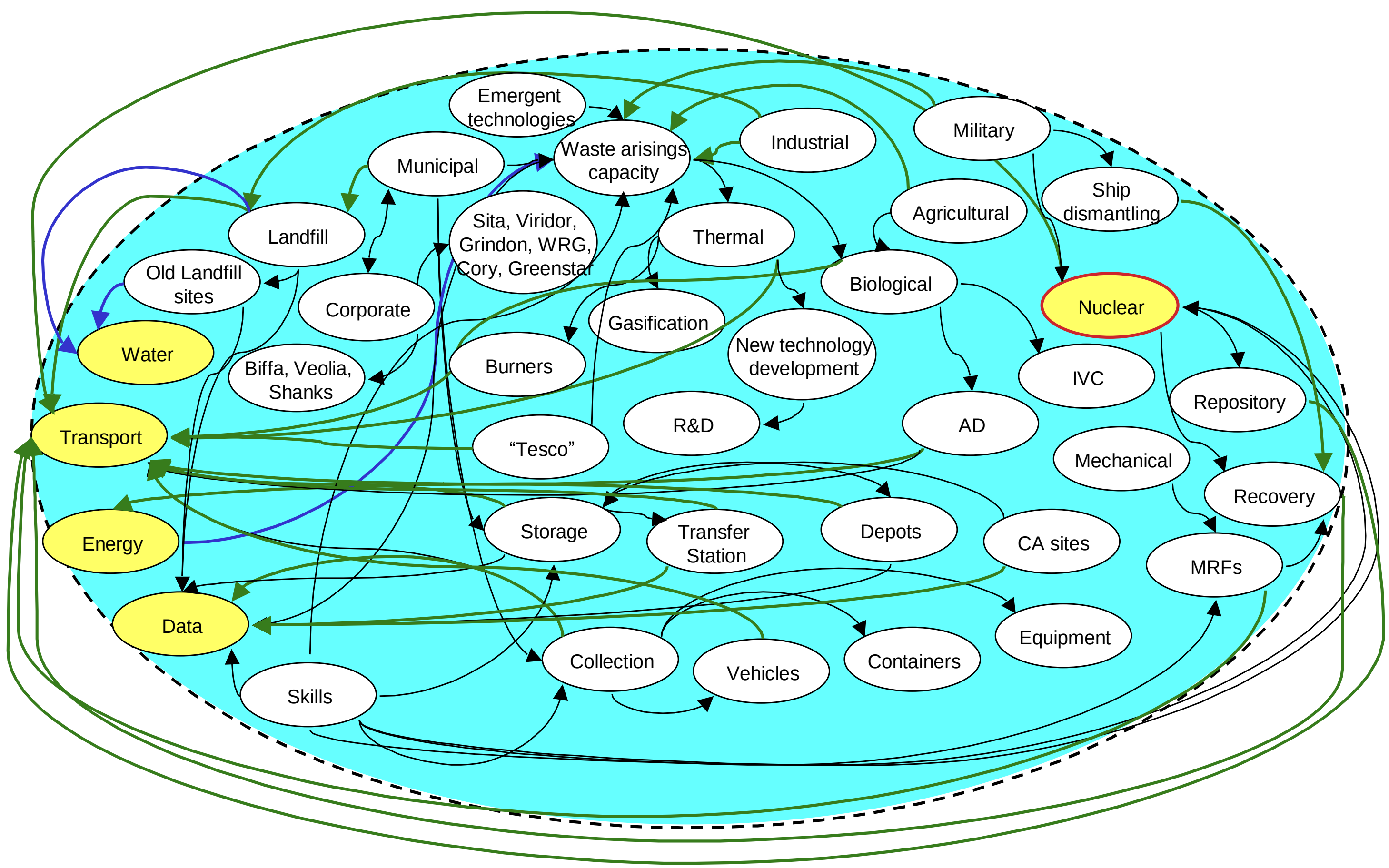
# ICT - Demand


Policy & Standards
Licensing, Ownership, Governance, Direction, Constraints
Infrastructure
Supply & Delivery Systems, Owners, Business Systems
PFI
Outsourcers
Corporate Networks
Education
Defence
Policing & Security
Health
Local Gov't
Archives
Libraries
Museums
Domestic Consumers
Receivers
Modems
Routers
Wireless
Wired
Databases
Applications
Presentation
Demand
Industrial, Commercial and Domestic Users

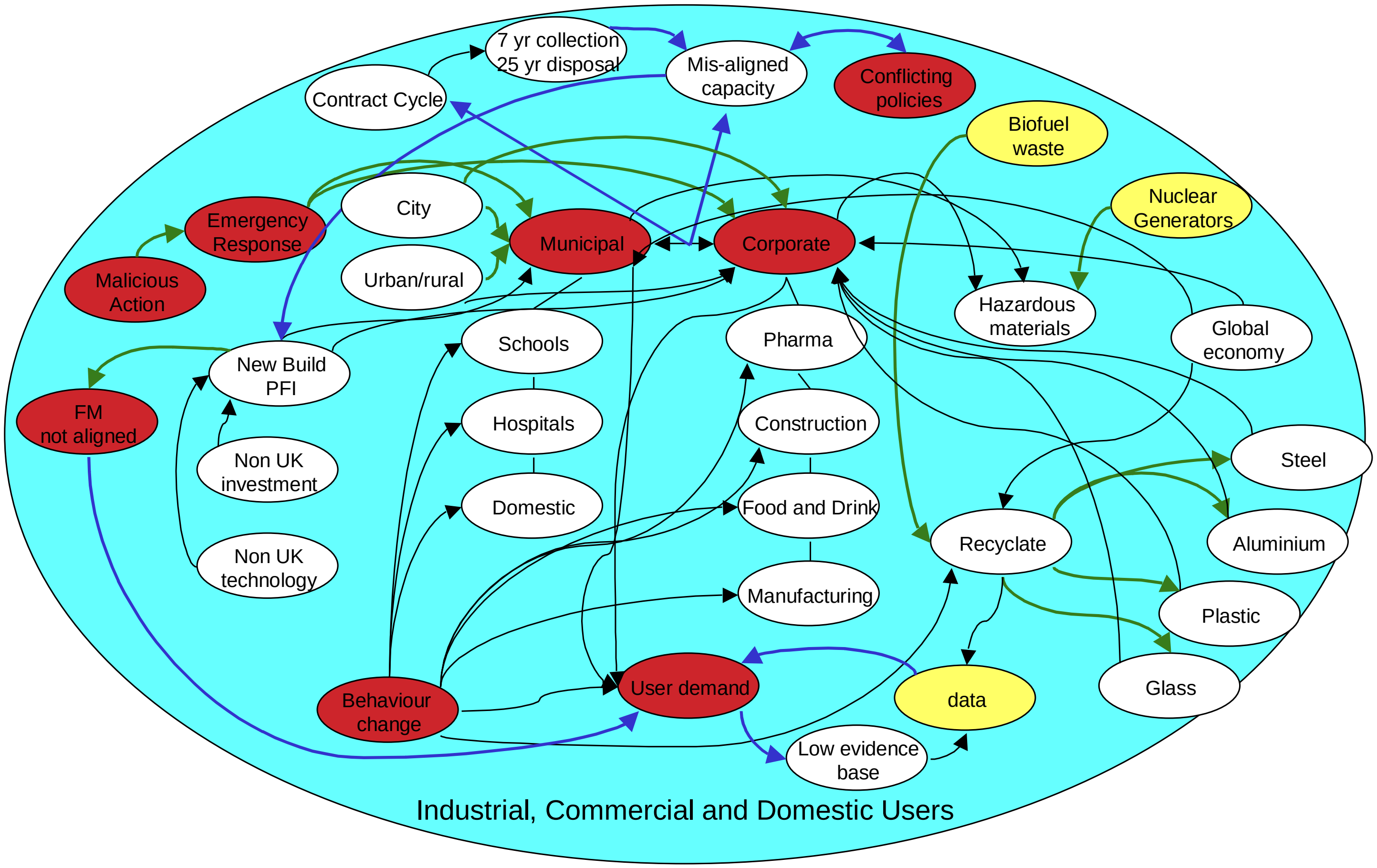
# Waste - Policy and Standards



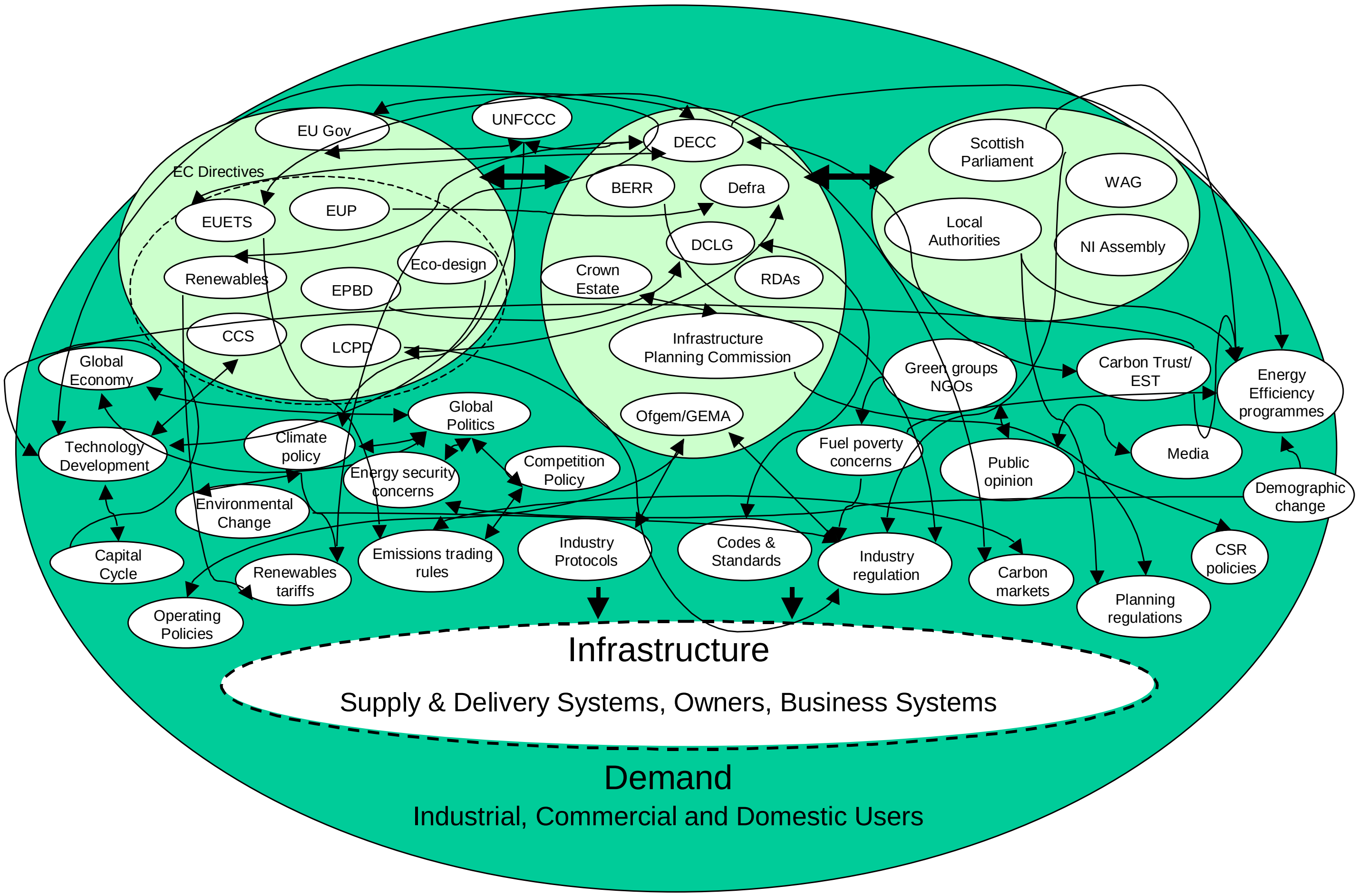
# Waste - Infrastructure



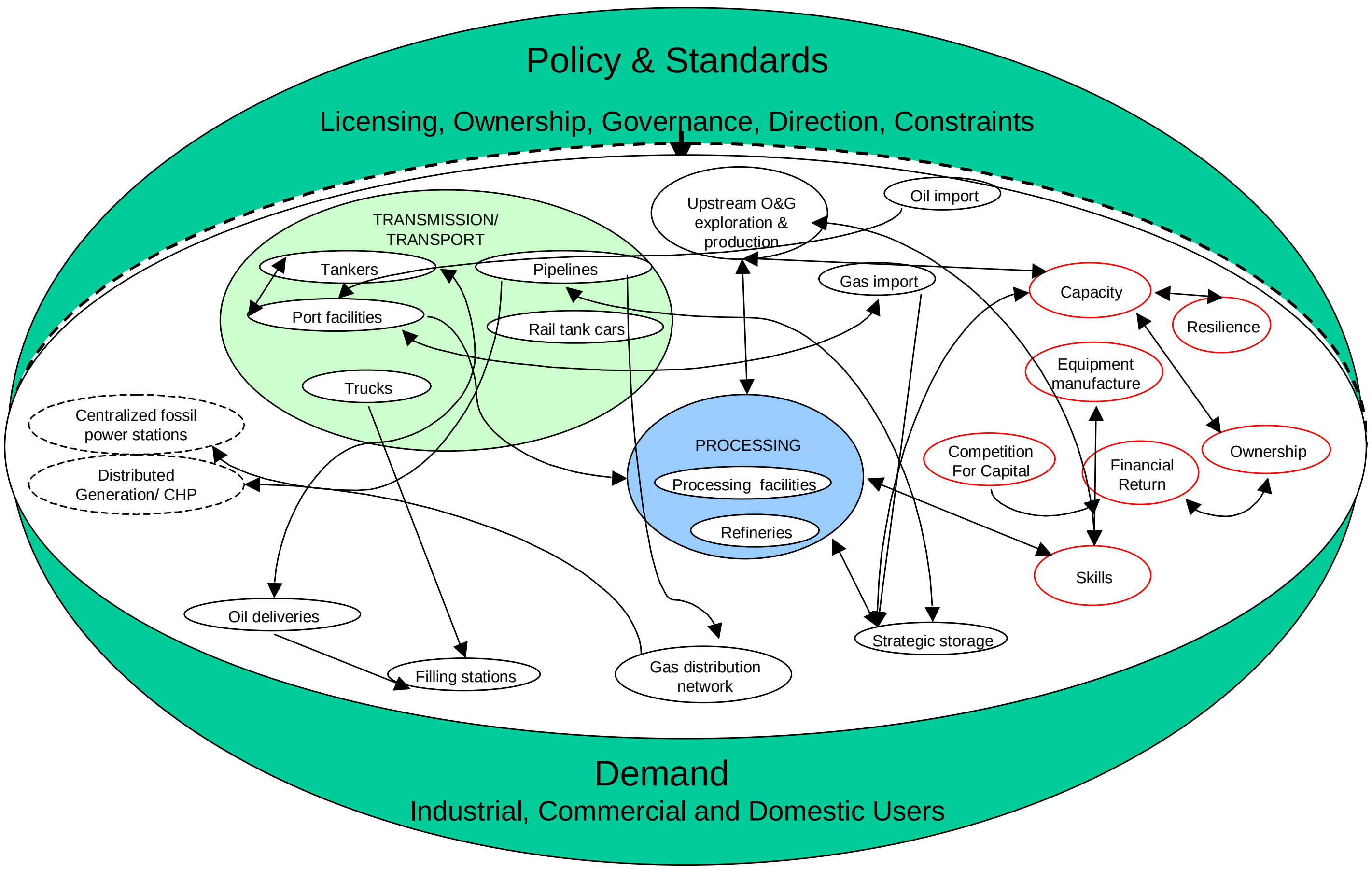
# Waste - Demand



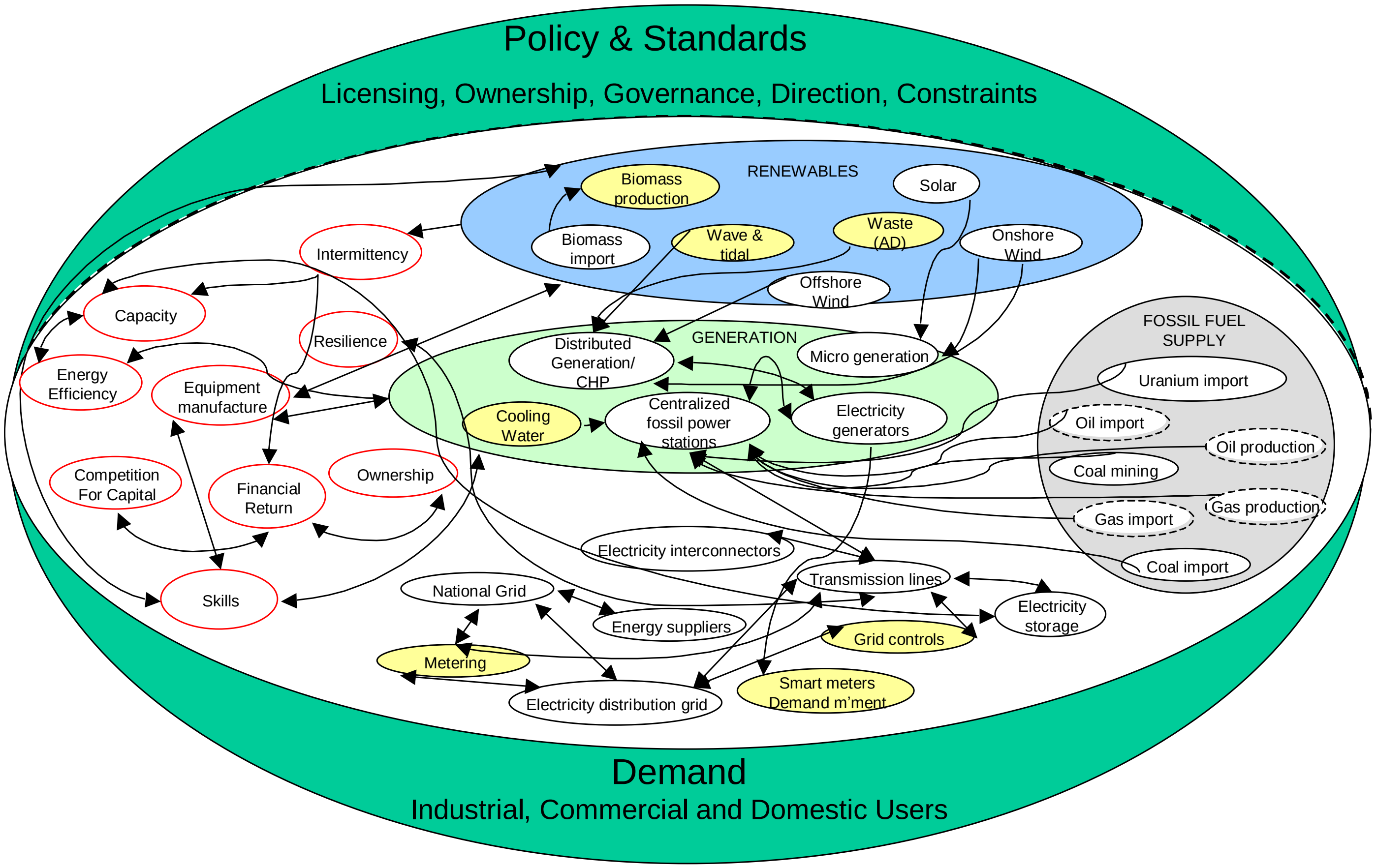
# Energy – Policy and standards



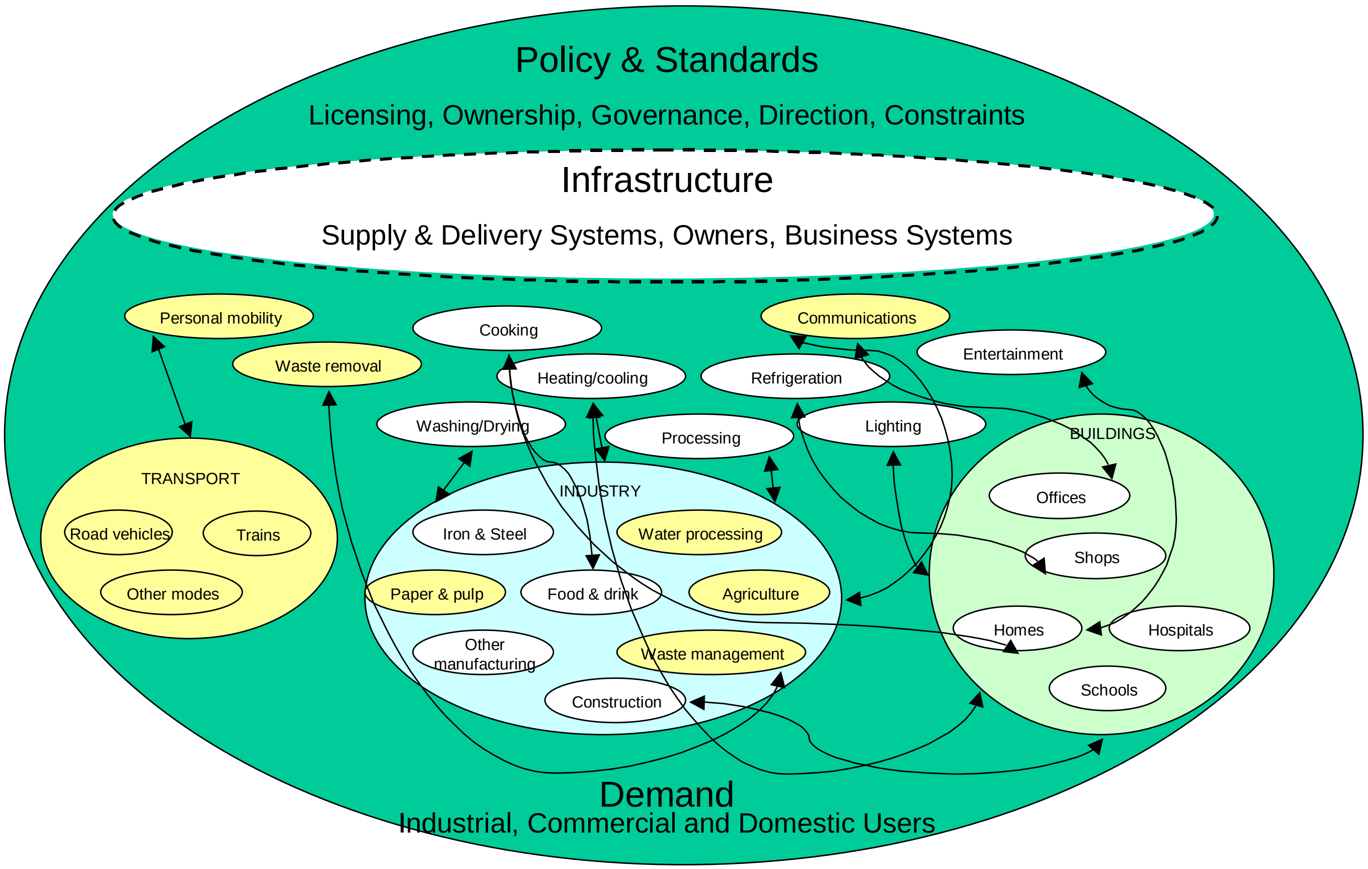
# Energy Infrastructure 1: oil and gas



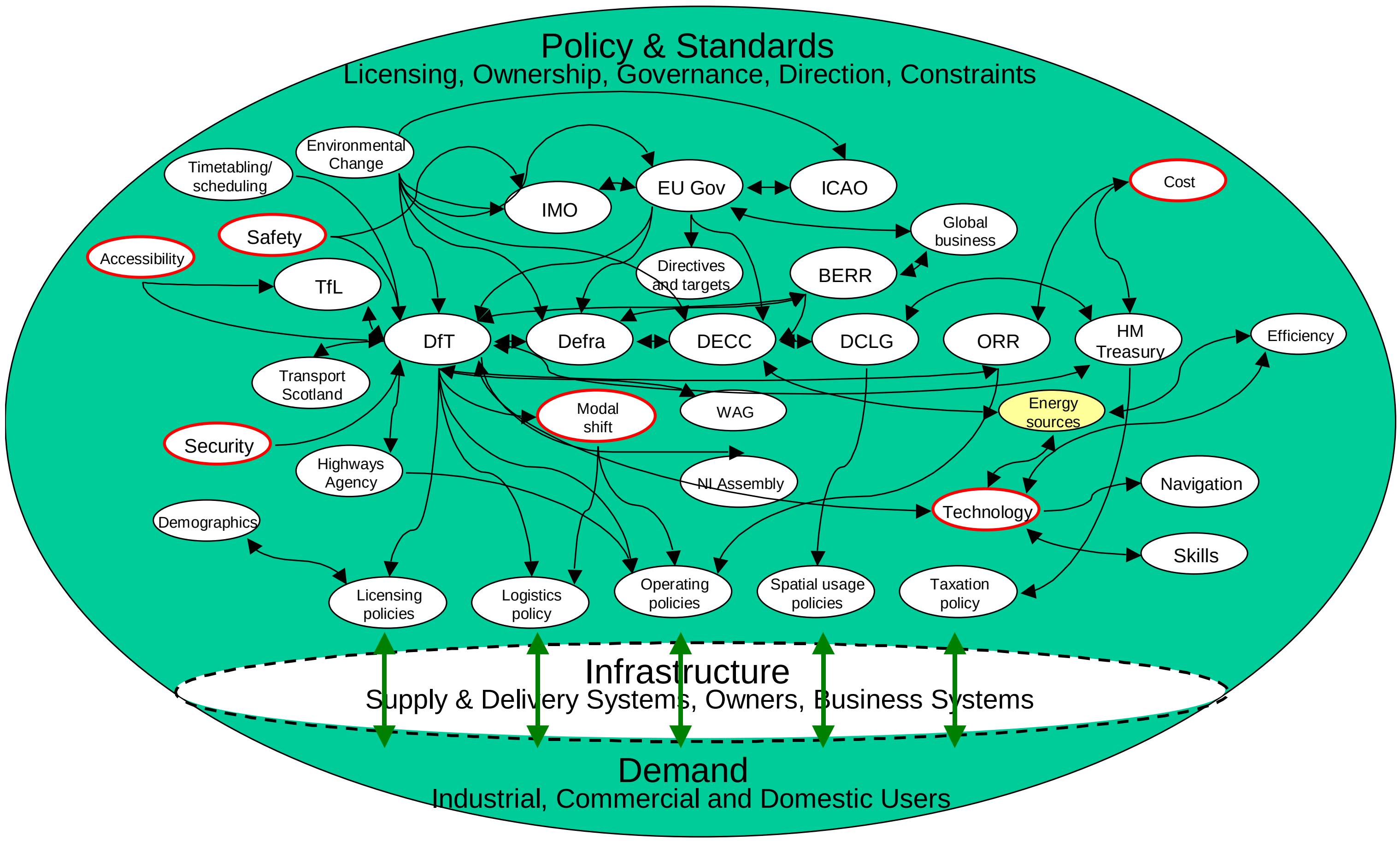
# Energy Infrastructure 2: electricity



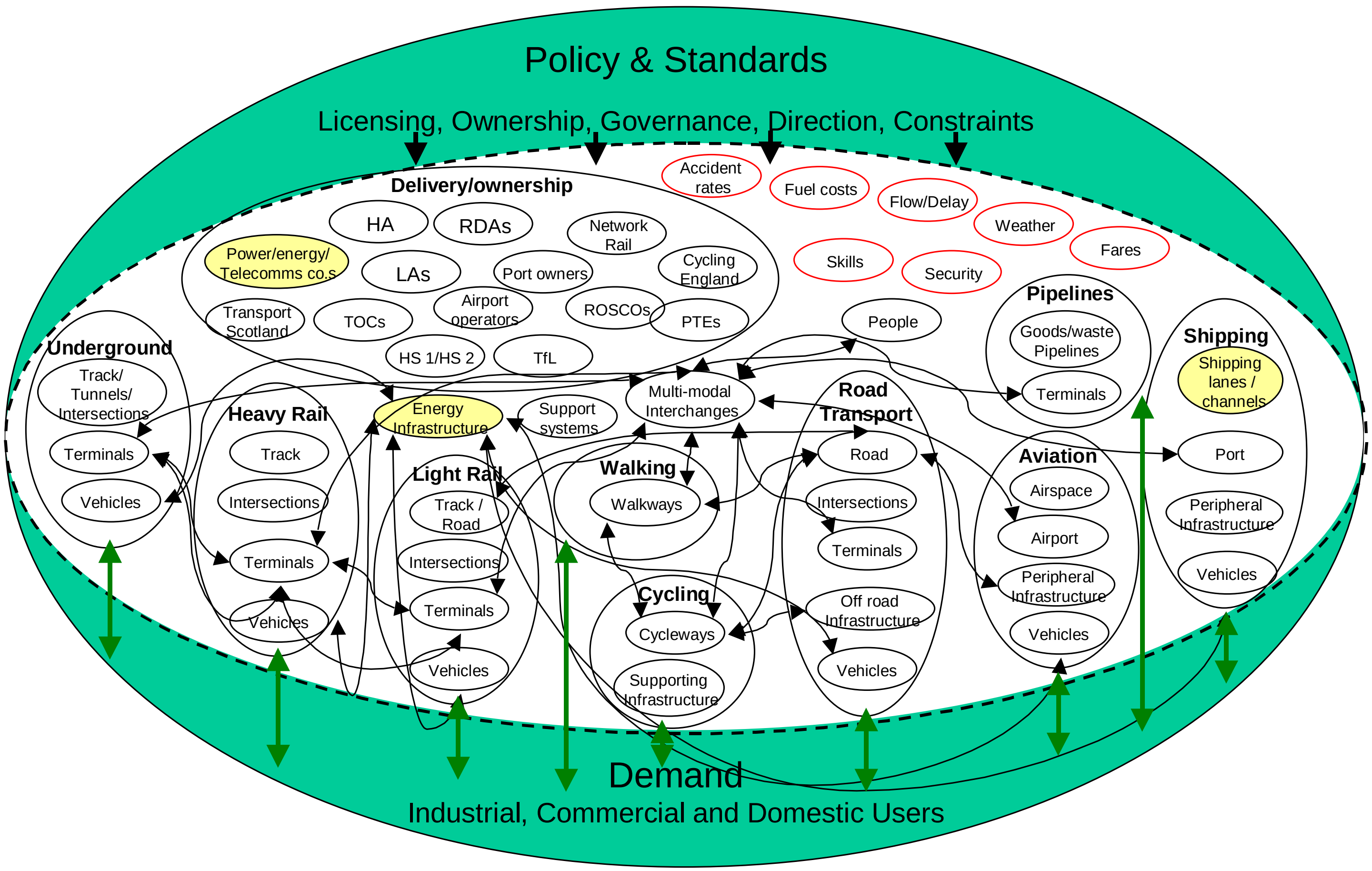
# Energy - Demand



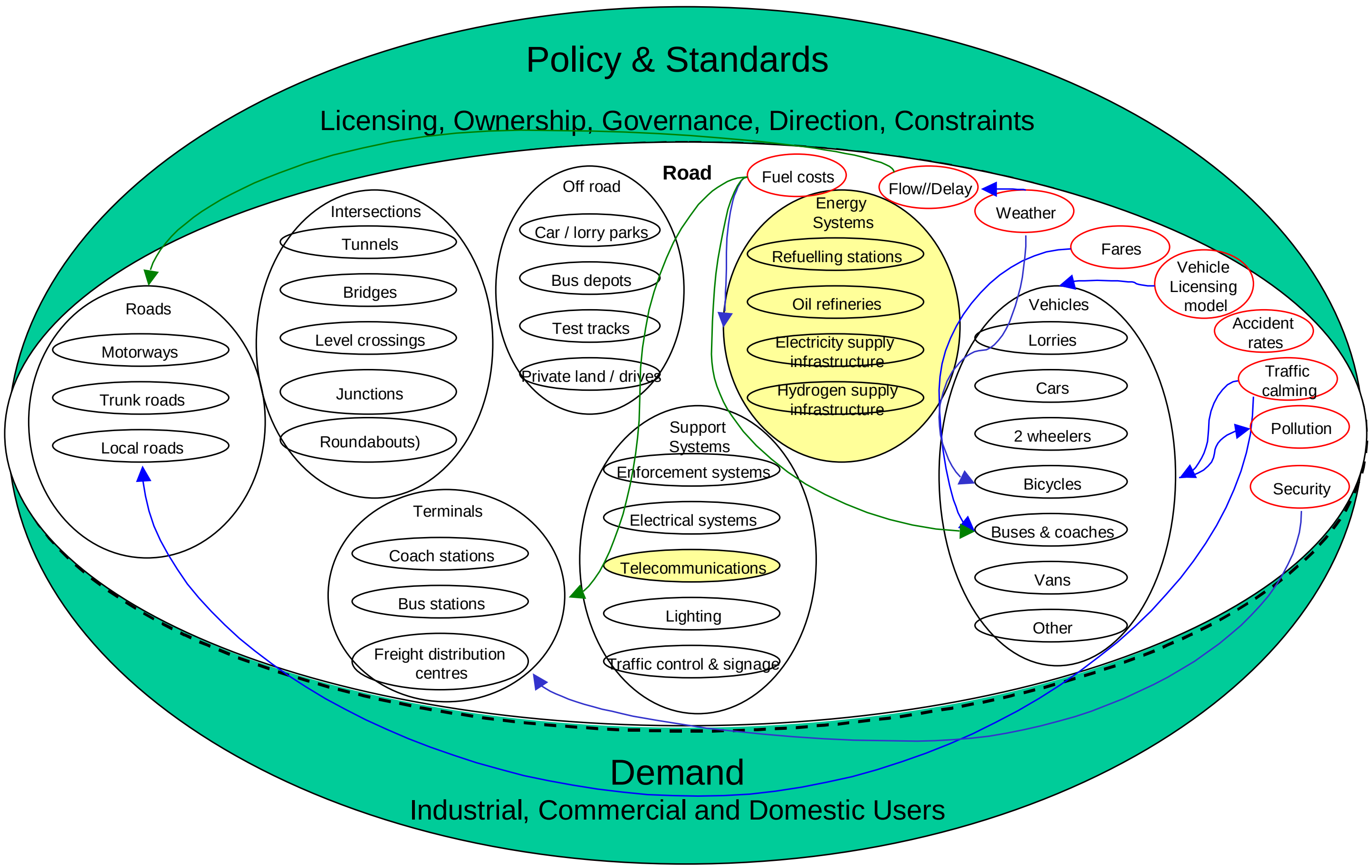
# Transport - Policy and Standards



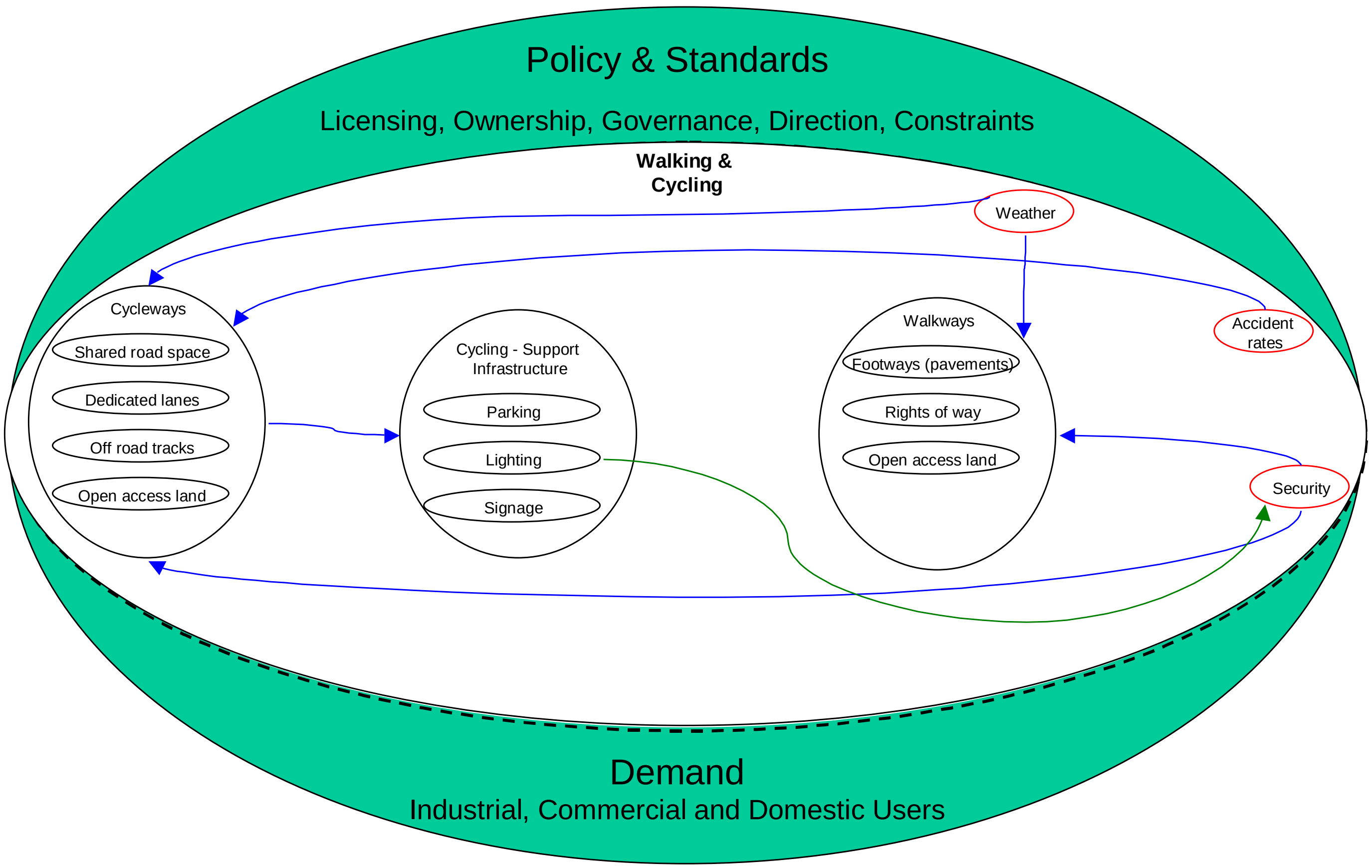
# Transport – All Infrastructure



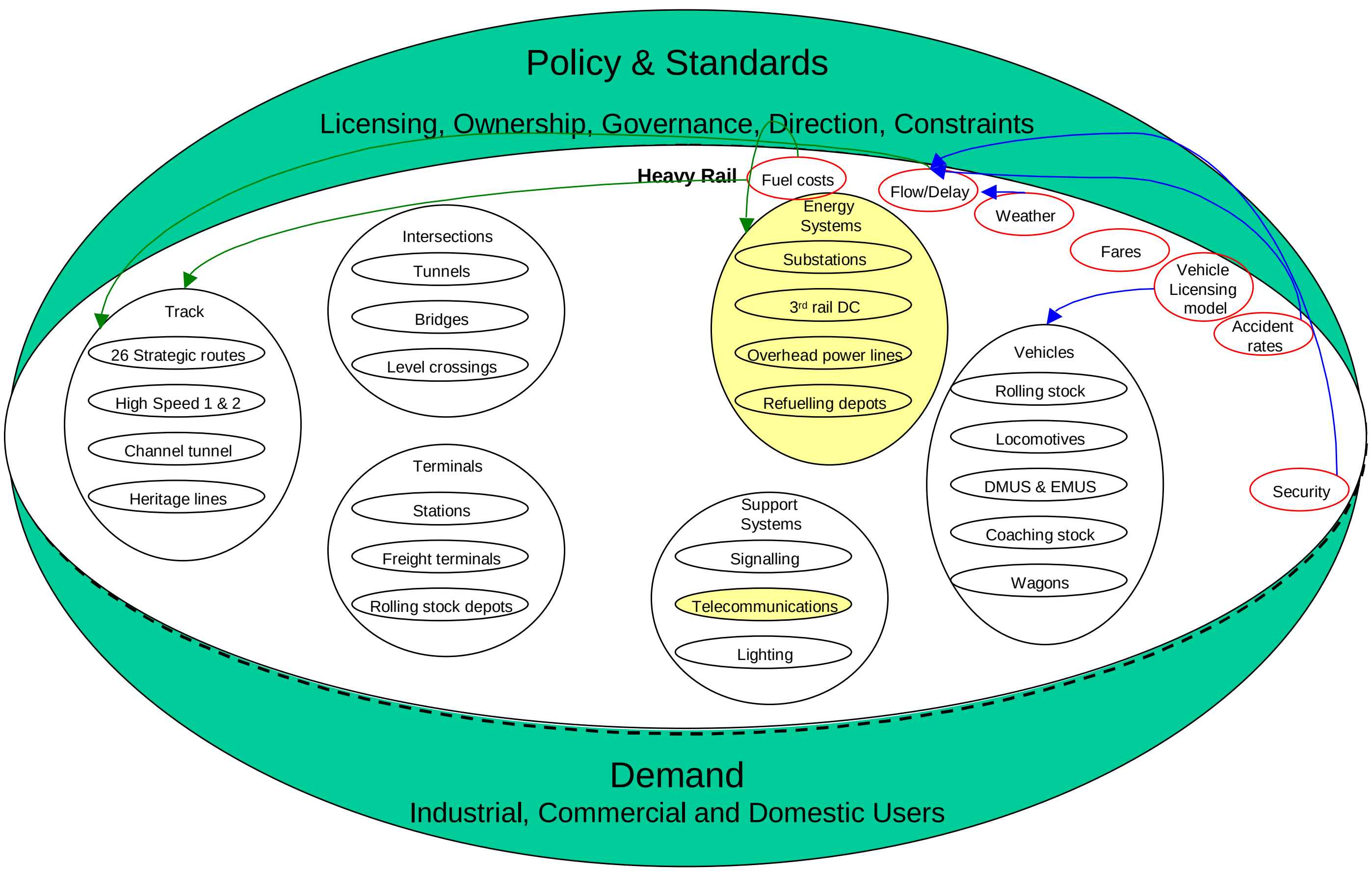
# Transport - Infrastructure 2; roads



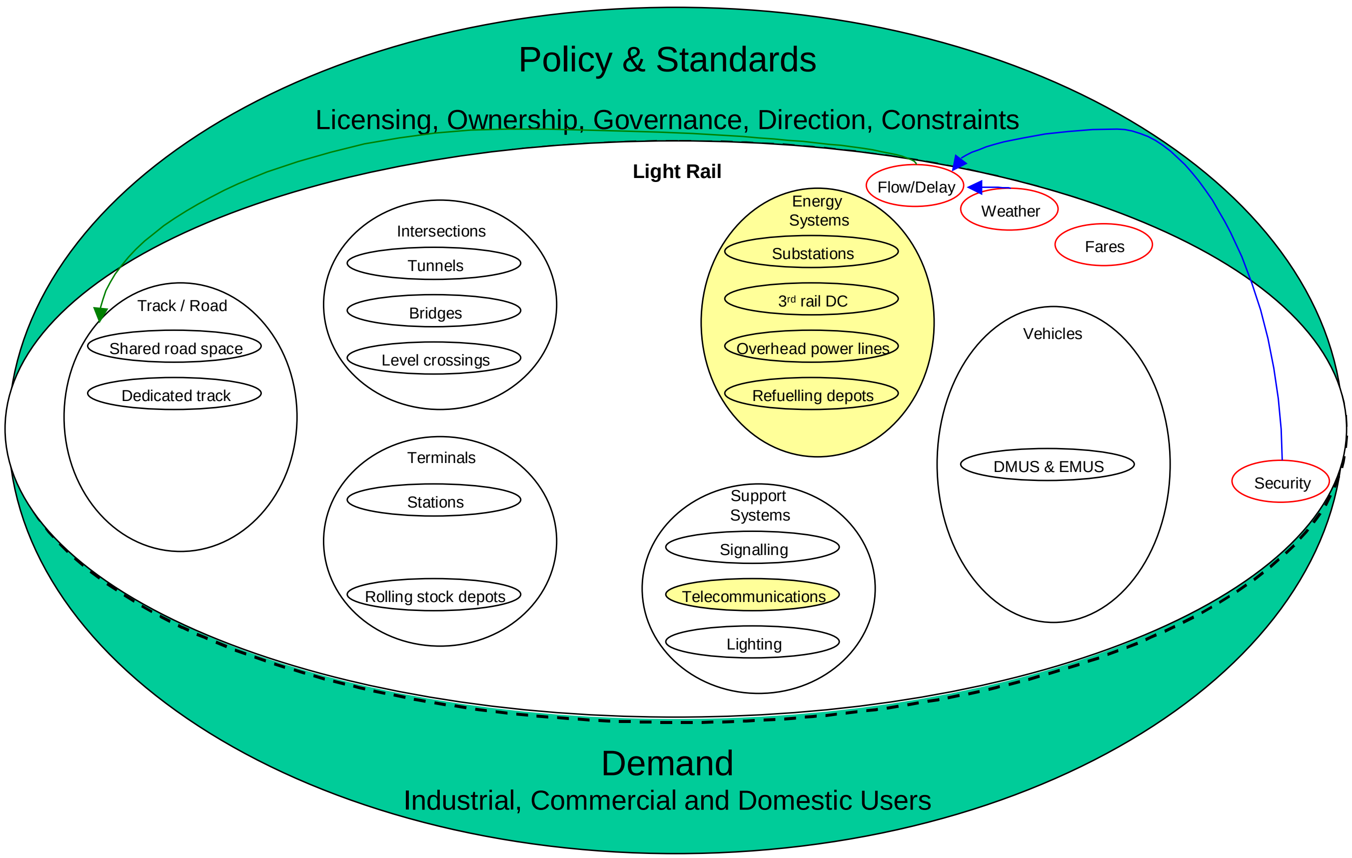
# Transport - Infrastructure 3; walking and cycling



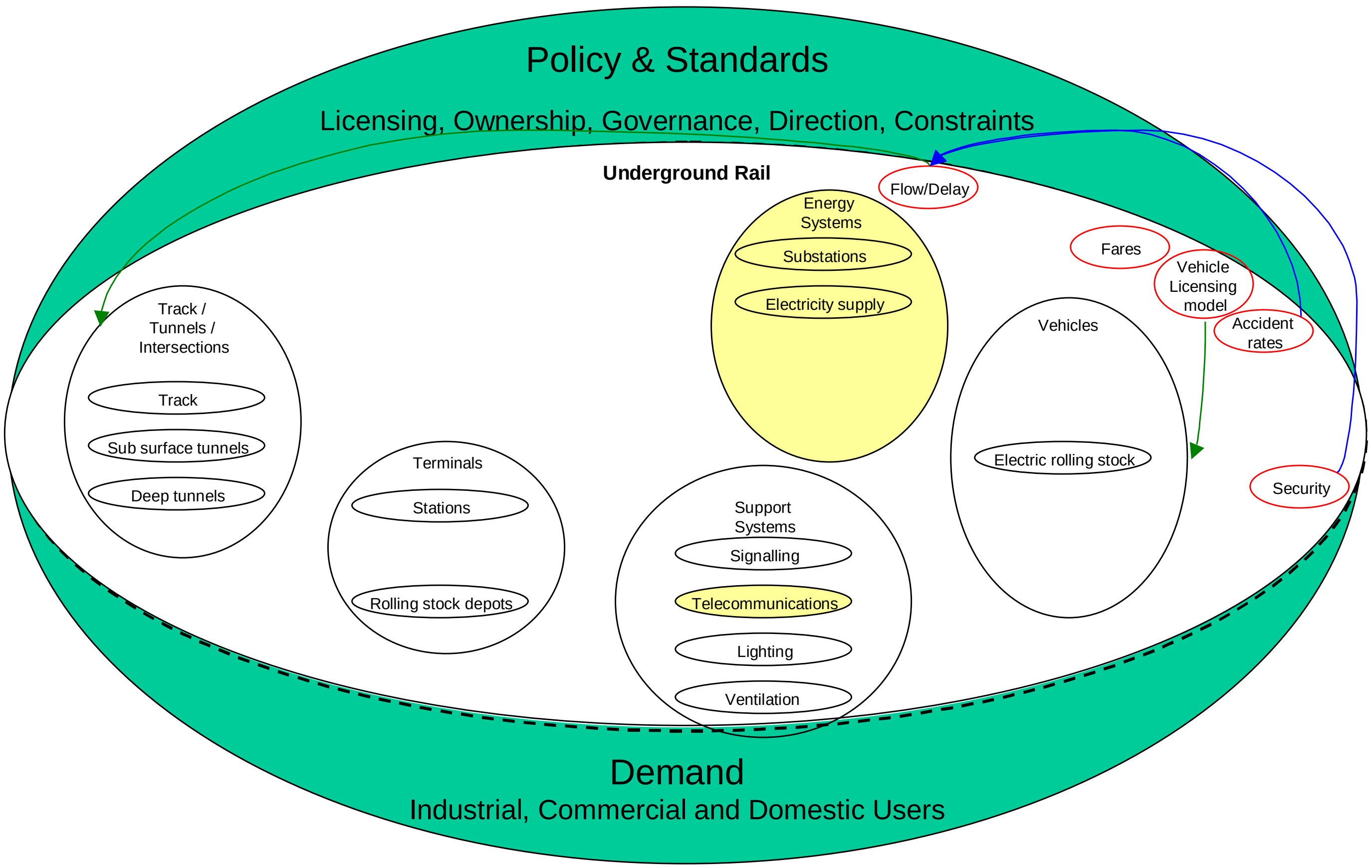
# Transport Infrastructure – 4; Heavy Rail



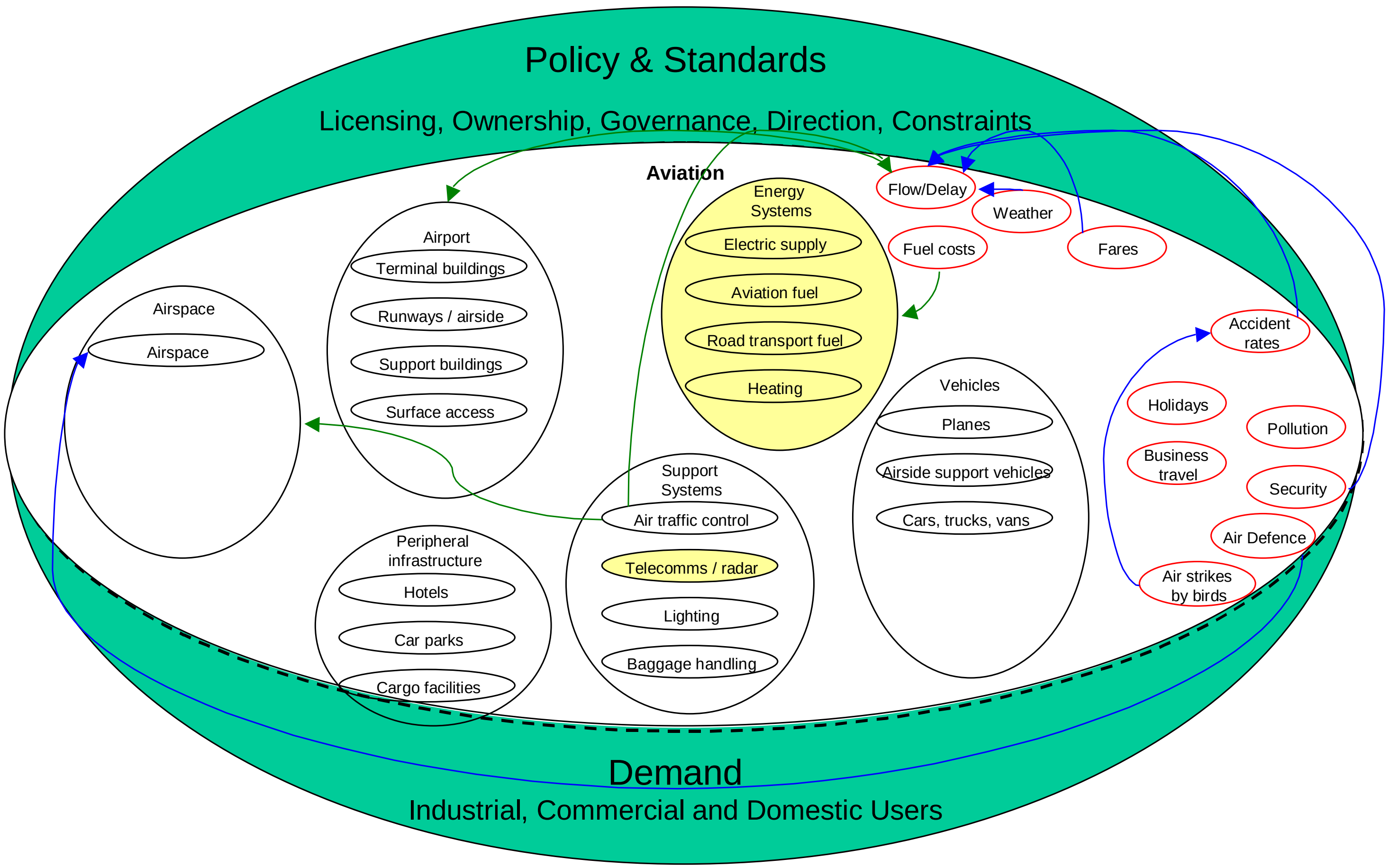
# Transport - Infrastructure 5; Light Rail



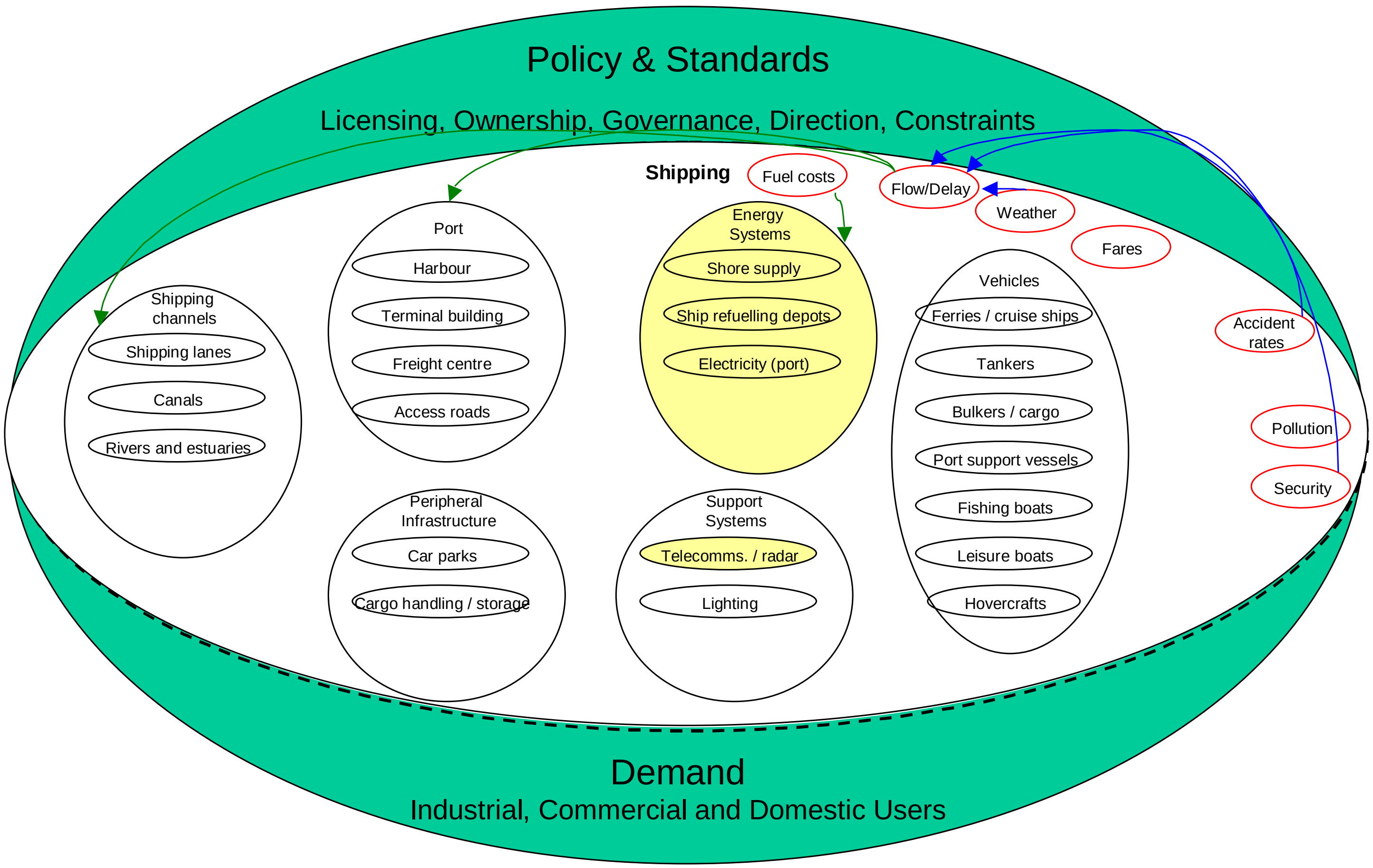
# Transport – Infrastructure 6; Underground



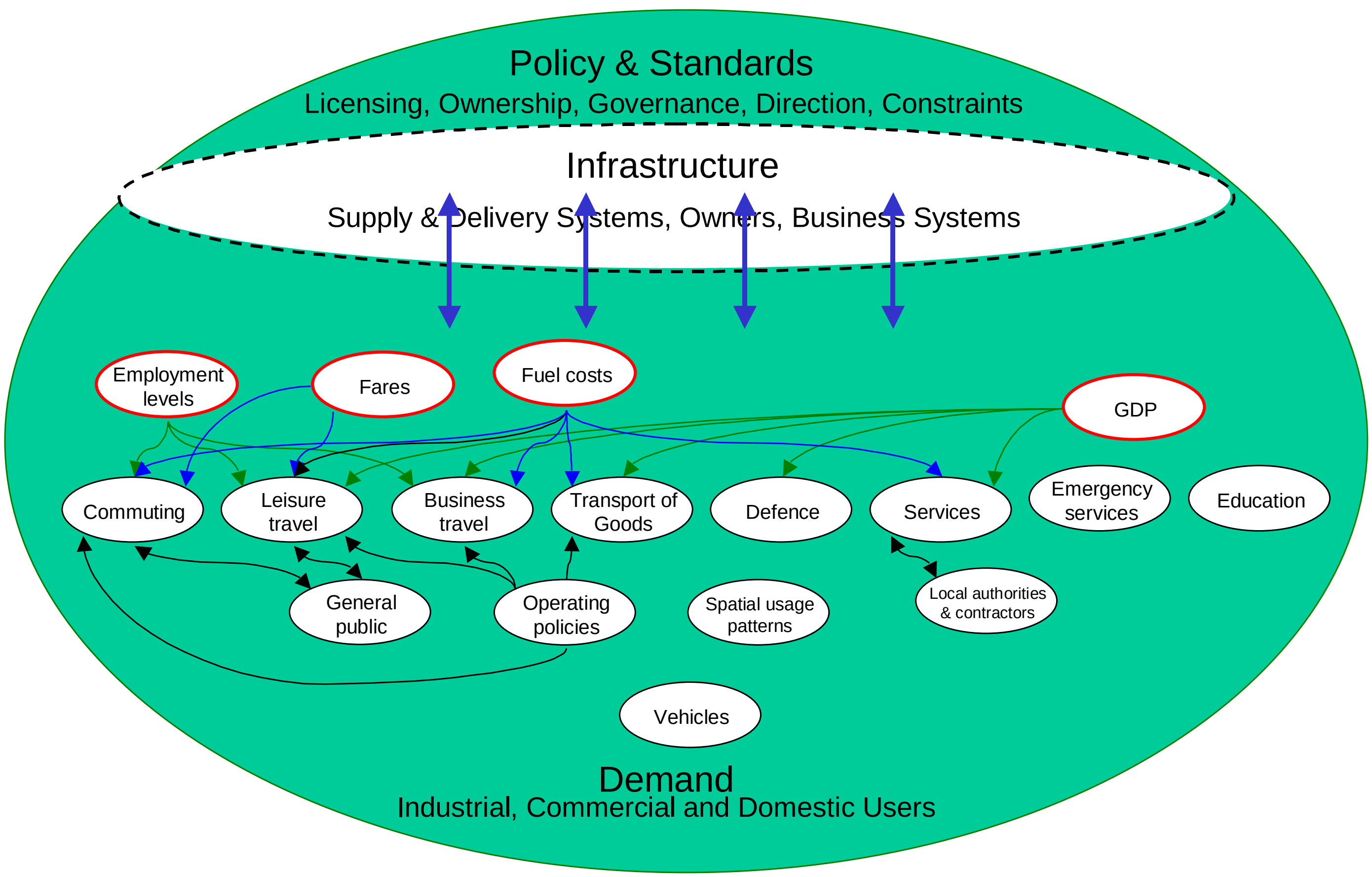
# Transport – Infrastructure 7; Aviation



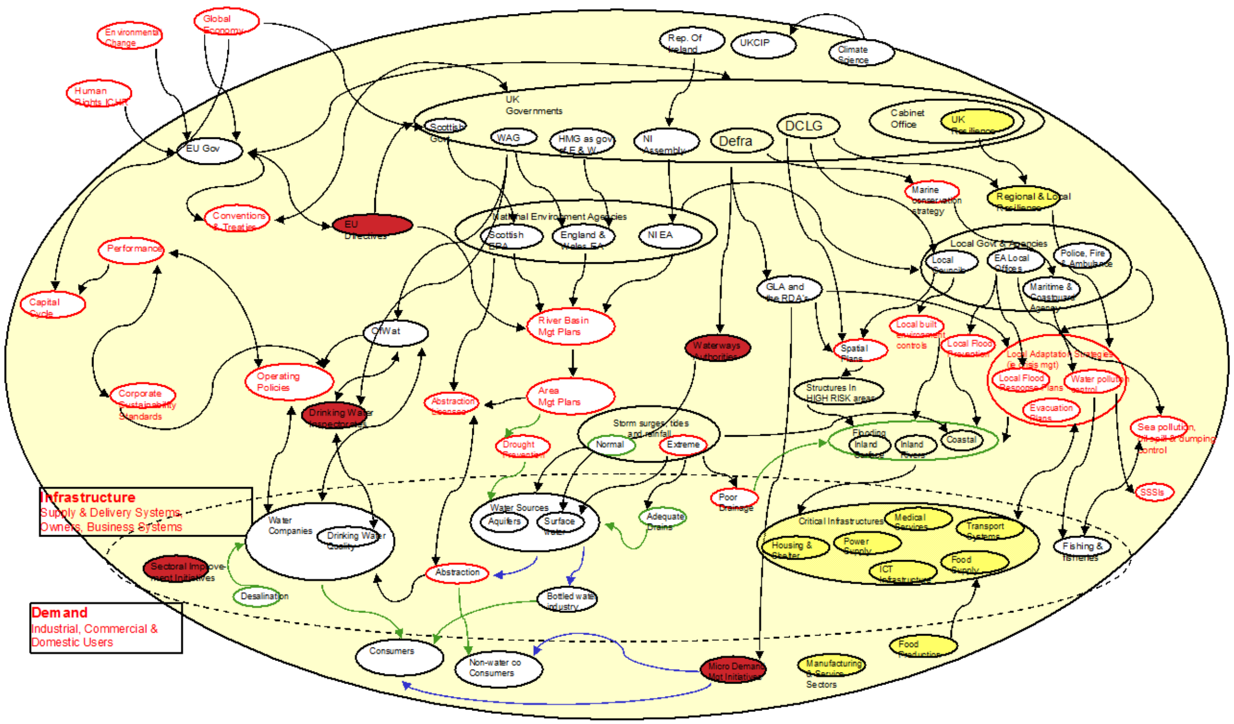
# Transport – Infrastructure 8; Shipping



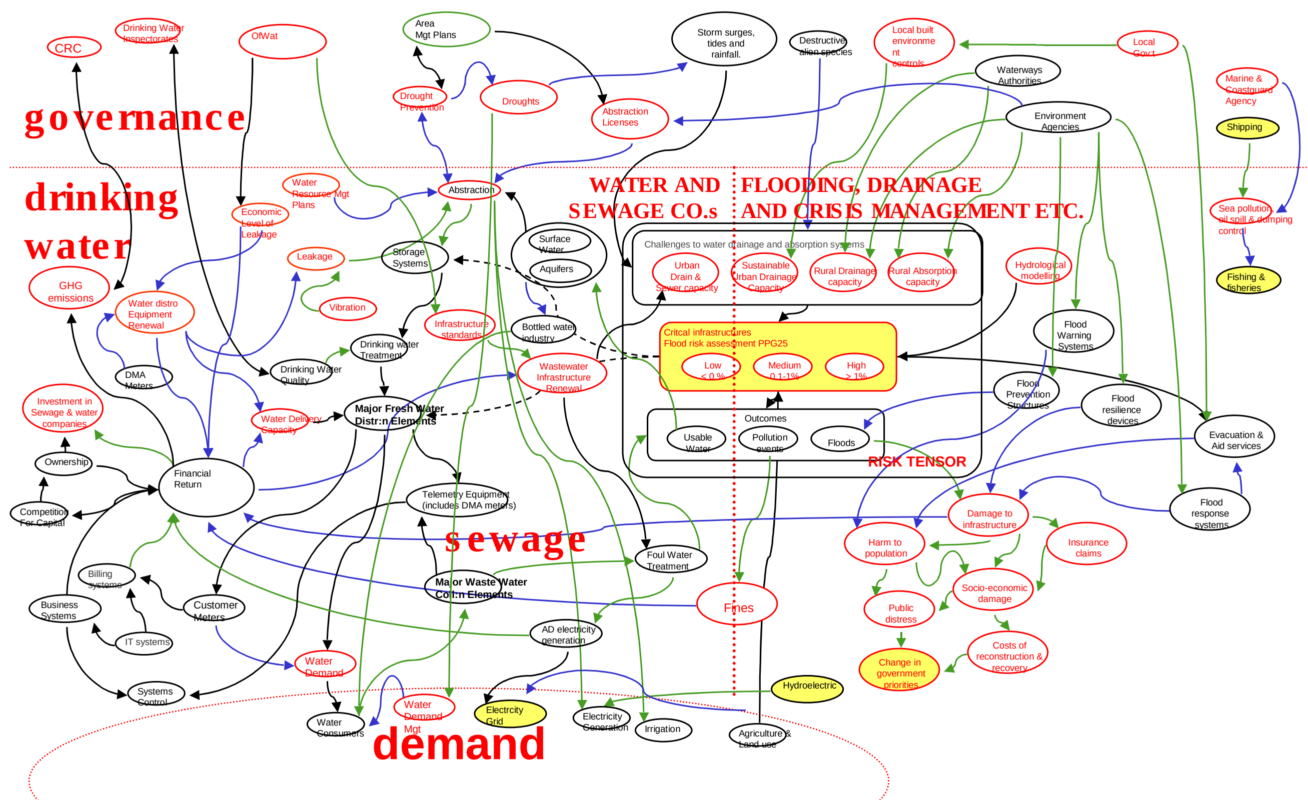
# Transport - Demand



# Water – Policy and Standards



# Water - infrastructure



# Water -Demand