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Constructing resilient futures: integrating UK multi-stakeholder transport and energy resilience for 2050

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Constructing Resilient Futures: Integrating UK multi-stakeholder transport and energy resilience for 2050



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ABSTRACT

The 2005 terrorist attacks in London and 2007 flooding throughout the UK revealed the shortcomings of the UK Government approach of 'governing through resilience' in practice: low levels of stakeholder co-ordination, lack of understanding about critical infrastructure interdependencies, and little attention to long-term adaptation. We found that developing futures scenarios coupled with natural and malicious hazard episodes provided an effective way to draw in key stakeholders to engage with and address these problems. Starting with a detailed analysis of extant futures studies, scenarios were combined with episodes in order to both draw stakeholders out of their institutional contexts by setting the exercise in the future and to elicit participant responses during future crisis events. A procedure was developed and applied to construct integrated scenario-episodes built upon existing scenarios in order to investigate multi-stakeholder interactions around the resilience of energy and transport infrastructures. The full resulting scenario-episode narratives are also presented. These scenario-narratives were applied in key stakeholder focus groups to address the gaps in the aforementioned 'governing through resilience'. Participants actively engaged with these scenario-episodes in order to highlight overlapping conceptualisations of 'resilience', identify critical infrastructure interdependencies, and reflect deeper and more collaboratively on the longer-term resilience implications.

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1. Introduction

Multi-stakeholder discussions using futures-based scenario narratives are vital to draw in important actors in order to build shared understandings of resilience, longer-term adaptation, and critical socio-technical interdependencies [2–5]. Key actors in socio-technical resilience are then able to engage outside their narrow institutional and sectoral contexts to reflect about resilience in a set of plausible future worlds. However, as we argue below, future scenarios by themselves often only examine 'business as usual' settings. Actors only began to effectively interrogate critical interdependencies, overlaps (or gaps) in understandings of resilience, and long-term adaption when we built in severe episodes to stress test the scenarios. Thus, we developed a set of integrated scenario-episodes designed to engage a plurality of key stakeholders across sectors in order to examine socio-technical resilience. Moreover, for scenario-episode development more generally, we found that

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using extant studies provided an effective way to quickly build future scenario-episodes. These scenario-episodes were also designed to concentrate on key interdependencies between different infrastructures. The UK government defines nine critical national infrastructure sectors – water, energy, transport, emergency services, financial services, food, government, health, and communications [1].

Whilst decision-making and chains of responsibility may be well-established for particular infrastructures, critical points of vulnerability exist where these sectors meet and where governance responsibility is more ambiguous and potentially absent. In response, our scenario approach is explicitly geared towards analysing key interdependencies between sectors and, crucially, making visible areas where oversight and responsibility may be lacking. Because developing scenarios to examine interdependencies across all nine infrastructure sectors was beyond the scope of the project (and potentially overly burdensome and complex for participants) we selected two specific interconnected infrastructures to focus on in order to animate key relationships and issues of governance. In doing so, we applied our integrated scenario-episode approach to address gaps in governing through resilience for interdependent energy and transport infrastructures.

This emphasis on connectivity across departments, organisations and sectors gained increasing prominence in the UK, particularly since 2000. During 2000 and 2001, the UK Government experienced a series of severe and complex events: protests and blockades in response to the level of tax on fuel led to reports that Britain had ‘ground to a halt’ [6]; unprecedented rainfall in October and November 2000 led to severe flooding in Sussex, Kent, and Yorkshire [7]; and the foot-and-mouth disease outbreak in July 2001 affected thousands of livestock and led to the culling of millions of animals, with the British media placing blame on the Government response [8]. These events led the UK Government to undertake a substantial overhaul of the national framework for emergency response. Responding to the aforementioned events, the British Government established the Civil Contingencies Secretariat (CCS) in July 2001 to provide support, advice, and co-ordination to government departments dealing with complex and severe emergencies that crosscut departmental competence [9]. The shift in Government policy focussed around the concept of ‘resilience’, which was enshrined in the 2004 Civil Contingencies Act (CCA).

The new approach spread responsibility for emergency management across a greater number of agencies, sought to provide a common understanding of ‘resilience’ in order to identify essential infrastructure necessary to ‘keep the country running’, find commonalities between different types of emergencies, and to better co-ordinate key actors in the face of severe natural and malicious hazards. Despite the legislative innovation and institutionalisation of ‘governing through resilience’ in the CCA, the 7 July 2005 bombings in London and the 2007 summer floods in the UK exposed continued weaknesses in an effective and co-ordinated multi-sectoral response to severe events. These crises highlighted: the lack of a common understanding of resilience; insufficient co-ordinated response within and across key agencies; and little multi-stakeholder deliberation on longer-term resilience or critical socio-technical interdependencies. Spreading the task of delivering resilience across increasing numbers of state and non-state actors generates greater challenges for sharing common priorities and, ultimately, new challenges of co-ordination and cohesion.

This paper sets out the provenance, development and wider utility of scenario-episodes to examine infrastructure resilience. The paper proceeds as follows: the next section outlines the rationale for integrated scenario-episode futures; the third section sets out the problems with engendering co-operation and long-term planning when ‘governing through resilience’; the fourth section summarises how this procedure was used to create a set of integrated scenario-episode futures related to infrastructure resilience; the fifth section includes the full narratives of the scenarios and episodes; and the final section discusses and concludes.

2. Building integrated scenario-episodes: developing existing approaches

Within the Resilient Futures project,¹ key stakeholders were engaged through the development of scenarios set in the year 2050 integrated with natural and man-made hazard events, with a focus on socio-technical resilience regarding interdependent energy and transport infrastructures. Futures scenario-based techniques can be a useful tool for developing a set of comparable and plausible futures, which can be used to draw out the implications of particular socio-technical configurations with differing benefits and vulnerabilities [10–12]. However, existing scenarios are often not designed to capture the uncertain and hazardous features of these worlds, nor examine transformative processes after a shock to the system, for example, how critical infrastructures may affect one another. Thus, a number of novel modifications were applied in order to help develop traditional scenario exercises meet the present-day challenges outlined above.

Emergency planners often examine existing levels of resilience through simulations or exercises in which malicious or natural hazard episodes disrupt existing systems via a sudden ‘environmental jolt’ [13], and participants enact existing response and recovery plans to return to the previous socio-technical status quo. In this paper, we use episode to mean a ‘rare and severe event’. Thus we make a key distinction in our approach between scenarios – different versions of the future amenable to interrogating issues of resilience that provide the context and broad parameters of the exercise – and episodes – severe events and jolts that stress-test the resilience of various networks, infrastructures and organisations as they are

¹ Resilient Futures was supported by the Engineering and Physical Sciences Research Council; and the Economic and Social Research Council [grant number EP/I005943/1], as part of the RCUK Global Uncertainties Programme. The project brings together expertise from complex systems modelling, material science, risk management, sociology, geography, criminology, and social psychology. For more information see: <http://r-futures.ecs.soton.ac.uk/>.

variously configured in future scenarios. Modern emergency exercises take many forms, including tabletop exercises (e.g. the Triton Exercise 2004 [14] that used a simulated tidal flood) and full role-play simulations (e.g. the London Metropolitan Police preparation for the 2012 Olympics by running a role-play exercise of a terrorist attack [15]).

Although these exercises can be helpful in highlighting vulnerabilities in current emergency planning practices, there are two significant shortcomings. First, these exercises focus on perturbations from 'business as usual', allowing stakeholders to remain in their respective comfort zones, since participants are familiar with the social context in which these exercises occur. The narrow focus on returning to the status quo during these exercises excludes the possibility of treating resilience as an open-ended concept of recovery, adaptation, and evolution in an uncertain future [16–18]. Secondly, and perhaps more importantly, these exercises only engage with events that provide a perturbation to the existing equilibrium to which the infrastructure systems eventually return. However, the disasters that provide the sternest test for resilience are those that cause a paradigmatic shift in thinking about the socio-technical nexus, in which natural hazards are compounded by human negligence and cascade failures of complex interdependent infrastructure systems, leading to 'corrosive social cycles'. To do this, it is necessary to play out severe incidents in future scenarios to bring stakeholders out of their narrow institutional contexts in order to create a space where they can question and be questioned about their assumptions related to the concept of resilience.

Thus, without playing out severe disaster episodes to 'stress-test' these future infrastructure scenarios, it is challenging for infrastructure and emergency planners to evaluate how their policy decisions affect resilience in the coming decades and how they must operate outside their institutional 'silos' to most effectively govern through resilience. To interrogate the concept of socio-technical resilience across all three generations, we found it necessary to integrate appropriate future scenarios alongside serious hazard episodes.

The integrated scenario-episodes were developed through a triangulation of several qualitative social-scientific approaches, starting with an extensive review of relevant existing scenario-based studies. We began with a review of extant scenario-based or future studies in the initial stage of scenario development for three primary reasons. First, access to high-level strategic stakeholders is difficult, and to expect repeated meetings to develop and then to test the scenarios given the timeframe of the project would be difficult. Second, consulting existing literature allows us to include a wider set of perspectives in the scenario-building process compared to relying solely on interviews, and thirdly, the prevailing scenario methodologies prescribe starting with individuals [4,19–21] instead of analysing past research. However, this assumes that high-level stakeholders engage with scenario building (e.g. filling out consistency matrices) without assumptions about the future built on understandings of existing studies. However, these actors tend to be well-informed, so engaging with these stakeholders early without referring to extant studies would be unnecessarily duplicating previous work.

It is important to note that the review of relevant studies identified a set of common features and themes in order to formulate a set of futures scenarios to interrogate stakeholder understandings of resilience in the face of severe hazards. Reviewing the strengths and weaknesses of these individual studies was beyond the scope of the procedure. More importantly, it is crucial to identify common drivers and characteristics across a broad range of these energy and transport sectors – reviewing either existing energy-focussed or transport-focussed scenario studies in isolation would have helped perpetuate the 'silos' between sectors and between infrastructure and emergency planners.

An important part of developing the scenarios and episodes to help engage key stakeholders is the use of detailed 'stories', which must strike a fine balance between plausibility yet not be embedded in the status quo. Narrative approaches have been long recognised as an important currency of cultural experience. For example, approaches as temporally and conceptually distinct as Aristotle's 'mimetic theory' [22] and Lévi-Strauss's 'Structural Anthropology' [23] hold consensus on the power of stories to engage people. More recently, such potency has been recognised across academic disciplines and in the development of futures scenarios. Moreover, in the context of scenario-based future studies, narrative is used, since the alternative worlds being explored are complex and difficult to encapsulate using other more determinate methods employed in social inquiry. Thus, the focus shifts from the realm of 'evidence' to that of storytelling, where establishing 'what could be' depends on providing plausible future worlds that encourage suspension of belief [24,25]. However, scenario building is unlike 'fanciful dreaming', and narratives must combine data, intuition, and creativity to effectively engage with participants [26]. It is also important to set the scenario 'future' to both use a respondent's expertise and to challenge the respondent to think beyond current day-to-day operational responsibilities in order to better link the futures to present-day policymaking [27,28]. The recommended timescales vary from: 5 to 10 years [29]; 10 to 30 years [30]; 20 to 25 years [11]; or even 50 years [31,32].

There are already a number of other existing scenario development methodologies outlined in the literature. For example, Goodier et al. [2] proposed a causal mapping process with the following steps:

1. Choose theme and create groups
2. Decide causal map goal/outcome and timeline
3. Individually brainstorm issues, factors and barriers
4. Place issues and factors onto the causal map timeline
5. Introduce additional issues and factors
6. Identify dependencies
7. Challenge the map
8. Identify pathways
9. Plenary session and questions
10. Post-workshop production

Linneman and Kennell [33] suggested a five-step procedure for scenario-building:

1. Decide the audience and time horizon
2. Develop common factors across the scenarios using a PEST analysis
3. Choose drivers and scenario details (for 2–4 scenarios) using the factors resulting from the PEST analysis
4. Check consistency of scenarios
5. Test for the robustness of the scenarios

Although the schemas differ significantly, the scenario development in these processes share common steps: identification of key factors; deciding on drivers resulting in a set of scenarios; providing details of the scenarios guided by the drivers and factors; and checking the plausibility of the scenarios.

In response, our method for developing the Resilient Futures integrated scenario-episodes included seven stages:

1. Review of extant scenarios
2. Distillation of two primary drivers from existing studies
3. Use features from extant scenarios to conduct a PESTEL (political–economical–social–technical–environmental–legal) analysis to identify basic scenario characteristics
4. Refine and populate scenario details drawing on interview data with key stakeholders
5. Develop draft narratives of the four scenarios
6. Develop episodes to stress test scenarios (i.e. over three levels of resilience). Conduct further interviews with different key stakeholders to check the plausibility of the episodes alongside the scenarios.
7. Final refinement of the integrated scenario-episode narratives from stakeholder focus groups.

In addition to the common elements of scenario development found in previous procedures, our integrated scenario-episodes are different in two significant ways: use of extant studies; and integrating hazardous episodes into the scenarios.

3. Governing through resilience: background and shortcomings

The 2004 CCA sought to provide a policy shift in the UK by attempting to build a common understanding of 'resilience' amongst key actors in emergency planning and response. Analyses of resilience often break the concept down into three generations [34]. The first generation is that of robustness, i.e. how resistant a system is to hazards. The second generation of resilience is response and recovery, which focuses on whether the system can 'bounce back' in the short term. The third generation of resilience connotes adaptation and evolution, such that there is a progressive 'bounce forward' after a hazardous event. Yet, as our research shows, this third generation is often underplayed.

The draft CCA (quoted in Walker and Broderick [35]) defined resilience as 'the ability to handle disruptive challenges that can lead to or result in crisis'. The UK Cabinet Office [36] later outlined four components necessary for resilience: resistance; reliability; redundancy; and response and recovery. Thus, the essence of the CCA is multi-hazard planning; engaging a broad range of structural and non-structural measures to mitigate potential hazards [3]. Although the aforementioned components related to first-generation (resistance and reliability) and second-generation resilience (redundancy, response, and recovery), the UK Cabinet Office [36] conceded the importance of third-generation resilience, so that the concept connotes 'more than an ability to bounce back and recover from adversity and extends to the broader adaptive capacity gained from an understanding of the risks and uncertainties in our environment. But for the purpose of this guidance [36], a narrower definition [of resilience] has been adopted'.

During the Cold War, the UK focused on preparations in case of a Soviet ballistic missile attack on the US and its allies, followed by conventional military invasion. The UK Ministry of Defence (MoD), intelligence services, and military were the only agencies which would lead in the planning and preparedness against such attacks. By contrast, the CCA acknowledged a wider set of both natural (e.g. extreme climate events) and man-made (e.g. terrorism) potential hazard events where the threats are unknown, yet the responses to such crises have a high degree of commonality. Thus, according to the Home Office, '[c]ertain features will be common in the response to a variety of different forms of disaster' [37].

Hence, the CCA recognised the blurring between 'natural' and 'man-made' hazards, which lead to natural–technological disasters [38–40]. These events, in turn, can lead to a continuous 'corrosive social cycle' of blame and impacts which result in fundamental societal changes [40]. This type of 'corrosive loop' can also occur after terrorist attacks [40]. The resilience of vital infrastructure is crucial in avoiding 'corrosive social cycles'. To 'keep the country running', the UK Cabinet Office defined nine sectors of critical national infrastructure (CNI) that provide 'essential services' without which normal day-to-day life in the UK would be severely compromised: communications; emergency services; energy; finance; food; government; health; transport; and water [1].

Overall, providing a common language for response, recovery and understandings of critical interdependencies in the face of emergencies are crucial to governing through resilience, and this necessitates multi-sectoral stakeholder engagement between local, regional, and national actors from different agencies. Unlike the previous prevailing practice, the UK Home Office [37] now encourages an integrated multi-agency response to emergencies. The Home Office [37] also acknowledged that the policies necessitated intra-organisational integration to optimise resilience. The multi-stakeholder approach to

resilience is embodied in the creation of the Local Resilience Forums and Regional Resilience Forums stipulated by the CCA, and local emergency plans which spell out the roles for different agencies during emergencies. Therefore, offices within agencies have been created to operationalise resilience as it relates to an institution's objectives, which proliferates the number of stakeholders responsible for resilience.

Therefore, the current UK Government strategy is predicated on an approach that: harmonises understandings of resilience amongst both responders and strategic decision-makers; widens the notion of types of emergency, finding overlaps between man-made and natural hazard events; pays attention to critical infrastructure interdependencies; and underlines the importance of multi-stakeholder interaction during emergencies.

Despite the UK Government attempts to 'govern through resilience', the July 2005 London bombings and 2007 UK floods (after the ratification of the CCA) laid bare continuing weaknesses in co-ordinated multi-agency response, recovery, and adaptation after disasters. The Report of the 7 July 2005 Review Committee [41] concluded: 'The plans, systems and processes that are intended to provide a framework for the response to major incidents in London must be revised and improved'. Similarly, the Pitt Review [42] of the 2007 floods found: 'With no clear coordination and structure, responses to flood risk are piecemeal and not necessarily prioritised. Each of the organisations with a responsibility for flood management assets tends to carry out maintenance and improvement work independently, as there is currently little incentive to do otherwise. Investment decisions made in isolation can lead to inefficiencies and can even increase the risk of flooding'.

To address these critiques from the inquiries after the 7 July 2005 bombings and 2007 floods, it is necessary to bring key strategic and operational stakeholders into a deliberative space outside their own sector-specific 'silos' in order to: discuss different interpretations of resilience; reflect on their own assumptions about the term; think about how these notions affect interdependent critical infrastructures; and move towards longer-term joined-up thinking about third-generation resilience. Although we acknowledge and draw on the value of existing scenarios, we developed a set of futures scenarios integrated with natural and malicious hazard episodes specifically to foreground these issues as a tool to tackle aforementioned shortcomings of 'governing through resilience'.

4. Applying the procedure to the Resilient Futures project

Using the procedure outlined above, we developed a number of integrated scenario-episodes set in the year 2050 to engage with key strategic stakeholders and critically examine conceptualisations of resilience as they relate to critically interdependent infrastructures.

4.1. Review of extant scenarios

At the start of the project, the investigators narrowed the scope of the study to focus on two sectors of CNI identified by the UK's Cabinet Office – energy and transport – that cannot be considered separately during complex emergencies. Thus, we identified a number of existing scenario-driven future studies focusing on energy and/or transport infrastructure (Table 1). Although these extant studies focus on the UK/EU context, additional futures studies also exist examining energy and/or transport scenarios in other settings, e.g. energy and transport in Australia in 2050 [49]; energy in Colombia by 2020 [50]; renewable energy pathways to 2050 in Saudi Arabia [51]; Russian gas exports to East Asia in 2030 [52]; and green technology development in Asia in 2060 [53], amongst many others. The review of extant scenarios provided a means to guide the formulation of the future scenario-episodes and is not an end-goal of the procedure per se. As mentioned in the introduction,

Table 1
existing relevant scenario-based studies.

Future studies report (Year)	Institution (Nation)	Infrastructure Focus	Scenario Type (cf. Borjeson et al. [11])
Powering our Lives: Sustainable Energy Management and the Built Environment (2008) [32]	Foresight, Government Office for Science (UK)	Energy	Summary and quantitative data (Normative – preserving scenario)
Intelligent Infrastructures Futures (Towards 2055) (2006) [31]	Foresight, Government Office for Science (UK)	Transport	Narrative only (Explorative – external scenario)
Energy to 2050 (2003) [43]	International Energy Agency (Global)	Energy	Narrative and quantitative data (Predictive – what if and Explorative – external scenarios)
Shell Energy Scenarios to 2050 (2008) [44]	Shell (Global)	Energy	Narrative and quantitative data (Predictive – what if and Explorative – external scenarios)
Powering the Future: Mapping our Low Carbon Path to 2050 (2009) [45]	Parsons Brinckerhoff (UK)	Energy	Summary and quantitative data (Normative – preserving scenario)
Global Trends 2025: a Transformed World (2008) [46]	National Intelligence Council (US)	Energy and Transport	Narrative only (Explorative – external scenario)
IPCC Special Report Emissions Scenarios: Summary for Policymakers (2000) [47]	IPCC (Global)	Energy and Transport	Narrative and quantitative data (Predictive – what if and Explorative – external scenarios)
Energy Scenarios 2050 (2009) [48]	UKERC (UK)	Energy and Transport	Narrative and quantitative data (Predictive – what if and Explorative – external scenarios)

it is necessary and beneficial to consider bringing together studies on both infrastructure types (instead of analysing them in isolation) to avoid perpetuating prevailing sectoral ‘silos’.

4.2. Distil two primary drivers

Through careful examination of these existing future studies, there were a number of potential axes that could have been used, but we opted for two axes that best interrogate socio-technical resilience related to both critically interdependent energy and transport infrastructures. The year 2050 was deemed to allow for adequate time for infrastructure and governance systems to transform significantly, yet be close enough in the future for policy decisions initiating these changes to be made in the not-too-distant future.

We identified the following as the primary axes upon which to build the scenarios:

- The balance of infrastructure decentralisation/independency versus centralisation/interdependency.
- The extent to which social prosperity is presaged by greater technological innovation, including reciprocal infrastructure investment.

This leads to four scenarios:

- *iWorld*: An interdependent, convergent world embracing new infrastructure technologies.
- *Global Village*: An interdependent, convergent world resisting new infrastructure technologies.
- *High Tech Hamlets*: An independent, divergent world embracing new infrastructure technologies.
- *Local Power for Local People*: An independent, divergent world resisting new infrastructure technologies.

4.3. Carry out PESTEL analysis

To further define these four scenarios, we carried out a detailed PESTEL analysis to draw out patterns amongst existing relevant future studies relevant to energy and transport infrastructure sectors, which formed the basic skeletal narratives with which we engaged experts during the first round of key stakeholder interviews (Appendix 1).

4.4. Refine and populate scenario details using interview data

To provide richer and more plausible scenario narratives, we identified a set of key stakeholders who engage with strategic decisions related to energy and infrastructure resilience. These respondents included officials from local resilience forums, engineering firms, UK Government departments, risk management consultancies, and universities. We conducted semi-structured interviews with the sample of stakeholders ($n = 22$).

We ensured that there were at least five interviewees discussing each scenario, although respondents could comment on more than one scenario during the meeting. We asked questions around three broad themes:

- Healthy operation of energy and transport infrastructure
- Critical interdependencies between the energy and transport infrastructures
- Resilience strengths and weaknesses for a given scenario

Using the key stakeholder interviews, we obtained rich narrative data about the features and resiliency features for each scenario from key experts. The features of the scenarios extracted from the first round of interviews is summarised in Table 2.

The resilience benefits and concerns for each scenario are compiled in Table 3. It is important to note that although we derived the axes and basic descriptions of the scenarios through a careful review of existing studies instead of expert interviews, there were no significant objections to the foundations of the scenario development or the axes we selected.

Table 2
R-Futures scenarios.

	Resisting new infrastructure technologies	Embracing new infrastructure technologies
Interdependent, convergent world	Global Village: Role of transnational institutions; cohesive policy setting; focus on demand reduction; global aims are manifest locally; significant focus on nuclear and renewable energy; and very high density urbanism	iWorld: Internationally facing; solar arrays; dynamic smart grid; high cost energy and transport; high level of fuel poverty; many travel alternatives; and fewer transport options for the poor
Independent, divergent world	Local Power for Local People: National and insular focus on energy production; reliance on ‘proven’ technology; primacy of geographies close to energy production; localised micro-generation of power; limited motorised transport; and ageing society	High Tech Hamlets: Regional energy; primacy of urban/regional governance; localised micro-generation of power; large regional disparities in wealth; little inter-regional interoperability of systems

Table 3
Resilience benefits and concerns in R-Futures scenarios.

	Resilience benefits	Resilience concerns
Local Power for Local People	Increased local responsibility for resilience Local community cohesion and social capital Less pressure on central government, fewer bottlenecks	Varying resilience – less sharing of knowledge, skills and resources Rural areas are resilient, but urban areas are not Every piece of infrastructure becomes critical – no redundancy
High Tech Hamlets	Decentralisation mitigates cascade failure Local community responsiveness Fosters relevant innovation	Problems of co-ordinating regionally Lack of knowledge sharing and learning Uneven resilience Lack of support, backup and redundancy Problems of exclusion False sense of autonomy, hidden interdependencies
iWorld	Ability to create standards of regulation	Lack of relevance and responsiveness Centralisation is efficient but not resilient Lack of capacity to account for human behaviour Abdication of responsibility Over reliance on technology
Global Village	Active modes of transport (e.g. walking, cycling) would be encouraged and are more resilient as more adaptable (e.g. can be re-routed more easily).	Centralisation of infrastructure enables single point failures to become cascade failures. Terrorism becomes greater threat as transport enables terrorist movement and presents centralised targets but little technological mitigation possible. Terrorism increases as social unrest is pervasive driven by resistance to top-down governance system

4.5. Develop draft narratives of the four scenarios

After the first round of interviews, we brought together the basic features of each scenario, as well as strengths and vulnerabilities identified by key stakeholders, as the starting point to compose more extended draft scenarios. As mentioned in the previous section, it was important to write detailed story-like narratives to draw in expert respondents.

Table 4
Anonymised list of interviewees consulted during the construction of the scenario-episodes ($n = 29$).

Area of expertise	Hazard area	Infrastructure group	Sector
Rail transport security	Terrorism	Transport	Public
Aviation sustainability	All hazards	Transport	Private
Insurance	Flooding	n/a	Academic
Flood risk	Flooding	n/a	Public
Buildings and energy	All hazards	n/a	Academic
Energy infrastructure	All hazards	Energy	Private
Transport and society	All hazards	Transport	Academic
Counter-terrorism	Terrorism	n/a	Public
Counter-terrorism	Terrorism	n/a	Public
Counter-terrorism	Terrorism	n/a	Public
Rail transport and flood risk	Flooding	Transport	Public
Energy sustainability	All hazards	Energy	Academic
Rail transport	All hazards	Transport	Academic
Emergency preparedness	All hazards	n/a	Public
Sustainability	All hazards	n/a	n/a
Flood risk	Flooding	n/a	Academic
Transport project management	Flooding	n/a	Private
Critical infrastructure resilience	All hazards	n/a	Academic
Urbanisation and sustainability	All hazards	n/a	Academic
Emergency preparedness and response	All hazards	n/a	Public
Emergency planning and business continuity	All hazards	n/a	Public
Emergency preparedness and response	All hazards	Energy	Public
Electricity networks	All hazards	Energy	Private
Environmental consulting	All hazards	n/a	Private
Design and sustainability	All hazards	n/a	Academic
Risk management	All hazards	n/a	Private
Logistics	All hazards	Transport	Private
Sustainable transport	All hazards	Transport	Academic
Construction	All hazards	Transport	Academic

4.6. Develop episodes to stress test scenarios and conduct further interviews

We sought to engage with as many relevant strategic stakeholders as possible whose work is related to resilience. To do this, we used a compound natural and malicious hazard episode to bring in individuals both from counter-terrorism and flood risk management (as they relate to energy and transport) at local, regional, and national levels using snowball sampling. This allowed us to explore ways in which decision-makers from the two sectors can find common ground and provide a basis to reflect on the three generations of resilience. We sought events that would be realistic in the UK context, yet be severe enough to induce ‘corrosive social cycles’, so we drew on past natural and malicious hazard events, namely severe floods and terrorist attacks. For the flooding event, we looked at official and secondary literature on: the 1953 floods in the Netherlands and UK; 2011 Japanese earthquake and tsunami; and Hurricane Katrina. For the malicious hazard event, we interviewed counter-terrorism experts and drew on past terrorist attacks, including: the 9/11 attacks; and the bombings in London on 7 July 2005. The review of past episodes provided a basic outline for these crisis events, and we followed up with a second set of interviews with key stakeholders ($n = 7$) to provide further narrative details about the scenarios alongside narrative data about the episodes. An anonymised list of the 29 interviewees is shown in Table 4.

4.7. Final refinement of the integrated scenario-episodes

We ran a stakeholder to pilot the draft narratives. To do this, we invited a set of key stakeholders ($n = 20$) with minimal overlap between those interviewed for the scenario-episode development. Stakeholders were drawn from the academic, private, and

Box 1. Full background narrative for iWorld

The costs posed by the threats of energy insecurity and climate change have united the world’s leaders and multinational companies in pursuing advanced, though expensive, technological solutions. The UK government has led the way within international forums, such as the EU, in mobilising all sectors of the economy in assembling new large-scale energy infrastructures. The diverse energy attributes of particular countries are shared collectively on a continental scale across, and beyond, Europe: massive solar arrays in North Africa power European cities in return for free trade agreements and local infrastructure investment. An array of DC interconnectors links these modularised energy facilities into the European Super Smart Grid (ESSG). However, despite assurances to the contrary, some groups claim these energy agreements and technologies are a form of neo-imperialism – the newest phase of European exploitation of Africa. At a control centre in Bavaria, the ESSG coordinates a dynamic balance of energy production technologies, storage facilities, interconnectors and supply-side reduction technologies (including transport technologies) across the now 38 member strong European Union. The ESSG is a private company, owned by several large private investment bodies, governed by a statutory body: the Congress of European Energy Regulation (CEER). Major energy companies continue to supply energy to consumers via the ESSG. Whilst the CEER encourages energy security and efficiency, through various regulatory mechanisms, it has been criticised for allowing special tariffs that enable customers to pay to override default appliance settings for energy consumption. The ESSG defends such special tariffs as a necessary instrument to fund new investment in technology. During emergencies, where supply/demand balance is threatened, a “critical” phase tariff is introduced which allows power just for basic needs at a lower rate; consumers requiring additional energy are then charged at an exponentially higher price throughout the emergency. As a result of extensive energy-sharing infrastructure, political disagreements over energy policy, for example the construction of new nuclear power plants, become increasingly played out within European rather than national parliaments, often creating protracted political negotiations. Embedded power generation (i.e. micro-generation) is promoted and installation costs have fallen substantially, however EU laws requires that such generation must be shared within the ESSG through a grid interface system. Autonomous electric cars, powered either by batteries or in-road tracks, provide travel, within, and between, cities, road freight is now largely reliant upon biodiesel. An increasing proportion of freight utilises newly electrified rail corridors to Asia and the Middle East, especially as the cost of clean bunker fuels for shipping continues to increase. Air travel, by a range of super-efficient aircraft remains the preferred means of intercontinental passenger transport. However, the high cost of air travel places exceeds the means of most travellers, despite continued government subsidies and tax breaks. Within Europe high speed trains are increasingly used for transcontinental travel, whilst extensive light rail schemes now dominate the streets of most European cities. With the predominance of autonomous cars, and improved control systems in rail and air travel, transport is increasingly integrated as different modes communicate to create webs of interconnectivity. Energy and transport costs, national debts and taxation, have increased to pay for such massive investments in new infrastructure; this has, in turn, increased fuel poverty, social inequalities and tightened public spending. By contrast, the creation of novel, more desirable, infrastructure technologies such as high-speed rail networks that compete with air travel across continents and autonomous road vehicles free of congestion, has actually encouraged more travel, and prosperity, for the wealthy, despite increasing costs. The target of reducing GHG emissions by 80% is easily attained, as countries and working together to address global problems, and energy security looks assured. And yet, fuel poverty increases and there is markedly less energy and transport freedom: energy generation outside the ESSG and non-autonomous vehicles are illegal, spurring new black markets in “offline” energy and transport. Police operations have had some success in preventing the illegal import of fuels from North Africa and the Middle East though have been less effective in tackling criminals who have hacked into domestic grid interface systems. Eco-terrorism is also prevalent as groups respond when local environmental and economic concerns, such as a loss of local biodiversity due to biodiesel plantations, are downplayed in national and supra-national infrastructure plans.

public sectors, and had expertise related to resilience either in energy, transport, or more generally. Participants were introduced to the R-Futures project and notions of the three generations of resilience. After this initial session, these stakeholders were divided into four groups (one for each scenario). In each focus group ($n \approx 5$), participants were introduced to the scenario and asked to consider the strengths and weaknesses of the 'world' in 2050 guided by the three generations of resilience.

The facilitator then described the first (flooding) episode, after which the focus group discussed the flood defence and evacuation plans in place. After the flood hits, the focus group considered the impact and response/recovery operation. In the wake of the flooding event (36 h afterwards), a surprise crisis episode takes place: a malicious attack on energy infrastructure. The focus group then discussed the immediate impact, response, and recovery. Finally, to wrap up the discussion, the facilitator asked the focus group participants to consider the long-term effects on the society in the given scenario, thus including third-generation resilience into the integrated scenario-episode. Although participants were encouraged to focus on immersion into the alternative world, not questioning the basis of the scenarios and episodes, participants did have the possibility to suggest improvements. Any minor changes were included in the final version of the scenarios and episodes.

The approach outlined in the previous section produced rich, detailed narratives for the scenarios and complementary episodes that draw out implications across the three generations of resilience. The full scenarios and episodes are included in the next two sections.

5. Scenario narratives

Drawing on an integration of existing scenario building relevant to energy and transport infrastructure, the following section includes detailed narratives for each scenario, which can be used off-the-shelf in conjunction with the full episode narratives included in the next section.

Box 2. Full background narrative for High Tech Hamlets

The UK has experienced a resurgent localism in response to a global energy and environmental crisis. The cost of energy on global market has exponentially increased as states compete for diminishing fossil-fuel based resources. Powerful elected regional assemblies have been established across England complementing those in Scotland, Wales and Northern Ireland. Regional governance, coupled to increased power to local authorities, is intended to foster greater self-sufficiency. Trade in energy is increasingly bilateral and even non-monetary. The London Assembly, for example, negotiates a bilateral aviation fuel deal for Heathrow in exchange for professional services with the UAE.

Communities have adopted highly innovative infrastructure technologies in an effort to respond to local energy, and transport problems. Political devolution has encouraged regionally divergent infrastructure companies that specialise to exploit local resources and satisfy local needs. Public and private, regional energy service companies (RESCOs) provide finance to householders and communities to construct sustainable energy solutions. These RESCOs increasingly supplant centralised utility companies as the predominant energy investment instrument. Step-change in solar cell efficiency, and the effects of climate change, has led to extensive solar farms in Southern England which complement new nuclear power. In Scotland a ban on nuclear-sourced power has led to the development of extensive wind farms both onshore and offshore alongside large scale hydroelectric and tidal power schemes.

Increasingly less interconnected electricity, and transport, networks mitigate the potential for cascade effects. During critical episodes energy flows can still be enabled between regions providing essential backup. However these critical transfers invoke substantially higher energy costs therefore incentivising increased self-sufficiency as the resilience solution. In some rural areas of the UK the lack of regular investment in national transmission infrastructure has created failures in the ability of energy grids to provide backup transfers during emergencies. As a result differentiation in resilience is most pronounced in rural areas: some communities can afford to invest in elaborate backup systems to regional power supplies whilst others cannot.

Transport technology varies greatly across the UK, some regions continue to support fossil fuelled powered cars whilst other regions encourage the development of electric cars or fuel cell technology. There exists a high degree of divergence in infrastructure technologies. In transport, intelligent vehicle infrastructures often lack regional interoperability (e.g. between different battery exchange and charging systems), meaning that such technologies actually serve to further inhibit long-distance travel, although this helps to further reduce GHG emissions. Intercity transport lacks investment and coordination. The scope of ambitious intercity transport projects such as high speed rail has been scaled back. Some regional airports and distribution hubs have been mothballed completely. And yet, as regional economies become increasingly self-sufficient demand for intercity travel is greatly reduced. As the cost of food imports increases due to higher energy costs and the lack of co-ordinated investment in infrastructure for centralised food distribution, meat and processed foodstuff production and consumption decreases across most regions of the UK.

Public spending, debt and taxation differentiate regionally as investments are made in risky and expensive new energy and transport technologies that tend to either spectacularly succeed or fail. Some regions, particularly those with a high-technology skills base, easy access to sustainable energy resources, and a less energy dependent industrial base (e.g. professional services) have achieved remarkable success in promoting local prosperity and environmental health whilst ensuring energy security. However, the UK, as a whole, is falling short of meeting its 80% GHG reduction targets; for many, such global agendas appear ever more irrelevant.

Box 3. Full background narrative for Global Village

Global agreements on energy and environmental security are paying dividends as the world looks set to achieve ambitious GHG emission targets. Supra-national institutions, such as the UN, IMF and EU, have for years, provided a forum for policymakers, businesses and NGOs to coordinate global action. In an effort to promote sustainability in the developing world, developed nations focus on energy demand reduction and proven low carbon energy technologies over costly, and risky, new energy and transport technologies. For some, these policies represent a form of neo-colonialism as global trade with the developing world must now comply with strict environmental standards and energy security protocols.

By-passes of local, and even national political bodies to implement supra-national policies become routine and create increasing protest. For example, social unrest grows as fossil fuel powered vehicles are banned from all UK city centres by the EU. Local successes in achieving energy efficiencies are celebrated and shared worldwide. However, supra-national institutions are slow and unwieldy in responding to local environmental, transport and energy concerns.

Due to perceptions of unreliability, as well as their high cost, only a relatively limited number of energy interconnectors exist between countries. This pattern of limited technical integration in electricity and gas transmission is appealing for some whom advocate resistance to increased dependency on foreign energy markets. However various energy products, particularly LPG, continue to be shipped into the UK. Embedded power generation is limited in scope due to a lack of investment which has kept installation prices high. Technologies such as clean coal have failed to receive sufficient investment to make a prominent impact. Instead the UK, alongside the rest of Europe, continues to be heavily dependent on imported gas and nuclear alongside large-scale wind farms. This increasing lack of diversity in energy production is a concern for many commentators. Nevertheless significant results in adapting consumer and industrial behaviour to reduce energy demand, and improve efficiency through low-tech solutions (e.g. home insulation), has created a culture of adaptability to threats to energy supplies.

In transport, the desire to travel globally, and consume global products, is maintained. Whilst global travel by air has become more socially unacceptable, intercontinental travel by rail and sea has become cheaper and more popular, alongside a considerable increase in global teleworking. In increasingly high-density urban conglomerations travel costs are minimised and economies of scale in retro-fitting sustainable energy solutions are maximised.

Box 4. Full background narrative for Local Power for Local People

The world is experiencing a global depression partly caused by failed speculation by governments, investment funds and multi-national companies in costly, and risky, new infrastructure technologies. As a result, the UK government has adopted a 'grassroots' approach to tackling energy and transport challenges. Regional assemblies have been created to promote self-sufficient economic activity within local communities. Regional and local political parties have been formed that target resurgent local identities by reinforcing the value of energy self-sufficiency and independence. This localist political environment helps achieve a degree of energy security and demand reduction; however it proves less successful in developing low-carbon energy sources as regions inevitably harness their local energy resources.

Regional assemblies and a range of empowered local actors enable quicker and more responsive decision-making processes. Social enterprises and charities have become more significant institutions in developing, and adapting, energy and transport infrastructure. These organisations have helped make visible the costs of domestic energy and transport. Social enterprises have also offered individuals, families and communities support to invest in technologies that increase their self-sufficiency such as cavity-wall insulation and biomass heating. In some areas personal transport and energy credits are introduced to reduce energy consumption. In many communities road vehicles cars are increasingly publically rather than personally owned as the costs of vehicle ownership dramatically increases. Guided buses and light rail become more popular in many urban areas. Coach networks and demand responsive buses offer transport options between urban areas however intercity travel is greatly reduced. As economic activity is downscaled, people are encouraged to live, work, shop and unwind within walking distance, improving environmental and public health.

Less interdependent electricity, and transport, networks alleviate potential cascade failures. However the lack of regular investment in national transmission infrastructure has created difficulties in the ability of more localised energy networks to provide backup supply during emergencies. As a result many poorer communities that cannot afford extensive backup protection have been forced to adapt to a less reliable energy supply.

Whilst national economic activity is greatly reduced as a result of declining trade and investment, wealth is often distributed more evenly within most regions of the UK. Local co-operatives, owned by their employees, for example, become a prevalent mode of business organisation. This shift to "the local" has, however, created winners and losers as determined by the human and physical geography of a region. Poverty and ill health dramatically increase in some rural areas, with lower population densities, older populations and less renewable potential. While compact urban settlements, with access to nearby renewable resources can become relatively more successful. As a result urban densities have increased even within small market towns. Some rural areas become progressively depopulated.

The consequences of poorer global pension funds, caused by massively weakened stock markets, have been partly offset in some regions by increased multi-generational family habitation, providing social care and further reducing travel needs. Yet, despite such decreases in energy consumption, the UK as a whole is struggling to achieve its 80% reduction in GHG emissions, causing some regions to fear the effects of unmanageable climate change.

5.1. *iWorld*

In this scenario, there is a high level of connectivity and high acceptance of new technologies (upper right cell of [Table 3](#)) ([Box 1](#)).

5.2. *High Tech Hamlets*

In this scenario, there are low levels of connectivity, yet there is a high level of acceptance of new technologies (upper left cell of [Table 3](#)) ([Box 2](#)).

5.3. *Global Village*

In this scenario, there is a high level of connectivity, yet there are low levels of acceptance of new technologies (bottom right cell of [Table 3](#)) ([Box 3](#)).

5.4. *Local Power for Local People*

In this scenario, there are low levels of connectivity and of accepting new technologies (bottom left cell of [Table 3](#)) ([Box 4](#)).

6. Episode narratives

For the following episodes, the full narrative episode description will be followed by tables of additional features relevant to one more of the scenarios. For the tables below, the scenarios will be abbreviated as follows: Global Village (GV); Local Power for Local People (LP4LP); High Tech Hamlets (HTH); and *iWorld* (iW). Scenario-specific features of the natural hazard episode are included in [Box 6](#); and scenario-specific features of the malicious hazard episode are included in [Box 8](#).

6.1. *Episode 1 – natural hazard*

The full narrative background description of the flood episode is in [Box 5](#).

Box 5. Full narrative background of the natural hazard episode for all scenarios

An unprecedented storm surge caused by a combination of high winds, low pressure and peak high tides develops at sea. There is some uncertainty over the location and extent of the surge once it reaches land. However, advanced meteorological forecasting techniques point to a likely channelling of the surge along an estuary that borders the main commercial and residential urban centre.

Whilst flood defences do exist to protect valuable commercial sites upstream, continued unpredictable mid-21st century extreme weather has raised questions over their need for replacement. The defences traverse the estuary and sit at the border between high-density low-cost housing and valuable commercial sites upstream.

The surge enters the estuary as feared, overwhelming existing flood defences and spreads across several parts of one of the densely populated inland areas inundating several thousand homes, key sections of the extra-urban road network and threatening a local electricity substation and water-treatment plant.

Box 6. Scenario-specific features of the natural hazard episode

LP4LP: Neighbouring jurisdictions become affected by flooding and blame their plight on the failure of LP4LP to maintain their defences. Overall cross-jurisdictional co-ordination of the emergency response becomes problematic as a multi-site evacuation becomes needed.

HTH: Neighbouring jurisdictions become affected by flooding and blame their plight on the failure of HTH to maintain their defences. Previous migration of highly skilled workers to HTH has further weakened their ability to respond. Importation of energy is problematic given the restricted interoperability across regions. Neighbouring LRF communication systems also adopt different frequencies and bandwidths that further hamper cross 'border' assistance.

iW: Those from poor socio-economic classes, living in highest-density areas and having limited access to transport, are hit hardest. As fuel prices increase and transport options recede, tensions escalate. Displacement of effects onto aging infrastructure.

GV: Supra-national governance arrangements have dominated more localised recovery planning processes. Questions are raised over whether plans are too generic and insufficiently tailored to exceptional and localised circumstances.

Box 7. Full narrative background of the malicious hazard episode for all scenarios

Concerns over growing socio-economic inequalities, particularly related to unequal access to fuel and transport, have been intensifying since 2040. More radical elements have threatened direct action for some time and there is a sense that some groups possess sufficient capability to do so.

Sensing a moment of opportunity, and capitalising on growing anger over the impact of the floods, that occurred 36 hours earlier, a terrorist group launches an attack on the pumps feeding a nearby power plant. The attack immediately disables the cooling system causing dangerous overheating to occur. Initial safety measures fail and fires break out, generating a thick plume of smoke that engulfs the local landscape. As people attempt to leave the area, the limited remaining transport network becomes choked. The lack of electricity has also curtailed the ability to pump water into another nearby power station, compounding energy shortages.

The terrorist group release a public statement that the attack was aimed at striking infrastructures they see as serving the more privileged sections of society and symbolising their advantage. More attacks are threatened.

Box 8. Scenario-specific features of the malicious hazard episode

LP4LP: Continued demand on reduced energy production has reached its maximum capacity. Regional tensions mean that the prospects for importing energy are small with limited political will and problems of interoperability across regions. Of the options that do exist, energy is sold at an exorbitant price as other regions seek to profit from the disaster. Significant social capital exists within the community and there are considerable numbers of people volunteering their help. However, regular power shortages and increased tensions associated with the burgeoning informal economy mean that people are starting to leave the region...

HTH: Significant social capital exists within the community and there are considerable numbers of people volunteering their help. However, power shortages make it increasingly difficult to govern automated systems that are an embedded feature of life in High-tech Hamlets (domestic energy, access control systems, transport). Amid such sustained difficulties, people are starting to leave the region...

iW: Heavy reliance on technology exacerbates the impact of power shortages. Mobile communications are restricted and smaller businesses with fewer resources for business continuity are hit hardest.

GV: Continued demand on reduced energy production has reached its maximum capacity. Talks are underway to gain assistance and energy from other nations. However, this takes time and the (actual and perceived) distance of these supra-national political bodies generate tensions at the local level. As power shortages increase and transport options recede, further tensions escalate and reports of violence and looting begin to emerge...

6.2. Episode 2 – malicious hazard

The full narrative background description of the terrorist attack episode, which follows the flooding episode, is in **Box 7**.

7. Discussion and conclusions

The scenario-episodes generated were used to interrogate existing understandings amongst infrastructure and emergency planners regarding the resilience of interdependent infrastructures in the face of severe natural and man-made hazards. The procedure used to create the integrated scenario-episodes added to prevailing scenario development in two ways. First, we conducted an extensive review of existing studies in order to identify the primary drivers and hence conduct the PESTEL analysis. In this way, it was unnecessary to repeatedly interview stakeholders in the process of scenario development. The review of extant studies found resonances between scenario studies across energy and transport infrastructure sectors, which was found to be more instructive than considering the scenario studies individually. Second, the approach adds tailored crisis episodes to ‘stress test’ the scenarios, instead of operating in ‘business as usual’ circumstances.

Despite the wholesale changes to emergency response and recovery contained in the CCA, the inquiries into the July 2005 bombings and 2007 floods highlighted that implementing the resilience-focussed approach remains difficult. Crucially, our scenario-episodes have addressed the gaps in governing through resilience identified above: different understandings and priorities related to resilience within and across sectors and key agencies; insufficient focus on interdependencies between and within sectors that may lead to cascade failures; and little inter-agency understanding of resilience as it relates to long-term adaptation after hazard events. All of these gaps were interrogated by bringing together key responders and decision-makers in order to tackle existing narrow sectoral and institutional contexts. During the course of the interviews and focus groups, participants shared their differing operational assumptions about their own concepts of resilience whilst engaging with the futures presented, and how these differences might lead to inter-agency gaps or conflicts – and to cascading failures in interdependent critical national infrastructures.

In the focus groups, participants were able to identify areas of overlap amongst themselves, particularly through the prioritisation of the uncertainty of human behaviour in the recovery phase immediately after a disaster. Stakeholders also

debated long-term resilience in the R-Futures scenarios, providing a discussion on third-generation resilience (i.e. adaptation), largely absent in emergency planning and strategic infrastructure planning. As a result, key stakeholders were able to come to an understanding regarding the different priorities and meanings of resilience across their respective agencies, and appreciate how their actions have socio-technical consequences in complex interdependent energy and transport infrastructures. Most importantly, these stakeholders engaged with the integrated future scenario-episodes to find a real-world shared understanding of long-term challenges related to socio-technical infrastructure resilience.

Appendix A. PESTEL analysis using existing scenario-based future studies²

	Local Power for Local People	High Tech Hamlets	Global Village	iWorld
Political	Decline in governing role of state and supra-national organisations means increased trade tariffs and restrictions and more bilateral trade agreements. [A2, RR, SC, WWW] Increased importance of local authorities and regional bodies, including elected city mayors and elected English regional assemblies. [RR] Highly differentiated local, and regional, tax policies provide different outcomes on decreasing GHG emissions and energy-use. [RR, A2]	Decline in governing role of state and supra-national organisations means increased trade tariffs and restrictions and more bilateral trade agreements. [RR, SC, WWW, B2] Increased importance of local authorities and regional bodies, including elected city mayors and elected English regional assemblies. [RR] Local, and regional, tax policies provide different incentives for new technologies and innovation. [RR, SS]	Increased governing role of supra-national organisations means fewer trade tariffs and restrictions. [CC, BL, A1] Declining importance of local and national authorities. [GG] Rising importance of TNCs and NGOs. [DC, BL, A1, PNL]	Increased governing role of supra-national organisations means fewer trade tariffs and restrictions. [GG, CC, BL, B1] Declining importance of local authorities and national governments. [GG] Rising importance of TNCs and NGOs. [DC, BL, PNL]
Economic	1.5% UK economic growth but highly differentiated across the regions. [RR] Some regions are energy rich, others energy poor due to variations in natural resources. [RR, A2] Very noticeable regional economic inequalities. [RR, A2]	'Steady state economy' circa 0.5% growth due to high energy costs. [SS, B2] Some regions are energy rich, others energy poor but energy innovation and collective social capital can offset natural resource differences. [SS] Greater regional economic inequalities. [SS, B2]	Global, and supra-national, consensus on taxation/policies to reduce GHG emissions and energy demand, including substantial retrofitting of built environment. [CC] Circa 1.75% growth as more trade though less innovation. [CC] Increased global trade in fossil and nuclear fuels (and carbon credits). [CC] EU less has economic power compared to BRIC nations. [CC, WWW]	Global consensus on tax incentives for innovative energy and transport technologies, and GHG emissions and demand reduction taxes. [GG] Circa 2% growth as more trade and more innovation. [GG] Increased global trade (including energy, knowledge, carbon credits, and conservation credits). [GG]
Social	More energy intensive lifestyles. [DC] More travel locally, and within city-regions, but less nationally or globally, including migration. [RR, A2] Belief in individual material wealth dominates as marker of prosperity. [RR, DC] Population slowly declining at 69m in 2050 due to reduced net migration. ^a	Less energy intensive lifestyles. [SS] Belief in collective social wellbeing dominates over material wealth. [SS, CBNS] Population stable at 69m in 2050 due to reduced net migration.	More energy intensive lifestyles than today. [SC, A1] Consumerism dominant as marker of prosperity. [CC, DC, A1] Population at 77m in 2050.	Less energy intensive lifestyles. [CBNS, B1] Belief in collective wellbeing replaces individual material wealth as marker of prosperity. Focus on investment rather than consumption led growth. [B2, GG, CBNS] Population at 77m in 2050. State-funded reskilling of workforce. [GG] Increased mobility of people, goods and ideas. [A1]

² Abbreviations (in alphabetical order) – A1: A1 scenario (IPCC 2000); A2: A2 scenario (IPCC 2000); B1: B1 scenario (IPCC 2000); B2: B2 scenario (IPCC 2000); BL: 'Blueprints' scenario (Shell 2008); BS: 'Bright skies' scenario (IEA 2003); CBNS: 'Clean but not sparkling' scenario (IEA 2003); CC: 'Carbon creativity' scenario (Foresight 2008); DC: 'Dynamic but careless' scenario (IEA 2003); GG: 'Green growth' scenario (Foresight 2008); LCR: 'Low-carbon resilience' scenario (UKERC 2009); OS: 'October surprise' scenario (NIC 2008); PNL: 'Politics not always local' scenario' (NIC 2000); RR: 'Resourceful regions' scenario (Foresight 2008); SC: 'Scramble' scenario (Shell 2008); SS: 'Sunshine state' scenario (Foresight 2008); UKCP09: UK Climate Projections by DEFRA; UKERC: UKERC Energy Scenarios 2050; and WWW: 'A World Without the West' scenario (NIC 2008).

Appendix A (Continued)

	Local Power for Local People	High Tech Hamlets	Global Village	iWorld
Technological	Domestic or community energy generation, infrastructure and storage using locally favorable low, or zero carbon sources (include tidal, wind, hydro, solar, biogas, biomass, CCS, extraction of unconventional fossil fuels). [RR]	Domestic or community energy generation, infrastructure and storage using locally favorable low, or zero carbon source (including ground source heat pumps, biogas, micro-nuclear, microbial fuel cells, wind, solar, hydro, tidal, biomass, CCS). [SS]	National energy generation, infrastructure and storage using varied mix of technologies (include renewables, CCS, nuclear, biogas, biomass and especially CCS, extraction of unconventional fossil fuels). [CC]	National, and trans-national, energy generation, infrastructure and storage using varied mix of technologies (include Saharan and Iberian solar arrays, Scottish tidal, north sea wind, CCS, nuclear (inc fusion) and some embedded generation) and smart grids. [GG, BS]
	Electricity and non-powered sources used more for ground transport. [CBNS, LCR]	Hydrogen or electricity for local, intelligent ground transport (including automated coach network) depending on local preference. [UKERC]	International energy grid	Electricity and hydrogen sources used for intelligent ground transport. [BS]
	Biofuels for aviation air travel increases. [DC]	Greater teleworking, less car dependency more public transport. [B2, GG]	Electricity and hydrogen used for private, non-automated, ground transport. [CC, CBNS]	Biofuels for aviation, air travel decreases as less socially acceptable. [UKERC]
	Focus on retrofitting cities and rural housing. Continued suburban sprawl and out-of-town development. [RR]	Biofuels used for aviation, but air travel decreases. [LCR]	Biofuels for aviation, air travel increases. [UKERC]	Focus on new build, compact cities, less urban sprawl. [GG, B1]
Environmental	More well protected local conservation areas, urban tree cover and flood meadows. [RR]	Shift into new build higher density housing away from rural and older housing. [SS, B2]	Retrofitting of older properties, suburban sprawl and out-of-town development. [DC]	More teleworking, less car dependency more public transport. [GG, B1]
	Lack of platform for global consensus results in global failure (despite UK success) in meeting IPCC GHG targets. [A2]	More well protected local conservation areas, urban tree cover, grass roofs and flood meadows. [SS]	'Hard Engineering' solutions to flooding preferred. Flood plain development continues. [CC]	'Soft Engineering' solutions to flooding. [SS]
	Mean sea level change in UK up 26 cm and mean temperatures up 2–3 °C in winter (UKCP09). Greater regional, as well as local, devolution in some key legal areas (e.g. planning, transport, energy). [RR, A2]	Lack of platform for global consensus results in global failure (despite UK success) in meeting IPCC GHG targets. [B2, OS]	Global consensus results in global success in meeting IPCC GHG target. [B1]	Global consensus results in global success in meeting IPCC GHG targets. [B1]
Legal	Reduced international law. [RR, A2]	Mean sea level change in UK up 18 cm and mean temperatures up 1–2 °C in (UKCP09). Greater regional, as well as local, devolution in some key legal areas (e.g. planning, transport, energy). [RR, B2]	Mean sea level change in UK up 26 cm and mean temperatures up 2–3 °C in winter (UKCP09). Increased international law in areas such as transport, energy and environment. [CC, B1]	Mean sea level change in UK up 18 cm and mean temperatures up 1–2 °C in winter (UKCP09). Increased international legal consensus in areas such as transport, energy and environment. [GG, B1]
		Reduced international law and institutions. [RR, B2]	By-passes of local, and even national, laws to prevent NIMBYISM for developments of global strategic importance. [GG]	By-passes of local, and even national, laws to prevent NIMBYISM for developments of global strategic importance. [GG]

^a ONS population predictions from 2009 (69.8 million in 2033, 45% net migration). The National Grid predicts a population of 77 million by 2050. The current UK population is 61 million.

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