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ENGINEERING RECOMMENDATION P2 REVIEW (PHASE 1)

Options for future development of distribution network planning security standard

Energy Networks Association

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Objective:
This report builds on the various Consortium sub work streams under work stream 2 to develop and outline the options for future development of a distribution network planning security standard in the UK and identify a set of potential statements to be presented to the industry. These potential recommnedations outlined in this report have been refined with the DCRP P2 WG and presented to a workshop with the wider stakeholder community, creating the main deliverable of WS3. The outcome of this report forms the basis of the input to the formal consultation process..

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Executive Summary

Engineering Recommendation P2 has been in place since the 1950s and has played a major role in the development of secure and reliable distribution networks. Whilst a number of changes have been made over the years, notably the introduction of P2/5 in 1978, the document has served the industry and consumers well for over 30 years.

The most fundamental issue regarding the future evolution of the P2 standard is whether it continues to prescribe economically efficient investments, given the many changes affecting the energy market at present, including the (anticipated) prolific deployment of new and emerging technologies and the changing role of the customer, demand, generation and prosumer customers. This gives rise to the need for a fundamental review of the baseline philosophy of distribution network operation and design to ensure that the UK Government's energy policy objectives can continue to be met in a cost effective and pragmatic way.

The review is formed of two distinct phases. The objective of Phase 1 is to identify and agree a range of options for a future UK security standard and agree the most appropriate approach that should be taken forward into Phase 2 which is the development and codification of the new standard.

The fundamental review of Engineering Recommendation P2 is being directed by the Distribution Code Review Panel P2 Working Group (DCRP P2 WG) through the Energy Network Association (ENA).

In January 2014 the DCRP P2 WG through the ENA engaged a consortium consisting of DNV GL, Imperial College London (ICL) and NERA to carry out phase 1 of the P2 review.

The Consortium supported by DCRP P2 WG members has identified and assessed high level options for the reform of ER P2/6 through a range of quantitative and qualitative analysis. The high level options considered for reform include:

1. *Retaining the present deterministic*[1] *P2/6 standard without revision*.
2. *Retaining a deterministic planning standard, but with improvement.*
3. *Implementing a non-deterministic planning standard.*
4. *Implementing a high-level standard that obliges efficient investment, while retaining some deterministic elements,* represents a hybrid of options 2 and 3.
5. *Abolition of the planning standard*.

This report sets out the assessment of the high level options for reform of P2/6 drawing on evidence from various quantitative and qualitative tasks carried out and inputs from a range of stakeholders including DCRP P2 WG members. This report will be followed by an extensive industry consultation prior to making final recommendations for P2/6 reform to the DCRP and setting out the high level plan for the Phase 2 standard development and codification works.

Section 6 of this report sets out a substantial set of conclusions for each high level option 1 to 5 assessed and reported here. To avoid distorting the balance of the conclusion by summarising them here we would direct the reader to the full set of conclusions in Section 6.

[1] P2/6 is commonly referred to as deterministic in nature and throughout this report is also referred to as a deterministic standard in that the network security performance outputs from the standard are pre-determined based on group demand.

Based on the main conclusions from this report there are a number of potential recommendations that could be made for consideration by the wider industry stakeholders during the consultation process, leading to the development of a set of firm recommendations made by the WG. For guidance the following are potential recommendations reviewed by the WG that will form the basis for the set of questions to be addressed during the formal consultation process:

1. Considering today's environment and looking to the future, based on the quantitative and qualitative evidence to date the present P2/6 standard does require improvement and should not be retained unchanged.
2. Relaxation of the present P2/6 N-1 security requirement to improve overall economic efficiency where applied will potentially reduce the supply security customers presently enjoy. Hence it is also recommended that this impact be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken. It is recognised by the DCRP P2 WG that there is a trade of between the level of relaxation of the present security arrangements and the potential improvement in economic efficiency.
3. Subject to the outcome of recommendation 2, if feasible during the current RIIO ED1 price control period out to 2023, improvements to the economic efficiency of the present deterministic standard through reducing the level of resilience it obliges DNOs to provide at the HV[2] and higher voltage levels should be considered. It is noted that this may need careful consideration in terms of timing as the RIIO ED1 price control has already agreed load related reinforcement funding allocations with the DNO license holders. Any other transition issues will require to be considered in developing the plan to adopt the reformed standard.
4. Improvements to the present deterministic standard within the present price control period should also include the use of all non-network technologies including distributed generation (DG), demand side response (DSR), demand side management (DSM) and electricity storage where this can be demonstrated to be a suitable alternative to network redundancy.
5. The development of deterministic rules and associated look up tables for improved economic efficiency of future network security planning are to be carried out during phase 2 of this review and will consider both relaxing the present rules on network security and the use of non-network technologies (DG, DSM, DSR, and Storage).
6. Recognising that there will be a trade-off between economic efficiency of any new deterministic rules, the variables that can be considered, the ease of use of developed rules, and the network planning scenarios that can be covered, there will be a need for flexibility to permit network planning outside of the deterministic rules where necessary. It would therefore also be appropriate to supplement the existing standard with obligations on DNOs to conduct other economic analysis where new deterministic rules are not appropriate.
7. Work would be required at phase 2 to set the level of prescription for any non-deterministic obligations, and the required level of transparency in (and regulatory oversight of) DNOs' economic analysis.
8. Subject to the further planned industry engagement during Phase 1 of this review, the option of moving to an entirely non-deterministic standard to regulate the level of reliability DNOs are

[2] Throughout this report the stated voltage levels are based on industry terminology i.e. low voltage (LV) is 230V to 1000V, medium voltage (MV) is above 1000V to 6.6kV, HV is above 6.6kV to 22kV, and EHV is above 22kV to 66kV.

obliged to provide (Option 3), or possibly removing the planning standard altogether (Option 5), should not be ruled out at this stage. However, to support more radical changes than those set out in potential recommendations 2 to 7, some reform of other regulatory mechanisms would be required, such as strengthening the Interruptions Incentive Scheme, we have assumed this will not be possible before the commencement of the RIIO-ED2 price control process. In moving to less deterministic planning standards, the regulator would need to consider trade-offs between the improvements in economic efficiency that are feasible from such a change, and any associated increases in costs, such as the need for DNOs to undertake more complex planning activities. Changes to other codes and schemes and potentially licence conditions may also be required.

The selection of potential recommendations 2 to 7 would lead to the implementation of high-level option 2 or 4 depending on the ability to develop practical deterministic rules and look up tables covering more economically efficient security provision and also the application of DER. Option 2 is where this is possible and the standard is predominantly deterministic in nature and Option 4 has a greater element of economic assessment.

Based on the outcome of the work completed so far, there are a number of other potential recommendations that should also be considered:

9. The new standard should provide guidance as to the methods for the treatment of construction outages separately from maintenance outages and unplanned outages.
10. In addition, consideration at Phase 2 should be given to the concerns raised by export stakeholders in reviewing the treatment of construction outage risks to export customers; this may require guidance from Ofgem and further stakeholder engagement to consider how this subject could be included in the Phase 2 review and subsequent updates.
11. Any new or reformed standard must take cognisance with the transmission system interfaces and the requirements set out in the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS).
12. Regarding High Impact Low Probability Failures (HILP) and Common Mode Failure (CMF) some forms of low cost mitigation should be considered at the network security planning stage and covered by a reformed security standard. Mitigation would require to be justified through some form of CBA analysis, the form of which could be prescribed by Ofgem.

It should be noted that these recommendations are potential recommendations that have been reviewed by the WG at this stage of the project. They will be subject to further extensive stakeholder engagement still to be conducted based around this report through a formal industry wide consultation process.

Further key conclusions for a reformed security standard should include consideration of:

Distribution Losses

The enhancement of the present P2/6 deterministic standard, option 2, to include loss considerations in the design was in general not supported by respondents to the industry questionnaire. The consensus was that the interface between other industry standards/regulatory initiatives should be enhanced to ensure that any incentives work correctly in conjunction with the security standard to support its intent of ensuring the efficient provision of security of supply. This is also true of options 3, 4 and 5.

High Impact Low Probability Failures (HILP)

The present P2/6 standard does not directly consider HILP event mitigation in network designs. From the stakeholder engagement process to date, there is general agreement for planning standards not to include extreme events; such events should be dealt with by alternative regulatory mechanisms due to their low probability and unpredictable nature.

However, some WG members expressed an opinion that some forms of low cost mitigation could be considered at the network security planning stage, e.g. advanced control systems. It is likely that any such mitigation would require to be justified through some form of cost benefit analysis (CBA) and may not be suitable for the option of a reformed deterministic standard (option 2).

1 INTRODUCTION

In January 2014 the Distribution Code Review Panel[3] P2 Working Group (DCRP P2 WG) through the Energy Network Association[4] (ENA) engaged a consortium consisting of DNV GL[5], Imperial College London (ICL)[6] and NERA[7] (the Consortium) in a project to carry out a full back to basics review of Engineering Recommendation P2/6[8]. This engagement with the Consortium covers Phase 1 of a two phase project that will ultimately result in a new fully codified standard.

Phase 1 is essentially a comprehensive research, analysis and modelling engagement supported by a later consultation process to be carried out by the Consortium with direction and support provided by the DCRP P2 WG and the ENA. The objective of Phase 1 is to identify and agree a range of options for a future UK security standard and agree the most appropriate approach that should be taken into Phase 2 which is the preparation and codification of the new standard.

The project commenced in February 2015 with the development of a Project Initiation Paper (PIP)[9]. The PIP highlighted the key objectives of Phase 1 of the Engineering Recommendation P2/6 Review project to industry stakeholders and the process adopted to achieve these objectives.

The process to deliver the Phase 1 objectives outlined in the PIP consists of a number of work streams which can be broadly summarised as follows[10]:

- **Work Stream 1**; sets out the Phase 1 objectives and process, and included an initial engagement with all key industry stakeholders.
- **Work Stream 2**; identifies, researches and evaluates options for a future UK security standard.
- **Work Stream 3**; engages with the DCRP P2 WG to examine the deliverables from WS 2 and derive and describe a range of options that will inform the processes in WS 5
- **Work Stream 5**; includes an industry wide workshop that will focus on introducing and discussing the deliverables from WS 3 (both quantitative and qualitative exercises). The workshop will critically examine the proposed options, their underlying assumptions and the implications on both the technical and economic models.
- **Work Stream 6**; further supports WS 5, through a formal industry wide consultation to seek and gather written feedback for all industry parties on some of the more pertinent issues and concerns associated with the proposed new standard options.

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3 The Distribution Code Review Panel (DCRP) is the body responsible for overseeing the maintenance and development of the Distribution Code and its subordinate documents. Those subordinate documents include Engineering Recommendation P2/6. The ENA is the service provider to the DCRP for the physical maintenance of the Code and its subordinate documents.

4 Energy Networks Association is the industry body for UK energy transmission and distribution licence holders and is the voice and agent of the energy networks sector. ENA acts as a strategic focus and channel of communication for the industry and aims to promote the interests, growth, good standing and competitiveness of the industry. They also provide a forum for discussion among company members, and so facilitate communication and sharing of experience across the energy networks sector

5 DNV GL is a Global certification and advisory business working in the maritime, oil and gas, business assurance and energy sectors.

6 Imperial College London is a university of world-class education and research in science, engineering and medicine, with particular regard to their application in industry, commerce and healthcare.

7 NERA Economic Consulting is a global firm of experts dedicated to applying economic, finance, and quantitative principles to complex business and legal challenges.

8 To assist non DNO readers understand further relevance of ER P2/6 and how it fits into the DNO regulated business some summary notes are provided in Appendix A.

9 DNV GL, NERA and Imperial College document "Engineering Recommendation P2 Review (Phase 1), Project Initiation Paper", report number 16011094/110, rev 001, 13/04/2015.

10 Work Stream 4 is an optional work stream for further, more in depth modelling and analysis presently not commissioned by the ENA for the Phase 1 works and hence is excluded in the list shown. If necessary a second iteration of the techno-economic modelling could be carried out under Work Stream 4 during Phase 2 to confirm one option to proceed within Phase 2 if a single option is not fully identified at Phase 1.

- **Work Stream 7**; develops a summarised and tabulated view of the WS 6 consultation question responses and identifies and structures actions to be taken with regards to the final Phase 1 Report.
- **Work Stream 8**; produces the final Phase 1 report that will lay out the arguments and all the supporting evidence for the development route for any new standard while critically highlighting the benefits of such a route.
- **Work Stream 9**; scopes the work needed to implement the final recommendations from Phase 1 that will be undertaken in Phase 2 including a work programme for Phase 2 with an associated project plan.

This document reports on the WS 2 outcomes, the identification, research and evaluation of options for a future UK security standard to succeed Engineering Recommendation P2/6. The outputs produced through WS 2 feed into this Options Report that constitutes WS 3. This options report will be built on further with the DCRP P2 WG and the wider engagement of the stakeholder community through WS 5 to 8.

Following this introduction, section 2 provides a reminder of the background to the Phase 1 review followed by a description of the WS 2 research and evaluation process and associated sub-work streams in section 3. The outputs from sub-work streams 2.0 to 2.7 are detailed in section 4 including the underlying assumptions used. Section 5 sets out the high level options for a future network standard drawing on the analysis from WS 2.0 to 2.7 and developing the arguments for each option. Finally the main conclusions and potential recommendations for reform are set out in section 6.

2 PHASE 1 P2 REVIEW

2.1 Background to Project

Engineering Recommendation P2 has been in place since the 1950s and has played a major role in the development of secure, reliable distribution networks. Whilst a number of changes have been made over the years, notably the introduction of P2/5 in 1978, the document has served the industry well for over 30 years.

P2 is a 'deterministic' standard in nature[11] and is largely focused around ensuring sufficient network capacity is available to meet the 'peak demand' and securing access to acceptable capacity levels within a manner and timeframe consistent with the 'group demand' (or put simply, the size of network) in question. P2 is also 'risk based[12]' to such an extent that larger 'load groups' are in general deserving of a higher level of security.

Through the Distribution License and the Distribution Code, P2/6 is also a minimum standard.[13][14]

P2 has evolved as circumstances change and at the time P2/5 and P2/6 were developed they were considered appropriate. The most fundamental issue regarding the future evolution of the P2 standard now is whether it prescribes economically efficient investments. P2/6 now resides in a world where there are many changes affecting the energy market at present, including the (anticipated) prolific deployment of new technologies and the changing role of the customer. This gives rise to the need for a fundamental review of the baseline philosophy of distribution network operation and design to ensure that the UK Government's energy policy objectives can continue to be met in a cost effective and pragmatic way.

The requirement for a fundamental review of Engineering Recommendation P2 has been recognised by Network Licensees (i.e. the electricity Distribution Network Operator (DNO) companies and National Grid) for some time. The Licensees therefore believe that it is timely to undertake a comprehensive fundamental review of Engineering Recommendation P2 in relation to customer and system requirements and to develop an understanding of what is required to facilitate the long term development of networks.

This fundamental review of ER P2/6 is being directed by the Distribution Code Review Panel P2 Working Group (DCRP P2 WG) through the Energy Network Association (ENA).

The review is formed of two distinct phases. **Phase 1** is essentially a comprehensive research, analysis and modelling engagement and consultation process carried out by the Consortium with direction and support provided by the DCRP P2 WG and the ENA. Network licensees had no preconceived approach to future security standards. The Consortium has considered the spectrum of possibilities ranges from maintaining the present standard, or a modification and update of the current arrangements, or development of a completely new approach starting from first principles, through to recommending removal of any deterministic planning standard, relying instead on DNOs' regulatory incentives and other legislation to motivate efficient network design. The essential task of Phase 1 is to identify, research, develop and communicate a range of options for the overall approach to structure and detail the

[11] Referred to in this report as a deterministic standard as opposed to a probabilistic (stochastic) based standard, in that network design aim to comply with a set outcome in terms of outage events.

[12] P2/6 is risk and economic based in that the demand groupings consider the both increased risk impact and the levels of mitigation prescribed.

[13] Distribution Code, DPC4.2.1 Security "In accordance with the Condition 5 of the Distribution Licence, DNOs shall plan and develop their DNO's Distribution Systems to a standard not less than that set out in DGD Annex 1 Item 4, Engineering Recommendation P2/6 – "Security of Supply" or such other standard of planning as DNOs may, with the approval of the Authority, adopt from time to time."

[14] While DNO's can opt to invest in security above the minimum requirement prescribed by P2/6 where they can justify this, to propose design solutions below the minimum level the DNO is required to seek a derogation for this from the Regulator where they cannot self-derogate.

appropriate level of network security standards and then to propose how such options can be evaluated. The Consortium will then evaluate these agreed options and recommend the most appropriate approach that should be taken forwards into **Phase 2**, and ultimately codified.

Phase 1, poses some fundamental questions about the means of providing the most appropriate level of security of supply to customers, via a combination of network assets, customer owned assets and both technical and commercial operational management techniques, and as such will be of great interest to many stakeholders. Hence as part of this phase the consortium believed that it was important to widely consult with industry stakeholders throughout the process.

2.2 The Way Forward Phase 1

It is the view of the DCRP P2 WG and the Consortium (DNV GL, ICL and NERA) that a fundamental review of the security standard must essentially entail imagining a world where ER P2 does not exist and trying to ascertain what the best approach to addressing security of supply in distribution networks is, based on today's parameters. There are potentially a number of options that could emerge from carrying out such an assessment, namely; to keep the standard as it is, to amend or rewrite it, or to eliminate it all together, possibly replacing it with another mechanism. It is important that any change, when placed alongside the wider regulatory framework to which DNOs are subject, motivate and support the efficient planning and development of their networks to meet the needs of customers. Specifically, it is important that DNOs are encouraged, as far as possible, to provide the economically efficient level of network capacity, accounting for the trade-offs between the costs of adding capacity, the value such capacity additions provide to consumers and other network users through improved resilience, and the costs and technical performance of "smart" alternatives.

A major output of the Phase 1 work is to identify alternative options for updating the distribution network security of supply design standard, potentially including operational aspects, while considering their strengths and weakness under different future development scenarios. This has been based on an established cost benefit framework[15] that involved assessment of the performance of alternative options in relation to:

(a) characterised and quantified service quality delivered to end user customers, considering frequency and duration of outages together with risk profiles and robustness associated with construction outages, common mode failures and high impact events (considering the corresponding costs),

(b) application of advanced automatic control schemes and/or area-wide operational measures that might be considered to contribute to security of supply,

(c) a combination with non-network technologies, such as demand side response, distributed generation and energy storage,

(d) investment cost in network assets, and

(e) while taking into account the regulatory framework, EU codes, and market design changes.

The output and decisions form a key deliverable for any subsequent Phase 2 work that will prioritise options identified based on a number of criteria defined through workshops with the DCRP P2 WG and consultations with stakeholders.

15 Cost benefit framework established by Imperial College London. Discussed in Section 4.1 (Model Framework).

2.3 Main Challenges

Although the distribution networks, designed in accordance with the historic deterministic standards, have broadly delivered secure and reliable supplies to customers, in considering reform of the standard it is important to consider the efficiency benefits from using non-network technologies to deliver security of supply to consumers as a substitute for the addition of conventional network assets. This review therefore reviews the philosophy of distribution network operation and design. Overall, there are two key areas of interests:

1. What is the level of security performance delivered to end user consumers by the present network design standard/practices? Is the present network design standard efficient? Does it deliver value for money to all network customers? Does it deliver the level of security customers wish now and in the future and are willing to pay for? In other words, does it balance the cost of network infrastructure with the security benefits delivered to distribution network customers now and into the future? This area requires considering the difference between theoretical and actual performance of the present standard as in practice many 11kV and LV designs are considerably more secure than the P2/6 standard requires and the account of security benefits from embedded generation in network planning can vary in practice.
2. Given that the present network design standards have predominantly resulted in network security provided through asset redundancy, will this impose a barrier for the innovation in the network operation and design and prevent implementation of technically effective and economically efficient solutions that enhance the utilisation of the existing network assets and maximise value for money to network customers?

Under these two key areas, there are a significant number of more specific issues to consider:

(a) The degree of security provided by the deterministic security criteria, using generic rules applied to all situations, will not be optimal in all instances if the cost of providing the prescribed level of redundancy, the reliability of assets, or the benefits of reliability vary. For similar reasons, providing the prescribed level of redundancy does not deliver the same level of reliability to all customers in all situations. It is important to recognize that deterministic standards assume that all contingencies are equally likely, which is clearly problematic: for example, faults on a long exposed line are much more frequent than failures of a closely monitored transformer. (The standard however does allow a departure from a defined level of security subject to detailed risk and economic studies. DNOs can provide more redundancy if they can justify it, or less through a derogation.) The evaluation of service quality that different consumers actually experience is therefore critical for conducting the cost-benefit analysis of alternative network design approaches.

(b) The binary approach to risk as in the present deterministic standard is fundamentally problematic: system operation in a particular condition is considered to be exposed to acceptable risk if the occurrence of faults, from a preselected set of contingences, do not violate the operational limits; while the system is considered to operate at an unacceptable level of risk if the occurrence of a credible contingency would cause some violations of operating limits. Clearly, neither of these is correct, as the system is indeed exposed to risks of failure and outages even if no preselected contingency leads to violations of operating constraints, and the risk of some violations may be acceptable if these can be eliminated by an appropriate (post fault) corrective action that can include a fast response of flexible demand or some form of distributed generation. Probabilistic consideration of the interruption risk profile that individual consumers are exposed to would therefore be required to address this issue.

(c) The lack of differentiation between construction and maintenance outages in the present distribution planning standards may present a significant problem given the expectation of considerable asset replacement in the future. This is likely to affect particularly large Demand Groups[16].

(d) Understanding of the parameters that can be used for measuring the reliability of supply received by consumers has considerably improved in recent decades with a shift from energy not supplied type indices to service outputs such as frequency and duration of interruptions and customer damage functions[17]. Furthermore, there is no explicit recognition that the reliability indices are not deterministic but inherently stochastic parameters. Consideration of these effects is required, allowing, as required by the assignment, valuation of reliability using either complex customer damage functions, or more traditional approaches to valuing un-served energy based on an assumed level of the value of lost load (VoLL)[18]. It would be interesting to understand generator stakeholders' views on the curtailment costs and whether the broad assumption that the curtailment costs will inevitably be less than VOLL is valid.

(e) The present standard does not deal well with common mode failures and it does not provide any guidance for dealing with High Impact Low Probability events. Should resilience of the network when exposed to common mode failures and high impact low probability events be explicitly recognised?

(f) Over the past decade, there has been a marked improvement in the reliability of much of the UK's electrical distribution networks due to measures DNOs have taken that have been encouraged and funded through the Interruptions Incentive Scheme. Furthermore, the focus of the Interruptions Incentive Scheme has been on overall system performance rather than on individual customer focused indices. System indices capture the impact of network behaviour on an "average" customer, while the security of supply seen by real customers will be radically different from these summary indices currently used to drive network development.

(g) There is a growing interest in incorporating non-network solutions (such as flexible generation and demand, new storage technologies, dynamic line rating, automatic network monitoring and control based on new information and communication technology etc.) in the operation and design of future distribution networks. It is not, however, clear to what extent the application of such solutions changes the security of supply delivered to the end consumers – the reliability and availability of light current control systems is fundamentally different to that of power system components. This is clearly critical for quantifying the ability of non-network solutions to substitute network assets.

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16 As demonstrated in KEMA/Imperial report to Ofgem ("Review of Distribution Network Design and Performance Criteria", G06-1646 Rev 003, 19 July 2007, Kema Limited.)

17 Value of Lost Load (VoLL) is the estimated amount that customers receiving electricity would be willing to pay to avoid a disruption in their electricity service. The value of these losses can be expressed as a customer damage function (CDF). A CDF can be defined as:

Loss (£/kW) = ƒ (duration, season, time of day, notice etc.)

Based on the calculated outage cost, a CDF can be obtained for various customer groups.

18 In line with the latest analysis and values used in the Electricity Market Reform carried out by the Department of Energy and Climate Change VoLL of £17,000/MWh is used by Imperial College in their studies as the central value. Imperial Collage has also carried out the analysis using a larger value of VoLL (£34,000/MWh) to assess the sensitivity and robustness of identified solutions. Imperial College has also analysed a set of different customer damage functions, expressing the dependency of the cost of interruptions on their duration and unserved energy. For various customer damage functions different equivalent VoLL values have been determined. It is important to stress that there are no widely agreed customer damage functions parameters, while there is agreed VoLL, used by the government and the regulator VoLL.

(h) At present, the choice that many network users (both demand and generation) can exercise in relation to their security of supply is limited.

(i) The scope of the present network standard is limited to the compliance at a particular point in time looking forward based on demand estimates, but given the uncertainty in penetration levels of various low carbon demand and generation technologies in distribution networks, it may be desirable to extend the scope of the standard and consider cost-effective network planning under uncertainty, particularly taking advantage of smart grid technologies.

(j) In the longer time scale the introduction of smart metering and in-home energy management devices may theoretically facilitate reliability-based choices of consumption. Rather than having full interruptions and indiscriminate demand curtailment in case of constraints, it may be possible to prioritise categories of demand within the home and hence facilitate network management at lower cost to customers. It is noted that this may be a longer term aspiration for policy makers.

Although some improvements of the existing P2 standard have been made to recognise the contribution that distributed generation could make to network security (move from P2/5 to P2/6), this was carried out without reviewing the fundamental principles on which the standard is based. Therefore, service quality profiles delivered to customers by the distribution network and cost-benefit performance of the existing standard need to be fully reviewed and understood. Furthermore, there are also alignment issues associated with the interface between distribution and transmission standards (i.e. the National Electricity Transmission System Security and Quality of Supply Standards / NETS SQSS) that need to be addressed.

3 WS 2 OPTION EVALUATION PROCESS (PHASE 1)

The aim of Work Stream 2 was to provide the analysis required to (1) understand the impact of P2/6 in its current form on the economics of network planning and design, and (2) identify the options for improvement and reform. The key outputs produced through Work-stream 2 are summarised and used to assess the future options for the improvement and reform of the P2/6 security standard in this report. This options report will be further refined with the DCRP P2 WG following its release to the wider industry for further consultation and development.

The analysis performed under Work-stream 2 through a number of sub work streams covers a range of topics, and entailed comprehensive desktop research, modelling of key issues and gathering of stakeholder input activity to identify the current impact of P2/6 and possible impacts from alternative security standard options. Amongst the primary areas of focus were the following:

- **Work Streams 2.1** Provision of a scope and framework for assessing security performance and measures of characteristic network designs;
- **Work Stream 2.2.** Analysis of the distribution network service quality performance associated with the present network design standard and alternative options for its update;
- **Work Streams 2.3.** Assessment of risk associated with asset replacement, common mode failures and high impact events;
- **Work Streams 2.4.** Analysis of the impacts of Smart Grid solutions on security of supply;
- **Work Streams 2.5.** Assessment of impacts of alternative control and operation strategies on security of supply;
- **Work Streams 2.6.** Loss inclusive design of distribution networks and impact on security of supply;
- **Work Streams 2.7.** Interface between distribution network standards and the regulatory framework (RIIO), EU codes, capacity mechanism and balancing services significant code review, and
- **Work Streams 2.7.** Defining the interface between distribution network standards and IIS and SQSS.

Work Streams 2.1 to 2.6 predominantly related to the techno-economic model and quantitative analysis performed. **Work Stream 2.7** introduced the high level options for improvement and reform of the P2/6 security standard and reviewed these against a range of regulatory and market mechanisms. Work stream 2.7 also carried out an initial assessment of the pros and cons of the high level options for reform which this report builds on. **Work Stream 2.0** related to the gathering of input from stakeholders that supported these elements and also formed the basis for a qualitative analysis relating to the existing P2/6 standard and proposed alternative options. The results of the quantitative and qualitative analysis from all sub work streams has been used to review the options for development of a future distribution network planning security standard under **Work Stream 2.9** which produced an early initial draft of this Work Stream 3 options report.

Subsequent sections of this repot describe the approach in detail associated with each of the sub work streams that make up work stream 2.

An overview of the framework used to assess alternative design standard proposals is provided in Section 3.1 and is a fundamental part of the Work Stream 2 activities.

3.1 Framework for the development of future network design standards

For developing any new network security standard, it is critical to examine the cost effectiveness of the standard, and its ability to balance the cost of interruptions against the cost of network infrastructure, which will involve application of alternatives (i.e. alternatives to Expected Energy Not Supplied (EENS) which underpins the current standard) indices such as: Value of Lost Load (VoLL) and customer damage functions. In high level terms, this cost-benefit framework involved application of the Imperial College optimisation models to identify the costs of a "perfectly designed" or "economically efficient" network, which was compared with the costs of a system designed and built in compliance with P2/6.

A range of studies have been carried out with the aim of estimating *the breakeven value of VoLL* at which the existing network would be upgraded cost effectively and to estimate the least-cost redundancy levels. A set of different customer damage functions[19], expressing the dependency of the cost of interruptions on their duration and unserved energy were analysed. This enabled the equivalent cost of interruption to be compared with the cost of interruption when the central VoLL of £17,000/MWh, adopted by the UK government for the Electricity Market Reform, was applied. In order to assess the robustness of the findings, the optimal degree of redundancy was also estimated for a VoLL of £34,000/MWh, with lower values of VoLL driving lower optimal degrees of redundancy.

This framework enabled the consideration of alternative network design standards that could potentially replace (refine or improve) P2/6, and the evaluation of how much of the gap they would close between the current P2/6 and the economically efficient system.

In addition to these potential quantifiable savings from reform of P2/6, the framework for cost-benefit analysis also accounted for more qualitative considerations, such as the transparency and simplicity of proposed design standards, and the ease with which DNOs' compliance with these standards can be appraised in the future – for example to demonstrate licence compliance. Part of the stakeholder engagement process in WS 2.0 assisted in accounting for these more qualitative aspects in the overall evaluation framework. The influence of the DCRP P2 WG as part of WS 2.0 also greatly assisted in assessing the impact of the more qualitative aspects in the assessment framework.

Further detail of the Imperial College optimisation models are discussed in section 3.1.1.

3.1.1 Imperial College Model Framework

In the context of Work Stream 2, the overall aim of the proposed work was to carry out a fundamental cost-benefit analysis, from first principles, of the performance of alternative distribution network design philosophies considering the quality of service delivered to end user consumers and the associated network investment and outage costs. This analysis additionally also considered optimising the use of

[19] Imperial College has analysed a set of different customer damage functions (CFD), expressing the dependency of the cost of interruptions on their duration and unserved energy. For different CFDs different equivalent VoLL values are determined. It is important to stress that there are no widely agreed CFD parameters, while there is agreed VoLL, used by the government and the regulator VoLL. For various CDFs the estimated equivalent VoLL might be lower than values used in the Imperial College analysis report. This will lead to lower optimal degrees of redundancy. In that sense the Imperial College results are conservative.

advanced network control technologies (e.g. active network management, dynamic line rating) including demand side response, distributed generation and energy storage technologies. The key objective of this being to inform the debate and develop options for the evolution of the present security planning standard in order to support the development of efficient, secure and sustainable electricity distribution networks and assist facilitate cost effective transition to a low carbon future.

Specifically, the work was to identify alternative approaches to updating existing and developing distribution network security planning standards, while considering their advantages and disadvantages under different future development scenarios. This included characterising and quantifying the service quality delivered to end user customers (considering frequency and duration of outages and corresponding costs) compared with network investment and operating cost. Given the probabilistic nature of network failures, a probabilistic cost-benefit based framework was used as a benchmark for assessing different options for the development of network planning security standards. As illustrated in the figure below, a probabilistic approach can provide the basis for risks of supply interruptions to be understood, quantified and managed through optimising the level of the network capacity that should be made available to network users in both operational and investment time horizons. Essentially, this approach enables the costs of network investment to be balanced against the benefits that the released network capacity delivers to the network users.

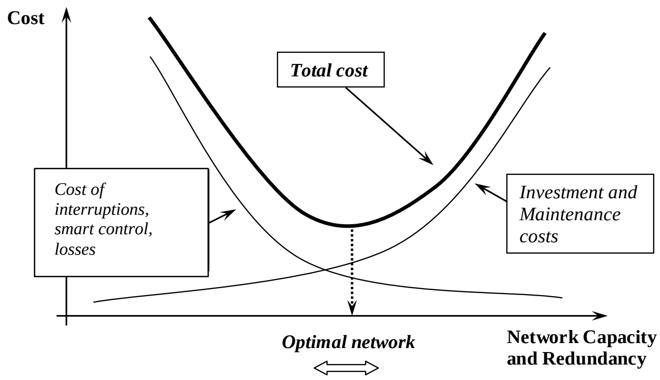

Figure 3-1: Probabilistic cost-benefits analysis framework for distribution network operation and planning (balancing of network operation costs that includes cost of service interruptions and application of alternative non-network control technologies, with cost of investment in network assets)

The probabilistic approach provides a framework (as illustrated in Figure 3-1) within which both network and non-network solutions, such as flexible demand and generation, can objectively be compared in solving network problems. Therefore, this framework provides a benchmark for assessing economic efficiency of any future standard.

To undertake such assessments of alternative network design standards, Imperial College's specialised large-scale probabilistic distribution network models were applied. The majority of existing reliability tools and techniques in the context of distribution network planning focus on the average or expected performance of the system. In addition to these, Imperial College has developed a number of optimisation and simulation models for network design and operation, which can explicitly characterise the network reliability performance as well as the service quality profile delivered to an individual customer. Clearly, this approach will support a detailed and explicit representation of the effects of alternative network design and operation strategies, involving both network and non-network solutions, on customer reliability of supply. This is critical since the actual service quality delivered by distribution networks to individual customers varies massively and is generally very different from the system-wide reliability indices.

As indicated in Figure 3-2, below, the use of Imperial College's tools enables a complete characterisation of security of supply experienced by individual customers, in terms of frequency and duration of contingent events. Red and green lines represent the probability that frequency and duration will be less than or greater than 5%, respectively. For example, there is 5%[20] probability that the number of outages will exceed 15 for this particular group of customers, and also 5% probability that the annual outage duration of consumers supplied from this particular distribution transformer will be greater than 75.7 hours.

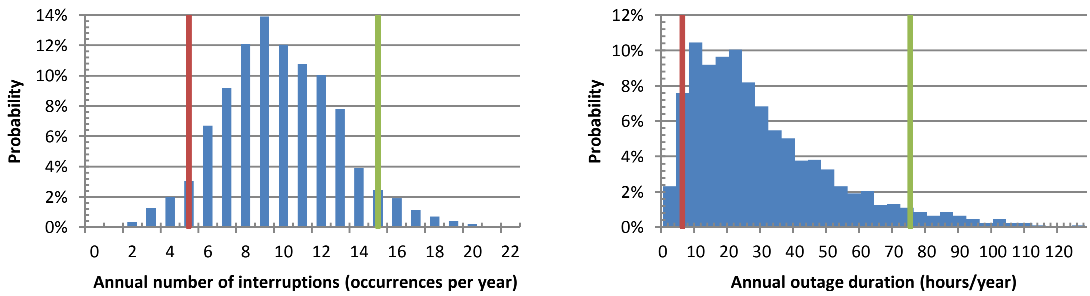

Figure 3-2: Impact of inherent variability of security of supply

Information about the variability of these indices is critical for determining the cost-benefit case for a particular network operation and design approach and also vital for establishing the robustness and risks associated with any alternative design and operation standards. Similarly, when the impacts of construction outages are considered, it is essential that the risk profile of alternative provisional supplies are understood and quantified, which is a key feature of Imperial College's models.

Figure 3-3, below shows the variability of reliability performance indicators associated with individual load points (more than 45,000 distribution transformers) across the HV network of a GB DNO. It is observed that there are a significant number of load points with the probability of experiencing more than 5 interruptions per annum with the total duration of outages exceeding 18 hours, is greater than 0.5 (i.e. 50%), although the frequency and duration of outages for a large proportion of the load points is expected to be relatively low. It is observed that although the entire network is built in accordance with P2/6, the actual service quality performance experienced by individual consumers widely varies. Hence, understanding the impact of alternative network operation and design approaches on the outage frequency and duration is a key aspect of the review work. This is critical as the cost associated with interruption of services is highly non-linear, particularly in relation to duration of outages, and hence "system" based indices (e.g. CIs and CMLs) are not sufficient for establishing the balance between the network investment cost and benefits delivered to network users.

20 Note that in interpreting the result in both graphs in Figure 2 all blue bars right from the green line should be summed and half of the blue bar below green one (for example 15 interruptions bar represents all interruptions from 14.5 to 15.5) to get the cumulative number.

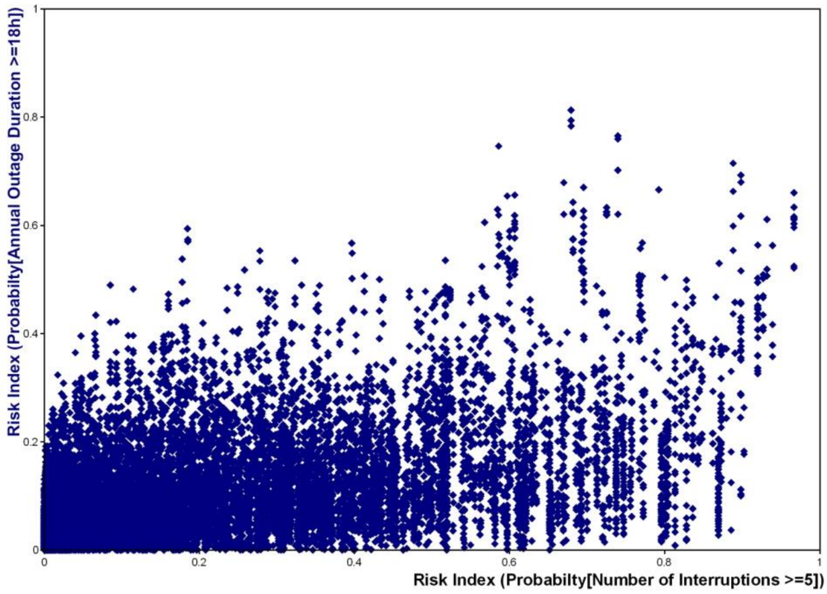

Figure 3-3: Risk indices of outage frequency and duration of different load points across the distribution network of a UK DNO

Imperial College's tools take account of an array of advanced concepts and models to assess system features that affect distribution network security performance including in particular:

- Common mode failures of network infrastructure through the application of Markov based reliability models;
- Risks associated with extended construction outages and the role and benefits of infrastructure reserves and provisional supplies;
- Role of flexible generation, demand response and energy storage technologies in enhancing the utilisation of existing network assets.

Imperial College has utilised these applications in a number of projects with industry and academic papers, including the 2007 KEMA/Imperial College report where strengths and weaknesses of the existing ER P2 were discussed. Further detail of the Imperial College model framework elements are discussed in Work Stream 2.1 in section 3.2.2.

3.2 WS2.0 Stakeholder Input

Stakeholder inputs were split into two key areas:

1. Data more directly related to Imperial College's techno-economic modelling and analysis which is predominantly quantitative analysis and
2. Data which related to the qualitative analysis e.g. relating to issue such as transparency, practicality, and usability of P2/6 and the proposed replacement options.

Area 1 data for the quantitative analysis was gathered from the DNO stakeholders. For efficiency and consistency the data was extracted from the regulatory reporting packs (RRP) for the fourteen GB DNO licenced areas. To protect the commercial value of the data the DCRP P2 WG collated the data and anonymised it prior to providing to the Consortium. The data provided addressed the areas of asset reliability performance and cost range data for various electrical plant.

Area 2 data associated predominantly with the qualitative analysis involved a wide range of stakeholders which were split into two categories:

1. stakeholders that make use of the ER P2/6 on a regular basis and where P2/6 has a direct impact on their business (DNOs and NGET) and those who have responsibility for oversight (DECC and Ofgem). The questionnaires and interviews were aimed at those in the DNOs setting planning policy, operational engineers (i.e. those that have experience of operating the network or managing outages), LCNF teams (i.e. those looking at future developments and new technologies) and regulatory/commercial teams (i.e. those concerned with the impact of any change to P2 in terms of change control and financial management). Each one of the stakeholders was provided with a questionnaire to complete covering a range of pertinent areas. Having reviewed each questionnaire submission the Consortium held interviews with key representatives for the DNOs, DECC and Ofgem to ensure our understanding of the questionnaire responses.
2. the wider group of interested parties and industry participants who do or may have an interest in the P2 review process to ensure that relevant industry participants have had a chance to provide significant input into the final analysis. This wider group of stakeholders include representatives from Offshore Transmission Owners, independent DNOs (IDNOs), and trade organisations covering Solar, conventional and renewable generation, hydro generation, demand side response and domestic customers. Each stakeholder in this wider group was sent the same questionnaire provided to the DNOs, DECC and Ofgem to ensure full transparency. However, since the original full questionnaire included some specific questions directly designed to elicit responses from the DNOs (as the main users of ER P2/6) and they may not have been relevant (or too detailed) for the wider set of industry participants, guidance was provides on which questions may be pertinent. That said the wider group of stakeholders were offered the opportunity to provide their views and answer any of the questions posed in the questionnaire. The consortium reviewed all questionnaire responses and where necessary conducted follow-up calls to clarify responses.

The questionnaire[21] consisted of four main areas:

1. Developing a better understanding of the strengths and weaknesses of ER P2/6;
2. Alternative approaches to Security Standards and Regulatory and Commercial considerations;
3. Real time network operation and security of supply, and
4. Additional questions and points for consideration.

This last area was included to allow all respondents to raise their own questions and respond to these where they felt these were important.

All question responses were reviewed and used to support some areas of the quantitative analysis and also to develop the qualitative analysis for each of the high level options for a new standard.

The key findings from the questionnaire responses and follow up interviews and how these impacted on the quantitative analysis and the qualitative analysis of each high level option for a new standard are summarised in Section 4.1.

21 Full details of the questionnaire and interview process, responses and analysis are include in the Consortium report “Findings of the qualitative review associated with the future development of the P2/6 distribution network planning security standard”, report no. 16011094/290, rev 002, Nov 2015.

3.3 WS2.1 Scope and framework for assessing security performance and measures of characteristic network designs

Given that the measure of the underlying risk in ER P2/6 is based on Expected Energy Not Supplied (EENS), in this task, the Consortium investigated a spectrum of alternative measures for quantifying security of supply experienced by customers. The strengths and weaknesses of various customer risk measures, particularly focusing on frequency and duration of outages and customer damage functions, were evaluated. Given its probabilistic nature, the consumer reliability indices were represented by the probabilistic density functions rather than expected values only. This is essential for understanding of the risks profile associated with service quality delivered to network customers and for assessing the robustness of the alternative network design strategies.

Historically, electricity networks are planned on the basis that all consumers place the same value on continuity of supply and use of their appliances when required. Furthermore, it has been assumed that the continuity of supply is binary: electricity supply is 100% available under normal operating conditions (all devices can be used) or not at all under outage conditions (no devices can be used). This historic approach usually characterised by valuing avoided interruptions using a single value of lost load (VoLL), although widely understood and recognised, is overly simplistic. First, the estimation of VoLL is subject to considerable uncertainty, driven by the fact that the damage caused by interruptions is different for different classes of consumers, in different locations, and at different times of the year/day. Also, smart metering coupled to in-home energy management devices could change the way customers value supply continuity through facilitating reliability-based consumption choices. By setting design standards that allow networks to be planned in accordance with the differing priorities of different categories of in-house demand, it may be possible to develop and operate networks at lower costs to customers.

In this task Imperial College therefore developed their existing models to allow a range of alternative approaches to valuing interruptions to be taken. For instance, they analysed cases in which the value of interruptions is simply at VoLL, e.g. drawing on recent studies, such as those prepared for DECC, that estimate VoLL[22]. The analysis also considered other cases in which the valuation of avoided interruptions is represented by a customer damage function, such that value depends on the customer type(s) affected, timing and frequency of outages, and duration of the outage. In all cases, the value of reliability-differentiated continuity of supply service was assessed through comparisons with the historical approach to security with having full interruptions and indiscriminate demand curtailment in case of constraints.

In order to support a broad range of network designs with associated network cost characteristics and corresponding performance (which can be found in operation and planning practices), Imperial College developed a high-level probabilistic approach for assessing the security of supply delivered to the end consumer under different conditions. Imperial College also established a set of characteristic network designs, across the range of Group Demand levels and populated these with relevant technical, cost and performance data.

The key activities of this Task included:

[22] In line with the latest analysis and values used in the Electricity Market Reform carried out by the Department of Energy and Climate Change VoLL of £17,000/MWh was used in Imperial College's studies as the central value. Imperial College has also carried out the analysis using larger value of VoLL (£34,000/MWh) to assess the sensitivity and robustness of identified solutions. A more detailed discussion on Customer Interruption Costs (CIC) and VoLL can be found in Imperial Colleges report "Review of Distribution Network Security Standards", for the Energy Networks Association, February 2016.

(a) a critical review of recent studies on quantifying costs of interruptions and identify strengths and weaknesses of different customer risk measures including EENS, frequency and duration of outages and different approaches to costing interruptions.
(b) Gathering network and load data (across all voltage levels and demand groups), and statistics associated with network failures, outages and service restoration procedures.
(c) Establishing a set of characteristic network designs, across the range of Group Demand levels and populating these with relevant technical, cost and performance data. This involved characterisation of failure and repair rates through not only average values but also a range of associated probability distributions.
(d) Based on the range of Imperial College models for assessing distribution network reliability performance, establish key high-level modelling approaches for assessing key load-point focused security indices, including evaluation of the expected values of the key indices based on Markov models and also their distributions through full Monte Carlo based models. This was used to derive equivalent VoLLs form different Customer Damage Functions. A range of studies have been carried out with the of estimating the breakeven value of VoLL at which the existing network would be upgraded cost effectively, and to estimate the least cost redundancy levels. This enabled equivalent cost of interruption to be compared with the cost of interruption when the central VoLL of £17,000/MWh, adopted by the UK government for the Electricity Market Reform, is applied. In order to assess the robustness of the findings, the optimal degree of redundancy is also estimated for higher VoLL of £34,000/MWh (with lower values of VoLL driving lower optimal degrees of redundancy). Sequential Monte Carlo analysis was carried out to determine the impact of reducing the level of network redundancy prescribed by the present standard on the frequency and duration of customer interruptions.
(e) Selected case studies carried out to demonstrate and agree the range of model outcomes to be used in subsequent tasks.

The output was a framework for the development of future network design standards.

3.4 WS2.2 Service quality and cost effectiveness of the present network design practices

For developing new network security standards, it is important to understand two key aspects of the present standard (a) the service quality inherent in the present network design practices (which may deliver networks with a security in excess of that required by P2/6) and implicit in the design standards, including contribution of distributed generation (b) the cost effectiveness of the standard, and its ability to the balance cost of interruptions against the cost of network infrastructure, which involved application of alternative indices such as VoLL and customer damage functions (see previous sub-section). Imperial College carried out a high-level analysis of average reliability performance, including an examination of the variability of key service quality indicators, and assessed the risk profile implicit in the present network standard across different Group Demand (GD) levels and selected network configurations. The probability density functions of various measures of reliability performance were estimated by application of suitably designed probabilistic analysis techniques. This facilitated comparisons of the level of security of supply implicit within the present standard with alternative formulations. Furthermore, the reliability analysis was combined with the various forms of customer damage functions, in order to estimate the monetary value of unreliability and to inform the optimal network design. This analysis enabled an evaluation of the magnitudes of VoLL and characterisation of the Customer Damage Functions that are implicit in the present standard. This also included analysis of the appropriateness of demand group definitions and treatment of interconnection/ transfer capacity.

Key activities of this task included:

(a) Based on samples of real distribution networks and the set of characteristic networks created across all voltage levels and group demands, analysis was carried out to assess service quality delivered to consumers by the present network design practices. This included rural, sub-rural/urban and urban network topologies and different consumer mixes across different demand groups. Understanding the actual performance of the present network security standard was important when developing alternative network design propositions. This included evaluation of various reliability indices in the form of expected values, and also the risk profile driven by the variability of key parameters.

(b) Cost benefit analysis for the existing network design practices was carried out to assess the efficiency of the present network design standard. A range of studies have been carried out with the aim of estimating the breakeven value of VoLL at which the existing network would be upgraded cost effectively, and to estimate the least-cost redundancy levels. Also, the impact of reducing levels of network redundancy on duration and frequency of interruptions has been determined. Some sensitivity analysis was carried out to demonstrate the impact of various key parameters and assess the robustness of the present practice.

(c) Assessing by how much the assumed cost of interruptions affects the fundamental design of networks, particularly when considering different consumer mixes. According to the London Economics study[23] the central VoLL of £17,000/MWh is attributable to a mix of residential and commercial consumers, while industrial customers would have lower VoLL and hence lower levels of redundancy than proposed in the report may be applicable. On the other hand, predominantly commercial consumers would be characterised with higher values of VoLL and given the conservative approach adopted in the Imperial College work, analysis is also carried out with VoLL of £34,000/MWh. In order to provide the insights of the impact of different values of VoLL on the degree of redundancy, *the breakeven value of VoLL* at which the existing network would be upgraded cost effectively, is also determined. This can be used to inform the debate regarding the question of "who/what are future distribution networks being built for"? It was also important in accounting for how uncertainties around the value of avoided interruptions (including how this varies across customer classes) feed through into network planning decisions.

(d) High-level analysis was carried out to establish appropriateness of demand group definitions and treatment of interconnection/transfer capability.

3.5 WS2.3 Risk associated with asset replacement, common mode failures and high impact events

The acceleration of major asset replacement programmes introduces risks not explicitly recognized when the planning standards were developed. Some construction outages will potentially last for long periods, thus exposing potentially large numbers of customers to an increased risk of loss of supply, unless comprehensive contingency measures for emergency restorations are established. The lack of differentiation between construction and maintenance outages in the distribution planning standards represents a significant shortcoming given that a period of potentially considerable asset replacement is underway. Imperial College conducted high-level assessments of materiality of this effect and estimated the risk profiles of supply security for typical configuration characteristics for large Demand Groups. This

[23] London Economics (2013). 'The Value of Lost Load (VoLL) for Electricity in Great Britain: Final report for OFGEM and DECC'.

included consideration of the appropriateness of the specified return to service periods (outage duration) for a first circuit outage and hence the period at risk of a second circuit outage.

Furthermore, the present standard does not address explicitly common-mode faults. These may be relevant when considering overhead line (OHL) circuits on the same tower or laying multiple cables in the same trench (that are expected to provide redundancy for one another), or especially the loss of a busbar or switchboard. This may be a particularly material issue for large demand groups exposed to potentially high risks of common-mode failures. Furthermore, this task also analysed the significance of high impact low probability events and alternatives for dealing with prolonged outages. Imperial College also considered the cost of interruptions and represented it through a non-linear function of the outage duration (see above).

Key activities of this task included:

(a) Carrying out high-level assessment of the risk profiles of security of supply associated with typical configurations for large Demand Groups and impact of different constriction outage durations. This also included establishing the principles of the cost-benefit analysis associated with alternative supply arrangements for construction outages.

(b) Assessment of the driving factors and the importance and materiality of considering common-mode failures. Case studies were carried out on the established set of characteristic network designs, particularly associated with large demand groups, with particular focus on parallel circuits and losses of busbars and switchboards[24].

(c) Carrying out high-level assessment of high-impact low-probability events, such as blackouts of critical districts, outages driven by very extreme weather conditions[25] and consequences of significant reductions in demand diversity following prolonged outages were carried out to identify key indicators, assess their importance and assess the benefits of expenditure on reliability improvements / mitigation measures of reducing their impact on the security of supply.

3.6 WS2.4 Impact of Smart Grid technologies on service quality risk profile

A high-level assessment to quantify benefits from flexible generation, responsive demand including storage, to security of supply was completed. A range of generic case studies with characteristic parameters for various flexible generation and demand technologies were carried out to assess the ability of these non-network solutions to substitute network assets without degrading the reliability performance seen by the end consumers. Imperial College's analysis suggests that when assessing the contribution of demand side response contribution to network security, it may be appropriate to consider response time, duration, energy recovery characteristics and cyclic sustainability. In this context, diversity effects associated with multiple demand side response providers/aggregators were considered. This task also included assessment of the role and value of advanced network technologies, such as automation and remote control of switchgear, soft Normally Open Points (NOPs), on-line voltage regulators, in enhancing the security of supply. Imperial College's models were applied with embedded Monte Carlo techniques to estimate effects of these technologies in enhancing security of supply (through mostly reducing outage time).

24 It is recognised that in the future common mode failures could relate to external factors e.g. computer failure of a DSM aggregator.

25 This relates to weather events that are considerably more extreme than a 1 in 10 year event.

This task also considered benefits of permitting islanding-mode operation of the distribution system in order to minimise interruptions in customer supply after the occurrence of severe low probability and high impact events.

The task was carried out in the context of different time frames (2020, 2030 and 2050), considering the future changes in the GB generation mix and the increasing growth in the penetration of distributed generation and demand composition. This involved consideration of effects associated with a lack of system inertia, exports from distributed generation and challenges that electrified heat and transport sector may bring.

Spatial and temporal properties of demand growth are characterised by a significant degree of uncertainty. In this context, non-network technologies may provide flexibility and make the future network reinforcement more certain and hence cost effective in the long run. This would create the option value of non-network technologies, through temporarily postponing investment decisions until more accurate information regarding the spatial and temporal properties of demand growth becomes available, while not compromising the service quality performance experienced by customers. It may be appropriate that such considerations become a part of the future network design standard. Furthermore, this may have implications for the regulatory framework associated with cost recovery for network and non-network solutions, which are considered in this work (see Work Stream 2.7 following).

Key activities of this task included:

(a) Through illustrative case studies on the established set of representative network designs, identifying alternative criteria for incorporating non-network solutions in future network planning standards, on a non-discriminatory basis. This in particular included:
   - Distributed generation of different technologies, response times and availabilities.
   - Responsive demand, considering availability, response time, duration, energy recovery characteristics and cyclic sustainability.
   - Energy storage technologies.

(b) Identifying alternative approaches to assessing the contribution that these technologies could make to network security in the case when they also provide other system support services, such as different forms of reserve and/or frequency response services. This was supported by relevant case studies.

(c) Identifying the role and value of advanced network technologies including automation and remote control of switchgear, application of soft NOPs, on-line voltage regulators, in enhancing the security of supply. Alternatives for including islanding-mode of operation were identified.

(d) Identifying alternative approaches to dealing with uncertainty in future developments when designing distribution networks (particularly in the context of integration of low carbon demand and generation technologies in distribution networks) in order to facilitate the debate of the role and scope of future network security standards. In this context, modelling was carried out to demonstrate possible evolution of the compliance requirement, considering present only, or also a least-cost compliance approach considering uncertainty in future development.

3.7 WS2.5 Assessment of impacts of alternative control and operation strategies on security of supply

While the previous task focused on the contribution of various Smart Grid technologies[26] to security of supply, this task centred on assessing the implications on network control and operation strategies (including those affecting new technology) required to enable these technologies to contribute to security of supply while simultaneously enhancing the ability of the distribution network to accommodate increased levels of demand and generation (and hence power transfers). Hence, in this task the Consortium considered alternative control and operation strategies that can be implemented through advanced Distribution Management Systems (DMS) and/or through distributing control functions among various controllers, and accompanying commercial arrangements that would support the use of demand and generation resources in supporting security of supply.

Currently, real time distribution network control is largely preventive with very little real-time control (except supply restoration), and security of supply is delivered through preserving sufficient margins in loading of network assets. These margins may be reduced without degrading security of supply, provided that a portfolio of corrective control actions is effectively optimised. Given that a higher degree of integration and participation of corrective control will require an increased reliance on ICT infrastructure, the security risks associated with these technologies need to be assessed. The key aspect of this work is consideration of both advantages and constraints associated with new monitoring, control and communication technology, reflected in the latency (time to operate), common mode failures and reliability of response.

This task involved:

(a) Carrying out wide consultation with industry and relevant stakeholders regarding the changes in real time network operation and control facilitated by appropriate software and ICT infrastructures that will be required to facilitate the transition to a smart grid paradigm, focusing on the impact on security of supply. Analysis of experiences and lessons from Low Carbon Network Fund (LCNF) projects and associated trials will also inform this task.

(b) Carrying out high-level case studies to estimate key drivers that will impact the risk profile of future actively managed distribution networks. This includes exposure to common mode failures associated with ICT infrastructure.

3.8 WS2.6 Loss inclusive design of distribution networks and impact on security of supply

The present policies for distribution circuit design are driven by security of supply criteria and the cost of losses has not historically been given adequate consideration. Recent regulation developments through RIIO encourage implementation of minimum life-cycle cost distribution network design that balances the capital investment against the cost of the system losses. Imperial College’s recent modelling demonstrates that the optimal peak utilisation of distribution network circuits (LV and HV in particular) should be very low. The implication of this on network reliability may be significant as the optimal network capacity should be much larger than peak demand, which would provide additional headroom and could potentially increase reliability of supply. However this effect has never been quantified and the

26 These technologies include embedded generation, voltage control technologies (tap-changing transformers, shunt compensation, in-line voltage regulators), energy storage technologies, responsive demand (smart appliances, electric vehicles), dynamic line rating etc.

purpose of this Task is to assess the implication of minimum-life cost driven network design on security of supply.

This task involved several activities:

(a) Based on Imperial College's loss-inclusive, minimum life-cycle cost LV and HV network designs, using the established set of characteristic LV and HV networks, carrying out modelling to assess the impact on network reliability performance.

(b) Identification of implications on the future network security standards and opportunities that this may open to cost-effectively further improving reliability performance through enhancing flexibility and reconfiguration capabilities of LV and HV networks.

3.9 WS2.7 Alignment of security of supply standard in distribution networks with other codes and schemes

Network planning standards interact with a wide range of other schemes, codes and regulatory arrangements in the British (and wider EU) electricity market. As part of this task, therefore, the Consortium examined the interactions of the high level options for improvement and reform of P2/6 with a range of other arrangements. The Work Stream 2.7 report covered a range of topics, as follows:

- It discusses the need for regulatory measures to constrain or influence the level of network reliability that DNOs choose to provide for their customers, and discusses the concept of "economically efficient" investment that such regulation should strive to achieve;
- It provides historical background and context of ER P2/6, which is one element of the regulatory framework imposed on DNOs that aims to encourage the efficient provision of network reliability to customers;
- It describes other regulatory instruments that may affect the British DNOs' decisions regarding the levels of network reliability they provide for their customers;
- It describes briefly the range of measures applied in the regulation of electricity distributors in other jurisdictions to encourage them to provide efficient levels of network reliability;
- Drawing in part on the range of regulatory measures observed internationally as described, it sets out a range of options for the reform of P2/6;
- It discusses the advantages and disadvantages of each of the options for the reform of P2/6, focusing on interactions with other aspects of the regulatory framework; and
- It concludes by describing the conditions under which each of the options for reform is most likely to promote the efficient provision of network reliability, and notes what other forms of evidence would be required to make a full appraisal of the options. In particular, the WS2.7 report describes how the evidence produced from the quantitative modelling being undertaken by Imperial College through other aspects of this project will inform the overall assessment of the P2/6 reform options we identify in section 4.1 of this report and appraised in section 5.

4 OPTIONS FOR FUTURE DEVELOPMENT OF DISTRIBUTION SECURITY OF SUPPLY STANDARD

The aim of Work Stream 2 was to provide the analysis required to (1) understand the impact of P2/6 in its current form on the economic efficiency against an idealised standard, and (2) identify the options for improvement and reform considering not just the techno-economic efficiency but also other key influencing factors such as transparency, practicality, usability, performance measurement etc.

The analysis performed under Work-stream 2 covered a range of topics, and entailed comprehensive desktop research, modelling of key issues and gathering of stakeholder input activity to identify the current impact of P2/6 and possible impacts from alternative security standard options. Amongst the primary areas of focus were the following:

- **Work Streams 2.1** Provision of a scope and framework for assessing security performance and measures of characteristic network designs;
- **Work Stream 2.2.** Analysis of the distribution network service quality performance associated with the present network design standard and alternative options for its update;
- **Work Streams 2.3.** Assessment of risk associated with asset replacement, common mode failures and high impact events;
- **Work Streams 2.4.** Analysis of the impacts of Smart Grid solutions on security of supply;
- **Work Streams 2.5.** Assessment of impacts of alternative control and operation strategies on security of supply;
- **Work Streams 2.6.** Loss inclusive design of distribution networks and impact on security of supply;
- **Work Streams 2.7.** Interface between distribution network standards and the regulatory framework (RIIO), EU codes, capacity mechanism and balancing services significant code review, and
- **Work Streams 2.7.** Defining the interface between distribution network standards and IIS and SQSS.

In addition to the above predominantly quantitative analysis, Work Stream 2.0, provided stakeholder input to assist in the development of the qualitative analysis performed.

4.1 High Level Options for Reform of P2/6

The analysis of the future distribution network operation and designs under different future development scenarios considered a comprehensive range of high level options for improvement and reform of the present network planning security standard including:

1. Retaining the existing P2/6 standard as is;
2. Enhancing P2/6 but retaining the deterministic nature/structure. Enhancements considered included:
    a. Non-network solutions – including: generation, energy storage, DSR, advance automation,

b. High impact low probability events,
c. Long term outages for asset replacement,
d. Common mode failures.

3. Replacement of P2/6 with an obligation to perform probabilistic CBAs;
4. Development of a hybrid standard with an obligation to perform probabilistic CBAs but retaining some deterministic elements. This is viewed as a hybrid of options 2 and 3, and
5. Complete removal of P2/6 security standard.

The Consortium has evaluated the range of options using the cost benefit framework established by Imperial College and described in section 3. This cost benefit framework considers the (quantitative and qualitative) costs and benefits of:

- Different service quality delivered to end customers, assessing frequency and duration of outages together with risk profile and robustness associated with construction outages, common mode failures and high impact events.
- Options for incorporation of demand side response, distributed generation and energy storage technologies in the future network design standards are discussed, while considering application of advanced automatic control schemes and/or area-wide operational measures that might contribute to security.

Furthermore, the Consortium has also considered the appropriateness of conducting experiments within present LCNF projects in order to inform the analysis and the development of alternative distribution network standards.

The key outputs and conclusions from the analysis carried out under sub work streams 2.0 to 2.7 that impact on the high level options for improvement and reform of the present security standard are summarised in the following sections. Section 5 includes a full assessment of the options for reform based on the key conclusions from the sub work streams.

4.2 WS 2.0 Key Outputs and Conclusions.

The qualitative analysis from WS2.0 is based on the review and analysis of the Consortium's industry questionnaire containing a set of high level and more detailed questions that sought and gained the input of the many industry stakeholders regarding their opinions and views on the status, usability and adequacy of the existing P2/6 security standard and how this could be improved[27]. To ensure that a wide range of inputs and views were captured and opinions recorded, all relevant industry parties and organisations were invited to provide their views and positions through a written response to the questionnaire. This has enabled the Consortium to build a fully representative understanding from industry stakeholders of their own views and opinions of the strengths and weaknesses of the existing P2/6 security standard and identify potential alternative approaches to security standards and regulatory and commercial considerations. Follow-up interviews were also held with key users of the existing P2/6 standard to clarify statements and opinions and to provide additional details to their organisation's responses.

[27] Full details of the questionnaire and interview process, responses and analysis are include in the Consortium report "Findings of the qualitative review associated with the future development of the P2/6 distribution network planning security standard", report no. 16011094/290, rev 002, Nov 2015.

The stakeholder responses were analysed and reviewed to identify key themes that are used as a basis for input to the development of this initial options report that considers the benefits and problems associated with the identified high level options for the successor to P2/6.

The stakeholder engagement outlined in the WS2.0 report has been the first opportunity for wider industry stakeholders (outside of the DCRP P2 WG) to input directly to the development of the options review process to identify a successor to the existing P2/6 security standard.

From the analysis of the various stakeholder questionnaire responses and details of the clarifications gathered by stakeholder interviews, a number of key themes emerged relating to the potential reform of P2/6.

The key themes identified and summarised from the WS2.0 review of the stakeholder responses[28] are summarised below. There is no prioritisation stated or intended in this list, as respondees were not asked to provide a view as to the level of importance relating to the potential standard updates or replacement strategies. Some questions were only directly relevant to specific stakeholder groups[29]; however, a number of key themes were identified by the majority of stakeholders:

1. **Embrace the strengths of the existing standard** – a strength of the existing standard is its simplicity. Many respondents (from both categories [30]) suggested this simplicity and transparency should remain to ensure the usability of any future standard. Respondents suggested that any new sections should be clear and concise. Any new obligations placed on DNOs to undertake more complex planning exercises should consider the availability and cost of planning staff required to apply the new standard methodologies.
2. **Provide consistency with the regulatory framework** – the new standard should be developed in such a manner that it is consistent with the existing regulatory framework and flexible enough to adopt potential future changes without a major review of the regulatory system. The new standard will need to align with, or accommodate regulatory incentives, including the IIS. Some respondents discussed the possibility of delaying implementation of any new standard that imposes new obligations on DNOs until the start of the next price control period.
3. **Remain sufficiently intuitive and easy to audit –** Some respondents noted as a benefit of the existing standard the ease with which it can be explained in legal proceedings, such as Wayleave hearings or disputes, which can minimise dispute costs and delays. Further, it helps

[28] It should be noted that the views summarised in this report are those of the industry respondents. Statements made by respondents should not be taken to represent the views of the Consortium or the DPCR P2/6 Working Group. The analysis in this report is based on the questionnaire and interview responses, it does not argue or analyse whether the stakeholder views are justified or correct. Subsequent work in further work streams that utilise the summaries in this report will consider whether the stakeholder views are accurate and relevant for the inclusion in the future development of a potential replacement security standard.

[29] All respondents wish their submissions to remain anonymous, however, the full WS2.0 questionnaire report does provide more detailed information on the questionnaire responses and the associated stakeholder category or general business type e.g. DNO or non DNO etc.

[30] To ensure that the views and comments for all relevant industry parties were sought and recorded, the stakeholders were split into two broad categories: Category 1 - stakeholders that make use of ER P2/6 on a regular basis and where P2/6 has a direct impact on their business (DNOs and NGET) and those who have responsibility for oversight (DECC and Ofgem). Category 2 - the wider group of interested parties and industry participants who do or may have an interest in the P2 review process. This wider group of stakeholders include representatives from Offshore Transmission Owners, independent DNOs (IDNOs), and trade bodies and organisations covering traditional and renewable resources: solar, conventional and renewable generation, hydro generation, demand side response and domestic customers.

DNOs to demonstrate compliance with the Electricity Safety, Quality and Continuity Regulations (ESQCR).

4. **New network technologies must be fully represented** – it is clear from all parties that the revised standard must consider both demand and export sites and other network technologies. This should include (but are not limited to) energy storage devices, DSM, DSR and other commercial arrangements. It is important that such devices and arrangements are included in the standard to enable them to be part of the network design process and provide their range of services to the market and the network. This will enable the future network design to consider the benefits that are provided by such devices with a view to fully utilising their capabilities to maintain the required level of security while minimising the cost of such services to the network operator.

5. **Provide a clear and consistent set of definitions** – some of the existing P2/6 statements are open to interpretation which leads to different views being formed of some of the statements and requirements, all terms in any new standard ought to be comprehensively and clearly defined, including the inclusion of a definition of Firm Capacity (if this term is used in any new standard).

6. **Reflect network user expectations** – the new standard should fully reflect all network user expectations (both demand and export), be able to include customer willingness to pay for levels of security and meet their requirements as they evolve in the future.

7. **Introduction of Cost Benefit Analysis –** there is general support for the use of CBAs in the new standard to help inform decision making and guide optioneering but only as one component of the overall process and the method should be used within a closely defined context.

8. **Treatment of network losses should not be included –** Most respondents took the view that the security standard should not be adjusted to explicitly consider network losses, but suggested that the interface between other industry standards/regulatory initiatives should be enhanced to ensure that any incentives work correctly in conjunction with the security standard to support its intent of ensuring the efficient provision of security of supply.

9. **Statements of requirements should remain prescriptive** – Many respondents took the view that the description of the requirements imposed by the planning standard should be prescriptive, ensuring all DNOs are designing to the most economically efficient and stated common sets of planning methods. This will provide a level of supply security that offers the best value for customers but also balanced with adaptability to facilitate new/innovative methods of managing the network / network demand.

10. **Include the management of construction outages** – Some respondents expressed a desire for the new standard to provide guidance as to the methods for the treatment of construction outages that will provide a more consistent approach for all DNOs to adopt and provide consistency across networks. This will become increasingly important as the shape of the network demand becomes more difficult to forecast as the penetration of new LCT increases and DNOs will have less choice of when to minimise the risk associated with a construction outage.

11. **Treatment of Extreme events** – extreme events as characterised by HILP (high impact, low probability) should not be included in the new/revised standard. Such events should be treated within the regulatory framework. It was noted that a wider debate (which is outside the scope of this project) should be initiated across the industry to agree the most efficient way to treat such events.

4.3 WS 2.1 to 2.6 Key Outputs and Conclusions.

The quantitative modelling and analysis of WS2.1 to 2.6 carried out by Imperial College is set against the context where the UK electricity system is facing exceptional challenges in the coming decades. Meeting the medium and longer-term carbon emission reduction targets will require intensive expansion of the use of low carbon electricity generation and demand technologies. Under the UK Climate Change Committee ambitions (greenhouse gas emission reductions of at least 80% in 2050) it is expected that the electricity sector would be significantly decarbonised by 2030, with potentially significantly increased levels of electricity production and demand driven by the incorporation of heat and transport sectors into the electricity system.

Delivering these targets cost effectively, will require fundamental review of the historical philosophy of network operation and design. Although the distribution networks, designed in accordance with the historic deterministic standards, have broadly delivered secure and reliable supplies to customers, the key issue regarding the future evolution of the standard is associated with the question of cost effectiveness of the use of existing assets and the role that advanced, non-network technologies and intelligence based control could play in the future development and delivery of security of supply to consumers. A fundamental review of the philosophy of distribution network operation and design has hence been carried out by Imperial College [31] to inform the industry, consumers, regulator and government, in order to support the transition to a cost effective delivery of the UK Government energy policy objectives considering the requirements of future customers.

Overall, there are two key questions addressed by Imperial College's work:

1. Is the present security network design standard efficient? Does it deliver value for money to all network customers? In other words, does it balance the cost of network infrastructure with the security benefits delivered to distribution network customers?
2. Given that the present design standard has predominantly resulted in network security provided through asset redundancy, will this impose a barrier for innovation in the network operation and design and prevent implementation of technically effective and economically efficient solutions that enhance the utilisation of the existing network assets and maximise value for money to network customers[32]?

4.3.1 Specific objectives and scope of the work

In order to meet the key objectives of WSs 2.1 to 2.6, a large volume of studies covering a broad spectrum of analyses addressing the key distribution network design problems from different aspects were required. In order to manage the work effectively, several sub-tasks were developed with specific objectives and scopes as listed in the following descriptions[33]:

Subtask 1: *Evaluates the cost effectiveness and review the performance of the present network design standards.*

The specific objectives of this task were to:

[31] Imperial College report "Review of Distribution Network Security Standards", for the Energy Networks Association, February 2016.

[32] P2/6 does not provide guidance on the usefulness of non-network technologies to provide supply security (with the exception of distributed generation), nor does it consider the potential impact these technologies have on the efficient level of supply security that could be achieved.

[33] These sub-tasks cover the objectives of WSs 2.1 to 2.6 set at the commencement of the review but have been reorganised by Imperial College to aid the communication of their comprehensive work.

- Assess the value of lost load that can justify the case for network upgrade and identify the key parameters that drive the value of security;
- Identify the optimal degree of redundancy for a range of cases which are built by varying the value of important parameters;
- Analyse the results and compare with the present standard.

The objectives were addressed by analysing the results of the comprehensive studies carried out using a set of reliability tools developed by Imperial College for distribution networks with different voltage levels, loading, structures (Overhead Line and Underground Cable), configurations, and reliability parameters.

Subtask 2: *Assesses the benefits of smart grid technologies in supporting efficient distribution network design.*

In this task, the aim was to demonstrate the benefits of smart grid technologies for improving the efficiency of network investment and operation by enabling higher utilisation of the assets, releasing network latent capacity, and improving network control capability to manage operational constraints. A range of smart grid technologies were analysed including DLR[34], overloading capability of transformers and cables, storage, and DSR[35].

In terms of the business case for automation the key aims of this task were to:

- identify and quantify the potential benefits of automation for reducing the restoration time and therefore improving the reliability performance of the electrical distribution system measured by the CI, CML and Expected Energy Not Served (EENS) indices and for reducing the associated interruption costs and;
- assess the business case for automation for different equipment costs, network availability parameters, VoLL and assess the materiality at the GB level.

Subtask 3: *Investigates the impact of construction outages and asset replacement on distribution network design and planning strategies.*

The aim of this task was to analyse on a high-level construction outage and asset replacement programme risks not explicitly recognized when the present planning standard was developed.

Subtask 4: *Investigates the impact of distributed generation on reliability driven design of distribution networks.*

The key objective of this activity was to investigate the extent to which distributed generation may drive network investment in the context of security of supply.

Subtask 5: *Investigates the impact of common-mode failures and high-impact-low-probability events on distribution network operation and planning.*

The focus of this task was on the impact of simultaneous outages triggered by common-mode failures (CMF) and the increased probability of component failures during high-impact-low-probability (HILP)[36]

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34 DLR – Dynamic Line Rating.

35 DSR – Demand Side Response.

36 High impact low probability events can be where multiple or common mode faults or failures impact on the network outside of the designed security arrangements and where the supply loss impacts many customers or high profile customers. The reason why designs may not cater for such events is that they are assessed to be very unlikely to happen or difficult to predict and the mitigation costs are potentially very high. Rather than design networks to cater for HILP, operators may consider how they respond to such events.

events. These factors in the design and planning of future distribution networks could be important and the impacts need to be understood. The objective of this task was to:

- Illustrate the cases where CMF may affect considerably the design of distribution networks;
- Demonstrate the potential impact of HILP events on the reliability performance of the distribution networks which may influence future network design;
- Quantify the benefits of mitigation measures to reduce the severity of the faults due to CMF and HILP.

Subtask 6: *Assesses the impact of uncertainty and demonstrate various approaches for optimising the investment decisions for distribution networks across different scenarios*.

The main objectives of this task were to:

- Demonstrate cases where the uncertainty can influence the investment decisions and enable adoption of strategic or incremental approaches to network planning under uncertainty considering risks of stranded assets;
- Demonstrate that distribution network planning problems can be formulated in different ways depending on the investor's attitude towards risk;
- Demonstrate the option value of investing in flexible technologies such as DSR to deal with future uncertainty.

A stochastic optimisation approach and min-max regret approach were used to demonstrate cases and quantify the option value of DSR. The uncertainty addressed in these studies was limited to the uncertainty in the future demand growth. Sensitivity studies on the cost of DSR were also carried out for this task.

Subtask 7: *Determines the long-term optimal design of distribution networks.*

In this task, the objective was to investigate the optimal configuration of distribution networks taking into account network capacity that has been optimised considering the impact of losses in the lifetime of the assets. The studies were carried out to determine the optimal configuration by implementing cost benefit analysis on different configurations which also offer different degrees of network redundancy. The impact of providing mobile generation was also investigated.

4.3.2 Key findings and Conclusions

Based on the results of Imperial College's comprehensive studies, including comprehensive literature surveys, the following key conclusions are made:

Cost effectiveness of the present network security standard

The present security standard tends to be conservative, dealing with worst case scenarios. This implies that the present security standard would be cost effective only for "extreme" cases with high failure rates, long restore/repair times and low upgrade costs. However, in most cases particularly at HV level, in the short term the existing networks (both feeders and substations) could accommodate demand growth by relaxing the N-1 redundancy requirement up to the point where reinforcement becomes economically justified. For reliable HV networks, with low failure rate and low MTTR[37], the peak load can

[37] MTTR – Mean Time to Repair.

nearly be doubled before reinforcement is economically justified. The potential benefits of relaxing the N-1 security constraints at the GB level could reach 42% to 67%[38] of the projected reinforcement capital expenditure by 2030 in case of significant load growth at LV and HV level[39].

The optimal level of network redundancy is case specific, depending on many parameters (reliability characteristics, investment cost, VoLL[40], mitigation measures) and therefore it may be difficult to implement a "one size fits all" standard with the expectation to be cost-effective in all cases. On the other hand, implementation of a single deterministic standard, could deliver simplicity and transparency but with lower cost savings to the customer[41].

The studies have demonstrated that networks with low reliability (i.e. higher failure rates, longer time to restore or repair), low upgrade cost, and with high VoLL (£34,000/MWhr) tend to require a higher degree of redundancy compared with networks with relatively high reliability, short time to restore or repair, high upgrade cost, and low VoLL (£17,000/MWhr).

For networks supplying larger demand groups, a higher degree of redundancy is found to be efficient. Although this trend is consistent with the present P2/6 standard, it does not necessarily justify the efficiency of the present standard.

The requirement for network upgrade due to demand growth is also less when other corrective measures such as mobile generation and load-transfer facilities are available. The costs of such corrective and preventive measures are taken into account in the analysis. As a trade-off, increasing the load demand on the existing network capacity will in turn degrade the service quality; increasing CI, CML, and Expected Energy Not Supply (EENS)[42]. Customer expectation in any decision to reduce service quality would need to be considered. However, given the present VoLL, it is still beneficial (in financial terms) to defer the investment if possible.

It is worth mentioning that the Imperial College analysis shows that VoLL for some HV UG networks with high reliability and high upgrade cost, may need to be more than £3,500,000/MWh and as high as

38 It is noted that the Imperial College reinforcement projections from their modelling may differ from DNO load related reinforcement projections using the Transform model. However, there are many reasons why this may be the case. For example the proportion of reinforcement benefits estimated in the Imperial College study may not materialise as some parts of the network may need to be replaced due to condition and refurbishment driven replacement. Load related reinforcement and non-load related asset replacement are treated as separate budgets under distribution network regulation. It should also be noted that the Imperial College assessment assumes that the network starts from a point where the capacity limit has been reached and then uses a forecast load growth to estimate reinforcement requirements to 2030. While there may be some argument over the level of benefits that materialise by 2030 due to existing spare capacity in the network and the load growth forecast used, these benefits will materialise over some time period and in fact potentially could be much higher over longer time periods. To allow for any discrepancy between the DNO forecast reinforcement capital expenditure to 2030 and the Imperial College modelled results the potential benefits from relaxing the security levels prescribed by P2/6 are expressed in percentage form.

39 It is noted that the potential reinforcement capital savings of deferring network reinforcement by relaxing the level of prescribed redundancy as modelled by Imperial College is dependent on the forecast demand growth and the time period over which this is considered. The cost savings determined by Imperial College are based on demand forecasts from the Committee on Climate Change "core decarbonisation" (CD) pathway, which assumes very high deployment levels of low-carbon technologies. The cost savings come from HV, EHV and 132kV network reinforcement deferments. The projected cost savings do not include the cost of any potential enabling technology. The impact on losses due to reduced redundancy is also included in the CBA carried out at the GB level. While other demand forecast assumptions could be used that would result in a lower cost saving, Imperial College consider that the demand forecast used demonstrates the potential for high cost savings over a defined period using a credible demand forecast. The Imperial College report demonstrates that very high deployment of low-carbon technologies (LCT) does not necessarily result in high savings, a distribution system may need upgrading anyway due to asset condition. The Imperial College report also considers a "Delayed Electrification" (DE) pathway which is comparable with the National Grid Future Energy Scenarios (FES) Gone Green scenario. Importantly in scenarios with lower levels of low-carbon technologies deployed, higher savings are observed.

40 VOLL, the Value of Lost Load modelled by Imperial College was £17k/MWhr with studies also carried out at twice this value £34k/MWhr. The VOLL of £17k/MWhr is based on a value determined by DECC and presently used across government departments.

41 The impact of a deterministic standard on potential cost savings would be very dependent of the standard developed and would require to be investigated during the codification phase to determine the potential cost savings against the present P2/6 standard.

42 The Imperial College modelling work in general shows when comparing the N-1 and economically efficient designs, that CI will increase due to the use of automation to control demand during an outage event if demand is greater than the remaining feeder thermal constraint. Otherwise there is no increase in CI given that for all disconnected customers in the N-1 degree of redundancy CI is taken into account and the decrease in redundancy does not lead to any new fault incidents. Similarly, due to the lower provision of redundancy in the economically efficient designs, load curtailment is needed when demand is greater than feeder thermal constraints and CML increases. The increase in EENS is greater than the increase in CML, given the demand increase which is not relevant for CML; this is the case even if the number of connected customers increases with the demand increase. In this context, the Imperial College approach used will produce conservative results regarding the optimal level of redundancy.

£64,900,000/MWh, to maintain the economic case for a N-1 degree of security when considering reinforcement due to demand growth.

Generation driven distribution network investment

There is no need for network redundancy to secure DG output, assuming that impact of the loss of distributed generation at the national level is marginal. This implies that the present N-0 security level is adequate for DG as the cost of generation curtailment would be typically much lower than network reinforcement cost as the Value of Lost Generation (VoLG) is typically two orders of magnitude lower than the Value of Loss Load (VoLL)[43].

Reverse power flow may pose risks for demand customers, increasing the possibility of load interruption However, network reinforcement to solve this problem is unlikely to be the cost effective solution for this problem even in the worst case scenario being studied (i.e. low network reliability performance) as the use of a smart system protection scheme, i.e. inter-tripping scheme can limit the negative impact of the reverse power flow on demand reliability. However, smart protection systems may be exposed to failures of real-time communication and control systems, which have also been considered, showing that the redundancy in protection would provide efficient solutions rather than network reinforcement.

Long-term optimal design of distribution networks

The capacity of optimal loss-driven distribution networks is much larger than peak demand, given that the savings in losses exceed the extra cost of oversizing the network[44].

Taking advantage of large spare capacity through loss-driven network designs, in the long-term it will be cost effective to increase redundancy of LV and HV distribution networks beyond the level prescribed by the present standard[45].

Value of automation

Automation can significantly reduce the CML and CI indicators on HV networks[46] by 56% and 88% respectively due to significantly shorter supply restoration times when compared to manual switching. This benefit of automation might not be very significant in circuits with very high reliability.

Contribution of Distributed Energy Resources and Energy Storage to network security

DER (Demand Side Response, Distributed Generation and Energy Storage) can support network flow and voltage management and provide the capacity required which can, to a certain extent, substitute for network capacity cost effectively. However, the capacity contribution of DER will depend on both network reliability characteristics and DER parameters including availability, size, number of sites, technical characteristics (e.g. ability to operate in islanding mode). For energy limited sources, such as energy storage, the amount of energy that can be stored will be an important parameter. Imperial College's work has also shown that due to the number of variables determining the security benefits of DER, it is very site and case specific. Hence it is not clear how a simple deterministic standard could be applied to DER in relation to network design considering security.

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43 It is noted that while the Imperial College probabilistic economic analysis shows this to be the case, a number of DNO and DG representatives on the WG have cited the issue around long term DG outages due to circuit reinforcement and also the case where network areas are dominated by DG rather than demand. These issues could increase in the future as DG increases and may need to be considered where DG operational support may be relied upon to a greater extent in the future. These points are discussed under construction outages later in this report.

44 It should be noted that under the present regulations the value of losses that DNOs are incentivised against does not reflect the full value of losses e.g. the capital investment in power generation plant to supply network losses. Regulatory changes would be required for DNOs to deliver optimal loss-driven network designs.

45 On a practical level it should be noted that loss-driven network designs would not simply mean installing larger cables or overhead lines but may require additional cables or overhead lines running in parallel. This may further enhance the opportunity to improve network security.

46 The Imperial College work indicates that these networks could be enhanced with automation to reduce CI and CML at low cost compared with other voltage levels.

Smart management of network overloads through disconnection of non-essential loads

At present, network overloads would be managed through demand disconnections, with some consumers being completely disconnected and some consumers fully supplied. The roll-out of smart metering will provide a unique opportunity for smarter management by potentially facilitating the switching off of non-essential loads when a network is stressed while maintaining supply of essential loads[47]. This would result in a significant enhancement of the reliability of supply delivered by the existing network, as more consumers would have their essential load supplied during network stresses. Furthermore, this could open up the potential for customer choice driven network design. The analysis demonstrated that the integration of consumers' preferences in network planning would yield an equitable outcome - consumers with lower flexibility enjoy higher security of supply at the expense of higher DUoS charges, while consumers with higher flexibility are rewarded for their lower security of supply through lower DUoS charges. The proposed framework increases the overall reliability levels without the need for additional network capacity, as it would allow serving of the critical loads during network congestion, in contrast to the traditional framework leading to complete curtailment of some consumers' demand. Implementing smart management of network overloads through disconnection of non-essential loads has the potential to further enhance network utilisation and eliminate the need for network reinforcement leading to projected additional savings of about £2-3bn at the GB level by 2030.

Since the barriers to implementing this concept have still to be fully understood, the potential savings indicated by Imperial College's work have not been considered in the key conclusions of this report.

Enhancing network assets utilisation

The definition of capacity in the standards should allow the use of emergency loading, for both transformers and cables, as they potentially can provide additional capacity for short-term periods which reduces the amount of demand to be interrupted, if any. Imperial College has found that, it may be cost effective to increase the life-loss of the assets by overloading these during emergency conditions as most of the time the assets are operated below the nominal rating[48].

In addition, the definition of capacity in the standards should also allow and guide the use of asset cyclic ratings and dynamic rating technologies. It is noted that additional sensors might be needed to increase assets observability and support management of overloads.

Also, voltage management could be important on distribution network. At LV, network capability is frequently constrained by voltage rather than by the network thermal (current) limits. Reduction of minimum voltage limit (during emergency conditions) could enhance utilisation of the network. Network capacity can be nearly double (by releasing latent capacity which is constrained by voltage limits). Therefore it may be important to lower the present lower voltage limit as a strategy to accommodate increased demand and to facilitate integration of DG by alleviating voltage rise effects.

In addition to enhanced network utilisation, lowering the voltage limit can be used as a strategy to lowering load at periods of high demand. Most of the domestic devices could operate at 85% of the current nominal voltage. Increasing the upper voltage limit is not recommended due to safety reasons[49] and failure of some devices during the tests.

Impact of construction outages and asset replacement

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[47] It is noted that the present smart meter roll out does not include this functionality at present.

[48] It is recognise that flexible ratings are generally already used by DNOs.

[49] There is a greater risk that devices might fail if voltage is increased above the upper voltage limit and there might be an increased risk of catastrophic failure of some devices.

The Imperial College study demonstrates that it would be economically efficient to provide provisional supplies and reduce risk of consumer interruption during asset replacement. Longer construction-outages will expose the system to greater risk which in turn, increases the value of developing provisional load-transfer as a risk mitigation measure considered in this study.

Long-term optimal design of distribution networks

Network losses are an important factor to be considered in planning the capacity and design of future distribution networks. The Imperial College's analysis demonstrated that the capacity of distribution networks may need to be oversized significantly above the peak demand requirements in order to reduce losses such that the savings in losses exceed the extra cost of oversizing the network. For example, studies have shown that an optimally sized LV cable would be operated at maximum demand no higher than 12-25% of its thermal rating. Imperial College's analysis shows that loss-inclusive network design clearly requires a much greater capacity of network components, which would be significantly above the peak loading.

If such a loss inclusive network design strategy were adopted then taking advantage of the large spare capacity, in the long-term the analysis demonstrated that it would be cost effective to potentially increase redundancy of LV and HV distribution networks beyond the level prescribed by the present standard. The CBA carried out by Imperial College demonstrated that the costs of the additional network assets needed to increase the connectivity and enhance reliability may be lower than the savings in EENS delivered by such a new design strategy.

Distribution network resilience

Diversity in the portfolio of technologies, network and non-network, will not only reduce the total system costs (cost of investments in network assets, availability and utilisation costs of DSR/DG/ES and cost of expected energy not supplied), but could reduce exposure to CMF[50] and HILP events, improving the distribution network resilience.

The Imperial College study demonstrates that the concept of Conditional Value at Risk (CVaR) could be applied to limit the probability of large outages. This would result in increased network investment and/or DSR costs, while reducing the consequences of high impact outages.

In the context of developing the future security standards addressing the CMF and HILP issues, a number of options have been identified, including the following:

- Robust design of distribution substations with balanced portfolio of network and non-network solutions. Considering the customer density and scale of demand, this is particularly important for urban networks; some work has been carried out by the ENA Urban Reliability (HILP)[51] working group indicating the importance of reducing the risks associated with HILP for Central Business Districts.
- Emergency operation and investment actions to deal with HILP. From the results of case studies, Imperial College has demonstrated that the use of emergency operation and investment actions such as the provision of mobile generators, and transfer cables can cost-effectively reduce the impact of HILP significantly. Resource constraints[52] should also be considered especially during the restoration of the system after a HILP event.

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50 Common Mode Failure.

51 ENA Urban Reliability Report, not publically available.

52 D.J.Clements, P.Mancarella,"Resource Constrained Distribution Network Modelling under Severe Weather Conditions," Proceeding of IET International Conference on Resilience of Transmission and Distribution Networks, Birmingham, Sep 2015.

- Expanding the scope of the risk assessment to consider cyber-physical systems (CPSs). Imperial College has demonstrated that the failure of ICT infrastructure may cause CMF which renders multiple sources (e.g. DSR, special protection scheme that requires communication) providing network services unavailability[53].

However, it is still an open question whether the assessment of CMF and HILP should be included in the standards for the following reasons:

- There is a lack of comprehensive data to derive CMF and HILP parameters (e.g. frequency, the scale of impact) that can be used to consider cost effective mitigation measures.
- The impact of a certain hazard is very network specific. For example, the risk of having flood in plateau areas is much lower compared with lowland areas; impact on urban networks will be different in comparison with the impact on sparse rural networks. Different networks may be exposed to different types of hazards. Hence the justification of the investment via CBA will be case specific.
- The basis of appropriate risk level thresholds is difficult to define rigorously and establish corresponding confidence in the process by all relevant stake-holders.

While there may be difficulty in demonstrating any economic case for CMF or HILP mitigation, the case for some form of link into a security standard for these to be considered may exist in a wider context and could be considered at the codification stage of any standard reform. This may require a wider and separate consultation.

Robust distribution network planning under uncertainty

Given uncertainty associated with demand and generation growth, and significant economies of scale associated with network reinforcement, it will be important to consider benefits of both strategic and incremental approaches to network development. Hence, it may be cost effective to consider compliance with the network security standard in the context of uncertainty in growth of future demand.

A number of distribution network planning approaches (e.g. min-max regret approach, Conditional Value at Risk (CVaR) optimisation) to address short-term and/or long-term uncertainty have been developed and could be used to inform the planning strategy taking into account different risk attitudes.

Existing NPV valuation rules inherently biases towards committing to long-term solutions that exhibit considerable scope for scale economy effects. However, in the event of an unfavourable scenario realisation these capital-intensive investments have an increased stranding risk. In view of this, new planning frameworks would be required, capable of identifying strategic investments and enabling planners to consider investment in flexible technologies such as DSR as an alternative to conventional reinforcements. Otherwise, planning can systematically favour non-flexible large-scale capital projects that may lack the necessary flexibility to enable the adoption of a ‘wait-and-see’ approach.

Factoring in real options valuation techniques to cost benefit analyses may address this problem. **T**he real options approach to valuation (and thus also to cost benefit analyses used to select optimal reliability levels) has the potential to improve the robustness of the planning decisions taken by DNOs, including when selecting the optimal levels of reliability. For instance, this approach can account for the value of flexibility that comes from using operating solutions to address network capacity constraints and

[53] A related topic not considered here is Cyber Security which is likely to be driven in the future by government policy to protect national infrastructure from cyber-attacks.

deferring investment, while the network owner waits for uncertainty about the future to be resolved. This uncertainty might arise due to factors such as demand growth, generation connections, technological development, and so on.

In the same way as P2/6 prescribes the same restoration times for a particular demand group in all cases, and thus ignores differences in consumer type, location, cost, etc., it also ignores the option value that some technological solutions might bring. A real options approach would account for this “value from waiting”, and would allow DNOs to consider the merits of letting reliability deteriorate temporarily, and/or using smart solutions to avoid or defer costly, long-lived capital investments where there is a chance they might be stranded if the future turns out in a certain way.

To the extent that real option value could be an important driver of what investments are economically efficient, and we have not assessed this through quantitative modelling that would need to be considered in phase 2, this would tend to reinforce our finding that the redundancy requirements in the current P2/6 could be scaled back in the near-term, and that less deterministic requirements should be considered in the longer-term. The real options approach does, however, add a layer of complexity to a traditional CBA modelling exercise, so it is likely that some study of this approach and some guidance would be needed before DNOs were asked to consider it.

We note, however, that through the business planning and cost assessment methods used by Ofgem at price control reviews, Ofgem encourages companies to undertake rigorous CBAs, and real options analysis could form part of their submissions. Indeed, the rewards companies earn through the price control process from putting forward innovative and low cost business plans means they probably have an incentive to use this form of analysis where they can. It is possible that, to the extent that companies do not use real options methods, this reflects a lack of familiarity with these relatively complex methods rather than any failing of the regulatory framework.

Analysis assumptions

The analysis carried out by Imperial College is based on current asset costs provided by DNOs[54], reliability parameters provided by DNOs[55], losses at system marginal price and a VoLL of £17,000/MWh (value adopted by the UK government for all Electricity Market Reform related analysis used by DECC and Ofgem) with a sensitivity value of £34,000/MWh applied. Furthermore, a comprehensive range of studies have been carried aimed at estimating the breakeven value of VoLL at which the existing network would be upgraded cost effectively. The studies are carried out on generic configurations of HV, EHV, and 132 kV networks that provide conservative estimates of optimal levels of network redundancy.

4.4 WS 2.7 Key Outputs and Conclusions.

The output from “Workstream 2.7” focuses on the alignment of P2/6 (or any possible replacement thereof) with the broader regulatory framework to which DNOs are subject, and that may influence the degree of security of supply they choose to, or are obliged to, provide for consumers. The WS 2.7 outputs and conclusions summarised in the following sections reflect the range of topics outlined in section 3.9 of this report and are fully detailed in NERA’s WS2.7 report[56] .

[54] Refer to section 15.2 of Imperial College’s report for further detail.

[55] Refer to section 15.5 of Imperial College’s report for further detail.

[56] “Engineering Recommendation P2 Review Workstream 2.7: Alignment of Security of Supply Standard in Distribution Networks with Other Codes and Schemes”, prepared for the Distribution Code Review Panel, P2 Work Group, 20 November 2015.

The WS2.7 report sets out the high level options for reform of P2/6 and while developed before the detailed results from the WS2.0 qualitative analysis report and Imperial College's WS2.1 to WS2.6 quantitative analysis the WS2.7 report sets out an initial assessment of the arguments for and against each high level reform option. While the following sections summarise the key conclusions from the WS2.7 report, Section 5 of this report builds on the WS2.7 options assessment to develop a fuller appraisal of the arguments for and against each security standard high level reform option drawing on the key conclusions from the WS2.0 qualitative analysis and Imperial College's quantitative analysis.

4.4.1 WS 2.7 Summary and Conclusions

4.4.1.1 Different Mechanisms for Regulating Network Supply Security

The system of revenue caps imposed on the privately owned electricity network companies in Great Britain provides strong incentives to reduce costs, including (potentially) savings made at the expense of lower quality of service. Some regulatory mechanisms are therefore required to encourage or mandate DNOs to provide an efficient level of quality of service, including the provision of assets or other operational measures to provide an economically efficient level of network security.

ER P2/6 is one such regulatory instrument that requires DNOs to achieve certain restoration times following the failure of a distribution asset. Complying with these minimum restoration times often requires DNOs to put in place particular amounts of redundancy, with increasing security requirements for assets serving more load. In practice, a range of other regulatory instruments are used that also affect DNOs' decisions over what level of network security to provide, most notably the IIS. Other jurisdictions use different types and combinations of regulatory instruments to achieve the efficient provision of supply security. Notably, not all jurisdictions use deterministic planning standards, of which P2/6 is an example.

Our review of alternative approaches to regulating supply security, as well as other discussions with the DCRP P2 Working Group, leads to a range of options for the reform of P2/6:

1) Retaining P2/6 without revision;
2) Retaining a deterministic planning standard that seeks to define the efficient network supply security requirements DNOs should provide, but with improvements compared to P2/6 such as to better account for the role of non-network solutions such as embedded generation, storage, demand side response, etc.;
3) Implementing a non-deterministic planning standard, which would involve abandoning the approach of specifying required levels of investment or service levels and placing more discretion in the hands of DNOs to plan their network efficiently, such as by conducting cost-benefit analyses;
4) Implementing a non-deterministic planning standard that obliges efficient investment (following option 3), while retaining some deterministic elements that define a "bare minimum" level of network security; or
5) Abolition of the planning standard, and relying instead on other regulatory mechanisms to encourage DNOs to plan their networks efficiently.

These options are in line with those set out in Section 4.1.

4.4.1.2 Appraising the Economic Efficiency of these Alternatives

Quantifiable effects

A deterministic planning standard, by its nature, instructs DNOs to provide certain levels of network security. If the levels of network security P2/6 prescribes are economically efficient, then the current deterministic planning standard may itself be considered economically efficient. However, if a large "gap" exists between the economically efficient level of network security and that prescribed by P2/6, then there may be case for reform (i.e. adopting one of the reform options 2-5 listed above). The quantitative modelling conducted by Imperial College estimates the size of this "gap".

In assessing whether option 2, the updating of the current deterministic standard, can address any such efficiency gap, two considerations are particularly relevant:

- First, it is important to evaluate whether alternative distribution planning standards can close the gap between the economically efficient level of investment and that prescribed by P2/6. For instance, if the Imperial modelling finds that P2/6 prescribes systematically too much or too little network security, then there will be a case for changing the requirements it imposes on DNOs accordingly. This may lead to a recommendation to adopt option 2 above.
- However, even if it is possible to specify a new deterministic standard that closes the gap between the economically efficient level of investment and that prescribed by P2/6 in many cases, it is also important to consider the variability of the gap. The Imperial College modelling may show that the economically efficient level (or type) of investment to provide network security depends on external factors that can be observed by the network planner (e.g. network configuration, topography of the region). If these factors cannot easily be accounted for when codifying a deterministic planning standard, then a new deterministic standard that seeks to prescribe the level of network security it is efficient to provide on average (option 2) will in many cases prescribe too much or too little provision of network security. This finding would lead to a recommendation to consider adopting one of options 3-5 above.

Options 3-5 all place more discretion in the hands of DNOs to decide the economically efficient level of investment, such as by conducting CBAs to identify the optimal level and type of investments to provide network security. In this sense, the difference between these options is hard to quantify as they can all, in principle at least, oblige or incentivise DNOs to plan their networks efficiently, without defining specifically what levels of network security they are required to provide[57]. In principle, a quantitative comparison of these options would all lead to the same answer, i.e. that the DNO reaches the economically efficient solution. The consideration of these options, at least within the scope of this report, can only be qualitative, as discussed below.

However, the one exception is option 4, which does require DNOs to plan efficiently such as by using CBAs, but prescribes minimum levels of supply security that the DNO is allowed to provide. Obliging DNOs to provide minimum levels of security may have some benefit because it simplifies network planning (as discussed below). But on the other hand, if even the minimum requirements are set too high in some cases, some loss in efficiency may result. The Imperial College modelling could have in theory been used to quantify any such loss in efficiency with de minimis deterministic planning requirements imposed by option 4. However, this would have required a de minimis to be set and the loss of cost efficiency evaluated which could be an iterative process and is outside the present scope of work.

57 Option 5 (removal of the planning standard entirely) will, of course, only incentivise DNOs to provide the economically efficient provision of reliability if the financial incentive mechanisms are calibrated to encourage DNOs to value improvements in reliability at the value consumers themselves place on such improvements. For this reason, as discussed above, some improvements to the IIS mechanism might be desirable if option 5 were selected.

Qualitative effects

A benefit of deterministic planning standards, that would be lost if one of options 3-5 were adopted[58], would be a loss of simplicity in the planning process. While there may be an economic efficiency loss associated with a deterministic planning standard that prescribes potentially inefficient levels/types of investment to provide network security, it does simplify the task undertaken by network planners, as they do not need to decide on the economically efficient level of network security. Placing more discretion in the hands of DNOs may add cost and complexity to their planning activities, which would need to be offset against any potential economic efficiency improvement.

DNOs' network planning decisions may also become less simple to understand for those outside the DNO who take an interest in them (e.g. embedded generators, large customers, government, Ofgem). This factor is a cost that ought to be taken into account in the overall evaluation of the reform options. However, there may be ways to offset its effect, such as by developing a process whereby DNOs publish their investment plans and policies. There may also be value in having a process whereby Ofgem approves the planning methodologies published by DNOs, e.g. because it may help DNOs to defend investment decisions against legal challenges as they can cite a regulatory document setting out the investment planning process they follow.

Options 3-5 might also create less uniformity in the planning procedures adopted, and the levels of network security provided by different DNOs. This is a natural result of abandoning a common deterministic planning standard, but we are sceptical as to whether it is a significant problem:

- Variation in the degree of network security provided is probably economically efficient as the costs of providing network security vary across the country, as may the value network users place on network supply security. The 42% to 67% potential savings in reinforcement capital expenditure to 2030 estimated through the Imperial College modelling of the "ideal solution" is based on an economic assessment of the reduction in supply security that can be achieved before there is an economic case for network reinforcement[59]. This shows that the optimum supply security level varies across the network due to a range of variables:
- It may be the case that, at the higher demand groups, P2/6 provides some consistency on the risk of consumers being affected by a major incident. Nonetheless, with the deterministic planning requirements in respect of network security imposed by P2/6, the actual levels of network supply security consumers experience vary enormously, so to suggest P2/6 achieves uniformity across network users is incorrect; and
- Having different DNOs applying different investment planning policies brings potential benefits in the form of innovation in planning; but
- Some network users that engage with multiple DNOs might face higher costs as a result of having to understand multiple investment planning policies. This factor is a cost that ought to be taken into account by Ofgem in the overall evaluation of the reform options[60]. However, as in the case of the costs DNOs face due to more complicated network planning (see above), these

[58] Albeit to a lesser extent under option 4, which still sets some minimum deterministic requirements.

[59] For clarity this cost saving is due to relaxing the N-1 security requirement only. It does not include any benefits from advance automation or the substitution of network redundancy with other non-network technologies e.g. DSR, DSM, Storage or DG. Imperial college has looked at benefits from advance automation and the substitution of network redundancy with other non-network technologies separately.

[60] This is a "softer" consideration that Ofgem ought to consider in assessing the case for reform. The Consortium cannot account for this or the other qualitative factors in an objective way as any attempt to estimate them is out of the present scope of work. However, the Consortium believes that the quantifiable benefits of a less deterministic approach are significant and that these "softer" effects are probably more marginal.

effects could be mitigated through making DNOs' planning procedures and the standards they apply as transparent as possible, and possibly engaging with network users on planning procedures and the standards through public consultation.

The need for additional regulation to support more flexible planning Standards

Option 5 is a relatively extreme case in which Ofgem essentially ceases to explicitly regulate the level of supply security provided by DNOs, or the means by which they provide it. Instead, this option relies on other regulatory mechanisms, the IIS in particular, to encourage DNOs to provide efficient levels of network security using the cheapest means possible. As discussed in the WS2.7 report, while theoretically compelling, for this solution to encourage DNOs to provide efficient levels of network security, some reform of the IIS would be required to provide greater exposure to the costs of interruptions, in particular high impact[61] events that are currently excluded from DNOs' CI/CML indices. Such a change in the IIS might affect the financing costs (i.e. the Weighted Average Cost of Capital) and financeability (i.e. ensuring DNOs can cover interest costs and obtain an investment grade credit rating with a sufficient degree of certainty), though further work would be needed to assess these effects in phase 2 of the P2 review[62]. Any such increase in financing costs might increase costs to consumers, but they would also be passing some of the risk around interruptions through to the DNO, so consumers would achieve some offsetting benefit in exchange.

Option 3 is similar to option 5, in that it also places increased reliance on DNOs to plan efficiently, but it reinforces the incentives conveyed through the IIS and other mechanisms to oblige DNOs to plan efficiently and select the economically efficient level and type of investments to provide network supply security in accordance with a CBA. As discussed in chapters 6 and 7 of the WS2.7 report, there are different ways in which this obligation could be specified, with varying degrees of prescription. Such an obligation could also be combined with reporting requirements placed on DNOs to publish their CBA modelling, which may support sharing of innovation, to procure non-network solutions competitively (e.g. following the Australian "RIT-D" approach, as discussed in Chapter 5 of the WS2.7 report), and/or for DNOs to obtain Ofgem's approval for their planning methodologies.

Given (1) the benefits from disseminating information that follows from obliging DNOs to publish their planning methodologies and/or models, and (2) the challenges involved in redesigning the IIS to facilitate complete removal of any planning standard, option 3 may therefore be preferable to option 5.

In terms of the choice between options 3 and 4, i.e. whether to combine a CBA obligation with some minimum deterministic elements (see above), option 4 only adds value if there are certain aspects of network planning for which the minimum efficient levels and/or types of investment to provide network security can be codified in a way that will apply to all network configurations, etc. If so, setting some deterministic requirements may simplify the planning process, and thus reduce DNOs' planning costs.

The Imperial College modelling shows that cost efficiency improvements may be possible through a reduction of the existing N-1 redundancy. In principle, this reduction could be codified as a reduction in the level of redundancy required by P2 (option 2). However, the Imperial College modelling also shows that the application of reduced redundancy solutions is dependent on a number of variables some of

[61] This refers to "exceptional events" which might or might not be classed as HILP. Particular large interruptions can occur that DNOs have limited ability to prevent. In order to reduce the volatility and impact of these occurrences on their performance (and future target setting), these "exceptional events" are excluded from annual performance figures. Exceptional events are classified as being either a severe weather exceptional event or a one-off exceptional event.

[62] For DNOs to manage the financial risk of any inclusion of HILP events in the CI/CML indices they would need to be able to assess and mitigate the exceptional events which is not easily achieved due to the unpredictable nature of HILP events, discussed in section 5.

which are local network dependent. The Imperial College modelling also shows that the application of non-network solutions (DSR, DSM, DG and storage) is dependent on a number of variables. Hence, it may be extremely complex to codify the role of reduced redundancy and non-network technologies in providing network resilience using deterministic rules. This introduces some development risk associated with options 2 and 4.

Moreover, the Imperial College modelling also shows that, as network assets are replaced with new assets with higher thermal ratings in order to minimise losses, the cost of providing resilience through traditional network solutions falls, making it efficient to provide higher levels of network reliability. Hence, the finding that it is appropriate *in general* to reduce the existing redundancy requirements may not apply in all cases. This finding further undermines the case for options 2 and 4, suggesting more flexible approaches may be required.

4.4.1.3 Other Considerations

Other benefits of network assets

In setting the new planning standard, it may be desirable to consider the other benefits of network assets in defining the economically efficient level of investment, in particular the benefits of loss reduction. Under option 2 (and possibly option 4, to some extent), this means factoring in any other benefits into the definition of what level of supply security is required by a deterministic standard. Under option 3 (and also under option 4), this involves allowing/obliging DNOs to consider other factors in determining the efficient level of investment when undertaking CBAs. Under option 5, this involves providing DNOs with new financial incentives for other benefits (to the extent they do not already exist) to encourage them to plan efficiently.

Ensuring consistency with the regulatory settlement

If this review process concludes that reform of ER P2/6 is necessary, the implementation of any reform option that places additional material costs during RIIO ED1 on DNOs, and/or exposes them to more financial risk may well be impractical before the end of the RIIO-ED1 settlement in 2023. However, the advantage of such a delay in implementation is that it would allow DNOs time to prepare to adopt the preferred option, such as the development of suitable models and training of staff to adapt to new, potentially more demanding, working practices.

More modest reforms that retain the nature of the current deterministic model (options 2 or 4), and/or do not alter materially the requirements placed on DNOs, may be implementable before the end of the current control period. In fact, even if this review process concludes that one of options 3 or 5 should be implemented, an improved deterministic model (options 2 or 4) could be implemented as an interim measure with a view to implementing a more enduring solution after the end of the ED1 control period in 2023.

5 APPRAISAL OF THE HIGH LEVEL SECURITY STANDARD OPTIONS

We have identified a range of "high level" options for the reform of P2/6.

1. *Retaining P2/6 without revision* might be desirable if there is no clear evidence that (i) alternative deterministic standards would materially improve efficiency, and (ii) there is also evidence to show that, taking as given evidence on other aspects of the regulatory regime, a deterministic planning standard remains necessary to ensure DNOs invest efficiently;

2. *Retaining a deterministic planning standard, but with improvement,* such as to account for the role of non-network solutions such as embedded generation, storage, demand side response, etc. If adopting this approach, it would also be desirable to update the requirements it imposes to ensure the level of redundancy prescribed reflects an efficient trade-off between investment costs and the costs of interruptions. If a deterministic planning standard were retained, it would also be important to consider whether the scope of the obligations it imposes should be expanded or curtailed compared to the current standard;

3. *Implementing a non-deterministic planning standard* would involve abandoning the approach of specifying required levels of investment or service levels, placing more discretion in the hands of DNOs, obliging them to plan their network efficiently, such as by conducting cost-benefit analyses. In practice, such a non-deterministic standard could be implemented in many different ways, and in particular, with very different levels of prescription regarding DNOs' obligations to use specific methods and assumptions for network planning. For instance:

   Option A. At one extreme, a new planning standard could simply state that DNOs have an obligation to plan their networks in a way that they can demonstrate is economically efficient, without defining how they should plan their networks, or defining the term "economically efficient" explicitly. DNOs would then be responsible for interpreting this obligation as they see fit, thus affording them extensive discretion and flexibility, and justifying their approach to the regulator;

   Option B. At the other extreme, network planning procedures could oblige DNOs to plan their networks by conducting CBAs, and specifying how these CBAs should be conducted, the investment options they should consider, the specific types of costs and benefits that DNOs should consider, the assumptions they should make, such as in respect of the benefits of avoided interruptions or lower losses, and so on. In fact, the standard could go so far as specifying that DNOs should use a specific model, which could be developed through some later industry process;

   Option C. Of course, in between these extreme positions, there may be intermediate approaches that oblige DNOs to plan their networks efficiently (following option 3A), but making some high-level requirements on how they should conduct CBAs (taking some aspects of option 3B). This might include, amongst other things, instructing DNOs on the economic values to place on avoided interruptions, or the discounting rates/time horizons to be used in CBAs;

4. *Implementing a high-level standard that obliges efficient investment, while retaining some deterministic elements* represents a hybrid of options 2 and 3. This option would work by imposing deterministic requirements for some aspects of network design, such as those for which prescribing economically efficient levels and types of investment through a "rule" does not entail material risk of

error, while leaving other elements of network design at the discretion by the DNO and placing an obligation on them to plan efficiently. For instance, this approach could also be used to determine a *minimum* level of service that all consumers can expect to receive, leaving DNOs to provide higher levels of security of supply if it can be justified using a CBA model.

5. *Abolition of the planning standard*, may be desirable if other regulatory mechanisms are already in place to encourage DNOs to plan their networks efficiently to provide security of supply. This option would offer DNOs more flexibility than options 1 to 4, but achievement of efficient outcomes for consumers would place much greater reliance on other aspects of DNOs' regulatory incentive package, such as the IIS. Indeed, if such an approach were adopted, consideration as to whether any requirement to strengthen other aspects of the regulatory settlement to send stronger or clearer signals to DNOs regarding the economic value of reliability should be made.

The range of options identified is supported by our review of regulatory mechanisms that are in place both within Great Britain and internationally to encourage efficient investment in distribution systems[63]. Of course, the high-level nature of these options mean that some of them, if adopted, would require further work to design and codify.

In this section of the report, we appraise each high level option for reform of P2/6 against retaining the present P2/6 standard. This work builds on the appraisal carried out under work stream 2.7[64] but now incorporating the findings of the modelling and quantitative analysis conducted as part of the review process by Imperial College[65] and further considering the qualitative findings from the stakeholder engagement in work stream 2.0[66] to provide a full appraisal at this stage of the phase 1 review process.

5.1 Retaining P2/6 without revision

There are two key questions relating to economic efficiency addressed by Imperial College's work:

1. Is the present security network design standard efficient? Does it deliver value for money to all network customers? In other words, does it balance the cost of network infrastructure with the security benefits delivered to distribution network customers?
2. Given that the present design standard requires that the network security is provided through asset redundancy, will this impose a barrier for innovation in the network operation and design and prevent implementation of technically effective and economically efficient solutions that enhance the utilisation of the existing network assets and maximise value for money to network customers?

In terms of the first question the Imperial College work concluded that the present security standard tends to be conservative, dealing with worst case scenarios. This implies that the present security standard is only cost effective for "extreme" cases with networks characterised with high failure rates, long restore/repair times and low upgrade costs. However, in most cases particularly at HV level, in the short term the existing networks (both feeders and substations) could accommodate demand growth by

63 The key findings from our WS 2.7 review are included in section 4.4.

64 NERA report, "Engineering Recommendation P2 Review Workstream 2.7: Alignment of Security of Supply Standard in Distribution Networks with Other Codes and Schemes", prepared for the Distribution Code Review Panel, P2 Work Group, 20 November 2015.

65 The Imperial College modelling work was carried out under work stream 2.1 to 2.6 with the key findings detailed in sections 4.3 of this report.

66 The key findings from work stream 2.0 are detailed in section 4.2 of this report.

relaxing the N-1 redundancy requirement up to the point where reinforcement becomes economically justified. For reliable HV networks, with low failure rate and low MTTR[67], the peak load could almost be doubled before reinforcement is economically justified. The potential benefits of relaxing the security constraints across the HV, EHV and 132kV network at the GB level could reach 42% to 67% of the projected reinforcement capital spend[68],[69] by 2030 in case of significant load growth at LV and HV level[70],[71]. As a trade-off, increasing the load demand on the existing network capacity will in turn degrade the service quality; increasing CI, CML, and Expected Energy Not Supply (EENS). The impacts of relaxed redundancy levels on network performance is discussed in detail in section 5.3 of the Imperial College report extended summary and section 2.4 of the main report. While changes in CI may be less obvious, Imperial College has provided some modelling of potential changes in expected CML and considered 4 case studies to give guidance on CML changes. The four cases are summarised in Table 5-1 with the change in CML per customer per annum provided in Table 5-2.

Parameter	Case A	Case B	Case C	Case D
Construction	**Overhead**	**Underground**	**Overhead**	**Overhead**
Failure rate (%/km.year)	5	10	20	5
Switching time (minutes)	2 and 30	2 and 30	2 and 30	2 and 30
MTT Repair (hours)	24	24	24	24
MTT Restore (hours)	24	24	3	3
Least-cost degree of redundancy	N-0.75	N-0.5	N-0.25	N-0

Table 5-1: Case study parameters for network with N-1 feeder peak demand of 2,500 kW

Case	ΔCML, ST=30 minutes	ΔCML, ST=2 minutes
A	1.3	1.6
B	22.3	23.7
C	13.7	17.1
D	6.5	7.7

Table 5-2: Increase of CML if the P2/6 N-1 design requirement is relaxed; ST – switching time

67 MTTR – Mean Time to Repair.

68 It is noted that the Imperial College reinforcement projections from their modelling may differ from DNO load related reinforcement projections using the Transform model. However, there are many reasons why this may be the case. For example the proportion of reinforcement benefits estimated in the Imperial College study may not materialise as some parts of the network may need to be replaced due to condition and refurbishment driven replacement. Load related reinforcement and non-load related asset replacement are treated as separate budgets under distribution network regulation. It should also be noted that the Imperial College assessment assumes that the network starts from a point where the capacity limit has been reached and then uses a forecast load growth to estimate reinforcement requirements to 2030. While there may be some argument over the level of benefits that materialise by 2030 due to existing spare capacity in the network and the load growth forecast used, these benefits will materialise over some time period and in fact potentially could be much higher over longer time periods. To allow for any discrepancy between the DNO forecast reinforcement capital expenditure to 2030 and the Imperial College modelled results the potential benefits from relaxing the security levels prescribed by P2/6 are expressed in percentage form.

69 Imperial College estimate the potential savings from avoidance or deferral of HV network reinforcement (including HV feeders, primary substations and EHV and 132kV networks), while considering the increase in customer interruption costs and cost of losses.

70 From the Imperial College report Table 5.20 "Potential benefit (£m) of avoiding reinforcement of networks due to security standard constraints at GB level" it is observed that the estimated maximum benefit is relatively similar for a relaxed degree of redundancy from N-0.5 to N-0 for combined HV, EHV and 132kV networks. Even at a modest relaxed degree of redundancy of N-0.75 there is a substantial potential benefit.

71 The Imperial College assessed benefit is based on network reinforcement which could include new or upgraded circuits and substations to accommodate load growth out to 2030.

Any reduction in supply quality due to reducing the level of security would also potentially impact on export customers as well as demand customer, although, there is the potential for export customers to improve network security. While to some extent this is happening now there is greater potential for this in the future through more advanced control and communication.

Customer expectation in any decision to reduce service quality would need to be considered. The 42% to 67% benefit figures account for the penalty cost of increased CI and CML and the cost from increased losses through running networks at higher power demands. The Imperial College results indicate that relaxing the degree of redundancy between N-0.5 and N-0 show similar cost benefits and even a modest relaxation to N-0.75 shows a potential benefit between 19% and 41% of projected reinforcement capital spend.

In addition to the impact on network performance where costs are included in the potential benefit assessment i.e. CI and CML penalties of reduced performance, the possible impact on network resilience to common mode failures and high impact low probability events cannot be quantified.

The level of benefits indicated by the Imperial College work are based on a VOLL range from £17,000/kWhr VOLL adopted by the UK government for all Electricity Market Reform related analysis up to a VOLL of £34,000/kWhr. It is recognised that VOLL is a controversial subject, however, Imperial College has considered various customer damage functions and their equivalent VOLL as well as VOLL used in other countries and concluded that the best approach was to use the present VOLL used by the UK Government but apply a sensitivity range of VOLL to £34,000/kWhr. The Imperial College studies also indicate the economic break even value of VOLL where reinforcement is economically justified in all their reported studies.

Imperial College has also carried out some analysis based on ACE 51[72], this shows that in the cases examined the cost benefit analysis indicates applying reduced N-1 redundancy rather than reinforcement is the economically efficient solution. The results from the ACE 51 case studies also indicate that Imperial College's modelling used to review P2/6 may be conservative in the potential economic benefits determined.

The move away from the level of security prescribed by P2/6 would require detailed modelling of network areas potentially on a case by case basis to achieve the benefits indicated[73], and there are some practical issues of how to quickly shed demand should an outage occur. However, the Imperial College work clearly demonstrates that from an economic view point the present P2/6 standard could be improved by relaxing the present minimum level of security to defer reinforcements. Introducing the concept of losses driven network design at the time of deferred reinforcement would introduce capacity well above peak demand as discussed in section 15 of Imperial College's extended summary report with the potential to increase network security. Hence the potential reduction in supply quality would eventually be corrected and possibly improved[74].

Regarding the second key question, DER (DSR, DG and Energy Storage) can support network flow and voltage management and provide the capacity required which can, to a certain extent, substitute for

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72 Imperial College analysis based on ACE Report No.51, 1979, "Report on Application of the Engineering Recommendation P2/5 Security of Supply" is presented in section 2.5 of their report covering WS2.1 to WS2.6 of this review.

73 The Imperial College work concludes that the optimal level of network redundancy is case specific, depending on many parameters (reliability characteristics, investment cost, VoLL, mitigation measures) and therefore it may be difficult to implement a "one size fits all" standard with the expectation to be cost-effective in all cases.

74 Since the capacity of electrical assets are finite or are procured in finite capacities future losses driven designs could incorporate additional lines/cables or possibly circuits to achieve the losses efficient design which would potentially increase network security above present design levels.

network capacity cost effectively. However, the capacity contribution of DER will depend on both network reliability characteristics and DER parameters including availability, size, number of sites, technical characteristics (e.g. ability to operate in islanding mode). For energy limited sources, such as energy storage, the amount of energy that can be stored will be an important parameter. This conclusion does however indicate that the present standard should be modified to include all forms of DER when planning network security. It is recognised that the present standard does cover the contribution to security from DG through the P2/6 supporting document Engineering Technical Report 130 "Application Guide for Assessing the Capacity of Networks containing Distributed Generation".

Imperial College's work has shown that due to the number of variables, determining the security benefits of DER is very site and case specific. Hence it is not clear how a simple deterministic standard could be applied to DER in relation to network design considering security. The present ETR 130 provides a method for quantifying the potential contribution to network capacity through the calculation and application of "F Factors" to different forms of DG. The Phase 2 work should consider whether this could be extended to all forms of DER. The phase 2 work should also review the quantifying of F Factors for all forms of DER and consider whether there is any improved alternative to the ETR130 methodology.

Based on the qualitative analysis from WS2.0 regarding new technologies, it is clear from all parties that the revised standard must consider both demand and export sites and other network technologies. This should include (but are not limited to) DG, energy storage devices, DSM, DSR and other commercial arrangements. It is important that such devices and arrangements are included in the standard to enable them to be part of the network design process and to stimulate their range of services to a market for network support[75]. This will enable the future network work design to consider more fully the benefits that are provided by such devices with a view to fully utilising their capabilities to maintain the required level of security while minimising the cost of such services to the network operator[76]. Hence again there is a conclusion that the present P2/6 standard should be reviewed with a view to improvement or possibly wider reform.

The WS2.0 qualitative analysis does show a strong desire amongst some stakeholders to retain a simple deterministic standard for various reasons including ease of use and keeping network planning costs low. Other strengths of the present standard expressed by WG members during the review process include:

- Compliance testing by DNOs, the Regulator and others is straight forward and hence transparent.
- The simplicity and transparency mean that it is straight forward to explain to customers and other stakeholders the need for reinforcement.
- The simple rules as a security standard assist in the consent process and necessary Wayleave process when justifying need.
- The standard provides consistency of security applied in different licenced areas

However, the modelling conducted to date suggests the efficiency costs of retaining a simple deterministic standard could be significant and setting deterministic rules for all non-network technology solutions would require extensive analysis and may have a risk that any such rules are too complex to

75 It is noted that EHV system export customers with non-zero F Factors can potentially receive use of system credits under certain conditions described in the Extra High Voltage Charging Methodology (EDCM).

76 The Imperial College report (see section 5.7 of the Imperial College extended summary report) indicates potential benefits of deferring/avoiding reinforcement from peak demand control through smart control of low carbon technologies of £0.8 to £1bn could be added to the benefits forecast by relaxing the present security requirements. The Imperial College report also demonstrates potential benefits of £2bn to £3.4bn through smart disconnection of non-essential loads. However, in both cases the cost of implementation is not accounted for which will reduce the benefit figures indicated.

allow simple application[77]. As a minimum improvements to the ETR130 method should be reviewed to see if it can be extended to all DER and also potentially improved.

5.2 Improvements to the deterministic planning standard

One of the options identified is to introduce a new deterministic standard, similar to the P2/6 standard, but updated to reflect the Imperial College assessment of the value of reliability as compared to the costs of investment, as well as factors such as accounting for those non-network solutions that provide reliability. This option is supported by the evidence gathered through the qualitative analysis of WS2.0 discussed in section 4. While an improved deterministic standard, achieved by making adjustments to the ER P2/6 would not bring about fundamental change in the way DNOs are regulated and the way they plan their networks, it would still serve to improve the economic efficiency of the investment decisions taken by DNOs to comply with the standard. Having no explicit requirement to implement a fundamental change to the way in which DNOs are regulated and so not requiring any changes to the regulatory arrangements could also be seen as an advantage.

Before we discuss the conditions under which the introduction of a new deterministic planning standard is beneficial to DNOs and their customers, it is useful to review the general costs and benefits of deterministic planning standards (compared to more flexible arrangements).

5.2.1 The benefits of deterministic planning standards

There are some clear advantages to deterministic standards, relative to the more flexible arrangements involving the use of CBAs, or the abolition of any formal planning standard. These advantages include the relative simplicity and transparency of planning decisions that can be taken from the use of a deterministic standard, which may keep down the costs of planning the network, and the ease with which compliance with the rules can be tested by the regulator and the DNOs' own management, as discussed below.

The simplicity of deterministic planning standards reduces the complexity, and thus the costs, of network planning faced by DNOs. For instance, deterministic standards such as P2/6 specify the minimum levels of reliability DNOs are required to deliver, in effect determining the minimum level of asset redundancy DNOs must provide and avoiding the need for DNOs to decide themselves what level of redundancy it would be economically efficient for them to provide.[78] In essence, DNOs know what levels of redundancy are necessary to comply with investment planning rules, and do not need to evaluate whether it is economically efficient to provide particular levels of reliability.

Conversely, under a non-deterministic approach in which DNOs are required to conduct CBAs or there is no formal planning standard at all, DNOs would have discretion in deciding the optimal level of reliability (based on customer demand for reliability and the costs of providing reliability), and in deciding on the least-cost way of delivering this level of reliability. This increased flexibility and independence (while it may enhance economic efficiency – see 5.3.1) will also increase the responsibilities and planning costs of

77 The cost implications of continuing with the present standard based on Imperial College's studies are provided in section 5.2.3, i.e. the cost saving between P2/6 and the "ideal solution". The cost implications from an improved deterministic standard cannot be assessed at present as additional work would be required in Phase 2 to evaluate new deterministic rules. In doing this the cost savings against P2/6 and the "ideal solution" would require to be assessed as part of this process.

78 While the P2/6 does recognise the contribution of embedded generation to security of supply, it does not recognise the role of other forms of non-network solutions in increasing reliability. Thus, in the majority of cases, P2/6 requirements effectively dictate the level of redundancy DNOs must provide. For a further discussion, please see Chapter 3.

DNOs. For instance, DNOs may need to hire more network planning experts to conduct CBAs and decide on the optimal levels of supply reliability. Thus, deterministic planning standards keep DNO's network planning costs low.

However, in assessing the increase in costs that would result from placing more discretion to plan networks in the hands of DNOs, and requiring them to undertake CBAs, it is important to recognise that DNOs already perform CBAs, at least for some categories of investment, to support their submissions to Ofgem at price control reviews. Extending the use of CBAs by placing more discretion to select optimal levels of reliability in the hands of DNOs might therefore not add materially to the range of capabilities DNOs need to retain in their businesses.

Deterministic standards also make it relatively simple for DNOs (and for Ofgem) to check compliance with the rules: a DNO's network either meets the pre-set criteria, or it does not. This ease of testing compliance may simplify legal or regulatory challenges to DNOs' planning decisions, such as Wayleaves hearings. Having a deterministic standard may, in some cases, reduce the administrative costs associated with demonstrating the need for investments, as the need for certain levels of reliability is specified explicitly in regulation. However, no deterministic standard can ever be comprehensive, and there may be different ways in which DNOs can comply with requirements to achieve a certain level of reliability. Hence, even a deterministic planning standard cannot remove entirely the need for DNOs to justify investment decisions in such proceedings using more evidence than simple references to regulatory requirements to provide particular levels of reliability, such as P2/6. The stake holder engagement supports this point with examples where the design option of a second circuit for redundancy, based on economic assessment, has been replaced with an option for the provision of standby mobile generation.

Moreover, other infrastructure industries are not regulated through deterministic planning standards, and companies in these industries may still have to defend their investment decisions in legal proceedings. Hence, while a non-deterministic standard may increase the complexity and the cost of defending investment decisions, this increase in costs cannot (in itself) justify retaining a deterministic standard. As discussed below, deterministic standards may prescribe economically inefficient reliability requirements and investments, and the benefits of removing this inefficiency may need to be compared to any potential increase in the costs of legal challenges to DNO planning decisions[79].

Deterministic planning standards may also keep costs for Ofgem low, as checking compliance with deterministic standards is relatively straightforward. By contrast, if DNOs were obliged to plan the level of reliability provided by their networks using CBAs, with more discretion and flexibility given to DNOs, checking compliance would be more complex, and potentially costly, for the regulator. Removing the planning standard entirely, in contrast, would remove the need for explicit regulatory oversight of compliance with regulatory requirements in respect of reliability, and thus probably reduce the direct costs of regulation. However, removal of the standard would introduce other issues as discussed later in section 5.3.

Some stakeholders have also noted that deterministic planning standards mitigate the regulatory risks DNOs face, as they provide a defined standard against which some investments will be considered necessary (or "efficient", in the vernacular of the Ofgem cost assessment process) and thus funded through the price control mechanism. However, we do not consider that removing or reducing the use of

[79] This issue is probably one for Ofgem to consider and is outside of the Consortium scope of work and competence. This area was discussed with the DCRP P2 WG during the review of the WS2.7 report and potential for evidence was discussed. However, no evidence has been presented as to whether the cost of legal challenge would increase or remain the same.

deterministic planning standards would have such an effect, as the Ofgem cost assessment process, which sets DNOs' allowed revenues, has seen a substantial departure from scheme-by-scheme appraisal. For instance, Ofgem's totex benchmarking, which at RIIO-ED1 received a 50% weighting in the cost assessment, uses a high-level regression equation to predict expenditure as a function of network size. Scheme-by-scheme appraisal was used for some elements of the remaining 50% of the cost assessment, but Ofgem and its technical experts only examined a sub-set of DNOs' proposed capital schemes.[80]

We do agree, however, that abandoning a common deterministic standard across DNOs might increase the extent to which some companies incur higher costs to provide reliability than others. Given that Ofgem conducts comparative benchmarking when setting DNOs price controls, as discussed above, a decision to remove a common deterministic standard could increase the risk that differences between DNOs' costs could be mistaken for differences in their relative efficiency. Hence, any future decision to remove a common deterministic planning standard might require that Ofgem considers whether changes to its cost assessment methodology are required to address this at the next price review. This would, however, not be a significant change from the current situation, as Ofgem has changed its cost assessment methodology at each periodic review anyway.

5.2.2 The costs of deterministic standards

Deterministic planning standards prescribe the level of supply reliability DNOs are expected to provide, and may prescribe or limit the way in which such reliability should be delivered. However, in practice it may be difficult for any regulator to accurately determine the required optimal levels of reliability that should be written into a deterministic design standard, and/or the least cost means of delivering or improving security of supply. In practice therefore, deterministic planning standards may come at the cost of reduced economic efficiency. This is reflected in the key conclusions from Imperial College's modelling and analysis, see section 4.3.

In specifying the required level of reliability, a deterministic planning standard should be reflective of the benefits to consumers of security of supply, and the costs of providing it. In other words, the reliability requirements should be set at a level that targets the allocatively efficient level of reliability. However, a deterministic planning standard, such as the P2/6[81], that prescribes uniform reliability levels across demand groups at all parts of the network is likely to be inherently inefficient for two reasons:

- First, the value customers place on electricity when they are without supply varies from consumer to consumer. While it is impossible to vary reliability at the level of the individual customer, due to the shared nature of network assets and technological limitations, some reflecting of differences in the value of reliability across customer types, regions, etc., would enhance efficiency.
- Second, the cost of providing a certain level of supply reliability varies depending on factors such as the density of population, topography, and so on.

Thus, a planning standard that prescribes the same level of supply reliability across all consumers and regions is likely to prescribe inefficient levels of investment to provide reliability in many cases. Since

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80 In addition, Ofgem may limit this potential risk increase. For instance, under the alternative option of a non-deterministic planning standard with a CBA obligation, Ofgem could introduce a compliance verification procedure, e.g., it could approve the CBA methodologies of DNOs ex ante. Alternatively, Ofgem itself might prescribe the exact methodology DNOs should use to conduct CBAs, or even some of the assumptions DNOs should make as part of their CBAs. A higher degree of prescription would further limit regulatory risk. We discuss this option in Section 5.4.

81 It is recognised that while P2/6 is defined as a minimum standard for security through the Distribution License and Distribution Code, DNOs can provide security above the standard where they can justify this or below the standard either through self-derogation or by seeking a derogation from the regulator.

DNOs themselves may be best informed about the costs and benefits of improving reliability in their own supply areas, giving more flexibility to DNOs in determining optimal reliability levels, and reducing the use of deterministic planning standards, may increase economic efficiency. A deterministic planning standard may not only prescribe the required level of supply reliability, but may also prescribe the means through which such reliability should be provided. This may limit productive efficiency, as DNOs may be prevented from delivering supply reliability through the least cost option. For example the P2/6 planning standard does not recognise the role of some non-network solutions in improving security of supply.[82] For instance, while P2/6 does recognise the contribution of embedded generation to reliability in a simplistic way, it does not account for electrical storage or demand side response. These solutions may come at a lower cost than investments in network redundancy (or in embedded generation). Thus, the same level of reliability could potentially be provided at a lower cost, if more flexibility was given to DNOs in network planning.

Another cost of setting deterministic planning standards is that the level and type of investment they prescribe may not remain economically efficient if the costs or value of reliability change over time, for reasons such as changes in the costs of providing network assets, the available technological solutions for providing reliability, and the value placed on reliability by customers. In principle, this requires periodic review and reform of planning standards to assess whether they remain appropriate, which imposes cost on the industry and the regulator.

5.2.3 Potential improvements to P2/6

Based on the advantages and disadvantages identified above, it may be possible to retain a deterministic standard but introduce some improvements to the current P2/6 engineering recommendation. This way, the key benefits of the P2/6 standard (such as its simplicity and transparency) may be preserved, while its costs in terms of economic efficiency may be reduced. As noted in Section 5.2.2, some potential improvements to P2/6 to better promote economic efficiency are:

- Updating of the prescribed level of reliability. Imperial College's quantitative modelling has identified substantial future cost savings 42% to 67% of reinforcement capital expenditure over the next 15 years) by considering the potential to reduce the present HV network N-1 redundancy [83] [84] requirement of P2/6 as demand increases and only reinforce existing networks when there is an economic case based on probability of outages, the cost of reinforcement, and the value of Expected Energy Not Supplied (EENS). However, Imperial College's work also indicates that the level of redundancy reduction for the optimum economic efficiency is potentially case specific to the network location and influence by a number of factors including VOLL, reinforcement costs, local network reliability, local network operational response times etc. While it is not clear how this could be

82 For a more detailed and specific list of the limitations of engineering recommendation P2/6, please see Section 3.3 of NERA report, "Engineering Recommendation P2 Review Workstream 2.7: Alignment of Security of Supply Standard in Distribution Networks with Other Codes and Schemes", prepared for the Distribution Code Review Panel, P2 Work Group, 20 November 2015.

83 The Imperial College modelling considers that redundancy can be reduced between N-1 and N-0. This effectively means potentially running assets above 50% of their continuous current rating under normal conditions (50% limit equates to N-1 on a pair of circuits i.e. if one circuit trips 100% of the demand on the faulted circuit could still be supported in theory via the remaining circuit) N-0.8 means that for a pair of circuits if one trips out, 80% of the demand on the faulted circuit could be supported by the remaining circuit. N-0.8 equates to a pair of circuits potentially operating at up to 60% of their continuous rating under normal conditions. The cost of the 20% demand not supplied under this N-0.8 example would be accounted for in the Imperial cost analysis. The enabler for this concept is the ability to have control over the level of demand at times when there is a circuit outage. For unplanned outages e.g. faults, a fast demand reduction response may be required depending on the level of demand post fault to ensure the remaining circuit is not tripped out by the circuit over load protection. Commercial schemes for fast demand reduction as a result of outages are already being trialled under the regulator's innovation funding. The cost saving projection of 42% to 67% on reinforcement capital expenditure does not include the potential cost of any required enabling technology.

84 Under N-0 redundancy planned outages could potentially result in an increase in customer interruptions – or increased costs associated with mobile generation. However, even if standby generation is used, in most cases the corresponding increase in cost would not justify network reinforcement and increased network redundancy.

accommodated in a simplistic determinist standard it may be feasible to achieve a more complex deterministic set of rules considering the main variables involved. This would require substantial analysis and time[85] during the Phase 2 standard codification to achieve this and there is a risk that the rules developed do not cover sufficient cases and hence do not achieve the optimum efficiency savings compared with the optimum solution. There is also a risk that more complex deterministic rules result in a standard that is impractical to use. However, based on the qualitative analysis where some stakeholders express the desire to retain a deterministic standard, there is considered to be merit in considering this deterministic standard update further at Phase 2. It is also noted that reliability variability is likely to increase if the security requirements are relaxed e.g. customers supplied from networks with no load growth will generally see their supply security maintained whilst those supplied from networks where there is demand growth will see their supply security reduce. Customers may have a view on the variability in supply performance that they believe would be acceptable.

- Varying reliability requirements based on (1) the cost of providing (and increasing) reliability in different conditions or (2) differences in the VOLL for different customer types[86]. In general, more granular approaches to setting reliability requirements in deterministic planning standards allow the planning standard to better recognise such fundamental variations in the efficient levels of reliability. However, more granularity comes at the cost of complexity, and requires that the regulatory body setting the planning standard has sufficient information to robustly set different reliability requirements for different conditions.[87]
- Incorporating non-network solutions (besides distributed generation) in the planning standard. For instance, an improved deterministic planning standard, while prescribing redundancy requirements, could set out more ways in which non-network solutions (DG, DSM, DSR, storage etc.) can substitute for traditional network assets. Under a well-designed planning standard that accounts for non-network solutions, DNOs would be able to provide the prescribed level of reliability at the lowest cost, by substituting between network investments, embedded generation, demand side response, and electrical storage, and thus improve productive efficiency. However, Imperial's modelling suggests it may be challenging to codify how DNOs should treat non-network solutions within a deterministic framework. While it may be easy to recognise the firm non-network services the DNOs contract for with third party providers, the contribution of DSR or electrical storage to security of supply may vary enormously depending on the circumstances. In these circumstances, any standard that specifies the contribution of non-network solutions to providing network reliability may be wrong in a large number of circumstances, and thus promote the inefficient take-up of these alternative technologies. Imperial College's modelling and analysis has shown that there are a number of factors that influence the potential security contribution of non-network solutions making their contribution variable and local network case specific[88]. Hence it is not realistic that simple deterministic rules could be added to the present P2/6 standard to allow network planners to utilise non-network technologies. However, it may be feasible to achieve a more complex deterministic set of rules considering the main variables involved. This would require substantial analysis and time[89] during the Phase 2 standard codification to achieve this and there is a risk that the rules developed do not cover all cases or that there are unknowns or uncertainties that seriously degrade deterministic

85 Imperial College estimate a 12 to 18 month programme of analysis.

86 WG members recognise that it may be difficult to establish agreed differences in VOLL for different customer types, and given it is probably efficient to set different VOLLs for different customer groups, some process guided by regulators is probably required to help license holders manage this. It is noted that in the GB water sector, for instance, companies all conduct their own valuation research to understand how their customers of different types value reliability.

87 In fact, because of information asymmetry, DNOs themselves may be best placed to estimate the benefits and costs of providing additional reliability. Thus, rather than improve P2/6, removing a formal planning standard or imposing an obligation on DNOs to perform CBAs to determine efficient reliability levels may be the optimal approach. We discuss these options below.

88 Add suitable reference.

89 Imperial College estimate a 12 to 18 month programme of analysis.

rules[90]. There is also a risk that more complex deterministic rules result in a standard that is impractical to use. However, based on the qualitative analysis where some stakeholders express the desire to retain a deterministic standard, there is considered to be some merit in considering this deterministic standard update further at Phase 2.

The above improvements to P2/6 are not necessarily mutually exclusive, and a combination of such improvements might well improve efficiency. However, as noted above simplistic determinist rules that would achieve high levels of improved cost efficiency are not realistic and achieving suitable but more complex rules during the Phase 2 codification could take considerable time and effort with some risk involved to achieving suitable rules that are practical to use.

5.2.4 Using the Imperial College modelling to assess the case for retaining a deterministic planning standard

Imperial College's quantitative modelling optimises the use of network investment and non-network solutions to provide an economically efficient provision of reliability for network users. In essence, therefore, Imperial's model identifies the "right" levels and types of network investment, use of non-network solutions, reliability, redundancy, and so on. Imperial College has also run this model in a way that constrains it to build the network following the investment requirements imposed by P2/6. P2/6, as a relatively simple deterministic standard, will not achieve precisely the efficient levels of investment (etc.), for the reasons described above.

The cost differential between the "right answer" and the run in which the model is constrained to follow P2/6 defines the efficiency loss associated with having a deterministic standard. In essence, this gap quantifies the "error" in the deterministic requirements imposed by P2/6, and the higher this cost gap, the higher the potential benefit from reforming the planning standard. As discussed earlier the cost differential is substantive with an estimate between 42% and 67% of the reinforcement capital expenditure projection over the next 15 years which makes the retention of the present P2/6 standard, option 1, a potentially poor option in terms of the value to customers[91].

Since the gap is substantial, there is merit in considering improvements to the deterministic standard (Option 2). However, the key component of improving the cost efficiency which is relaxing the N-1 redundancy requirement allowing load growth beyond this point until there is economic justification for reinforcement requires consideration of many variables and results in a variable level of redundancy. Hence there is no simple deterministic rules that would demonstrate cost efficiency improvements near the level of the "right answer" scenario determined through Imperial College's model. Deterministic rules will produce variable cost efficiency results due to the number of and variability of parameters some of which will be local network specific as well as DNO specific. This supports a conclusion that the "right answer" in terms of the provision of reliability cannot easily be codified in a deterministic way. While more complex deterministic rules may have merit as discussed in section 5.2.3, the industry may need to consider other options that place more discretion on DNOs to plan their networks efficiently (see options 3 to 5 in section 5).

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[90] See further discussion on unknowns and uncertainties in section 5.2.4.

[91] It should be noted that the Imperial College economically efficient "right answer" is based on the value of VOLL *adopted by the UK government for all Electricity Market Reform related analysis. It is recognised that this is a controversial subject.* While the Imperial College "right answer" economic model accounts for the cost of increasing CI and CML through relaxation of the present P2/6 N-1 security requirement, any proposals that intentionally reduce the present security of supplies to customers should be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken. This is particularly important since there may be increased reliance on the electricity infrastructure for heating and transport as penetrations of LCTs increase in the future; such changes may increase the value customers place on the security of supply.

A similar conclusion follows from Imperial College's finding that the efficient provision of reliability and/or the security contribution of non-network solutions also requires consideration of many variables and results in a variable level of redundancy. Hence again, this supports a conclusion that the "right answer" in terms of the provision of reliability through non-network technologies cannot easily be codified in a deterministic way.

A similar conclusion follows from Imperial College's finding that the efficient provision of reliability and/or the security contribution of non-network solutions depend on factors that are uncertain now, but will become less uncertain in the future. In this case, it probably does not make sense to codify new deterministic requirements that may become inappropriate as new information emerges, such as in respect of the costs of new non-network technologies. In this case, it would be more natural to recommend either adopting options for reform of the planning standard that place more discretion in the hands of DNOs, or recommending that reform of the planning standard be considered again once the underlying uncertainty has been resolved.

The efficient provision of reliability and/or the security contribution of non-network solutions in some cases could depend on factors that are unknown now *and will remain unknown for the foreseeable future* and have different implications for the reform of P2/6 e.g. the reliance that can be placed on customer behaviour dependent DSR concepts. If the "right answer" depends on such factors, there would be little value in placing a high degree of discretion in the hands of DNOs, unless they are better placed to assess the impact of this factor than the regulator or independent parties such as the Consortium or the Working Group. In this case, retaining a deterministic approach might be more appropriate.

Overall, the option of introducing reasonable and measurable cost efficiency improvements to the P2/6 standard either through relaxing the level of redundancy or through the use of non-network technologies while retaining a deterministic planning standard may not easily be achieved. The mechanisms that provide the bulk of the cost efficiency improvements are highly sensitive to circumstances. A deterministic rule can only function effectively if the regulator is able to codify the optimal solution ("the right answer") within a reasonable margin of error. It may be feasible to achieve a more complex deterministic set of rules considering the main variables involved, this would require substantial analysis and time[92] during the Phase 2 standard codification to achieve this and there is a risk that the rules developed do not cover all cases or that there are unknowns or uncertainties that seriously degrade deterministic rules[93]. There is also a risk that any resulting standard is not practical to use. While there is considered to be some merit in pursuing this deterministic standard update, the Imperial College results also support the case for an alternative option that places more discretion for network planning in the hands of DNOs.

5.3 Removing the Planning Standard Entirely

Possibly the most radical option for reforming ER P2/6 would be the complete removal of the planning standard (option 5). Under such an approach, the importance of financial incentives would increase substantially, as these incentives and DNO's assumptions of investment costs would ultimately determine the level of reliability delivered. As we discuss below, for this option to be effective in promoting efficiency, the existing financial incentives provided to DNOs to improve reliability would need to be strengthened to ensure that DNOs build and operate networks in an economically efficient manner.

[92] Imperial College estimate a 12 to 18 month programme of analysis.
[93] See further discussion on unknowns and uncertainties in section 5.2.4.

5.3.1 The benefits of removing a formal planning standard

As discussed in Section 5.2.2, deterministic planning standards may constrain economic efficiency because they do not account for the variability of the costs associated with providing additional security in different areas, and the variability of the value consumers place on uninterrupted network access. The existing standard also omits any treatment of non-network solutions, save for distributed generation. Removing the planning standard would address these issues and enhance economic efficiency by recognising the informational, commercial and technical advantage that DNOs have over the regulator (or any external body, including the Working Group) in defining the efficient levels of network reliability.

To a large extent, the benefits of this approach rest on how closely the financial incentives on DNOs to maintain or improve reliability reflect the economic value of reliability to consumers. Based on the financial incentive scheme and DNOs' own estimates for their costs of providing reliability, DNOs estimate the profit-maximising level of reliability to provide, including the least cost way of providing this identified level of reliability. If the financial incentive scheme reflects the true economic value of reliability to consumers, this profit-maximising outcome is also economically efficient.[94] In Section 5.3.4, we discuss how the design of the present Interruptions Incentive Scheme (IIS) could be changed to better align the marginal financial incentives DNOs face with the marginal value of reliability to consumers.

Overall, the complete removal of the planning standard, if DNOs respond effectively to a financial incentive scheme that better reflects the marginal value that consumers place on reliability, would give rise to a range of benefits to consumers:

- Allocative efficiency would increase, as the level of reliability provided by DNOs would get closer to the economically efficient level. While the regulator may have reliable information on the value of reliability to customers, DNOs have an informational advantage in estimating the costs of providing reliability. Instead of imposing deterministic requirements on DNOs in respect of restoration times, as under P2/6, the DNO itself would determine the level of reliability to provide, based on its own cost assumptions and the financial incentive rate, which is set by the regulator to reflect the marginal value of increased reliability to consumers.
- The removal of the planning standard would enhance productive efficiency, as DNOs would be motivated by the financial incentive and by their revenue control to find the least cost means of providing reliability. DNOs would be free to invest in network or non-network solutions as they see fit, to deliver a level of performance at the lowest possible cost, and would not be constrained by deterministic requirements in respect of how to treat non-network solutions for the purpose of network planning.[95]
- Compliance cannot be tested, as there is no defined planning standard against which to test compliance. Instead, consumers' interests would be protected through the financial incentive scheme (and possibly through reputational mechanisms), and the regulator's compliance testing costs would fall to zero.
- An additional benefit of the complete removal of the planning standard is that it will likely promote innovation. P2/6 may limit innovation in the provision of supply reliability, because it does not

94 Financial incentive schemes, such as the IIS, operate by setting performance targets and financial incentive rates. According to economic theory, only the financial incentive rates actually impact DNO behaviour, and thus the level of reliability provided by DNOs. By proxy (i.e., through performance indices), the incentive rates determine the marginal value to DNOs from improving reliability. DNOs will maximise profits by setting reliability at the level where the marginal value and the marginal cost of increasing reliability are equal. By contrast, the performance targets do not affect behaviour, but determine the allocation of resources between the government (ultimately consumers) and DNOs. As long as performance targets are not set too high (such that DNOs would prefer to leave the market, rather than to operate), incentive rates alone affect DNOs' network planning.

95 We note that it is irrelevant for productive efficiency considerations whether the financial incentive rate set by the regulator actually reflects the value consumers place on reliability improvements.

recognise the role of some non-network technologies in providing network reliability. As a result, DNOs are not incentivised to employ new and innovative ways of maintaining or increasing reliability. Non-network solutions, such as embedded generation, electrical storage or demand side response may provide reliability to consumers at a lower cost than network redundancy[96]. By allowing DNOs to select the cheapest ways of providing reliability, DNOs will be encouraged to innovate to find the lowest cost solution to providing the efficient levels of supply security. Any resulting innovations may decrease the costs of providing reliability in the future.

The following sections touch on some of the issues and risks around the removal of the P2 standard highlighted through the stakeholder engagement carried out to date through WS1, WS2.0 and regular DCRP P2 WG meetings. Some of these issues have been discussed in the foregoing sections or are discussed further in the following sections. Typical issues and risks raised include:

- The potential lack of clarity in DNO network planning decisions and the issues previously discussed around legal challenge of decisions.

- The views expressed that a common network architecture may be lost if the prescriptive rules in P2/6 are removed.

- The challenges of such a radical change and the need to review and modify all other impacted regulatory tools, codes standard etc., e.g. the DCUSA EDCM charging methodology presently relies on "F Factor" allocation based on P2/6 and the associated ETR130 in determining credits for embedded generation that defers the need for network thermal reinforcement; the new Competition in Connections Code of Practice refers to P2/6 compliance.

5.3.2 The costs of removing a formal planning standard

The costs of removing a formal planning standard are, in essence, the converse of the benefits of a deterministic planning standard, as set out in Section 5.2.1. We do not discuss these factors in this section for the sake of brevity, but they include the likely possibility that network planning becomes more complicated and costly for DNOs as they are provided with more discretion, and that the costs of defending legal challenges might rise as demonstrating the need for certain investments becomes more subjective. Such costs need to be offset against the potential efficiency gains from removing deterministic planning standards identified by the Imperial College modelling (see Section 5.2.4 above).

Further, some parties have expressed concern through the stakeholder engagement process that, without a common national deterministic planning standard, such as P2/6, differences will necessarily emerge in the procedures adopted by DNOs in deciding what level of reliability to provide, and in the level of reliability consumers in different parts of Great Britain experience[97]. We consider that this should not be a material cause for concern for the following reasons:

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96 A key conclusion from Imperial College's work, see section 4.3, is that DER (DSR, DG and Energy Storage) can support network flow and voltage management and provide the capacity required which can, to a certain extent, substitute for network capacity cost effectively. However, the capacity contribution of DER will depend on both network reliability characteristics and DER parameters including availability, size, number of sites, technical characteristics (e.g. ability to operate in islanding mode). For energy limited sources, such as energy storage, the amount of energy that can be stored will be an important parameter.

97 In general respondents indicated that "P2/6 sets out a long term clear minimum standard required for the networks to meet (or exceed if required)" and "provides a common framework for price control baseline". These are statements extracted from section 4.1 of the Consortium report "Findings of the qualitative review associated with the future development of the P2/6 distribution network planning security standard" summarising respondents general views on the key strengths of the P2/6 standard.

- First, a range of evidence suggests that customers in different areas experience vastly different levels of supply reliability, even with P2/6 already in place. For instance, based on data from 2002/03-2011/12, the recent average reliability performance of DNOs, as measured by CIs and CMLs has varied widely. For CI and CML, there are threefold and twofold differences between the best- and worst-performing DNOs, respectively.[98] New unplanned CI and CML targets - set by Ofgem in the RIIO-ED1 Final determinations - also vary widely by DNO[99]. Imperial College's quantitative modelling shows that security of supply differs across different feeders and connection locations on feeders within the same region. This variability is greater than the variability across different regions of GB. The Imperial College results corroborate the finding that there are substantial differentials in reliability levels even under the current deterministic planning standards, hence, the above concern would seem not to be serious.
- Second, since the cost of delivering security of supply varies across the country, differences in the level of reliability provided to consumers in different parts of the country, or even to different customers in the same region, may be economically efficient. Hence, even if current levels of reliability were equal throughout the country, a shift in regulation to one that recognises these differences in costs would enhance economic efficiency.
- Third, some stakeholders have suggested that the existence of a common planning standard across the country benefits larger industrial and commercial consumers that operate across multiple regions. Whilst common planning procedures may simplify such consumers' utilities procurement activities, this cost would need to be offset against any cost savings associated with more efficient network planning, and the benefits of innovation that come from more diverse planning procedures. Moreover, even if network planning procedures are common across the country, as noted above, effective reliability levels differ materially even with a common deterministic standard in place.
- Fourth, under all of the identified reform options, Ofgem could impose some restrictions on DNOs to harmonise assumptions or approaches (see option 3, section 5),[100] which may mitigate these stakeholder concerns.

5.3.3 The impact of current financial incentive schemes to encourage improved reliability

Encouraging the efficient provision of reliability through financial mechanisms requires that the marginal incentives DNOs face are closely aligned with the marginal value of providing reliability. We understand anecdotally from the stakeholder engagement process conducted through this study that the IIS and the Guaranteed Standards of Performance[101] already influence network development and operation and encourage DNOs to undertake some measures to improve reliability[102]. In fact, CIs and CMLs have trended downwards since the implementation of the IIS scheme.[103]

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98 Ofgem, "*Strategy consultation for the RIIO-ED1 electricity distribution price control - Reliability and Safety: Supplementary annex to RIIO-ED1 overview paper*", 122/22, 28 September 2012, p. 24. Only figures on EHV lines are compiled using data spanning 2002/03 to 2011/12. Figures for all other voltage levels are compiled using data spanning 2008/09 to 2011/12. These figures refer to unplanned interruptions.

99 Ofgem, "*RIIO-ED1: Final determinations for the slow-track electricity distribution companies, detailed figures by company: Supplementary annex to RIIO-ED1 overview paper*", 28 November 2014, pp. 14-15.

100 For instance, under the non-deterministic planning standard option, Ofgem could decide to oblige the DNOs to adopt a common procedure in conducting cost-benefit analyses. Ofgem could in theory even determine some of the assumptions DNOs must make in their CBA procedures, such as setting a common VOLL value (for all consumers, or for specified consumer groups).

101 Section 4.2, NERA report "Engineering Recommendation P2 Review Work stream 2.7: Alignment of Security of Supply Standard in Distribution Networks with Other Codes and Schemes", Prepared for the Distribution Code Review Panel, P2 Work Group, 14 August 2015.

102 Regarding the removal of P2/6, some DNOs indicated that there would initially be no change as P2/6 was largely irrelevant for Group Demands below 100MW and that the IIS incentive drives system design, to ensure that losses of supply are minimised both in number and duration. Although it was agreed that this incentive could be altered/removed by Ofgem and it did not constitute or seek to replace a

However, the DNOs consider that these instruments have only a limited influence over their investment decisions. From the stakeholder engagement process we understand that the IIS has primarily motivated investments in relatively low-cost automation and other operating measures aimed at reducing the impact of outages. We also understand that it does influence the level of reliability provided at the low voltage (LV) level, but not at the high and extra high (HV/EHV) voltage levels[104]. Therefore, while in their current form the impact of financial incentives for reliability on DNOs' investment decisions may be limited[105], there is no reason in principle why financial incentive schemes could not be used as the primary mechanism for encouraging DNOs to provide the efficient level of reliability in the future.

5.3.4 Possible improvements to the efficiency of financial incentive schemes

First, if P2/6 requires a higher level of investment than DNOs can economically justify when valuing reductions in interruptions at IIS incentive rates, then it is obvious that the IIS will not affect decisions over what level of reliability to provide while P2/6 remains in its current form. If the IIS incentive rates were higher, possibly reflecting policymakers' estimates of the value of reliability, then it would encourage a greater provision of reliability.

Second, there are a number of design features of the IIS that limit the incentive it confers on DNOs to invest to manage interruptions and provide reliability efficiently, and these features could, in time, be altered if more reliance were placed on the IIS as a means of ensuring the efficient provision of reliability. These possible changes include the following:

- Removing the cap and floors on rewards and penalties. If a DNO expects to hit a cap/floor, or believes there is some reasonable probability that it will do so, then the marginal incentive to further improve performance to reduce penalties or earn greater rewards is muted;
- Including exceptional events e.g. HILP events in the CI/CML performance indices. Currently, because relatively high-impact events are excluded from the CI/CML performance indices, the IIS mechanism provides no incentive to reduce the likelihood or impact of such incidents, such as by providing additional redundancy or deploying other non-network solutions. If a DNO was exposed to IIS penalties associated with HILP type events, there would be an incentive to incur costs to mitigate

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design standard. Statement from section 3.2, question 2.4, of Consortium report "Findings of the qualitative review associated with the future development of the P2/6 distribution network planning security standard".

103 For instance:

(1) "The impact of measuring average performance using the most recent actual data over the four years from 2010/11 to 2013/14, in place of the dataset from 2009/10 to 2012/13 relied on by the Authority, is significant: the average CI performance is 3.2% better than for the earlier period; and the CML performance is 6.1% better." [British Gas Trading Ltd v. The Gas and Electricity Markets Authority – Notice of Appeal, 2015, para 4.35]

(2) "Adopting an initial target based on a four year average means that companies would in any event be expected to outperform the index, irrespective of the four years used. This is simply because performance has improved over the four year period, and the average will therefore be worse than the most recent performance achieved." [Ibid, para 4.36]

104 It was generally indicated by respondents (category 1) that the IIS may change more frequently than a planning standard and that DNOs can react to changing IIS by rapid deployment of technologies such as remote control or automation, but network design has a much longer time horizon. It was noted that IIS reinforcements were generally undertaken at 11kV and below. Reinforcements at 33kV and above are usually as a result of compliance requirements stated in P2/6. The implementation of P2/6 on the network has left most primary substations (e.g. 33/11kV) with dual circuits or automatically switched alternatives, so the total loss of supply of primaries is not likely to contribute greatly to CI/CML figures. DNOs indicated that relying on IIS incentives for the security of this level of demand is likely to lead to a reduction in security. Statement from section 3.2, question 2.6, of Consortium report "Findings of the qualitative review associated with the future development of the P2/6 distribution network planning security standard".

105 It is noted that some DNOs consider there are strong incentives on them to provide economic networks already through Fast Track rewards, IQI, ISS and the Utilities Act.

these risks. However given their unpredictable nature it may be difficult to quantify the benefits of incentivising mitigation. One DCRP P2 WG stakeholder expressed a view that there should be a GB view on the types of events that should be mitigated against;

- Making the representation of consumer benefits from reduced interruptions more granular (e.g. variable by customer type, location, etc.). This change in approach would send more efficient signals to DNOs regarding the economic value of reliability improvements, and possibly account for the fact that different types of customers place a higher value on reliability than others;
- Implementing a predictable mechanism for updating targets over time so that DNOs know what share of the benefits from investing in reliability schemes they will capture. Currently the methods used to set targets for reliability are not fixed, and depend on the methods Ofgem decides to use at periodic reviews. Absent a predictable mechanism for resetting targets, DNOs' incentive to reduce the likelihood and impact of interruptions will be muted, especially towards the end of each regulatory control period, given the possibility that the benefit of any reduction will be "taken away" by Ofgem in the form of a more stringent target for the next control period;
- Ensuring the share of benefits DNOs retain from improved reliability (and vice versa) is the same as the share of costs they bear under the IQI[106] from spending marginally more money. This would ensure that DNOs make an efficient trade-off between the costs and economic benefit of projects to reduce interruptions, such as in deciding whether to provide additional reliability.
- Consideration would have to be given to short term verses long term investment incentives to ensure long term network planning efficiency.

Some of these possible changes to the IIS scheme would, if implemented, increase the risks that DNOs bear, especially the inclusion of high impact events in the calculation of CI/CML indices and the removal of caps and floors. This might have implications for DNOs' Weighted Average Cost of Capital (WACC). The possibility of greater shocks to cash flows might increase default risk, increasing DNOs' cost of debt and/or reducing debt capacity, both of which would tend to increase the WACC. The possibility of large IIS penalties driven by major interruptions without an equal and offsetting scope for upside rewards would also expose DNOs to additional asymmetric risk, which may increase DNOs' cost of equity, and thus the WACC. Alternatively, DNOs may be able to purchase insurance to protect them from financial exposure to penalties under the incentive scheme resulting from high impact events. While this might offset any increase in the WACC, it would create a new cost DNOs would need to recover from consumers.

However, it is important to recognise that, while these additional risks impose costs on DNOs that they would ultimately need to recover from consumers, consumers are bearing these risks already which itself imposes a cost on them. Imposing larger penalties on DNOs or offering them larger rewards in respect of interruptions would, in effect, amount to a reallocation of risk from those who cannot control it (customers) to those who can (DNOs), which for the reasons discussed above, may improve efficiency.

5.3.5 Possible changes to other regulatory instruments

There may be some other improvements Ofgem could make to the regulatory framework for DNOs that would be particularly beneficial if DNOs were provided with more discretion to plan their networks efficiently. For instance, the RIIO model seeks to remove capex biases through the application of benchmarking to all cost categories, combined with the IQI and totex incentive mechanism. However,

[106] Information quality incentive.

there might still be a degree of a capex bias in the LI/HI[107] output obligations. Specifically, obliging DNOs to reduce loading and improve the health of assets might reduce the incentive to find ways of delivering the same benefits to consumers but with fewer assets.

5.3.6 Other Considerations

The removal of a security planning standard that has served the industry well for many decades may appear to be the most radical of the high level options for reform considered, however, there are some additional points worth noting.

- Based on the potential cost savings to consumers between the ideal network development solution over the coming decades based on the probabilistic CBA modelling by Imperial College compared with the continued use of P2/6, it is difficult to argue that P2/6 should be retained unchanged, see section 5.1. The results of the stakeholder engagement process also support changes to incorporate potential new non network DER solutions (DSR and storage) into the standard along with supportive CBA to assist planning future networks. It should be noted while the Imperial College ideal network development solution economic model accounts for the cost of increasing CI and CML through relaxation of the present P2/6 N-1 security requirement, any proposals that intentionally reduce the present security of supplies to customers should be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken. This is particularly important since there may be increased reliance on the electricity infrastructure for heating and transport as penetrations of LCTs increase in the future; such changes may increase the value customers place on the security of supply.
- However, the option of introducing reasonable and measurable cost efficiency improvements to the P2/6 standard either through relaxing the level of redundancy or through the use of non-network technologies while retaining a simple deterministic planning standard is not realistic as discussed in section 5.2.4. A more complex deterministic standard may be feasible but would require substantial work at the Phase 2 codification stage to determine suitable deterministic rules but would also have a risk that the rules developed do not cover all cases or that there are unknowns or uncertainties that seriously degrade deterministic rules. It is likely that the standard would require an element of CBA based network design to cover cases that cannot be covered by the complex deterministic rules.
- The above points leave reform solutions that are potentially entirely or substantially based around CBA based network designs, options 3, 4 and 5. All of these options would be a departure from the present P2/6 deterministic standard and all would require consideration of amendment to other design, policy and regulation details to varying degrees. In particular option 3 for a non-deterministic standard and option 5 for the removal of the security standard would have similar requirements as discussed in section 5.4. It can also be argued that the original intention of P2 was to include an option for CBA analysis (DNOs can already justify more investment with CBAs if they want to.)[108], hence option 2 to improve the existing P2/6 standard

[107] Load index/Health Index.

[108] ACE Report No. 51, published in 1979, makes clear that the deterministic recommendations in P2/5, which are similar to those in P2/6, may not be appropriate in all cases, and "Where it is considered that the costs of providing the normal levels of reliability of supply implied by Engineering Recommendation P2/5 are too high, or where it is thought that a higher level may be justified, or in appropriate cases to assess the contribution to be made by generation, an examination using cost-benefit studies may be called for". See ACE Report No. 51 1979, Report on the Application of Engineering Recommendation P2/5 Security of Supply, Energy Networks Association, Section 3.3.

and option 4 to retain some deterministic elements are almost identical in the way they would be codified, they would just differ in the level of CBA obligation.

- Security is not the only design consideration for developing networks and it may be worth considering as part of the process of removing P2/6 the review of all network development standards, policies and regulatory incentives e.g. quality of supply, losses incentives, interruption incentives etc. This would take some time to complete and a suggested target would be to have revised design standards, policies and regulation including all necessary incentives ready and understood by all parties for the business case submission for RIIO ED2. This process would also have to consider the need to review the interfacing transmission standards such as the NETS SQSS.

5.4 Implementing a Non-Deterministic Planning Standard

5.4.1 The rationale for an obligation to undertake CBAs

An alternative to P2/6, and to deterministic planning standards in general, is to implement a non-deterministic planning standard that places an obligation on DNOs to perform CBAs to identify efficient levels of reliability and the most efficient means of delivering this reliability through a combination of network and non-network solutions (option 3).

As with the complete removal of the planning standard, discussed in the previous section, this option places more discretion in the hands of DNOs to plan efficiently than would be the case under a deterministic standard. In fact this option is similar to the option of complete removal, as DNOs would still need to undertake their own CBAs to compare the costs of reliability with the value they would earn from financial incentive schemes, and to identify the cheapest means of delivering reliability.

What this option adds, therefore, is simply a regulatory requirement to undertake CBAs. This would have the effect of making the DNOs' decision-making processes subject to regulatory scrutiny, and potentially improving the transparency of this process to other interested parties. Therefore, in theory, the addition of the CBA obligation should not change the investment and reliability outcomes compared to the option of removing the planning standard and improving the efficiency of financial incentive mechanisms. Instead, it increases accountability of DNOs to justify planning decisions. An obligation to plan in accordance with CBAs might also compensate for any shortcomings in the financial incentive mechanisms, e.g. if it is not possible to make the reforms listed in Section 5.3.4 above.

5.4.2 Degree of prescription in a non-deterministic planning standard

A non-deterministic planning standard can in practice be designed in many different ways. In particular, Ofgem can impose a number of constraints on DNOs' CBAs, or at the other extreme could give DNOs a completely free hand in deciding the approach they follow and the assumptions they make. In essence, by varying the degree of prescription in a non-deterministic planning standard, Ofgem can either increase the discretion of DNOs in planning their networks, or it can impose common restrictions on all DNOs, in effect creating a common methodology:

- At one extreme, a new non-deterministic planning standard could simply state that DNOs have an obligation to plan their network in an economically efficient way, without making explicit requirements on how they should interpret this requirement. DNOs would then be responsible for interpreting this obligation as they see fit, and for justifying their approach to the regulator, if required.[109]

- At the other extreme, the new network planning standard could oblige DNOs to use a specific CBA model (developed through an industry process, for instance) to determine the economically efficient level of supply reliability, and the economically efficient way of delivering the identified optimal level of reliability. This common framework (the CBA model) would identify precisely the types of costs and benefits DNOs should consider and the assumptions they should make.

However, there are a range of potential intermediate options for a non-deterministic planning standard. For instance, the regulator could impose some high-level requirements on DNOs on how exactly the CBAs should be conducted, such as the types of costs and benefits to consider, and the way to account for non-network solutions. The regulator could also specify what economic value DNOs should place on particular economic benefits associated with providing network assets, which could simplify the planning process, especially where such parameters are particularly uncertain or difficult to estimate. For instance, they might wish to specify particular levels of VOLL per customer class that DNOs should use in planning, or a value to place on reduced losses (see Section 5.6 below).

In general, more prescriptive requirements to perform CBAs tend to simplify, and thus reduce the costs of, network planning. However, less prescriptive requirements might allow DNOs more scope to innovate and potentially identify more economically efficient solutions than a more prescriptive "rule book" for undertaking a CBA would allow.

5.4.3 Regulatory oversight and compliance testing

Under the option of completely removing the planning standard, no compliance testing can be in place as there is nothing to test compliance against. The financial incentive mechanism and reputational incentives ensure that consumers' interests are protected. In theory, these incentives would ensure the same outcome under the CBA-obligation (non-deterministic planning standard) option. However, if such financial incentive mechanisms were supplemented with an obligation to perform CBAs when planning the network, the regulator would need to have a mechanism for testing compliance with this obligation, and holding DNOs to account in instances where they fail to comply.

As discussed earlier, testing compliance with the deterministic P2/6 standard is straightforward, as the reliability requirements determine the required level of network redundancy, in the majority of cases. In general compliance with P2/6 only changes over time as demand increases, noting in some cases compliance also has to consider support from embedded generation. Compliance testing is inherently more difficult when the rules allow more discretion for DNOs in planning their networks. If compliance was CBA based, any changes in customer mix, VOLL, the cost of network assets and the cost of say DSR services etc. could continually change and influence the compliance of a network. The cost of maintaining an overview of all these factors for all parts of the network where compliance may be marginal would need to be taken into account if there was a move to a CBA approach.

There are a range of different ways in which the regulator could check compliance with a non-deterministic requirement to undertake CBAs in network planning. For instance:

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109 Such an approach would not impose any further requirements on DNOs, compared to the option of having no planning standard in place, and relying on the financial incentive scheme. This option is thus only interesting as a theoretical extreme, and not as a credible alternative to consider.

- The regulator could conduct regular spot checks to assess whether DNOs' CBAs meet the criteria set out in the planning standard.
- DNOs could also be obliged to publish their CBAs, allowing industry stakeholders and interested parties to scrutinise these analyses, which would allow Ofgem to monitor compliance by investigating complaints from stakeholders that DNOs are not planning efficiently. This approach would also support dissemination of innovative planning approaches across the industry.
- Ofgem could also provide ex ante approval of DNO's planning methodologies, if DNOs are left with some discretion in their approaches to conducting CBAs, or approve the CBA modelling tool itself if a common methodology were adopted across all networks. Such an ex ante approval of CBA methodologies could follow a process similar to the approach Ofgem uses to approve tariff methodology statements from regulated transmission and distribution networks.
- Another option for oversight is the ex post scrutiny of individual investment decisions (and associated CBAs) by the regulator. However, such an approach would be very costly for both the regulator and the DNOs, impose significant regulatory risk on the DNOs, and distort DNOs incentives in respect of the choice between capital and operating measures to improve reliability.

5.4.4 CBA-obligations within a deterministic framework

It is also possible to place obligations on DNOs to conduct CBAs within a deterministic framework. In this context, CBAs would not be used to determine the optimal levels of reliability to provide, but would be aimed exclusively at identifying non-network solutions to providing the desired level of reliability and thus reducing costs to the DNO. In essence, once the need for an investment to meet the reliability requirements specified in the deterministic standard is identified, a CBA would be used to determine the least cost way of delivering it. Such an approach is in place in some Australian states.

The Australian Regulatory Investment Test for Distribution (RIT-D)[110] requires distributors to publish planned network investment projects above the cost threshold of $5 million. Third parties can then bid to provide the same level of reliability through alternative, cheaper investments. Australian Distribution Network Service Providers (DNSPs) are required to conduct CBAs for capital expenditures on network extensions that meet certain criteria, and required to consider a range of credible network and non-network options in the planning process. The RIT-D is intended *inter alia* to increase the use of non-network technologies when appropriate, and to enhance productive efficiency in providing security of supply.

Combining a CBA-obligation with a deterministic standard may therefore enhance productive efficiency in delivering reliability more efficiently. However, this type of obligation, as long as it is combined with a deterministic standard that prescribes what level of reliability to provide does little to improve allocative efficiency[111] because DNOs will not have the ability to adjust the level of reliability they provide according to prevailing conditions.

110 The Australian national regulatory framework includes provisions affecting reliability planning, which exist alongside the regional rules. In 2014 a Regulatory Investment Test for Distribution planning (RIT-D) was introduced, which requires that distributors perform CBAs for capital expenditures on network extensions that meet certain criteria. The aim of RIT-D is to ensure that once a need for investment is identified (which is driven by locally set reliability standards) the distribution businesses deliver it by the most economical means. The test is applied to projects above a certain financial threshold ($5m million), which are not aimed at addressing urgent system contingencies, such as for renewal of aging assets. The legal principles underlying the RIT-D recognise that projects with negative net economic benefits would still pass the regulatory test if they are addressing reliability needs.

111 The concept of economic efficiency requires that DNOs should provide additional benefits to consumers in the form of enhanced reliability up to the point where network users' willingness to pay for additional reliability equals the marginal cost of providing it. If they provide less

5.4.5 Conclusions on non-deterministic planning standards

Obligations to plan networks in accordance with CBAs can increase the accountability of DNOs, and the transparency of DNOs' investment decisions and they may provide justification for investment decisions taken by DNOs in forums such as legal proceedings. They also provide a back-stop that obliges efficient planning, should financial incentive mechanisms be limited in their ability to encourage DNOs to plan efficiently. However, enforcing the obligation to undertake CBAs themselves are costly, and the regulator would need to have compliance testing and enforcement procedures in place to ensure that DNOs meet the obligations placed on them.

The potential costs savings between the "right" answer and those prescribed by P2/6 based on Imperial College's modelling discussed in section 4.3.2 illustrates the potential cost benefit of moving to a non deterministic planning standard. While there will be transitional costs and possible ongoing costs for DNOs moving to a non deterministic standard and possibly for the regulator, these are likely to be significantly lower than the potential cost benefit[112].

The introduction of a non deterministic planning standard to replace P2/6 will take a period of time to transition to. Although, DNOs are using CBA analysis at present, the level of prescription will require to be agreed between the various stakeholders as discussed in section 5.4.2. DNOs will also require time to revise internal policy, adopt new procedures, train staff etc. The regulator will also require revising regulatory policy, regulations and incentives. A sensible timescale for adoption of a reformed standard may be alignment with the business plan submissions for RIIO ED2 similar to the option to remove the P2/6 security standard.

Since a non deterministic standard is flexible by nature, alignment with other interfacing standards such as the NETS SQSS is not viewed as greatly problematic. Interface issues with the NETS SQSS would be design option related rather than related to the standard itself.

5.5 Combining Deterministic and Non-Deterministic Elements into a Single Planning Standard

The further option we consider for the reform of the P2/6 planning standard is combining some deterministic elements into a non-deterministic planning standard based on an obligation to perform CBAs (option 4).

In principle, if DNOs were obliged or incentivised to undertake CBAs to identify efficient levels of reliability and the least-cost means of delivering it, then they should achieve economically efficient decisions without placing additional deterministic requirements on them. However, setting deterministic requirements regarding the level of reliability could be codified as a deterministic standard for some types of investment if the level of economically efficient reliability rarely falls below a specific threshold. Setting this minimum level of investment as a deterministic planning requirement would save the DNO the costs of conducting CBAs to confirm that this level of reliability is required, on the basis that it almost always will be. The modelling conducted by Imperial College sought to identify cases in which the lowest level of economically efficient investment to provide reliability is robust to changes in circumstances and

reliability than this, there is an efficiency gain to be had by incurring additional cost to enhance reliability, and vice versa. Similar logic applies to other benefits such as loss reduction. Economists refer to this dimension of economic efficiency as "allocative efficiency".

112 This issue is probably one for Ofgem to consider and is outside of the Consortium scope of work and in some areas our competence.

assumptions, and hence could be codified. However, the results from Imperial College's modelling indicate that economically efficient investment is not robust to changes in circumstances and hence is not feasible to codify in practical and simplistic form.

An implication of such a *minimum* deterministic requirement is that, should (in specific circumstances) a CBA identify that a lower level of reliability were economically efficient, the planning standard would prevent the DNO from targeting this lower level. In general, such an approach would introduce economic inefficiency to network planning, but this problem could be overcome by applying to the regulator for derogations from the deterministic requirements imposed by the planning standard. However, it can be concluded from Imperial College's work that to achieve a high level of economic efficiency the level of derogation request would be high and hence imply that the standard is not suitable.

To determine if there is a potential *minimum* deterministic requirement leading to a high level of economic efficiency[113] without resorting to derogations from the deterministic requirements imposed by the planning standard would require Imperial College to conduct a substantial programme of additional studies. However, there is a risk that this work would confirm that a suitable potential *minimum* deterministic requirement cannot be achieved. Which is what the outcomes of the present Imperial College work suggests.

Regarding the deterministic part of the standard, this would need to ensure alignment with the present NETS SQSS at the network interfaces.

Regarding the transition to such a combined deterministic/non deterministic standard, the additional work required identifying a suitable *minimum* deterministic requirement leading to a high level of economic efficiency and the codification around this would lengthen timescales compared with other options. A risk here being that the resulting standard will not deliver the high level of future cost efficiency desired, but will still have gone through the process of introducing a substantial element of CBA related transition similar to options 4 and 5. The difference being that options 4 and 5 would deliver the desired cost efficiencies.

5.6 Interactions with Distribution Losses

There is a link between network assets and losses. More network capacity can deliver more reliability depending on how this is implemented, but it can also reduce electrical losses as a side-benefit. Similarly, the converse is also true; increasing network capacity to reduce losses can deliver more reliability. Therefore, it can be efficient to plan distribution networks considering the benefits of both increased reliability and loss reduction[114]. Moreover, because the benefits of loss reduction accrue to consumers, regulation is necessary to encourage DNOs to consider losses in their planning process.

The value of loss reduction could be factored into each of the reform options. The deterministic approach could, for example, prescribe a capacity headroom in sizing of network assets to achieve reduced loading. Alternatively, the regulation could take the form of a specific requirement to procure low-loss assets in the nature of energy efficiency design standards in buildings, or white goods. The inherent weakness of these approaches, however, is the inability to accommodate the changing cost base of network assets, wholesale electricity price and uncertainty in demand growth.

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113 The *de minimis* deterministic requirement would be related to the reduction in redundancy from N-1. The optimal level of reduced redundancy varies due to a number of parameters some of which are local network specific. Hence setting rules that result in a similar high level of cost efficiency may not be achievable. A similar conclusion is made regarding the benefit of utilising DSR and storage to substitute for redundancy and improve cost efficiency.

114 It should be noted that there are other technical issues in addressing losses through increased capacity such as increased capacitance and associated capacitive effects on voltage control and quality of supply.

With the options for reform of P2/6 that place greater reliance on DNOs' discretion to plan networks (options 3, 4 and 5), the regulator could define a value to be placed on loss reduction by the DNOs in network planning. Re-introducing a financial incentive mechanism to reduce losses would be necessary for the reform case which dispenses with the planning standard, but this may bring other undesirable consequences due to the technical difficulties in measuring losses and the potential for windfall gains and losses by DNOs. Smart metering technology may resolve this difficulty, however.

The enhancement of the present P2/6 deterministic, option 2, to include loss considerations in the design was in general not supported by respondents to the industry questionnaire. The consensus was that the interface between other industry standards/regulatory initiatives should be enhanced to ensure that any incentives work correctly in conjunction with the security standard to support its intent of ensuring the efficient provision of security of supply.

5.7 High Impact Low Probability Failures (HILP) and Common Mode Failures (CMF)

The present P2/6 standard does not directly consider HILP or CMF event mitigation in network designs.

The Imperial College work on HILP and CMF concluded that it is still an open question as to whether the assessment of CMF and HILP events should be included in the security of supply standard for the following reasons:

- There is a lack of comprehensive data to derive CMF and HILP events parameters (e.g. frequency, scale of impact) that can be used in probabilistic approaches.
- The impact of a certain hazard is network specific. For example, the risk of having a flood in plateau areas is much lower compared with lowland areas, and the impact on urban networks will be different with respect to the impact on sparse rural networks. Different networks may be exposed to different types of hazards. Therefore, the justification of the investment via CBA will be case specific.

In any case, it is important that all stakeholders in this area have confidence in the process used to identify and assess risk, so that appropriate decisions can be made on its management.

From the stakeholder engagement process to date, there is general agreement for planning standards not to include extreme events; such events should be dealt with by alternative regulatory mechanisms due to their low probability and unpredictable nature.

In general DNOs were of the view that there would be limited (cost) benefit to support the inclusion of such events in the design stage and any response or approaches to CMF and HILP would normally sit outside of those considered to be BAU. There was general agreement amongst respondents that there needs to be a wider discussion regarding the way to address CMF and HILP events outside of the P2 review. Some respondents viewed that it is difficult to understand how the planning for, and management of exceptional events would be consistent with the design of an economically efficient network as it would be difficult to identify/agree a common set of rules that could apply equally to all networks under all circumstances without major differences in investment to provide compliance.

However, the subject of HILP events has been discussed with DCRP P2 WG members during the review process and opinion expressed that some forms of low cost mitigation could be considered at the network security planning stage, e.g. advanced control systems. However, it is likely that any such mitigations would require to be justified through some form of CBA analysis and may not be suitable for the option of a reformed deterministic standard (option 2).

Also based on discussions with DCRP P2 WG members it is noted that while the Imperial College work has highlighted that the application of the present requirements of P2/6 which requires a higher than economically efficient level of security, it inherently provides some measure of resilience against CMF and HILP type events. DNO experience of large scale, and protracted interruptions show that resilience provided, for example by interconnection, is of considerable value to customers and society mitigating collapse of other infrastructure such as communications, water supplies and fuel. It could be argued therefore that whilst further work is required to more fully understand these events, a simple move to relax the level of security prescribed by P2/6 in the longer term may expose customers to a higher level of HILP and CMF risk than they experience at present if some other recognition of mitigation is not allowed for either within a reformed security standard or from some other mechanism.

5.8 Construction Risks

There is a lack of differentiation between construction and maintenance outages in the present distribution planning standards. This may present a significant problem given the expectation of considerable asset replacement in the future. This is likely to affect particularly large Demand Groups[115].

While the WS2.0 stakeholder engagement indicates that presently DNO's recognise and mitigate against construction outages on a case by case basis, generally driven by the Interruption Incentive Scheme (IIS), some respondents expressed a desire for the new standard to provide guidance as to the methods for the treatment of construction outages that will provide a more consistent approach for all DNOs to adopt and provide consistency across networks. This will become increasingly important as the shape of the network demand becomes more difficult to forecast as the penetration of new LCT increases and DNOs will have less choice of when to minimise the risk associated with a construction outage.

The Imperial College studies demonstrate that it would be economically efficient to provide provisional supplies and reduce risk of consumer interruption during asset replacement. Longer construction-outages will expose the system to greater risk which in turn, increases the value of developing provisional load-transfer as a risk mitigation measure considered in the Imperial College study.

Further engagement with DNO WG members and WG members representing embedded generation has highlighted a concern over the impact on long term outage constraining of embedded generation export. While this may be considered a commercial risk for export customers associated with the connection security that they opt to pay for, some stakeholders in the WG expressed concerns that the present system around export connections and wider network planning does not fully recognise their need for network security. The planning of long term outage mitigation in network areas dominated by generation may be a worse case that should be considered as part of a review of improvements to the security standard around construction outages. The potential for DG support to network operations in the future may require the issue of long term outages to be considered when planning networks and any new standard should allow flexibility for this to be considered.

It is concluded that the new standard should provide guidance as to the methods for the treatment of construction outages separately from maintenance outages and unplanned outages, with the aim of

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115 As demonstrated in KEMA/Imperial report to Ofgem ("Review of Distribution Network Design and Performance Criteria", G06-1646 Rev 003, 19 July 2007, Kema Limited.)

providing a more consistent approach for all DNOs to adopt and provide consistency across their networks. In addition consideration at Phase 2 should be given to the concerns raised by DNOs and export stakeholders in reviewing the treatment of construction outage risks to export customers; this may require guidance from Ofgem and further stakeholder engagement to consider this at Phase 2 of the review. Ofgem may wish to consider how to guide the DCRP on the treatment of construction outages for export customers prior to Phase 2 including the case of networks dominated by export customer use of systems.

5.9 Ensuring Consistency with the Regulatory Settlement

The assessment in section 5.1 concluded that the option to retain P2/6 unchanged cannot realistically be justified based on the Imperial College evidence on its cost efficiency going forward. The implementation of more radical reform options (3, 4 and 5) may well be impractical before the end of the RIIO-ED1 settlement in 2023 given that these options would change the demands being placed on DNOs as compared to those agreed in setting the price control. The advantage of such a delay, however, is that it would allow DNOs time to prepare to adopt the preferred option, such as the development of suitable models and training of staff to adapt to new, potentially more demanding, working practices.

More modest reforms retain the nature of the current deterministic model, and thus do not alter materially the requirements placed on DNOs before the end of the current control period. In theory an improved deterministic model could also be implemented as an interim measure with a view to implementing a more radical approach after the end of the RIIO ED1 price control period. However, the Imperial College work suggests that determinist rules to improve cost efficiency through a relaxation of the N-1 redundancy requirement or the use of non-network technologies may take time to determine, may not be simplistic and may have a much reduced impact on cost reductions than other non-deterministic based options. This is due to number of variables including local network factors that require to be considered in optimising the use of these planning options to reduce the future cost of security. Whether suitable interim deterministic rules could be achieved would require further studies at the codification stage of an interim standard.

6 CONCLUSIONS AND POTENTIAL RECOMMENDATIONS

Based on the analysis carried out to date through the various P2/6 review work streams, both qualitative and quantitative, including engagement with stakeholders, we have identified the following key conclusions in the terms of options for the reform of the network security standard and developed a set of potential recommendations that are designed to form the basis of the wider industry review and consultation exercise.

Retaining P2/6 without revision (Option 1)

While qualitative analysis does show a strong desire amongst some stakeholders to retain a simple deterministic standard for various reasons including ease of use and keeping network planning costs low, the quantitative modelling conducted to date suggests the lost efficiency costs of retention could be significant. The Imperial College work concluded that the present security standard tends to be conservative, dealing with worst case scenarios and implies that the present security standard is only cost effective for "extreme" cases with networks characterised with high failure rates, long restore/repair times and low upgrade costs. In most cases particularly at HV level, in the short term the existing networks (both feeders and substations) could accommodate demand growth most efficiently by relaxing the current level of N-1 redundancy[116] requirement up to the point where reinforcement becomes economically justified. For reliable HV networks, with low failure rate and low MTTR[117], the peak load could almost be doubled before reinforcement is economically justified.

The potential benefits of relaxing the security constraints across the HV, EHV and 132kV network at the GB level could reach 42% to 67% of the projected reinforcement spend[118] in case of significant load growth at LV and HV level by 2030[119]. The Imperial College results indicate that relaxing the degree of redundancy between N-0.5 and N-0 show similar cost benefits and even a more modest relaxation to N-0.75 shows a potential benefit between 19% and 41% of the projected reinforcement spend.

The level of benefits indicated by the Imperial College work are based on a VOLL range from £17,000/kWhr VOLL adopted by the UK government for all Electricity Market Reform related analysis up to a VOLL of £34,000/kWhr.

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[116] The Imperial College modelling considers that redundancy can be reduced between N-1 and N-0. This effectively means potentially running assets above 50% of their continuous current rating under normal conditions (50% limit equates to N-1 on a pair of circuits i.e. if one circuit trips 100% of the demand on the faulted circuit could still be supported in theory via the remaining circuit) N-0.8 means that for a pair of circuits if one trips out, 80% of the demand on the faulted circuit could be supported by the remaining circuit. N-0.8 equates to a pair of circuits potentially operating at up to 60% of their continuous rating under normal conditions. The cost of the 20% demand not supplied under this N-0.8 example would be accounted for in the Imperial cost analysis. The enabler for this concept is the ability to have control over the level of demand at times when there is a circuit outage. For unplanned outages e.g. faults, a fast demand reduction response may be required depending on the level of demand post fault to ensure the remaining circuit is not tripped out by the circuit over load protection. Commercial schemes for fast demand reduction as a result of outages are already being trialled under the regulator's innovation funding. The cost saving projection of 42% to 67% of reinforcement capital expenditure does not include the potential cost of any required enabling technology.

[117] MTTR – Mean Time to Repair.

[118] Imperial College estimate the potential savings from avoidance or deferral of HV network reinforcement (including HV and EHV and 132kV feeders and primary substations and 132kV substations), while considering the increase in customer interruption costs.

[119] It is noted that the Imperial College reinforcement projections from their modelling may differ from DNO load related reinforcement projections using the Transform model. However, there are many reasons why this may be the case. For example the proportion of reinforcement benefits estimated in the Imperial College study may not materialise as some parts of the network may need to be replaced due to condition and refurbishment driven replacement. Load related reinforcement and non-load related asset replacement are treated as separate budgets under distribution network regulation. It should also be noted that the Imperial College assessment assumes that the network starts from a point where the capacity limit has been reached and then uses a forecast load growth to estimate reinforcement requirements to 2030. While there may be some argument over the level of benefits that materialise by 2030 due to existing spare capacity in the network and the load growth forecast used, these benefits will materialise over some time period and in fact potentially could be much higher over longer time periods. To allow for any discrepancy between the DNO forecast reinforcement capital expenditure to 2030 and the Imperial College modelled results the potential benefits from relaxing the security levels prescribed by P2/6 are expressed in percentage form.

Imperial College has also carried out some analysis based on ACE 51[120], this indicates that in the cases examined, the cost benefit analysis indicates applying reduced N-1 redundancy rather than reinforcement is economically beneficial. The results from the ACE 51 case studies also indicate that Imperial College's modelling used to review P2/6 may be conservative in the potential economic benefits determined.

In terms of quality of supply there will be some increase in CI, CML and EENS and the impacts of relaxed redundancy levels on network performance is discussed in section 5.1. While the Imperial College economic model accounts for the cost of increasing CI and CML through relaxation of the present P2/6 N-1 security requirement, any proposals that intentionally reduce the present security of supplies to customers should be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken and the Phase 2 works commence. Any reduction in supply quality due to reducing the level of security would also potentially impact on export customers as well as demand customer, although, there is the potential for export customers to improve network security. While to some extent this is happening now there is greater potential for this in the future through more advanced control and communication.

However, the Imperial College work clearly demonstrates that from an economic view point the present P2/6 standard could be improved by relaxing the present minimum level of security to defer reinforcements. Introducing the concept of losses driven network design at the time of deferred reinforcement would introduce capacity well above peak demand as discussed in section 15 of Imperial College's extended summary report with the potential to increase network security. Hence the potential reduction in supply quality would eventually be corrected and possibly improved[121].

While the Imperial College work has highlighted that the application of the present requirements of P2/6 requires a higher than economically efficient level of security, it inherently provides some measure of resilience against CMF and HILP type events. DNO experience of large scale, and protracted interruptions show that resilience provided, for example by interconnection, is of considerable value to customers and society mitigating collapse of other infrastructure such as communications, water supplies and fuel. It could be argued therefore that whilst further work is required to more fully understand these events, a simple move to relax the level of security prescribed by P2/6 in the longer term may expose customers to a higher level of HILP and CMF risk than they experience at present if some other recognition of mitigation is not allowed for either within a reformed security standard or from some other mechanism.

The move away from the level of security prescribed by P2/6 would require detailed modelling of network areas potentially on a case by case basis to achieve the benefits indicated, and there are some practical issues of how to quickly shed demand should an outage occur.

The Imperial College work also concluded that the present standard should be modified to include all forms of distributed energy resources (DER) when planning network security. This conclusion was also reflected in the qualitative analysis where it is clear from all parties that a revised standard must consider both demand and embedded generation as well as other non-network technologies including (but not limited to) Energy Storage, DSM, DSR and other commercial arrangements. It is recognised that the present standard does cover the contribution to security from DG through the P2/6 supporting document Engineering Technical Report 130 "Application Guide for Assessing the Capacity of Networks

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[120] Imperial College analysis based on ACE Report No.51, 1979, "Report on Application of the Engineering Recommendation P2/5 Security of Supply" is presented in section 2.5 of their report covering WS2.1 to WS2.6 of this review.

[121] Since the capacity of electrical assets are finite or are procured in finite capacities future losses driven designs could incorporate additional lines/cables or possibly circuits to achieve the losses efficient design which would potentially increase network security above present design levels.

containing Distributed Generation". As a minimum improvements to the ETR130 method should be reviewed to see if it can be extended to all DER and also potentially improved.

The Imperial College work indicates that there may be potential benefits of avoiding or deferring network reinforcement through control of demand particularly at peak demand times. This includes smart control of low carbon generation export and through smart disconnection of non-essential loads. However, the implementation costs of such DSM related control schemes are not clear at present.

The key conclusion from the evidence to date is that the present P2/6 standard does require improvement and should not be retained unchanged. As a minimum, improvements to the ETR130 method should be reviewed to see if it can be extended to all DER and also potentially improved. If a decision is made to relax the present security arrangements to improve economic efficiency at the expense of the potential reduction in supply quality further reform of the standard would be required.

Retaining a deterministic planning standard, but with improvement (Option 2)

Overall, the option of improving P2/6 either through relaxing the level of redundancy or through the use of non-network technologies may not easily be achieved while retaining a simple to apply deterministic planning standard. The Imperial modelling demonstrates that the efficient level of redundancy and the role of non-network technologies is sensitive to circumstances, which means it may not be practical to codify the optimal solution ("the right answer") within a reasonable margin of error. It may be feasible to achieve a more complex deterministic set of rules considering the main variables involved, this would require substantial analysis and time (12 to 18 months) during the phase 2 standard codification to achieve this and there is a risk that the rules developed do not cover all cases or that there are unknowns or uncertainties that seriously degrade deterministic rules. There is also the risk that a complex deterministic standard is not practical to use.

These factors support the case for an alternative option that places more discretion for network planning in the hands of DNOs, such as by requiring them to use economic based analysis such as CBA analysis to identify appropriate investments. However, the desire by many stakeholders to retain the transparency of a deterministic standard is a significant factor. Hence it is concluded that improvements to P2/6 through the development of deterministic rules for relaxing the levels of redundancy and also the use of non-network technologies (DG, DSR, DSM and storage) should be considered as part of the phase 2 works.

Any deterministic rules developed would require considering the NETS SQSS to ensure alignment between the standards across network interfaces.

Implementing a high-level standard that obliges efficient investment, while retaining some deterministic elements (Option 4)

In principle, if DNOs were obliged or incentivised to undertake CBAs to identify efficient levels of reliability and the least-cost means of delivering it, then they should achieve economically efficient decisions without placing additional deterministic requirements on them. However, setting deterministic requirements regarding the level of reliability could be codified as a deterministic standard for some types of investment if the level of economically efficient reliability rarely falls below a specific threshold. Setting this minimum level of investment as a deterministic planning requirement would save the DNO the costs of conducting economic assessment through CBAs to confirm that this level of reliability is required, on the basis that it almost always will be. The modelling conducted by Imperial College sought to identify cases in which the lowest level of economically efficient investment to provide reliability is robust to changes in circumstances and assumptions, and hence could be codified. However, the results from Imperial College's modelling indicate that economically efficient investment is not robust to changes in circumstances and hence is not feasible to codify in practical and simplistic form.

An implication of such a *minimum* deterministic requirement is that, should (in specific circumstances) a CBA identify that a lower level of reliability were economically efficient, the planning standard could prevent the DNO from targeting this lower level. In general, such an approach would introduce economic inefficiency to network planning, but this problem could be overcome by applying to the regulator for derogations (or possibly self-derogating) from the deterministic requirements imposed by the planning standard. However, it can be concluded from Imperial College's work that to achieve economic efficiency the level of derogation request would be high and hence imply that the standard is not suitable.

To determine if there exists a *minimum* deterministic requirement that would provide economically efficiency investment[122] without relying on a significant number of derogations would require Imperial College to conduct a substantial programme of additional studies, and this work may well confirm that a suitable potential *minimum* deterministic requirement cannot be achieved. Similar to the option of improving the existing deterministic standard, it may be feasible through extensive studies to achieve a more complex deterministic set of rules considering the main variables involved. Again there is a risk that the rules developed do not cover all cases or that there are unknowns or uncertainties that seriously degrade deterministic rules.

Relaxation of the present P2/6 N-1 security requirement to improve overall economic efficiency where applied will potentially reduce the supply security customers presently enjoy. This impact is of concern to some WG members and hence this impact should be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken. It is suggested by the WG that there may be an acceptable level of relaxation to the present security arrangements that improves economic efficiency and is acceptable to stakeholders. This in effect is part of agreeing a proposed new minimum deterministic standard. Determining the acceptable minimum level would require being established as part of the phase 2 works.

Regarding the deterministic part of the standard, this would need to ensure alignment with the present NETS SQSS at the network interfaces.

Regarding the transition to such a combined deterministic/non deterministic standard, the additional work required identifying a suitable *minimum* deterministic requirement leading to a high level of economic efficiency and the codification around this could lengthen timescales compared with other options. A risk here being that the resulting standard will not materially simplify the network planning effort required to identify efficient levels of investment, because by design it would define a minimum level of investment below which it is rarely efficient to fall, but will still have gone through the process of introducing a substantial element of CBA related transition similar to options 3 and 5.

Abolition of the planning standard (Option 5)

Possibly the most radical option for reforming ER P2/6 would be the complete removal of the planning standard. Under such an approach, the importance of financial incentives would increase substantially, as these incentives and DNO's assumptions of investment costs would ultimately determine the level of reliability delivered. For this option to be effective in promoting efficiency, the existing financial incentives provided to DNOs to improve reliability would need to be reviewed and strengthened if

[122] The *minimum* deterministic requirement would be related to the reduction in redundancy from N-1. The optimal level of reduced redundancy varies due to a number of parameters some of which are local network specific. Hence setting rules that result in a similar high level of cost efficiency may not be achievable. A similar conclusion is made regarding the benefit of utilising DSR and storage to substitute for redundancy and improve cost efficiency.

required to ensure that DNOs build and operate networks in an economically efficient manner. If DNOs respond effectively to a financial incentive scheme that better reflects the marginal value that consumers place on reliability, this would give rise to a range of benefits to consumers:

- Allocative efficiency would increase, as the level of reliability provided by DNOs would get closer to the economically efficient level.
- The removal of the planning standard would enhance productive efficiency, as DNOs would be motivated by the financial incentive and by their revenue control to find the least cost means of providing reliability.
- Compliance cannot be tested, as there is no defined planning standard against which to test compliance. Instead, consumers' interests would be protected through the financial incentive scheme (and possibly through reputational mechanisms), and the regulator's compliance testing costs would fall towards zero.
- An additional benefit of the complete removal of the planning standard is that it will likely promote innovation. By allowing DNOs to select the cheapest ways of providing reliability, DNOs will be encouraged to innovate to find the lowest cost solution to providing the efficient levels of supply security.

Security is not the only design consideration for developing networks and it may be worth considering as part of the process of removing P2/6 the review of all network development standards, policies and regulatory incentives e.g. quality of supply, losses incentives, interruption incentives etc. This would take some time to complete and a suggested target would be to have revised design standards, policies and regulation including all necessary incentives ready and understood by all parties for the business case submission for RIIO ED2. This process would also have to consider the need to review the interfacing transmission standards such as the NETS SQSS.

Implementing a non-deterministic planning standard (Option 3)

An alternative to P2/6 and to deterministic planning standards in general, is to implement a non-deterministic planning standard that places an obligation on DNOs to perform economic assessment through CBAs to identify efficient levels of reliability and the most efficient means of delivering this reliability through a combination of network and non-network solutions.

As with the complete removal of the planning standard, discussed above, this option places more discretion in the hands of DNOs to plan efficiently than would be the case under a deterministic standard. And in fact this option is similar to the option of complete removal, as DNOs would still need to undertake their own CBAs to compare the costs of reliability with the value they would earn from financial incentive schemes, and to identify the cheapest means of delivering reliability.

What this option adds, therefore, is simply a regulatory requirement to undertake economic assessments through CBAs.

Obligations to plan networks in accordance with CBAs can increase the accountability of DNOs, and the transparency of DNOs' investment decisions [123] and they may provide justification for investment decisions taken by DNOs in forums such as legal proceedings. They also provide a back-stop that obliges efficient planning, should financial incentive mechanisms be limited in their ability to encourage DNOs to plan efficiently. However, enforcing the obligation to undertake CBAs themselves are costly, and the

[123] A key strength of the present P2/6 standard expressed by stakeholders through the qualitative analysis was the transparency of security design decisions made, and the concern that transparency could be lost if a non deterministic standard was adopted. Section 5.4 of this report discusses factors that impact on accountability/transparency of CBA based decision making. The methods of setting the transparency required would be a subject for the phase 2 codification stage which would consider the level of CBA prescription and scrutiny by the regulator.

regulator would need to have compliance testing and enforcement procedures in place to ensure that DNOs meet the obligations placed on them.

The potential costs savings between the "right" answer and those prescribed by P2/6 based on Imperial College's modelling discussed in section 4.3.2 illustrates the potential cost benefit of moving to a non deterministic planning standard. While there will be transitional costs and possible ongoing costs for DNOs moving to a non deterministic standard and possibly for the regulator, these are likely to be significantly lower than the potential cost benefit.

The introduction of a non deterministic planning standard to replace P2/6 will take a period of time to transition to. Although, DNOs are using CBA analysis at present, the level of prescription will require to be agreed between the various stakeholders as discussed in section 5.4.2. DNOs will also require time to revise internal policy, adopt new procedures, train staff etc. The regulator will also require revising regulatory policy, regulations and incentives mechanisms. A sensible timescale for adoption of a reformed standard may be alignment with the business plan submissions for RIIO ED2 similar to the option to remove the P2/6 security standard.

Since a non deterministic standard is flexible by nature, alignment with other interfacing standards such as the NETS SQSS is unlikely to be problematic. Interface issues with the NETS SQSS would be design option related rather than related to the standard itself.

Further conclusions regarding a future security standard are:

Distribution Losses

The enhancement of the present P2/6 deterministic standard, option 2, to include loss considerations in the design was in general not supported by respondents to the industry questionnaire. The consensus was that the interface between other industry standards/regulatory initiatives should be enhanced to ensure that any incentives work correctly in conjunction with the security standard to support its intent of ensuring the efficient provision of security of supply. This is also true of options 3, 4 and 5.

High Impact Low Probability Failures (HILP) and Common Mode Failure (CMF)

The present P2/6 standard does not directly consider CMF and HILP event mitigation in network designs. From the stakeholder engagement process to date, there is general agreement for the planning standard not to include extreme events; such events should be dealt with by alternative regulatory mechanisms due to their low probability and unpredictable nature.

The Imperial College work on HILP and CMF concluded that it is still an open question as to whether the assessment of CMF and HILP events should be included in the security of supply standard for the following reasons:

- There is a lack of comprehensive data to derive CMF and HILP events parameters (e.g. frequency, scale of impact) that can be used in probabilistic approaches.
- The impact of a certain hazard is network specific. For example, the risk of having a flood in plateau areas is much lower compared with lowland areas, and the impact on urban networks will be different with respect to the impact on sparse rural networks. Different networks may be exposed to different types of hazards. Therefore, the justification of the investment via cost benefit analysis (CBA) will be case specific.

However, some WG members expressed an opinion that some forms of low cost mitigation could be considered at the network security planning stage, e.g. advanced control systems. However, it is likely that any such mitigation would require to be justified through some form of CBA analysis and may not be suitable for the option of a reformed deterministic standard (option 2).

The potential impact of relaxing the present P2 N-1 security requirements on reducing future network resilience and the potential reduction in Common Mode Failure and High Impact Low Probability event mitigation is noted.

Construction Outages

It is concluded that the new standard should provide guidance as to the methods for the treatment of construction outages separately from maintenance outages and unplanned outages. In addition consideration at Phase 2 should be given to the concerns raised by some DNOs and export stakeholders in reviewing the treatment of construction outage risks to export customers; this may require guidance from Ofgem and further stakeholder engagement to consider this at Phase 2 of the review. Ofgem may wish to consider how to guide the DCRP on the treatment of construction outages for export customers prior to Phase 2 including the case of networks dominated by export customer use of system.

6.1 Potential Recommendations

Based on the main conclusions from this report there are a number of possible recommendations that could be made for consideration by the wider industry stakeholders during the consultation process, leading to the development of a set of firm recommendations made by the WG. For guidance the following are the potential recommendations reviewed by the WG that will form the basis for the set of questions to be addressed during the formal consultation process:

1. Considering today's environment and looking to the future, based on the quantitative and qualitative evidence to date the present P2/6 standard does require improvement and should not be retained unchanged.

2. Relaxation of the present P2/6 N-1 security requirement to improve overall economic efficiency where applied will potentially reduce the supply security customers presently enjoy. Hence it is also recommended that this impact be thoroughly reviewed by all stakeholder groups including DECC, Ofgem and customer representative groups before a decision to change is taken. It is recognised by the DCRP P2 WG that there is a trade of between the level of relaxation of the present security arrangements and the potential improvement in economic efficiency.

3. Subject to the outcome of recommendation 2, if feasible during the current RIIO ED1 price control period out to 2023, improvements to the economic efficiency of the present deterministic standard through reducing the level of resilience it obliges DNOs to provide at the HV[124] and higher voltage levels should be considered. It is noted that this may need careful consideration in terms of timing as the RIIO ED1 price control has already agreed load related reinforcement funding allocations with the DNO license holders. Any other transition issues will require to be considered in developing the plan to adopt the reformed standard.

4. Improvements to the present deterministic standard within the present price control period should also include the use of all non-network technologies including distributed generation (DG), demand side response (DSR), demand side management (DSM) and electricity storage where this can be demonstrated to be a suitable alternative to network redundancy.

[124] Throughout this report the stated voltage levels are based on industry terminology i.e. low voltage (LV) is 230V to 1000V, medium voltage (MV) is above 1000V to 6.6kV, HV is above 6.6kV to 22kV, and EHV is above 22kV to 66kV.

5. The development of deterministic rules and associated look up tables for improved economic efficiency of future network security planning are to be carried out during phase 2 of this review and will consider both relaxing the present rules on network security and the use of non-network technologies (DG, DSM, DSR, and Storage).
6. Recognising that there will be a trade-off between economic efficiency of any new deterministic rules, the variables that can be considered, the ease of use of developed rules, and the network planning scenarios that can be covered, there will be a need for flexibility to permit network planning outside of the deterministic rules where necessary. It would therefore also be appropriate to supplement the existing standard with obligations on DNOs to conduct other economic analysis where new deterministic rules are not appropriate.
7. Work would be required at phase 2 to set the level of prescription for any non-deterministic obligations, and the required level of transparency in (and regulatory oversight of) DNOs' economic analysis.
8. Subject to the further planned industry engagement to come during Phase 1 of this review, the option of moving to an entirely non-deterministic standard to regulate the level of reliability DNOs are obliged to provide (Option 3), or possibly removing the planning standard altogether (Option 5), should not be ruled out at this stage. However, to support more radical changes than those set out in potential recommendations 2 to 7, some reform of other regulatory mechanisms would be required, such as strengthening the Interruptions Incentive Scheme, we have assumed this will not be possible before the commencement of the RIIO-ED2 price control process. In moving to less deterministic planning standards, the regulator would need to consider trade-offs between the improvements in economic efficiency that are feasible from such a change, and any associated increases in costs, such as the need for DNOs to undertake more complex planning activities. Changes to other codes and schemes and potentially licence conditions may also be required.

The selection of potential recommendations 2 to 7 would lead to the implementation of high-level option 2 or 4 depending on the ability to develop practical deterministic rules and look up tables covering more economically efficient security provision and also the application of DER. Option 2 is where this is possible and the standard is predominantly deterministic in nature and Option 4 has a greater element of economic assessment.

Based on the outcome of the work completed so far, there are a number of other potential recommendations that should also be considered:

9. The new standard should provide guidance as to the methods for the treatment of construction outages separately from maintenance outages and unplanned outages.
10. In addition, consideration at Phase 2 should be given to the concerns raised by export stakeholders in reviewing the treatment of construction outage risks to export customers; this may require guidance from Ofgem and further stakeholder engagement to consider how this subject could be included in the Phase 2 review.
11. Any new or reformed standard must take cognisance with the transmission system interfaces and the requirements set out in the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS).

12. Regarding High Impact Low Probability Failures (HILP) and Common Mode Failure (CMF) some forms of low cost mitigation should be considered at the network security planning stage and covered by a reformed security standard. Mitigation would require to be justified through some form of CBA analysis, the form of which could be prescribed by Ofgem.

It should be noted that these recommendations are potential recommendations arising from those that have been reviewed by the WG at this stage of the project. They will be subject to further extensive stakeholder engagement still to be conducted based around this report through a formal industry wide consultation process.

APPENDIX A BACKGROUND NOTES ON ER P2/6

To provide the reader with some background to the influence in the licensed distribution industry of ENA Engineering Recommendation P2/6 Security of Supply document the following short summary is provided.

ER P2/6 and EREP 130

ER P2/6 recommends minimum security of supply requirements that network planners use to assist them plan and design new or reinforced networks. P2/6 is supported by ENA Engineering Report 130 "Application Guide for Addressing the Capacity of Networks Containing Distributed Generation". EREP 130 allows network planners to assess the contribution of embedded generation to network capacity and assess compliance with the P2/6 minimum security of supply requirements.

Distribution License Conditions

ER P2/6 is referenced in the license conditions placed on distribution license holders through the Gas and Electricity Markets Authority, ELECTRICITY ACT 1989, Standard conditions of the Electricity Distribution Licence. The pertinent condition is provided below:

"Condition 24. Distribution System planning standard and quality of performance reporting
Distribution System planning standard

24.1 The licensee must plan and develop its Distribution System in accordance with:

(a) a standard not less than that set out in Engineering Recommendation P.2/6 of the Energy Networks Association so far as that standard is applicable to it; or
(b) such other standard of planning as the licensee, with the Authority's approval, may from time to time adopt after consulting (where appropriate) with the GB System Operator and any other Authorised Electricity Operator likely to be materially affected.

24.2 The Authority may (after consulting with the licensee and, where appropriate, with the GB System Operator and any other Authorised Electricity Operator likely to be materially affected) give a direction ("a derogation") to the licensee that relieves it of its obligation under paragraph 24.1 in respect of such parts of the licensee's Distribution System, to such extent, and subject to such conditions as may be specified in the direction."

Compliance Testing and Load Related Regulated Expenditure

Compliance testing against the minimum security of supply requirements in ER P2/6 allows network planners to forecast when network reinforcements will be required due to demand growth. This allows the DNOs to submit load related forecast expenditure as part of their price control business plan submissions as part of the regulated price controls. This in turn establishes the total load related expenditure that the regulator agrees can be collected by the DNO from customers via their approved charging methodologies.

DCUSA and Charging Methodologies

The charging methodologies are contained in the Distribution Connection and Use of System Agreement (DCUSA) which provides a single centralised document which relates to the connection to and use of the electricity distribution networks.

Within the DCUSA the Extra High Voltage Distribution Charging Methodology (EDCM) allocates charge credits to generators that are assessed to support network capacity and defer or avoid network reinforcements. Generator capacity credits assessed under EDCM require inputs regarding generator capability to contribute to network capacity that are defined through P2/6 and the supporting EREP 130, referred to as F Factors.

ESCQR

The Electricity Safety, Quality and Continuity Regulations 2002 clause 23 "Precautions against supply failures" requires that "(2) Subject to regulation 29, a distributor shall at all times take all reasonably practicable steps to avoid interruptions of supply resulting from his own acts." This is in part addressed through the minimum security of supply requirements defined in ER P2/6.

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