Electricity Engineering Standards Review

Independent Panel Report

December 2020

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If implemented fully, and with matching changes to markets, regulation and other aspects, our recommendations will avoid one-off costs of £5-£10bn and avoid recurring costs of £2-£6bn per annum on the expanded electricity system needed for net zero, as well as improving the customer experience and giving the a first mover advantage for the UK globally

A complex interlocking current context

- Policy
- Markets
- Regulation
- Industry codes
- **Engineering standards**
- Customers
- Established players
- New entrants
- Regional, city, local government

Standards are generally fit for the legacy system but do not yet reflect how the system is changing

Engineering standards need to…

- Enable affordable supplies to customer
- Enable customers' experience, be clear about desired outcomes
- Ensure resilience
- Ensure compliance
- Enable innovation
- Unlock access to those not steeped in the industry
- Underpin the system we are moving to, embracing the inevitable uncertainty

In the short term we recommend…

- Reworking value of lost load to acknowledge the opportunity for real time and granular control
- Create a new resilience standard making clear what customers can expect during extreme events
- Size new or refurbished circuits to optimise electrical losses
- Remove arbitrary voltage limits to allow voltage optimisation
- Build on existing work to move to full coordination of interoperability
- Methodology to use distributed resources in power islands during outages
- Continuous whole system health surveillance
- Source and publish granular energy and engineering data

…leading to ideas for more comprehensive reform to help unlock net zero, on which we need to start work

- Reframe the system of standards around customer expectations and obligations
- Improve transparency and accessibility of the system of standards
- Drive coherence, consistency and coordination through appropriate and agile governance
- Fill critical gaps for a smart flexible system, especially interoperability, data, operations
- Put in place agile change processes based on evidence based evolution and data driven innovation

Summary report

This is the final report of an independent panel commissioned by BEIS and Ofgem to review:

- engineering standards in the GB electricity sector[1],
- the extent to which engineering standards in electricity are or will be blockers to an effective and affordable energy transition, and
- what, if anything, needs to change.

This report summarises work undertaken over the period April 2019 to September 2020, and described in detail in the Appendices. The Panel was supported in detailed engineering analysis by Frazer-Nash Consultancy, whose report is published separately alongside this report.

Engineering standards drive common solutions and best practice in design and operation of the electricity system. Such standards are applied to system components, system performance and system interactions to ensure a safe, efficient, reliable electricity supply. They embody learning from the past and have helped ensure the high-quality system we have today[2]. However, whilst the industry is active in maintaining and enhancing standards, the level of change now and expected in the future is challenging this legacy.

Going forward, engineering standards need to enable the outturn of a range of scenarios as we transition to net zero, adapt to diverse technologies and support interactions between different energy vectors[3] as we decarbonise the economy. The impact standards (and policies, regulation and markets) have on investment and operational decisions needs to be analysed systematically on an ongoing basis, and balanced with the ability to remain flexible to future uncertainty.

Engineering standards interact with policy, markets, regulation and the institutional environment to influence how the electricity and energy systems operate and develop, and how they interact with and influence customers. This has created a complex landscape and, historically, a lack of agility, that has tended to constrain innovation, be slow to react to technological and commercial stimuli and to customers' needs, and has major gaps in data, interoperability, smart operation and a whole system approach.

As we move towards a much faster pace of technological and other innovation in the drive towards net zero, the role and function of engineering standards will need to change. Standards will need to become enablers to innovation that improve performance and reduce costs across the whole system, and are themselves agile to future change.

Over time this will require less reliance on traditional standards, which are based largely on a presumption of hardware based solutions, and shift the balance towards performance based standards for new world of smart energy system, and software standards, the latter requiring continual updating as practice evolves.

Further context is provided in Appendix A.

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[1] The work excludes Northern Ireland because of the integrated nature of the electricity system of the island of Ireland, although many aspects are likely to be applicable

[2] The history of development of the engineering standards underpinning the electricity system is complex, and is summarised for completeness in Appendix F.

[3] Energy vectors allow transfer of energy in space and time, eg electricity, gas, oil, hydrogen, heat, synthetic fuels

The changing electricity system

The electricity system will be the backbone of the UK's response to net zero greenhouse gas emissions by 2050. The energy handled within the system will increase by two to four times by 2050 as transport and much of heating become electric.[4,5] This implies either that we need a very much larger electricity system, or that the increased energy is managed much more smartly within a system that is expanded more modestly. All the energy handled will need to be near zero carbon. The implied need for renewables, storage and smart demand will drive fundamental changes in how flexible the system needs to be and how it is operated – and also drive further changes to technical parameters such as inertia and fault infeed that will make operation much more challenging (Figure 1).

At the same time, the efficient utilisation of energy by customers and communities will require much greater levels of local integration. City and community level net zero planning will need to drive a massive expansion of decentralised energy, which will coexist with large scale centralised near zero-carbon power stations. Citizens will play their part though a plethora of customer grade products and solutions, which will change their total energy use, change energy usage patterns over the daily cycle, and make use of local renewable resources and storage. Dynamic energy cost signals, smart technology and flexibility will reduce the amount of new network needed[6]. These digitally enabled approaches will ensure the supply security and resilience society expects.

Customers: we are all different, and our dependence on electricity will increase

Customers are all different, and include people in the context of their homes and places of work and recreation, commerce and industry, and critical physical and social infrastructure. Solutions need to be inclusive. Some customers will engage willingly with the changes, others will not or will be unable to.

Delivering an electricity system to play its part in a decarbonised economy by traditional means would be very complex, expensive, and prone to future uncertainty. Fortunately, pervasive digitisation and data will drive better, cheaper solutions, and better ways to communicate with customers' equipment in real time, and will become as important as physical assets in the system

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[4] Committee on Climate Changehttps://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/, particularly Figure 6.4.Other scenarios may shift the balance more towards a decarbonised gas system, but it seems clear that substantial increases in electrical energy are inevitable as GB decarbonises.

[5] Analysis of Alternative UK Heat Decarbonisation Pathways', Report prepared for Committee on Climate Change, 2019. https://www.theccc.org.uk/wp-content/uploads/2019/05/CCC-Accelerated-Electrification-Vivid-Economics-Imperial-1.pdf

[6] Network size is driven by the peak demand which typically occurs only for a short time each day, and is seasonal. If generation is connected this may drive network size, and only produce full output intermittently.

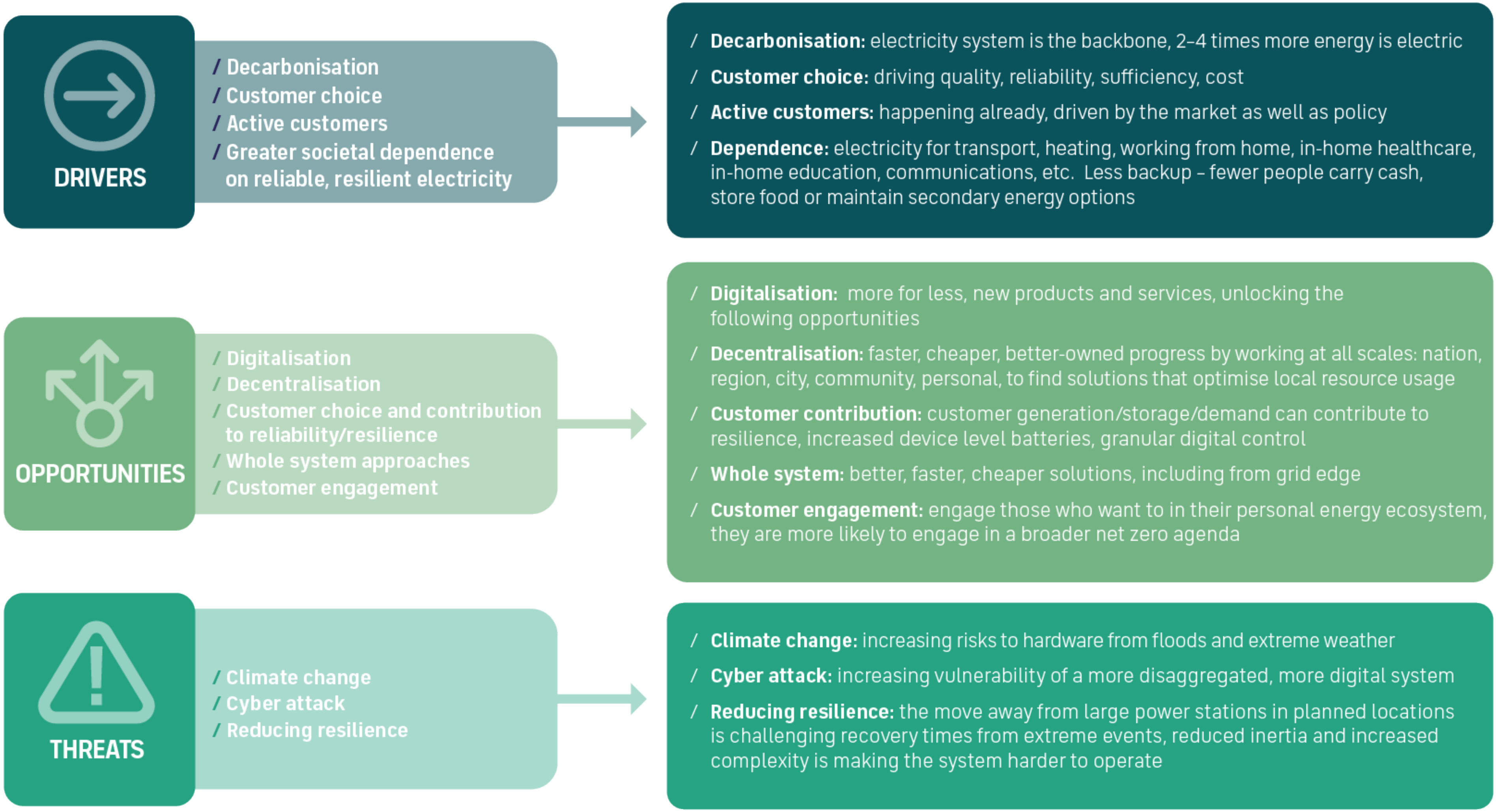
of the future. Market incentives could bring new energy players and disruptors (ie those with business models that challenge the established industry norms) to the electrical system to deliver innovation, drive efficiency, and improve customer satisfaction.

How customers currently see electric vehicle charge point interoperability

At the same time climate change will bring a greater frequency and severity of exceptional events such as extreme weather, and a highly digital-enabled system has the potential to become more vulnerable to cyber-attack.

Reliance on electricity is increasing. As well as underpinning all other utilities such as water and broadband, electricity is essential to, for example, an increasingly cashless society, working at home, digital healthcare, and is now starting to underpin personal mobility and space heating to a much greater extent than in the past.

Reliability and resilience: consequences for commuters of the 9 August, 2019 system incident (Image: James Marlow)



DRIVERS

/ Decarbonisation
/ Customer choice
/ Active customers
/ Greater societal dependence on reliable, resilient electricity

- **Decarbonisation:** electricity system is the backbone, 2-4 times more energy is electric
- **Customer choice:** driving quality, reliability, sufficiency, cost
- **Active customers:** happening already, driven by the market as well as policy
- **Dependence:** electricity for transport, heating, working from home, in-home healthcare, in-home education, communications, etc. Less backup – fewer people carry cash, store food or maintain secondary energy options

OPPORTUNITIES

/ Digitalisation
/ Decentralisation
/ Customer choice and contribution to reliability/resilience
/ Whole system approaches
/ Customer engagement

- **Digitalisation:** more for less, new products and services, unlocking the following opportunities
- **Decentralisation:** faster, cheaper, better-owned progress by working at all scales: nation, region, city, community, personal, to find solutions that optimise local resource usage
- **Customer contribution:** customer generation/storage/demand can contribute to resilience, increased device level batteries, granular digital control
- **Whole system:** better, faster, cheaper solutions, including from grid edge
- **Customer engagement:** engage those who want to in their personal energy ecosystem, they are more likely to engage in a broader net zero agenda

THREATS

/ Climate change
/ Cyber attack
/ Reducing resilience

- **Climate change:** increasing risks to hardware from floods and extreme weather
- **Cyber attack:** increasing vulnerability of a more disaggregated, more digital system
- **Reducing resilience:** the move away from large power stations in planned locations is challenging recovery times from extreme events, reduced inertia and increased complexity is making the system harder to operate

Figure 1: The changing electricity system

This all points to a need to build on the already high and currently still improving reliability of electricity networks, acknowledge the increasing potential for customers to self-provide, and to ensure increased resilience to allow fast recovery from local and national extreme events, which although rare, can have widespread societal and economic impact. The national risk register categorises that risk of widespread electricity failure as second only to a pandemic.[7]

Managing the net zero transition will be a major challenge, globally comparable in scale and complexity to the most challenging achievements of humanity. For the electricity system, engineering standards are an essential underpinning and enabler to this transition. Whilst inappropriate arrangements will inhibit the transition, make it more expensive and create a higher risk of falling short, the right standards frameworks will enable the transition by striking the right balance between codifying best practice and enabling competition and innovation.

Further comment on the case for change is provided in Appendix B.

The panel’s diagnosis

The Panel has reviewed the current landscape of standards governing the engineering of the electricity system as a whole, using an approach set out in Appendix E (Figure 2). These standards have served customers well as the system evolved in public ownership through to 1990, and have developed further through the last thirty years of private ownership. However, the changes now happening reveal a number of shortcomings. Most of these shortcomings arise partly through engineering standards, but also through issues with market design, regulatory arrangements and the way the industry is organised and governed, all of which are highly interconnected and subject to continued reform[8]. The Panel’s work has focused on engineering standards, but these other aspects will also require attention to realise the benefits quoted below.

Standards as currently framed will cost customers money as we move forward through the energy transition. Studies by organisations such as Imperial College[9], Ovo Energy[10] and Wales and West Utilities[11] University of Bath[12] indicate this could be in the range of £2-6bn per annum, and one-off savings of potentially £5-10bn[13]. These costs arise during an anticipated large scale system expansion, mainly because of gaps in the interoperability landscape, an approach to supply security that does not fully recognise the potential of digital, outmoded constraints on voltage enshrined in legislation, and a governance regime that is insufficiently agile and inclusive of a wide spectrum of current and future stakeholders. Realising these savings will also require attention to markets, regulation and other issues.

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[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644968/UK_National_Risk_Register_2017.pdf

[8] Consultation on Reforming the Energy Industry Code, 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/828302/reforming-energy-industry-codes-consultation.pdf

[9] ‘Roadmap for Flexibility Services for 2030’, Report to the Committee on Climate Change, 2016. https://www.theccc.org.uk/wp-content/uploads/2017/06/Roadmap-for-flexibility-services-to-2030-Poyry-and-Imperial-College-London.pdf

[10] https://www.ovoenergy.com/binaries/content/assets/documents/pdfs/newsroom/blueprintforapostcarbonsociety-2018.pdf

[11] https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf

[12] https://www.northernpowergrid.com/asset/0/document/5414.pdf

[13] Imperial College London, “Review of Distribution Network Security Standards” , report to Energy Networks Association, 2015. http://www.dcode.org.uk/assets/uploads/IC_Report_exec_summary.pdf

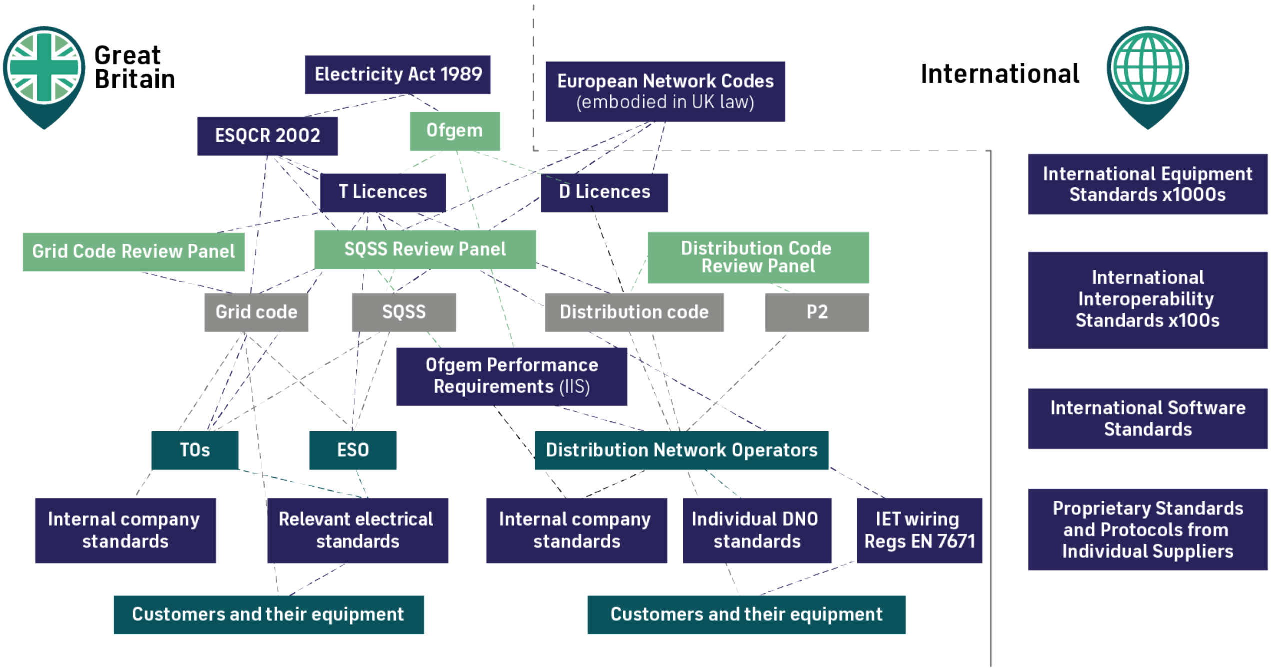

Figure 2: Indicative summary of existing standards landscape governing the GB electricity system

- **Standards are framed from the system's perspective, not from the end user's**
  - The current system of standards focuses too much on how things are done, rather than what should be achieved for customers.
  - There is no standard dealing with what customers can expect following extreme events.
  - Much of the success of a smart flexible system relies on devices in customers' ownership. Standards have yet to catch up with this.
- **The current standards landscape is larger and more complex than it needs to be.** This makes it difficult for all parties (eg system and network operators, innovators, end users) to navigate, identify and apply relevant standards.
- **Ownership and management of the suite of standards (as opposed to individual standards) is lacking**. This makes it hard to drive and coordinate changes to standards.
- **There are critical gaps for a smart flexible electricity system, especially for interoperability, data and operations**
  - There is a major gap in the interoperability of digitally connected assets and systems, around which there are plenty of emerging standards but limited coordination to ensure new devices and systems work seamlessly together, and with traditional electro-mechanical equipment.
  - Data will be as important as physical assets in the system of the future.[14] There are insufficient data standards to fully unlock their role in managing the system transition, and from an engineering perspective the electricity system is data-poor.

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[14] Key Message 4, National Grid ESO Future Energy Scenarios 2020 https://online.flippingbook.com/view/621114/6/, and numerous other sources.

  The Energy Data Task Force and subsequent Modernising Energy Data Group has done good work in this area, but more is needed.

  - Active operation, particularly at the distribution level, as currently being used much more widely, is largely missing from the standards landscape.

- **The opportunity to provide a better and more customised service at lower cost is being missed.** Engineering standards need to recognise society's increasing dependence on electricity, the value different customers place on supply reliability, and the inherent capability within a much more data driven system to meet customers' requirements at lower cost and with reduced lead time than they are today.

- **Processes for changing standards lack agility**

  - Most historic standards are based on a presupposition of solutions being limited to physical assets under the control of generators or network operators. This is no longer appropriate to the decarbonising, decentralising and digitising world we are moving to, it risks imposing unnecessary costs, and limits accessibility and choice.

  - There is insufficient coordination between national, regional and local systems, particularly when the system is under stress or broken.

Why should changes be made?

Reasons for change identified by the Panel include:

- Academic research indicating very significant potential for cost savings. Different studies use different assumptions, and claimed savings often require a number of inter-related changes. However overall there is potential that could be realised over time for customers to save £2-£6 billion per annum in overall costs of service, with further one-off savings, although to realise this markets, regulation and other aspects will need to change as well as engineering standards.

- Improvements in customer experience resulting from placing a greater focus on what customers value. Customers would have greater choice in how they engage with electricity (for example they may seek greater self-sufficiency and lower carbon, requiring less grid energy and less reliability from networks), and in the extent to which they (or organisations acting on their behalf) can take control of their own energy economy.

- Improvements in transparency giving greater clarity in what the electricity system can provide for customers, what customers would be obliged to do in return and also new freedoms for customers to support themselves.

- Improvements in accountability so all parties would be clearer about what they need to do, and who leads in situations involving multiple parties.

- A clearer view for customers as to how their supplies will recover from extreme events, and any actions they should take for themselves.

- Improvements in coordination between the existing central system and the emerging city scale and local systems in delivering low cost, low carbon and resilient supply

- The availability of alternative, sometimes disruptive, options that allow faster and cheaper decarbonisation without compromising the energy services that customers expect.

What changes should be made – Recommendations

Our headline recommendations are listed in this section. Appendices C and D to the report contain supporting commentary and implementation proposals, ie means by which the Panel consider the outcomes recommended could be achieved in practice. There are many nuances and interdependencies to consider in implementation. We have grouped our recommendations into two sets – recommendations on specific engineering matters (SEM) investigated by the Panel, and recommendations on reforming standards processes to support net zero by 2050 (NZ). Where benefits are suggested, these very often depend on associated market and regulatory developments, as well as changes to engineering standards. They are also forward-looking, and assume substantial growth in electricity's role in the energy system in line with delivery of a net zero economy.

The system incident of 9 August 2019, and its subsequent investigation, occurred during the Panel's work, and was a useful case study on which to test emerging recommendations. Appendix G below summarises the incident through the lens of the Panel's work (Figure 3).

Figure 3: the 9 August 2019 system incident versus whole system failure

Panel's Recommendations on specific engineering matters

SEM 1: Revisit completely how the value to customers of supply reliability is assessed, to include duration of power interruptions, and take into account how customers may value reliability differently for different electrical devices. (BEIS/Ofgem)

The Panel has noted that supply security is becoming an increasing complex interplay of system capacity and customers' own capabilities and flexibility (Figure 4). It is clear that the economics underpinning network investment decisions does not necessarily reflect the full possibilities of customer flexibility, use of data, smart control systems and other digital technology. The two key standards for transmission and distribution (SQSS and EREC P2/7) are not particularly integrated and are at different stages of maturity. In practice P2 is effectively overtaken by Ofgem's Interruption Incentive Scheme in driving the reliability of supplies to customers, and in its current version (ie P2/7 which superseded P2/6 in August 2019) has made specific provision to recognize flexibility as a contribution to system security.

The Panel does not consider P2/7 to be a blocker to flexibility. The Panel did not examine SQSS to the same extent but notes that it does not have the same explicit recognition of demand flexibility as P2/7 to substitute network capacity. In this regard SQSS is therefore similar to previous versions of P2. The Panel observes that both these standards are essentially deterministic in application and are built on an approach to Value of Lost Load (VoLL) that is outmoded in the much more digital system we are moving towards. The Panel has also noted that the recently revised P2/7 does allow for a less deterministic (ie probabilistic) interpretation than P2/6 but that SQSS is still deterministic in application for both generation and demand.

A reframing could make the concept of VoLL broader and more granular, or explore other metrics that may be more meaningful to energy customers and the role that their grid edge devices can play in supply reliability, and hence promote network innovation and competition. In turn, this would allow standards such as P2 and SQSS to be refreshed or replaced accordingly, and possibly for them to become more explicitly focused on ultimate resilience than day-to-day reliability. The Panel has a number of detailed recommendations for P2 and SQSS contained in Appendix C, and believes that BEIS and Ofgem should also consider the integration of these two standards.

This reframing, with associated market and regulatory changes, will assist in flexibility replacing reinforcement, which academic work suggests could realise a potential saving of £4-7bn in a decade of high load growth.[15]

Appendix C.2 explores the reasons behind this recommendation in more detail.

Decentralised assets in customers' control (Image: Nissan)

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[15] Goran Strbac et al, "Review of Distribution Network (Extended Report)," March 2015. [Online].Available: http://www.dcode.org.uk/assets/uploads/IC_Report_main_report_-_red.pdf

CRUDE APPROACH TODAY

- One VoLL for all customers
- Special arrangements for customers deemed to need them

BUT

- Different customer types have very different VoLL
- Individuals have different VoLL from each other
- Most people would assign different VoLL to different devices (eg TV versus dishwasher), and device characteristics are changing (eg internal batteries)
- VoLL varies with length of the duration of unserved demand
- Technology is becoming more available to help customers help themselves

DIGITAL

- Digital systems allow granularity and complexity to be unlocked, and customer or device-level participation in the system
- This would be subject to some practical limits (eg single feeders at low voltage level)

OPPORTUNITY

- Bespoke reliability offerings to suit customer needs
- Opportunity to surface and address real needs (eg care homes, vulnerable customers)
- System gains greater access to flexible demand resources
- Opportunity to target network investment to areas of highest VoLL more rigorously than today
- Opportunity to consider recovery times more explicitly in network planning and operation, to recognise how VoLL varies with time
- Opportunity overall to both improve customer experience and reduce costs

Figure 4: Granular approaches to Value of Lost Load unlocked by digital technology

SEM 2: Create a new standard, setting out what different customer types can expect from the system's recovery from extraordinary events. (BEIS/Transmission Companies/DNOs)

The Panel has identified that the electricity system's current overall risk identification and mitigation is both incomplete and opaque to customers (Figure 5). A number of factors have come together to make system resilience a much more important issue for customers than in the past. In particular:

- The likelihood of significant disruption is increasing and will continue to grow. The drivers for this are primarily climate change (causing more frequent and more extreme severe weather), and cyber attack on an increasingly digital system whose points of vulnerability now include customer-owned devices as well as utility infrastructure.
- Customers have a greater reliance on electricity for heating, transport and other essential services via the internet. Hence the loss of electricity for even short periods has greater disruptive effects than in the past, and historical dependencies of other key services, such as water, sewerage and telecommunications, remain key vulnerabilities.
- Predicted black start recovery times have become longer. The changing nature of the generation mix in GB, and its partial migration to the distribution networks, has meant that more time will be needed to restart the GB energy system and balance supply and demand, should the need ever arise.
- The growth of local generation and storage means that some customers have more opportunity to be self-reliant, and potentially to help with re-starts of local networks. However the conditions under which self-reliance can be used/deployed are not clear and there are some institutional barriers to full deployment of such capabilities (see recommendation SEM6).

The new standard would allow customers to understand the limits of electricity supply services and help them plan their own responses to such emergencies. The standard would have implications for investment and for operational responses for both transmission and distribution, and therefore its development should be led by BEIS. This recommendation aligns with and develops further that contained in the recent National Infrastructure Commission report on infrastructure resilience.[16]

Appendix C.3 explores the reasons behind this recommendation in more detail.

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[16] https://www.nic.org.uk/wp-content/uploads/Anticipate-React-Recover-28-May-2020.pdf

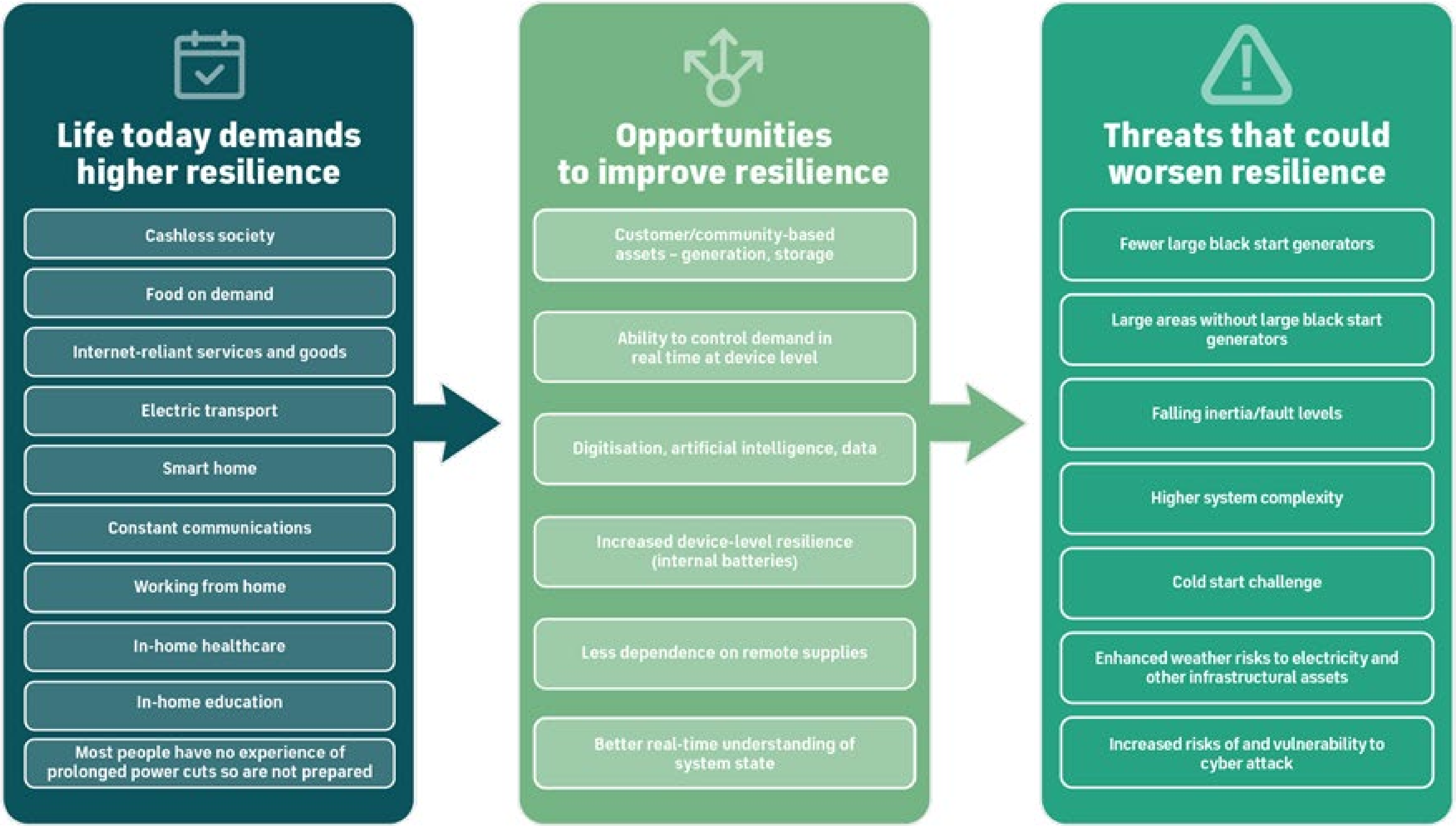

Figure 5: The changing nature of electricity system resilience

SEM 3: When new or refurbished circuits are being installed, to size this capacity to optimise system losses. (Ofgem/DNOs)

The Panel has noted that network capacity is primarily a by-product of the considerations of reliability and resilience.

The Panel also notes that the opportunity should be taken to ensure that new final connections to new and refurbished property are appropriately sized to be future proof, and notes ongoing industry work in this area, for example by Western Power Distribution.[17]

Recent academic work has shown that the capacity of circuits has a profound effect on losses, and suggested that new assets should have a thermal capacity at least four times that required to meet peak demand.[18]

This approach also gives headroom for demand growth in future, without further interventions such as additional street works, further improving customer experience.

Appendix C.4 explores the reasons behind this recommendation in more detail.

SEM 4: Remove the limits in legislation for voltage to allow the industry and stakeholders to determine appropriate limits. (BEIS)

The Panel has noted that the voltage limits imposed by law in Great Britain[19] have been essentially unchanged for over 80 years, in which time the voltage tolerances of devices has improved dramatically. The future strict application of these limits is likely to drive significant unnecessary reinforcement or other mitigating actions.

Potential savings of £2-4bn in avoided reinforcement may be available[20]. The Panel notes that further (monetary and carbon) savings to customers could accrue as relaxation of the limits will allow lower supply voltages by design, which will reduce energy consumption by many devices with no loss of utility, although these savings need to be balanced with increased network losses where they occur.

Appendix C.5 explores the reasons behind this recommendation in more detail.

SEM 5: Build on the existing BEIS/BSI work on smart system interoperability to provide full coordination of smart system interoperability. (BEIS)

The Panel identified the potential of better interoperability to reduce significantly the cost of transforming and operating the electricity system to achieve net-zero decarbonisation targets while maintaining high levels of reliability and resilience. This would involve enabling greater interoperability between system components and between the system and equipment on customer premises (eg vehicle to grid and other smart appliance performance) . This is key to flexibility, will reduce the cost of energy, improve the customer experience, and enable new technologies and business models to compete more effectively. Interoperability needs to be enabled by an appropriate approach to engineering standards, which we recommend, but also

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[17] Western Power Distribution *Losses Strategy,* 2018, section 7

[18] Strategies for reducing losses in distribution networks," Goran Strbac, Predrag Djapic, Danny Pudjianto, Ioannis Konstantelos, Roberto Moreira, February 2018.

[19] Electricity Safety, Quality and Continuity Regulations (2002), SI No 2665/2002

[20] Element Energy, Imperial College, "Infrastructure in a low-carbon energy system to 2030: Transmission and distribution," April 2014. [Online]. Available: http://www.element-enenergy.co.uk/wordpress/wp-content/uploads/2014/06/CCC-Infrastructure_TD-Report_22-04-2014.pdf

by changes to market and regulatory constructs to support relevant use cases, and unlock the potential of innovation to discover new and beneficial use cases.

Studies have demonstrated that greater energy system flexibility, enabled by increased interoperability of customer-controlled devices, could reduce energy bills for flexible customers by as much as 50%, and reduce total energy system costs by £2bn- £6bn per year. Please note that some of this saving will overlap with that from recommendation SEM 1 – both are necessary.

BEIS and BSI have existing work in progress exploring this issue for domestic appliances, this needs to be expanded across the whole interoperability landscape.

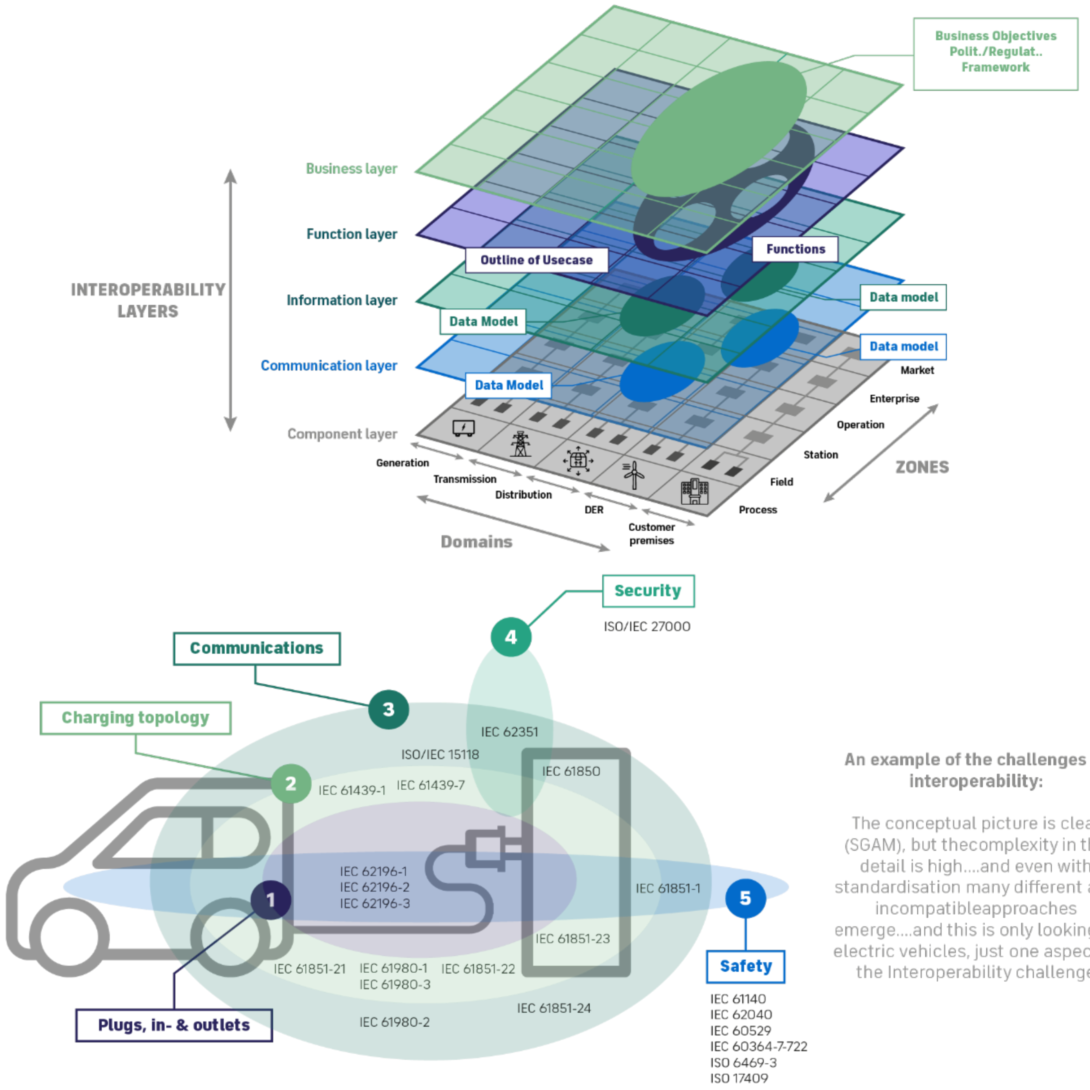
Much of the Panel's thinking on the transformed approach to engineering standards that we believe needs to underpin net zero is to support full interoperability and contained in later recommendations. However we here identify early priorities for action.

Appendix C.7 explores the reasons behind this recommendation in more detail.

SEM 5a: Ensure the full coordination of interoperability standards development across the whole landscape.

Interoperability standards are numerous and fragmented (Figure 6). This makes it difficult for service developers and equipment manufacturers to identify and adopt relevant standards, adding cost and delay to adoption of new solutions. It also makes it difficult to assure performance of connected equipment and services and their compatibility with the existing system. The Panel sees this activity as part of, or a pathfinder for, the standards coordination function recommended in NZ3 below.

Interoperability is a global challenge, this is an opportunity for UK leadership in setting the thinking and standards. Not acting would likely result in the UK becoming a user of what evolves elsewhere, which is likely to be less suitable for UK needs.



An example of the challenges of interoperability:

The conceptual picture is clear (SGAM), but thecomplexity in the detail is high....and even with standardisation many different and incompatibleapproaches emerge....and this is only looking at electric vehicles, just one aspect of the Interoperability challenge

CHARGEPOINT STANDARDS BY PLUG/SOCKET TYPE

Common Name	International standard	Location(s)
AC Fast Charging		
Yazaki/J1772	IEC 62196-2 (type 1)	US and Japan
Mennekes	IEC 62196-2 (type 2)	Widespread, mandatory in the EU
Scame	IEC 62196-2 (type 3)	Used in France, Italy
DC Fast Charging		
CHAdeMO	IEC 62196-3 (type AA)	Mostly used in Japan and by Japanese manufactured vehicles
GB/T	IEC 62196-3 (type BB)	Mostly used in China
Combo1	IEC 62196-3 (type EE)	Mostly used in North America
Combo2	IEC 62196-3 (type FF)	Widespread, mandatory in the EU
Tesla Type 2	IEC 62196-2 (type 2)	Tesla chargepoints globally

Figure 6: The many layers and complexities of interoperability: electric vehicle example

SEM 5b: Develop use cases for exploiting VoLL or its successor metric, to realise customer cost savings and other value.

The value of interoperability and the flexibility this can provide is often unclear. This makes it difficult for system and network operators, equipment manufacturers and service developers to identify where smart, interoperability-based services should be adopted in preference to traditional hardware-based solutions. This increases the likelihood that whole system costs (and hence customer costs) will be higher than necessary. Examples of use cases include network capacity management, fault management.

SEM 5c: BEIS needs to consider how the benefits of flexibility and interoperability will be identified and used to guide the optimum whole system development of zero carbon generation.

Flexibility technologies and systems can significantly reduce investment in low carbon generation needed to meet the carbon target. In contrast to updated network design standards and a capacity market that recognise the contribution of flexibility technologies to meeting system peaks, there is no mechanism / standard that would reward flexibility technologies and systems for reducing the overall cost of decarbonisation. Furthermore, there is no methodology that compares the whole system costs (ie the levelized cost of energy plus the system integration costs) of zero carbon generation, and no market mechanism to incentivise either the correct mix at national, regional and local scales, or the development of flexibility services to this end. BEIS should consider both methodology development and market implications.

Particular issues behind this recommendation SEM5c are explored in Appendix C.8.

SEM 5d: Standards to set clear performance, monitoring and assurance criteria for grid edge[21] devices and associated services, and to provide an appropriate data driven compliance regime.

It is difficult for network and system operators to have confidence in smart, interoperability-based services. They have less experience of such services compared to traditional solutions, less data on their performance, and less direct control over services provided by third parties. This all constrains adoption of interoperability-based services and realisation of the benefits they offer. This recommendation will help build confidence that portfolios of edge devices will deliver the required service, and so can be effectively contracted as part of the solution to fulfil a DSO's obligations. Such performance and assurance standards, and associated compliance regimes, should be developed as a matter of priority. Appropriate allowance will need to be made for assurance and compliance costs. This work can build on existing activity by Ofgem.[22]

SEM 5e: Development of interoperability standards should continue to maintain awareness of the need to adequately protect privacy and be resilient to cyber attack.

Interoperability with devices such as customer appliances can have significant implications for privacy and cyber-security. If not adequately addressed, these concerns could significantly constrain adoption of interoperability-based services by customers and system operators. This is a key focus of current BEIS/BSI work on interoperability.

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[21] A grid edge device is something that contributes actively to the performance of the electricity system at local level but is not part of its utility infrastructure, for example a small generator, an electric vehicle charger or a home energy management system.

[22] : https://www.ofgem.gov.uk/publications-and-updates/call-evidence-visibility-distributed-generation-connected-gb-distribution-networks

SEM 6: A methodology to be developed to use distributed resources to supply customers in power islands under outage conditions. (DNOs)

A major change of recent years is the extent to which system resources (generation, storage, flexible demand) has shifted into the hands of customers. This affords the possibility for customers to supply themselves and potentially other customers under outage conditions. However at present there is no provision for islanded operation. Recommendations SEM1, SEM3, and SEM5 are relevant also. Benefits would include greater reliability and resilience, and the potential to avoid significant cost in providing this reliability and resilience from elsewhere. Implementation of these recommendations would require a number of industry codes and standards to be revised, and new specific requirements introduced.

Potential concerns over portions of the system remaining energised after faults would need to be resolved with the HSE, however the HSE has indicated to the Panel a willingness to work through these issues.

Appendix C.3 explores the reasons behind this recommendation further.

SEM 7: Publish a regular statement of system performance and assessment of system health for the whole electricity system. (System Operator)

Since changes to the system are challenging various aspects of its design basis, the Panel believe it important for there to be transparency and informed debate about the pace of change and its impact in the short and longer term, to allow appropriate, cost-effective and timely engineering, regulatory, market and policy responses. This statement should build on what National Grid ESO does currently on system operability, but formalise it, and make it whole system, not just transmission, perhaps making use of performance data at distribution level currently collected by Ofgem for other purposes. The Panel would see the result being a formal but accessible review of how current health and projections are changing year on year, how this varies across a range of future scenarios, audit of actions taken, results obtained, and clarity of how the go-forward plan is changing

Appendix C.3 explores the reasons behind this recommendation further.

SEM 8: Move forward quickly to publish granular data on customer service performance, loads and power flows and connected active equipment. (BEIS/Ofgem/industry)

Building on the work of the Energy Data Task Force, and Modernising Energy Data Group, publication of this engineering data would facilitate the ability of communities, innovators and others to find new sources of value. Standards should be updated/developed to define what data should be captured and published and in what form. This should start with currently available data and experience on innovation projects such as OpenLV, and moving towards real time publication of fine-grained data as quickly as reasonably possible.

Appendices C.7 and D.6 explore the reasons behind this recommendation further.

Panel Recommendations to create a framework for electricity engineering standards for net zero

The Panel identified that the electricity system is moving from a period of relative stability, focused on continuous improvement of existing standards, to one of transformational change in order to achieve net-zero targets, capture the benefits of digitalisation and meet changing customer needs. The cost of making this transformation could be significantly reduced by developing a clearer overview of existing standards and better support for managing, reforming and governing them. This would reduce risk during the transformation and make it easier both to deliver clear service guarantees to the end user and for innovators to develop the new technologies, services and business models that will help to deliver the target at an acceptable cost.

Work published by National Grid ESO in December 2020 suggests a net present value £200 billion saving in taking a strongly consumer led approach to the net zero journey[23]. The Panel's recommendations below are intended as key enablers to such an approach, and as such are necessary (along with market, regulatory and other changes) to unlock these savings.

The Panel's investigations into specific engineering matters identified several areas where engineering standards have been slow to change to address the challenges and opportunities created by new technologies, and key areas (eg data and interoperability) where standards are lacking or ill-structured. The Frazer-Nash report accompanying the Panel's work provides detailed examples, eg in interoperability with electric vehicles, to support this. As well as inhibiting change and therefore missing opportunities to increase value for money, this can create significant risks: one cause of interruption to rail networks during the system event of 9 August 2019 appears to be inconsistencies in standards defining how end-user equipment should deal with frequency excursions.

The Panel has recommended a roadmap for implementation, driven by when we foresee major system changes on the road to net zero. This requires that the foundational elements recommended below are put in place over the next few years, and certainly by 2025. Given the time needed to make and embed such institutional changes work needs to start at pace as soon as possible.

This will clearly be a significant effort involving the whole industry, and should be led by BEIS.

Our recommendations in this area are as follows. Appendix D explores the reasons behind these in more detail.

NZ 1: Reframe the system of standards around what customers can expect from the system, and what they are expected to provide in return.

Standards are currently framed from the system's perspective, not from the end user's (ie input based rather than outcome based – stating what should be done rather than what should be achieved, or expressing outcomes in system terms not end user terms). This makes it hard to define clear service levels in terms relevant to the end user. This in turn makes it hard for users to design their own systems and operating processes, and may cause them to over- or under-design, creating cost and risk for them. The Panel therefore recommends that a clear, overarching set of service levels is developed setting out what the electricity system will deliver to its customers, and what it expects from them in order to deliver this. Codes and regulation should align to these service levels. This will give clarity to both customers and network operators, and provide each with a clear basis to plan against. This clarity should also allow investment to be directed more appropriately, especially important as the system is expanded in the coming decades.

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[23] Analysing the costs of our Future Energy Scenarios | National Grid ESO

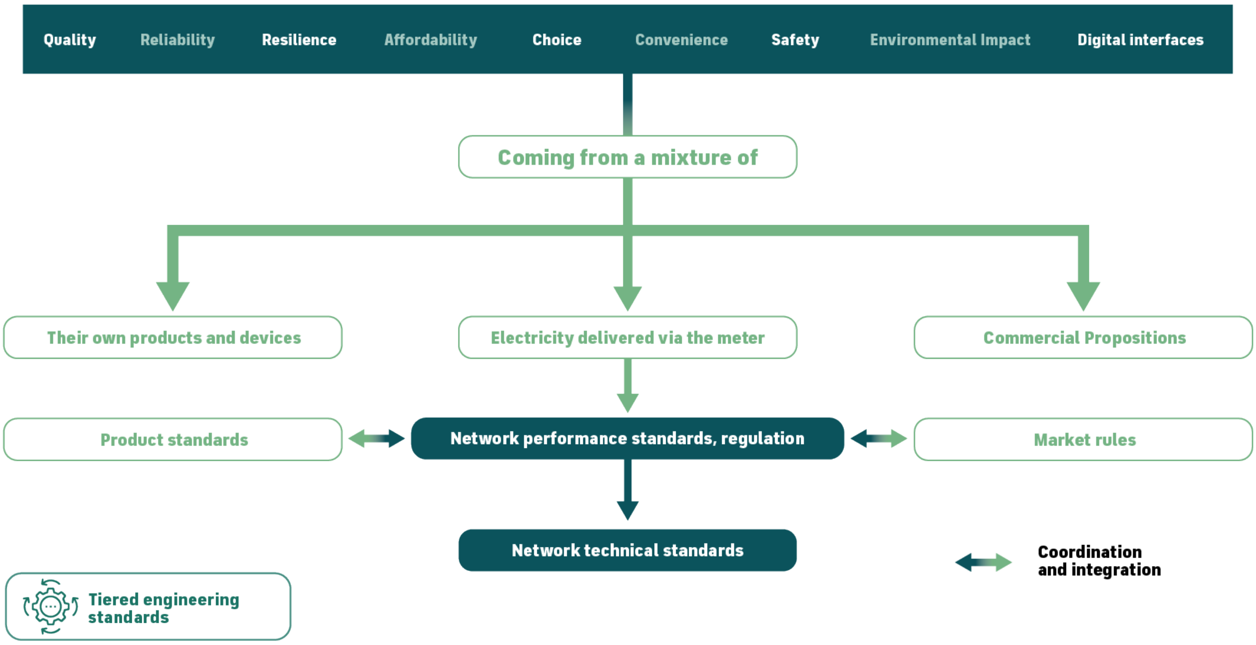

Figure 7: A tiered perspective on engineering standards, starting with the end user, improving transparency and accessibility.

NZ 2: Improve transparency and accessibility of the system of standards.

The suite of relevant standards has evolved over time to become larger and more complex than it needs to be. This makes it hard for all parties (eg system and network operators, innovators, end users) to identify and apply relevant standards. It also increases the risk of gaps and inconsistencies between standards. The panel therefore recommends that:

- a tiered perspective on standards is put in place (Figure 7), driven from the service levels recommended in NZ 1, defining how the system is designed to meet those service levels, and how products operate to achieve the designed performance. These all represent engineering considerations alone, and should not be embedded in regulation or codes, and

- existing standards should be mapped onto this tiered perspective and refactored over time to remove overlaps and simplify the standards suite, and to more clearly separate service levels from how they are delivered.

The benefits will be in terms of greater accessibility to parties other than established incumbents, which will help facilitate innovation to drive new customer services and cost reduction.

NZ 3: Drive coherence, consistency and coordination through appropriate and agile governance.

Ownership and management of the suite of standards (as opposed to individual standards) is lacking. This complicates driving and coordinating changes, and identifying gaps and overlaps. It also reduces the UK's ability to influence international standards, which often drive global equipment manufacturers. The panel therefore recommends that:

- a party is designated to be responsible for standards coordination. This is an important role. The Panel notes proposals for a Codes Management body[24], and one option may be to expand its remit to ownership of engineering standards. This party would be responsible for maintaining an overview of standards and coordinating their development, within GB and across relevant international standards development. There is in any case a lot of overlap between the technical Codes and engineering standards.

- This coordination party will have to undertake a range of functions including interoperability coordination (see recommendation SEM5), horizon scanning, international benchmarking, and the coordination of research, where the Panel has identified several examples of topics requiring attention:

    - Further reduction of lower voltage limits beyond the -10% currently supported by the evidence base, for example -15 or -20% under abnormal operating conditions (in time to implement in RIIO ED3)

    - Performance of very low inertia and fault level power systems, beyond the time horizons currently used by the System Operator, to the extent the SO itself is not undertaking and publishing such work, with the intent to make anticipatory changes to the specification of long-lived hardware such as generators (by 2023)

    - The costs and benefits of dc distribution within homes and communities (by 2023)

    - a roadmap towards a digital twin of the electricity system (by 2022)

    - what needs to be changed in electricity to create customer outcomes for energy or infrastructure service as a whole (by 2023)

    - assuring compliance in a world of artificial intelligence, and of mass-market smart grid appliances (eg EV smart chargers) (by 2023)

    - widening engineering interoperability into commercial, market and other aspects (by 2023)

    - the mutual inter reliance of a smart flexible electricity system with communications infrastructure (by 2023)

    - the objective function against which we optimise the electricity system, and how outcomes could change depending on how this is chosen (by 2023)

- Co-ordination will need to be set up to allow standards to be dynamic and evolving which in turn will allow standards to support and unlock the potential of innovation in providing customers with better value new services and routes to deliver net zero.

- Designate a forward-looking and agile owner for the service level tier of standards, accountable to BEIS or Ofgem. Other tiers of standards should be under industry governance, but with well-defined and public compliance regimes.

- The Panel notes the need for diverse technical expertise to be available to support this work

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[24] Please see BEIS's consultation on this: https://www.gov.uk/government/consultations/reforming-the-energy-industry-codes

NZ 4: Fill critical gaps in standards for a smart flexible electricity system, especially for interoperability, data and operations.

There are gaps in areas of critical importance to a smart, flexible system, especially for interoperability, data and operations. This is appropriate in the early stages of technology development, but becomes an inhibitor as we seek to deploy new technologies and services at scale. The panel therefore recommends that:

- **Interoperability:**- is a key area requiring additional work on standards, as described in Recommendation SEM5.
- **Data:**- should be managed as a key component of the system, as important as physical assets. To this end, there should be a **presumption of data capture** – all new and updated equipment should capture and publish real-time data on its performance unless there is a clear reason not to do so.
- **Data driven assurance:**- all new and updated standards should define what data should be collected in order to demonstrate performance against the standard. This data should then be collected as a matter of course, and used by the appropriate body to monitor performance and assure compliance.
- **Operational Standards:**- Smart, flexible systems entail much more active operations, especially at distribution level. Current standards were developed when networks were operated much less actively, and so rightly focused on upfront design. Standards should be extended to cover operational concerns as well as design, but having regard to avoiding limitations in the potential for innovation in operation.

NZ 5: Put in place agile change processes.

Processes for changing standards lack agility. This makes it difficult to update standards to reflect what can now be fast moving changes, for example to technology and end user needs. In addition to recommendation NZ3 above, the Panel therefore recommends the following:

- **Evidence-based Evolution:**- Data collected under recommendation NZ 4 should be used to drive evolution of standards, for example using analysis of actual performance to identify places where standards can be adjusted or where new standards are necessary.
- **Data-driven Innovation:**- Create a presumption that new products and services can be trialled at small scale and contained risk with minimal overhead, provided only that these trials openly publish sufficient data for independent bodies to analyse their impacts. If no adverse impacts can be demonstrated, then the trials would be allowed to scale up progressively, as a matter of course. This implies change to how regulation operates currently.

What would happen if no changes were made?

The Panel believes that not making changes will make net zero targets significantly more difficult to achieve, and certainly much more expensive for customers. Other consequences would include:

- Customers would pay more for the services electricity provides to them, which will be a greater proportion of their income than today because more of their energy will be supplied electrically (rather than, for example, as natural gas or petrol).

- The range of customers' experiences and choices will be less rich in the future than it could be, and interoperability concerns may make customers less willing to make smart technology choices, leading again to higher costs.
- At the same time as the risk of extreme disruptions to supply increases with global warming, the supply system would be less able to recover from such events, customers would have lower confidence in the recovery of the system from such events, and less clarity on what measures to take themselves.
- The electricity system would be less accessible to new, innovative, organisations, increasing costs, and reducing the opportunity for the UK to show leadership and develop export potential for products and services.

How difficult will it be?

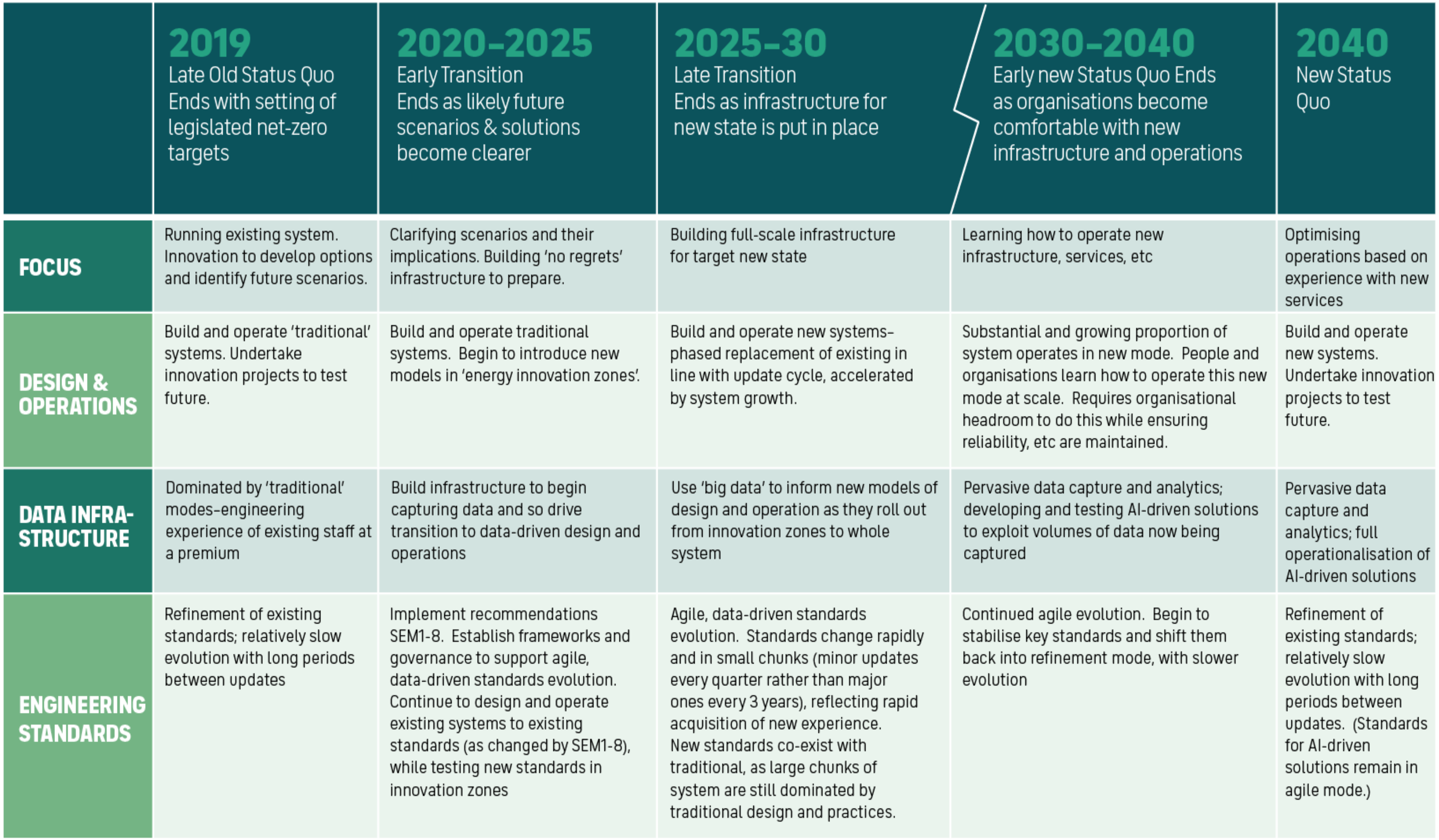
The global response to climate change is one of humankind's most profound challenges. The UK has shown leadership by committing to net zero greenhouse gas emissions by 2050, consistent with the Paris Agreement. This is by any standards an enormous challenge, but one with immense potential rewards for the planet, for people, and for the UK economy as an early mover.

Engineering standards are only part of the tapestry of transformational change needed, and will need to be considered alongside changes to every aspect of electricity and energy system policy, governance, regulation, markets, supply chains and skills, as well as many aspects of life outside the energy sector. Among other things there are balances to be struck between how standards or their absence enable markets to evolve, and encourage innovation.

The Panel's work has identified a number of relatively straightforward adjustments to existing arrangements that can be put in place quickly and start to deliver benefits.

In addition, we have started to shape a new framework for standards and their governance we believe to be necessary to underpin the shift to a decarbonised, data driven, and customer centric system for the future. Delivery of that framework will be complex, take time, and needs to start at pace straight away if it is to realise value as the system starts to experience large increases in demand, expected from the late 2020s onwards. A possible transition roadmap is shown in Figure 8.

The amount of work to do is significant, and will need the full commitment of government and industry. Not acting will make achievement of net zero much more difficult and expensive.



	2019 Late Old Status Quo Ends with setting of legislated net-zero targets	2020-2025 Early Transition Ends as likely future scenarios & solutions become clearer	2025-30 Late Transition Ends as infrastructure for new state is put in place	2030-2040 Early new Status Quo Ends as organisations become comfortable with new infrastructure and operations	2040 New Status Quo
FOCUS	Running existing system. Innovation to develop options and identify future scenarios.	Clarifying scenarios and their implications. Building 'no regrets' infrastructure to prepare.	Building full-scale infrastructure for target new state	Learning how to operate new infrastructure, services, etc	Optimising operations based on experience with new services
DESIGN & OPERATIONS	Build and operate 'traditional' systems. Undertake innovation projects to test future.	Build and operate traditional systems. Begin to introduce new models in 'energy innovation zones'.	Build and operate new systems–phased replacement of existing in line with update cycle, accelerated by system growth.	Substantial and growing proportion of system operates in new mode. People and organisations learn how to operate this new mode at scale. Requires organisational headroom to do this while ensuring reliability, etc are maintained.	Build and operate new systems. Undertake innovation projects to test future.
DATA INFRA-STRUCTURE	Dominated by 'traditional' modes-engineering experience of existing staff at a premium	Build infrastructure to begin capturing data and so drive transition to data-driven design and operations	Use 'big data' to inform new models of design and operation as they roll out from innovation zones to whole system	Pervasive data capture and analytics; developing and testing AI-driven solutions to exploit volumes of data now being captured	Pervasive data capture and analytics; full operationalisation of AI-driven solutions
ENGINEERING STANDARDS	Refinement of existing standards; relatively slow evolution with long periods between updates	Implement recommendations SEM1-8. Establish frameworks and governance to support agile, data-driven standards evolution. Continue to design and operate existing systems to existing standards (as changed by SEM1-8), while testing new standards in innovation zones	Agile, data-driven standards evolution. Standards change rapidly and in small chunks (minor updates every quarter rather than major ones every 3 years), reflecting rapid acquisition of new experience. New standards co-exist with traditional, as large chunks of system are still dominated by traditional design and practices.	Continued agile evolution. Begin to stabilise key standards and shift them back into refinement mode, with slower evolution	Refinement of existing standards; relatively slow evolution with long periods between updates. (Standards for AI-driven solutions remain in agile mode.)

Figure 8: Possible Transition Roadmap

Core Supporting Appendices

Core Supporting Appendix A: Context for this review

A.1 The Panel and its remit

BEIS and Ofgem have commissioned an independent expert panel to report on engineering standards in the GB electricity system, and in particular whether the current standards landscape is reducing or will reduce customer value, especially bearing in mind the changes happening through decarbonisation, digitisation and the rise of local energy solutions. The terms of reference for the Panel can be found in Appendix E.1. The Panel membership can be found in Appendix E.2. The core areas of interest identified within the remit are:

- Economic efficiency
- Enabling of new technologies in a fair and neutral way
- A whole systems approach
- System performance, reliability, security and resilience
- International context
- Standards ownership and governance

The review has considered the whole electricity system, including both utility and customer components, and has embraced all provisions that impact engineering decision making, whether formally called standards or not. It has explored the differing roles of international and national standards, and considered the complex interplays between policy, regulation, markets and engineering standards. The focus has been on electricity, but the Panel has had regard to the impacts on and of other energy vectors, other utilities, and those other systems such as transport that are becoming increasingly interdependent with the electricity system.

The Panel has been supported in its work by consultancy Frazer-Nash, whose focus has been on the detailed evidence base. Their report is published alongside this report. The panel has worked closely with Frazer-Nash in arriving at its conclusions and recommendations, and has appreciated their support.

A.2 Today’s GB electricity system

The electricity system connects and integrates everyone and everything that uses mains electricity with sources of electricity, across the whole of Great Britain, and with connections to the systems of the island of Ireland, France, the Netherlands, and potentially other countries in the future.

The system of today and the future is different to the system of past decades. We have moved from large, remotely sited, power stations supplying power over long distances through networks to individual users, to a system that blends this existing infrastructure with much more local approaches to production, storage and use. Your rooftop solar panels might supply your domestic needs and charge your electric car on sunny days, in the future the same car might supply you with electricity during the night when there is no sunlight. At city level the same thinking applies, with district scale or city scale energy and infrastructure planning potentially creating new opportunities to optimise energy and electricity sources and uses.

All of this implies a system where data and the insight it creates become as important as the physical assets involved, and ongoing debate about where authority for different issues should lie – with customers, at local scale, at city or region scale, at national scale.

Much of the discourse on electricity is in the Panel's view unhelpfully limited by the legacy of what has been important in the system in the past, and how it has been subdivided and regulated. Noting the wholesale changes taking place the Panel has used a wider definition, to be inclusive of the fullest range of issues and potential solutions, and therefore to relate to the whole electricity system. Our definition of the whole electricity system is: *the complete electricity system including networks, all sources of generation, equipment connected to networks, equipment on customer premises, touchpoints with other energy vectors, related data and communications systems, relevant legislation, regulation and market arrangements, commercial contracts and associated supply chains.*

A.3 What is an engineering standard?

Standardisation first arose in the eighteenth century when the mass production of the industrial revolution demanded that manufactured items of similar function should be interchangeable. Thus it can be argued that standards underpin much of the development of society since. Standards drive common solutions to similar problems, through interchangeable products of a given function, governance of the outputs or outcomes to be produced from systems or subsystems, and prescription of the relationships between different systems.

In the case of electricity there are standards that describe system outputs such as voltage, frequency or reliability, standards that describe the configuration and performance of equipment, and standards that define how different systems should work together. However, some of these requirements are defined in documents that are not officially described as standards. This is a result of how the industry's governance has evolved over time.

The growing importance of data and intelligence leads to additional layers of standards on top of the traditional electrical hardware baseline layer, addressing factors such as:

- Communications protocols
- Data and interface protocols and syntax
- Data ontologies
- Business processes and systems

This takes standards into the world of software engineering as well as in electrical engineering, to address key questions such as interoperability between the myriad smart technologies now beginning to be deployed.

Rather than be limited by the nomenclature currently used in the industry the Panel decided to adopt that definition of an **engineering standard** as *any provision that drives engineering decision making on the whole electricity system.*

A.4 Why and how to standardise

When a technology or industry is new there tend to be few standards. Compliance with standards can limit innovation, and companies want to compete to set the benchmark. As industries mature, users do not want to be locked into single vendors' systems, and start to demand the benefits of common approaches. Users also want to see consistent approaches and levels of performance, and the ability of systems from multiple vendors to work together seamlessly. Standards developed in this way tend to be backward looking – they learn from experience of deployment and capture what works best into standards that then support mass production and application.

Software standards are somewhat different, because once designed the cost of production is very low, and changes once in service are relatively straightforward. Standardisation in this area often tends to be forward looking – it tries to create a framework for people to understand the issues and to design solutions.

Economies of scale for manufactured goods tend to result in internationally applicable standards being negotiated. At system level, though, it is more normal for national standards to emerge. This is very much the case for GB electricity to date.

The distinction between national and international standards is important. Almost all manufactured products are sold into global markets and hence made to international standards. Requiring something different to this tends to either cause vendors to decline to supply, or to raise the price substantially, both for equipment purchase and subsequent spares and service support.

If the energy transition requires products – either products used within the electricity system or by customers - to perform differently to international standards, the best way forward is to work as part of international standards committees to influence changes to the standard. Given all countries are going through their own energy transitions at present this might find common cause, but the UK does need to be at the table, something we have not done consistently well in recent years.

There is also an issue in standards-making of performance versus prescriptive standards. Performance standards describe a required outcome without stating how that outcome should be achieved. A prescriptive standard describes what should be done to achieve a particular outcome. Both have advantages and disadvantages, see Table A-1.

Table A-1 Performance versus prescriptive standards

	Advantages	**Disadvantages**
Performance Standards (tell you what has to be achieved)	Leaves opportunity to innovate existing solutions or develop entirely new solutions. Transparency of and accountability for outcomes is easier to achieve.	Less obvious what to do when asked to design a solution. Requires testing and data to demonstrate compliance. Requires more proof in defending action after an incident.
Prescriptive Standards (tell you how to do something)	Gives clear instruction as to what has to be done. Easier to demonstrate compliance or defend action after an incident.	Tends to shut out innovation. Accountability for overall outcomes can be unclear.

A.5 How standards are made

Standards can arise through multiple routes. At the most basic level a group of stakeholders sufficient to influence the market convene in some way, and make an agreement to standardise. In practise this is usually mediated by some form of standards organisation (eg BSI), who will then publish and manage the standard. In most cases adherence to the standard is voluntary, although the intent is that a critical mass will be achieved so the standard gradually achieves universal adoption. This method is common worldwide, both internationally and nationally.

Sometimes standards become enshrined in legislation. For example, every electrician in the UK is obliged to work in accordance with the IET Wiring Regulations BS 7671. This is to help ensure public safety.

Other standards may be internal to organisations or companies. For example, Shell has standards for equipment that are made available for use on its installations globally.

A.6 The existing engineering standards landscape relating to electricity

The standards governing the planning and operation of the traditional electricity system have their origins in what were effectively organisational standards for the nationalised electricity industry. These were reframed at privatisation in 1989, and have evolved since. Appendix F sets out the some of the history and complexities of this process.

Standards that impact engineering decision making for the whole electricity system today include:

- Performance requirements of Ofgem, principally around reliability of distribution systems
- Industry codes
- Standards relating to the planning and operation of power networks, referenced in industry licences (and codes) and thus a requirement
- Electricity industry technical standards and guidance for power equipment and systems
- International standards governing equipment and systems used by electricity customers
- Relevant data protocols
- Custom and practice in electricity network companies around the application of standards when creating solutions. These may be written or unwritten and may vary from company to company
- Ungoverned spaces where no standards exist, usually because the area concerned is relatively new

Many of these standards overlap, contradict or are not mutually consistent. For example, Ofgem's performance requirements usually require an outcome significantly better than what would result from application of the applicable distribution network security standard P2/7.

Ungoverned spaces are not necessarily bad. It may be wise to let new technologies evolve before trying to agree standards.

Many of the standards used in the electricity industry are developments of original documents that go back many years, in some cases the 1930s. The industry is effective in their maintenance and periodic updating, but it is relatively rare for fundamental reviews to take place.

A.7 Engineering Standards, Policy, Markets and Regulation

The engineering, markets and economic regulation aspects of electricity are intertwined, and all exist within an environment set by Government policy. Quite often there are engineering and market alternatives to solving problems that need to be weighed against each other. It is rare for there to be no knock-on effects from changes to any one aspect. Any review of engineering standards cannot help but become engaged with these other dimensions. This may be illustrated by the following example:

In the case that generation and demand flexibility at national level is insufficient (for example through insufficient interconnection or flexible technologies), it would be cost effective to reinforce distribution networks beyond what normal standards might require, to make use of local distributed energy resources to achieve this flexibility. This would mean spending more money locally on networks to save money at national level, but only if policy, market and regulatory arrangements were in place to drive the provision of more distributed energy resources locally.

This review has sought to be pragmatic in approaching this, focusing on the engineering aspects, but having regard to the totality.

A.8 Wider contexts beyond the electricity system

The electricity system is becoming much more integrated with other energy systems, with other infrastructure systems, and with wider systems in society. Its future shape will depend on and impact other areas. For example were personal mobility to move from personal vehicles to shared vehicles this would change the timing and geographic pattern of on-street charging of electric vehicles, and were healthcare to become more home based this might require higher reliability and resilience for electricity supplied to vital equipment in homes.

At the level of built infrastructure there are considerations of co-ordination. Any street works inconvenience citizens and are costly. Utility trenches can carry multiple services at little extra cost provided planning is integrated and some allowance made for investment ahead of need. Benefits to citizens come in reduced costs, reduced disruption and improved air quality, but require coordination across multiple permitting and regulatory agencies.

Both these pose challenges for engineering standards (which tend to apply within rather than across industries) and for the remit of the Panel (electricity only). The Panel has attempted to build flexibility into the standards landscape going forward to facilitate flexible and creative responses to these challenges, and noting its remit.

A.9 Conclusions

Engineering standards are an immensely complex field, and way beyond the resources of an expert Panel to explore in every detail. Our recommendations are the starting point for detailed implementation work, and for fundamental change in how the process of standards making, implementation and compliance works in an information based world. The right standards supporting the right future system are key to customer value, and an appropriate and significant level of effort will be needed going forward to realise that value.

Core Supporting Appendix B: The case for change

B.1 Impact on standards of the changing landscape

Why change? The current system of standards has served adequately from privatisation and before. These standards have evolved over thirty years since privatisation to integrate renewable and low carbon technologies, facilitate competition and continue to improve supply security.

As decarbonisation intensifies, the system is becoming increasingly interconnected, dynamic and complex, forming a system of systems at mega scale. This future system will have very different characteristics to those our legacy standards are designed for. We know this much, but do not know the detail of how the system will evolve – and it is important for customer value that standards enable positive change rather than inhibit such change as we deliver the net zero agenda.

This section outlines the drivers for change in electricity, why they impact on engineering standards and the opportunity they present.

B.1.1 Net Zero

The UK was the first major economy in the world to pass laws to end its contribution to global warming by 2050. Delivering net zero greenhouse gas emissions cost-effectively by 2050 requires radical change from today. It is impossible to predict the exact mix of technologies, models and behaviours that will evolve, but analysis presented by the Committee on Climate Change[25] suggests extensive electrification, particularly of transport and heating, with all electricity produced from low-carbon sources. Given the resulting predicted doubling or quadrupling of electricity demand, the pace, scale and nature of the change are completely outside recent sector experience. Whilst some important policy decisions will need to be made soon there is no roadmap as to how this will evolve – we will need to anticipate and react to scenarios, and innovations in business models, services and technologies globally.

We will need to optimise the use of smart technology in enabling a diversified portfolio of low carbon generation, storage and demand management solutions at a range of scales from domestic to major, and ensure we have an underlying system design that will allow this much more complex and dynamic system to operate predictably and optimally.

Distributed solutions, electrification of transport and heat and smart technology are evolving quickly, and will have impacts on the electricity system overall that we do not understand fully yet. Deployment tends not to be centrally controlled or regulated to the same extent as traditional solutions, creating a need to manage much higher levels of fragmentation.

Engineering standards need to enable this change by promoting flexibility and option value, to help mitigate the risks these present, and to not limit choice as technologies and business models evolve in the future by creating lasting lock-ins in a particular direction. Furthermore, whilst it is possible to analyse energy mix scenarios, much is dependent on economic and policy choices, as well as technological advances.

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[25] Committee on Climate Change https://www.theccc.org.uk/publication/net-zero-technical-report/

Engineering standards need to enable the outturn of a range of scenarios, adapt to diverse technologies and support interactions between different energy vectors as we decarbonise. The impact standards (and policies, regulation and markets) have on investment decisions needs to be analysed systematically on an ongoing basis, and balanced with remaining flexible to future uncertainty.

B.1.2 The changing role of customers

The current standards landscape models most customers as the recipients of a service provided by a centrally controlled and managed system. This has changed and will change further as renewable generation, electric mobility and smart controls become part of many peoples' daily life experience. Whilst only small numbers of customers wish to engage with their electricity supply at a technical level there are many technology providers eager to manage this on their behalf, creating a very different commercial and technical dynamic at the point of electricity end use.

This means that typical homes and businesses will soon contain a range of active devices that at best could provide highly cost-effective system services but at worst could act in ways that are commercially beneficial for other parties but harmful and/or costly from a systems perspective.

Customers also increasingly wish to exercise the same kinds of choices over their energy as in other aspects of their digitally enabled lives. Differing customer segments may have very different energy access and energy choices. This is in contrast to the existing arrangements where the efficiency and security of supply do not recognise differing customer needs and preferences.

There is every chance that new technologies and business models will both enable customer choice and service innovation, and help ensure system integrity and minimise overall costs, but this needs to be supported by standards where appropriate to make it happen. If customer and system objectives are not compatible this needs to be handled.

Many customers may not elect to make the choices outlined above, and will need to continue to receive a reliable and affordable electricity supply, something engineering standards need to take into account when considering acceptable levels of system performance and capacity.

B.1.3 The changing whole system

The current system architecture presupposes a core transmission system to which large power stations and demands are connected, regional distribution to meter points in homes and businesses, and end use by customers. The interfaces between generation and transmission, transmission and distribution, and distribution and the customer, are clearly defined and separable, and this has prompted industry silos around generation, transmission and distribution that have solidified over past decades. Regulation is applied separately to each. Interactions between the different silos were understood well enough that the behaviour of the complete system could be managed through codified interactions between the different organisations involved.

This model worked well over many years but is now under severe pressure, and this pressure will increase.

The reasons for the pressure have been alluded to already – the proliferation of active devices and controls at all levels, most notably in distribution and on the customer side of the meter, something it was not necessary to consider historically. These range from solar farms connected to the distribution system to local battery storage.

The impact of this so far has been:

- to change radically the nature of power flows on the system,
- to increase substantially load forecasting errors,
- to create major difference in the contribution of distributed generation between normal and abnormal conditions, and
- to reduce system inertia substantially.

All of these cause substantial increases in operating costs.

We can expect this to continue and be compounded by large new controllable loads and sources at customer level at mass scale (EVs, heat pumps, smart appliances, local storage, potentially vehicle to grid). The control of most of these is not currently part of how the electricity system is managed[26].

We do not know how far and how quickly this will evolve, however it is clear that these devices in customers' hands cannot be treated as passive in the planning and operation of the electricity system. Industry silos are becoming a key barrier to the economic management of system security, and achieving whole-system resource optimisation in a highly complex system. Engineering standards will need to embrace this inevitability, and encourage greater participation from customers and third parties to bring forward new solutions to support the harnessing of its opportunities and mitigation of its risks.

B.1.4 Generation - a shift from the few to the many

Large power stations will continue to form an important part of the electricity system, especially given the expected increases in electricity demand. As we decarbonise these are likely to include nuclear plants that operate largely in baseload (ie at constant output all the time), and offshore wind plants whose load factors are reasonably high but depend on resource availability. Future roles for gas fired plant with CCUS[27] and/or hydrogen fuelled plant are unclear but may evolve.

However there is an equal shift towards localisation of a large proportion of generation. Generators connected to the distribution network have doubled from around 15 GW in 2011 to over 31 GW in 2019, including around 9 GW[28] of capacity on the customer side of the meter.

Local generation:

- allows exploitation of local resources (eg domestic solar, or small hydroelectric schemes),
- reduces network losses,

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[26] Methods and Tools for Planning the Future Power System: Issues and Priorities, 2015. https://strathprints.strath.ac.uk/54341/1/Bell_IET_2015_Methods_and_tools_for_planning_the_future_power_system.pdf

[27] Carbon Capture, Utilisation and Storage, a technology system to remove carbon dioxide from exhaust gases arising from power stations or other fossil fuel usage, and prevent it from entering the atmosphere permanently

[28] BEIS, DUKES (2019) - Digest of UK Energy Statistics (DUKES): electricity 2019.

- facilitates greater resource exploitation and the circular economy through better integration locally, and
- promotes ownership by communities, and greater personal and community accountability for energy.

The pace of localisation of generation has been high in recent years, and this seems highly likely to continue. Smart technologies will allow local management of generation, demand, and storage, and provision of system services, potentially at much lower cost than today[29][30].

Management of the system is moving from involving a small number of large power stations, with assumptions made about local generation, to a much more complex challenge involving the interactions between perhaps millions of connected generation, storage and demand responsive devices. This will need much higher levels of automated and local decision making than today, and a high level of confidence in how all aspects of this much more complex system relate to each other - both in normal conditions and during faults and emergencies.

Engineering standards will need to recognise and support this shift, developing better alignment between large and small energy producers in connection, operation, control and compliance, accommodating its fundamentally uncertain nature.

B.1.5 The digital transformation around us

Our everyday lives are increasingly digital. Many industries and services have moved beyond digitally augmenting historic practices to a complete digital reinvention of the service or experience being provided. The electricity industry, in common with most of the economic infrastructures and the construction industry, is still largely at the stage of using digital to augment and improve what it has always done.

However, technology companies are seeking ways to engage customers with innovative digitally driven products and services in the energy area, for example home energy management, and the electric vehicle is evolving fast into what is primarily a digital device. In turn customers are starting to expect a digital engagement with their energy.

This shift is only beginning to affect the electricity industry. Fully embracing digital will mean not only a huge change in how customers relate to the system, but also the digitising of the system itself, and a much wider usage of data-driven and algorithmic techniques in planning and operation to substantially increase the utilisation of existing network and energy assets[31].

As with the other drivers involved, the standards regime will need to support the evolution of a digitised system to increase the visibility, predictability, and controllability of the supply system as we maximise asset utilisation, provide protection against adverse interactions and consequences, and be able to evolve as we learn.

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[29] Vivid Economics, Imperial College, Accelerated Electrification and the GB Electricity System, Report prepared for Committee on Climate Change, 2019. https://www.theccc.org.uk/wp-content/uploads/2019/05/CCC-Accelerated-Electrification-Vivid-Economics-Imperial-1.pdf

[30] Aurora Energy Research, Power Sector Modelling: System Cost Impact of Renewables, Report prepared for National Infrastructure Commission, 2018. https://nic.org.uk/app/uploads//Power-sector-modelling-final-report-1-Aurora-Energy-Research.pdf

[31] Big Data Analytics for Flexible Energy Sharing: Accelerating a Low-Carbon Future', IEEE Power and Energy Magazine, 2018. https://purehost.bath.ac.uk/ws/portalfiles/portal/173870502/Big_Data_Analytics_for_a_Flexible_Sharing_Energy_System_Accelerating_a_Low_Carbon_Future_final.pdf

B.1.6 Resilience

Resilience is the system's response to and recovery from low probability high impact events. When such events occur there are strong industry traditions of working together to get customers back on line. However there are currently no standards for resilience, and the evolution away from large power stations (almost totally in some parts of the UK) towards a more distributed system has led to concerns amongst the Panel that restoration times from serious events may be at risk of being considerably longer than in the past. Work by the National Infrastructure Commission published during the course of the Panel's work supports this perspective.[32]

This is at the same time as society becoming more reliant on electricity, for example many people now carry no cash, expecting cashless payment to always work – which needs an electricity supply. At the same time some of the equipment used in homes and business has or could become more resilient – for example laptop batteries last several hours (although domestic and small business internet routers have no batteries, in general).

The BEIS and industry E3C Black Start Task Group has been exploring these issues, and has proposed a resilience standard for recovery following a black start, which has been taken into account in the Panel's work.

Engineering standards need to recognise society's dependence on electricity, and the value different customers place on supply reliability[33,34,35], and the inherent capability within a much more data driven system to meet customers' requirements at lower cost and with reduced lead time than they are today.

B.1.7 Pace of Change

The electricity industry is set up around long time cycles. Physical assets take years to develop and build, and then have typical lives of many decades. There are one or two price control reviews each decade. The current standards landscape mirrors this, with changes to standards being debated at length, and not easily revisited once agreed. The institutional environment in turn mirrors the standards landscape, with industry people expecting to use consistent standards to solve different application problems.

By contrast the world of customer devices now impacting the system changes much more quickly. Device lives are measured in years not decades, and device characteristics can be changed quickly and frequently by remotely delivered software upgrades. Capabilities not envisaged in standards, such as frequency response, can sometimes be provided at near zero cost. Customers are also buying new types of smart electrical devices: batteries, EV chargers, heat pumps.

Engineering standards in this world are different to traditional engineering specifications. They tend to establish general principles of design and define interfaces, but leave functionality much more open to iteration and development.

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[32] National Infrastructure Commission, 2020: *Anticipate, React, Recover: Resilient Infrastructure Systems* https://www.nic.org.uk/wp-content/uploads/Anticipate-React-Recover-28-May-2020.pdf

[33] The Value of Lost Load (VoLL) for Electricity in Great Britain', 2013. https://www.ofgem.gov.uk/ofgem-publications/82293/london-economics-value-lost-load-electricity-gbpdf

[34] 'Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review', 2015. https://www.frontiersin.org/articles/10.3389/fenrg.2015.00055/full

[35] 'Study on the Estimation of the Value of Lost Load of Electricity Supply in Europe', 2018. https://www.acer.europa.eu/en/Electricity/Infrastructure_and_network%20development/Infrastructure/Documents/CEPA%20study%20on%20the%20Value%20of%20Lost%20Load%20in%20the%20electricity%20supply.pdf

The electricity industry is now entering a hybrid world where both approaches are likely to have their place. There will need to be alignment between asset-driven and intelligence-driven approaches to system development, and between prescriptive rule-based and incentive-driven system performance. However the pace of change is likely to mean ways need to be found to evolve standards continually and potentially at different speeds, rather than treat them as fixed points to be changed only rarely.

B.1.8 Complexity

The existing engineering standards landscape is complex in part because the electricity system is one of the most complex achievements of the industrial era. Many of its phenomena were understood through trial and error during the period of its initial development up to the 1970s, and standards developed to help support the safe and reliable system we enjoy today. For the next few decades the system, and its supporting standards developed incrementally, and privatisation drove a shift away from engineering matters to innovation in commercial approaches and solutions.

For the last fifteen or so years this has been changing once more, as a result of decarbonisation, decentralisation, digitisation and the changes occurring in customer-controlled parts of the system. The number of active devices has increased by orders of magnitude and will increase by several more. Control actions are being applied by large numbers of independent parties, and ever cheaper consumer grade technologies, as well as smart grids, will drive this much further.

Standards have evolved incrementally to absorb this. There is now growing coordination between the transmission and distribution system, greater visibility and controllability at the distribution level, and the increased emphasis on the use of AI, big data and algorithms to better understand, forecast, and manage system demand, congestion and constraints. Core transmission and distribution standards such as SQSS[36] and P2[37] have been enhanced to reflect the changes in generation mixes and technologies.

However the accelerating pace of digitisation, and the drive to decarbonisation are challenging what can be done through incremental change. One of the most complex achievements of the industrial era is being made more complex as it embraces the riches of the digital era.

As behaviours become harder to predict, the ability to drive active feedback loops becomes more important. The traditional system had few active controls, particularly close to customers, so it has relied heavily on predicting behaviour and then building in capacity to meet it. Behaviour is becoming more complex, but the trends which are driving this are also driving improved capabilities to monitor and exert real time control. The system has to balance these trends – if it tries to meet changing customer behaviours under traditional predict-and-build techniques, it will probably both fail and over invest.

B.1.9 Clarity of outcomes for customers, and citizens

The current landscape of standards can perhaps best be described as industry-centric. It is complex, in places inconsistent, and does not give a transparent view of what customers should experience to anybody other than an experienced specialist. This has a number of consequences:

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[36] National Grid Electricity System Operator's Security and Quality of Supply Statement – a licence required standard

[37] The ENA's Engineering Recommendation P2 – which is a licence requirement on all the distribution companies.

- Customers find it hard to engage with the system other than on terms set by incumbent players
- Trade-offs of self-provision versus utility service are hard for customers to assess
- The lack of clarity can result in poor application decisions (for example this appears to have contributed to an inappropriate response to the design frequency range by a train manufacturer that contributed to the impact of the 9 August 2019 incident)
- The opacity also makes it more difficult to engage in wider debate around changes in provision, for example moving to a model of customers contracting for a mix of firm and interruptible capacity

As we move towards a system where customer-owned devices have greater importance, engineering standards need to be more transparent and accessible, and reflective of the opportunities in this change.

B.1.10 Opportunities and focus areas

The resources available to the Panel have not allowed a comprehensive review of all aspects of electricity industry standards, nor would it have been appropriate to undertake such a review without a much wider stakeholder engagement than has been possible in the time.

Instead we have chosen to focus in areas in which changes offer clear opportunities to remove current barriers and add value.

We think the greater value would reside in lowering costs for customers whilst offering a better experience, whilst the main barriers to address are the need for greater transparency and accountability and the ability to unlock future potential, and have summarised the principal opportunities below.

B.1.10.1 Lower Customer costs

The review gives an opportunity to assess whether the current standards, when implemented, are locking in unnecessary direct and indirect cost and whether high levels of system reliability and resilience for the end use of electricity by customers can be delivered at lower cost.

Direct costs flow from the codes and standards maintained by the supply industry, eg the Grid and Distribution Codes and all their daughter documents (eg P2/7, G99 etc), the Relevant Electrical Standards (Grid Code). This will include the costs for new customers associated with the standard designs of connections, particularly domestic customers. Relaxation of voltage standards is also likely to allow some customers to make savings from overall reduced energy consumption.

Indirect costs are the internal costs to network companies from following standards, again for example the Grid and Distribution Codes and related documents. Compliance with these documents drives both investment and operational costs for the companies that are included in their charging arrangements and hence end up being paid for by end customers.

B.1.10.2 Better Customer experience

Customers impacted by engineering standards are wide ranging along the energy value chain, from developers and operators of conventional, new and renewable generation, all the way to residential and business customers. The impact is also wide ranging: connection and connectivity, service, voltage, power quality, outages time, and increasingly on choices – choices of sources and vectors as well as devices and appliances. Customers' expectations are driven by experience with other industries, such as transport and retail. The challenge is to provide a simple, easy, flexible, tailored and responsive experience in a complex sector.

B.1.10.3 Unlocking of future potential

Standards are often cited as a barrier to innovation and to the potential of realising immediate customer benefits. Whilst appropriately designed standards could guide the development of innovations and increase uptake, standards with insufficient flexibility and overly large margins in performance requirements can hinder the deployment of solutions which could reduce customers' costs and, or, contribute to the net zero goal. The challenge is to ensure that standards are developed with the right balance between ensuring the purpose of the standard and the ability to be more agile and flexible in the deployment of novel solutions and services

B.1.10.4 Greater transparency and clearer accountabilities

Perhaps due to the organic way in which the current electricity system evolved, we see that there are very many codes and standards, overlapping and with gaps. Standards and codes have different change processes, many of these difficult to penetrate other than for large companies with specialist resources. It is hard to see which of them affects any initiatives or projects or what should be in standards or codes versus what should be in bilateral contracts, with contracts themselves sometimes opaque. It is not a simple landscape, making it hard for the uninitiated to understand how standards are developed, adopted, reviewed and complied with. It is not easy to clearly identify where accountabilities lie and processes can seem lengthy. Much of the responsibility resides with the consensus between industry, accredited bodies, regulatory bodies and government departments, each with different objectives, therefore not always aligned. Furthermore no party has jurisdiction to assist outside their own domain. The implications are inherently longer timescales, increased risks of gaps and duplications, conflicting standards and codes as well as risk of recommending misconstrued actions. Greater transparency and clearer accountabilities would be key enablers of opportunity.

B.1.10.5 Confidence

Achieving net zero at reasonable cost will require customers to have confidence in new technologies, for example replacing their car with an electric one, or their gas boiler with an electric heat pump. These technologies will need to interact with the electricity system. Aside from a few early adopters most customers will need to experience this change as seamless. Error messages, the need to seek advice, or technician visits, will not be welcome. Engineering standards will need to play their part in ensuring this.

Appendix E.3 explores how we have used these opportunities to frame our approach to the work.

B.2 Alignment of recommendations to Future Energy Scenarios

National Grid ESO has recently published its 2020 future energy scenarios[38]. The approach is a shift from previous years to accommodate net zero, and introduces an axis of "level of societal change" to add to established considerations of the speed of decarbonisation.

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[38] https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents

Four scenarios are proposed:

1. *Steady progression*, which does not achieve net zero, and is essentially incremental change from today, with slow decarbonisation
2. *System transformation*, which achieves net zero through policy and system driven approaches that do not require high engagement from customers
3. *Consumer transformation*, which achieves net zero through much greater customer participation in the energy system, and making changes at home to improve energy efficiency substantially
4. *Leading the way*, which achieves rapid decarbonisation through high levels of customer engagement in smart energy services and energy efficiency

Engineering standards will play a key role in all of these scenarios. The Panel would assess this role as follows:

- Under *Steady Progression*, the focus for standards would be on reducing costs to customers. Many of the Panel's recommendations support this, eg those on voltage, frequency, capacity, reliability and resilience. There would also be merit in addressing issues such as interoperability, agility and a shift to standards centred on customer outcomes, but perhaps not with the urgency that the Panel recommends. *Steady Progression* is more about optimising the current way of doing things than transforming it. Innovative companies interested in bringing new technologies and business models to the market would tend to move elsewhere. Customers would continue to receive reliable electricity supply at a reasonable cost, but not the range of more customised and personalised services that some innovators envisage. And of course, we would not hit our net-zero target.
- For *System Transformation* we would use standards to push things slightly further and faster. Again, the Panel's recommendations on voltage, frequency, capacity, reliability and resilience would help contain and reduce costs to customers. Interoperability across devices and subsystems within the traditional electricity system would grow in importance, but that with customer equipment would develop more slowly. The potential to reduce customer costs through better use of data and digitalisation will probably not be fully achieved. Electricity networks would become smart and flexible, but the customer would continue to be an appendage at the end of the network, not a fully engaged part of it. There would be little urgency to shift to a framework of more customer-centred standards. Overall, standards would help contain cost increases seen by customers but not eliminate them. So customers would pay more in order to benefit from a net-zero system with little need for personal change (at least in their electricity consumption).
- *Consumer Transformation* requires the full suite of changes recommended by the Panel. In this scenario we would begin to use the full potential of data, digitalisation, agility and customer-centred standards to deliver customised and personalised services, and so engage customers (or at least their equipment) more fully in the energy system. This fully unlocks the potential cost savings that new technologies promise, both reducing costs for customers and allowing them to fully benefit from new products and services. Importantly, by engaging customers in the transformation, we also support the wider aspects of the transition to net-zero – customers who see that they are receiving tangible benefits from the transition will be more likely to engage in other aspects of behaviour change required to achieve net-zero.

- *Leading the Way* takes this even further. We would use the shift to agile, customer-centric standards to underpin a shift across all aspects of the energy system and how people within it work. This could turn the UK into an exemplar for energy systems transformation, leading the world in the transition to net-zero as we did in the transition to privatisation in the 1980s. As well as accelerating the delivery of the benefits of flexibility, agility and digitalisation to UK customers, this would open up export markets to our innovators and service providers.

The approach taken by the Panel has been to develop an approach and recommendations that do not constrain the scenario that eventually outturns. We believe that fully absorbing what digital, data and telecommunications can do has the power not only to minimise the very substantial costs of electrifying much of the energy system, but also to change completely the customer experience, and in so doing drive customer engagement and behaviour change.

Adopting the full suite of the Panel's recommendations allows all four scenarios to be achievable. Work published by National Grid ESO in December 2020 suggests a net present value £200 billion saving in taking a strongly consumer led approach to the net zero journey[39]. We believe it important that the full range of possible scenarios is to be unlocked, with engineering standards reform one of a number of key areas where attention is needed. A partial adoption of our recommendations, limited to shorter term adjustments to existing standards, will limit development to either *steady progression*, or, possibly, *system transformation*. In the Panel's view this would be a poor outcome for customers, businesses and the UK.

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[39] Analysing the costs of our Future Energy Scenarios | National Grid ESO

Core Supporting Appendix C: Detail and Implementation Proposals for Recommendations on Specific Engineering Matters

C.1 Introduction

This appendix C provides the rationale behind recommendations SEM1 to SEM8, and sets out means by which the Panel believe recommendations could be implemented. There may be other means to achieve the recommended outcomes, however the Panel would suggest appropriate engineering and industry expertise is deployed in determining alternative implementations – the subject matter is nuanced and complex in both engineering terms and the existing regulatory landscape (in the widest sense). Further engineering justifications and supporting evidence is contained in the accompanying report by Frazer-Nash Consultancy.

This appendix is structured as follows:

- Section C.2 deals with supply security and reliability (recommendation SEM1)
- Section C.3 deals with resilience (recommendation SEM2, SEM6, SEM7)
- Section C.4 deals with capacity (recommendation SEM3)
- Section C.5 deals with voltage limits (recommendation SEM4)
- Section C.6 deals with frequency (no high level recommendation)
- Section C.7 deals with interoperability (recommendations SEM5, SEM8)
- Section C.8 provides more support to recommendation SEM5c

C.2 Supply Security and Reliability

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 5

C.2.1 Why do we need to change?

Security is the ability to continue to provide the necessary capacity to maintain supplies, or how quickly supplies can be restored, following the loss or damage of some part of the electricity network. The Panel has taken the view that Security is a term that encompasses reliability, capacity and resilience – which are all intertwined topics. Nevertheless, in considering what is important to customers, the Panel believes that the key qualities are reliability and resilience as these are directly experienced.

Reliability is the ability of the system to withstand normal disruption (principally from everyday asset outage and single failures) and capacity is the capability of the system to fulfil customers' requirements – usually taking into account reliability. Resilience encompasses the system's ability to resist much larger (however defined) events and its ability to then restore services to customers.

The two key standards relating to supply security are the Security and Quality of Supply Standard (SQSS) and Engineering Recommendation P2/7. Their purpose historically was primarily to define the amount of assets that network companies need to have invested in to support the existing (and, often, the expected future) loadings imposed on the system by customers and provide a defined level of response to the event of a single network fault. As such they both address reliability and, to some extent, resilience. Resilience is not specifically referenced in these standards, and being important in its own right is considered in more detail in Section C.3. The rest of this section C.2.1 focuses on reliability.

P2 and SQSS are therefore a key driver of investment in networks, and hence costs to customers. Net zero and decarbonization are expected to drive significant increase in the use of electricity for heating and transport. It is fundamentally important to ensure that these standards are driving the right investments and are not either underspecifying the necessary investments to meet customer needs, nor that investment is over and above what is required, leading to uneconomic costs to customers.

The standards were written with the explicit purpose of creating redundancy in networks, so that in the loss of one or more circuits, the remaining ones can pick up all (or most of) the demand. This approach is often described as an n-1, n-2 standard etc. As such it is adopted in many networks across the world.

The low voltage networks do not generally have redundancy; the loss of the circuit implies the loss of supply to affected customers until that circuit is repaired. In the language of n-1, this is actually n where n=1 (written by some commentators as n-0 instead).

As described more fully in section C.4, it is economic to reduce losses significantly by increasing the capacity of circuits over that which would traditionally be installed for new or replacement circuits. For the low voltage networks in GB at LV this provides the opportunity for significantly increased reliability and resilience of these networks as new parallel capacity would become available.

The built-in redundancy in networks designed to be compliant with P2 and SQSS means that their capacity is only fully used in the rare event of a fault occurring at the worst time of the year when the system is supporting its maximum demand. At all other times of the year, the assets overall are only part loaded, often less than 50% of their capacity. As such there is a significant capacity that is underutilized. Recent developments in system operation, and formally recognized in P2/7, has allowed that spare capacity to be used to some extent to support additional load growth without new investment.

The reliability of distribution networks, as seen from the customers' viewpoint has increased substantially in the last couple of decades, driven by Ofgem's Interruption Incentive Scheme. Reliability is actually much better than P2/7 requires; it was already better than P2/5[40] required when the interruption incentive scheme (IIS) was introduced in 2001 and has continued to improve thereafter. From a pure reliability standpoint the IIS has superseded P2; the resilience aspects of P2 are addressed in section C.3. P2 (and SQSS) has an economic analysis underpinning it, and uses a notional value of lost load (VoLL) which is the loss of value a customer suffers from being deprived of supply. Similarly the IIS incentive rates were set with reference to analysis of customers' willingness to pay (for interruption avoidance and service restoration). However although both are supposed to be based on value to customers, there is a clear discrepancy in the outcomes that they are driving to. There is also good evidence to show that the VoLL used in the underpinnings of P2 is inappropriate as a single value. Research shows that VoLL could be much more usefully expressed as a number of values for different

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[40] The sixth version of P2 was published in 1978 as P2/5, updated in 2004 as P2/6 and again in 2019 as P2/7.

customers and different uses of energy, and in all cases as an increasing monotonic function of time[41,42].

The prospect now exists that customers' smart devices and appliances (especially EVs, home storage, heat pumps etc) can be scheduled by customers' home energy management systems to react to network, generation and supply availability and capacity, through cost signals, providing an opportunity to flex demand to meet supply availability. Such an approach could use the differing values of VoLL described above to provide automatic (ie from a customer's point of view, with no active customer involvement) flexing and scheduling of consumption (or production for storage or generation) to meet supply and/or network needs in the most efficient way overall. Whilst technology offers the prospect of such automation allowing significantly increased demand from decarbonization to be accommodated with even better reliability and at lower cost, it does bring new issues of resilience – see Appendix C.3.

Most of the above applies to the SQSS too, although SQSS has a broader scope than P2. Both define deterministically the minimum reliability of networks (and partially define resilience). However SQSS also covers the overall balance of supply and demand in Great Britain, ie ensuring that the system frequency is maintained within its close operational limits, and also deals with the security of generation connexions to the transmission system. There is no direct equivalent of the IIS for transmission – the incentive on maintaining supplies is based on energy not supplied from the transmission system – but usually this is zero or close to it, so the incentive properties are limited and not symmetrical, ie it is impossible to outperform zero loss.

P2/7 specifically allows substitution between services from customers and the capability of network assets to secure demand. The Panel is concerned that SQSS does not easily or formally permit the same equivalence and this should be reviewed.

The Panel has also noted that whilst there is flexibility in the SQSS to secure the system to a greater extent based on perceived risk, there is no matching flexibility to relax system security for a reduction in such risk. The Panel notes that such flexibility exists for other transmission system operators internationally, whilst not believing that there is necessarily a case for change, it would be worth reviewing by the SQSS Panel to ensure that this apparent lack of flexibility consideration does not lead to over-investment.

Finally the Panel notes that the differences between SQSS and P2 cause distortions across the transmission/distribution interface, both in terms of optimising system performance and in the commercial treatment of connecting generation to the two system.

C.2.2 What needs to be changed?

The Panel believes that the merging of reliability and resilience in an undefined way within both P2 and SQSS is detrimental to the development of the whole electricity system, where all generation, the network and customers' own devices all contribute separately to both reliability and resilience. As such these two key system requirements should be explicitly treated separately in terms of objectives and outcomes, whilst noting that they will always interact.

The Panel believes that network development should follow the approach in Figure C-1below, ie where the three key drivers are reliability, resilience and efficiency (ie mainly losses

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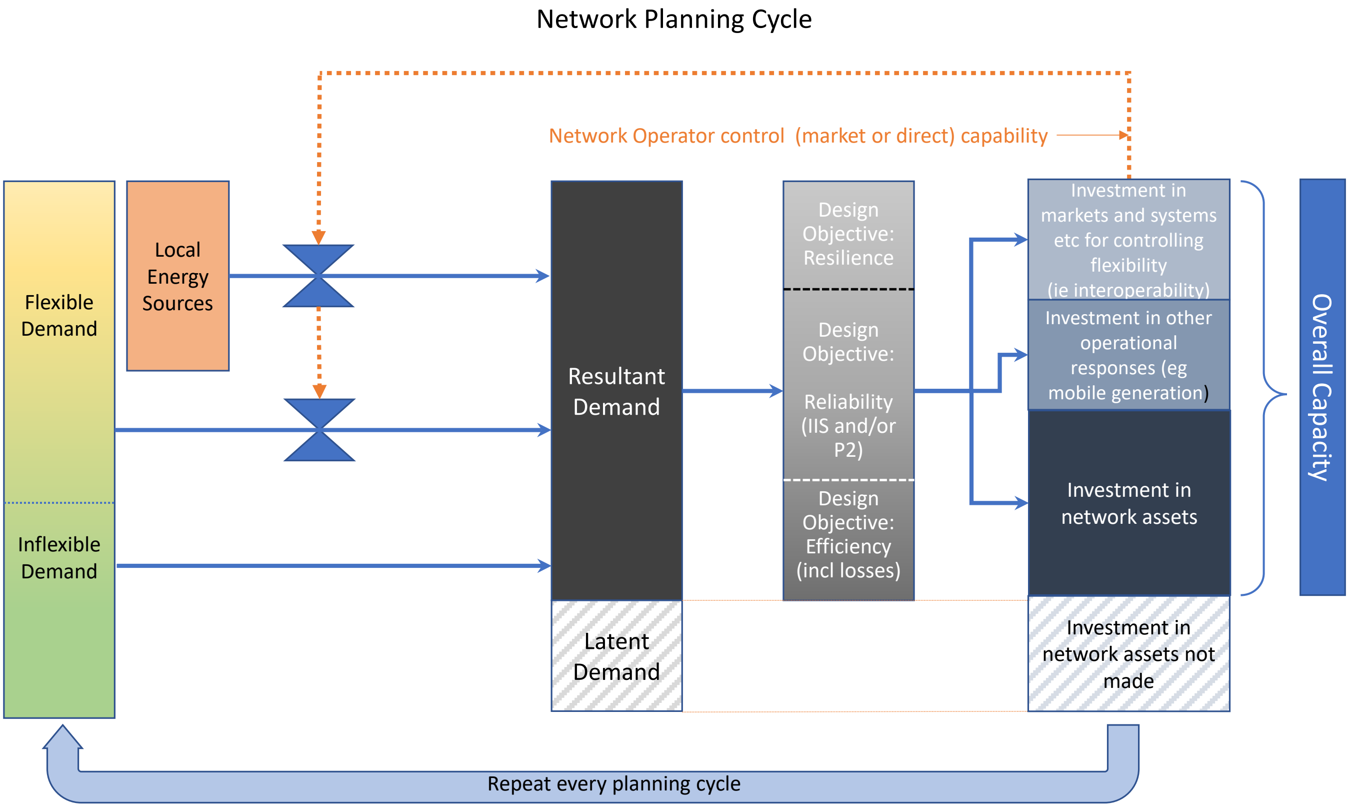
[41] The Value of Lost Load (VoLL) for Electricity in Great Britain', 2013. https://www.ofgem.gov.uk/ofgem-publications/82293/london-economics-value-lost-load-electricity-gbpdf

[42] Study on the Estimation of the Value of Lost Load of Electricity Supply in Europe', 2018. https://www.acer.europa.eu/en/Electricity/Infrastructure_and_network%20development/Infrastructure/Documents/CEPA%20study%20on%20the%20Value%20of%20Lost%20Load%20in%20the%20electricity%20supply.pdf

considerations) separately drive investment in market systems, operational capability and assets. This underlines the value in differentiating between reliability and resilience as concepts, and shows how capacity arrives from their combination (together with consideration of losses) rather than as an independent objective.



The key input into both reliability and resilience is their value to customers. Hence the Panel believes that a fundamental re-assessment of VoLL should be undertaken (also discussed in section C.7). Such a review of VoLL could consider the appropriateness of different formulations of VoLL that could be created to cater for the distinction between customers, customer groups, different appliance types (eg storage, both energy generally and electricity, devices are likely to present very different VoLLs to internet routers) and to cope with how these all vary with duration. This should then be used in future analysis and incentive schemes relating to the provision of network assets and services.

The new VoLLs should be used initially to rebase the IIS so that it properly reflects customers' needs. In the longer term, VoLL driven flexibility and the increasing prevalence of smart appliances will shift the need to incentivize the avoidance of interruptions to incentivizing sufficient delivery of the energy required by devices that operate flexibility. For example incentives should drive to maximize the ability to charge storage devices at times of low system stress and high availability to ensure the capacity exists for flexibly reducing system demand at times of high price or system stress. Customers should not need to consider if their appliances are powered by energy from the network or from their own generated or stored resources. This is a considerable change from today's situation, and will depend on the ready availability of new devices and appliances with the requisite interoperability (again, see section E.7). The Panel does not expect this to be a particularly rapid change across of all society and GB, and could well move at very different pace for different technologies, in different regions etc. However the emergence of electric vehicles and heat pumps now underlines the urgency of starting to appropriately standardize the approach. This offers the opportunity for the cheapest long term path to decarbonization and steps should be taken immediately to ensure that standards such as P2 and SQSS do not inhibit this transition.

Although the Panel's analysis has focussed on network costs, it notes that there are significant overall system savings available from flexibility and interoperability. Standards such as P2 and SQSS can ensure that networks are sized and operated efficiently taking into account flexibility. The Panel notes that there is no standard, mechanism or approach for assessing the contribution of flexibility and interoperability towards the lowest overall system costs, taking into account the hugely different capital and operational costs of a zero carbon generation portfolio, ie renewables and nuclear.

Although beyond the scope of this work, the Panel notes that as well as the significant savings in electricity network costs that interoperability will bring, it also opens up the possibility of differential network charging based on customers' appliances ability to offset network costs.

Also in the short term the SQSS Panel should review both the equivalence of system services and network assets, and the ability to flex requirements, both up and down, to match risk.

Managing Dynamic, Customised VoLL

Recognising that customers place different value on lost load depending on factors such as usage, time of day, season, length of interruption, etc, is of little use if the system cannot use this information to deliver differentiated service, with the cost savings and reliability enhancements this makes possible. The panel's recommendation that VoLL should accommodate these factors is driven by the recognition that solutions that could dynamically negotiate service levels between customer equipment and the system have been tested in innovation trials and are now beginning to come to market as customer products.

For example, Span[43] has introduced a home electrical panel that "*gives customers the flexibility to be able to choose what to power in an outage scenario and make changes to this in real-time. Customers can mark loads as must have, nice to have, and non-essential. Non-essential loads are not powered by the battery during backup, must have loads are always powered, and nice to have loads are powered when the battery is over 50% charged.*" This essentially gives domestic customers, or their agents, the ability to set and dynamically manage the value they assign to different loads in the home.

Span is backed by investors who helped found Nest, developer of smart thermostats, and led by a former leader of Tesla's product development team, indicating that this market is beginning to draw serious attention from institutional investors and developers of customer tech products. Lack of standards supporting this type of innovation risks preventing a full market developing for such equipment and the accompanying services. We therefore recommend that we begin incorporating such considerations into standards for reliability, resilience and network capacity.

C.2.3. Implementation Proposals

Ofgem and BEIS should support immediate research into VoLL. This will not be a one off exercise. Customers differing use of electricity over the coming years, coupled with advances in technology, will mean that a range of VoLLs are likely to be needed and these will change as behaviour and technology changes. Initially the time varying nature of VoLL should be recognized and used to rebase the IIS incentive rates. Overtime multiple values of VoLL should emerge for the differing usage of electricity.

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[43] https://www.span.io/

As P2 is ineffective for reliability at 11kV and LV, it should be withdrawn at these voltages, leaving system design for reliability to be driven by the IIS. Over time it might be possible to extend this approach to the rest of the distribution system, with a successor to P2 only addressing resilience issues. Ofgem would, as now, have oversight of these changes to ensure customers are protected in both performance and cost terms.

The governance and design of P2 and SQSS should be combined such that any distortions caused by the different treatment of issues at the T/D boundary are eliminated over time.

Number	Implementation Proposal	Importance	Urgency
C.2-1	Ofgem/BEIS should consider a wholesale review of VoLL, bearing in mind how customers' use of electricity is changing, taking into account both the increasing reliance on electricity for the operation of essential services and also customers' ability to use the opportunities presented by flexible demand, local generation and storage, and smart appliances.	H	H
C.2-2	The IIS incentive should then be redesigned by Ofgem to reflect the differentiation particularly of demand types, ie those elements of demand that need a firm supply can be treated differently in IIS terms from those which can be modulated or interrupted	H	H
C.2-3	Ofgem/BEIS should consider (if not already included in the Code Governance review) if the governance of P2 and SQSS should be integrated.	M	M
C.2-4	The IIS incentive should be reviewed to see if/how it can be applied across both the transmission (assuming both TO and ESO rôles) and distribution system, as opposed to the current split incentive régime.	M	L
C.2-5	The DCRP should note the lack of appropriate values for VoLL and the disconnects between VoLL, the IIS and historic P2/7 assumptions and look to address as part of its current review of P2/7	H	M
C.2-6	The SQSS Panel should review the benefits and risks of introducing more flexibility into the operation of the transmission system based on variable risks such as weather.	M	H
C.2-7	The SQSS Panel should review the benefits and risks of introducing more flexibility into the connection of generation to the transmission system.	M	H
C.2-8	The SQSS Panel should review whether in terms of system security the SQSS treats the performance of network assets completely comparably with services bought from customers.	H	H

C.3 Resilience

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 6

C.3.1 Why do we need to change?

As explained in sections C.2 and C.4, resilience, capacity and reliability are interrelated topics; reliability is the ability of the system to withstand normal disruption (principally from asset outage and single failures) and capacity is the capability of the system to fulfil customers' requirements – usually taking into account reliability. Resilience encompasses the system's ability to resist much larger (however defined) events and its ability to then restore services to customers. By definition events that test the system's resilience are much rarer than the business-as-usual events that are covered by reliability norms[44,45].

Events that test resilience include for example:

- black start,
- significant storm damage and/or flooding,
- cyber attack against multiple relevant assets,
- long duration interruptions of supply to large or small groups of customers so that natural diversity is depleted or lost.

All these events are becoming more likely or evidently more frequent. Most of them will also be associated with very serious disruption to other key infrastructure services. A good description of such an event is provided in the Royal Academy of Engineering report "Living without electricity"[46]. The report makes it clear that society has become increasingly reliant on electricity, but systems outside the electricity sector are often only resilient to short power outages. Within a fairly short time no power means

- no point of sale transactions,
- no public communications (except battery operated or wind-up radio),
- no supermarket, etc, logistics,
- potentially no heating,
- issues with water supply,
- no personal transport – EVs or conventionally fuelled once refuelling is required.

Coupled with present day customer behaviour, where customers hold no stocks of basic foodstuffs, do not have substitutable fuels for heating, and do not carry cash, the consequences of prolonged power outages rapidly become much more significant than in the past.

A number of responses and standards have evolved over the years to deal with resilience challenges. For first consideration are the existing security standards of P2 and SQSS. As discussed in Section C.2 these are framed more in terms of reliability; ie how the system caters for single fault events only. Nevertheless they require a base level of assets which does provide the background for resilience. Turning to focussed resilience issues, for example the Grid Code includes the black start requirements for NGESO to be able to restart the transmission system but with no time constraints that must be met. The Grid Code also contains the defence against predictable events such as the impact of significant frequency excursions. However the significant change in generation mix, the decrease in system inertia and damping, and emergence of cyber risks are all new and complex. The Panel notes that the existing standards tend to frame responses in terms of what the existing assets and systems can be stretched to do in extremis, rather than identifying the need for the wider framing of standards for events that

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[44] 'Battling the Extreme: A Study on the Power System Resilience', 2017. https://researchportal.bath.ac.uk/en/publications/battling-the-extreme-a-study-on-the-power-system-resilience

[45] 'Planning to manage power interruption events', 2010. https://pureportal.strath.ac.uk/en/publications/planning-to-manage-power-interruption-events

[46] https://www.raeng.org.uk/publications/reports/living-without-electricity

sit outwith the norm. They are also based on foreseeable events or failures. The increasing complexity and interconnectedness of modern infrastructure means that not all events can be foreseen, possibly leading to gaps in planned responses.

Illustrating the above point the Panel notes that the transmission companies and DNOs have internal standards to protect against flooding and for the ability of overhead lines to withstand assumed levels of wind and ice loading during significant storms. But not against events that are worse than specified: beyond this the industry then falls back on its emergency plans. In the main these do not specify return-to-service times.

Customers' own equipment is already an important component of how the whole system can recover from disruption. The electricity system has been designed based on a very significant amount of diversity between customers[47]. This diversity is lost when supplies have been interrupted for a duration beyond a few minutes – and will be a far greater challenge in the future when the quantity of electric heating, EVs and other storage has all increased significantly.

During the Panel's work, the National infrastructure Commission has published "Anticipate, React, Recover. Resilient Infrastructure Systems[48]." The Commission's report encompasses all infrastructure and calls for the government to require overall resilience standards for all infrastructure provision, together with appropriate governance and regular stress testing.

C3.2 What needs to change?

The Panel has found that there is a complex, but incomplete, existing landscape of obligations and standards all dealing with some aspect of resilience and which have implications for both the ability to resist the event, and how recovery is effected. Network licensees exist to manage this complexity and in the main stakeholders should be shielded from it. The Panel has formed the view that network licensees should be working to a high level statement, of how the system will recover from events that cause disruption that can be classified as beyond business-as-usual. Such a resilience statement would need to recognize the range of risks and events, and state these in terms that were meaningful to stakeholders. It would state the maximum time the disruption might last and the profile of how supplies would be restored. It would include detail of how customers' own electricity resources could be deployed and/or integrated into the recovery.

The objectives of the resilience statement should be set by appropriate reference to VoLL, or more specifically to the appropriate values of VoLL for different customers and durations as recommended to be developed in Section C.2 The Panel also notes the historic putative development of resilience plans for high impact low probability (HILP) events which were based on gross value added (GVA) for the affected area. The development of the resilience statement should revisit this work and ensure that VoLL and GVA are appropriate aligned.

The proposed resilience statement should be designed to implement government defined requirements which define what is acceptable to the UK, its economy and wider infrastructure. It can be simple and easily understood. It should not both be set and policed by a regulator. These functions should be separate. The resilience statement will also need to change over time. Changes in societal needs and technology will drive both what is required in terms of resilience, and how it can be achieved. The resilience statement will need to be updated periodically, and its implications widely promoted.

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[47] Diversity is an important tool in the cost-effective provision of electricity networks. Network design assumes that not all customers will use their most energy-intensive electrical appliances at the same time, hence allowing smaller networks to be sufficient based on this diversity of usage.

[48] https://www.nic.org.uk/publications/anticipate-react-recover/ May 2020.

An existing feature of resilience that needs to be retained and updated is the guaranteed standards régime that compensates customers for losses of supply beyond defined time periods. This also acts as a powerful incentive on network licensees as potentially they have to fund these payments. However the payment values should be updated to reflect the VoLLs developed above, and probably made more sophisticated to recognize that future events might result in the loss of ability to operate certain appliances freely, rather than be a complete loss of supply.

One of the key opportunities to meet these challenges is the use of the interoperability of customers' devices and appliances (as discussed in Section C.7 and Appendix D) together with the clear expectation of what is required as articulated in the statement of system recovery. Of course such interoperability is likely itself to be adversely affected by widespread electricity failure and which also needs to be addressed. Dealing with the trade-offs between the huge advantages that interoperability brings to reliability and the very significant new risks that it introduces for resilience will be one of the key future challenges for the industry.

Nevertheless interoperability brings other great opportunities and allows for a significant new way of thinking about resilience, at least at local levels. The Panel is aware of the initiative being run currently by NGESO to investigate how to include distributed generation in its black start capabilities. Whilst supporting this work, the Panel recognizes that much more could be done by network licensees to use the capabilities of distributed generation and storage to both support a depleted network and crucially to be able to supply isolated islands of distribution (and possibly transmission) network and customers when normal network connectivity has been lost.

In this context, local district microgrids, with appropriate enabling technologies, will facilitate the paradigm shift in delivering resilience and security of supply from redundancy in assets and preventive control to more intelligent operation through corrective control actions supported by a range of enabling technologies, interoperability and appropriate information and communication infrastructure[49,50]. Such developments could also be accepted by the DNOs as part of their armoury of responses to certain business-as-usual incidents too, enable a faster restoration of supplies to customers, as well as increased turnover for the distributed generators involved (compared with being unable to generate until the DNO fault was restored).

The resilience statement can then be used by the regulator and/or government to hold companies to account for their preparedness and performance, against the most economic methods of securing the statement's requirements. In turn the statement can be used by all dependent stakeholders including other infrastructure industries (transport, water, sewerage, medical, logistics, telecommunications etc) to plan their own response to such events.

The Energy Emergency Executive Committee is doing useful work in this area, leading to improved system wide resilience commitments, but the Panel believe this needs to be built on to translate into information to stakeholders in terms of what they can expect and what they should plan for.

C.3.3. Implementation Proposals

BEIS and Ofgem should consider how a resilience statement should be developed, administered and governed. Preparation of the resilience statement would enable an appropriate debate for these stakeholders to collectively express their priorities which will shape the regulatory

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[49] Impact of Uncertainties on Resilient Operation of Microgrids: A data-driven Approach,2019.

[50] Microgrids: Enhancing the Resilience of the European Megagrid, IEEE Power & Energy Magazine, 2015

necessities and network licensees' responses. It will also allow issues of regional differences/inequalities to be exposed and tackled transparently.

The Panel is aware of the current development of a black start restoration standard that is expected to be included in NGESO's licence. This is a starting point, as a result of increasing awareness of, and pressure from, external parties outside of the regulator and ESO of the increased risks of such an event. It also underlines the drawback of the current arrangement where the standard is both set by the regulator and then policed by the same body.

The Panel notes that network licensees already respond to financial incentives on business-as-usual events with measurable probabilities. Licensees' approach and response to more significant risks would be incentivized by being held to licence compliance requirements relating to the system recovery statement. It will nevertheless be a significant challenge to agree the content of the statement to have the appropriate level of measurable detail, pre and post performance indicators etc for regulatory compliance purposes.

Monitoring of compliance with the statement will become a key activity. A suite of metrics relating to the planned and unplanned depletion of the network, of key network support infrastructure (eg IT, protection, operational communications etc), and other critical unavailabilities should be initiated. Initially this would focus on the transmission system, but in time it might be appropriate to extend it to all networks. Other international jurisdictions do use such measures routinely.

Much useful information is already published by both the transmission and distribution companies, but it is disparate and not focussed on building a forward and backward looking view of the overall risk of disruption to customers' supplies. Some of the detailed reporting is to Ofgem for regulatory purposes and is not in the public domain.

By way of example of the sort of reporting the Panel envisage the North American Electric Reliability Council (NERC) has published an annual State of Reliability report for nearly twenty years, following the significant power outages across the north east of the US in 2003[51]. Such a report could form a useful model for tailoring for adoption in GB. The NERC State of Reliability Report covers:

- Event analysis
- Reliability Indicators
- Severity Risk
- Trends in Reliability Issues

The NERC analysis covers individual asset and system-wide metrics.

As noted in C.4.1 above the National Infrastructure Commission's report "Anticipate, React, Recover" makes a series of overall recommendations in relation to improving resilience. A central recommendation of their report is the need to establish, and then regularly test, standards of resilience. The Panel believes that its recommendations below are entirely consistent with the Commission's report and provide appropriate detail to support the Commissions broad recommendations.

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[51] https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2019.pdf

Number	Implementation Proposals	Importance	Urgency
C.3-1	BEIS and Ofgem should initiate the development of a resilience statement. This could be undertaken by joint work by the SQSS Panel and DCRP The statement would describe supply resilience expected for exceptional events outwith 'normal' standards and scope to include whole system integrity from generator to customer, taking into account the behaviour of the whole system (including customers' installations and appliances) and all risks (including those of interoperability). The specification would be informed by the development of VoLL described in Section C.2, and set out binding maximum times for restoration of aspects of normal electricity services as determined by the nature of the initiating event.	H	H
C.3-2	Ofgem should work with NGESO and the DNOs to develop a series of leading metrics for underlying system resilience	H	M
C.3-3	BEIS and Ofgem should initiate the development of the governance regime for the resilience statement, including its upkeep, incentives for compliance and enforcement	H	M
C.3-4	Following completion of actions C.3.1, C.3.2 and C.2.1 to C.2.4 the DCRP and SQSS Panels should consider if P2 and the equivalent part of SQSS should be repealed.	M	L
C.3-5	A specification for the behaviour of demand should be developed by network licensees that takes into account the impact of the statement developed in C.3.1 above on all types of demand, especially smart demand that has autonomous control capabilities.	H	H
C.3-6	Under the regime proposed by Appendices J and L of this report, the government should ensure that all appropriate appliances sold for use in GB conform to the specification in C.3.5	H	H
C.3-7	BEIS/Ofgem should review the Guaranteed Standard legislation to recognize its changed role in supporting defined resilience.	H	M
C.3-8	NGESO and DNO work on distributed black start should continue as a priority.	H	H
C.3-9	NGESO and DNOs review the overall approach to islanding, including particularly the need for anti-islanding protection, and investigate if the safety considerations and other operational requirements can be achieved by other means.	H	H
C.3-10	DNOs should modify the framework and rules to allowing, or even promote, islanding on distribution networks (including the market arrangements for settling resultant energy trades).	H	M

C.4 Capacity

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 7.

C4.1 Why do we need to change?

As explained in sections C.2 and C.3, resilience, capacity and reliability are interrelated topics; both reliability and resilience drive investment that result in overall capacity. As such general considerations of capacity are catered for by the reliability and resilience drivers. However there are a couple of areas where these considerations do not have a bearing and where it is useful to consider the approach in the interests of overall economic efficiency.

The first of these areas is network losses. Although traditional network design has relatively modest levels of losses, recent research has shown that they are a lot higher than is economic, taking into account the costs of losses compared to the cost of lower loss components. The economics are not sufficient to initiate investment solely for loss reduction, but as and when other drivers mean network components need to be extended or replaced, the marginal increase in cost from lower loss designs is more than outweighed in the savings in losses.[52] The adoption of lower loss designs will also significantly reduce future losses as system demand and utilisation increase with the decarbonisation of heating and transport.

In summary it is economically rational to extract the maximum value from the existing assets, including as explained in section C.2, using interoperability and flexibility to load up the existing assets beyond historic levels, but when the limit of flexibility is reached, replace with as high capacity assets as possible.

The second area is also driven by considerations of decarbonization. It is likely that the existing standard design of domestic service equipment might prove to be inadequate, or certainly not optimal, in some cases for the demands of both heating and transport. Again the marginal cost of increasing the capacity of the connexion between properties and the passing main is small compared to both the saving in losses and cost of future disruption if it ever needed to be upgraded. A standard design of service capacity could be used for all new build housing developments, and for necessary replacements.

C4.2 What needs to change?

Both these issues are network design issues, where the standards are under the control of the individual network companies. There are no common design standards for losses, although all the original DNOs (ie not including the independent DNOs) and the transmission companies have licence obligations in relation to losses. The Panel is aware of the steps that DNOs have already taken in this direction, but does not know if progress is sufficient or uniform.

For the capacity of final service connections the Panel believes that the DNOs should collaborate on a review of the likely issues and losses implications and develop a set of standards to be applied in typical cases.

C4.3 Implementation Proposals

The Panel notes the existing licence obligations on (the original) DNOs to maintain a losses strategy, and believes that this should be sufficient to drive the right outcomes. The Panel believes Ofgem should review its requirements in the light of the Panel's investigation in this area to ensure they are sufficiently prescriptive of outcome. Connection design to a large extent is within the scope of the Distribution Code so it would probably be appropriate for the scope of the Distribution Code standards to be reviewed in this regard.

Number	Implementation Proposals	Importance	Urgency
C.4-1	Ofgem to review the licence condition on losses strategy to ensure network companies are appropriate taking losses research into account and are delivering against it.	H	M
C.4-2	The DCRP should initiate research into the future needs of service connexion design and implement appropriate binding standards	M	M

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[52] See "Strategies for reducing losses in distribution networks," Goran Strbac, Predrag Djapic, Danny Pudjianto, Ioannis Konstantelos, Roberto Moreira, February 2018.

C.5 Voltage Limits

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 3.

C.5.1 Why do we need to change?

One of the key objectives of electricity network design is to always remain within the voltage limits laid down in the Electricity Safety, Quality and Reliability Regulations 2002 (ESQCR), and in some cases is a key driver of network reinforcement. To date most reinforcement has been driven by network thermal capacity, but in the future, as distribution networks connect the substantially bigger (than traditional domestic) demands of EVs and heat pumps, and also more generation and storage, it is commonly accepted that voltage limits will become a driver of significant network reinforcement and investment. The panel believes that with the ESQCR limits unchanged a lot of this investment will be made, but to no practical purpose.

Historically, over the first one hundred years of public electricity supply, equipment and appliances were designed to specific standard voltages, and the then available technology was relatively very intolerant of deviations from the nominal. Progressively this situation has just about reversed, with modern equipment and appliances being indifferent to the supply voltage. A very clear example of this is the power supplies for laptops etc, which work perfectly happily whether powered from 240V in the UK, from 220V in continental Europe and from 110V in the USA. The historic intolerance is reflected in UK legislation ie in the ESQCR. These effectively take the fixed 240V ±6% of the 1937 and 1988 Electricity Supply Regulations, and convert it to 230V +10%, -6%. Compliance with these limits is absolute in the sense that a momentary excursion outside the limits is not allowed for. The Regulations generally appreciate that 100% compliance at all times with their general requirements is not possible and use the specific phrase “as far as is reasonably practicable” to acknowledge this. However this phrase is specifically not used in relation to voltage limits, creating the uncertainty as to whether any momentary excursion outside of the prescribed limits (apart from during fault conditions) is legally allowable.

There are a number of benefits that will flow from removing the precise absolute voltage limits in the ESQCR[53,54,55]. It would allow network companies to design to wider tolerances and avoid reinforcement, especially reinforcement driven by very short duration conditions. This would benefit the connection and ongoing management of both demand and generation, allowing network companies to fix nominal voltages to maximise the available headroom for the predominant local use of the local network, ie reducing the lower thresholds to accommodate more demand, whilst increasing the upper threshold to accommodate more generation.

An ability to set different voltage operating ranges around the 230V nominal would allow network operators to optimise for both losses and energy efficiency. There is not a simple relationship between these phenomena and voltage. All other things being equal, historically lowering the supply voltage has both reduced final energy consumption (with no noticeable effect for customers) and also reduces LV system losses. However modern electronic devices (including lighting) confound this simple approach as the power they draw is independent of voltage: lowering the supply voltage to this sort of demand would increase LV system losses. The balance of these effects is uncertain, but removing hard voltage limits would allow more scope

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[53] ‘Engineering Technical Report 140 - Statutory Voltage Limits at customers’ terminals in the UK and options for future application of wider limits at low voltage’, July 2017.

[54] ‘LV Network Templates For A Low-Carbon Future Close Down Report’, 2013.

[55] ‘Smart Street - Project Closedown Report’, 2018.

for network operators to make the trade offs and find the optimum supply voltage on a case by case basis.

C.5.2 What needs to be changed?

Recent research and experience recognizing the high penetration of modern appliances has shown that there do not appear to be any negative effects on customers. This has been investigated in a number of research projects (see Frazer-Nash report[56] section 3.2) and is subject to further research currently by the distribution network licensees. The findings to date are that appliances, even relatively old ones[57] are not adversely affected by lower voltages than the 230V -6%, potentially even down to 200V or even lower. However there would need to be practical limits agreed to avoid situations where the majority of appliances work fine, but some start to maloperate. There is also a risk that some customers have retained extremely old appliances that will not tolerate new extremes. The risks and issues that these present will have to be addressed. We would note that replacing very old appliances with modern equipment will often bring other benefits such as energy efficiency improvements, which would rapidly outweigh the costs, and scrappage schemes could be considered to encourage this contribution to carbon reduction.

Less work appears to have been done to investigate the tolerance of modern appliances to high voltages.

Both high and low voltages do lead to overheating risks. High voltages not surprisingly can give rise to overheating on various components, but low voltages can lead to some devices, particularly motors, drawing more current or stalling – which can lead to overheating. Both these risks will need to be considered.

For larger industrial and commercial customers fed from the LV network, there is pretty much the same issue as for domestic customers, save with the complication that there is likely to be more old capital intensive equipment that could be adversely affected. However it might well be that there are more options for amelioration of the problem with such customers (such as replacing obsolete control gear or even introducing near unit ratio transformers to compensate for the voltage change). Customers fed at HV are already potentially insulated from the effects as they will have their own dedicated transformers supplying their installations (which of course they can tap to change the received voltage).

A further impact to be considered is the effect on emergency demand control used by NGESO and the DNOs where this is implemented through voltage reductions. The effectiveness of voltage reductions have reduced over the years as a means of demand control as modern electronic loads have grown. Reducing voltages on the network could also remove some of the remaining benefit from voltage reduction techniques. This would need to be evaluated.

The Panel is not advocating the complete absence of statutory references to nominal voltage and ranges, but believes this might be better expressed as a range of nominal values, and a requirement to develop a methodology for expressing ranges around these nominals. As a starting point the Panel is aware that the measurement of voltages is based on 10 minute rolling averages in BS EN 50160, and this might also be a practical basis to express what the limits should be.

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[56] FNC 62482/50117R Issue 1 “Electricity Engineering Standards Review - Technical Analysis of Topic Areas”

[57] Engineering Technical Report 140, “Statutory voltage limits at customers’ terminals in the UK and options for future application of wider voltage limits”7 July 2017, Energy Networks Association

Hence a key part of effecting change will be to collate and complete relevant industry research into the voltage tolerance and behaviour of as wide a range of equipment and appliances as possible.

In addition to any changes that may or may not be made to voltage limits the behaviour of the LV system is not well monitored historically and there are a number of initiatives that look to improve the information and data available from the LV network[58, 59]. The Panel believes these initiatives, together with any data that might become available from smart meters, will be crucial to understand the opportunities and savings from the management of network voltages.

The spread of voltage ranges might allow for further optimization between appliance standards and nominal voltages and ranges, subject to appropriate liaison between standards bodies and network companies.

The focus of this analysis has been on the LV system and its 230V +10%, -6% tolerances. However the Panel believes that the same approach should be taken with all voltage levels in the ESQCR and the prescription on absolute limits removed.

C.5.3 Implementation Proposals

The key control on voltage is the ESQCR 2002. Its limits are repeated in documents such as the Grid Code, Distribution Code etc that are either under formal change control (generally signed off by Ofgem) or are bilateral agreements. So any desirable changes can flow from a relaxation of the prescription in ESQCR 2002.

The Panel envisages that network companies would be able to use new voltage limits flexibly and roll out actual changes on demand, ie programmes driven by local need. Network companies would be able to select relevant sections of networks where the changes to limits were to be applied, and tailor the interaction with the affected customers. This implies that there would be a long period, possibly in perpetuity, where parts of the network would have slightly different nominal voltages, or voltage limits.

Number	Implementation Proposals	Importance	Urgency
C.5-1	Network companies to complete recent and current research to underpin the opportunities in cost savings from a relaxation of voltage tolerances as expressed in the current ESQCR. This analysis should also produce a probabilistic distribution of voltages (distribution in time, ie hours per year etc) based on relaxed tolerances. This analysis should be complete in a year.	H	H
C.5-2	Network companies, or others, review research into the effects of wider voltage variations on equipment and appliances, identify any gaps and initiate research to fulfil those gaps. This analysis should be complete in a couple of years.	H	M
C.5-3	BEIS consult publicly on the prospect of relaxing the ESQCR limits. The consultation would need to draw on the research from 1 and 2 above and seek data from customers and affected parties on the costs of accommodating such changes, as well as more general views on the proposals.	H	M
C.5-4	BEIS amend appropriately the ESQCR regulations.	H	M
C.5-5	Network companies to build new limits, tolerances etc into industry documents and agreements.	M	M

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[58] Western Power Distribution, Low Voltage Network Templates project.

[59] Electricity North West's (ENW) Customer Load Active System Services (CLASS) project.

C.6 Frequency

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 4.

C.6.1 Why do we need to change?

The Panel is aware of the considerable costs of frequency management in Great Britain.

The system nominal frequency is defined in the ESQCR as 50Hz with an operating tolerance of ±1%. The legal framing of this requirement does not formally allow for any excursions outside of the 1% tolerance. The European Network Codes (which are now part of UK law) do define wider operational limits than the ESQCR (ie within the range 47.0HZ to 52.0Hz) as the possible extremes to which the system might be operated in the most unusual emergency situations, and within which all generation equipment, and any other equipment providing frequency management services, must be capable of operating.

System frequency does need to be managed within fairly tight limits, the necessity for which has been recently demonstrated by the events of 9 August 2019 where the simultaneous loss of two large generating installations caused a frequency drop down to 48.8Hz and resulted in the loss of supplies to 1.1 million customers on the operation of the low frequency demand disconnection scheme.

NGESO plans to operate the system such that the frequency is normally within ±0.1Hz of nominal, ie well within the ±0.5Hz (ie 1%) ESQCR limits. To achieve this NGESO buys a range of services from industry parties, principally large generators, but also energy suppliers, aggregators and large customers. These services generally relate to having additional generation and storage capacity available to support the system automatically, reducing demand automatically, or running or avoiding running specific generation (including interconnectors) to manage both the largest single possible loss of infeed and the system inertia.

The Panel has reviewed NGESO's operation and management of system frequency, and notes that irrespective of the ESQCR requirement, maintaining a tight tolerance on system frequency is necessary for the secure operation of the system. Maintaining the system frequency costs about £275M per annum (based on 2018/19 costs published by NGESO) of which £143M was expended on keeping the rate of change of frequency (RoCoF) within its current limit of 0.125 Hz/s. The RoCoF costs in particularly are expected to more than double in the next three or four years – NGESO's estimate for 2019/20 is about £180M[60].

The Panel has also reviewed the current Accelerated Loss of Mains Change Programme (ALoMCP), which is concerned with reducing the costs of managing frequency within the 0.125Hz/s limit. This limit is determined by historical loss of mains protection settings used by distributed generation. The ALoMCP is aiming to change all these protection settings, involving approximately 50 000 distributed generation sites, to 1.0Hz/s by September 2022. When this is complete NGESO will be able to allow the system frequency to change a faster rate than 0.125Hz/s – possibly by up to 0.3Hz/s – which will largely avoid the current RoCoF costs.

C6.2 What needs to change?

The Panel has noted NGESO's recognition of the need to plan for a very low inertia future system and is supportive of this work. System inertia has been falling for many years with the retirement of traditional large synchronous fossil fuel generation. Reduction in system inertia aggravates

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[60] National Grid , 'Monthly balancing services summaries,' 2019. https://www.nationalgrideso.com/balancing-data/system-balancing-reports

the challenges of managing RoCoF, and again the ALoMCP will reduce one immediate impact of falling inertia.

The Panel has formed the view that the general management of frequency by NGESO by a variety of market mechanisms still remains appropriate and that the requirements and parameters for these mechanisms should continue to be set under industry governance rules (notwithstanding that these rules themselves might be modified as part of other work on industry and code governance). In particular inertia is just one such system service which can be subject to market arrangements. Noting other medium/long term system developments, significant research is being made into low inertia power systems internationally[61,62,63,64] and it does not seem necessary or appropriate to therefore recommend any particular standards for inertia per se. Nevertheless the Panel is concerned that the trajectory for inertia (and fault level) is inexorably downwards, and there is little understanding of the performance of very low inertia power systems. The Panel believes that research is needed in this area, potentially to inform standards for equipment and systems being purchased in the shorter term.

The Panel has noted that most demand is insensitive to variations in frequency, both the absolute value and the rate of change, so customers in general are not affected by frequency variations. This would still be true even if the current operational limits were relaxed.

The exception to this general position is some rotating machinery – particularly induction motors. In general this should not be a particular problem as motors of sufficient size for this to be a relevant issue will have protection systems that will prevent problems or damage. However this will be a key consideration of how such customers would be affected by any relaxation of the current operational limits. Engagement with large power station owners and particularly nuclear power station owners, will be key as such power stations have very large induction motors and their efficient operation under system stress could be important both to system stability/integrity and for nuclear, for the safety case.

Other generating equipment of all types is already specified to take account of frequency ranges between 47.0Hz and 52.0Hz, and the allowable rate of change, so it is not envisaged that any opportunities to relax the current operational standards would create problems.

The Panel is also concerned that the current RoCoF protection used for anti-islanding protection for distributed generation might be counterproductive when considering the rôle of, and scope for, customers during system emergencies or even to help restart the system during a black start. Whilst not directly an Engineering Standards issue the Panel believes that it is timely to encourage DNOs (particularly) and NGESO to consider the implications of intentional islands and anti-islanding protection. NGESO's Distributed ReStart project and SSEN's Resilience as a Service project are currently both investigating the engineering challenges of powering islands from distributed generation (see also section E.3).

C.6.3 Implementation Proposals

Based on the foregoing the Panel would only recommend removing the requirements for frequency in the ESQCR so that temporary excursions outside of the ±1% limits is not uncertain

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[61] 'Studying the Maximum Instantaneous Non-synchronous Generation in an Island System-Frequency Stability Challenges in Ireland," IEEE Transactions on Power Systems, 2014.

[62] 'Demand Side Contributions for System Inertia in the GB Power System', IEEE Transactions on Power Systems, 2018.

[63] 'Potential Solutions to the Challenges of Low Inertia Power Systems with a Case Study Concerning Synchronous Condensers,' International Universities Power Engineering Conference (UPEC), 2017.

[64] 'Assessment of the Role and Value of Frequency Response Support From Wind Plants', IEEE Transactions on Sustainable Energy, 2016.

as to whether this is a legal infringement or not. However the Panel believes that all the other limits on frequency as expressed in the European Network Codes and the Grid Code remain appropriate and that it also remains appropriate for them to be subject to public governance (within limits allowed by the European Network Codes) with changes signed off by Ofgem.

Number	Implementation Proposals	Importance	Urgency
C.6-1	BEIS consult publicly on the prospect of removing the ESQCR frequency limits.	M	L
C.6-2	NGESO to continue to sponsor appropriate research and development into system operation of very low inertia systems	H	H

C.7 Smart Energy System Interoperability

See also Frazer-Nash Report FNC 62482/50117R issue 1, Section 8.

C.7.1 Summary

Greater interoperability between elements of the electricity system, and especially between the traditional system and edge devices such as electric vehicles, heat pumps, smart appliances and distributed generation, would improve economic efficiency, as it would enable the system to better exploit the flexibility within customer devices and systems and so avoid investment and operational costs associated with building greater capacity for peaking generation and networks. This could also enable new mechanisms for delivering network performance, reliability, security and resilience, thus allowing these important attributes to be maintained and even enhanced as the system decarbonises. Interoperability also enables new technologies to compete with existing approaches in a fair and neutral way, opening up routes to new ways to deliver value to customers.

Well-defined interoperability standards are a key gap in the current standards landscape. Their lack is likely to be constraining the pace at which the system adopts smart, flexible services and hence realises the benefits they offer. It is also likely to be constraining development of new, innovative products and services. BEIS has already recognised this in sponsoring BSI to develop PASs on interoperability for domestic DSR. Work on interoperability standards now needs to be broadened and further developed as a matter of urgency.

We therefore recommend that:

1. An immediate priority for the standards coordination function defined in Appendix D should be to establish a task force on interoperability standards.
2. VoLL provides a core metric for managing interoperability use cases in areas such as network capacity management, fault management, etc. Use cases for exploiting VoLL should therefore be developed by the interoperability task force. This work should recognise that, from the customer perspective VoLL is rarely a single parameter – it varies with season, time of day, length of interruption, period between interruptions, etc.
3. VoLL is one parameter that helps quantify the value edge devices provide to the electricity system. There may be other parameters which are more meaningful to energy customers. The research on VoLL should also seek to identify other parameters with similar properties.

4. Standards should set clear performance, monitoring and assurance criteria for devices and associated services. This will help build confidence that portfolios of edge devices will actually deliver the required service, and so can be effectively contracted as part of the solution to fulfil a DSO's obligations. The task force should therefore ensure that such performance and assurance standards are developed as a matter of priority.
5. We note that issues of compliance and enforcement of standards applying to interoperability of products such as smart appliances and EVs are key. This is addressed in Appendix D.
6. We also note that interoperability with customer appliances can have significant implications for privacy and cyber-security. This is a key focus of the BEIS/BSI work on interoperability. Development of interoperability standards should continue to maintain this awareness of the need to adequately protect privacy and cyber-security.

C.7.2 The opportunity

The "electricity system" can no longer be separated from the large number and diverse range of smart "edge devices" that connect to it. Devices such as electric vehicles, heat pumps, smart appliances and energy storage systems are increasingly connected via data flows as well as electrical ones, opening up new affordances for system design and monitoring, and new control vectors to deal with operational issues and exceptional circumstances. Managed well, this provides significant scope to reduce costs, increase reliability and resilience, accelerate deployment of low carbon technologies, and give greater value to customers. Conversely, it exposes the system to risks such as cyber-attack and unintended consequences of correlated behaviours between equipment, if left unmanaged.

The cost saving opportunities across the whole electricity system are significant, particularly so for a net-zero economy. Recent modelling by Imperial College, summarized in section C.8, suggests that flexible operation of the majority of sources of energy, storage and demand could lead to savings of up to £8bn per annum. About half of these savings arise primarily from avoided investment in nuclear generation and system operation costs. The remainder represents savings in other conventional generation and the reduction of network reinforcement costs, as described in section C.2, associated with network planning standards.

Capturing these opportunities and avoiding the accompanying risks requires greater interoperability between the devices and the platforms which manage the electricity system and networks. Increased interoperability will enable outcomes such as:

- Mutually beneficial interaction between sources of flexibility and the system, hence enabling a whole-system approach to delivering decarbonisation, affordability and security;
- Active interaction between subsystems, allowing increased supply efficiency under normal operating conditions and increased security of supply through sharing of responsibilities and resources under contingent and extreme conditions;
- Multi-vector coordination to allow the electricity system to access flexibility and other resources provided by other energy vectors;
- Greater interaction and coordination between national, regional and local systems, enabling both greater citizen engagement in the energy system and improved resilience when the system is under stress;
- Faster response to changes in technologies, markets and customer behaviours;

- Easier access for innovators to provide new services to the energy system, with resultant benefits to energy costs, security of supply and decarbonisation;
- More finely tuned management of the relationship between the system and its customers.

Standards to support this interoperability must operate at multiple levels, eg data communication protocols, data syntax and semantics, ontologies, business processes and use cases, market structures and organisational models.

What is interoperability?

The Energy Systems Catapult defines interoperability as "the ability of a product or system to cooperate with other products or systems to share resources".[65]. They identify 19 types of interoperability between various components, subsystems and actors in the energy system, grouped into six classes – Customer, Commercial, Data, Device, Physical, and Vector. Data, Device and Physical interoperability are of most relevance to engineering standards, but standards cannot be defined without awareness of the use cases they must support so this review has considered all aspects of interoperability between products and systems within the energy system (which we have defined widely, eg to include customer products that use energy and can provide flexibility to the system).

C.7.3 Impact of change on customers

Improved interoperability enables provision of new, high value services to customers, eg for heat-as-a-service or mobility-as-a-service. It also enables edge devices to offer various types of flexibility to the system (eg to timeshift demand to periods of lower energy costs or lower energy flows across the network; to accommodate interruptions). Customers can then be rewarded for this flexibility either directly (eg through payments from flexibility markets or discounts to their bills) or indirectly (through lower overall system costs and improved reliability). Studies by organisations such as Imperial College[66], Ovo Energy [67], Wales and West Utilities[68] and University of Bath[69] have demonstrated that this could result in significant savings for customers, with savings of as much as 50% off the energy bill for flexible customers.

Interoperability standards also make it easier for customers to install and connect equipment and reduce the risk of their becoming locked into a single service provider, thus creating a more liquid market with accompanying price competition and product and service innovation. Well framed standards can also help ensure that customer's data privacy and cyber-security are adequately protected. All of these effects make it easier for customers to invest in low carbon technologies such as EVs, heat pumps, etc. Thus they help accelerate deployment of the technology necessary to achieve decarbonisation targets.

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[65] https://es.catapult.org.uk/news/an-introduction-to-interoperability-in-the-energy-sector/

[66] 'Roadmap for Flexibility Services for 2030', Report to the Committee on Climate Change, 2016. https://www.theccc.org.uk/wp-content/uploads/2017/06/Roadmap-for-flexibility-services-to-2030-Poyry-and-Imperial-College-London.pdf

[67] https://www.ovoenergy.com/binaries/content/assets/documents/pdfs/newsroom/blueprintforapostcarbonsociety-2018.pdf

[68] https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf

[69] https://www.northernpowergrid.com/asset/0/document/5414.pdf

C.7.4 Impact of change on other stakeholders

Improved interoperability gives system operators and other parties greater visibility of edge devices and their behaviour, thus enabling better system planning, design and operations. The flexibility offered by smart edge devices can enable the system to make greater use of low cost and low carbon generation and improve the utilisation of constrained network resources both during normal operations and under fault and other abnormal situations. And many of the benefits of enhanced management of VoLL to reduce costs and improve system reliability, as identified in section C.2, can only be realised via interoperability between the system and devices on customer sites.

This all offers significant potential to reduce system costs and improve reliability and resilience. Interoperability is a key enabler to the benefits of demand side flexibility, which reports such as those referenced in section C.7.3 have valued at of the order of £2-6bn pa to the UK energy system.

Interoperability standards also increase the size of the market available to equipment manufactures and reduce the cost and risk of market entry.

C.7.5 Longer term impacts

Interoperability enables data on device performance, customer behaviours and preferences, system performance as seen by the device, etc, to be captured and shared with authorised parties. This data has the potential to transform the way we think about and design system services, manage and govern the system, assure performance, deal with risk and uncertainty, etc. This data also supports innovation by product and service developers, giving them greater insight into customer and system needs and thus greater scope to develop new and well targeted products. Finally, data allows greater independent visibility and assurance of system performance, leading to greater accountability of and confidence in key stakeholders. This in turn has the potential to significantly increase citizen understanding of and engagement in questions of system design and operation. Such citizen engagement will be critical to making an effective transition to Net Zero.

Assured interoperability also reduces uncertainty and risk for the customer, giving them greater confidence to buy new products and services.

There is a risk that converging on interoperability standards too early, before the capabilities of new technologies and the scope of new markets and services is well understood, will constrain innovation. If inappropriate protocols and data standards are “locked in”, for example, it can make it difficult for more advanced services to emerge and gain a foothold in the market. This risk can be mitigated by ensuring that standards evolve rapidly enough to account for emerging technologies and requirements. That requires that adequate ongoing attention is paid to maintaining and evolving the standards and to ensuring that new entrants are enabled to participate in the standardisation process.

C.7.6 What would need to change now?

As outlined in the accompanying Frazer-Nash report[70], there is already substantial work under way, by various bodies, to address interoperability standards, and closely-related data standards. Figure C-2 illustrates the landscape of interoperability standards development we have identified during this review. This is not a complete map – many bodies other than the IEC

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[70] “Electric Vehicle Smart Charging - Standards Mapping”, doc ref FNC 62482-49996R.

(eg BSI, openADR consortium, numerous IoT[71] initiatives) are undertaking relevant standards-development efforts.

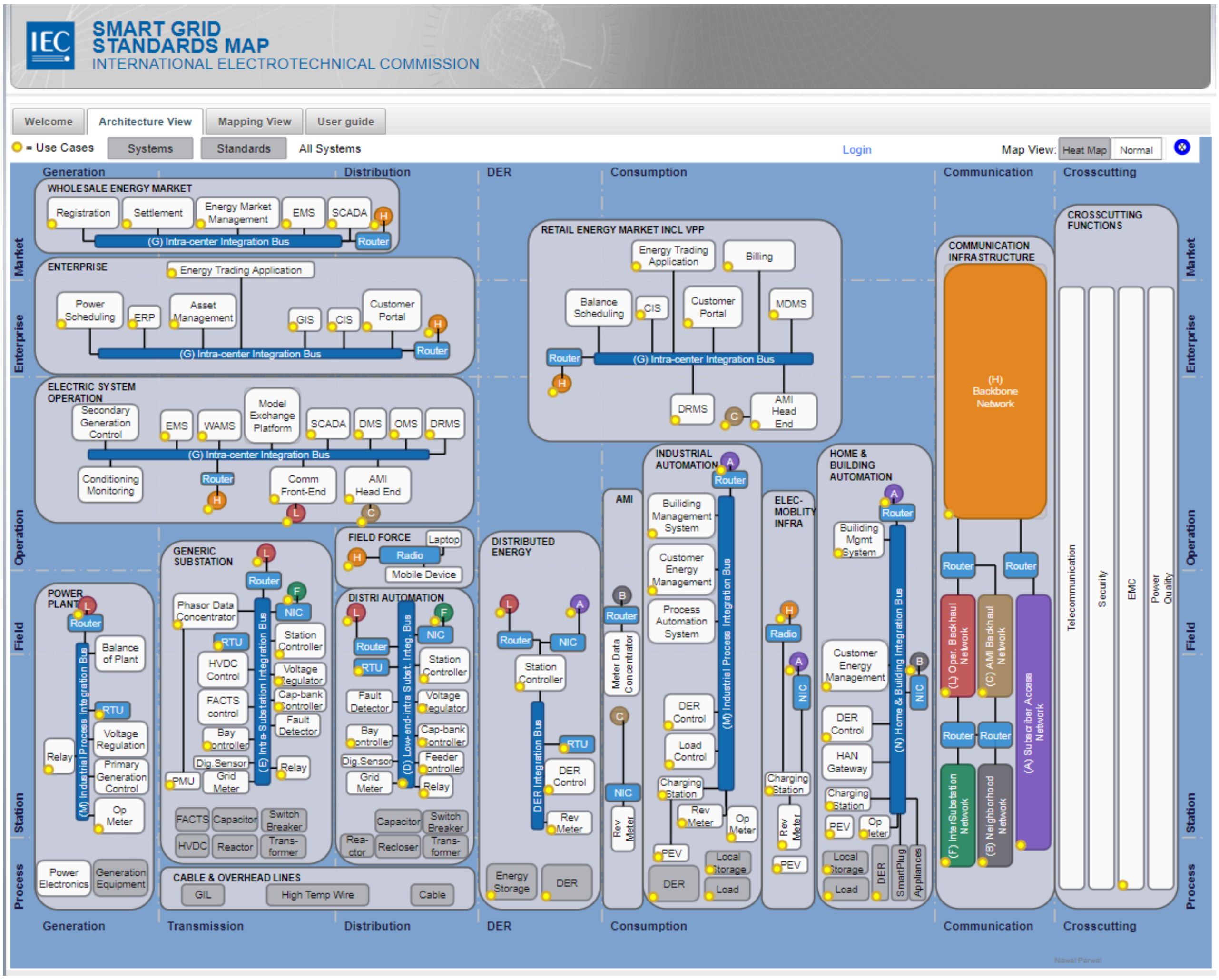

Figure C-1 IEC Map of Standards for Smart Grid Development (from http://smartgridstandardsmap.com/).

Note that although this map identifies 110 standards, this is only a subset of the standards relevant to interoperability, eg most of the EV charging standards identified in the Frazer-Nash report do not appear in it, and it shows no standards for significant load elements such as domestic heat pumps and white goods.

The Frazer-Nash report drills into one aspect of this landscape, EV charging, more deeply and identifies many standards not illustrated in Figure C-2. It also identifies that closed proprietary protocols play a significant role in many aspects of EV charging and management, highlighting the need for better development and coordination of standards in this area. We also note that EVs are an area where there has been significant effort made to develop interoperability standards – the situation for appliances such as heat pumps or white goods is even more fragmented and dependent on proprietary protocols, while cross-appliance interactions have rarely been addressed.

This is partly addressed by an initiative where BEIS has sponsored BSI to develop industry-led standards for Energy Smart Appliances in a domestic setting. This work will provide a basis for interoperability in key DSR use cases. Given its breadth of coverage, at the appliance level it

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[71] Internet of Things, the interconnection via the internet of computing devices embedded in everyday objects, enabling them to send and receive data

does not go into a high level of detail on concerns such as data syntax and semantics for specific appliance types, and it does not address cross-appliance interactions. At DSR Service Provider level, it specifies technical requirements to provide interoperability for key DSR use cases across a range of domestic appliances.

The complexity of the landscape also suggests that there is abundant scope for gaps, overlaps and inconsistencies between standards. A quick analysis of the existing standards confirms this. For example, the Frazer-Nash report identifies that *“In the case of load shifting of EV charging demand, large scale (1000s of EVs) trials in the UK and internationally suggest that interoperability is not a significant barrier to this use case. However even for this more mature service, communications protocols and applicable standards between EVSE and aggregators/eMSPs are proprietary and not often disclosed. Trial owners have encountered implementation challenges even with open standards such as OCCP and have reported issues with interoperability of different EVs, EVSE and aggregator platforms.”*

For less mature use cases, issues such lack of standards, prevalence of proprietary protocols, and inconsistencies between standards are even more likely. And cross-appliance use cases (eg on the interaction between EV charging and home heating) sit outside much standards development activity. The boxes below give some further examples of the types of issue we have come across in this review. The Frazer-Nash report gives additional examples of innovation projects and use cases related to interoperability and data.

Likewise, there is significant overlap between communications and data standards in the “IoT world” (applying mostly to devices which use electricity in order to achieve their primary purpose, eg smart appliances, heat pumps, EVs) and the “IEC68150 world” (applying mostly to devices whose primary purpose is to enable delivery of electricity). This overlap is likely to prove problematic for DSO platforms and suchlike, which must integrate services across the two classes of device.

Although there is much work on interoperability going on in each of these “worlds”, there is much less work being done to maintain alignment between them. There is therefore a significant risk that these two major areas of interoperability development, for smart devices and smart grids respectively, will not integrate cleanly, especially as they are extended to an ever-wider range of devices, solutions and systems. This would both make it difficult to coordinate and share data across the wider system, increase the likelihood of unintended interactions between subsystems, and increase the potential attack surface for cyber-attack and similar threats.

Finally, the sheer complexity of the landscape is problematic for system and network operators, innovators and companies that are developing new equipment, services and business models. There is significant risk that they will overlook or bypass key standards. This also creates difficulties for assuring compliance – in the absence of a clear landscape of relevant standards, it is hard to know what standards equipment must be compliant with or how that compliance is to be tested and monitored.

This complexity also makes it difficult for service providers and equipment manufacturers to understand the underlying system. Without such understanding, they cannot develop innovative products that afford new and disruptive capabilities to system and network operators for system monitoring and control. A key role for standards could be to support a better dialogue about service design between these two “worlds”.

Examples of Interoperability Use Cases and Issues

Black Start: Following a major system outage, it is likely that many EV batteries will be depleted and temperatures in electrically heated homes will be low. Thus when the power comes back on, there is a risk that a large number of devices will seek to power up at the same time, destabilising the black start. It is also likely that IoT communications infrastructure to these devices will be disrupted by the power outage, so external control of the devices will be limited. It is not clear that current device standards address such issues, eg by defining backoff protocols for such equipment to follow when powering up. Such issues could become a threat to system stability as electrification of heat and transport leads to growing volumes of such devices on the system.

Active Connection Management: It is possible to envisage that a Mobility-as-a-Service provider (eg linked to the lease plan for a private EV) will manage EV charging by using “spare” capacity on a customer’s network connection, eg by measuring the load on the connection and constraining charging to only use available capacity up to an agreed limit. At the same time, a separate Heat-as-a-Service provider managing the heat pump in the home might have an agreement to reduce load at peak times, in response to a signal from the DSO. If the DSO signals for the heat pump load to be reduced, then EV charging would then ramp up to use the capacity which has been “freed up”, countering the DSO’s need to reduce load on the network. Current standards do not fully address such interactions between different equipment and service providers in the home.

Reserve management: A DSO that has contracted with owners of smart devices (EVs, wet appliances, heat pumps, etc) to provide flexibility services to help manage network performance and fault conditions is likely to need to be able to forecast the profile of energy reserves and power capacity available to it over the next few hours. However, each device class may report its capacity in different ways, and some may not be able to report key parameters (eg EV chargepoints do not necessarily know the state of charge of the EV’s battery). Current standards do not appear to address such use cases.

Chickens and Eggs: One way to create greater flexibility in managing domestic connections would be through the concept of “core access”, ie that a customer has firm rights to a connection of a defined capacity, then interruptible access to further capacity above that limit as network conditions allow. Implementing such a concept requires development of standards for monitoring and enforcement of access limits, reporting, etc. It also has significant implications for standards on network capacity planning and design. Standards development (and data capture to support their assurance) is expensive, so such standards are unlikely to be developed unless there is some confidence that the concept will be implemented. Yet lack of standards prevents development of the concept and associated charging models, etc. Similar dilemmas apply to a wide range of models that might be of significant benefit to future networks. Ultimately, someone must break the impasse. From the principle that (lack of) engineering standards should not constrain the development of otherwise attractive regulatory, management and market models, it follows that standards developers must be prepared to develop such standards, at least in outline form, to help inform the wider debate.

Negotiating Power Quality: Interoperability between the electricity system and an appliance or service may require more than agreeing a number of kW for a specific time. Electrical loads are not created equal: some may provide benefits and/or challenges beyond simple kW. Switch mode power supplies such as found in many forms of domestic equipment (TVs, laptop chargers, phone chargers, entertainment devices) often have a significant capacitive front end which may change the system’s reactive power position. Pumps (such as those found in white goods and heat pumps) are more inductive and skew reactive power in the opposite direction. Switching them on or off in sufficient numbers may therefore affect the overall reactive power position on the system. This may lead to need for interventions elsewhere, with associated costs, or it may compensate for issues elsewhere, with associated benefits. As smart devices are deployed at scale, such issues will need to be made more visible and actively managed.

Coordination between competing schemes: For example, consider the combination of large numbers of smart appliances, Battery EVs providing V2G services and grid connected battery storage solutions. If each of those technologies is providing the same flexibility service (eg frequency response) to the electricity system, then there needs to be some level of co-ordination between them to ensure that they don’t all respond simultaneously to an observed condition or parameter. If all 3 technologies monitor the frequency of the electricity supply and switch at a certain threshold, we must ensure that they don’t all switch at the same time and cause large swings from over to under supply or vice-versa, leading to extreme system oscillations.

Cross-vector coordination: For example, the expectation that hydrogen may be produced using surplus electricity generated from low-carbon sources (normally assumed to be wind) requires that sufficient capacity is installed and available and that the systems are interoperable to communicate when there is surplus capacity, etc.

Coordination with adjacent systems: For example, public EV charging infrastructure is often reliant on availability of parking spaces for the cars while they charge. This may require coordination between electricity systems and parking systems to ensure capacity is available in both systems at a given location at the same time.

Locational services: Some issues can only be solved by appropriate action in a specific location, eg to resolve a network constraint or to address a localised air quality issue. (And note that both of these examples may require locational information beyond simple map coordinates. The former requires understanding of network topology, and the latter may be influenced by factors such as weather and wind conditions.)

Smart home: Customers will expect that smart appliances purchased for use in a home have compatible syntactic and semantic interoperability with other equipment in the home, not just with the electricity system. Thus, for example, control signals sent by the electricity system may need to be coordinated with those from home security systems, care management systems, etc.

C.7.7 Implementation Proposals

Well-defined interoperability standards are a key gap in the current standards landscape. Their lack is likely to be constraining the pace at which the system adopts smart, flexible services and hence realises the benefits they offer. It is also likely to be constraining development of new, innovative products and services. BEIS has already recognised this in sponsoring BSI to develop PASs on interoperability for domestic DSR. Work on interoperability standards now needs to be broadened and further developed as a matter of urgency. We therefore recommend that:

1. An immediate priority for the standards coordination function defined in Appendix D should be to establish a task force on interoperability standards. This task force should bring together expertise in areas including the electricity system (ESO, DSO, networks, wholesale markets, settlements, etc), devices (EVs, heating, wet appliances, energy storage, etc), smart systems, cyber-security and standards development, with the remit to:
    - Define a schema to classify different types of interoperability for electrical systems
    - Map the current landscape of interoperability standards more fully (building from the initial study done as part of the BSI PAS development)
    - Developed a rationalised view of this landscape to inform standards applying in UK
    - Develop a consistent approach for defining and categorising system needs and service options, and the necessary information, communication and security required under different system operating conditions (normal and abnormal)
    - Identify key gaps, overlaps and inconsistencies in current standards, testing and certification regimes, roadmaps of standards development bodies, catalogues of system requirements and use cases, etc, and hence establish mechanisms to deal with them
    - Define the mechanisms for ongoing governance (including testing, certification, regulation), evolution and coordination of interoperability standards, including engagement with international standards development (noting that many device manufacturers address global markets, so the UK cannot divorce itself from international standards)
    - Establish the remit of an Observatory function to monitor ongoing developments in interoperability

Given the urgency of this task, if there is any delay in setting up the standards coordination function, then this task force should be established independently, and brought into the function's remit when it is ready. The task force should be adequately resourced to devote serious attention to this critical activity.

This task force should prioritise the alignment of interoperability development between smart grids and smart energy devices, to ensure greater convergence of the two over time. The challenges are two-fold. On the one hand, smart grids have a range of complicated needs over multiple domains and timescales; these need to be translated into a set of relatively simple device requirements that can drive development of new, innovative solutions at reasonable cost. On the other hand, smart devices come in a range of sizes, forms and capabilities; these need to be translated into a collective set of availability, capability, reliability, cost, etc, to the electricity system, allowing it to coordinate their activity in order to optimise performance, efficiency and stability of the overall system. Greater alignment between these two perspectives will enable mutual understanding and benefits, avoid the legacy system dictating low carbon development, and smart energy devices undermining key systemic attributes.

2. Interoperability standards link closely to work such as that on VoLL, recommended in sections C.2 and C.3 of this report – VoLL effectively provides the core metric for managing interoperability use cases in areas such as network capacity management, fault management, etc. Use cases for exploiting VoLL should therefore be developed by the interoperability task force in conjunction with the work on VoLL. This work should recognise that, from the customer perspective VoLL is rarely a single parameter – it varies with season, time of day, length of interruption, period between interruptions, etc. Gaining a fuller understanding of the dynamic nature of VoLL and how it could be used to influence adaptive performance of the system in order to optimise outcomes for all parties should be a focus for this work.

3. VoLL is one parameter that helps quantify and manage the value edge devices provide in interacting with / providing services to the electricity system. There may be other parameters which capture aspects of the value, and/or which are more meaningful to energy customers. The research on VoLL and associated interoperability use cases should also seek to elucidate and define other key parameters with similar properties.

4. Engineers in organisations that are accountable for achieving high levels of security of supply and suchlike will naturally prefer to trust the equipment they own and operate, rather than that owned and managed by customers. So edge devices have an inherently higher hurdle to get over than traditional network equipment. Standards can help reduce this hurdle by setting clear performance, monitoring and assurance criteria for the devices and associated services. This will help build confidence that portfolios of edge devices will actually deliver the required service, and so can be effectively contracted as part of the solution to fulfil a DSO's obligations. The task force should therefore ensure that such performance and assurance standards are developed as a matter of priority. These standards should be developed at both device (deterministic) and portfolio (stochastic) level. Enabling the system to make full use of the flexibility within edge devices in this way will be critical to achieving the benefits outlined in section C.7.3.

5. We note that issues of compliance and enforcement of standards applying to interoperability of products such as smart appliances and EVs are key. This is addressed in Appendix D.

6. We also note that interoperability with customer appliances can have significant implications for privacy. This is a key focus of the BEIS sponsored BSI work on

interoperability and has also been addressed by the Energy Data Task Force / Managing Energy Data programme, so appears to be adequately covered by these initiatives. Development of interoperability standards should continue to maintain this awareness of the need to adequately protect privacy.

C.8 Whole System Benefits of Flexibility

This section explores further the role and value of flexibility technologies and systems in facilitating whole system cost effective transition to low carbon energy future

In an assessment of the benefits of flexibility (eg demand side response (DSR) and energy storage) in the whole GB electricity system, it has been demonstrated *that flexibility solutions could deliver cost savings of £8bn per year*, while meeting the carbon intensity target of 50g CO2/kWh, as shown Figure C-3 (the operation of DSR and the location of new energy storage were optimised to maximise system benefits)[72].

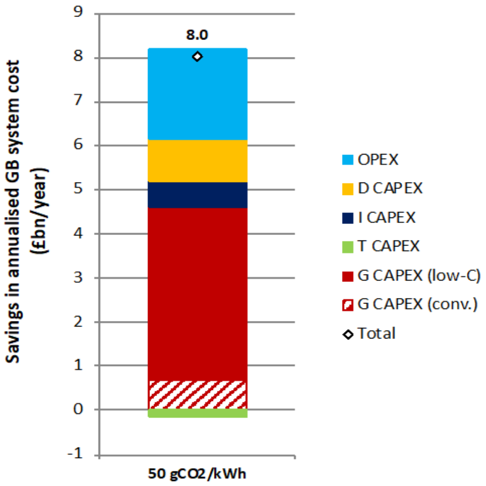

Figure C-2 System cost savings enabled by provision of decentralised flexibility

As presented, the key components of the savings delivered by decentralised flexibility resources include lower operating cost (OPEX), reduction in network reinforcements in Distribution networks (D CAPEX), Interconnection (I CAPEX) and minor increase in Transmission network (T CAPEX), reduced investment in conventional generation capacity (G CAPEX conv.) and reduced investment in low-carbon generation assets (G CAPEX, low-C), which is the most dominant benefit of end-use flexibility due to high cost of firm low-carbon generation technologies, ie carbon capture and storage (CCS) and nuclear. It is important to stress that *in contrast to updated network design standards and capacity market that recognise the contribution of flexibility technologies, there is no mechanism / standard that would reward flexibility technologies and systems for reducing the cost of decarbonisation in the overall delivery chain.*

Different levels of flexibility would affect significantly the cost-optimal low-carbon generation mix as presented in Figure C-4. Note that in the low flexibility scenario, the emission target of 50

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[72] Imperial College London and NERA Economic Consulting, "Value of flexibility in a decarbonised grid and system externalities of low-carbon generation technologies", report for the CCC, 2015. https://www.theccc.org.uk/publication/value-of-flexibility-in-a-decarbonised-grid-and-system-externalities-of-low-carbon-generation-technologies/

g/kWh is achieved by a significant capacity of firm low carbon generation (nuclear and CCS). Wind and PV generation is not selected as a part of the optimal generation portfolio, suggesting that despite having much lower levelized costs their whole-system cost are comparatively higher than that of nuclear. In the other extreme case, where a high level of flexibility is available , we observe a massive shift in the generation mix towards renewable technologies, with more than 95 GW of wind and PV capacity, reflecting the reduced system integration cost of renewable energy technologies enabled by enhanced flexibility. The analysis carried out clearly demonstrated that increasing system flexibility could significantly reduce system integration costs of renewable energy technologies.

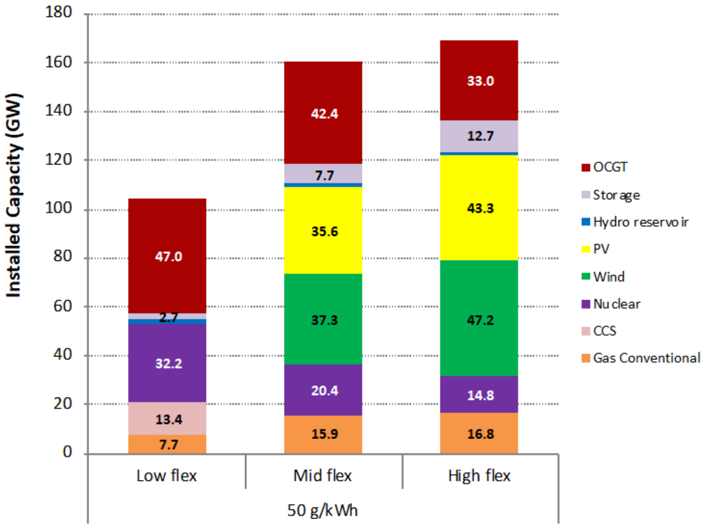

Figure C-3 Impact of system flexibility on optimal low carbon generation mix

In this context, the development of efficient mechanisms that would appropriately reward flexibility technologies and systems will be critically important for facilitating the cost-effective decarbonisation of the GB electricity system. However, there is currently no established mechanism / standard that would enable the overall comparison of different low-carbon generation technologies, including the flexibility technologies/systems, on a level playing field. It is hence critically important to align the future engineering standards and market design with low carbon agenda.

Core Supporting Appendix D: Detail and Implementation Proposals for recommendations to support net zero greenhouse gas commitments

D.1 Summary

The GB electricity system is in the midst of a significant transformation. Driven by the **imperative to decarbonise**, customer expectations of **greater personalisation of service without reducing reliability**, and the affordances created by **digitalisation**, it is making far greater use of smart, decentralised assets. Using these assets intelligently creates new opportunities to optimise utilisation of networks and generation and so **reduce costs** while maintaining reliability, and to develop **new products and services** targeted more directly at the needs of individual customers. Clarifying how their assets can interact with the system and the service levels they will receive from it will also **reduce customers' non-energy costs and risks**, for example where they under- or over-design their own backup power infrastructure due to lack of clarity on system service levels.

Standards framed for a centralised system with very little intelligence or capability at the edge, where real-time data is sparse, and where capabilities for dynamic, adaptive control are limited need to be extended to support this transformation. Done wisely, this also creates an opportunity to **simplify the complex web of standards** and associated regulatory instruments that has arisen over the last four decades, and to build an **agile process for developing and maintaining future standards**. Such a future-fit standards framework would **reduce the cost and risk of transforming the electricity system**. It would also make it easier to give **clear service guarantees to end users of the system**, and for innovators to develop **new technologies, services and business models.**

The panel therefore recommends that the GB Electricity System:

1. **Develop a tiered perspective on standards, with a focus on what the system delivers to its customers.** Standards should be divided into customer service levels (setting clear expectations for what the electricity system delivers to its customers), system planning and design (defining how the system delivers those service levels) and products (specifying how equipment operates to achieve the designed performance). **Existing standards should be mapped onto this perspective and refactored** to align more closely to it over time, and all new standards should be framed to focus on a single tier. Codes and regulation should focus on the customer service tier, defining what the system must deliver and leaving the details of implementation to underlying engineering standards.

Refactoring and Agility

Refactoring is a key element of agile software development. A type of kaizen[73], it essentially promotes the philosophy that every time you touch a piece of code, you make

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[73] Japanese term meaning "Continuous Improvement", a business philosophy widely used both in and outside Japan that sees improvement in productivity and performance as a continuous, gradual and methodical process, involving all employees, and thus making their work more fulfilling.

it a little better, eg by eliminating duplication within the code or improving its readability. This reduces the likelihood of bugs and the cost of future change. Applied to standards, refactoring would mean actively seeking to remove overlaps, deprecate redundant standards, improve readability, restructure to align to the tiered framework, etc, as we update the suite of standards.

2. **Develop a clear, overarching set of customer service levels.** The top tier of the standards framework should be driven by a clear statement of what service levels the electricity system will deliver to its customers. This should be written in terms understandable by the customer or their agents, and should have scope to deliver different levels of service to different customer segments where that is appropriate. It should also set out what the system expects in return from the customer and their equipment in order to deliver these service levels, eg in terms of how equipment must connect to and interoperate with the system.

3. **Designate a party responsible for standards coordination.** This party would ideally be an extension of an existing body. It would maintain an overview of standards and coordinate their development, within GB and across relevant international standards bodies. Within the remit of this party, establish two task forces to address standards for smart grid interoperability and software-intensive equipment, to ensure the standards we need for the 2030's and beyond are in place for the generations of equipment that will be deployed in the mid- to late-2020's. This party would also be tasked to reach out internationally to take in best practice, eg by setting up an authoritative third-party observatory.

4. **Designate a forward-looking, agile owner for the service level tier of standards, accountable to BEIS or Ofgem.** Clearer ownership and governance would enable rapid evolution and adoption of standards as new technologies and business models emerge. This should be driven from the customer's perspective, by a party responsible for overall integrity and agility of the framework of standards. System design and planning and product tiers of standards should remain under industry governance but with well-defined, public compliance regimes.

5. **Manage data as a key component of the system, as important as physical assets.** Building from the work done by the Energy Data Task Force, we recommend that all new and updated standards, and their accompanying governance, address:

   a. **Data to measure performance and compliance.** New and updated standards should define what data should be collected to demonstrate performance against the standard. This data would also support **evidence-based evolution of standards.**

   b. **Presumption of data capture.** Create a presumption that new and updated equipment will capture and publish real-time data on system performance unless there is a clear reason not to do so. This reverses the (often implicit) assumption that we only capture data when there is a clear case to do so, and recognises the high optionality value of data.

   c. **Data-driven innovation.** Create a presumption that new products and services can be trialled at small scale and contained risk with minimal need for permission and derogation, provided only that these trials capture and openly publish sufficient data for independent bodies to analyse their impacts.

Supporting Agility through Data-driven Innovation

It is important that trials of new products and services do not adversely affect customers, either in the level of service they receive or in the charges they must pay. This is typically managed through upfront trial design, with carefully considered derogations to existing standards and regulations where necessary. However, this can be a substantial barrier to innovation – obtaining derogations can be complex, time-consuming and entail significant expense.

This route will remain appropriate for many innovations. However, many could be also trialled at small scale with acceptable risk levels provided that they were suitably open to public scrutiny. For example, DNOs could trial new network charging models with limited groups of customers. This would extend willingness-to-pay information obtained from current customer engagement techniques (eg surveys and focus groups) to provide evidence on actual customer uptake, data and system requirements, etc, and could be done at very low risk to the customer. Obtaining derogations creates significant friction to conducting simple real-world trials such as this.

This could allow the system to actively explore a large number of ideas that are currently dropped before they can be tested properly. It still requires suitable trial design to manage risks and ensure that customers are not damaged, but then places the emphasis on using open data capture and analysis rather than upfront paperwork to protect and demonstrate benefit to the customer. Such an approach would also have significant symbolic value, signalling a shift from complex, paperwork heavy regulation to one which allows small trials to be established and data captured from them rapidly – an approach that is core to agility in other sectors. We understand that Finland currently uses this approach, requiring minimum permission and regulation for small trials particularly if they stem from local people. This echoes our expectation of how customers might engage with a future smart, flexible energy system as active participants rather than passive recipients.

6. **Address standards for network operation as well as design.** Current standards were developed when networks were largely build-and-forget, and so rightly focused on upfront design. Smart, flexible systems entail much more active operations, and so standards should be extended to cover operational concerns as well as design.
7. **Undertake research to support future standards development.** The observatory identified in recommendation (3) above should initiate and monitor research in key areas.

Table D-2 (page 95) outlines a possible roadmap illustrating the role of standards to support the electricity system’s transition to net-zero. We are currently in the early stages of a transition that will have major impacts on the way we build and operate the electricity system over the course of the 2020’s and 2030’s if we are to achieve net-zero by 2050. By addressing the above recommendations, we will make this transition much easier by building a framework and governance model that allows more agile development and evolution of engineering standards, and hence of the system they support.

D.2 Why do we need to change?

The GB electricity system has been remarkably successful over the last 40 years. It delivers very high, and constantly improving, levels of reliability and safety in a very cost-effective way. This has been done through rigorous attention to and constant refinement of engineering standards. This is a legacy of which we can be proud, and which we do not want to jeopardise.

Society is now setting new challenges for this system. The imperative to decarbonise requires new technologies to be deployed in a much more decentralised manner, with accompanying shifts to patterns of energy flow, data and control flow, ownership, etc. At the same time, customer and citizen attitudes have shifted dramatically, expecting much more engagement from service providers and greater customisation or even personalisation of the services they deliver. Rapid advance of digital technologies has made these shifts possible. To meet these new challenges, the electricity system cannot rely solely on the constant, steady refinement which has served it so well to meet historical challenges; it must undertake transformative change.

In times of rapid change, standards represent "islands of stability”, fixed points defining the framework within which new solutions can emerge. As such, they are a key support for innovation. As solutions prove themselves, they in turn become fixed in standards that record and disseminate “good practice”. Ongoing refinement of this practice is then captured into updates to the standards and development of adjacent standards. Over time, however, this can result in a complex network of standards that become locked in, inhibiting further change. Standards then support incremental improvement well, but become barriers to transformative change.

How are current standards inhibiting change?

Over the course of this review, the Panel has observed that the standards underpinning the GB electricity system have evolved over the last four decades to form a complex, interconnected web that is tightly coupled to the associated codes and related regulatory instruments. This complexity forms a significant barrier to change.

For example, changes to a single engineering parameter such as voltage (see Appendix C.5 of this report) may require changes to multiple standards, codes, etc. Addressing systemic concerns such as reliability or resilience (in Appendices C.2 and C.3) may require changes to an even larger number of standards. As well as increasing the time and cost associated with any change, this significantly adds to the risk that change will create inconsistencies within the standards set, eg because changes across standards are not synchronised or because it would be easy to overlook relevant standards. Such an inconsistency, in defining the system frequency range under which connected equipment must operate, may have been one cause (amongst several) of the significant disruption to the rail network experienced during the system event on 9 August 2019.

As outlined in Appendix E.3, the Panel chose to focus on a small set of “hot spots” (eg voltage, frequency, reliability) due to the limited time and resources available to us. In each case, we observed similar complexity in the web of relevant standards. We have no reason to believe that we would not have found similar complexity in all the areas we chose not to examine in detail. This problem of complexity appears to be endemic to the current system of standards, and is now being exacerbated because the standards are the creation of a centralised system model which is now shifting towards a decentralised system of systems.

This complexity creates a number of other barriers to change, for example:

- **There is no single, clear definition of the service levels a customer should experience.** This makes it difficult for customers to assess the impact of change on their systems and operations, creating a significant barrier to their acceptance and management of change.
- **Ownership of the suite of standards (as opposed to any individual standard) is unclear**. Thus it is not clear who should assess and manage the broader impact of

changes to any individual standard, deal with unintended consequences of such changes, maintain the overall clarity of the standards set, etc. This all inhibits people's willingness to make significant changes to standards even as new technologies and customer needs emerge

- **There are key gaps in the set of standards.** New technologies have emerged to create significant opportunities and requirements in areas such as data and interoperability. However, the suite of standards has not been able to move at the same pace.

- **Standards are subject to significant variations in interpretation.** For example, we have been given widely varying interpretations of what the P2 standard for network design does or does not allow when designing networks to accommodate growing volumes of smart, flexible equipment. The way network engineers interpret the standard often appears to be quite different to what the standard would actually seem to allow. This creates a significant barrier to change – entrepreneurs and innovators put forward ideas, but then are blocked by network engineers' interpretation of what the standard (or "standard solutions" based on it) will allow. This then leaves them uncertain as to just whether or how they can progress with their ideas.

The earlier sections of this report give several examples of the types of change that are inhibited by such barriers – deployment of solar PV at the edge of the network is inhibited by voltage standards designed for a centralised system; accessing the capabilities of smart appliances to provide flexibility to the system is inhibited by lack of clarity of interoperability standards and lack of their support for key use case; unclear standards for reliability and resilience lead to customers under or over designing their own backup power infrastructure.

Beyond this, the **major impact is in what people don't do**. We have spoken to innovators who have not taken ideas forward because the complexity of standards and associated instruments makes it difficult for them to identify which standards apply, how those standards influence their solution, who they should engage with, etc. And it is likely that the time, cost and risk associated with changing standards is inhibiting many ideas from coming forwards. Thus ideas that might lead to solutions that would improve the system or create new products and services of great value to specific customer groups are being lost before they even get into early stage trials simply because it is too complex or too risky for innovators to engage with standards which were framed for a very different set of circumstances. As a very specific example, much innovation in algorithms and AI is stymied by lack of data on which to develop and train them, a situation reinforced by lack of standards on data capture and publication.

This is where the electricity system is right now. A complex web of standards (and associated codes, licences, incentives, etc) embeds traditional practice and supports incremental refinement to it. This has proven to be highly effective for dealing with the challenges for which that practice was framed. But the sector is now facing new challenges, new technologies and new business models, and so needs new practices. These are emerging, but they remain to be proven at scale before they can be disseminated in operating procedures and embedded in new standards. The existing web of standards risks inhibiting this process, unless its application and evolution is managed carefully.

Note that there is always a risk involved in changing something that works well, as the current electricity system clearly does. Change may create a (temporary) decline in performance, eg as new technologies prove themselves and people learn how best to deploy and operate them. We need to manage this transition well in order to attain the higher performance ultimately promised by these technologies. For example, contingencies may need to be put in place during the transition, and incentives may need to be adapted to account for temporary declines in performance or increases in costs.

D.3 Principles for Future-Focused Engineering Standards

We have defined the following principles to support this process of defining and evolving new engineering standards in a time of rapid change. These principles help define what an ideal set of standards might look like:

1. **User-centred.** Standards set out a clear description of the "contract" between the electricity system and its users. They define what users can expect from the system, and what they are responsible for, in language they can understand. This then drives design and operation of the system, performance of equipment, etc. Standards also ensure that the system provides users with the data and information they need to understand the system, monitor its performance, and interact with it to achieve their goals. Standards enable people to take control where they are willing and able to do so.

   Such standards are also cognizant of the fact that not all users are the same, and that they use the system for a diverse range of purposes. Thus standards allow the services provided by the system to be tailored to the needs of different classes of user and different types of usage. They also recognise that user value may be driven by more than considerations of lowest cost, and so allow alternative value points to be defined and delivered in the way the user wants.

2. **Clear separation of concerns.** Standards separate the what (eg what performance users can expect from the system) from the how (eg how that performance is delivered). Likewise, they separate that which is mandatory from guidance and recommendations; and they separate decisions driven by engineering factors from those which are driven by societal choice (through legislation, licences, markets, etc). Such separation of concerns enables better overall decision making, better system design, and greater resilience of the design to evolutionary change.

3. **Data-driven.** Standards recognise that data is a fundamental component of the future system, every bit as important as physical assets. Good data enables improved design and operation of the system. It enables users to adjust their interactions with the system so as to optimise the value they obtain from it. And it enables us to openly and transparently measure the performance of the system, its components, and the bodies responsible for managing it. Standards therefore support the transition to a system where data is pervasive and data-driven system planning, design and operations is the norm. Finally, standards themselves are data-driven – we use data to assure compliance with the standards, and to support evidence-driven evolution of the standards.

4. **Generative.** Engineering standards enable us to generate options for society, maximising the choices available to it. For example, standards (or lack thereof) should not unnecessarily constrain market and regulatory models. Instead, they set out the boundaries of what is feasible and enable technical, economic and other trade-offs to be identified and understood. We expect that many developments in smart, flexible energy systems will be driven by technology and markets so standards will emerge from technology and commercial development. These standards should be framed so that

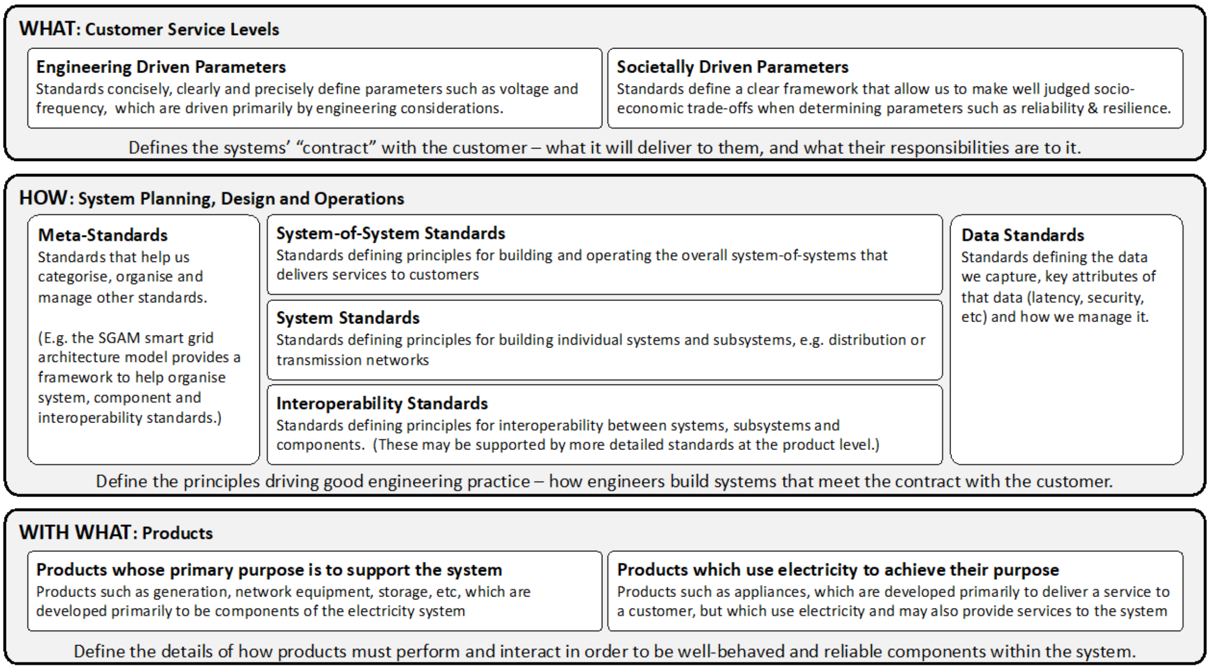
markets and regulation can be structured to exploit them in the way most acceptable to society.

5. **Iterative and feedback-driven.** Standards evolve rapidly to accommodate changes to technology, user needs and societal expectations. In particular, we use access to data to drive tight feedback loops so as to learn from experience and constantly evolve and adapt these standards. We also recognise that governance structures, system designs, operating models, etc, may need to be equally agile to accommodate this evolution: standards support them to do this. And we note that the rate of iteration may vary between different system components with, for example, long-lived hardware solutions changing much more slowly than solutions which are embedded in software. We expect digitalisation will drive an open system that allows capabilities embedded in software to be updated more frequently, so requiring much faster evolution of the overall suite of standards over time.

6. **Actively managed.** It follows from the above that standards must be actively managed. Thus we must build and resource the structures necessary to manage standards and their evolution and dissemination. These structures will also act to keep them aligned to developments across the sector, in the UK and internationally. Where appropriate, this will include using experience in the UK to inform international standards development, ensuring both that international equipment is suitable for the UK and that international markets are open to UK companies.

D.4 An Organising Framework for Future Standards

A complex web of standards (and associated legislation, licences, codes and incentives) informs planning, design and operation of the electricity system. As noted above, this web has enabled the system to achieve very high performance, but its complexity now risks inhibiting emergence of new technologies, approaches and business models. We have begun to recognise three “tiers” of standards within this web, as outlined in Figure D-1 below:



WHAT: Customer Service Levels

Engineering Driven Parameters
Standards concisely, clearly and precisely define parameters such as voltage and frequency, which are driven primarily by engineering considerations.

Societally Driven Parameters
Standards define a clear framework that allow us to make well judged socio-economic trade-offs when determining parameters such as reliability & resilience.

Defines the systems’ “contract” with the customer – what it will deliver to them, and what their responsibilities are to it.

HOW: System Planning, Design and Operations

Meta-Standards
Standards that help us categorise, organise and manage other standards.

(E.g. the SGAM smart grid architecture model provides a framework to help organise system, component and interoperability standards.)

System-of-System Standards
Standards defining principles for building and operating the overall system-of-systems that delivers services to customers

System Standards
Standards defining principles for building individual systems and subsystems, e.g. distribution or transmission networks

Interoperability Standards
Standards defining principles for interoperability between systems, subsystems and components. (These may be supported by more detailed standards at the product level.)

Data Standards
Standards defining the data we capture, key attributes of that data (latency, security, etc) and how we manage it.

Define the principles driving good engineering practice – how engineers build systems that meet the contract with the customer.

WITH WHAT: Products

Products whose primary purpose is to support the system
Products such as generation, network equipment, storage, etc, which are developed primarily to be components of the electricity system

Products which use electricity to achieve their purpose
Products such as appliances, which are developed primarily to deliver a service to a customer, but which use electricity and may also provide services to the system

Define the details of how products must perform and interact in order to be well-behaved and reliable components within the system.

Figure D-4 An organising framework for engineering standards

Figure D-1 shows that existing standards focus on System and Product standards. This leaves gaps around Customer Service Levels, Interoperability, Data, and System of Systems and may mean that existing standards are unnecessarily complex.

1. **Customer Service Levels.** These define the performance a customer (or the equipment they own) can expect from the system, and the responsibilities they have towards the system. They need to be couched in terms that are **meaningful to the customer** and their agents, rather than to energy system engineers. They also need to be **concise, clear and precise** so that customers can gain a clear understanding of the "contract" between themselves and the electricity system, and so that clear lines of accountability can be drawn. This clarity will also enable well defined incentives to be developed against achievement of the service levels.

   Many aspects of these service levels will be defined by societal choices rather than engineering ones, eg in making economic and other trade-offs on questions of resilience and security of supply. The role of engineering standards here is to define how such attributes can be specified and the feasible bounds within which they can be achieved. This then creates a **clear framework for societal decision making**. Some of these standards, however, will be determined largely by engineering choices, eg in specifying the frequency and voltage levels the system operates at. In this case, standards will also define the **acceptable range for these engineering parameters**. There should be a clear separation of these two different types of standard within this layer.

   This layer is currently poorly developed and communicated, and spread across multiple individual standards and associated elements (licences, etc). We recommend that it be refactored into a single, cohesive set of standards, that can then be enacted by appropriate regulation and incentives. (This will almost certainly entail adjustments to existing codes and incentives. We therefore recommend that this refactoring be done in conjunction with the changes being made under the Codes Review and other changes to governance arrangements across the electricity system.)

   In undertaking this refactoring, it is worth noting that:

   - Current standards for many of these parameters were set a long time ago, so are not necessarily reflective of current technologies, demand patterns, societal expectations, etc. As this tier is refactored, a prioritised programme of work to review and revise these standards should be established. The "hotspot" recommendations above, for factors such as voltage and frequency, represent initial steps on this journey.

   - It is likely that **different service levels for different classes of user or different types of usage** can be defined for some parameters. For example, medical equipment and EV chargepoints have very different service availability requirements. Growth of digital technologies is making it increasingly feasible and advantageous for the system to recognise such differences. This also aligns to the wider trend towards greater customisation and personalisation of the services delivered to (and expected by) customers. As standards in this tier are reviewed and refactored, they should also be updated to accommodate this trend.

   - This will then allow well-defined customer service levels to drive refinement and evolution of the underlying system and product standards, supporting a transition to **customer service driven system design.** Over time, we would expect this increasingly to be driven by **dynamic negotiation of service levels** between customer equipment and the wider electricity system, supported by suitable developments in interoperability standards. Experience in other sectors suggests that this will allow service providers to create new value for customers, and so shift the dialogue in the electricity system away from cost cutting and towards value creation.

- Service levels may also vary between normal, abnormal and emergency conditions. Where this is relevant, standards should be clear about how such conditions are defined and how service levels vary between them.

- There are significant **social aspects** to these standards, eg in the extent that new smart grid control paradigms may have adverse impacts on some social groups. These impacts can be mitigated by recognising that agents (either technical agents such as home energy management systems, or organisational ones such as ESCOs and social landlords) will often act on the customer's behalf. In such cases, standards help define the interfaces and responsibilities for those agents. Nonetheless, it must also be recognised that it will be important to engage people to some extent with smart controls, so that they, as customers, can make informed choices and, as citizens, participate meaningfully in questions of the energy transition. This is a complex area and we recommend that standards development must be cognisant of relevant social and user research, eg through the observatory function discussed below.

2. **System Planning, Design and Operations.** These are **engineer-facing standards** that define how the system is planned, built and operated in order to deliver the above service levels. There is a complex mesh of historical standards and codes at this tier (most notably standards such as SQSS and the Grid and Distribution Codes and their daughter documents – P2, G59, etc – but also standards in areas such as Smart Metering). These standards have evolved in a piecemeal way over many years, so there is abundant scope for gaps, overlaps and contradictions across them. And the complexity of the web of standards is itself often a barrier to new entrants and innovators. We therefore recommend that this tier be consolidated, rationalised and updated to align to support a more decentralised system and be driven by the customer-centred standards of the above tier as it is developed.

   In undertaking this work, it is worth noting that:

   - Planning, design and operations is often about making trade-offs between different options – the best solution is context-dependent and shifts over time, eg as new technologies emerge. This suggests that standards in this tier should be less prescriptive than those in the above tier. Moving to more principles-based standards would give more scope for dialogue and flexibility as new technologies and business models emerge.

   - This layer should be engineering-driven. Codes, licences, incentives and other regulatory instruments should focus on specifying outcomes, as embedded in the Customer Service Level tier, and so not overly constrain the emergence of new engineering solutions.

   - Standards for Systems-of-Systems, Data and Interoperability are currently less well developed than those for Systems. Interoperability is addressed in section C.7 of this report; the other two areas are addressed in more detail below.

   - The SGAM (Smart Grid Architecture Model) is become more widely adopted, and could be a useful tool to classify and organise standards within this tier. Mapping standards onto such a model will make it easier to identify gaps and overlaps in existing standards.

   - This tier also needs to consider standards in adjacent sectors, eg telecoms standards that will have a growing impact as data and smart grid control systems become more pervasive in the energy system.

3. **Product Standards.** These standards define how individual components, pieces of equipment and suchlike operate and interoperate in order to deliver the system-level performance designed in the above tier. There is a very large number of standards within this tier, reflecting the diversity of equipment from which the electricity system is built. And the number of relevant standards will grow enormously as aggregations of edge devices such as EVs, heat pumps, etc, playing an increasingly active and important part in the system's operation. Thus this tier is inherently complex. This makes it especially important that the above tiers are made as coherent as possible, so that the interface between them and products can be kept manageable.

   Product standards are inherently **detail-oriented**. You can't make devices work and interoperate without attending to the details. They can also evolve rapidly, driven by emergence of new technologies and user preferences. However, the standards tend to lag the technology – technology needs to achieve a certain level of maturity and deployment experience before a meaningful standard can be developed. This is a particular challenge to the rules-driven model of governance extant in the energy system: it has no clear way to integrate and accommodate emergent technologies in the pre-standard stage. This is a key driver for a transition to more **data-driven governance**, as outlined below.

   Standards in this tier will address elements such as:

   - **Network asset design and operating standards.** These set out how individual network components perform and operate. Such standards are best governed by the networks themselves, working with the relevant manufacturers, provided that they can demonstrate to regulators that they achieve the required customer service levels and are in line with good engineering practice at periodic reviews.

   - **Compliance requirements for connected equipment.** These make clear the requirements under which equipment of all kinds can be connected. For most equipment this is likely to be "plug and play" requirements for connection and data exchange. These standards may need to differentiate between equipment which has a primary purpose to support the delivery of electricity (eg network, storage, and generation equipment) and that which uses electricity but which has a primary purpose to deliver some other form of utility to the customer (eg EVs, heat pumps, appliances), as these tend to be driven by very different groups of stakeholders and standards.

   - **Interfaces and interoperability.** These will address all aspects of interoperability between the electricity system and products connected to it, including factors such as ontology, data syntax and semantics, communication, etc. This is an area requiring early focus, as discussed in the interoperability section C.7 above.

   Many of the standards in this tier are inherently international – the UK is served by international manufacturers and so its standards need to align to markets elsewhere, or we will incur additional costs as manufacturers either design specific equipment for us or choose not to serve us. Equally, the UK has a strong interest in influencing these standards in order to ensure that export markets remain open to UK manufacturers and service providers.

Finally, it is worth noting that many customer products are themselves strongly influenced by the service levels of the top tier above: products rely on the electricity system to deliver certain attributes to them, act to protect themselves when it does not, and are expected to deliver certain performance in order to discharge their responsibilities to the system when they connect to it.

Example: Mapping Existing Standards to the Organising Framework

Figure D-2. illustrates how a customer service level for system availability, eg identifying what Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) they can expect of their electricity supply, might be mapped onto existing standards. Currently, this exercise would identify a large number of existing system design and product standards, often with overlapping scope and even conflicting requirements, with significant gaps in areas such as data, interoperability and system-of-system standards.

We recommend that, once the set of relevant standards (or a sizeable subset of them) has been identified through such a mapping exercise, that they be refactored to reduce and simplify the total set of standards. For example, where multiple standards overlap, this area might be refactored into a single standard that addresses that specific concern. Or, where a single standard addresses multiple concerns (meaning that changes to one cannot be made without risking impacts on others), it might be broken into several smaller, simpler standards.

1. The full framework could be then populated and refined iteratively over time by starting with a small set of key customer service levels and applying an approach along the lines of:
2. Start with the customer: identify a first cut at what parameters should be covered by an end-user service standard.
3. Pick 2 or 3 key parameters and map then onto the standards that drive them & assign these to the framework, as per Figure D-2.
4. Use this analysis to:

- Identify gaps in current standards, at all layers in the framework. Hence prioritise needs to develop new standards.
- Identify overlapping standards, and standards which span across multiple areas. Hence prioritise opportunities to refactor existing standards to reduce duplication and overlap, improve separation of concerns, etc. End goal is to have fewer, simpler standards with each one focusing on a small, clear set of concerns, and with clear relationships between standards (shown via the framework).
- Identify places where the framework itself could be improved to aid clarity, etc. This is likely to be a key activity in the early iterations, while the framework is still tentative and being refined.
- Identify existing standards which don’t fit into the framework cleanly. Again, this would help identify opportunities to refine the framework.

- As we do this, also identify other elements (codes, etc) that also define or influence this parameter. Capture their link to standards, and work with relevant body (eg for codes management) to clarify any ambiguities, reduce overlaps and duplication, fill gaps., etc.

- Iterate the above to address further end user parameters and hence refine the framework and full set of standards.

Once in a steady state:

- Shift attention to monitoring changes to technology, end user needs, etc and so mapping these onto the framework and set of standards so as to identify needs for new or refactored standards, updates to the framework, etc

- Regularly review the suite of standards across the landscape to identify areas where standards, or gaps in them, create cost and risk, or limit innovation or competition.

In summary, we recommend that existing standards and associated mechanisms are mapped onto this framework and then refactored over time to establish a clear separation between the tiers and between distinct elements within them. This refactoring should start with the top, customer service, tier in order to drive a more customer-centred perspective on the suite of standards. The main focus of future regulation and incentives should then be on the customer service tier.

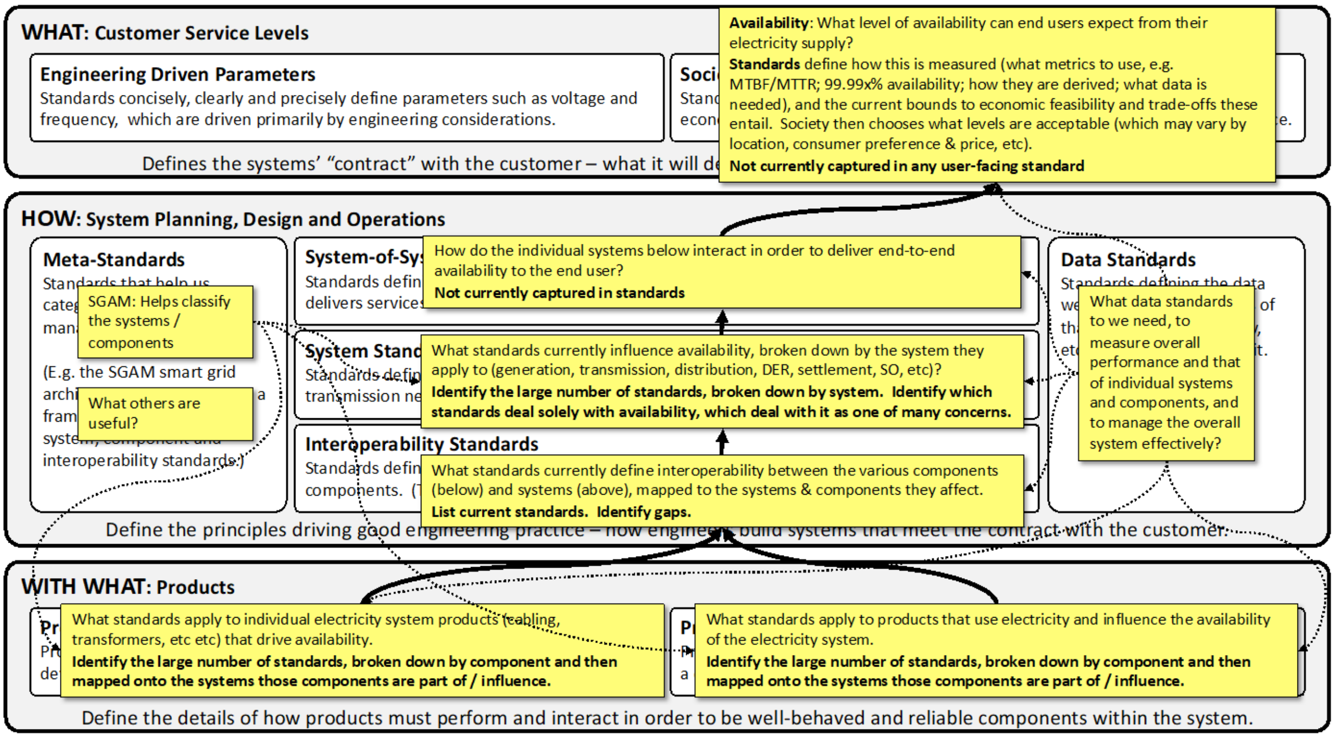


Figure D-5 Mapping standards into the organising framework.

D.5 System-of-Systems Interaction Standards

Despite significant change to technology, customer requirements, market structures, and social and political context, the underlying basis for the electricity system's design and operation has barely changed over many years. The system is assumed to have a relatively simple, single centralised structure. Thus system-wide efficiency and security rest largely on a national system protecting against failure of the largest infeed generation. Customer equipment is assumed to be largely passive, with centralised systems acting to respond to their demand. Or, in extreme circumstances, acting to switch them off to protect the system. Standards are set independently for each subsystem, creating potential for inefficiencies and damaging interaction errors. Furthermore, these standards tend to be uniformly applied across the system despite the diversity of network utilisation patterns and differences in customers' tolerance to supply interruptions.

As digitalisation and decarbonisation intensify, the electricity system becomes increasingly distributed, interconnected, dynamic and complex. It is becoming a system-of-systems, with very different characteristics to those that legacy standards were designed for. Continuing to rely solely on existing standards will not only limit participation of new technologies and business models, it will drive up the cost of decarbonisation and create growing risks to security of supply.

We therefore recommend that a layer of standards to coordinate design and operations across national, regional, local and customer systems needs to be defined. These would address issues such as:

- Different roles, characteristics, design and operating principles at different scales;
- Whole-system defence against system-wide threats to security and resilience;
- Management of systemic issues such as cyber-security;
- Architectures for decentralising responsibilities to different subsystems across voltage levels, geographic boundaries, etc, and for managing cost and risk trade-offs across subsystems;
- Evolution of standards to embrace new technologies and customer services while continuing to safeguard security of supply;

We recognise that programmes such as the ISCF (Industrial Strategy Challenge Fund) Prospering from the Energy Revolution are beginning to deal with such issues, and recommend that development of these standards should be coordinated with this work via the observatory identified below.

D.6 Data standards

Data is of growing importance to effective design and operation of the electricity system. Thus it will be a key element of many of the standards addressed in the framework of section D.4. We therefore recommend building from the Energy Data Task Force's findings by making data a primary element of all new standards development. In particular, we recommend that:

1. **Performance against standards:** All new and revised standards should define the data that should be collected to demonstrate performance against the standard. The appropriate bodies (as defined by codes/regulation) can then collect this data as part of the process to assure compliance and monitor performance. This data should also be used to support evidence-based evolution of the standards, and as a precursor to help define future standards in areas such as digital control of distributed equipment. Note also that the presumption of openness recommended by the Engineering Data Task Force would suggest that this performance data should be openly published unless there is a strong reason not to do so.

2. **Interoperability**: Interoperability standards, addressing communication, syntax and semantics of data, be addressed as a matter of urgency, as outlined in Appendix C.7.

3. **System performance:** Key system performance data be defined, gathered and published as a matter of urgency (see Table D-1 for examples).

4. **Presumed data capture and publishing:** Develop all future standards with a presumption that they should do all that is possible to enable greater real time visibility of network and system state at all levels. Such data would enable system operators and innovators to develop new services that would, for example, allow much higher utilisation of network assets through adaptive control of loads to smooth energy flows across the network. There should therefore be a presumption that such data will be captured and published unless there is a clear reason not to do so (reversing the current mindset that data is only captured if there is a strong reason for it). Table D-1 outlines some initial areas where we believe it would be valuable to collect and publish more data. The accompanying Frazer-Nash report identifies some additional use cases for such data, and discusses innovation projects (eg the openLV project) that have explored potential for capturing more system and network data in more depth.

5. **Data-driven service introduction:** As all new services will gather data to demonstrate their performance and impact on the system (recommendation 1), this data should be used to drive rapid adaption of standards in areas such as network design to accommodate the new services. Lack of support for a service in existing standards is often a barrier to its wider adoption, creating a chicken-and-egg dynamic: standards don’t evolve to support new services until they have been demonstrated at scale, yet new services can’t be deployed at scale until standards support them. This dynamic could be broken by creating a presumption that standards will evolve to accommodate a new service unless the data it collects shows a clear reason not to accommodate it.

   This could be done by allowing new products and services to be trialled at small scale with minimal need for permission and derogation, provided only that these trials capture and openly publish sufficient data for independent bodies to analyse their impacts. If no adverse impacts can be demonstrated, then trials would be allowed to scale up progressively, capturing and publishing yet more data for independent scrutiny. This reverses the current presumption that trials can only take place once permissions and derogations have been obtained, which can be a significant barrier to rapid innovation.

6. **Privacy:** We note that note that increased capture and publishing of data could have significant implications for cybersecurity and customer privacy. This is a key focus of the BEIS sponsored BSI work on interoperability and has also been addressed by the Energy Data Task Force / Managing Energy Data programme, so appears to be adequately covered by these initiatives. Development of data standards should continue to maintain this awareness of the need to adequately protect cybersecurity and privacy.

These recommendations are the first step on a journey towards treating data as a primary component of the electricity system. Over time, we would expect that data will become pervasive to all aspects of the electricity system, and data-driven system planning, design and operations will become the norm. Standards will therefore need to evolve to support this mode of operations; the above recommendations ensure we begin gathering the data necessary to inform effective definition of these new standards and ways of working.

NB this does not represent an exhaustive analysis, but rather identifies some of the issues and opportunities that have come up during the course of this review.

Table D-2 Potential Areas for Greater Data Capture and Publication

Area	Notes
System Performance	Summarised data on overall system health and performance against key metrics, giving clearer visibility to trends in performance, stress levels, etc. This might cover parameters such as emergency alerts, outage rates, protection system performance, reserve margin, plant margin, network margin, inertia, frequency, voltage operating range, response time to resolve faults, etc. While some of this data is available now, it is spread across multiple sources and lacks common data definitions and measurement standards.
Customer Service	Statistical data on the levels of service delivered to customers. This would map to the parameters in the Customer Service Level standards outlined in section D.4. For example, standards establish the voltage range which customers should receive. So the system might publish the statistical distribution of voltages seen at customer connection points over a period, with the ability to drill in by region, time of day, etc. Ideally this would be updated and published within a well-defined (and short) time after the end of each period.
Load and Power Flows	Data on the load, thermal status, power flows, etc, at individual substations on the network. For example, the OpenLV project has identified a number of such parameters that could be published retrospectively or in real time with suitable instrumentation on LV substations. This data could support development of a wide range of innovative services, eg for active load management to optimise utilisation and increase reliability of network infrastructure.
Connected Equipment	The location, status and capabilities of equipment connected to the system (eg EV chargepoints, distributed generation, heat pumps, …). Such data is a focus of the Managing Energy Data initiative, and lack of it was an issue for the system event on 9 August 2019. As well as static data on the location and configuration of such equipment, greater visibility into the status and operating performance of such equipment would enable system operators to better plan their operations, reserve requirements, etc, and would give greater assurance that the equipment is performing within agreed parameters. It could also support development of innovative services for flexibility management, etc.
Equipment and Service Performance	Data on performance of connected equipment portfolios, especially where its performance is of systemic significance or it has been contracted to provide services for ESO, DSO or other key parties. For example, it is not clear how well providers of frequency response services performed against their contracted service levels (including expected tolerance levels) during the system event on 9 August 2019.

D.7 Operational Standards

Current standards were developed when networks were largely build-and-forget, and so rightly focused on upfront design. This is particularly so at the edge of the system. Smart, flexible systems entail much more active operations, able to tap into a range of unconventional instruments, such as network backup capacity, customer resources, gas network, etc. And they must cope with constantly shifting network congestions and constraints, and rapidly changing system dynamics from a low inertia system. As interoperability expands through the system, interaction between subsystems and between the system and customers will rise, ensuring energy flow to where it valued most and driving the system even closer to their physical limits. The increased efficiency from the whole-system resources optimisation will help to build a mutually beneficial relationship for the key players. They will also increase the operational complexity. This can create major challenges in managing/coordinating millions of active devices when subject to major system events, particularly if the roles and responsibilities are not clearly defined for the asset owners at different part of the supply chain.

So standards should be extended to cover operational concerns to clearly define the roles, responsibility and accountability for network operators as well as key energy system actors under normal, abnormal and emergent system conditions, accounting for potential risks from increasing operational capabilities and their potential impact to network design.

D.8 Coordination and Governance

There needs to be a single, clear point of responsibility for driving the rationalisation and refactoring of standards outlined in section D.4 above, and for maintaining the landscape as standards evolve. Thus we recommend that a party responsible for standards coordination be established. This responsibility parallels the need for codes management identified by the Codes Review.

This party would take responsibility for maintaining the landscape of engineering standards, ensuring that engineering standards are kept up to date, ensuring that new engineering and adjacent (eg product) standards are developed in a coordinated way, and ensuring that adjacent mechanisms (regulations, codes, incentives, etc) are coordinated with engineering standards. Its responsibilities would include:

1. Develop and maintain a map of the standards currently applying to the electricity system (framed widely to include relevant adjacent standards in areas such as products, including smart appliances, heating and electric vehicles), and identifying their relationship to the codes, regulations, licences, incentives, etc that govern the sector.

2. Use this map to drive the rationalisation and refactoring of standards recommended above.

3. Be a point of contact for innovators and other parties, eg helping them understand what standards are relevant to their activities and to interpret these standards appropriately

4. Monitor developments within this landscape, and so identify areas where standards development or coordination is required.

5. Coordinate the sector's engagement with bodies developing relevant standards, in the UK and internationally (eg IEC, ISO, etc). For example, it might support energy system actors to be more aware of emerging product standards and so either to specify services that align to these standards or to engage with international standards development efforts in order to ensure product standards better align to the GB system’s needs.

6. Support regulators to identify areas where existing standards inhibit new solutions, and recommend “derogations” which might be applied to support development and proving of these new solutions (and, eventually, new standards).

7. Initiate focused action to develop new standards or coordinate other bodies’ activities in emerging areas with high impact on the energy sector and its ability to decarbonise.

8. Maintain a risk register of key issues currently being addressed or that need to be addressed by standards, and a roadmap of standards development. A particular focus

here might be cross-cutting issues, eg cyber-security, that touch on many standards in all parts of the system.

9. Undertake suitable actions to disseminate and communicate relevant standards and their implications to policy makers, regulators, engineers and customers.
10. Establish an observatory, responsible for scanning global developments in the area of systems and system of systems engineering for electricity and its relationship to wider energy systems, and producing an annual report, with recommendations, used to inform both changes to the standards landscape and the wider energy policy debate. Government to be bound to provide a detailed response to this report. This observatory might initially monitor, or even initiate, research in the following areas:
    - **Further reduction of lower voltage limits** beyond the -10% currently supported by the evidence base, for example -15 or -20% under abnormal operating conditions (in time to implement in RIIO ED3)
    - **Performance of very low inertia and fault level power systems**, beyond the time horizons currently used by the System Operator, to the extent the SO itself is not undertaking and publishing such work, with the intent to make anticipatory changes to the specification of long-lived hardware such as generators (by 2023)
    - **The costs and benefits** of dc distribution within homes and communities (by 2022)
    - a roadmap towards a digital twin of the electricity system (by 2022)
    - what needs to be changed in electricity to create customer outcomes for energy or infrastructure service as a whole (by 2023)
    - assuring compliance in a world of artificial intelligence (by 2023), and of mass-market smart grid appliances (eg EV smart chargers)
    - widening engineering interoperability into commercial, market and other aspects (by 2023)
    - the mutual inter reliance of a smart flexible electricity system with communications infrastructure (by 2023)
    - the objective function against which we optimise the electricity system, and how outcomes could change depending on how this is chosen (by 2023)

The first action under item 7 above would be to set up two “task forces”:

1. **Interoperability:** to coordinate the definition, dissemination and application of standards for interoperability, smart grids, microgrids, and associated smart control systems. A key focus for this would be to develop standards that support key energy system use cases to deliver resilience and security of supply from smart, distributed generation, storage and demand.
2. **Software-intensive equipment:** to coordinate updates to existing standards and practices for assuring performance against standards to account for the emergence of equipment in which a growing proportion of the functionality is embedded in software, which is subject to regular change and update.

Building from recommendations made by the codes review, standards coordination would link closely to the code management body, together forming a clear point of coordination of both codes and standards for the energy system. The key word behind this function is **visibility** — it helps make it clearer what is going on in a complex and growingly dynamic landscape.

It should be noted that this point of coordination does not in itself change the fundamental governance of standards. We have considered the following roles applying to standards:

- **Coordination:** Maintaining a map of the landscape, identifying gaps or overlaps and commissioning work to address them, linking between different standards development bodies, communicating and disseminating standards. This is a key gap in the current landscape, and so the focus of our recommendations here.

- **Definition and Development:** Writing and updating standards. This needs to be done by people with expertise and experience in the relevant area, so is best left to the current mechanisms for developing standards, eg through industry-led fora convened by specialist standards bodies.

- **Approval and Adoption:** Many standards add value simply by providing a reference point to product developers, system designers, etc, and need no formal adoption beyond the review and version management process managed by standards development bodies. However, where added force is required, they may be included into licence conditions, codes, etc. This is best left to the existing legal and regulatory mechanisms. (Noting also that a number of other reviews are currently looking at codes and wider energy system governance.)

D.9 Compliance and Enforcement

When the whole electricity system comprises both the upstream networks and generation, together with millions of smart, intelligent active devices, the collective behaviour of the millions of mass market devices becomes critical. If a particular type or types of device installed in millions of homes and business reacts in an unexpected way to unusual system conditions, that behaviour, multiplied millions of times could be enough to destabilise the system and precipitate a national blackout.

Mechanisms for assuring that equipment and systems comply with standards range from upfront testing to ongoing monitoring of performance data. The electricity system does not have mechanisms for addressing upfront testing, apart from the largest power stations, and is also weak on the performance data collection. The events of 9 August 2019 demonstrate that even the compliance mechanism for large power stations do not necessarily historically cover all risks.

There are several important aspects to such assurance:

- **Safety and security:** Are devices manufactured to comply with key safety and security requirements, so that their behaviour en masse does not endanger the system?

- **Interoperability:** Do devices operate together with the system and other devices in the ways expected by customers, the energy sector, third parties and the energy market generally?

- **Installation:** Even if equipment has been designed and manufactured appropriately, poor installation can cause it to operate incorrectly. Thus we need to be able to assure that equipment has been installed and configured correctly.

- **Operation:** Likewise, inappropriate operation can cause it to behave outside its designed parameters, so we must consider ongoing monitoring to assure compliance.

The first two of these can be assured through suitable testing of equipment as it is designed and manufactured, possibly coupled with subsequent performance monitoring. This testing needs to be combined with suitable support for manufacturers, who sometimes build non-compliant equipment as much through lack of appreciation of the detail as anything else.

The latter two aspects can be addressed through ongoing data collection – eg of built in self-test data to assure correct installation, and of ongoing performance monitoring data to assure appropriate operation. This then raises the questions of who analyses the data, and how do we enforce correct operation of equipment once it has been installed. These can to some degree be addressed by system-of-system standards: if the wider system can access device performance data, then it can recognise non-compliant devices and protect itself from them (eg by building additional headroom around them, linked to appropriate charging regimes, or building a closer relationship with manufactures to enhance devices' awareness and responsibility). However, there will be times when stronger ongoing enforcement of equipment compliance will be appropriate and necessary.

For the regulated part of the system, where standards have been adopted into licences, codes, etc, we recommend that the relevant regulatory authority should also define the appropriate compliance and enforcement mechanisms. For mass market smart devices, the evaluation of performance and behaviour data will definitely help understand compliance. However when there are millions of devices installed, discovering a flaw in the behaviour is arguably too late. Hence a significant amount of assurance needs to be completed by manufacturers, and others, in the introduction of new devices to market, and ongoing manufacture, to ensure this risk is mitigated. BEIS have recognised this through their sponsoring of BSI to develop standards for smart appliances. We recommend that a testing and certification regime should be developed following this work and it should consider the extent to which strong compliance and enforcement mechanisms are needed to mitigate system risks and maximise opportunities for the system to capitalise on demand side flexibility. We also recommend that the standards coordination function should consider whether additional classes of equipment, not covered by the BEIS sponsored BSI work, also need to be brought into this regime. In all cases, it must be recognised that any compliance regime must be proportionate to the risks and benefits associated with the appliances: if certification is very arduous, then devices either won't be developed or they will become too expensive for the market, and so won't deliver the flexibility required by the system.

Finally, open publication of performance and assurance data also creates the possibility of independent scrutiny by other parties, which can itself be a powerful enforcement mechanism.

D.10 Data-Driven Evolution and Assurance

As part of the above actions, we recommend that the system create more agility by moving from a mindset of rules-driven governance (of standards and other instruments) to one of data-driven governance. That is, It should shift from a mode where it defines extensive rules that new equipment and services must be tested against before they can be deployed, to one where new equipment and services can be readily deployed at small scale provided that they capture and openly publish extensive data on their performance. Then, if no harm can be demonstrated from the collected data, they would be allowed to scale up progressively as ever more data gives greater assurance of their safety and efficacy. This would help eliminate one barrier to agility and innovation, the need for extensive compliance testing prior to deployment of new equipment and services, and help to create a system that is inherently more transparent and agile.

This transition will be supported by the above recommendations in section D.6, especially (1), (4) and (5).

D.11 Communication and Dissemination

Over the course of the review, it has become clear that many of the problems ascribed to standards are not created by the standards themselves, but are the result of people's (mis)interpretation or lack of awareness of the relevant standards. For example, "common practices" which are compliant with a standard often become equated to the standard, even though the actual standard may allow a much wider range of solutions. Thus a key aspect of developing future standards must be ensuring that these standards are communicated appropriately. Thus one role of the standards coordination body outlined above is to ensure that standards are communicated effectively to key stakeholders (including policy makers, regulators, system engineers, equipment manufacturers and service providers, customers) and, where necessary, providing suitable guidance on the interpretation of standards.

D.12 Transition roadmap

Table D-2 illustrates a possible roadmap for standards to support the GB electricity system's transition to become smart, flexible and net-zero. It suggests 5 stages the system might go through in making this transition:

1. **Late Old Status Quo.** The system is running under the traditional, centralised model, although signals that a new paradigm will be required are becoming ever stronger. Design and operation of the system is focused on building and maintaining hardware, while innovation projects focus on testing a range of new models enabled by decentralisation and digitalisation. Standards change relatively slowly, primarily acting to capture refinements built up through years of engineering practice and continuous improvement. The phase ends as the weight of signals for a change reaches a critical point, forcing recognition that a transformation is required. The legislated net-zero target, for example, sets objectives that simply can't be met under the old paradigm; a powerful signal that deep transformation is required.

2. **Early Transition.** Although it is clear that transformation is required, the exact shape of that transformation and the resulting new system is still unclear. The bulk of system design and operations remain much as before, although new models are now coming out of tightly controlled innovation projects and being tested at larger scale within "innovation zones" in the operational system. Infrastructure to support the new system, eg for digital operations and data management, is beginning to be built. Existing standards and standards governance still predominate, but we begin to establish new frameworks and governance to support rapid change through the transitional period. This phase ends as results from innovation zones develop a clear picture of the shape of the new system.

3. **Late Transition.** As the shape of the new system becomes clear, we begin to build the infrastructure it entails, eg rolling out digital equipment and flexibility services at scale. This begins to give us the data we need to constantly refine and improve these services, and to optimise the way we operate and exploit the new infrastructure. This data also helps us refine our standards, exploiting the standards infrastructure built in the previous phase to do this in an agile, data-driven way. This phase ends as new systems and services begin to predominate within the system. For example, when the proportion of flexible demand on a portion of the network is relatively low and unproven, system operators cannot rely on it as a major source of reliability, resilience or capacity. However, once the proportion of flexible demand begins to dominate that of inflexible demand (as will happen as smart EV charging and especially V2G become common), the system

essentially goes through a phase change, switching to a state where it can no longer be managed effectively (or at least efficiently) without fully accounting for and managing this flexible load.

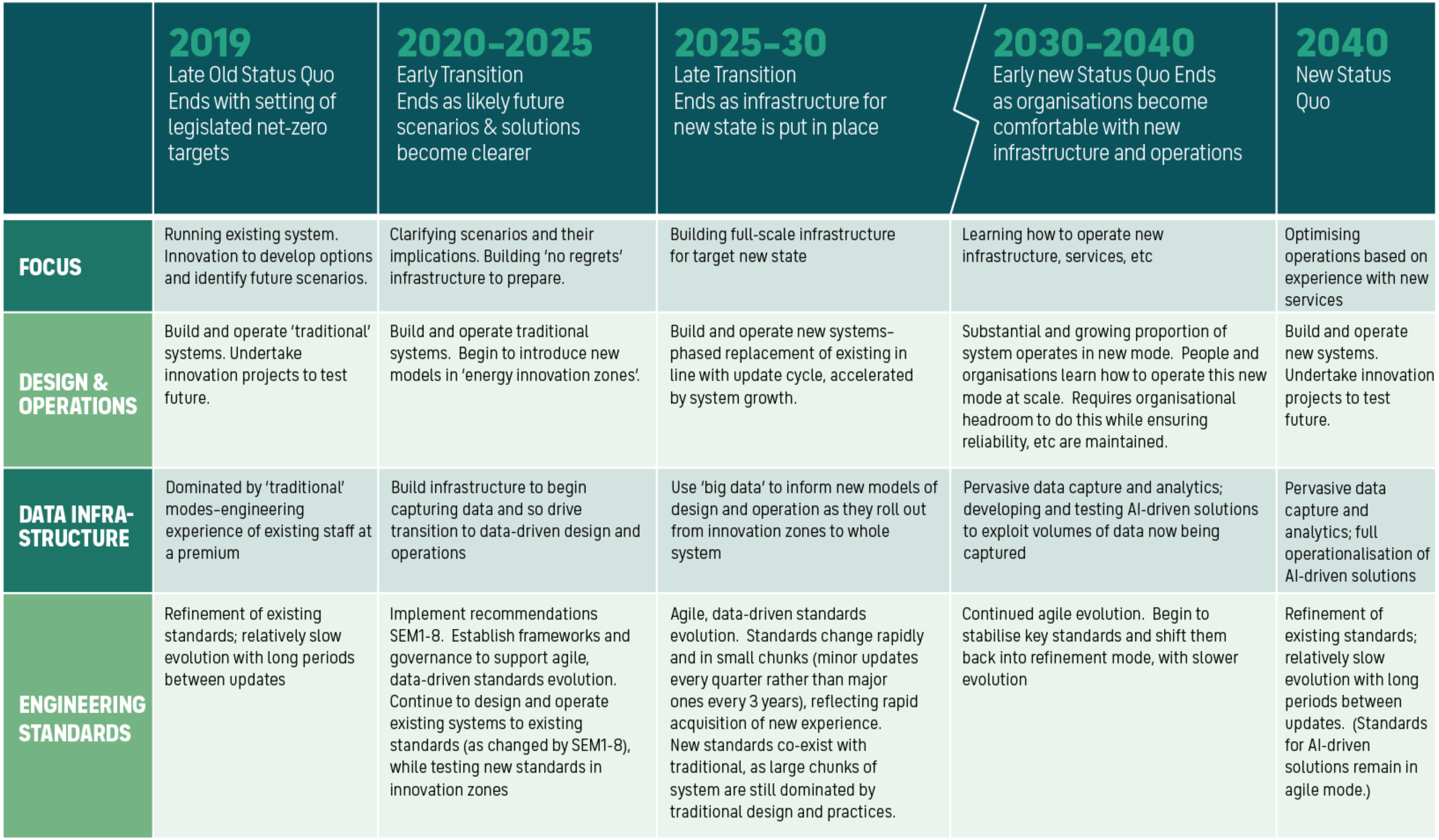
4. **Early New Status Quo.** The new system and infrastructure is now established. However, we probably still far from operating it in the optimal way, as we are still learning from experience with it (supported by the data we are capturing and analysing). During this phase, design and operating procedures, standards, etc, evolve rapidly to capture and embed good practice as we continue to develop and refine it. This phase ends as this pace of learning declines, shifting to one of continuous improvement to a known system rather than learning the full depth of the characteristics of a new one.

5. **New Status Quo.** The move back to a state of continuous improvement and optimisation of what is now a reasonably well understood system. Standards start to look more like those in stage (1) – changing relatively slowly in order to capture good practice built up through years of engineering experience and continuous improvement.

The current system is essentially in Early Transition. We have recognised the need to change and are running large numbers of pilots, demonstrators, innovation zones, etc, to clarify our understanding of the new system and how we will build and operate it. Standards like P2/7, while making some allowance for change, are still grounded largely in a paradigm where physical assets predominate (as they will for some time yet). The standards framework and governance models presented in this section of this report begin to set out the “infrastructure” we will need to manage and evolve standards through the balance of the transition.

This infrastructure is intended to help us manage the transition: transformations tend to be highly disruptive if not prepared for and managed well. Conversely, the evidence is strong that trying to defer the transition will be very expensive, eg in the additional investment in physical infrastructure that would require – we must embrace the change, but do it in a managed way. That is our goal here. We are trying to prepare the infrastructure of standards needed to help us recognise trigger points along the way to the transition (hence the emphasis on data), and then to move quickly and seamlessly through the transition in order to exploit flexibility as it becomes a growingly important resource.

Finally, we note that standards are only part of the story. Factors such as skills and tooling to allow network planners and operators to design for and manage flexibility will be critical. They are not in scope for this review, but must be recognised as a critical factor and allowed for in investment plans during the early transition phase.



	2019 Late Old Status Quo Ends with setting of legislated net-zero targets	**2020-2025** Early Transition Ends as likely future scenarios & solutions become clearer	**2025-30** Late Transition Ends as infrastructure for new state is put in place	**2030-2040** Early new Status Quo Ends as organisations become comfortable with new infrastructure and operations	**2040** New Status Quo
FOCUS	Running existing system. Innovation to develop options and identify future scenarios.	Clarifying scenarios and their implications. Building 'no regrets' infrastructure to prepare.	Building full-scale infrastructure for target new state	Learning how to operate new infrastructure, services, etc	Optimising operations based on experience with new services
DESIGN & OPERATIONS	Build and operate 'traditional' systems. Undertake innovation projects to test future.	Build and operate traditional systems. Begin to introduce new models in 'energy innovation zones'.	Build and operate new systems-phased replacement of existing in line with update cycle, accelerated by system growth.	Substantial and growing proportion of system operates in new mode. People and organisations learn how to operate this new mode at scale. Requires organisational headroom to do this while ensuring reliability, etc are maintained.	Build and operate new systems. Undertake innovation projects to test future.
DATA INFRA-STRUCTURE	Dominated by 'traditional' modes-engineering experience of existing staff at a premium	Build infrastructure to begin capturing data and so drive transition to data-driven design and operations	Use 'big data' to inform new models of design and operation as they roll out from innovation zones to whole system	Pervasive data capture and analytics; developing and testing AI-driven solutions to exploit volumes of data now being captured	Pervasive data capture and analytics; full operationalisation of AI-driven solutions
ENGINEERING STANDARDS	Refinement of existing standards; relatively slow evolution with long periods between updates	Implement recommendations SEM1-8. Establish frameworks and governance to support agile, data-driven standards evolution. Continue to design and operate existing systems to existing standards (as changed by SEM1-8), while testing new standards in innovation zones	Agile, data-driven standards evolution. Standards change rapidly and in small chunks (minor updates every quarter rather than major ones every 3 years), reflecting rapid acquisition of new experience. New standards co-exist with traditional, as large chunks of system are still dominated by traditional design and practices.	Continued agile evolution. Begin to stabilise key standards and shift them back into refinement mode, with slower evolution	Refinement of existing standards; relatively slow evolution with long periods between updates. (Standards for AI-driven solutions remain in agile mode.)

Table D-3: A possible roadmap for standards to support transition to a smart, flexible, net-zero electricity system

D.13 Recommendations

The electricity system is moving from a period of relative stability, focused on continuous improvement of existing standards, to one of transformational change in order to achieve net-zero targets, capture the benefits of digitalisation and meet changing customer needs. The cost of making this transformation could be significantly reduced by developing a clearer overview of existing standards and better support for managing and governing them. This would reduce risk during the transformation and make it easier both to deliver clear service guarantees to the end user and for innovators to develop new technologies, services and business models.

The Panel has proposed a roadmap for implementation, driven by when we foresee major system changes on the road to net zero. This requires that the foundational elements recommended below (or other measures of equivalent effect) are put in place over the next few years, and certainly by 2025. Given the time needed to make and embed such institutional changes work needs to start at pace as soon as possible. This will clearly be a significant effort involving the whole industry, and should be led by BEIS.

1. **Develop a tiered perspective on standards, with a focus on what the system delivers to its customers.** Standards should be divided into customer service levels (setting clear expectations for what the electricity system delivers to its customers), system planning and design (defining how the system delivers those service levels) and products (specifying how equipment operates to achieve the designed performance). Existing standards should be mapped onto this perspective and refactored to align more closely to it over time, and all new standards should be framed to focus on a single tier only, to maintain clearer separation of concerns. Codes and regulation should focus on the customer service level tier, defining what the system must deliver and leaving the details of implementation to engineering standards (while always mindful that the "what" must be physically and economically achievable).

2. Section D.4 describes this tiered framework in more detail and illustrates how it might be developed. This same section D.4 sets out principles to support further development of the framework and the standards within it. Section D.5 discusses a key gap in existing standards, System-of-System Standards, and how it might be addressed within the System Planning, Design and Operations tier of this framework. Section D.6 addresses data standards, another key gap in existing standards, as recognised in recommendation (5) below.

3. **Develop a clear, overarching set of customer service levels.** The top tier of the standards framework should be driven by a clear statement of what service levels the electricity system will deliver to its customers. As outlined above, this should be written in terms understandable by the customer or their agents, and should have scope to deliver different levels of service to different customer segments or customer use cases where that is appropriate. It should also set out what the system expects in return from the customer and their equipment in order to deliver these service levels, eg in terms of how equipment must connect to and interoperate with the system. This is further elaborated in section D.4.

4. A key element of these service levels should be a **customer level commitment on supply reliability and resilience,** so that customers are able to understand how long they should plan to be without electricity, including the scope to be self-sufficient, under normal circumstances and following events such as extreme weather or cyber-attack, which the Panel sees as increasing in probability. This is further elaborated in Appendices C.2 and C.3.

5. **Designate a party responsible for standards coordination.** This party would ideally be an extension of an existing body, eg linked to the code management body recommended by the Codes Review. It would be responsible for maintaining an overview of standards and coordinating their development, within GB and across relevant international standards bodies. Within the remit of this party, establish two task forces to address standards for smart grid interoperability and software-intensive equipment, to ensure the standards we need for the 2030's and beyond are in place for the generations of equipment that will be deployed in the mid- to late-2020's. This party would also be tasked to reach out internationally to take in best practice, eg by setting up and authoritative third-party observatory. The remit for this coordination function is further elaborated in section D.8.

6. This party is also likely to play a key role in communication and dissemination of standards, section D.11. A key aspect of developing standards should be ensuring that they are communicated effectively to all relevant parties.

7. **Designate a forward-looking and agile owner for the service level tier of standards**, accountable to BEIS or Ofgem. Clearer standards ownership and governance would enable rapid evolution and adoption of standards as new technologies and business models emerge. This should be driven from the customer's perspective, with this party responsible for overall integrity and agility of the framework of standards. However the system design and planning and product tiers of standards, which must embed good engineering practice, should remain under industry governance but with well-defined and public compliance regimes. Standards governance is discussed further in sections D.8, D.9 and D.10.

8. **Manage data as a key component of the system, as important as physical assets.** Building from the work done by the Energy Data Task Force, we recommend that all new and updated standards, and their accompanying governance, address:

9. **Data to measure performance and compliance.** New and updated standards should define what data should be collected to demonstrate performance against the standard. The appropriate bodies (as defined by codes/regulation) would then collect this data to assure compliance and monitor performance. This data should also be used to support **evidence-based evolution of standards**, and as a precursor to help define future standards in areas such as digital control of distributed equipment.

10. **Presumption of data capture.** Create a presumption that all new and updated equipment will capture and publish real time data on system performance unless there is a clear reason not to do so. This reverses the current (often implicit) assumption that we only capture data when there is a clear case to do so. It recognises that data has high optionality value, eg to drive transparency and accountability and as a source of innovation, that is not well recognised in existing standards.

11. **Data-driven innovation.** Create a presumption that new products and services can be trialled at small scale and contained risk with minimal need for permission and derogation, provided only that these trials capture and openly publish sufficient data for independent bodies to analyse their impacts. If no adverse impacts can be demonstrated, then trials would be allowed to scale up progressively, capturing and publishing yet more data for independent scrutiny. This reverses the current presumption that trials can only take place once permissions and derogations have been obtained, which can be a significant barrier to rapid innovation.

12. Data standards are discussed in more detail in section D.6.

13. **Address standards for network operation as well as design.** Current standards were developed when networks were largely build-and-forget, and so rightly focused on upfront design. Smart, flexible systems entail much more active operations, and so standards should be extended to cover operational concerns as well as design. Section D.7 discusses operational standards.

14. **Undertake research to support future standards development.** The observatory identified in recommendation (3) above should seek to initiate and monitor research in the following areas:

    - Further reduction of lower voltage limits beyond the -10% currently supported by the evidence base, for example -15 or -20% under abnormal operating conditions (in time to implement in RIIO ED3)
    - Performance of very low inertia and fault level power systems, beyond the time horizons currently used by the System Operator, to the extent the SO itself is not undertaking and publishing such work, with the intent to make anticipatory changes to the specification of long-lived hardware such as generators (by 2023)
    - The costs and benefits of dc distribution within homes and communities (by 2022)
    - a roadmap towards a digital twin of the electricity system (by 2022)
    - what needs to be changed in electricity to create customer outcomes for energy or infrastructure service as a whole (by 2023)
    - assuring compliance in a world of artificial intelligence (by 2023), and of mass-market smart grid appliances (eg EV smart chargers)
    - widening engineering interoperability into commercial, market and other aspects (by 2023)
    - the mutual inter reliance of a smart flexible electricity system with communications infrastructure (by 2023)
    - the objective function against which we optimise the electricity system, and how outcomes could change depending on how this is chosen (by 2023)

Reference Appendix E: The Work of the Panel

E.1 Terms of Reference

Electricity Engineering Standards Review Independent Panel Terms of Reference

Objectives

Our industrial strategy has articulated a grand challenge of clean growth: realising our decarbonisation objectives and maintaining reliable, secure and resilient electricity supplies at minimum cost. A key part of this is delivering an efficient electricity network within a whole electricity system, which maintains high levels of reliability and security of supply in Great Britain at least cost to customers.

The electricity system performance requirements, codes and network standards which govern design and security considerations represent the minimum technical requirements for the development and operation of networks in GB. Some of these standards and recommendations, particularly at distribution level, have only seen incremental changes since the 1950s. There is a risk that out-of-date standards lead to sub-optimal build decisions by network companies, which fail to reflect changing technologies and approaches, increasing costs to customers.

Although recently industry, with support from Ofgem, has undertaken a review of P2, the distribution planning standards, we believe more could be done to achieve the benefits of a future flexible and responsive electricity system.

In order to unlock these benefits, BEIS and Ofgem are launching an independent review of electricity system standards. The objective of the review is to consider how the planning and, where appropriate, operational and investment engineering standards should be updated in the face of our changing electricity system, whilst maintaining security of supply to customers.

Scope

There are a large number of engineering standards, guides and recommendations with varying degrees of impact on how networks are planned, designed, built and operated. For example, standards such as Security & Quality of Supply Standard and P2/6 are well known, however, others such as Electricity Safety, Quality and Continuity Regulations (ESQCR), Engineering Recommendations G98 and G99 which deal with distributed generation connections also play a significant part in shaping the electricity system. In addition, related provisions such as Ofgem's Information and Incentive Scheme, other aspects of regulation, and the industry Codes influence industry behaviours in how systems are planned and operated. As the system is transformed in coming years through decarbonisation, digitisation, decentralisation and the desire of customers to express their preferences this also reaches into standards relating to aspects of the built environment, transport and potentially other areas.

The review is expected to make recommendations relating to these standards, recommendations, and associated documents, but may also take a wider view where other elements of the system interact with engineering standards. Any gaps in the current suite of documents will also be identified.

This work will consider standards and recommendations linked to planning of the electricity system and of system operation in Great Britain. Product standards are in scope to the extent that they have an impact on the electricity system. Northern Ireland is out of scope. European network codes are in scope, although it is recognised that change in this area is likely to be more difficult.

The review will have regard to other relevant work underway, for example the Data Taskforce working currently under the auspices of the Energy Systems Catapult, and the Codes Review being undertaken by Ofgem and BEIS.

Workstreams

Workstream Title	Contents of workstream
Economic efficiency	Whether the current standards, when implemented, are locking in unnecessary cost and whether high levels of system reliability and resilience for GB customers can be delivered at lower cost.
Enabling of new technologies in a fair and neutral way	Whether the current standards or prescribed decision- making processes within network companies are designed in ways which favour network build compared to alternative solutions, such as energy efficiency, demand side response, storage, distributed generation or commercial solutions.
Whole systems approach	Whether the current standards should be changed to increase the focus on an end-to-end whole systems view[74] when developing the networks and what the impact of this would entail.
Network performance, reliability, security and resilience	Whether technology change means that current standards need change to reflect new challenges to network security, for example cyber-security, and to facilitate effective digitalisation needed for increasingly smart/intelligent systems.
International Context	Whether comparable electricity systems have updated their standards, and if so, how and what lessons can be learned.
Standards Ownership and Governance	Whether the current ownership and governance of standards is appropriate and recommendations for any changes.

Outputs

The outputs of this review would be:

- Proposals for how engineering standards should evolve, including any specific recommendations to Government, Ofgem and industry of how to do this, meeting the needs of GB energy customers and overall system costs and benefits;
- Indicate how Government can best work with other bodies to consider how the proposals they set out can be delivered; and
- Where action can be taken to achieve quick wins to address known problem areas.

We expect this panel to provide an independent report with associated recommendations for both government and industry to implement appropriate changes to the engineering standards by the end of March 2020.

We are keen that the outputs of this review are available for incorporation into network operators' business plans, and that this review does not disrupt implementation of other changes in the

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[74] Whole systems here means the complete electricity system including equipment on customer premises, touchpoints with other energy vectors, related data and communications systems, relevant legislation, regulation and market arrangements, commercial contracts and associated supply chains

industry in this space. This review will build on changes already taking place in industry, taking into account the wider sector, and not be undertaken in isolation.

Governance

We have appointed Simon Harrison as Chair of the panel, who are a group of engineering experts. The panel will be independent of Government.

An organisation will be appointed under a service contract to undertake research for the Panel to identify standards and produce information required for Panel to review the standards. This appointment will be undertaken by Government.

E.2 The Panel

The Panel was appointed by BEIS and drew together a diverse range of engineering experts covering power system, community energy, digital and other perspectives from both practitioner and academic standpoints. The members of the Panel were:

Faye Banks (Independent Consultant)

Simon Harrison (Mott MacDonald) – Chair

Mike Kay (Independent Consultant)

Furong Li (University of Bath)

Graham Oakes (Independent Consultant)

Robin MacLaren (Independent Consultant)

Filomena la Porta (EdF)

Goran Strbac (Imperial College, London)

Observers were:

Damitha Adikaari (BEIS)

Ben Eyre White (BEIS)

Simon Rickenbach (BEIS)

Lizzie Allen (BEIS)

Peter Bingham (Ofgem)

Mark Dunk (Energy Networks Association)

The Panel met monthly over the period May 2019 to September 2020, with fortnightly calls between most meetings, and corresponded extensively. Its work was supported by Frazer-Nash Consultancy, which has issued a separate report to support this report.

The Panel would like to place on record its thanks and appreciation to all who have engaged with and supported its work (as described in Appendix E.3). We have drawn heavily on the insights gained, but any errors and omissions in the work are our own.

E.3 Working methods

Summary

The Panel's focus has been to explore potentially fruitful areas that could improve customer value in the short to medium term, and then to learn from that to determine how the system of engineering standards needs to develop to support the more profound challenges of net zero. The Panel has engaged a range of stakeholders, and worked with other government and industry programmes being undertaken concurrently. The process used to select topics for investigation is set out, and principal assumptions, constraints and exclusions noted.

E.3.1 Working method

The approach to the work was developed by the Panel during its early meetings. The Panel was interested to explore both:

- potentially fruitful areas that could improve customer value in the short to medium term through specific recommendations for change, and
- building on this and learning from it, how the system of engineering standards needed to be developed to make it an enabler to net zero and other profound changes impacting the sector, noting that the form of the future electricity system cannot currently be articulated with any confidence and will be subject to ongoing change.

With the resources and time at our disposal we had to prioritise to draw useful insights from the work.

Our approach was therefore initially to:

- agree what we believed the electricity system was, and what constituted an engineering standard (see section A.3)
- agree to focus on engineering standards relating to the planning and operation of the GB electricity system,
- agree not to focus on specific asset or product standards, although we agreed to take an interest in the landscape of these standards overall
- within this to identify a longlist of potential areas to explore, and then prioritise this to a shortlist of six topics
- to test this choice through a stakeholder event

- then to use the consultancy support available from Frazer-Nash to explore the six topics in reasonable depth, and
- to develop a framework for standards to move towards that would be "future fit"

E.3.2 Stakeholders and their engagement

Within the limits of the Panel's capacity we were keen to engage with stakeholders, and did this through two Industry Days, a challenge session with the Institution of Engineering and Technology and presentation to and discussion with the Smart Systems Forum.

We also held a number of meetings with those undertaking other key reviews, and other official stakeholders, with the aim of learning, aligning scopes and providing support, at the time our work was in progress, including:

- Energy Data Taskforce, and work being down subsequently by the Energy Systems Catapult
- Codes Review team from BEIS and Ofgem
- EV Energy Taskforce
- BEIS/BSI team looking at smart appliance standards
- Health and Safety Executive
- National Grid ESO in respect of black start standards being developed by E3C
- Ofgem's Access and Forward Looking Charging Review
- BEIS work on cybersecurity
- Energy Network Association's work to revise planning standard P2

The Panel meetings were observed by the Energy Networks Association, BEIS and Ofgem.

The Panel would like to thank all people with whom we engaged. In all cases we received willing support.

E.3.3 Assumptions and constraints in the work

The Panel was very aware that the standards landscape is highly complex, and has many groups active in and deeply knowledgeable about different aspects, both in the UK and internationally. We were equally aware that apparently simple changes can have complex consequences, and that unconscious biases could quite easily close off whole pathways that could be very helpful. We sought to address this through diversity of thought amongst the Panel members selected, and consultation, but are aware this is inevitably imperfect.

The assumptions we have made consciously are:

- Net zero greenhouse gas emissions by 2050 or sooner being the key driver
- A continuing drive towards digitisation and digitalisation, driven at least in part outside the control of government and regulators

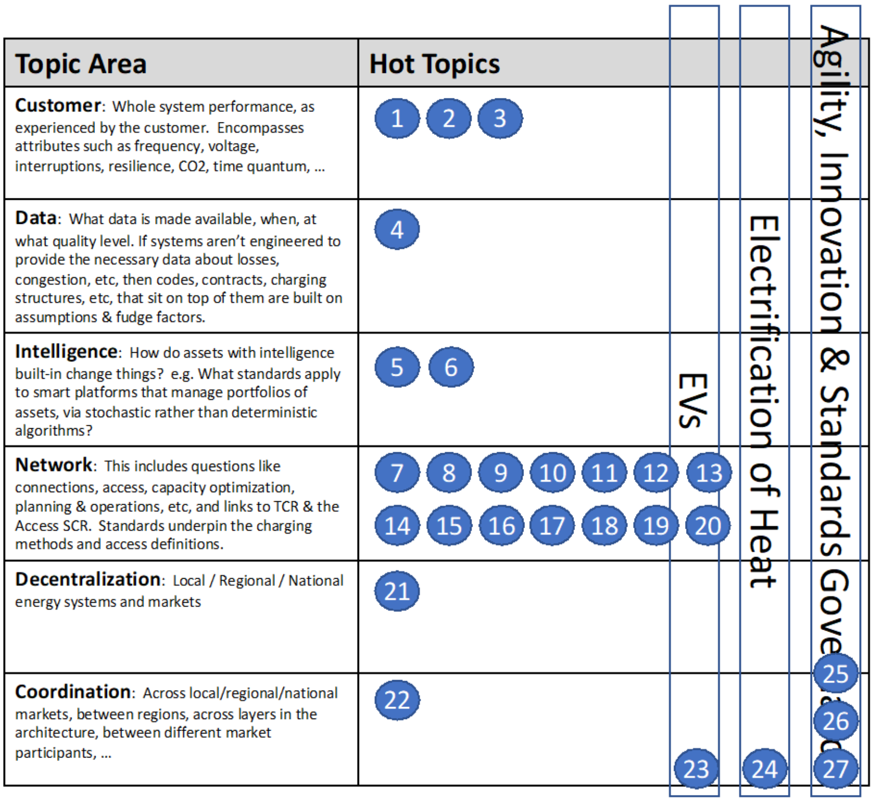
- A continuing drive towards decentralisation, and customer and community control of significant amounts of generation, storage and responsive demand
- Very large increases in demand on the electricity system through demand transfer from electrification of other energy vectors (mobility and space heating)
- That the electricity system could evolve in a number of different ways, varying from centrally led development to microgrids aggregating into wider systems. We have sought to be neutral in approaching this.
- Whilst dc systems might evolve at local level, the core national infrastructure will continue to be 50 Hz alternating current for the foreseeable future, because of the extent of legacy investment in this infrastructure
- Whilst the core technical behaviours of the electricity system exist independently of how it is owned and governed, we have assumed a continuing complexity and fragmentation of ownership, and some form of market arrangements and/or regulation of monopoly aspects, although not necessarily a continuation of what we have today
- The UK will continue to buy equipment built to international standards, and the European Network Codes will remain relevant to UK practice
- There will be wider reforms to the electricity system that create a more agile and flexible governance of change that is inclusive of a wide set of stakeholders

We also had to determine scope boundaries with the other work ongoing, which we did as follows:

- We took the Energy Data Task Force as defining how data should be surfaced and curated, but not which engineering data should be involved, which we determined as in our scope
- We took the Codes Review work as defining how governed engineering standards should be governed, rather than defining a different governance
- We took the EV energy task force work as defining the principles in this area, but saw a gap between these principles and implementation that we treated as in our scope
- We took the BEIS/BSI smart appliances work as handling this area, so did not duplicate this work
- We assumed international standards-making processes would not change as a result of this review, although we did consider UK participation in these processes

E.3.4 Selection of topics to investigate

Discussions amongst the Panel explored a range of 27 potential topics, which were then assessed against a categorisation of Customers, Data, Intelligence, Network, Decentralisation and Coordination, and where the Panel felt there was significant customer impact in the short term. Figure E-1 shows the longlist.



Topic Area	Hot Topics
Customer: Whole system performance, as experienced by the customer. Encompasses attributes such as frequency, voltage, interruptions, resilience, CO2, time quantum, …	1 2 3
Data: What data is made available, when, at what quality level. If systems aren't engineered to provide the necessary data about losses, congestion, etc, then codes, contracts, charging structures, etc, that sit on top of them are built on assumptions & fudge factors.	4
Intelligence: How do assets with intelligence built-in change things? e.g. What standards apply to smart platforms that manage portfolios of assets, via stochastic rather than deterministic algorithms?	5 6
Network: This includes questions like connections, access, capacity optimization, planning & operations, etc, and links to TCR & the Access SCR. Standards underpin the charging methods and access definitions.	7 8 9 10 11 12 13 14 15 16 17 18 19 20
Decentralization: Local / Regional / National energy systems and markets	21
Coordination: Across local/regional/national markets, between regions, across layers in the architecture, between different market participants, …	22

	Topic
1	Frequency/Inertia – challenges of future management. Does this need a case study to make it sufficiently focussed?
2	Voltage Limits, ie current absolute versus relaxed or probabilistic
3	What service level guarantees should the system give the end customer?
4	What data should equipment make available to whom & how?
5	Flexibility – what else is needed?
6	Probabilistic versus Deterministic standards
7	Connexion and control of storage in D networks
8	Flexible connexions – exploitation of interoperability
9	Fault levels – ie protection and black start issues.
10	Management of high volts on the transmission system
11	Lack of operating standard for DNOs, particularly for active network management and its customer effects
12	P2/7 from a non-DNO perspective – what next?
13	Transmission Scheduling & Constraint management
14	SQSS
15	Implications to standards from the current Significant Code Reviews on charging
16	Technical and non-technical losses
17	Relevant Electrical Standards for Transmission Connexion
18	Work Force Requirements/Qualifications/Training
19	Transmission Outage management
20	Transmission Alarm Management
21	The case for regional standards
22	Implications to support innovations from trial to full scale
23	EVs – use of flexibility, control of charges etc, platforms for charge management
24	Electrification of heat
25	Where standards are blocking innovation
26	Are standards needed (or not needed) to help or remove blocks on innovation offshore?
27	Are any new standards required to enable innovation?

Figure E-6 : Longlist of potential topics, and their categorisation

From this longlist we determined a shortlist of:

- Voltage
- Frequency
- Security
- Resilience
- Interoperability
- Capacity

This list was explored at an Industry Day in June 2019, and was supported by participants.

E.3.5 A future state that supports an uncertain future system

The Panel gave considerable thought to the characteristics that engineering standards would need to display in an uncertain future energy system, which we believe will be characterised by a much faster pace of change and much more need for agility and flexibility than today. We then compared this with the system we have today and constructed the From-To journey shown in Figure E-2 to help shape our thinking. The end point in this journey is not a defined electricity system, rather a defined mechanism to evolve engineering standards that can handle and enable continuous change. This review has not been able to define the journey in any detail, but has explored how the system needs to be reframed to facilitate this journey.

Figure E-7 Proposed from-to journey for engineering standards

From

- A mix of standards evolved from those inherited from the 1980s and before
- Freeze-thaw-refreeze review processes
- A focus on single licensed entities not whole system, and silos either side of meter
- Embodiment of legacy learning from the industry's first century
- Somewhat incoherent mix of Ofgem performance requirements, Ofgem-governed codes and standards and a large body of network industry standards
- Limited recognition of the changes now upon us
- Not generally supportive of innovation except through special initiatives
- Focused on electricity as a silo within the energy system

To

- Performance based standards at end user level, connected to performance based standards at licensed entity level. Open systems and interoperability wherever practical
- Agile review processes based on emergent learning
- Whole electricity system focus (G,T,D, users), with awareness of other vectors
- Important legacy learning retained, obsolete learning removed, best international practice adopted
- Clear hierarchy/purpose of ownership and accountability between Ofgem and industry parties for design, implementation and ongoing performance/suitability
- Embracing and enabling 2030 and beyond
- Devolving responsibilities to consumers and communities so consumer choice drives development
- Innovation enabled, routinely
- The recognition of the role of electricity within the energy system reflected

E.3.6 Important areas not explored in this work

The landscape of engineering standards in electricity is large, complex and deeply technocratic. This review has been able to explore six important topics, and make recommendations, and to propose a framework for future change. It has not considered:

- The 21 topics on the longlist not taken forward, and other relevant issues
- Asset and product standards in any detail
- Work necessary to implement recommendations, which will need to engage stakeholders and explore detail in a way we have not been able to
- Industry and cultural change to move from current arrangements to more agile and flexible standards-making
- Interactions with other energy vectors, in any detail
- Issues outside the relatively narrow field of engineering standards, although we have had regard to policy, regulatory and market contexts.
- Economic analysis. Where possible we have noted and interrogated the analysis of others but have not undertaken our own economic studies. Suitable analysis should be undertaken as part of moving forward from our recommendations.

The pace of activity needed to deliver net zero means that these issues would benefit from attention if customers are to receive best value.

Reference Appendix F: Historical Context for Electricity Industry Engineering Standards

At privatization in 1990 the industry had a set of documents relating to security of supply – about half a dozen various CEGB operating memos (OMs), standards (eg PLM-SP-1, PLM-ST-9) and ER P2/5 ER G59, ER G5/3 etc. The industry also had hundreds of specifications for individual generating and network components. Historically there were a number of collective names for these documents and engineering standards is a good a name as any.

Transmission

In spite of the legacy of engineering standards the on privatization National Grid did not inherit an appropriate suite of documents that related to the connexion to and operation of independently owned generation – because this was all internal practice (some documented and some not) within the CEGB.

Hence the Grid Code was written to deal with the interface between the transmission system and its users – principally large power stations and the 12 Regional Electricity Companies (note that Scotland was different then and is a bit different still). A licence condition was created for the Grid Code and a parallel licence condition required the maintenance of the 5 security standards. The Grid Code was set up with a governance panel from its inception, but there was no equivalent for the security standards. In 1997 after a multi-year project the old CEGB security standards were updated and amalgamated into the Safety, Quality and Security Standards (SQSS). The SQSS was maintained by solely by National Grid, but at that time, if it was amended, it necessitated Ofgem consulting on a change to the relevant transmission licence clause. The governance of this was changed at some stage, probably 2004, to be under a SQSS review panel.

A list of a small number of other CEGB standards was maintained by National Grid and used in parallel with the Grid Code for equipment etc on shared sites, and for the telemetry etc for communicating with power stations. The successors to these standards are known as the Relevant Electrical Standards (RES). There are about two dozen of them and until 2004 were the private preserve of National Grid, even though they affected customers directly. In 2004 Ofgem required them to be included (albeit imperfectly) within Grid Code Governance.

In hierarchy terms the SQSS is the prime document because it sets out what is to be achieved. The Grid Code then specifies what and how customers have to do to meet the SQSS requirements. The Grid Code and the SQSS therefore have a deep relationship, and it could be argued that their separation is an artefact of what appropriate documentation was available in 1990. Whilst arguments could be made for the continued separation of the two documents and governance, these have never been advance to the Panel’s knowledge. In terms of efficiency and simplicity it would seem sensible to remove the distinctions in documentary and governance terms between the SQSS and the Grid Code.

Distribution

The situation in Distribution in 1990 was somewhat different. DNOs (or RECs or PESs at the time) really traditionally only had demand customers. However in 1990 there were still a lot of coal power stations in the size range 100MW to 200MW range embedded in the 132kV system. Also, although embedded generation apart from this was almost non-existent, G59 had been written by the Area Boards (RECs/PESs forerunners) as a response to the 1983 Energy Act which allowed for private ownership of generation.

So the Distribution Code was written in 1990 to mirror the Grid Code for the management of the ex CEGB generation (and other similar developments) embedded in the 132kV system, and also to avoid the effort of writing the equivalent requirements into the Distribution Code for smaller generation by just citing G59. The same approach was taken in the Distribution Code by citing other ENA documents for issues such as power quality, earthing etc. In an ideal world they would have written much of those standards directly into the Distribution Code, which to a greater extent the Grid Code does. The most likely reason why this was not done (to make it more like the Grid Code) was probably just the time pressures of the privatization timetable. And because the two codes were developed in parallel by different personnel, the equivalence of the Distribution Code appended documents to the RES was not remarked, thus leaving a different governance approach in place until the RES was brought into the Grid Code governance in 2004.

Governance

The two technical codes were set up in 1990 with review panels, representing stakeholders and the network licensees, to oversee changes and to keep the documents up to date. At that time the governance and change process did not unambiguously include the daughter documents (such as P2/5, G59/1 etc). The governance was formally extended to all daughter documents in 2004.

The efficient, representative and transparent governance of these documents remains an issue and is the subject of the BEIS/Ofgem ongoing review of code governance.

Summary

Engineering Standards have a long history going back decades into the nationalised electricity system of the 1960s to 1980s. Within the general scope of the term is the Grid Code, Distribution Code, their daughter documents, and hundreds of other technical standards that the network licensees use internally for the procurement of equipment and the operation of their networks.

The Engineering Standards Review has focused primarily on those standards that are the Codes themselves and their daughter documents. The codes and their daughter documents have direct effect on customers because these documents describe requirements or behaviour at the interface between network licensees and their customers, and thus can also impose costs and constraints on customers. Therefore it is appropriate they are publicly governed and subject to Ofgem approval. Conversely standards which the network licensees use for wholly internal purposes with no direct effect on customers are not within scope of the Engineering Standards Review.

Reference Appendix G: Lessons from the 9 August 2019 incident

Issue	Lesson
Loss of Hornsea wind farm, resulting from control software issue	Need for more rigorous compliance assurance for connected active devices – Panel recommendation Need for more rigorous approach to applying and assuring software updates. Panel has recommended task force to look into this.
Subsequent loss of generators at Little Barford, which did not behave as expected	Need for more rigorous compliance assurance for connected active devices – Panel recommendation
Unexpected loss of large amounts of distributed generation	Lack of visibility of DG to the system operator. Panel recommendation on moving to a data driven system.
	RoCoF and Vector Shift settings had not been changed on much of the distributed generation. Panel has considered and believe steps in progress to make changes are sufficient
	Incorrect frequency settings: Need for more rigorous compliance assurance for connected active devices – Panel recommendation
	Insufficient reserve held by NGESO to counter for loss of distributed generation – subject to Ofgem review and within existing SQSS governance. Not all contracted reserve delivered. Openly published data on reserve performance would help make this visible (Energy Data Task Force recommendation) ESO may have been able to use its reserve more effectively with dynamic and adaptive feedback loops but its products are not currently designed for that. Panel recommendations on VoLL open the path to these kinds of developments.
LFDD disconnected sites that were deemed important	More clarity in what the electricity system is expected to deliver to customers – Panel recommendation Networks that respond to value of lost load, segmented by customer type – Panel recommendation
Class 700 and 717 trains disconnected on under-frequency and locked out	A clearer statement as to what the electricity system can be expected to deliver to different customer groups may have made this clearer to the train designers – Panel recommendation Software reset should be within driver capability. Not addressed by Panel.
Concern over the extent of change making the system more fragile than in the past	More agile mechanisms to ensure standards respond to change in the future – Panel recommendation System health assessment – Panel recommendation
Ofgem both the reviewer of the incident and responsible for relevant standards.	Separation of ‘policing role’ and ‘sign off’ of top level standards to avoid marking of own homework on issues with regulatory signed off standards eg SQSS, Codes, Panel recommendation on governance

Glossary

Engineering standard: *any provision that drives engineering decision making on the whole electricity system.*

Whole electricity system: *the complete electricity system including networks, all sources of generation, equipment connected to networks, equipment on customer premises, touchpoints with other energy vectors, related data and communications systems, relevant legislation, regulation and market arrangements, commercial contracts and associated supply chains*

BEIS	Department of Business, Energy and Industrial Strategy, a Ministerial Department of the UK Government whose responsibilities include energy
BSI	British Standards Institution, a standards making body
CEGB	Central Electricity Generating Board, from 1958 until industry privatisation in 1990 the state-owned generator and transmitter of electricity in England and Wales
D	distribution (of electricity, locally)
DCRP	Distribution Code Review Panel
DG	Distributed Generation, smaller generators connected within local networks
DNO	Distribution Network Operator
DSO	Distribution System Operator, at local scale
DSR	Demand Side Response, the ability of sources of electricity demand to reduce or increase according to wider system needs
E3C	Energy Emergency Executive Committee, a partnership between government, the regulator and industry which co-ordinates resilience planning across the energy industry
ENA	Energy Networks Association, the trade association for energy network operators
ESCO	Energy Services Company, a provider of multiple energy services, usually at local scale
ESO	Electricity System Operator, at national scale
EV	Electric Vehicle
GW	Gigawatt, a unit of power. One GW is one thousand Megawatts (MW). One MW is one thousand Kilowatts(kW). The maximum electricity demand in the UK is around 65 GW currently, and a typical house that does not use electricity for space heating or transport has a demand on average of about 1.5 kW, an electric kettle about 3 kW.

HV	Voltages above 1000 V
IET	Institution of Engineering and Technology
IT	Information Technology
kW	See definition of GW
LV	Voltages below 1000 V
MW	See definition of GW
Ofgem	Office of Gas and Electricity Markets, the economic regulator for energy in Great Britain
PAS	Publicly Available Specification – a standardisation document that closely resembles a formal standard in structure and format, but which has a different development model designed to speed up standardisation.
T	Transmission (of electricity, usually at national scale)
V2G	Vehicle to Grid, a way to use electric vehicles as stores of energy to help the electricity system when needed
VoLL	Value of Lost Load, a means to assess the economic cost to customers of power interruptions

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