Understanding The National Infrastructure Landscape

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Abstract: Infrastructure UK has been established within UK Government to coordinate the provision of National Economic Infrastructure, defined as energy, water, waste, transport and ICT. Co-ordination is not, however, easy. The lead for Government policy over the five infrastructure areas is shared across different Departments and arms-length bodies, sometimes with strong delineation and sometimes with wide cooperation. Policy is constantly developing and changes the overall landscape. To allow progress a snapshot of overall UK infrastructure policy across the five infrastructure areas has been developed, which provides a framework from which interdependencies between and among infrastructure polices and plans can be examined. This is enabling the identification of areas where a lack of discernible policy could lead to wider failures in interdependent sectors of UK national infrastructure or where synergetic opportunities should be captured. The author directed this work.

Key words: Infrastructure; Policy timelines; Interdependencies; Systems

I. Introduction

Infrastructure UK was formed in 2009 as a unit within HM Treasury, with a remit to help prioritise and secure private sector investment funding in the UK's long-term infrastructure. It addresses the UK's national economic infrastructure (defined as energy, transport, water and flood management, waste and ICT) and is responsible at UK Government level for:

- co-ordinating and simplifying the planning and prioritisation of investment in UK infrastructure, and
- improving UK infrastructure by achieving greater value for money on infrastructure projects and transitions.

At the request of Infrastructure UK, Engineering the Future (EtF)[1], the alliance of engineering professional bodies hosted by the Royal Academy of Engineering, has created a 'snapshot' of UK infrastructure policy across these five infrastructure areas. The information has been presented in the form of parallel timelines with a short narrative to explain the nature of interdependencies and why they have an important role in the development of government policy. The timelines provide a convenient and accessible way to assess policy and planning across the sectors of the UK's economic infrastructure. The linear presentation allows the reader to begin to visualise the interdependencies and opportunities and see, at a glance, where and when events resulting from lack of capacity, co-ordination or planning are likely to occur.

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These timelines provide a framework from which interdependencies between and among infrastructure polices and plans can be further examined. As the timelines evolve and the ability to analyse interdependencies develops it will enable the identification of areas where a lack of discernible policy could lead to wider failures in interdependent sectors of UK national infrastructure or where synergetic opportunities presented by those interdependencies should be captured.

The lead for government policy over the five infrastructure areas is shared across a number of Departments of State, sometimes with strong delineation and sometimes with wide cooperation. Policy is constantly developing and, as policies are consulted on and published, the overall landscape will change. The timelines should continue to provide an updatable tool that can chart the changing policy and delivery landscape. The authors of this paper acted as Steering Group Chair and Secretary of the EtF study team.

II. Understanding the Timelines

The Infrastructure Timelines (Figure 1), are based on current known policies and plans (as set by government and by infrastructure operators and owners) and expert opinion from the EtF community. These are dynamic and evolving and, as such do not provide a completely comprehensive coverage of policies and plans.

They show significant planning in some areas of national infrastructure and a paucity of planning in others. They also show that planning in some infrastructure areas, such as ICT, has naturally much shorter time horizons as technological development and replacement is much more rapid than in other areas, such as transport. It is important to note that the issues driving the policies and plans vary across sectors, ranging from high level policy commitments such as carbon emission reduction, to commercial developments such as 4G mobile communications. As well as providing this visual mapping capability, the timelines can be used to identify where positive and negative interdependencies exist both within infrastructure sectors and across multiple sectors. Engineering the Future has and will continue to utilise the timelines to provide examples of where this may occur. In providing these examples and explaining when, where, how and why they may occur, interdependencies experts and engineers will assist decision makers with their current and future policy decisions.

The timelines are colour-coded to indicate where policies and plans appear to be in place (green), where the outcome of plans or delivery may be less certain or where policy statements are expected (amber) and where crises have been predicted unless action is taken (red). Beyond the known plans in the infrastructure sectors, there is some speculation by engineering experts (blue) which could impact on future plans. In many cases, the speculated developments represent areas where policy decisions will be required based on technological or behavioural developments that are currently far from certain; for example, if plug-in hybrid or fully electric vehicles come to dominate the UK market in the 2020s, a substantial increase in electricity generating capacity is likely to be required but there may also be opportunities to adapt infrastructure to take advantage of load spreading and vehicle-to-grid energy storage.

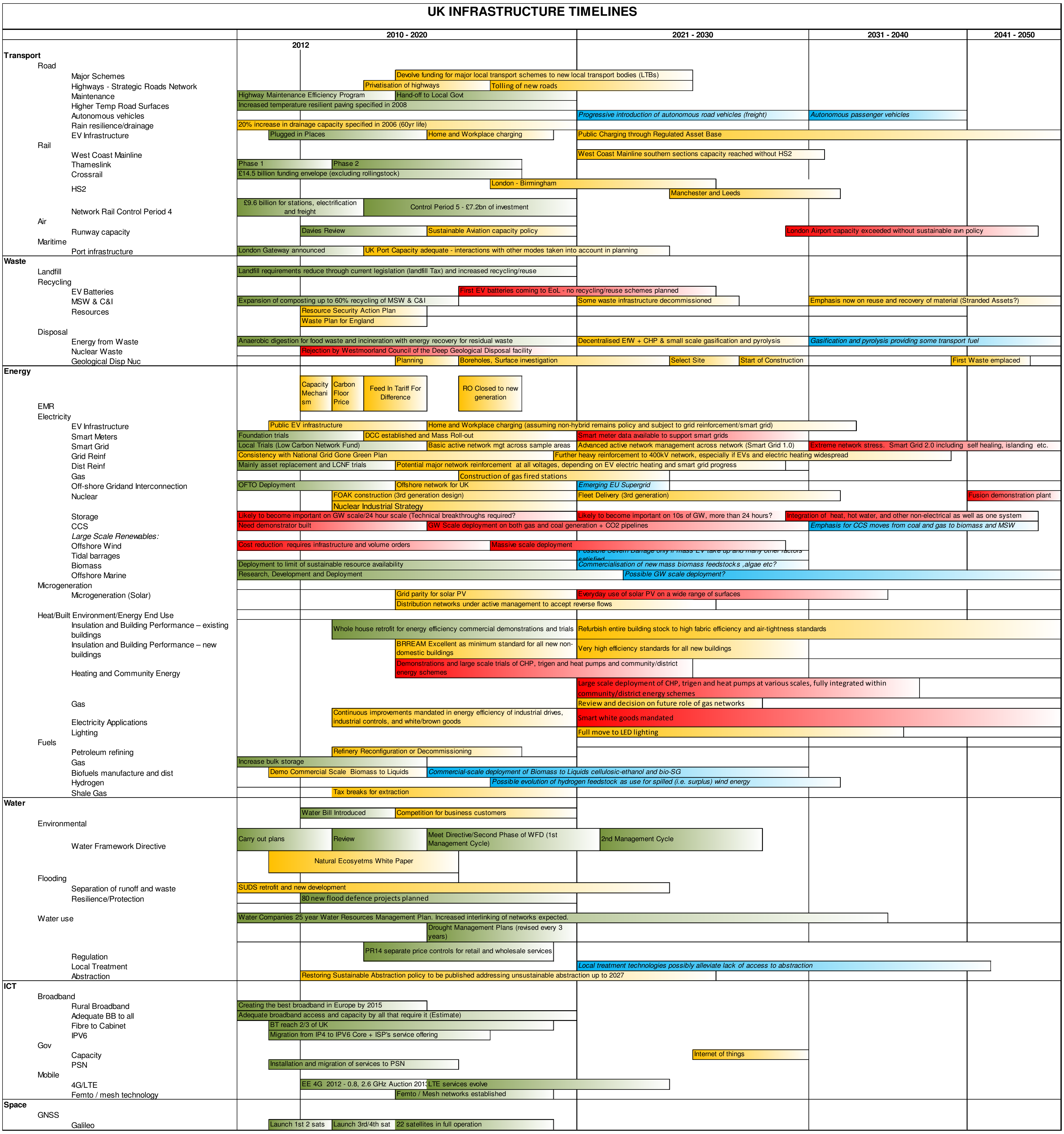

Figure 1: UK Infrastructure timelines.

III. Interdependency Analysis – Methodology

EtF comprises a number of engineering institutions, which have contributed evidence to the research base for the infrastructure timelines. Staff from each institution has engaged with expert members through their various networks and expert groups to gain an insight into the policy and planning taking place across the five main infrastructure sectors. The analysis of intra sector and inter sector interdependencies used an Interdependency Planning and Management Framework (IPMF), which is being developed jointly by University College London and the University of Bristol[2]. This was employed within a workshop that brought together experts in the five key infrastructure sectors. Using the projects, policies and plans outlined in the Infrastructure Timelines, workshop delegates investigated both intra and inter sector interdependencies. Attendees discussed the intra sector interdependencies using five projects, policies or plans from each sector within the Infrastructure Timelines. They then undertook a similar activity, looking across the five sectors. As well as this, attendees indicated whether the interdependence was physical, digital, geographical and/or operational. Table 1 provides an explanation of these types of interdependence. The output of the workshop has been distilled and analysed into case studies, exemplified by those described below.

Table 1 - Description of Infrastructure Interdependencies

	Type	Description
P	Physical Interdependency	• A transfer of resources, the output of one element becomes the input to another. This could be further refined to capture the nature of the transfer (e.g. Transfer of people). • A shared physical dependency between the two elements on a third resource (i.e. both elements consume the same fuel or use the same trained staff)
D	Digital Interdependency	• A cyber transfer of information. Again this could be refined to capture additional detail of the transfer. • A shared dependency between the two elements on the transfer of information from a third party source.
G	Geographic Interdependency	• The elements are located in the same place, or within close proximity.
O	Organisational Interdependency	• The elements are linked through a financial or logical mechanism. • The elements are organisationally linked by shared ownership, shared governance, or shared oversight. • The elements are mutually dependent on the services provided by a third party organisation

IV. Intra Sector Interdependencies

The following case studies highlight the types of intra sector interdependencies considered. Although the physical, digital, geographic and organisational interdependencies were available for analysis, almost 70% of the relationships discussed focussed on either physical or organisational interdependencies; therefore, these are the two interdependencies that will be addressed in the examples below.

A. Water Resource Management & Flood Risk Management

Three separate entries on the Infrastructure Timelines were discussed by the water sector experts. The relationship between the flood defence schemes and sustainable drainage systems, the review of the sustainable licensing regime and the water company Water Resource Management Plans (WRMPs) were shown to have both physical and organisational interdependencies[3]. Flooding is generally considered a risk to multiple stakeholders, including homeowners, agriculture and businesses. In certain situations, storage infrastructure could be built to capture and store run-off, reducing flood risk and also providing a ‘new’ source of water. This source could be used to reduce river and groundwater abstractions undertaken by multiple stakeholders in a catchment or river basin. This has potential benefits for the ecological status of groundwater and rivers, but also provides a mitigation mechanism during periods of water scarcity as the reliance on groundwater and river abstraction would be reduced. In turn, this has an impact on the WRMPs produced by water companies. They have a potentially new source of water to include in their long term plans, which will also drive their short and long term infrastructure expenditure.

Managing the capture of this run-off will require organisational coordination as water companies, lead local flood authorities and the government will have to discuss planning, funding, building, ownership and maintenance arrangements. Thus far, the delivery of Sustainable Drainage Systems (SuDS) in the UK has been poor and guidance has yet to be provided by government. If drainage and storage systems, such as SuDS, are utilised more widely and effectively the government may be in a position to introduce a level of flexibility into its abstraction licence regime. It is important that the government engages with this process, as the changes it decides to make to licences may act as either incentives or barriers to this type of shared scheme.

B. Transport

Organisational interdependence was considered one of the key areas for focus in the transport sector. In particular, collaboration was seen as important among the groups responsible for delivering strategic, multi-modal transport links in and around London and those responsible for highways funding and management. While there were a number of areas where positive interdependencies exist among these projects, there were considered to be two particular areas of focus.

First, the collaboration on Business Cases in each strategic transport project was seen as beneficial to the planning, design, delivery, governance and operation of the projects and policies. It was considered that there is clear value in an integrated transport approach, which should start at an early stage in projects such as the above. If the organisations involved in the stages of delivering these projects engage collaboratively then the multiple benefits can be identified early and actions implemented to achieve them.

Second, the under-utilisation of roads during certain hours was also raised as an area that could be addressed by improved collaboration and coordination among groups responsible for the delivery and management of these projects. Currently highways are available for night time movement of freight; however, local road policies often prohibit movement of freight. Delivery of strategic transport projects will require improved and more efficient movement of freight by the road network. Organisational collaboration in this situation would provide these stakeholders with a clearer view of the limitations of the current road policies, align their objectives to become mutually beneficial and allow them to resolve any issues in the achievement of these objectives. As such projects develop it is also important that the transfer and movement of passengers is considered and integrated. This will require organisational coordination.

V. Inter Sector Interdependencies

As with the intra sector discussions, approximately 70% of the inter sector interdependencies focussed on the physical and organisational interdependencies that exist. Figure 2 illustrates the full range of interdependencies that were discussed and captured at the interdependencies workshop. There are multiple examples of interdependencies contained within the table; however, the relationship between the energy sector and other sectors was seen as particularly important. Therefore, the energy sector provides an excellent case study with which to illustrate infrastructure interdependencies.

The energy sector provides necessary power to aspects of the ICT sector, such as cooling equipment, and relies on ICT for control systems. There is also a mutually beneficial relationship between ICT and Energy when the two sectors collaborate to create energy efficient equipment. Evidence from the workshop indicates that this partnership approach is currently inhibited by organisational and ownership issues that prevent best practice in the sharing of data. Smart metering, which has now been delayed in the UK by a further year, creates dependencies between energy and ICT. A high level of design solution and security is required of ICT in order to achieve functionality and public acceptance. Privacy is essential but at the same time it is beneficial for companies developing innovative solutions to home energy management to be able to access data with customer consent. A number of different parts of government need to work together with the industry to resolve these issues. While acknowledging the importance of confidentiality and ethics in data exchange, the workshop recommended that the appropriate sharing of data is incentivised to ensure the door is open for entrepreneurial activity.

Energy distribution and Transport assets can share the same physical space (route corridors) and the Energy sector provides the Transport sector with fuel (petrol and electricity for Electric Vehicles (EVs) and rail) and lubricants. The workshop on interdependencies identified the need to align Transport sector and Energy sector policies in order to avoid a potential failure from a lack of interdependency planning. This failure was seen as particularly concerned with the possible increase in electricity demand should there be a significant switch to electric vehicles and the government policy to electrify the rail network, which is currently underway and highlighted on the Infrastructure Timeline (Figure 1). There are particular transport projects where electrification of a small part of a network will allow use of electric traction for rail freight all the way through the network. This would have a wider economic benefit. While there is some suggestion that domestic EV charging may take place in off-peak periods, there is still a need for interdependency planning in this area. There is a need to ensure policy concerning uptake of EVs and the development of supporting infrastructure reinforces policy concerning energy use and vice-versa. There is also a requirement for the development of a recycling and/or waste policy for spent EV batteries. The infrastructure timelines show that there is currently no policy in place to reuse or recycle EV batteries as they begin to come to their End of Life period in approximately 2015.

Energy	P: Energy sector provides necessary electricity for operating and cooling ICT sector equipment (e.g. Server Farms)	P: (1) Energy sector provides necessary fuel (hydrocarbons) and lubricants to Transport sector; (2) Energy sector provides necessary electricity for electrified rail and Electric Vehicles in the Transport sector	P: (1) Energy sector is a source of general Waste transferred into Waste sector; (2) Energy sector is a source of Nuclear Waste	P: (1) Energy sector activities (e.g. Shale Gas) can transfer pollutants which contaminate ground water; (2) Energy sector provides necessary electricity to Water sector for pumping etc.; (3) Energy sector requires Water for cooling plant
		G: Co-location. Energy sector utilities and Transport sector assets share physical space		
	O:(1) Energy and ICT sectors can collaborate to create energy efficient equipment; (2) Energy and ICT sectors collaborate on sharing data (hindered by ownership issues)			O: Energy sector requires payment from Water sector for electricity provided to power pumps
P: ICT sector provides necessary resources to Energy sector	**ICT**		P: ICT components in space can become or produce space Waste	P: ICT sector requires protection from flooding provided by Water sector
D: ICT sector provides resources for Smart Grid, Smart Metering, Demand Management, Control and Billing to Energy sector		D: (1) ICT sector can potentially provide digital capability to reduce need for physical Transport; (2) ICT sector provides resources and capability for Transport sector activities: (a) Congestion charging (b) "Boris bikes" (c) Multimodal journey management (d) Global positioning (e) Comms. (f) Tracking (g) Stock control (h) Road use charging	D: ICT sector provides the capability for Waste and recycling 'tagging'	D: (1) ICT provides the capability for Smart Metering and management of/within Water sector; (2) ICT provides the capability for digital control of/within Water sector
		G: (1) Some ICT Plants and Services are geographically linked to the Transport network; (2) Co-location of some ICT physical assets (e.g. telecoms cables) and some Transport assets (e.g. roads)		
O: (1) ICT sector provides necessary control and communications systems to Energy sector during set-up; (2) ICT sector and Energy sector can collaborate to reduce ICT energy footprint; (3) ICT and Energy sectors collaborate on sharing data.		O: (1) ICT sector provides data management capability to Transport sector; (2) ICT sector and Transport sector collaborate on sharing data; (3) ICT sector provides capability for Transport sector to perform Logistics Route Planning; (4) ICT sector provides capability for general operational usage within Transport sector	O: ICT sector and Waste sector collaborate on sharing data	O: ICT sector and Water sector collaborate in sharing data
P: (1) Transport sector provides the capability to move Shale Gas; (2) Transport sector provides the capability to move fuel to power stations; (3) Transport sector could transfer excess heat from vehicle tunnels into Energy sector	P: Transport sector provides capability for JIT delivery for ICT sector	**Transport**	P: (1) Transport sector provides the necessary capability to move Waste; (2) Transport sector creates Battery Waste which requires disposal	P: (1) Transport sector can potentially provide: (a) an obstruction to Water or (b) facilitate its transfer; (2) Permeability of materials used to construct Transport sector assets can affect flood risk
D: Transport and Energy sectors share intelligence information	D: Transport sector relies on ICT sector for Road use charging capability.			
G: Co-location of Transport and Energy assets				G: Co-location of Transport and Water assets to provide utility corridor
O: (1) Transport sector requires network for Electric Vehicle (EV) charging; (2) Sector policies must be aligned to achieve goals (i.e. uptake of EVs and reduction in domestic energy use)			O: Transport and Waste sectors can collaborate to change behaviours on emissions (Nudge, wink, hug etc.)	O: Transport and Water sectors can collaborate on flood management planning rules
P: (1) Waste and by-products can potentially provide a resource for the Energy sector including processes such as Anaerobic digestion; (2) Waste can potentially provide a source of rare Earth metals needed by the Energy sector		P: Waste sector requires Transport sector for (1) Movement of hazardous waste; (2) Movement of general waste; (3) Movement of specific materials that cannot be disposed locally (e.g. Japanese knotweed)	**Waste**	P: (1) Waste sector can potentially produce contaminated water which is transferred to the Water sector; (2) Waste in landfill can potentially cause more Water runoff
				G: Co-location of Waste facilities and Water resources can potentially result in ground water contamination
O: Waste disposal plans may need to be in place before new power stations are approved (especially Nuclear)		O: Separation of Waste at source and separation of Waste at a dedicated facilitate have different transport needs (and affect Efficiency versus Quality)		
P: (1) Water provides a potential means to generate electricity; (2) Water provides a necessary means of cooling Energy plant; (3) Water provides a potential means of Energy storage; (3) Water sector may require Energy for Bulk Water Transfer		P: Water sector provides flood protection for Transport sector assets		**Water**
	D: Water sector relies on ICT Sector for Smart Meters and Demand Management			
		G: (1) Co-location of Transport assets and Water sources can increase the risk of flooding; (2) Water utilities can disrupt Transport network by digging up roads; (3) Water sector utilities can degrade road system due to sub-standard re-instalment		
O: Water sector provides payment to Energy sector for Pumping	O: Water sector collaborates with ICT sector for real time data exploitation to maximise efficiency, energy use and resilience			

Figure 2: Infrastructure Interdependencies Generated by the Workshop.

Energy is also important to the water sector as electricity is required for pumping and many waste water processes. This key relationship is emphasised by the successful attempts by some water companies to generate their own electricity from renewable sources or from waste by-products generated by certain processes. Water is also required for cooling within a number of electricity generating processes. This could be challenging in the future, particularly in situations where inland water sources are required for cooling purposes. According to the Climate Change Risk Assessment, lower river flows in summer caused by climate change may impact on the amount of freshwater inland energy stations can abstract for use in cooling[5]. This should be a significant factor in the government's approach to reviewing the abstraction licence regime.

Shale gas extraction is viewed by government as a potential source of energy to improve the UK's energy security. Although the viability of shale gas extraction is still unclear, there is interdependency with water that must be considered carefully. Water is required as part of the fluid used in the hydro-fracturing process. The process produces a brackish by-product that has to be disposed of carefully. Recycling wastewater where possible would reduce the volumes of wastewater in need of disposal as well as reducing the burden on freshwater abstractions. Wastewaters can be diluted with freshwater and then reused in subsequent fracturing operations[6]. It is important that the necessary parts of government collaborate on the development of fracking and that regulation is utilised to manage the water and environmental risks concerned with the process.

VI. Conclusions & Recommendations

The study described in this paper demonstrates the initial parts of an interdependencies toolkit which will allow improved understanding of potential synergies across multiple infrastructure sectors. Comparing policy, planning and project timelines across the infrastructure timelines should enable government departments to collaborate to identify the interdependencies that their particular policies may encounter elsewhere. The identification of these interdependencies should allow government departments to work together in order to mitigate any future issues that may occur and plan policies that are aligned. The infrastructure timelines should continue to evolve as a dynamic visual aid to inform the development of government policies.

Major recommendations include:

- Policy makers should utilise interdependency analysis and the Infrastructure Timelines to plot current and future policies and align policy development where necessary.
- Government departments should improve the coordination and communication between and among regulators and asset owners.
- Further research and implementation of interdependency analysis is required**.**

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