Resilience in our Net Zero Energy System

An Energy Research Partnership report produced in collaboration with Energy Systems Catapult

Contents

Foreword

Dr David Wright FREng, FIET, MIGEM
Co-Chair - Energy Research Partnership

Our energy system is undergoing a rapid transformation. By 2030, we aim to have a clean power system, and by 2050, the entire UK energy system should be Net Zero. This system is not just pipes, wires, molecules and electrons, it's the foundation that underpins our health, our economy and our modern society. Those more 'experienced' among us will likely recall "the candle drawer" that was a mainstay of most homes in decades gone past, kept "just in case" of a power cut. These days though, through incredible efforts, engineering expertise and infrastructure build we've largely got rid of the candle drawer, a sign that we have adjusted to an energy system that is incredibly reliable and resilient.

It's this energy system resilience that our report seeks to address. We cannot be complacent about the challenges that we face in this transition to Net Zero if we are to maintain the level of resilience that we've become gratefully accustomed to. Indeed, if we want to maintain the level of resilience we currently enjoy. Achieving Net Zero isn't just about reducing emissions; it's a challenge that affects and is impacted by our entire society and our changing climate. Energy system resilience, sometimes overlooked, is a crucial thread that runs through every part of this transition.

This is why, as co-chair of the Energy Research Partnership (ERP), I whole-heartedly supported creating a report on resilience within a Net Zero energy system. The ERP is uniquely positioned, with perspectives from across industry, government and academia, representing views from every corner of our energy system.

Our report truly challenges our thinking. By synthesising the views, experience, and expertise of our members, we've provided a pragmatic yet challenging discussion on how we can and should deliver the resilient, low-carbon system the public expects. While we haven't answered all the questions, we've certainly asked them. I encourage every reader to ask themselves: "Do I think about resilience enough?" If we all do, perhaps the candle drawer will remain a relic of the past.

Skip to our
10 priorities for action

Key Messages

- Resilience is the ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, resist, absorb, adapt to, and/or rapidly recover from such events.
- The UK has a strong track record for energy system resilience, exemplified by both National Grid and National Gas delivering effectively 100%[1] average network reliability – providing reliable energy for commercial, industrial and domestic consumers.
- Operating a Net Zero system will be different, combining less dispatchable low carbon and renewable resources with more electrified demand, such as domestic heating and transport. UK will be the first major developed (G20) nation to operate a zero-carbon electricity system. To do this, we will need to move from a system with hundreds of active participants, to one with millions. With proper attention and coordination, the UK can remain a leader in energy system resilience.
- **We must work towards a whole-system approach to maintain resilience throughout the transition to Net Zero, not just at the end state.** We need to understand the interfaces between co-dependent parts of the system, diagnosing and managing any risks. Our evolving energy system requires an evolving approach to resilience, with strong leadership and the ability to be agile in our approach to delivering it.
- **Resilience should be designed *into* our planning and investments**, not thought about retrospectively or in isolation. This should include consideration of potential future physical climate changes and socio-economic changes. This will ensure future energy systems are able to withstand impacts from climate change and respond to new demands under a net zero world, delivering long-term value for money.
- **Technology innovation can help to provide resilience at lower costs to consumers** – whether it be artificial intelligence or vehicle-to-home control systems, innovation can support resilience. Key decision makers in government and NESO should support innovation for resilience through clear policy direction, incentives and standards. Markets alone are unlikely to be sufficient.
- The electricity system's role in ensuring national resilience is evolving. It will have new critical, weather dependent and less predictable[2] demands like heating and transport relying on it. **There is a need for a fundamental shift in how we design and size our electricity system to maintain resilience in Net Zero.**
- **Decision makers across the sector must consider resilience implications of their decisions**, ensuring where possible that contributing evidence has factored it in. Training should be provided where possible across key institutions.
- **Resilience involves balancing cost,[3] public acceptance, and carbon emissions.** Achieving a resilient Net Zero system requires us to acknowledge and navigate the relationships between infrastructure investment, public risk acceptance and willingness to pay. Disparities must be anticipated and managed by responsible organisations.
- Delivering Net Zero is driving the introduction of new roles and responsibilities, whether that be NESO, Regional Energy Strategic Planners or regional mayors. It's critical to define responsibility and accountability for resilience. The ERP believes **NESO should be responsible for whole-system resilience, defining required outcomes, with delivery responsibility devolved to sector actors with deep knowledge of their areas.**
- **As a leader in delivering Net Zero, the UK should establish new or evolved metrics for resilience** that account for integrated energy systems to enable engineering justification, holistic cost benefit analysis and international benchmarking.

1. Reported as 99.999998% by National Grid 23/24 and 100% by National Gas in the latest available data in 22/23
2. A combination of weather and market dependence will inherently expose these technologies to more variables than other electric load and reduce comparable predictability. Whilst weather is likely becoming less predictable, some of the impacts on demand forecasts might be mitigated by automation, well-structured markets and advanced forecasting techniques.
3. 'Cost' here reflects both system cost (e.g. infrastructure) and costs of energy commodities (e.g. resources such as gas, biomass, nuclear fuels).

Skip to our 10 priorities for action

Introduction

The Energy Research Partnership (ERP), launched in 2005, is a public-private partnership bringing together senior leaders in the energy sector across government, industry, and academia to share learning and develop thought leadership. The aim of ERP is to provide independent support to national policy makers on the mission to achieve a net-zero energy system and guide and accelerate research and innovation activities.

Six years ago, ERP published our first report on resilience.[4] A lot has happened since. In May 2020, the National Infrastructure Commission published advice to government on how to deliver resilience across infrastructure sectors.[5] Much of this advice has been acted upon, including the Government confirming that they will introduce standards on resilience and develop an action plan to deliver these across the private sector.[6]

Specifically in relation to the energy sector, there has been a lot of change – not least the 2019 change to legislate for a Net Zero system in 2050. Then more recently, a new government with renewed determination to drive decarbonisation, the launch of the National Energy System Operator,[7] the establishment of Mission Control[8] which seeks to drive a faster pace of change and Great British Energy.[9] We've also experienced severe financial pressure from the Covid-19 pandemic and Russia's invasion of Ukraine, leaving 13% of UK households with the deepest levels of fuel poverty in 15 years.[10]

We've also seen some incredible technical achievements. We've seen a rapid growth in electric vehicle (EV) adoption, tens of GW of low carbon renewable energy installed and, in October 2024, the closure of the last UK coal power plant. We are one of the leading countries in the journey to Net Zero, with particular progress in decarbonising our electricity supply.

Our members, from across the sector, believe that now is the time to shine a light on resilience again with a Net Zero framing, helping to ensure that in a landscape where speed and decisiveness is key, we build a decarbonised system that is both brilliant and resilient.

This report offers a sector-wide perspective on the considerations and actions required to deliver resilience at each step in the UK's Net Zero transition. By convening and synthesizing diverse viewpoints and experiences from a range of individuals across public, private sector and academia from different parts of the energy system we address one of the topics that impacts nearly every aspect of it.

4 Future Resilience of the UK Electricity System, 2018

5 Anticipate, React, Recover: Resilient infrastructure systems, NIC, 2020

6 The UK Government Resilience Framework, Cabinet Office, 2023

7 As announced by NESO, September 2024

8 Chris Stark to lead Mission Control to deliver clean power by 2030, DESNZ Press Release, July 2024

9 Introducing Great British Energy: Policy Paper, July 2024

10 Annual Fuel Poverty Statistics in England, National Statistics, 2024

Why do we need to think about resilience now?

Resilience is the ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, resist, absorb, adapt to, and/or rapidly recover from such events.[11]

Applying resilience thinking to the whole energy system focuses on ensuring consistent outcomes for consumers, such as heating, mobility, and industrial productivity. By concentrating on outcomes, we can move away from siloed thinking and adopt a whole system approach to resilience.

In a decarbonising world, resilience faces new and evolving challenges alongside those that we are already experiencing, such as climate change.[12/13] Figure 1 below illustrates the considerations we should acknowledge when assessing energy system resilience, highlighting those that have either emerged, or have increasing importance in Net Zero systems.

The UK's energy system is reliable. National Grid's 100%[14] average network reliability in 2023/24 is matched by National Gas's in 2022/23.[15] Our largest gas network operator, Cadent, has a reliability of 99.99%[16] which is equalled by the most reliable electricity distribution network, UKPN, in 22/23.[17]

However, operational reliability is not equivalent to resilience. As the energy system evolves, and some of the considerations in Figure 1 materialise, we need to have designed and built a system that can absorb, adapt to and recover from these anticipated risks.

11 This builds upon our definition in our previous report on the "Future Resilience Of The UK Electricity System" as well as largely aligning with the National Infrastructure Commission's definition in "Anticipate, React, Recover" and the IPCC's Glossary of terms for "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation"

12 The UK Climate Risk Independent Assessment provides a good overview of current and future risks due to climate change

13 The Climate Change Committee also highlights the potential risks of Climate Change on resilience 'Delivering a reliable decarbonised power system', March 2023

	Types of Disruptive Events	Are Net Zero systems likely to be more exposed to these risks than our current system?
 Climate Change	**Increased extreme weather events** – such as prolonged high temperatures, low temperatures, high winds, water droughts, storms and low wind periods.	**Yes** – Higher levels of weather-dependent low carbon electricity generation technologies, with weather-correlated electricity system demand. Also, future Net Zero systems will have higher water requirements for low carbon technologies, including biomass, electrolysis, nuclear and carbon capture and storage.
	Secondary impacts – such as surface water flooding, water scarcity, wildfires and environmental capacity.	**Yes** – The electricity system is more vulnerable to these secondary impacts. We have hundreds of electricity power stations and substations at risk of flooding, whilst Net Zero becomes more electrified. We may have higher needs for water (e.g. biomass, CCS, nuclear) and wildfires are a particular risk to electricity networks.
 Geopolitical	International energy supply changes sabotage or global events impacting upon commodity availability/price.	**Probably not** – Whilst are future energy system will always be part of a global economy, with traded commodities required to build, maintain and operate our energy system, a system built around 'home grown' wind, solar and nuclear should be less exposed to geopolitical events.
 Technology Vulnerability	Significant technology failure that has widespread impact.	**Probably** – Our energy system will be undergoing rapid, transformational change, likely needing technologies that have not been used at scale before. Resilience assessments typically see these new technologies as having higher risks. Even the scaling up of existing technologies can expose unrecognised challenges. Net Zero systems make this existing issue more pertinent as nearly all 'tried and tested' unabated fossil-fuel technologies will need to be replaced.
 Societal Risks	Misalignment between societal behaviour and that required to maintain resilience (for example, choosing not to engage in flexibility due to negative media coverage, or using resistive heaters when asked to turn down their electric heating).	**Probably** – Whilst a democratised, decentralised Net Zero energy system has a wide variety of benefits to society and consumers, there is also a closer dependency on them. The less predictable, and sometimes non-rational behaviour that defines being human is also more challenging to manage. There are quickly emerging methods to help, but it's still a risk that Net Zero will need to accommodate for technologies will need to be replaced.
 Cybersecurity	A widespread cyber attack by a malicious actor on the digital infrastructure required to underpin a Net Zero system	**Unclear** - Discussions with stakeholders suggest that it's not clear whether risk is increased or decreased. There are two competing arguments here. The first is that a system with millions of actors reduces the scale of a single point of failure (e.g. taking out a major power plant). The other is that it's harder to control/ protect a system with millions of assets, and there may be more 'entry points' to cause disruption.
 System Interdependencies	Disruptive events that have cascading impacts on the energy system, or a different part of the energy system.	**Yes** – Net Zero systems will need to be more integrated, both across the energy system and with other sectors (such as water and digital). There are real risks of cascading failures between systems that need to be accounted for.

Figure 1 - Summary of potential risks to the energy system and whether they have a particular impact on Net Zero systems

The level of resilience we choose to design to is somewhere on a spectrum, illustrated in Figure 2. We shouldn't design an energy system for Armageddon at near-infinite cost, but we should also be able to continue to deliver our energy system outcomes beyond an 'average' condition, accounting for plausible risks and how they can potentially compound each other. 'Designed-in' resilience should be the cheapest way to build an energy system, balancing incremental cost against avoided risk of cost in the future.

Our rapidly evolving energy system, in a fast-changing, decarbonising world warrants us to consider how we can, across the energy sector, improve our understanding of, and approach to ensuring resilience within our future Net Zero energy system.

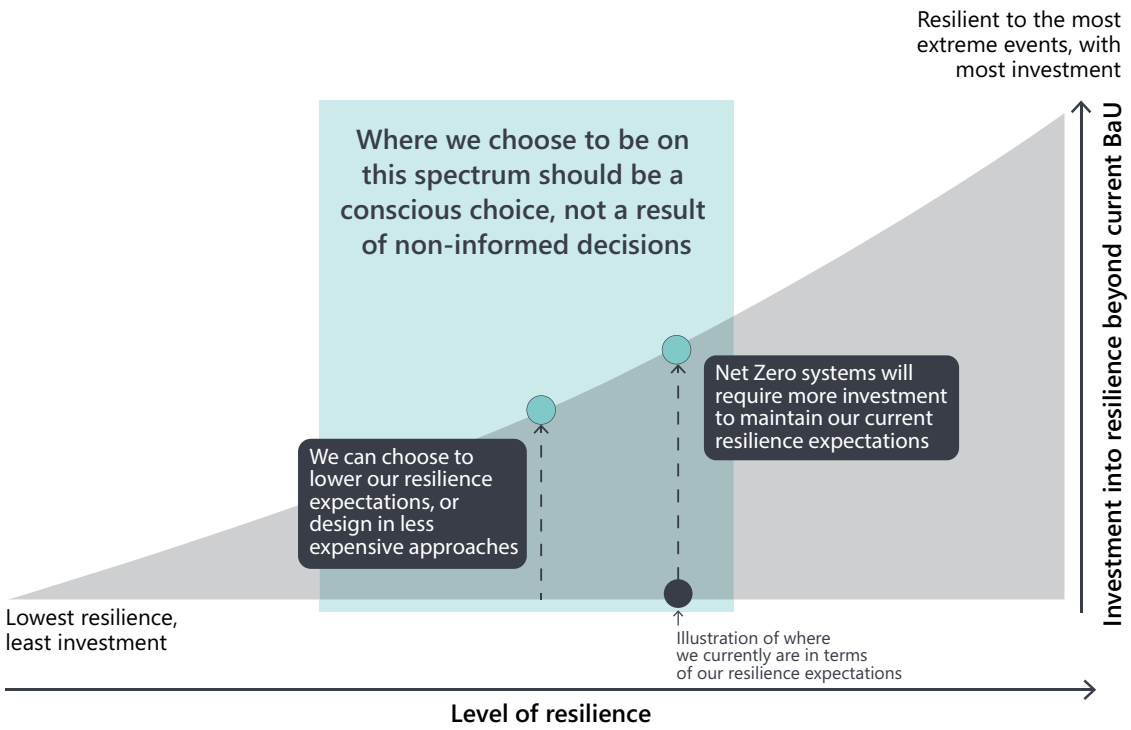


Figure 2 - Illustration of resilience vs investment and the need for conscious decision-making

14 Reported as 99.999998% for National Grid

15 Our Performance, National Gas Transmission, 2022/2023

16 The Future of the Gas Network, Cadent, September 2024

17 UK Power Networks Annual Review 2022/23

Resilience on the path to Net Zero is not just a technical challenge

Delivering Net Zero whilst ensuring energy system resilience is complex. Breaking down the cause of that complexity into parts can help stakeholders across the energy system to understand their responsibilities and recognise the wider resilience implications of their decision making.

Figure 3 illustrates how the decisions on whole energy system resilience are a function of three core elements within the UK: the energy system, the public and the climate. The choices made, or the changes that happen, within each have implications on the others. Therefore, our approach to resilience within a transition to Net Zero is not just a technical energy system challenge – it is a balance between climate security, public attitudes and the investment in and design of our energy system.

The Energy System: Our Net Zero energy system is our ability to meet the energy-related outcomes of our homes, businesses, transport and industry whilst ensuring that our net emissions are zero by 2050.[18] It will be undergoing unprecedented transformation over the next 26 years, with most reputable sources pointing to a highly electrified system, with significant roles for hydrogen, gas and heat networks.[19] However, many of these sources do not currently specify the design of a *resilient* Net Zero system sufficiently.

The Public: The cumulative actions of individuals both in preparing for and responding to high impact but low probability events is a crucial aspect of our energy system resilience. Society's response to the Covid Pandemic demonstrated that we can achieve collective action in such an event. However, any decision to rely upon public action for maintenance of energy system security in extreme events must be made consciously and transparently. In parallel, we need to recognise the long-term value of resilience and the ways to pay for it that will be acceptable to the public.

Climate Change: In 2019, the UK Government became the first major economy to pass a Net Zero emissions law. This commitment will shape our approach to providing energy system resilience. It is also our contribution to the global effort in fighting climate change and ensuring long term climate security. Whilst the UK can influence and lead the way, the potential impacts of climate change will still need to be accounted for, and Net Zero energy systems are potentially more impacted than our current system,[20] with low carbon energy systems potentially more vulnerable to weather-related impacts of climate change, including wind draughts[21] and compounding issues such as solar cloud cover, water shortages or extended cold conditions. It's in the best interest of the UK to continue to support the global fight against climate change, but we should still design our system to anticipate climate-related stress events. In this report, climate security is discussed as a requirement and component of resilience. Whilst we will not be recommending approaches to reduce the effects of climate change (such as adaptation approaches), we recognise the environmental management implications that can impact upon energy system design.

Governance: Our governance structures are responsible for reconciling the complexity illustrated in Figure 3 to empower and provide transparent and clear messaging and guidance to actors throughout UK society, from public bodies and supply chains to individual consumers and businesses. These structures need to incorporate new and proposed public sector organisations with key roles in the delivery of Net Zero and energy system resilience, such as NESO, GB Energy, Regional Energy System Planners (RESP), and city and combined authority mayors.

18 Also including emissions from non-energy sources such as agriculture and land use

19 Such as the CCC's 6th Carbon Budget analysis, ESOs Future Energy Scenarios and Energy Systems Catapult's Innovating the Net Zero 2024.

20 Whilst true, we also recognise that a low carbon system using more of our own resources provides energy system resilience in its own way through lower reliance on internationally traded commodities like gas.

21 How well do we understand the impacts of weather conditions on the UK's renewable wind and solar energy supplies?, Government Office for Science, November 2023

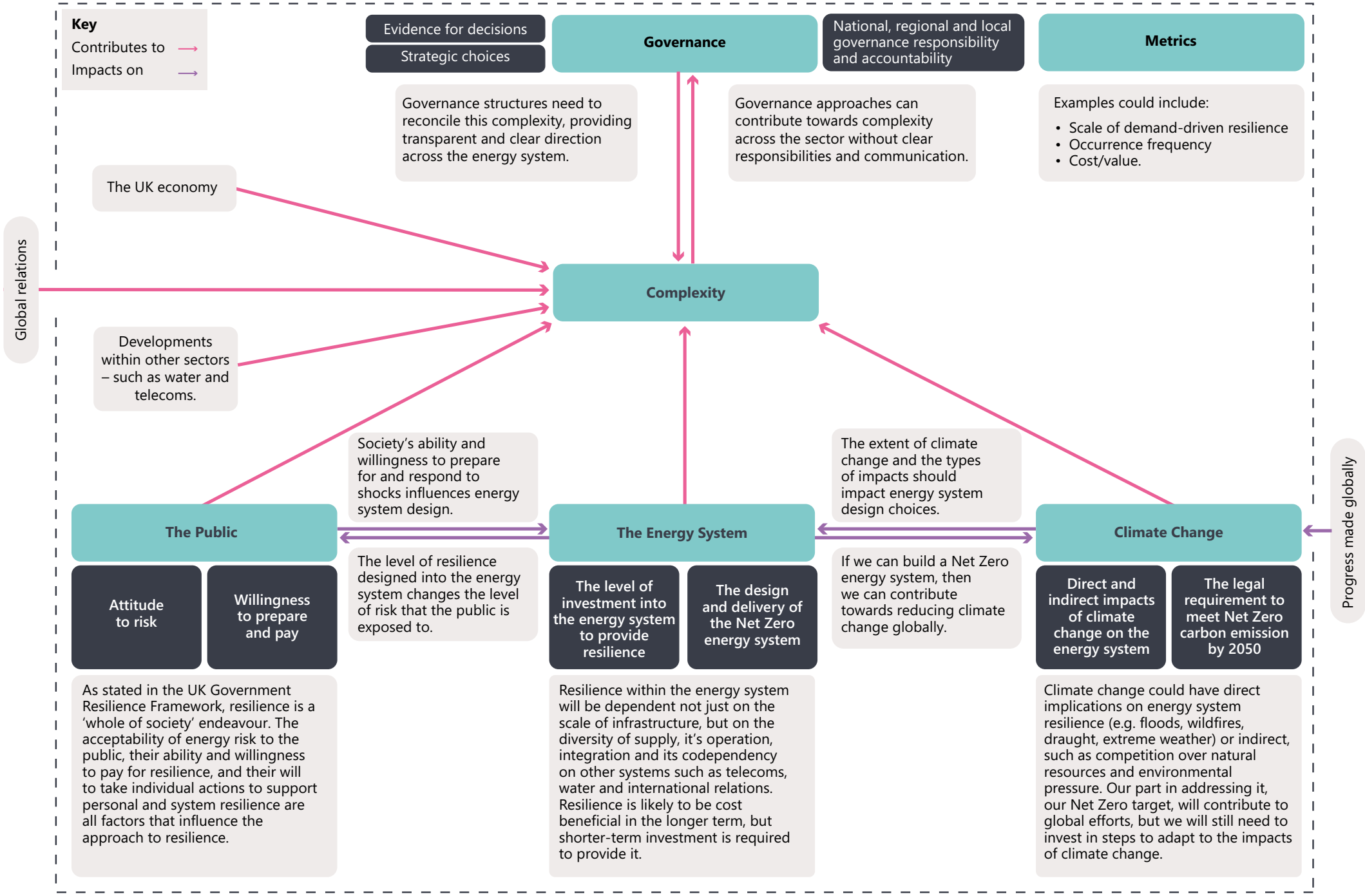


Figure 3 – An energy system resilience framework

The Energy System

How would a resilient Net Zero energy system differ from a non-resilient Net Zero energy system?

The range of Net Zero energy system designs that can be feasibly implemented by 2050 is quite limited, as shown within the Energy Systems Catapult's Innovating to Net Zero 2024 report.[22] This is also evident when comparing various published scenarios and pathways.[23] While many necessary features are known, some aspects remain uncertain. By applying a resilience perspective to Net Zero, we can:

- Improve our approach to implementing the features we know are needed, capitalising on opportunities to embed resilience and/or mitigate risks.
- Refine our energy system design to ensure resilience is designed in, not addressed as a potential expensive afterthought.

Figure 4 highlights some of the key anticipated features of a Net Zero energy system, the implications on resilience, and the considerations that should be taken into account when making decisions.

22 Such as: Innovating to Net Zero 2024, Energy Systems Catapult

23 E.g. the Future Energy Scenarios and the Climate Change Committee 6th Carbon Budget scenarios

Feature of a Net Zero system	Impact on resilience	Considerations
Electricity Backbone – our electricity sector will need to double in size, powering new loads like cars, heat pumps, industrial processes and more. To meet this demand, we will move away from a system of inertia to one that is more inverter based and supplied by more natural resources like solar, wind.	Whilst reducing dependency on imports, a system with weather-dependent supply and demand can risk exposure to extreme weather events, which are likely to become more common with climate change. Also, our electricity system has historically not been designed to be low inertia or manage heating and transport loads.	• How do we reflect the changing role of electricity in the electricity system design standards? • How can our evolving Net Zero system manage extreme weather events? • Whilst technology solutions exist to deal with low inertia, what engineering practices and standards are needed to deploy them at scale?
Diverse – whilst electricity plays a core role, the system will also be diverse, with heat networks, hydrogen and natural gas all playing a role. There will be diverse supply technologies (e.g. solar, wind, nuclear) and diverse demand technologies.	Diverse systems, when aligned to a single set of objectives, can be more resilient. They can achieve more reliable outcomes and can mitigate single points of failure targeting a specific technology or infrastructure. Diversity, can be represented in multiple ways, from technologies to demand, from supply chain to competitive marketplaces.	• How should we develop diverse systems that minimise risk and provide complementary functions? • How do we transition between energy vectors whilst maintaining resilience? • How can we ensure that diverse systems are aligned to the same objectives?
Integrated and complex – The pathways that energy takes from resource to demand will be more integrated. There will likely be more dependencies on other systems such as water and telecommunications. We'll be moving from hundreds of active energy system participants to millions.	A more intricate energy system 'web' could be more resilient, with less exposure to any part of the system? However, these systems will be more difficult to manage and operate. Unless mitigated, there are also resilience risks from cascading failures where one failure in one system perpetuates failures across other systems.*	• Are the approaches to implementing a Net Zero system using systems-thinking? • Are we recognising the risks on the energy system from other systems? • Have we developed the tools to operate a more complex system with more actors?
Digitised – a Net Zero system will require a robust underpinning digital architecture that enables data transfer, visibility, and standardised control of assets across the sector. There will need to be stronger system coupling with the telecommunications sector.	Digitisation can enable more tailored control of energy systems, increasing resilience. However, if we don't recognise and mitigate it, there is risk of over-reliance on telecommunications to maintain the integrity of energy infrastructure. With an increasing cyber-security threats, resilience of our energy system depends upon digital infrastructure design.	• Is our digital infrastructure being designed and deployed with sufficient resilience to account for its role in energy. • Are we making it easy enough for industry to develop robust decisions using available data? • Have we recognised the co-dependencies between energy and digital infrastructure?**
Flexible – our Net Zero system will move from a system of supply-side flexibility to one that flexes supply and demand. The Net Zero target places renewed importance on low carbon flexible technologies such as long duration hydrogen and heat storage, batteries and demand shifting to make best use of low carbon power when it's produced.	Flexible technologies and the mechanisms through which it is delivered can support resilience. Currently, flexibility is rewarded for balancing the system through national and local market conditions, but not for providing system resilience. Examples include the ability to recover from a cold start event, or the value of strategic long duration hydrogen stores.	• Is our digital infrastructure being designed and deployed with sufficient resilience to account for its role in energy. • Are we making it easy enough for industry to develop robust decisions using available data? • Have we recognised the co-dependencies between energy and digital infrastructure?**
Exposed markets – Net Zero systems will have markets that permeated from supply, right down to individual consumer level, reflecting the more decentralised system than we have today.	Increasingly, the demand profiles on our energy infrastructure are a result of markets and the resultant retail propositions that assets respond to. Markets should be a tool to support resilience, but we need to ensure that they are structured in such a way that promotes the evolution of a resilience system.	• Are we including resilience requirements when considering how to implement flexibility? • How can we effectively attribute the value of resilience to the technologies that can support it? • Do we need emergency flex control mechanisms for times of crisis?
A new relationship with the global economy - Our Net Zero system will likely have a lower dependence on internationally traded fossil fuels, but we will still rely on international relationships and agreements to deliver and operate our energy system resiliently through supply chains, interconnectors and carbon trading schemes.	The recent exposure to volatile gas prices impacted by international conflict should be more avoidable, with more secure UK-produced supply providing higher levels of resilience to external factors outside of our control. However, we are still part of a global economy, with international supply chains for both energy technology and digital infrastructure.	• Are we taking a systems view to our international relationships when assessing energy system resilience? • Are we consciously making decisions about any vulnerabilities to international interference in our energy system?
More energy efficient – Delivering Net Zero requires us to use less energy for a given outcome. Our system will need to be more efficient, from our industrial processes to our homes to our data centres.	Efficiency in producing outcomes not only makes Net Zero delivery easier, but also reduces exposure to risks from disruptive events. For example, efficiency can reduce peak demands during extreme weather events, and resource efficiency can reduce exposure to global supply chain shortages.	• Do we recognise the role of efficiency in providing energy system resilience? • Do we recognise in our decisions the relationships between cradle-to-cradle efficiency and energy system resilience?
More personal – Delivering Net Zero requires a closer relationship between people, their homes and the energy system. Our infrastructure, markets and retail propositions will be tailored around our understanding of consumers and their behaviour.	Individuals can be an asset and a risk to resilience. Together, the fabric of society can be supportive and resilient. However, people may also introduce personal or collective priorities (outside of energy) into a system better prepared to navigate rational, predictable behaviour focused on energy, with less consideration of other outcomes and priorities.	• How do we create stronger relationships between the energy system and individuals? • What markets, regulation and business models support a system that minimises risks from individuals whilst maximising the power of a resilient society?

Figure 4 - Features of a Net Zero system and their implications on resilience

*The cascade risks from AI and automation for example could arise when EV penetration reaches a tipping point in terms of load that can be switched on relative to local grid capacity. The deployment of multiple algorithms, primarily designed to ensure the lowest costs to their consumers, rather than grid stability, could create conflicts and overload the grid causing cascading network faults. Some of these risks are more near-term than others which may become risk scenarios once we reach a tipping point regarding decentralisation of the energy system and penetration of AI.

**As highlighted in this article for the National Preparedness Commission: nationalpreparednesscommission.uk/publications/communications-systems-for-energy-system-transformation-why-action-is-needed-now

Maintaining resilience on the transition between now and 2050 requires us to understand the relative changes to risks across each of these areas at any point in the transition. One approach we could learn from is the Environment Agency's Adaptation Pathway Programme[24] that has implemented a decision-making approach, that allows decision-makers to take actions under uncertainty. These pathways allow for a plan to be made, whilst providing a framework through which those plans can be adapted as more evidence and understanding is developed. By embedding resilience within our emerging planning frameworks, such as Strategic Spatial Energy Planning (SSEP), Regional Energy Strategic Planning (RESP) and Local Area Energy Planning (LAEP), we could also adapt our pathways to Net Zero to maintain resilience as we develop more evidence.

Alongside our evolving planning processes, we also should recognise the opportunities from the giant leaps made in technology in recent years. If harnessed appropriately, technology innovation can help to reduce the costs of providing resilient future energy systems. Examples are described in Figure 5.

24 Adaptation Pathway Programme, Environment Agency

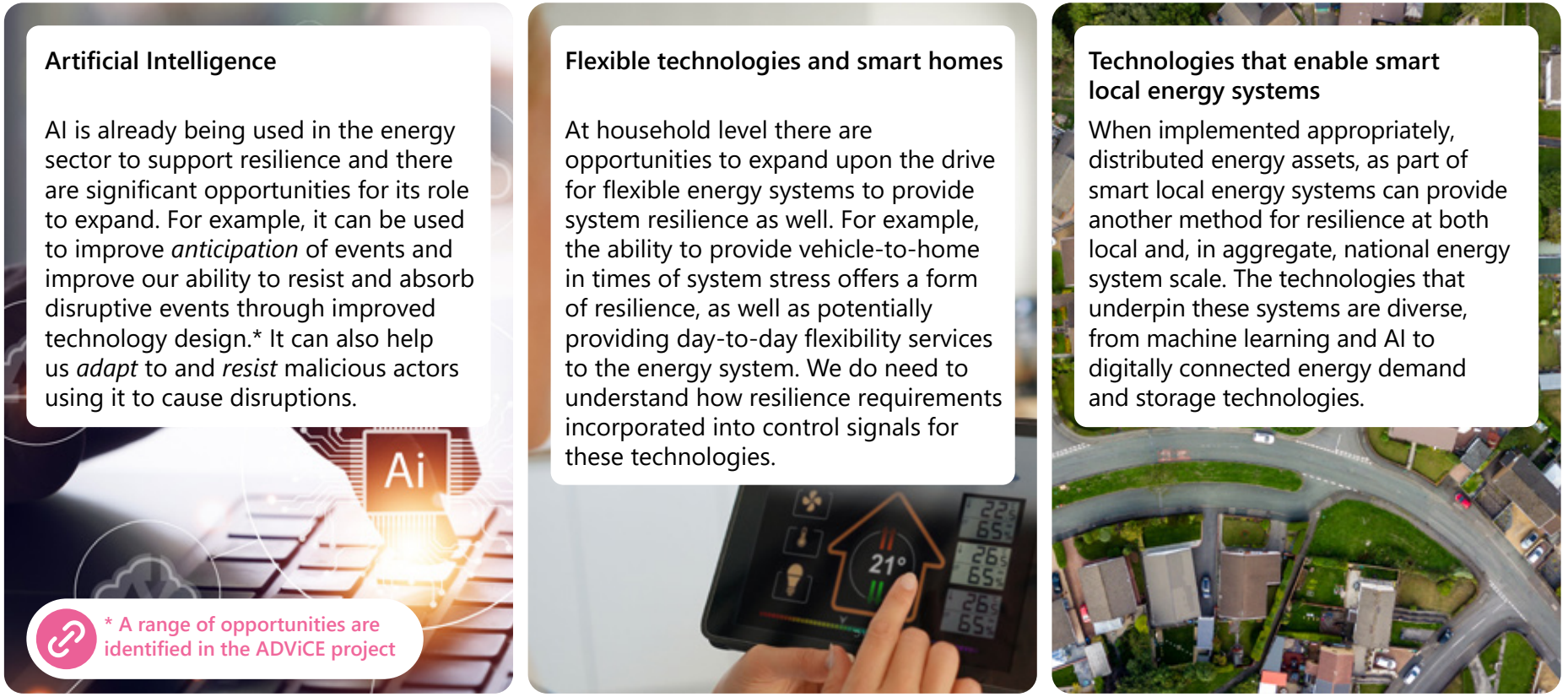


Figure 5 - Examples of new technologies and approaches that can support energy system resilience

The Public

What is the role of society in ensuring energy system resilience?

Consciously or not, the public have a role in providing energy system resilience today. Our existing resilience standards[25] ensure that our infrastructure is sized and operated to deliver the outcomes that we have grown to expect. The public pays for it through our bills and taxes. However, individuals don't typically question these standards and the associated costs to deliver them – they elect a government to take these decisions for them.

Historically, there has been little public appetite to consciously prepare for low probability events,[26] with people and organisations alike tending to underestimate their likelihood and impact until they experience them first hand. On the other hand, after experiencing an event, there is often a public outcry and demand for accountability, indicating a shift in appetite post-incident. This is particularly true for collective or societal losses, which seem to be perceived differently to personal losses, which are serviced through well-established insurance sectors.

Today, in part due to our own historic successes, the public expect resilient energy supply. However, in other areas, we've shown that a strong societal fabric and collective culture can be effective at minimising damage in response to disruptive events.[27] Deciding whether and how much to involve the public in providing active resilience for the energy system (whether that be in the resist, absorb, adapt or recover phases) should be a conscious decision with the implications understood. Such a decision raises several challenging questions which are illustrated in Figure 6.

The likely outcome is that we will pursue a combination of all forms of resilience. The UK Government Resilience Framework[27] suggests a wide-ranging approach to resilience. It emphasizes a 'whole of society' approach, providing "guidance to community organisations and individual householders, to help those people to make more informed decisions about investing in their own resilience and preparedness."[28] Applying this to Figure 6 would require creating pathways and opportunities for individual and community energy resilience, alongside significant national infrastructure investment. Additionally, it would involve clear communication about the expected impacts of climate change and the transition to Net Zero. As an example of government-led communication around resilience to the public, it is useful to see the recent example from the Swedish Government.[30]

Regardless of the approach government decides, it needs to be a conscious decision that accounts for the questions we have highlighted. To do so, we need a clear and effective governance structure.

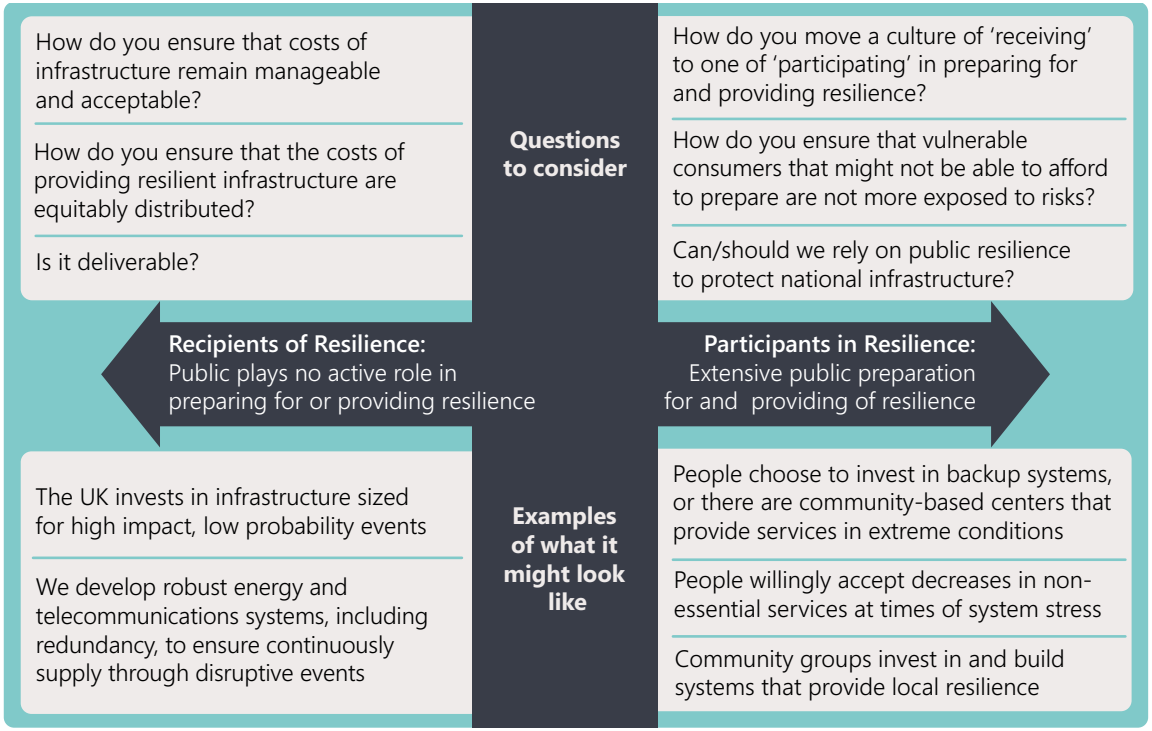


Figure 6 - Questions to consider when deciding on the role of the public in providing energy system resilience

25 Usefully summarised by the National Infrastructure Commission here.

26 These might include, for example, climate change-related weather events or cyber-attacks.

27 There were many of these within the Covid-19 pandemic across the world, from mass changes in behaviour to individual acts of kindness and generosity, helping those that are vulnerable.

28 Note: this was the previous UK Government

29 The UK Government Resilience Framework, Cabinet Office, 2023

30 In November 2024, the Swedish Government send a guide to residents to support individual and local resilience in case of crisis or war.

Climate Change

Within this report, we recognise the UK's legally binding Net Zero emissions target, and that the impacts of climate change on the UK will be largely dependent upon progress on emissions reductions made in the rest of the world. That is one reason why the UK needs to be a leader in the transition to Net Zero, and for strong international co-operation.

Whilst global emissions reductions are largely out of our control, the scale and rate of global temperature rise will pose specific choices and decisions for those concerned with UK energy resilience – namely, how should we plan, design and build infrastructure that is resilient to future climates. For example, the Environment Agency has issued screening guidance that suggests planning for both a 2 degree and 4 degree average temperature rise.[31] We cannot assume that the climate will change within the boundaries of what is tolerable to existing infrastructure, or that the UK environment will remain unconstrained; our supply of water for example will come under increasing pressure.[32] In more extreme (but plausible) scenarios, global supply chains will be impacted by extreme weather and international trade disrupted by climate impacts. The extent to which the UK energy system is dependent on those supply chains – for equipment and parts – will depend on how resilient it is to future shocks.

In Figure 7 below, we highlight a set of specific impacts of climate change, the dependent areas of energy system design, and the trade-offs and decisions that need to be made to ensure resilience to climate change uncertainties.

Given the dependency between climate change, the environmental boundaries within the UK and our Net Zero energy system design, our approach to energy system resilience should account more readily for the full range of climate impacts. We can do this by:

Strengthening co-operation and data sharing between critical national infrastructure providers (e.g. water and energy sectors) to ensure that interdependencies and whole system resilience is built into each sectors planning. The Cabinet Office have a role in facilitating this.

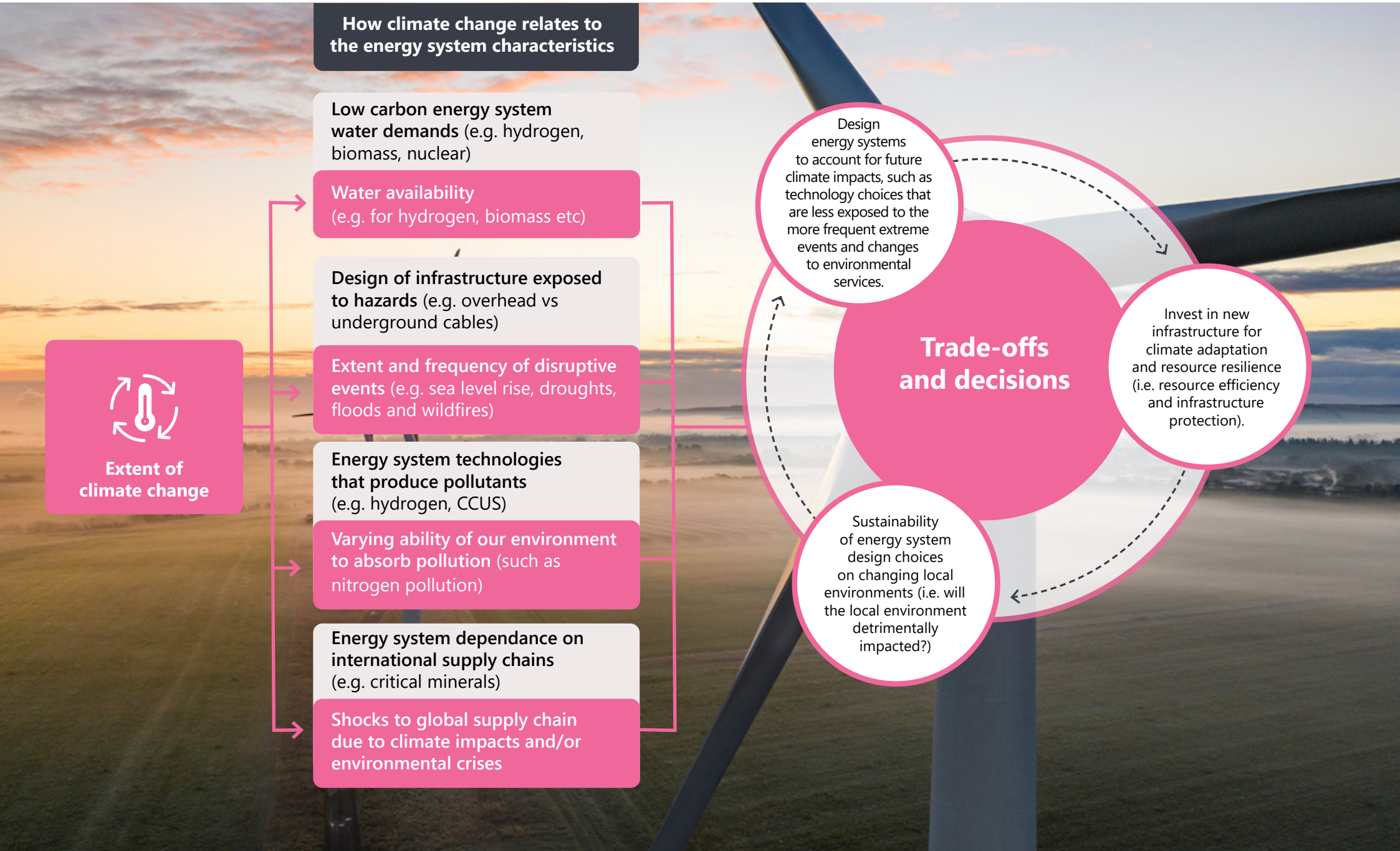
Strengthening understanding of our dependence on global supply chains in the energy sector, including for parts, equipment and critical minerals, and the extent to which climate impacts might disrupt international trade. The Department for Business and Trade should take a lead role in building this knowledge base.

Improving the route between adaptation plans and the actions taken by companies to account for climate security risks. For example, NESO and individual energy companies should undertake climate risk assessments and adaptation action plans.[33] Also, the National Adaptation Programme could be strengthened through a clearer vision, metrics and 'adaptation pathways' for the energy sector.

31 Climate impacts tool - GOV.UK

32 The Environmental Constrains of Net-Zero - The Energy Research Partnership

33 This would be part of the Climate Change Act Adaptation Reporting requirements. Currently energy companies do a trade body level report via Energy UK, but more help is needed to ensure individual companies integrate adaptation into their corporate structures.


How climate change relates to the energy system characteristics
Extent of climate change
Low carbon energy system water demands (e.g. hydrogen, biomass, nuclear)
Water availability (e.g. for hydrogen, biomass etc)
Design of infrastructure exposed to hazards (e.g. overhead vs underground cables)
Extent and frequency of disruptive events (e.g. sea level rise, droughts, floods and wildfires)
Energy system technologies that produce pollutants (e.g. hydrogen, CCUS)
Varying ability of our environment to absorb pollution (such as nitrogen pollution)
Energy system dependance on international supply chains (e.g. critical minerals)
Shocks to global supply chain due to climate impacts and/or environmental crises
Trade-offs and decisions
Design energy systems to account for future climate impacts, such as technology choices that are less exposed to the more frequent extreme events and changes to environmental services.
Invest in new infrastructure for climate adaptation and resource resilience (i.e. resource efficiency and infrastructure protection).
Sustainability of energy system design choices on changing local environments (i.e. will the local environment detrimentally impacted?)

Governance

Within our emerging Net Zero energy system, who is responsible and who is accountable for ensuring resilience is delivered and maintained?

The future Net Zero system will be more than just electricity; it will be a complex "system of systems" requiring integrated governance across different sectors. Reflecting this evolution, there has been significant change in our governance in the past few years. There are new actors (e.g. GB Energy and Regional Energy System Planners), transforming organisations (e.g. ESO becoming NESO) and evolving roles of existing actors (e.g. increased devolution of powers to some combined authorities). Figure 8 below summarises currently specified responsibilities of the various publicly owned governing actors.

The UK Resilience Framework and the establishment of NESO's responsibilities has started to clarify the roles and responsibilities across the sector. We must continue to clearly communicate these roles and responsibilities to reduce any perception of fragmentation of responsibilities for designing and delivering energy system resilience.

NESO will be an independent, technical body capable of providing advice to government and industry to improve the resilience of the electricity and gas sectors. NESO is both well placed and capable of being the single entity overseeing whole energy system resilience. However, there are several outstanding questions that need to be resolved. In Figure 9, we highlight these questions and suggest actions that can be taken to answer them.

Governance body	Responsibilities relating to energy system resilience
UK Government	The UK Government is responsible for emergency powers and systems to deal with any event that occurs, with the Cabinet Office producing the UK National Risk Register. Responsibility for ensuring Net Zero energy system resilience is split across 'Lead Government Departments (LGD)'.[34] DESNZ is the Lead for 'Disruption of electricity, gas and fuel services', overseeing joint industry resilience governance for these sectors through the Energy Emergencies Executive Committee (E3C). DESNZ also works in partnership with other departments and devolved Governments for related/impacted areas. Mission Control is part of DESNZ. As recommended by the National Infrastructure Commission, the government have stated that they "will introduce standards on resilience and develop an action plan to deliver these across the private sector, where these do not already exist, to give a clear benchmark on what 'good' looks like for resilience."[35]
Devolved Governments	Energy responsibility for Great Britain is reserved to the UK Government, but many areas linked to the risks associated with delivering a Net Zero energy transition are devolved (e.g. flooding, drought, fires) and require cooperation and collaboration.
Ofgem	Ofgem is responsible for the regulation of electricity and gas infrastructure, ensuring that specified standards are conformed to whilst minimising costs to the consumer. Since the amendment to the Energy Act in October 2023, Ofgem's remit includes compliance with Net Zero and interim carbon budgets. Ofgem doesn't have an explicit responsibility for resilience, beyond that implied in standards. Ofgem also has other related roles, such as regulating NESO and setting its license (e.g. the resilience requirements in the Day 1 license). They also set some strategic planning requirements such as setting the resilience requirements in Centralised Strategic Network Plan.
NESO	NESO will be responsible for cross-vector energy resilience for the electricity and gas sectors, readiness, post event learning, assessing security of supply, and cyber/physical security assessments[36] enabling NESO to help adopt a whole energy system response across energy vectors.[37] NESO provides independent insight to Government and Ofgem.
Regional Energy System Planners	NESO will be responsible for implementing up to 13 Regional Energy System Planners across Great Britain.[38] Ofgem have indicated that potential activities will include "Provide supporting information to guide when and where capacity is needed to form the basis for detailed network planning" where network planning is the responsibility of the Network Operators and includes "delivering sufficient capacity, when it is it is needed, using the most cost-efficient solutions whilst maintaining network resilience and reliability."
City Deal & Combined Authority Mayors	Whilst some cities and combined authorities have published resilience strategies, they are not responsible for local resilience.
Local Authorities	Category one responders in the Civil Contingencies Act, and key members of local resilience forums (LRF). The LRFs aim to plan and prepare for localised incidents and catastrophic emergencies. They work to identify potential risks and produce emergency plans to either prevent or mitigate the impact of any incident on their local communities. They have duties to assess risk and maintain plans for emergencies.
Great British Energy	Of its 5 identified functions, many refer to boosting energy independence. It is also looking to support Local Power Plans with community energy groups to support a 'more decentralised and resilient energy system'.

34 The Roles of Lead Government Departments, Devolved Administrations and Other Public Bodies, Cabinet Office, August 2023

35 Within the UK Government Resilience Framework - 2023

36 In collaboration with DESNZ and the National Cyber Security Centre (for cyber) and the National Security Protective Authority (for physical / personnel security)

37 As defined in Ofgem's decision on the framework for the Future System Operator's Centralised Strategic Network Plan.

38 As defined in Ofgem's "Future of local energy institutions and governance"

Figure 8 - A summary of currently specified responsibilities across public governing actors

Remaining questions	Recommended actions
How will NESO transition from a sector-based to a whole energy system approach to resilience?	Review the reporting requirements of NESO on whole energy system resilience, alongside any need for further capability development. These should include recommendations on the role of the public and businesses, and the required approaches to supporting them to provide resilience.
What are the pathways through which strategy and design are translated into investment and delivery? Who is responsible for integrating actions across sectors that influence the energy system but not within the remit* of NESO? For example, heat network planning, telecommunications, water system development, environmental What is the split of responsibilities and accountability between NESO, Ofgem, GB Energy and DESNZ in the delivery of national Net Zero resilience. Do organisations with responsibilities have the appropriate powers, duties, and tools to address the evolving risks and landscape?	1. With a focus on the whole energy system, clearly define and communicate resilience needs and the boundaries of responsibility, ensuring that all involved parties understand their roles. 2. Review the powers, duties and tools available to actors, ensuring that they have the capability to deliver upon their responsibilities. 3. Either create or assign an existing body the responsibility of overseeing the interactions between sectors – ensuring that where actions taken in one negatively effect the resilience of another, there are swift changes in requirements and responsibilities to re-instate resilience.
There are so many decision makers across public and private sectors that can impact upon energy system resilience. Are we confident that there is widespread understanding of resilience and personal responsibilities to consider it?	In all organisations with responsibilities for resilience, provide training on whole energy system resilience. The objective should be to ensure that resilience awareness and understanding is wide-spread, whilst enabling decision makers to be challenged on the basis of resilience.
Through what metrics will whole energy system resilience be assessed and communicate throughout the sector to ensure clear allocation of responsibilities for delivery?	Review and adapt our current metrics of resilience to be more appropriate to the outcome of achieving whole energy system resilience. The current Value of Lost Load is not appropriate in its current form.

Figure 9 - Outstanding questions on governance of resilience in the transition to Net Zero

*as specified in public documentation

Resilience Metrics

Resilience metrics underpin our ability to communicate, assign responsibility and deliver energy system resilience. They enable engineering justification, support cost benefit analysis and enable international benchmarking and collaboration. There are several potential resilience metrics that can be applied to energy systems.[39] To help define the approach to metrics to Net Zero resilience, we need to be able to answer:

- Which metrics should be used and who should define them at each part of the energy system governance and supply chain?
- How do these metrics then proliferate into delivery of a resilient Net Zero energy system?
- Where different metrics are required at different scales/parts of the system, how do we ensure a whole system approach to energy system resilience?

Which metrics should be used and who should define them at each part of the energy system governance and supply chain?

Energy system resilience is a societal need that would not be valued by markets alone. Therefore, the government, having considered independence advice from NESO, should be responsible for defining resilience metrics for the energy system. However, government should not seek to decide the mechanisms through which resilience can be delivered, leaving this instead to each sector. Getting the metrics right can provide clarity, encourage industry-led innovation and collaboration between sectors.

Whilst this report will not attempt to define the specific metrics to be used, we do propose their characteristics. Government-led energy system resilience metrics should be:

- **outcome-based** – focusing on the outcomes that individuals and businesses receive, or don't receive, from the energy system
- **supportive of whole-system approaches** - applicable across sub-systems, rather than driving siloed sector-specific thinking
- **dynamic** – recognising resilience is the need not only to prepare for, but to anticipate, resist, absorb, adapt to, and/or rapidly recover from disruptive events.

Government should challenge NESO to pursue whole systems approaches to resilience recommendations, and NESO should subsequently advise government on the appropriate resilience standards to define. This could include further research by academia on the pros and cons of different resilience metrics suitable to the UK energy system, and their ability to drive outcomes.

We do not feel that, in its current form, the Value of Lost Load is suitably defined for a Net Zero transition. This should be either improved significantly or replaced with something more suitable to the risks and potential consequences that Net Zero systems face.

How could these metrics then proliferate into delivery of a resilient Net Zero energy system?

Whilst the government should specify overall energy system resilience standards, their implementation will require more detailed standards to be developed and implemented across the rest of the energy system. We propose that these standards should be developed collaboratively by industry bodies representing different parts of the system (e.g. electricity networks, heat networks, appliances) and standard-setting bodies (e.g. BSI, ENA and IGEM). These sector-specific resilience standards should recognise the interfaces and interdependencies with other parts of the energy system, clearly articulating them and managing any resultant risks.

39 Such as attribute-based, performance-based and generalised, usefully summarised in NGET's WELLNESS Project, Deliverable 3: identification requirements

They should be developed in collaboration with NESO, who would then be responsible for assessing whether the portfolio of standards, together, will meet the whole energy system resilience standards. This proposed approach is illustrated below in Figure 10.

In addition to the proposed approach in Figure 10, the responsibilities of Great British Energy and the various regional and local planning bodies with respect to resilience standards need to be clarified.

Where different metrics are required at different scales/parts of the system, how do we ensure a whole system approach to energy system resilience?

The standards in specific industry sectors may need to use different metrics to support the efficient delivery of components and subsystems. NESO should be responsible for assessing whether, in aggregate, the various standards across the energy system are sufficient to provide the energy system resilience we need. They could use systems engineering approaches to assess the impact of these standards in aggregate, identifying areas that need reviewing as the system evolves.

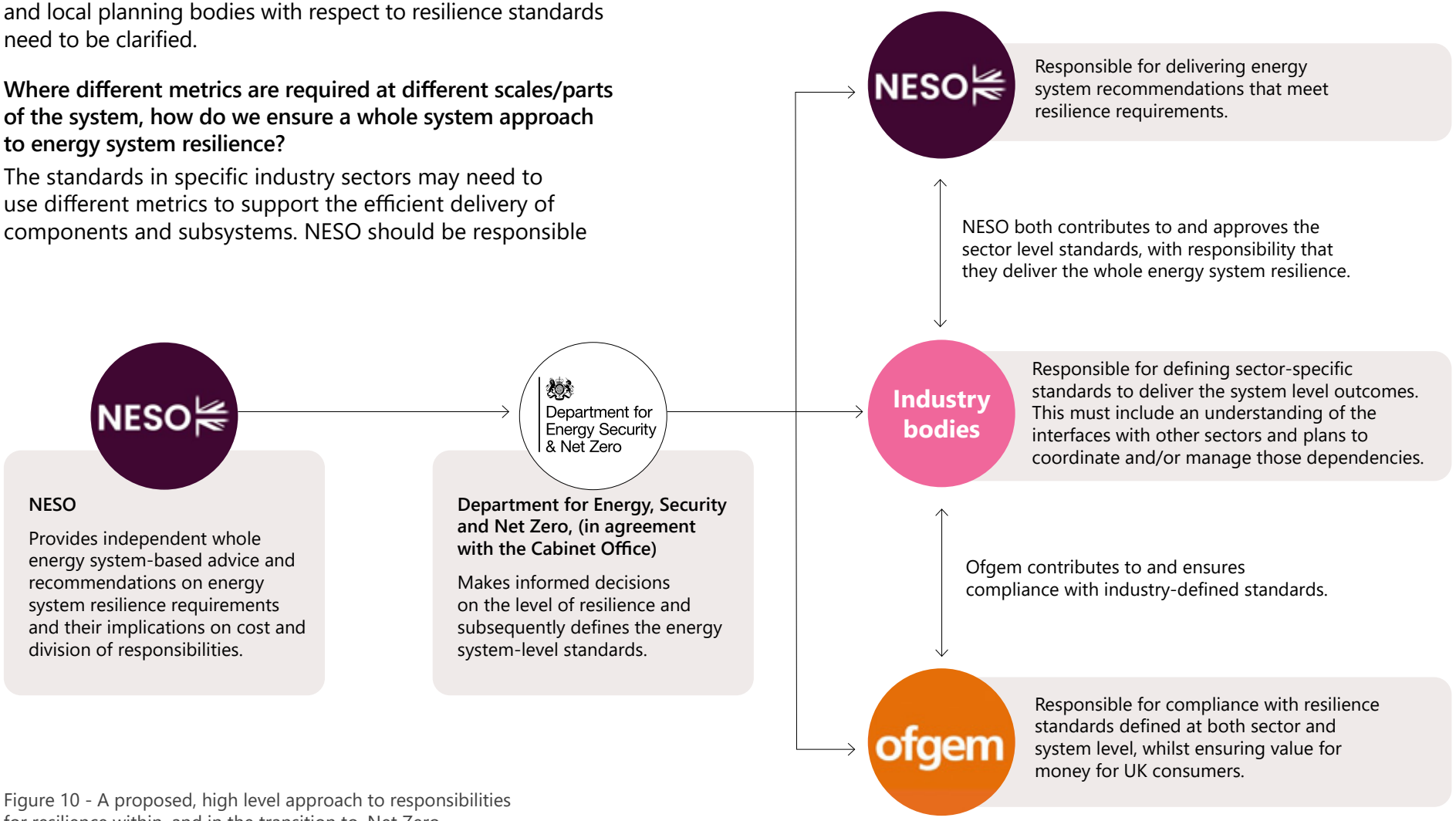


Figure 10 - A proposed, high level approach to responsibilities for resilience within, and in the transition to, Net Zero

10 priorities for action

Decisions happening right now will be influencing the resilience of the Net Zero energy system. Whilst not suggesting that we should stall decisions, as we have no time to lose, it is critical that we get clarity and direction on the approaches to delivering resilience in our changing energy system.

Urgent Priorities

If done now, the benefits will be felt for years to come.

- Government should clarify roles and responsibilities for defining and delivering energy system resilience within, and in the transition to, Net Zero.
- NESO should ensure that they have developed the capability to assess whole system resilience, ready to advise Government on appropriate metrics and whole system standards.
- Industry (e.g. ENA) through Ofgem should critically assess whether the existing standards are sufficient to provide resilience within systems evolving towards Net Zero.

Near term priorities

These should be done within 2 years to maximise our delivery.

- All organisations contributing to energy system strategy should integrate resilience into planning and investments from the outset to ensure long-term value for money. This includes ensuring that key planning reports do more than represent average winter days as the basis for energy system design.
- NESO should seek to recommend new or improved metrics for energy system resilience to government that reflect the needs of Net Zero systems, supporting collaborative and whole systems approaches to delivery. These metrics should be clear across each sector, whilst forming a whole system view when aggregated.
- Embed resilience within current and emerging planning frameworks – from National to Local level.
- Embed resilience in the design and implementation of new energy assets and systems coming online in the near term. These assets are likely to be around for a long time and we may otherwise suffer the consequences in the long term.

Ongoing actions

- All key institutions should provide training on resilience to ensure informed decision-making at all levels. Ideally, this should be consistently based upon a curriculum provided by the Emergency Planning College. In absence of this, training developed by each organisation. There are positive examples in government of a single day's training having good impacts, leading to better decision making.
- Adapt pathways to delivering resilience for Net Zero as more evidence and understanding develop.
- Use systems engineering[40] approaches, that account for the complexity of interdependent subsystems, to assess and improve resilience standards over time.

40 Systems Engineering is an interdisciplinary, whole life-cycle approach that helps to cope with complex problems by challenging assumptions; managing real world issues; to produce the most efficient, economic and robust solutions to the needs being addressed.

Conclusions

The journey to a resilient Net Zero energy system is both a challenge and an opportunity for the UK to lead globally in sustainable energy innovation. By adopting a whole-system approach, integrating resilience into planning and investments, and fostering collaboration across sectors, we can ensure that our energy system remains robust and adaptable. The evolving demands on our electricity system, driven by increased reliance on renewable energy and electrification of heating and transport, necessitate a fundamental shift in design and operation.

Clear roles and responsibilities, supported by training and well-defined resilience metrics, will empower decision-makers to navigate the complexities of this transition. Engaging the public and maintaining transparent communication about the impacts of climate change and the benefits of resilience will be crucial.

The time for incorporating resilience into our Net Zero thinking is now. The climate is changing. Energy assets are being installed. Systems are being developed. This report has described how decarbonisation and resilience go hand in hand – the pressure to deliver the former cannot hinder the latter. It cannot wait.

The UK's leadership in this area, supported by innovative governance structures and a commitment to holistic resilience, will set a benchmark for other nations. Together, we can create an energy system that is not only sustainable but also resilient, ensuring a secure and prosperous future for all.

Licence/Disclaimer

Energy Systems Catapult Limited Licence for "Resilience in our Net Zero Energy System"

The Catapult is making this report available under the following conditions. This is intended to make the Information contained in this report available on a similar basis as under the Open Government Licence, but it is not Crown Copyright: it is owned by the Catapult. Under such licence, the Catapult is able to make the Information available under the terms of this licence. You are encouraged to use and re-use the Information that is available under this Catapult licence freely and flexibly, with only a few conditions.

Using information under this Energy Systems Catapult licence

Use by You of the Information indicates your acceptance of the terms and conditions below. The Catapult grants you a licence to use the information subject to the conditions below.

You are free to:

- copy, publish, distribute and transmit the Information
- adapt the Information
- exploit the Information commercially and non-commercially, e.g. by combining it with other information, or by including it in your own product or application.

You must, where you do any of the above:

- acknowledge the source of the Information by including the following acknowledgement:
- "Information taken from Resilience in our Net Zero Energy System"
- provide a copy of or a link to this licence
- state that the Information contains copyright information licensed under this Catapult licence.
- acquire and maintain all necessary licences from any third party needed to use the Information.

These are important conditions of this licence and if You fail to comply with them the rights granted to You under this licence, or any similar licence granted by the Catapult, will end automatically.

Exemptions

This licence only covers the Information and does not cover:

- personal data in the Information
- trademarks of Energy Systems Catapult; and
- any other intellectual property rights, including patents, trademarks, and design rights.

Non-endorsement

This licence does not grant You any right to Use the Information in a way that suggests any official status or that the Catapult endorses you or your use of the information.

Non-warranty and liability

The Information is made available for use without charge. In downloading the information, You accept the basis on which the Catapult makes it available. The Information is licensed 'as is' and the Catapult excludes all representations, warranties, obligations and liabilities in relation to the Information to the maximum extent permitted by law.

The Catapult is not liable for any errors or omissions in the Information and shall not be liable for any loss, injury or damage of any kind caused by its use. This exclusion of liability includes, but is not limited to, any direct, indirect, special, incidental, consequential, punitive, or exemplary damages in each case such as loss of revenue, data, anticipated profits, and lost business. the Catapult does not guarantee the continued supply of the Information.

Governing law

This licence and any dispute or claim arising out of or in connection with it (including any noncontractual claims or disputes) shall be governed by and construed in accordance with the laws of England and Wales and the parties irrevocably submit to the non-exclusive jurisdiction of the English courts.

Definitions

In this licence, the terms below have the following meanings: 'Information' means information protected by copyright or by database right (e.g. literary and artistic works, content, data and source code) offered for Use under the terms of this licence. 'ESC' means Energy Systems Catapult Limited, a company incorporated and registered in England and Wales with company number 8705784 whose registered office is at Cannon House, 7th Floor, The Priory Queensway, Birmingham, B4 6BS. 'Use' means doing any act which is restricted by copyright or database right, whether in the original medium or in any other medium, and includes without limitation distributing, copying, adapting, modifying as may be technically necessary to use it in a different mode or format. 'You' means the natural or legal person, or body of persons corporate or incorporate, acquiring rights under this licence.

Energy Systems Catapult is an independent research and technology organisation. The Catapult's mission is to accelerate Net Zero energy innovation.

Launched in 2015 by Innovate UK, the Catapult has built a team of more than 250 people, with a range of technical, engineering, consumer, commercial, incubation, digital, and policy expertise. The Catapult draws on sector-leading test facilities, modelling tools, and data collected from its back catalogue of more than 500 research projects.

The Catapult uses that 'whole energy' system capability to support innovative companies - small and large – to test, trial and scale new products and services. Impact comes when those innovators attract new customers, new investment, and new grants so they can thrive in the future energy system.

Based in Birmingham, Energy Systems Catapult is part of a network of nine world-leading technology and innovation centres, established by Innovate UK. The Catapult Network fosters collaboration between industry, government, research organisations, academia, and many others to transform great ideas into valuable products and services.

Energy Systems Catapult

7th Floor
Cannon House
The Priory Queensway
Birmingham B4 6BS

www.es.catapult.org.uk

info@es.catapult.org.uk