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Sources of risk and uncertainty in UK smart grid deployment: An expert stakeholder analysis

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ABSTRACT

The shift to increasingly smarter grids will require preparation and planning on the part of a diverse selection of current and future stakeholders. There are substantive sources of uncertainty that will impact on the adoption of smarter grid solutions. Risks and uncertainties are placed in one of seven categories: markets, users, data and information, supply mix, policy, investment conditions, and networks. Each of these has the potential to add risk to the planning profiles of the stakeholders involved. Here, UK stakeholders drawn from industry, government, regulators, and academia are canvassed about potential sources of uncertainty within the UK's electricity sector and the attendant risks that might be engendered by them.

1. Introduction

This paper is concerned with a qualitative discussion of the many sources of uncertainty concerning the development of a smart grid (SG) provision within the UK's electricity industry. It builds on previous work to identify key issues likely to impact the need for a smarter grid, the most likely influencing factors for demand and to set out concerns arising from industry stakeholders. We use the definition of SG suggested by the Smart Grids European Technology Platform: "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies" [1].

This work synthesises knowledge from in-depth expert interviews and online surveys forming part of a UKERC funded project to produce scenarios for the development of SG in the UK. The scenarios [2] are the culmination of a multi-stage process and have been used to inform the national debate about drivers, barriers, and uncertainty of SG deployment. A key area of the process was the identification of the principal elements of uncertainty and attendant risk arising from the many variables inherent to SG which will be, to a lesser or greater degree, emergent. Questions have been raised about the uncertainty of the potential benefits and risks of unforeseen issues for SG [3]. It was clear from the interviews in particular that an extended discussion of these risks was warranted, and that risk and uncertainty need to explicitly inform the considerations that underlie development and application of energy policy and regulation. This paper aims to fulfil this gap by analyzing previously unpublished data from this project with a particular focus on risk and uncertainties arising from the UK context.

There have been very few broad assessments of the risks for the development and deployment of SG. For example, although Rossebø et al. [4]; assessed many sources of risk, their analysis concentrated on operational parameters expected to be important. In their modelling, Zio and Aven [5] explicitly recognized investment, environmental and energy policy, and technical issues. Digmayer and Jakobs [6] conducted a study of experts and laymen into the risks associated with innovation in direct current grids. The risk categories identified by Digmayer and Jakobs were technical, health-related, economic, environmental, privacy, infrastructure,

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and landscape-related, approximately 80% of the risks referenced were technical. Lastly, Tuballa and Abundo [7] review some elements of the deployment of SG.

The UK energy policy environment relating to carbon reduction and renewable energy deployment is strongly influenced by EU commitments, though selection of instruments rests with the UK. Security is primarily a national concern, while social issues such as fuel poverty have both national and wider influences. Security of supply has become significant in shaping the UK generation mix and this significance will continue to grow while old coal and nuclear capacity are removed from the mix and the Government attempts to incentivise sufficient new capacity to meet demand. This will be partially met by new renewable capacity. EU policy requires 20% of energy consumption to come from renewables by 2020 and the UK agreed an ambitious and legally obligatory target of 15%. It is not clear what happens if any Member State fails to achieve their target [8] though substantial fines cannot be ruled out. Clearly the negotiated exit of the UK from the EU is likely to impact substantially on the UK's commitments and any consequences. A newer EU wide goal of 27% for 2030 is not a legal obligation but may pressure continuing increases at the national level [9]. It is not currently clear how the result of the UK referendum on leaving the EU will impact the UK's position. The UK has seen steady growth in generation from renewable energy sources of electricity (RES-E), particularly onshore and offshore wind and solar [10] and this is expected to continue, with a widening diversity of sources over time. Decarbonisation of heat and transport via electrification may require a shift to greater electrical demand, impacting on overall demand and demand volatility. The government and regulator have acknowledged the challenges of integrating these technologies into networks and markets and the need for new approaches to network management.

All GB distribution networks are owned by six distribution network operators (DNOs). UK DNO R&D expenditure declined steadily following privatisation in 1990. The continued evolution of policy and the emergence of a requirement for decarbonisation saw Government and Ofgem come to view this as unacceptable in the face of the challenges now faced for continued provision of reliable, secure and low carbon energy delivery [11–14]. This has led to a number of policy initiatives to provide new incentives for investment.

The need to adopt new technologies and new approaches, potentially in different locations for generation, network management and supply and provided by existing companies and perhaps new market entrants creates substantial new sources of uncertainty for all stakeholders. This paper explores these uncertainties with a view to identifying the most important concerning future risk relating to solving the energy trilemma via smart methodologies.

2. Methodology

We used a multi-step process as part of a wider programme of work carried out to inform the development of SG scenarios for the UK [2]. An extensive initial literature review highlighted many areas of uncertainty and the specific issues arising from them [15]. A list of UK stakeholder institutions was derived representing regulators, consumers, and network operators. Eighteen semi-structured interviews were conducted with experts representing these key organisations to identify emerging issues and those factors thought to be the most important in shaping UK SG development. The interviews fed development of a two-stage stakeholder online survey ($n = 77$, $n = 44$); broad characteristics of the participants are given in Appendix A. We used a ranking system to identify the factors considered to be most important in characterising UK SG development. A Delphi Policy process [16] identified the key transition points, with results checked for credibility at an expert workshop with fifteen participants [17]. The entire programme was overseen by an expert advisory group comprising ten participants.

The interviews inform the writing throughout this paper and their content was added to during the following stages of the applied methodology. The nature of the process, drawing on additional information to add to a larger model, means more quantitative assessments using tools such as NVivo is less appropriate since it would tend to militate against factors emergent in the latter part of the process. The quantity and scope of the data collected means that we focused on the main points arising from the whole process, with the later elements of the method enabling us to select for perceived importance from expert stakeholders.

While there it is always possible to overlook or misunderstand important information, considerable effort was made to capture the widest possible information set, with stakeholders asked to add to the list of considered factors at every stage. A framework to organise the information was required as part of the scenario development process [2] following the interview stage. Using information from our literature review and the interviewees, and the views of our expert advisory group, we developed a classification system as follows: markets, users, data and information, supply mix, policy, investment conditions, and networks. This represents the most important categories identified by the stakeholders. These seven groups were a convenient way of ensuring consistency through the whole programme and we use them here for categorisation. Many issues overlap categories and the categories should not be seen as silos in this approach. Four cross-cutting issues emerged, and these are introduced first to assist with laying out the evolving situation in the UK electricity sector.

While our method identified and ranked the areas considered most important for dictating the likely direction of UK SG development to 2050, we qualitatively describe the wider range of possible sources of uncertainty and the potential risk arising from them.

3. Risks raised by stakeholders

Independent of whether the interviewees and survey respondents considered an issue to be a driver/barrier or benefit/pitfall of SG development, each has associated uncertainty. This implies risk when companies are making decisions about investing in new capacity, management or in bringing new services or technologies to market. The meanings of our seven groups, whilst widely applicable, are conceived in the context of the SG scenarios developed by Balta-Ozkan et al. [2]. We discuss the cross-cutting issues first, then summarise the key risks, and their associated uncertainties and drivers in Table 1.

4. Cross-cutting issues

Four issues were mentioned in multiple risk groups and warrant being discussed separately from the categories discussed below.

4.1. The broken value chain

The potential costs and value of smarter energy systems may be distributed across many stakeholders. However, it is not always clear which stakeholders will benefit from which actions and how value might be assigned [18]. This is a type of 'split-incentive' problem with the UK smart meter (SM) roll-out a prime example. Suppliers are bearing the cost for SM, but the usefulness to suppliers is largely limited to automated collection of consumption

Table 1
Summary of the principal sources of uncertainty and risk identified by interviewees and survey participants.

Category	Key Uncertainty	Risk	Impact
Markets	Commonality across the UK	Lack of co-operation between suppliers and DNOs	SG functionality
	Rate of market development	Lack of access to markets for small generators and aggregators	New energy services
	Changing policy	Supply market concentration	Competition
	Value for money for the consumer	Lack of customer engagement	Demand management
Users	Level of behaviour change	Lack of customer buy-in re demand-side response	Demand management
	Customer engagement	Failure of smart meter roll-out	SG functionality
Data and Information	Level of aggregation and availability	Lack of data protection and security	New energy services
	Level of public trust and acceptability	Lack of transparency	New energy services
	Commonality across the UK	Inadequate smart meter technology	Equality of outcome for consumers
	Level and timeliness of access	Lack of access for system operators	Cost reduction
Supply Mix	Planning for reinforcement	Curtailment of network access	RES-E targets
	Planning	Lack of public acceptability of RES-E	RES-E targets
Policy	Changing policy	Policy instability	RES-E targets
	Changing policy	Lack of long-term planning	CO_2 reduction target
	Misaligned aims and objectives	Lack of coordination between Ofgem and BEIS	Competition
Investment Conditions	Rate of return	Lack of access to capital	CO_2 reduction target
	Future price controls	Continued under-investment	SG functionality
	Rate of return	Lack of innovation	SG functionality
Networks	Rate of increase in RES-E	Low rate of decarbonisation	RES-E targets
	Rate of SG deployment	Industry inertia	Cost reduction
	Rate of SG deployment	Intelligence used as a temporary fix	Cost reduction

data from consumers. The potential for more substantive systemic benefit is in network management. However, this depends on the data that is captured, who can access it and under what conditions, and the services that it might enable should the network become more sophisticated. The benefits to suppliers are limited and may threaten their business models [2,11,19]. This represents a systemic threat to the wider UK conception of the SG. It has the potential to limit SG solutions for networks, inhibit innovation, reduce the potential for dynamic pricing and negatively affect many more anticipated elements of the smart grid.

Another issue raised was access to value generated from data. One supplier interviewed emphasised that if the introduction of a time-of-use tariff (ToU) or significant consumer behavioural change were to be achieved, then a challenge for their sector would be to ensure the benefit went right across the value chain [20]. This has significant potential to alienate consumers. Stakeholders noted that supply companies have the most established relationship with consumers and this might enable them to roll out new SG services. However, it was noted that UK electricity supply companies are also amongst the least trusted institutions and the Government has committed to ensuring that data access does not expand from the current position [21].

4.2. Public perception and media representation

A number of stakeholders raised the risk of negative public reaction to smart energy technologies and services. Low levels of consumer trust in utilities and media criticism of utility operations and profits were noted by many respondents. It was perceived that if the media were critical of new and emerging technologies or applications, it could inhibit uptake. Possible negative coverage might object to perceived cost, effectiveness, intrusion into the home and risk of health effects (regardless of evidence). The latter has already seen negative headlines in some territories and to some extent in the UK [22–24]. This risk of lack of public acceptance may affect the cost effectiveness of SM, data and information availability, and reduce the consumer base for new markets and services.

4.3. Skill shortages

Participants stated that the risk arising from a lack of appropriate skills was widespread in the industry. Uncertainty concerning which technologies will dominate affects investment in particular skillsets [25]. A shortage of skills would tend to reduce options for network operators and push up costs. Some action was noted e.g. the Power Academy, a scheme to encourage graduates into electrical engineering appropriate to the power sector, but this was thought unlikely to be sufficient due to the ageing profile of many DNO engineers. Other shortfalls included modelling skills amongst DNOs.

4.4. Institutional issues

Stakeholders were asked about the institutional barriers to UK SG development and the roles and effectiveness of the Department of Energy and Climate Change[1] (DECC), the Office of Gas and Electricity Markets (Ofgem) and the body they jointly support, the Smart Grid Forum. There was concern about the absence of high-level plans for moving the UK forward to its wider energy targets, the electricity sector reform and the necessity and scope for SG within this framework. The need for more leadership from Government was cited, specifically to identify and implement steps necessary to achieving long-term SG goals. This linked to a widespread concern as to the importance of effective co-ordination of the system-wide changes necessary to facilitate smarter energy delivery. To ensure different elements moved forward concurrently, for example, to ensure policy and regulatory change keep pace with technology.

5. Markets

'Markets' refers here to both the continuance of old and the provision of new energy services, by existing and new actors. This includes tariffs and business models which may be premised on the use or mediation of energy technologies.

Accessing future lower cost tariffs using demand-side response (DSR) may require consumers to make available a service to an energy company. This depends on the willingness and ability of consumers to change their energy-use behaviour sufficiently to

[1] In 2016 the Department of Business Innovation, and Skills and the Department of Energy and Climate Change were merged to form the Department of Business, Energy, and Industrial Strategy.

deliver an aggregated, cost effective benefit to demand management. The risk is in customer willingness to accept that it is worthwhile to spend time and resources to access tariffs linked to load-shifting. Both the willingness and capability to engage with DSR technology would be telling in terms of which consumers benefit. A key source of risk suggested by some respondents is consumers rejecting DSR technology, thus rejecting behavioural change as this would appear trivial in terms of energy and thus cost savings.

Owen and Ward [26] and Owen et al. [27] suggest that a typical UK household demand might be able to shift 9% of demand. Although the UK Energy Demand Research Programme found up to 10% short-term savings in 1–2 person households, the (limited) longer-term evidence suggested 3% or less [28]. This has the potential to increase with adoption of technology. Consumers without 'shiftable' load may come to subsidise those with such load, since the latter may eventually be able to take better advantage of dynamic pricing. It was noted that some new household tariffs might be regressive and that tariff structures rewarding shiftability might add to this since access to new and expensive technology may be limited to wealthier households. Energy efficiency programmes might most usefully be aimed at those without shiftable load. Since shiftability may dictate access to lower tariffs political repercussions may arise if some consumers can access lower tariffs while others cannot. Getting the right tariffs to incentivise consumers was also cited as important i.e. a tariff that works for the consumer rather than just bringing complex tariffs to market. It was also noted that a current UK political trend of simplifying consumer tariffs may be at odds with increasing complexity arising from dynamic pricing or ToU tariffs [29,30].

Load-shifting by industry is already commonplace with large consumers having bespoke contractual arrangements. Some sectors have high uptake of energy efficiency. Involvement in demand side activity might be determined by processes specific to each industry. It was suggested there may be little value in shifting for some industries and little opportunity in others, while some might benefit.

Electric vehicles (EVs) *may* be able to offer bulk energy and ancillary services (such as frequency support) to distribution networks. If properly managed and incentivised EVs might act as a key element of demand shifting and enhanced flexibility, but this would require the integration of numerous elements including willingness on the part of EV owners, DNOs and economics favouring adoption for both. Peterson et al. [31] and Bishop et al. [32] present evidence that the economics of battery degradation makes the provision of vehicle-to-grid (V2G) services unlikely, though this may change with technological innovation. The emergence of widespread EV adoption may also not emerge on the same timeframe as storage is needed, Relying on V2G as an important element of SG thus presents a risk [33].

Other issues considered by interviewees and respondents to be important were the risk of continued sector fragmentation, lack of co-operation between suppliers and DNOs, lack of opportunities for aggregators, lack of access to markets for small generators, and supply market competition and concentration. Also highlighted was the slow development of markets for storage, DSR, EVs, and heat. Uncertainty concerning uptake rates is likely to be highly significant as regards network planning and investment. Risk potential includes over and under investment in networks, with respective impacts on cost, return to networks or retardation of growth in renewables.

6. Users

'*Users*' here predominantly means residential, commercial, and small industrial consumers. Large industrial users already manage their risks in more advanced ways. The risks identified emerge mainly from the role and engagement of consumers.

Many stakeholders emphasised that the lack of a substantial uptake of DSR and consumer involvement was a risk to realising full SG potential, and in particular what might be achieved by demand management. It was also noted that current potential to shift demand will be limited if the *"… visibility of advantages …"* is not apparent. Customer awareness of SG and what it means for them was summed-up by one respondent as *"The degree to which people can understand and want a more complex relationship with their energy suppliers"*. When asked about consumer engagement stakeholders had concerns as to whether groups of consumers would benefit equally from SG. The extent to which consumers engage with smart technologies and products such as time-varying tariffs will impact on the provision of new services and system management methods [34]. Uncertainty as to the level of engagement might only be resolved once action is taken to open up markets [2] with one respondent suggesting that success may depend on the implementation strategy.

Stakeholders noted the degree to which residential consumers will tolerate high prices rather than take action, seeing the unknowns arising from this as a significant risk to the uptake of demand side measures. The concern of many utility and other stakeholders was that consumers would decline to become more proactive and that this put a key element of systemic flexibility at risk. Uncertainty arises in the uptake of new services and tariffs; Darby et al. [35] suggest novelty and behaviour change diminish in a few weeks. Consumer rejection of DSR might be partially mitigated by the development of automated DSR measures, with this dependent on whether and when these develop and if they can find a route to market. The uncertainty arises from the potential complexity faced by the residential consumer; commercial consumers with energy management capability may be better able to take advantage of the new energy services SG will offer. Consumer disengagement or resistance (scepticism) was considered by survey respondents as the biggest perceived barrier to the smartening of the networks. Further work is needed to determine the consequences of increased complexity of decision making on consumer engagement. Additional uncertainty about DSR arises from the rate at which automated and non-automated technologies emerge and the scope of what each can achieve [36]. Respondents identified a lack of common technical standards as a risk to widespread deployment and interoperability, highlighting the need for coordination [37,38].

An additional near-term risk is the scheduling of the UK's SM rollout. Approximately 53 million gas and electricity meters are to be replaced in domestic and small commercial GB premises by 2020 [39]. However, the rollout has already faced repeated delays and may be at significant risk of overrun, with the potential to become a "*costly failure*" without Government intervention [40]. Delays to the rollout completion presents risk to the emergence of opportunities for demand side response, and to addressing the lack of temporal knowledge about electricity consumption needed to improve network management. One respondent called for *"Joined up thinking between smart metering and smart grid programme[s]"* though this reflected the opinion of numerous stakeholders. This echoes a wider call from many stakeholders for greater levels of coordination relating to UK SG development, and particularly for UK Government to take a stronger role.

7. Data and information

This section is concerned with both historical and real-time data generation, collection, aggregation, accessibility and billing information. We consider the establishment of a technically and economically effective system for managing large volumes of data, and the limitations to SM and sensors (due to Government cost-setting). The three most frequently cited areas for risk by the survey respondents were data protection and security, privacy guarantees, and public trust and acceptability [17].

A significant source of uncertainty is whether data (or information) will reach where it can best be used. The level of aggregation, availability, and how rapidly it gets to stakeholders, will largely determine what services can be made available. This includes what network operators know about demand and the rapidity with which they can respond to network issues.

All data generated by SM will be passed to the Data Communications Company (DCC) for handling and passing on to stakeholders with access rights (currently suppliers only). This will allow suppliers to transfer data to and from consumers. The UK SM implementation strictly limits access to data to maximise customer privacy. Third party data access is strictly limited, with DNO access effectively disallowed in the supplier-led rollout. There was a supposition amongst many respondents that the frequency of data collection via SM and data aggregation was likely to become freer over time, with consequent implications for network services. The rate of change in data access will be a key determinant in how, when and which potential SG features become available [2] but this is subject to many factors including political will and public buy-in, making the rate of change unpredictable. Pullinger et al. [41] conclude that the current UK SM specifications may mean missed opportunities and that data resolution may prohibit some prospective uses of SM.

The supplier-led nature of the rollout also emphasises upfront cost saving against SM capability. Reduced capability risks a loss of future flexibility; one respondent suggested *"There is a real danger of installing a system which cannot deal with better than half hourly signals … and that would limit smart grids and require a second system to go in 5-6 years."*

A further source of uncertainty is that the three UK areas (North, Central, South) see communications provided by two service providers using two different communications technologies [42]. The risk is that different levels of performance may engender different outcomes for consumers.

Smart meter data has a broad range of possible uses for DNOs as well as other existing and potentially emergent stakeholders. Balta-Ozkan et al. [2] and Hall and Foxon [18] noted that there was a substantive risk for the UK in not recasting DNOs as DSOs or at least allowing them to adopt some of the characteristics. This evolution to DSO operations is being considered and may move ahead [43,44]. The need is for DNOs to have greater responsibility, and the tools, for system balancing. Denial of increased access to the SM generated datasets might lower the potential value for SM in aiding systemic cost reduction.

There was disagreement over the exact form of SM data outputs that might be usefully made available. Some respondents cast doubt on the need for real-time data, claiming that many key benefits were in greater volumes of data which need only be available on an aggregated or delayed basis. Understanding the usage landscape is the key point. There was general agreement that restrictions will be relaxed over time but uncertainty arises from stakeholders not being clear as to what data will be available, when, and how much control an individual stakeholder may exert to limit access. The risk lies in the lack of signals to trigger investment in new service provision, particularly for DNOs but also in uptake of usable options as they emerge in other national contexts.

The curtailment of data access arises from the need to protect consumer privacy. The UK default is to strongly protect privacy, but it is possible not all consumers will require this level of protection and may support some level of reduced privacy in return for potential tariff reduction. Consumer perception may dictate the rate of revised data access, but decisions will sit with Government and the regulator [45–47]. Furthermore, a lack of transparency about data exploitation was considered a risk for public opinion and media treatment of energy issues. One respondent considered the key point to be *"Consumer confidence in data relating to their energy use"*.

Security is a key issue for SM rollout, and closely linked to privacy [20]. Stakeholders had specific concerns about the vulnerability and consumer perception of vulnerability of SM and other 'internet of energy' systems to remote or physical interference. The risk of a lack of data security was raised by many respondents. This contrasts with access, giving rise to potential conflicts and therefore uncertainty about priorities. It is not possible to estimate how many consumers might allow third party access to their data and under what circumstances.

8. Supply mix

This section is concerned with the evolving roles of flexible, variable, and inflexible generation. There was an expectation that shifting demand will be an essential element of the future grid responsiveness to rapid shifts in output from intermittent RES-E generation and that should consumers decline to do so in bulk it would require alternatives that would be costly and potentially more difficult.

Some UK counties are effectively sterilised for new distributed generation above the domestic scale since reinforcement would have to be so extensive that costs are prohibitive. The key uncertainty for DNOs is when, where and to what extent reinforcement of networks should occur. This is predicated on many variables including growth in demand for generation connection, uptake and location of heat pumps (HPs) and EVs. Approaches used so far by DNOs, include prioritised constraint of generators on a 'last in, first out' basis and wind farms contracting to shut down when local PV output is high, that is, curtailment risk is transferred to the generator. This displaces smart solutions which many respondents considered would be cheaper than traditional reinforcement in the long run. Uncertainty in planning for SG arises from the unknown volume of RES-E resulting from current policy as well as from the types of technology that may be deployed. Offshore and onshore wind energy was looking likely to be most significant, but further deployment of onshore wind appears halted [48].

Political, geographical, market, social or technical factors create uncertainty in how RES-E technologies are adopted across the UK. The political imperative for RES-E is currently an important enabler but this does not imply certainty into the future. Respondents expressed concern over political commitments as well as continued rates of deployment as a major source of uncertainty. They also questioned whether it was possible to adequately support both RES-E and nuclear power from the public purse, citing the potential for conflict over policy frameworks and the flexibility issues around large-scale use of nuclear. The funding of these two technology groups from a single source, the 'Levy Control Framework', adds to potential uncertainty as to rates of expansion, with each requiring different approaches to network investment and future system balancing. It was noted that regardless of the comparative economics, RES-E will be impacted by decisions such as the UK Government's to provide greater support to nuclear fission than to the more mature RES-E technologies. Furthermore, protests against RES-E occur in many nations for reasons including cost and landscape impacts [24,49–52].

The political narrative may change, implying potential variance in support for the different technologies expected to impact the grid. This might mean:

1. Growing support, as has essentially been the case in most of Europe in the last decade,
2. Reduced support as with some EU Member States following the 2008 economic downturn, or
3. Rejection of one or more renewable energy technologies in favour of more general support for CO_2 emission reduction and low carbon technology without the RES-E emphasis.

This might favour increasing gas generation due to concerns over security and reliability of supply, or other policy initiatives, for example nuclear generation. The potential for different mixes of electrical generation – not just of RES-E – was cited as a major source of uncertainty in planning degrees of smartness [15].

9. Policy

Respondents highlighted the risks due to ineffective policy and in particular policy instability, not just in terms of changing what is required from the grid but in terms of the policy framework for smarter approaches to dealing with them. The impacts of policy on uncertainty and risk can be highly varied. Arguably, longevity is one element of good policy but this is too simplistic in terms of the selection process to achieve specific goals, possible failure of that instrument, and potential changes in broader policy aims with political and public agendas. The failure to create political certainty may impact on overall installed capacity of low carbon technologies, and the timeframe over which commissioning occurs. This uncertainty applies to all RES-E technologies and existing or emergent competing technologies (such as gas, nuclear and CCS).

A point raised by many respondents was consistency of approach to long-term planning, particularly between Ofgem and DECC. Furthermore, the risk of not aligning the goals, objectives, and strategies of DECC and Ofgem was raised frequently with one respondent saying: *"Both must agree on common aims and objectives"*, another accentuating the need for *"Linkage across price controls i.e. incentives for networks to work with each other to deliver optimal benefits to GB plc"*. *"Regulatory boundaries for network operators, must liaise better with the customer"* typifies the opinion of many respondents. The absence of more effective coordination was seen by many respondents as potentially restricting the development of smarter energy solutions and their integration into the wider electricity system. Two areas of risk were identified 1) a failure by Government and other stakeholders to develop the mechanisms and institutions to coordinate SG development, and 2) a failure to do so effectively, by selecting inappropriate policy instruments. Despite the formation of the Smart Grid Forum by DECC and Ofgem there were numerous calls for greater future coordination, and especially for DECC to take a much stronger role. Comments such as *"Certainty of legislation and regulation so that investments are secure"* summed-up the main issue. The regulatory system emerging from RIIO creates a new operational environment for DNOs.

The changes to UK policy in support of large-scale RES-E have been manifold [11,53–56]. They exemplify some of the wide range of factors which could impinge on the total volume of intermittent generation that will be developed on (and off) the UK network, the type of technology and thus the spatial variation in where it might occur. Each undermines the ability of the networks to plan for the future. The risk of lack of clear Government policy and leadership was summed-up by two typical comments from respondents *"We need a clear, consistent and steady policy on energy production"* and *"Government policy for example, a clear position on electrification as key (or not) to carbon reduction"*. Furthermore, one respondent specifically mentioned targets: *"Changing targets driven by the EU and/or national politics"* as indicative of the risk of unclear policy governance.

Concerning UK regulatory policy, the Government and Ofgem acknowledged that the RPI-X[2] system of network regulation introduced with privatisation in 1990 was incapable of delivering the innovation needed to integrate smarter grid management and thus decarbonisation [57,58]. They took steps to address this by:

1. Introducing the RIIO[3] system for network incentivisation and
2. Incentivising DNOs to invest in R&D via Registered Power Zones (RPZ), the Innovation Funding Incentive (IFI) (both 2005–2010), the Low Carbon Network Fund (LCNF, 2010–2015) and most recently the Network Innovation Competition (NIC) and Network Innovation Allowance (NIA).

While these where seen by the majority of respondents as positive changes a key criticism from various stakeholders was summed-up by one respondent as *"Regulatory incentives* e.g. *LCNF encourages piecemeal solutions without a clear UK strategy"*. There was also some concern that while these mechanisms might assist in creating new network options, there may not be sufficient capital available to the DNOs to roll them out across the networks. A recent review of the LCNF agrees that there is no clear path to wider rollout [59].

Ofgem introduced RIIO as the main instrument for incentivising the Transmission System Operators (TSOs) and the DNOs to invest in innovation and then deploy new approaches more deeply into network operations, something which RPI-X was unable to do. The aim was to allow greater flexibility for network investment. Stakeholder opinion varied as to its likely success and the extent to which it might achieve this aim. It is notable that many respondents did not consider that the failure of RIIO would rule out smarter networks [2].

10. Investment conditions

By *investment conditions* we mainly consider the trade-off between the cost of capital (cheap or expensive) and the regulatory investment framework (obstructive or helpful). The issues raised by participants indicated as most important were uncertain return on investment (ROI), new modes of financing and business models, and new value delivery mechanisms (e.g. flexibility). Also mentioned as significant risks were the elevated levels of investment required and the lack of access to capital. An overarching and recurring theme was long-term regulation and policy (un)certainty. Issues surrounding the impact of regulation on investment has been explored by Moisés Costa et al. [60].

A specific risk raised was under-investment by DNOs. Historically DNOs have focussed on incremental improvements to reduce costs, with the old RPI-X system of incentivisation set up to reward this and effectively ruling out more risky approaches. The SG transition presents a far more complex task.

Participants agreed that both National Grid and the DNOs will need to take more risks and that more innovation was required. This will increase costs and require a correspondingly greater ROI. Several respondents linked ROI to policy, for example *"Certainty of ROI – not government policy, but legally binding contracts"* was a typical comment. The level of additional risk that Ofgem will tolerate will be significant in determining the outcomes of future

[2] Price cap regulation of the form Retail Price Index (RPI) minus expected efficiency savings (X).

[3] RIIO, Revenue = Incentives + Innovation + Outputs UK price controls.

distribution price control reviews (DPCR). There is a risk Ofgem's perspective on allowable risk may remain more conservative than the DNOs, either collectively or individually, retarding innovation. A number of stakeholders referred to the issue of whether Ofgem would allow investment ahead of need, notably the allowance of investment which would not pay off until after the end of the ED1 DPCR in 2023. ED1 states this is permitted, but what Ofgem tolerates and what DNOs believe it will tolerate, is a source of uncertainty.

The RPZ, IFI, LCNF and NIA schemes aimed to address the fall in DNO R&D activity and have been credited with driving significant steps in revitalising the environment of driving investment in innovation [61]. However, participants criticised the piecemeal approach. One stakeholder criticised the IFI for ignoring operational innovation, and focussing too much on technical solutions.

The location were intellectual property rights rests was raised as a risk arising from the LCNF and its antecedents with the potential to deter investment. There was general agreement that the involvement of third-party companies in innovating system services was desirable. This has the potential to conflict with Ofgem perspective of capturing the benefit for the public of investment from regulated network funds. There was concern that Ofgem's approach needs to ensure these third-party businesses can benefit from their own side of the investment. The risk is whether RIIO can deliver the levels of innovative practice required and the adoption of new methods; failure may retard growth in multiple areas of enhanced network smartness.

A source of uncertainty raised by some stakeholders (notably those with an interest in distribution but not attached to a DNO) arose from doubts that the DNOs lack the structure to innovate. It was suggested that some UK DNOs may not have the intellectual capacity, capable personnel, or the will to drive innovative approaches. This is linked to issues such as skills shortages, but may go wider and present an institutional or cultural barrier. The institutions will need to evolve but at what rate will they need to invest in changes and what will an effective strategy look like?

11. Networks

We categorised networks as passive, partially active, and fully active. Much of what has already been reported here outlines sources of uncertainty for networks. Government decarbonisation policy drives increases of intermittent and firm distributed generation, and new volatile sources of distributed demand. However, uncertainty as to their capacity and location presents difficulties for TNO/DNOs when making investment decisions. Although not confined to network operators, industry inertia and resistance was identified as a source of risk with one respondent commenting *"It's comfortable to stay with BAU, least risk, least effort, pleases the owners"*. A key uncertainty is whether to deploy smarter alternatives ahead of immediate requirements or to minimise spending by reacting ad hoc. A respondent said that DNOs have a *"conservative nature"*; whilst this approach may appear as risk averse in the near-term, it may be a risky stance for the future, in an environment where many respondents regarded change as essential and with no possibility of a lasting status quo.

Many respondents highlighted the difficulty of making meaningful predictions for network needs after the 2020–2025 period i.e. the 2015–2023 RIIO-ED1 operating period. Many respondents identified a lack of a long-term vision for network development as a major risk to the successful deployment of SG. Some stakeholders said that while the Government has a vision for the system in the medium and long-term, it does not appear to have a staged-plan for implementation. Another stakeholder suggested Ofgem was allowing an open marketplace to *"let a thousand flowers bloom"* but questioned whether this was an optimal approach. Their view was that Ofgem should cut the options and engender a more specific route forward.

The different low carbon technologies present different risks to networks. One uncertainty identified was the uncoordinated charging of high numbers of EVs. Not only is the EV adoption rate unpredictable, but it may be gradual or may suddenly change as price parity is achieved [62]. Once EVs are present they imply risk in terms of impacts on overall demand profiles, in terms of creating new peaks. Exacerbating existing ones or causing rapid changes in demand [63,64]. The key uncertainty is the rate of emergence and of dissemination of technical network solutions but geographical distribution may also present issues. Balta-Ozkan et al. [2] identified that the rate of deployment is influenced by policy, success in trials, availability of finance, and whether the technology can be applied equally in urban and rural settings. This was summed-up by one respondent as making SG *"Complicated from the design perspective"*. These criteria increase the risk of over and under investment in different locations.

Demand-side management, DSR, and storage (amongst other solutions) are proposed as tools to enhance network management. Respondents suggested potential for conflict in trading for usage on markets for capacity and balancing. For example, the potential for National Grid to be in conflict over access to capacity produced from demand reduction which was contracted to other service providers.

The 'utility death spiral' [65], describes a possible situation of reducing network use and increasing volumetric charges, pushing users to seek alternatives and thus creating a vicious circle of reducing asset utilisation. Increasing the capacity of distributed generation and introducing smart technologies risks reducing asset utilisation, and therefore reducing income for TNOs and DNOs.

12. Conclusions and policy implications

This research emerges from work to build SG scenarios to 2050, taking an approach which identifies the main events which will shape them. Although primarily concerned with the UK many of our observations of uncertainty and attendant risks will be relevant to other nations and territories, though the specifics of any emergent SG will be unique.

Present UK electricity systems are passive, and many risks we identified are a consequence of increasing complexity of potential solutions. A repeated theme in our collected data was the need to think in terms of systems of steadily increasing smartness presenting SG not as a single artefact or endpoint, but as an ongoing process. Most outcomes dependent on multiple coordinated (or potentially uncoordinated) policy and regulatory changes. The key risk for the UK was seen by many to be the lack of long-term vision. There was difficulty even in predicting past 2020 and this uncertainty is the key source of risk for the many stakeholders involved. In terms of policy, the risk of continuing inconsistency of aims and objectives between DECC (now BEIS) and Ofgem was the most important. Many stakeholders highlighted the need for regulation – and the regulator – to evolve with technology and market services. Long-term regulation and policy certainty is a necessary condition for investment, and critical for the success of smartening the grid.

The drivers of the requirement for higher degrees of grid smartness are major sources of uncertainty in terms of the extent and pace of change required, as well as factors such as spatial variation in uptake. These drivers include greater volumes of intermittent generation on both transmission and distribution networks and greater volumes of RE sourced in areas not adjacent to the current network, the level and geographical spread of domestic consumers with distributed generation, and the potentially wide-scale but unpredictable uptake of HPs and EVs.

One of the most significant and difficult to mitigate risks was the so-called ‘broken-value chain’. Across several aspects of SGs there may be economic and other benefits in terms of wider societal goals such as facilitating renewable energy. In a number of cases there is no obvious way to monetise new technology and services for whichever stakeholder pays for it, or would like to pay for it. A similar issue was supplier concern arising from additional network costs pushing up overall costs, and the impact on consumer bills. Suppliers are considerably less concerned about demand-side management so long as supply is not interrupted. The decision to favour a supplier-led SM rollout was widely seen as having the potential to substantively delay evolution of the SG. Gradual relaxation of restrictions on access to data – most notably for DNOs and other parties – is expected, but may be slow to occur. Creating value from consumer data may be problematic and undermine consumer buy-in.

The need to act to enable the factors that will allow for a smarter grid is imperative, and it was widely accepted that the status quo cannot continue. As one stakeholder put it *“Doing nothing is the worst response – it guarantees failure.”* We emphasise that current assumptions about the network will stop applying, and current solutions will become less effective and more expensive. Assumptions must be questioned repeatedly by all relevant stakeholders with a view to identifying the continued evolution of the sector and maximising public benefit.

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Appendix A

The participants in the two survey rounds are characterised in Table A.1. and Table A.2.

Table A.1
Summary of the sectors which survey respondents represent.

Sector	Round 1	Round 2
Academic	33%	25%
Consultant	9%	0%
Consumer/community interest group	13%	5%
Generator	2%	2%
Network Operator	19%	25%
Policy	5%	2%
Regulator	2%	2%
Supplier	8%	9%
Other	11%	30%
	100%	100%

Table A.2
Summary of the self-identified area of expertise of the survey respondents.

Expertise		
Business	28%	18%
Economics	3%	11%
Engineering	34%	41%
Social Science	19%	16%
Other	16%	14%
	100%	100%

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