NIA ENWL010
Value of Lost Load to Customers

Conclusions and recommendations
Executive summary report

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Name	Role	Date
Tracey Kennelly	Project Manager	28 September 2018
Paul Turner	Innovation Manager	1 October 2018

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GLOSSARY

Abbreviation	Term
BEIS	Department for Business, Energy and Industrial Strategy
CI	Criticality index
CoF	Consequences of failure
CRMS	The control room management system (CRMS) is the real-time control system that holds Electricity North West's network topology and some asset data relevant to control.
DADS	DUoS and Associated Distribution Systems (DADS) is a web-based solution for all Distribution functions. It helps Electricity North West meet the regulatory requirement to separate Distribution and supply businesses so that it can operate in the competitive electricity market as a discrete business unit.
DECC	The former Department of Energy and Climate Change
DNO	Distribution network operator
DUoS	Distribution use of system
ECOES	The Electricity Central Online Enquiry Service ("ECOES") is operated by the Master Registration Agreement Service Company Limited. ECOES enables the use of meter point Information in accordance with the permitted uses set out in the MRA and any ECOES access agreement between MRASCo and a named person.
ECP	Engaged customer panel
EGS	Electricity guaranteed standard
EHV	Extra high voltage
Ellipse	Electricity North West's Ellipse database holds details of physical electrical point assets (ie switches and transformers), substations, link boxes and support structures such as woodpoles and towers. It provides a repository for static data from the nameplate and condition data captured during asset inspections.
ENA	Electricity Networks Association
EV	Electric vehicle
GDPR	General Data Protection Regulations
HI	Health index
HV	High voltage
IIS	Interruption incentive scheme
LAR	Load at risk
LCT	Low carbon technology

Abbreviation	Term
LE	London Economics
LV	Low voltage
MPAN	Meter point administration number
NaFIRS	National fault and interruption reporting scheme
NASD	Network asset secondary deliverables
NDM	Non-daily metered
NIA	Network Innovation Allowance
NOMS	Network Output Measures
NPV	Net present value
Ofgem	Office of Gas and Electricity Markets
ONS	Office of National Statistics
PoF	Probability of failure
PowerGIS Browser	PowerGIS Browser displays the location of our assets and details of our cables from our central GIS database as an online map.
PSR	Priority services register
PV	Photo-voltaic
RIGs	Regulatory instructions and guidance
RIIO-ED1	Electricity distribution price control 2015 to 2023
RIIO-ED2	Electricity distribution price control 2023 to 2028
SME	Small to medium enterprise
SMS	Short message service
TDCVs	Typical domestic consumption values
VCT	VoLL calculation tool
TO	Transmission Owner
VoLL	Value of Lost Load
WSC	Worst served customers
WTA	Willingness to accept
WTP	Willingness to pay

1 FOREWORD

This document forms the conclusions of a study which sought to re-examine the existing model used by distribution network operators (DNOs) to place a value on the loss of electricity supply to customers. This report is the result of extensive customer and stakeholder engagement to understand how the 'Value of Lost Load' (VoLL) is assessed by different customer segments and how this might change in a low carbon future.

The research objective was to deliver a comprehensive assessment of customer impacts associated with the loss of electricity supply, the relative importance of various supply interruption characteristics eg duration, how these components are valued by specific customer groups, and how this might change with the adoption of low carbon technologies (LCTs). It also examined if VoLL could be influenced by adopting different approaches to managing outages.

VoLL is defined as "a measure of the economic value given to an amount of electricity that is prevented from being delivered to consumers (ie is 'unserved') as a result of a planned or unplanned outage of one or more components of the electricity supply chain."[1]

At present in Great Britain (GB), a single VoLL is used to evaluate what customers would be willing to pay to avoid a supply interruption of average duration. This has been set by Ofgem for RIIO ED1 at a rate of £16,000/MWh. Although the VoLL metric is expressed in terms of hypothetical financial penalties or compensation, it incorporates supply reliability, which is a function of the frequency, duration, time, season and notice of supply interruptions.

Previous research has identified that VoLL varies significantly among three distinct customer groups: residential; small/medium commercial and industrial enterprises (SMEs); and large commercial/industrial users. The value may also vary considerably within each of these groups, for example, between rural and urban residential customers. The existing single VoLL is aggregated to provide an overall estimate of the value given to loss across all domestic and SME customer segments.

Modern network management systems allow DNOs to view the number and segmentation of customers fed from a specific asset to calculate the VoLL that should be applied in a given investment decision. Understanding the relative VoLL components at a much more granular level could allow greater efficiency in future investment decisions driven by customer need.

2 PROJECT SUMMARY

The project investigated whether the current single VoLL remains appropriate as GB moves towards a decarbonised economy. It involved extensive customer research that built on previous studies in this area, particularly that conducted by London Economics (LE) in 2013, to determine whether a revised VoLL model would benefit customers.

The project was funded by the Network Innovation Allowance (NIA), introduced as part of the RIIO-ED1 price control, which provides an allowance for RIIO network licensees to fund projects that have the potential to improve network operation and maintenance, and to deliver financial benefits to the licensee and its customers.

The overall research methodology was designed by Electricity North West and its market research project partner, Impact Research. The approach was also shaped following consultation with two key stakeholders: Citizens Advice and the former Department of Energy and Climate Change (DECC), now the Department for Business, Energy and Industrial Strategy (BEIS).

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1 Electricity Authority – Te Mana Hiko, 2012, Investigation into the Value of Lost Load in New Zealand – Summary of Findings.

The project commenced in October 2015 and has culminated in a comprehensive assessment of how VoLL should be defined across a range of customer segments to inform a potential revised model, which could help DNOs better plan their network investment and customer strategies.

This report summarises the final conclusions of the VoLL project and makes recommendations on how a revised model might be applied, using standard industry data sources, available to DNOs. The document explains how a more sophisticated VoLL calculation, informed by specific VoLL characteristics/drivers, can deliver greater efficiency in investment decisions, based on a richer understanding of the needs of customers served by particular network assets. It goes on to explain how this might be achieved through the demonstration of a simple VoLL calculation tool (VCT). This report should be considered in conjunction with other key project documents, specifically the customer survey (phase 3) key findings report and the accompanying technical appendices, which are published on the VoLL webpage. The following section outlines how the project met its objectives.

3 RESEARCH OBJECTIVES AND SUMMARY OF KEY FINDINGS

The research has delivered a set of VoLL estimates that reflect the varying needs of different customer groups far more accurately than the single-value approach currently used. This report demonstrates how these values (Appendices 9.1a and 9.1b) have been incorporated into a new VCT, which allows DNOs to accurately assess the collective VoLL of customers served by specific assets.

This report demonstrates how understanding relative VoLL components, at a much more granular level, provides an opportunity for improvements in DNOs' current cost-benefit analysis models, which could provide greater efficiency in future investment decisions. These will derive greater customer benefit by targeting investments on the basis of a more sophisticated VoLL model reflecting customer need and dependence.

The research has wider implications for Ofgem and GB DNOs in planning their future investment and customer strategies. It is anticipated that the values for segmented VoLL that have been calculated as part of this study will be important in informing DNO policies and investment plans for the RIIO-ED2 price control and beyond. A further consideration, outside the scope of the current project, is the societal and economic impact of an investment scheme which gives more consideration to the different needs of specific customer groups.

The project sought to redefine the value associated with the loss of electricity supply to customers by meeting the following research objectives:

- What is the impact on customers of loss of supply?
- What is the value of this impact – financial and social costs to customers in £ per kWh?
- How does this vary by customer type and supply interruption components eg duration?
- How can Electricity North West and key stakeholders mitigate the costs of lost supply to customers?
- How will VoLL vary with LCT adoption?

The project success criteria were:

1. An understanding of customer impact, how value is defined and how this might be influenced (eg better communications)

2. A credible segmentation and future VoLL model by key customer groups to guide investment decisions

3. A demonstration of how these values would help Electricity North West and other DNOs to better plan their network investment strategy

4. Guidance on customer compensation strategies.

The VoLL closedown report, published on the VoLL webpage, documents how these objectives and the success criteria were met.

Key findings from the study are summarised below; however this report focuses specifically on *success criteria 3 and 4* by making recommendations of how a segmented VoLL model would help Electricity North West and the wider DNO community to better plan their network investment and customer compensation strategies.

What is the impact on customers of loss of supply?

- Supply reliability was defined as the continuous availability of electricity with no interruptions.
- Duration was a key factor in determining the magnitude of disruption experienced.
- Customers are more tolerant of planned supply interruptions than unplanned interruptions, because the notice requirement allows them to prepare in advance.
- Supply interruptions are more disruptive to vulnerable customers, particularly those in fuel poverty, who should potentially be prioritised in:
    - Decisions influencing security of supply
    - Restoration following an interruption
    - Provision of support during an interruption.
- The most valued support from DNOs during an interruption is accurate, up-to-date and regular communication about the restoration time.
- Intuitively, VoLL is expected to be higher in winter than summer, given the impact of an interruption is likely to be greater and the same might be expected for outages occurring at times of peak demand. In contrast to the LE research, this study observed a higher VoLL in summer than winter. This is likely to reflect the context in which the customer survey questions were framed. Respondents were asked to base responses on the worst case scenario ie when an outage would be most disruptive. As such, it is not possible to make accurate seasonal comparisons.

What is the value of this impact – financial and social costs to customers in £ per kWh?

This study demonstrates that the figure customers are willing to accept (WTA), in compensation for loss of supply, is much higher than the amount they are willing to pay (WTP) to avoid a supply interruption. This finding was anticipated and is consistent with previous studies in this area.

The higher WTA value applies equally to domestic and small to medium enterprise (SME) customers. For domestic customers the average WTA figure is £17,481 and for the SME segment it is £47,560, giving a single load share weighted average value of £25,301[2]. The

2 Assumes a domestic / SME split of 74%/26%

single uniform WTA value for VoLL found by LE in 2013[3] was £16,940[4]. This figure, if adjusted for inflation, would now be closer to £18,500.

The increase suggests that VoLL is rising over time and this is likely to reflect higher customer need and expectations. However, there are also important differences between the two studies that may be influential in revealing the higher value.

The LE study specifically tested seasonal and time attributes. However, because the DNO is unable to influence the season or time that an unplanned outage occurs, Electricity North West's research asked respondents to express VoLL in relation to a power cut occurring at a time that would be most inconvenient. This rationale allowed respondents to base responses on the worst case scenario, ensuring that the VoLL captured was representative of the true disruption that would occur.

The higher values may also reflect a difference in the frequency of interruptions when compared to the LE study, which described the attribute as "an outage in one out of 12 years". Whereas this study based the scenarios tested on an outage occurring once every three years, to more accurately reflect industry service performance for supply reliability and availability.

Differences in the two approaches are more thoroughly documented in the customer survey (phase 3) key findings report.

How does this vary by customer type?

SME customers have a higher VoLL than domestic customers.

The domestic customer segments with the highest VoLL are the fuel poor, those in rural areas, those in low income groups[5], those classified as vulnerable[6], and current users of LCTs most notably, drivers of electric vehicles (EVs).

Domestic customer segments with the lowest VoLL are those with recent experience of a large scale, lengthy supply interruption and urban customers.

In the SME group, customers that have experienced one or more unplanned interruptions in the last three years have the highest VoLL and conversely, those that have not experienced any interruptions in the same period have the lowest VoLL.

How can Electricity North West and key stakeholders mitigate the costs of loss of supply to customers?

The research identified two main ways to mitigate the impact of loss of supply on customers:

- Proactive network investment, to reduce the duration and frequency of supply interruptions
- Communicating with customers during supply interruptions to provide accurate information about when power will be restored.

3 London Economics, 2013. The Value of Lost Load (VoLL) for Electricity in Great Britain, Final Report for Ofgem and DECC.
4 If adjusted for inflation, this becomes £18,500, notably lower than the new figure (based on Bank of England inflation figures averaged at 2.2% a year using the composite price index).
5 Social grade category DE: a socio-economic classification produced by the Office for National Statistics where DE largely represents unskilled occupations, pensioners and students. The WTA figure has been adjusted for income
6 WTA figure adjusted for income. Adjusted WTA for low vulnerable = £19,000 (x1.10), medium vulnerable = £21,000 (x1.20) and high vulnerable = £18,500 (x1.05) (specifically Medically dependent equipment users = £18,000 (x 1.05).

Proactive network investment

When an interruption is planned, with at least two days warning, VoLL is substantially lower than for unplanned outages of equivalent frequency and duration. In the case of a one hour outage once every three years, VoLL for domestic customers falls from £17,500 to £500 and a similar pattern is observed in SME customers.

However, values derived from this study (Appendices 9.1a and 9.1b) suggest that while there is tolerance for limited planned work requiring outages, acceptance diminishes when customers have experienced more than three full day interruptions over a three-year period.

This finding is significant in demonstrating how a proactive network investment strategy, to minimise the risk of asset failure and consequently unplanned outages, can mitigate VoLL. It does, however, highlight the importance of a cohesive approach to construction and maintenance strategies and the need to consolidate planned work where possible.

Communicating with customers during supply interruptions to provide accurate information about when power will be restored

Offering increased level of support to customers during supply interruptions demonstrates the importance DNOs now place on social responsibility, underpinned by regulatory stakeholder obligations; however, this study reveals that simple mitigation strategies also provide an economically efficient means to positively influence VoLL. The most effective mechanisms are:

- Telephone call(s) made to customers
- Short message service (SMS).

A targeted telephone call made to a domestic customer is more than three times as effective in diminishing the impact of a supply interruption as updates via social media, and this can directly mitigate the loss for up to five minutes in an hour. This finding underpins the importance customers place on effective communication, specifically the provision of regular updates with accurate information.

Priorities were found to be similar for SME customers but reveal the high value businesses place on the availability of real-time information through social media channels, with organisations now regarding access to instantaneous, updated information as an expectation rather than an aspiration.

The research also exposes significant differences in the value placed on various support and communication strategies by those aged 18-29, implying that mitigation strategies, adopted by DNOs, must evolve to reflect diversity and the changing needs/expectations of their customers.

How will VoLL vary with LCT adoption?

This study suggests that VoLL for current domestic users of LCTs is 9% higher than the average for all domestic customers. Within the general segment of current domestic LCT adopters, the EV users' VoLL is 23% higher than the average of all domestic customers.

This is a significant finding for determining future network investment needs and standards driven by VoLL as LCT adoption is projected to increase.

4 RECOMMENDATIONS FOR ADOPTING A SEGMENTED VOLL MODEL

This section of the report makes recommendations for adopting a segmented VoLL model and outlines the network and customer benefits of using a more sophisticated calculation to assist DNOs in better planning network investment and customer compensation strategies.

4.1 Background

From April 2015 DNOs have been regulated, by Ofgem, through the RIIO price control framework (Revenue = Incentives + Innovation + Outputs). This determines how much each DNO is allowed to charge its customers to fund network investment and operating costs, and is designed to drive real benefits for customers.

The RIIO price controls have been developed to ensure that the revenues collected from customers are linked to company performance. It limits the amount that costs can rise, ensuring value for money for consumers. Income in each year is largely fixed but is subject to increase or decrease depending on performance against the outputs delivered through a number of incentive mechanisms. These mechanisms aim to promote good customer service, minimise the number of interruptions that customers suffer and the average length of those interruptions.

Outputs are a fundamental element of the RIIO framework and there are outputs associated with baseline revenues that DNOs must deliver. Outputs fall into six categories:

- *Reliability and availability:* providing long-term reliability of supply, minimising the number and duration of interruptions and ensuring adaptation to climate change
- *Environment:* reducing carbon emissions and the environmental impact of the company's activities by managing carbon footprint, visual amenity and pollution
- *Connections:* connecting customers in a timely and efficient way, and enabling competition
- *Customer satisfaction:* maintaining high levels of customer satisfaction and improving service
- *Social obligations:* helping vulnerable customers
- *Safety:* providing a safe network in compliance with Health and Safety Executive safety standards.

This report focuses on outputs where the regulatory incentive is directly underpinned by VoLL, specifically network resilience and customer satisfaction measures.

Reliability and availability - Network output measures principles

The primary outputs monitor each Transmission Owner's (TO) performance against the delivery of end services to consumers.

Governance ensures that networks are designed and operated in accordance with relevant legislation, codes and standards, which include the Network Output Measures (NOMs). These are binding secondary outputs which show that the TOs are providing consumers with long-term value for money through a set of early warning measures and indicators.

The NOMs are designed to demonstrate that the TOs are targeting investment in the right areas to manage network risk effectively, ensuring they continue to deliver primary outputs in the future and the overall asset risk of the network does not deteriorate significantly. A set of principles relating to these metrics and regulatory reporting requirement enable Ofgem to evaluate performance.

Network asset secondary deliverables (NASD), covered by the Common Network Asset Indices Methodology form part of these metrics and relate to improvement in risk delivered by asset replacement and certain refurbishment activities.

NASD for reliability involves assessment of the health, criticality and monetised risk of asset failure and a load index. These are reported annually to Ofgem to provide transparency about how DNOs are investing in their networks, ensuring that cost savings are not being made at the expense of the network condition. This mechanism provides an important safeguard as a DNO could theoretically under-invest in its network for some time without any increase in interruptions and by the time interruptions occur, the network could have significant problems that are expensive to repair.

A range of factors are considered by the DNO when making significant investment decisions which focus expenditure on activities aimed at managing the risk of condition-based failures and the consequences of failure (CoF). This mechanism is summarised in Appendix 9.2 but is underpinned by a formula which uses a simple multiple of VoLL to derive a typical reference network performance CoF for the asset.

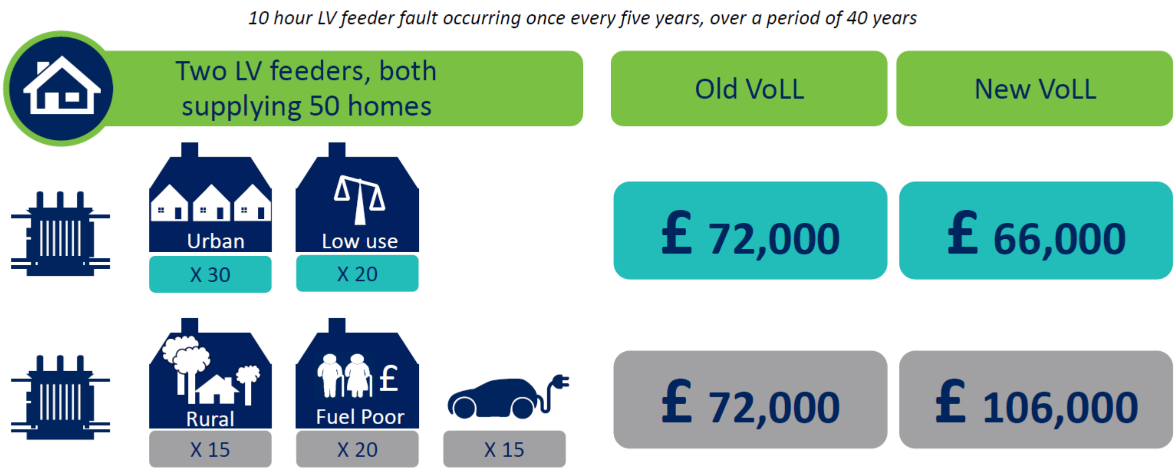
4.2 Recommended enhancements through applying a segmented VoLL

The VoLL study validates that different customers have quite different needs, which impact on electricity dependence and, consequently, changes the value that specific groups attribute to a supply interruption. On the basis of this research, Electricity North West believes there is merit in developing a more sophisticated model to replace the single ‘vanilla’ VoLL used in the calculation referenced above, which more accurately reflects the divergent needs of the customers served by individual assets.

This recommendation is not intended to replace the common framework, principles and calculation methodologies adopted by GB DNOs to assess condition-based CoF; rather it provides an additional tool to assist DNOs in prioritising decisions and delivering maximum benefit from the finite resources available in the capital programme.

The benefits of adopting a segmented matrix is simply demonstrated in Figure 1.1 using the example of two comparable feeders, serving the same number of domestic customers.

Figure 1.1: Example of VoLL application: single VoLL vs VoLL varied by customer type



In this representation, the first feeder is mainly composed of urban households with relatively low electricity usage. The second feeder serves a more complex mix of customers served by a rural network, which includes households in fuel poverty and high electricity consumers, owning electric vehicles.

Using the existing single uniform VoLL, the net present value (NPV) on each feeder for a ten-hour interruption, occurring once every five years[7] is £72,000.

The final column of the illustration shows how a VoLL, which reflects the mix of customer types, provides a very different set of results compared to the current model. By applying a blended VoLL calculation, the NPV for the first feeder is around 8% lower at £66,000, whereas it is almost 50% higher (at £106,000) on the second feeder than VoLL using the single value model.

The current single VoLL takes no account of diversity in the needs and dependencies of the customers served by the asset. For example if, using the above illustration, a third feeder was introduced supplying a diverse mix of 50 SME customers from across the retail, service and manufacturing sectors, the present VoLL calculation would result in exactly the same £72,000 NPV as a feeder serving 50 domestic customers of any broad customer type or mix thereof.

This simple illustration demonstrates that quite different figures are derived when the CoF for different assets is calculated applying a more sophisticated segmented model, than by simply multiplying a single uniform VoLL. In this example, the investment to mitigate the CoF of the asset on the second feeder could be justifiably prioritised over the first because of the greater needs of, and impacts on, the customers served, demonstrating how DNOs might better target finite resources to deliver greatest value.

However, it is recognised that these findings introduce questions about fairness, legitimacy and socialised costs, which require further investigation.

It is worth noting that this simple representation references certain customer characteristics which DNOs are unable to access using standard industry data at the present time. For this reason, these characteristics are not included in the VCT discussed in Section 5. However, future refined models, incorporating data from a range of external sources, may provide greater visibility about the specific demographic composition of particular networks. This is discussed further in Section 5.

4.3 Guidance on customer compensation strategies

This study demonstrates the importance of a granular understanding of VoLL in informing customer compensation strategies for RIIO-ED2 and beyond. Findings suggest that the industry may need to consider more nuanced standards to reflect the personal and societal impact of supply interruptions on specific groups such as the fuel poor and customers in vulnerable circumstances. For example:

- The standard £75 electricity guaranteed standard (EGS) payment, available to domestic customers when the DNO has failed to restore supply within 12 hours (EGS2 – normal weather conditions)[8], may no longer be appropriate in value or threshold, given the higher relative value of loss for customers in fuel poverty and on low incomes. This is more obviously demonstrated when considering lengthy interruptions, which fall below the 12-hour threshold for a payment.

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7 The 'Old VoLL' reflects the blended VoLL value currently used by Ofgem, which is £16,940MWh per household. The values used by DNOs take the form of two incentives: £25.40 per customer interrupted and £36.66 per customer hours lost. These are multiplied by the 50 households x 10 hour duration and assumed to occur once every five years for the next 40 years. The final value shown here is the NPV discounted by 4% per annum for that 40-year period.
The 'New VoLL' takes the survey results for each type of household shown in the example, some of which have a combination of features. The values for customers who had these particular combinations were taken directly from the survey results. The ratio of these values to the current VoLL value of £16,940 was then applied to the incentive values to produce new NPVs.

8 RIIO-ED1 regulatory instruction and guidance: Annex 7 - Interruptions

The study suggests that the financial impact of interruptions and, therefore, the value of any unrecoverable loss, is greater for individuals on low incomes than for those in higher income brackets, who are generally better placed to absorb the economic consequences. For example, those living in fuel poverty may be less able to replace items such as perished fridge/freezer contents or have insurance for such eventualities.

The relatively high value of the 12-hour EGS payment for customers on low incomes may represent an amount sufficient to compensate for actual financial loss. Whereas, the same monetary value of loss might equally be incurred as a result of a lengthy outage under the 12-hour threshold; however, in this instance, no payment is available to mitigate the impact.

- The 12-hour qualifying period also negates the large increase in VoLL for an unplanned interruption when the duration increases from one hour to six hours. The high magnitude of increase is apparent across the various frequencies tested for both domestic and SME customers, with a subsequent lower hourly rate incurred the longer the outage lasts. This suggests that the tapering payments governing severe weather conditions remain appropriate (EGS2B EGS2C EGS11A EGS11B and EGS11CB).
- There is a marked difference in VoLL between planned and unplanned interruptions, with a significantly lower VoLL for planned outages, where at least two days notice is given. This difference demonstrates the importance of effective communication, which allows customers to make appropriate arrangements to manage the effects. Currently customers are entitled to a payment if the DNO fails to provide the required notice (EGS4). Given the impact of effective communication in mitigating VoLL, future compensation strategies may need to similarly reflect the importance of adequate communication with those most impacted by unplanned outages, for the duration of the event.
- As outlined above VoLL for planned interruptions is significantly lower when compared to unplanned outages of the equivalent duration and frequency. However, VoLL rises exponentially as the frequency and duration increases. This is most notable for the worst level tested (a planned outage of more than six hours occurring 7-14 times every three years), when VoLL for SME customers exceeds that for comparable unplanned interruptions. This implies that tolerance for limited work requiring outages diminishes when customers are exposed to three full day interruptions over a three-year period.

  Regulation EGS2A (multiple interruptions) currently exempts planned outages from the count when assessing eligibility for a payment (four or more outages, over three hours in a 12-month period). The inference of these findings is that future compensation strategies may need to reflect acceptable levels of planned outages, ensuring DNOs plan their construction and maintenance activities in a consolidated manner, to mitigate customer impact and, consequently, VoLL.

5 THE VOLL CALCULATION TOOL

This section outlines recommendations for the application of a more sophisticated VoLL estimate, to inform future planning and investment strategy, facilitated by a proposed VCT.

This example of a potential VCT works on the assumption that each DNO produces a hierarchical database of every asset connected to its network. Modern network management systems allow DNOs to identify the number and segmentation of connection points on any given network, served by any particular asset. Customer numbers are identified by unique meter point administration numbers (MPAN) and the DNO has visibility of certain VoLL characteristics associated with these MPANs. This data could be harnessed to provide a simple mechanism for a richer, blended calculation of VoLL specific to a particular asset.

This does not involve a significant change in the way that DNOs assess the benefits of lost load mitigation but simply adds another customer-driven dimension to the cost of failure estimate, as determined by the common network asset indices methodology (refer to Appendix 9.2).

The relative simplicity of the approach means that the calculation is not limited by the number of customers. It can be applied to assess the VoLL of an extra high voltage circuit, serving many thousands of customers, as simply as for an estimate on a low voltage network serving a small number.

Figure 5.1, illustrates the VCT for households and SMEs. Each row represents a single MPAN. The MPAN has an associated list of attributes, which are derived from network data available to the DNO.

Figure 5.1: VoLL calculation tool for households

	VoLL		Customer Type		Region		Supply quality				LCT			Power Cuts		Vulnerability			Consumption		
mpan	Blended	Maximum	Domestic	SME	Rural	Urban	Worst served	Experienced large scale, lengthy supply interruption in last twelve months	Fuel poverty	Off-gas	EV	PV	EHP	No power cuts	Power cuts	Low	Medium	High	Low	Medium	High
1	£18,543	£18,543	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0
2	£21,314	£21,314	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0
3	£17,884	£17,884	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0
4	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
5	£21,493	£21,493	1	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0
6	£19,221	£19,221	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0
7	£21,493	£21,493	1	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0
8	£21,962	£22,610	1	0	1	0	1	0	0	1	0	0	0	0	1	0	1	0	0	1	0
9	£18,543	£18,543	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0
10	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
11	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
12	£32,470	£32,470	1	0	1	0	0	1	1	0	1	0	0	0	1	0	1	0	0	1	0
13	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
14	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
15	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
16	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
17	£51,341	£51,341	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
18	£22,987	£24,480	1	0	0	1	0	0	0	0	1	0	1	1	0	0	1	0	0	1	0
19	£19,443	£19,664	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0
20	£17,464	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0
21	£19,443	£19,664	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0
22	£47,560	£47,560	0	1	0	1	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0
23	£51,341	£51,341	0	1	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0
24	£32,470	£32,470	1	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0
25	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
26	£17,884	£17,884	1	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0
27	£71,173	£73,894	0	1	1	0	0	0	0	1	0	0	1	0	1	0	1	0	0	1	0
28	£45,722	£47,560	0	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0
29	£21,314	£21,314	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
30	£47,560	£47,560	0	1	0	1	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0

5.1 Estimating VoLL for customers with multiple characteristics

The prototype VCT was developed on the basis of detailed analysis conducted to predict VoLL for complex households (more than two sub-groups combined). This was complex, because, as a model, it is only useful if accurate across many scenarios. VoLL in itself is an estimation derived from simulating an unfamiliar environment and asking respondents to make choices. Therefore, developing a credible estimation tool, considering multiple VoLL characteristics, presents a significant challenge.

It was concluded that the most accurate method of deriving VoLL for different household structures was through the use of the original estimated values obtained directly from the survey sample. Restrictions were based on sample sizes for both domestic and SME segments, and confidence intervals were calculated for the VoLL produced. This approach ensures that the highest level of accuracy possible is taken into consideration in the interpretation of the results. The VCT produced for this purpose ensures quick access to VoLL estimations for different sub-group combinations of households and businesses.

At present, only VoLL characteristics that are currently available to the DNO from standard industry sources are included in the proposed model. However, if access to more refined data becomes available to DNOs during RIIO-ED2 and beyond, other characteristics, which have been proven to directly influence VoLL, may be incorporated into a more advanced

VCT model. The VoLL attributes tested in the study are listed in Appendices 9.1a and 9.1b. These tables highlight the characteristics which are recommended to be included in the prototype VCT.

It is recognised that further detailed vector analysis is required to explore the optimum level of complexity for the VCT and the most practicable mechanism for its implementation at scale. As such, more research is proposed to further develop the tool, which is expected to determine the level of detail at which VoLL variables might be combined/aggregated relative to network parameters.

5.2 Use of the tool

To calculate the blended VoLL of the multiple customers served, the user codes each MPAN in terms of its salient features (customer type, region, supply quality, LCT, power cuts, vulnerability and consumption).

The average and maximum VoLL for each MPAN is automatically populated when the user clicks on the ‘calculate VoLL’ button. The VCT then takes the two highest VoLL values relevant to each MPAN and multiplies these together for the final estimate. The maximum VoLL shown is the single highest segmented group value for that MPAN.

This prototype tool runs on a Microsoft Excel platform and should be regarded purely as a test instrument, which serves to demonstrate a quick and simple mechanism for calculating the aggregated VoLL of any particular asset. It is recognised that the tool may be required to calculate the aggregated VoLL of several thousand customers, for example, in the case of a primary transformer. As such, there is a requirement to develop a more efficient database platform, capable of processing large numbers of MPANS, which is also capable of being continuously or periodically updated with changing data from other sources, ie fault history.

Electricity North West intends to draw on these findings and conduct additional detailed analysis to understand the optimum level of sophistication for the revised model to aid its practical implementation across GB.

5.3 Network data sources

This section summarises the source of data used to populate VoLL characteristics in the VCT and where this data is available to DNOs and other authorised industry stakeholders.

Electricity North West processes and maintains network and customer data using a number of management systems and this is held in various repositories. In common with other DNOs, it is required to process specific information from these sources for regulatory reporting purposes on a periodic basis. Elements of this standard industry data have been used to support the VoLL study and the equivalent information is available to other DNOs via their unique information and network management systems. Appendix 9.3 identifies the network sources of the data utilised in this research and its purpose. These sources are broadly broken down into the two main categories: network (quality of supply) and customer data.

5.4 Network – quality of service data sources

Precision of the revised VoLL model is dependent on the availability of accurate, but not necessarily, real time information. Therefore, it is incumbent on each DNO to maintain the database for their respective licensed area, with up-to-date information, including customer interruptions.

At this stage, the VCT is a demonstration prototype, and the most appropriate IT architecture needed to continuously or periodically update a fully developed tool, has yet to be defined. However, it is assumed this would be facilitated by existing DNO management and reporting systems ie the national fault and interruption reporting scheme (NaFIRS) and other data sources used to populate the regulatory instructions and guidance (RIGs) workbook.

For simplicity, the VCT currently only references performance data at a high level ie those who have experienced power cuts and those who have not. Given the impact of frequency and duration on VoLL, a fully developed future model may incorporate specifics about the number of customer interruptions (CI) associated with each MPAN and the number of customer minutes lost (CML), to provide a more sophisticated and precise calculation. However, it may be more appropriate to aggregate CI/CML data at feeder or asset level. Further analysis will determine the appropriateness of including specific VoLL drivers in the final tool along with the requisite degree of aggregation and the complexity of the overall formula. A brief summary of the mandated reporting requirements that might be used to supplement the revised VoLL model are provided in Appendix 9.4.

High impact events

As outlined above, this information is sourced from NaFIRS. While not currently included as a VoLL attribute in the prototype VCT, it is possible that a finessed future model may need to specifically consider the frequency of exceptional, widespread and long duration events. It is, however, recognised that this information tends to be more difficult to report at a disaggregated level because the nature of disruption during extreme events and appropriate mitigation will need to be built into the VCT to reflect this.

Worst served customers

DNOs are obliged to keep customer bills low and improve or at least maintain current levels of reliability across the entire network. The RIIO framework introduced a use-it-or-lose-it allowance to improve network reliability for customers with “a significantly worse than average service”.[9] Analysis of worst served customers (WSCs) has helped Electricity North West to shape its investment programme to improve network performance in these areas and the RIIO incentive mechanism provides visibility of the number of WSCs benefitting from each scheme to give an assessment of costs per customer.

However, the current model fails to demonstrate the relative VoLL of WSCs. A refined, segmented VoLL provides a more accurate reflection of the long-term benefits delivered by individual schemes by more accurately forecasting the CoF of a particular asset on the community it serves. This may be significant in real terms, even where a relatively small number of customers directly benefit from the investment.

Insufficient numbers of WSCs were available in the research to provide a reliable WTA value for this segment; however, an indication of VoLL for customers who perceive their ‘service is poor’ is revealed in the responses of those expressing that they wish to see an improvement in supply. In this group VoLL is 45% higher than average. Further research is being conducted to provide clarity on factors responsible for the low VoLL expressed by customers served by relatively poorly performing networks. This will establish the appropriateness of applied weightings in the VCT to recognise an apparent lower reference state of this customer segment.

Better understanding the VoLL of customers served by poorly performing networks and how this figure should be applied in a future tool will help to inform appropriate, targeted investments to improve resilience and the overall satisfaction in these communities. The VoLL calculation in this context will demonstrate where the customer benefits of certain investments may outweigh the costs of making improvements and can therefore be justified.

9 A worst served customer (WSC) is defined by Ofgem as a customer who has experienced 12 or more high voltage interruptions in the last three years, with a minimum of three interruptions per year.

5.5 Customer data sources

Customer type

Every electricity service can be identified by the unique MPANs associated with the connection point. This provides core data about the characteristics of the supply including the profile classification, which identifies the domestic or commercial status and if the service is half-hourly or non-half hourly metered.

The Electricity Central Online Enquiry Service (ECOES) system is populated from information sent from the supplier, relating to the metering system and allows authorised industry parties to search for supply details using the MPAN and other sources, to determine a range of supply-related data including: address, meter details, energisation status and appointed parties (ie the supplier).

It is recognised that sometimes more than one MPAN is associated with a single connection point because of multiple (or secondary) MPANs, which arise due to the type of tariff and/or metering arrangements (eg import/export meters). For the purpose of the prototype VCT, the primary MPAN is used for the basis of the VoLL calculation; however, the most appropriate way to manage multiple MPANs will require addressing as the tool is developed and finessed.

Low carbon technology users

The majority of Electricity North West's 2.4 million customers are domestic (around 75%) and are supplied from LV networks, which for many years have followed predictable and stable demand patterns. One of the biggest challenges facing network operators is the unpredictability in the future adoption of LTCs such as photo-voltaic (PV) micro generation, heat pumps and electric vehicles. This will significantly change daily loading patterns and the magnitude of power consumption on legacy networks.

To ensure DNOs plan for, and deliver, customers' future needs, they must develop much more sophisticated methods of demand forecasting to mitigate risks associated with uncertainty around LCT uptake.

This study demonstrates that the VoLL of current domestic LCT users is greater than that of the comparable average, with domestic EV users expressing a VoLL of 23% over the average. While this risks the assumption that future adopters will have the same values as current users, it is an important consideration given the anticipated uptake in LCT adoption and the implications for DNOs' long-term investment strategies.

The revised VoLL model provides an additional tool to assist in targeting investment to meet the future expectations of customers served by networks with high penetrations of LCT. This visibility will help inform the most appropriate solutions and level of investment to satisfy these needs efficiently.

Electricity North West, in common with other DNOs, maintains its own database of distributed generation (DG) and LCTs connected to its network. These records provide the most comprehensive indication of the level and location of these technologies. However, it is recognised that the true penetration of LCTs, and thus the potential for constraint, is compromised by the common failure of installers to provide DNOs with the required Electricity Networks Association (ENA) notification on installation. To improve the accuracy of data in the VoLL matrix it is possible to support DNO-held information with generation data from the feed-in tariff installation report produced by Ofgem, which is based on the installations registered on the Central FIT Register and can be broken down by post code and local authority area. Without changes to governance which facilitates the sharing of disaggregated LCT information, there will remain challenges in identifying true penetrations across specific LV networks. Forecasting the potential uptake of LCTs across specific networks and regions is expected to be an important component of an evolved VCT, which will need to consider the CBA/lifetime costs of particular decisions about specific assets.

Vulnerable customers

This study has demonstrated that the VoLL assignment of those with vulnerabilities is on average 12% higher than that of the average domestic customer. This value is further influenced by the type of vulnerability and consequently, the level of dependency on the electricity supply, as indicated in Figure 5.2. The study utilised Ofgem's classifications of vulnerability to categorise specific customer groups, as referenced in Appendix 9.5.

Figure 5.2: VoLL by dependency

Domestic segment	VoLL £/MWh	Damage function *(multiple of average domestic VoLL)*
All domestic customers	£17,500	x 1.00
Low vulnerable[10]	£19,200	x 1.10
Medium vulnerable[11]	£21,100	x 1.21
High vulnerable[12]	£18,300	x 1.05
Medically dependent equipment users [13]	£18,000	x 1.05

The study identified a higher VoLL among customers with medium vulnerability. Evidence from other studies supports this, with the inference being that high dependency vulnerable customers are comparatively more likely to have access to support, enabling them to mitigate the impact of a supply interruption.

The DNO's responsibility falls into two broad categories which are briefly summarised as follows:

Vulnerability and social obligations

DNOs are required by their licences to maintain a priority services register (PSR) and customers from eligible groups can request to be registered, enabling the licensee to identify those who are most dependent on their services.

Customers on the PSR are collated from multiple sources, which include data flows from suppliers via the DUoS (distribution use of system) and Associated Distribution Systems (DADS). This assigns a PSR code/s, identifying the nature of the vulnerability, to an MPAN. Electricity North West supplements this data with that obtained via its fault management system and customer interface systems. All PSR data is voluntarily provided by the customer or an authorised person acting on their behalf. This data, because of its very nature, will progressively become outdated and therefore requires continual cleansing to ensure its accuracy.

DNOs have certain regulatory obligations governing how they deal with PSR customers that are affected by an outage and how this is reported. Electricity North West takes its responsibility to vulnerable customers seriously and attempts to contact those signed up to the PSR when affected by power cuts, in recognition that they are likely to be most impacted.

10 Adjusted for income (unadjusted WTA = £17,447 (Index 100)
11 Adjusted for income (unadjusted WTA = £16,608 (Index 95)
12 Adjusted for income (unadjusted WTA = £15,211 (Index 87)
13 Adjusted for income (unadjusted WTA = £13,487 (Index 77)

The VoLL study demonstrates that this is both an appropriate and socially responsible approach. The research also reveals that proactive telephone calls can mitigate the loss of supply to domestic customers for up to five minutes in an hour, with a similar value being placed on providing accurate information about when power will be restored. This clearly illustrates the importance of appropriate support strategies for the most vulnerable customer groups and it is expected VoLL might be mitigated further by additional enhancements in the way that PSR customers are managed, including:

- A telephone greeting system which advises PSR customers they have been recognised and transfers them to the appropriate team, as a high priority
- Introduction of a generator policy for those who are medically dependant during power cuts
- Welfare packs and support from the British Red Cross, where appropriate
- Proactively communicating information about imminent extreme weather events, with pertinent advice.

The study demonstrates that the PSR customer strategy, underpinned by effective support and communication, provides an appropriate and efficient mean of mitigating VoLL. However, the effectiveness of any support strategy is directly proportional to the quality of the customer data held. Therefore, to ensure that details of the PSR, and consequently the salient features included in the VCT, remain accurate, it is incumbent on the DNO to maintain its customer data. The energy sector recognises the significant challenges in this area and must work to continuously improve the way it identifies and supports the vulnerable customers it serves.

Vulnerability and resilience

In addition to the direct support strategies outlined above, DNOs have a responsibility to improve network reliability in areas with high concentrations of vulnerable customers. They are generally aware of the location of large critical sites, such as hospitals, and ensure networks serving key infrastructure of this type are targeted for appropriate investment, to provide the requisite level of resilience.

The PSR register makes it possible to identify customer vulnerability on an individual basis from the specific ‘needs code’ associated with the MPAN. The revised VoLL model provides greater visibility of the relative level of dependency of all vulnerable customers served by a particular asset, revealing a greater understanding of the true consequence of failure on a vulnerable community. This is simply achieved from understanding the penetration of vulnerability by broad classification (high, medium and low dependency), when aggregated to the asset.

This insight will facilitate more informed decisions to improve resilience and will provide a justifiable mechanism to demonstrate the societal benefits of investment in assets, such as automation equipment, to reduce the risk of prolonged supply outages on the most vulnerable communities. This understanding is also expected to be influential in decisions concerning the deployment of new innovative technology such as Smart Street and where the greatest benefit might be achieved, as new techniques are adopted into business as usual strategies. These wider customer benefits are not apparent or quantifiable using the traditional single VoLL model.

Fuel poverty

It is currently estimated that around 4 million UK households are in fuel poverty, which equates to roughly 15% of all households[14]. DNOs are under increasing pressure to improve service while keeping operational costs low, to address this growing issue. The RIIO incentive mechanism ensures customers share the benefits of the DNO's performance and the efficiencies it generates. Application of a segmented VoLL will allow DNOs to target investment more efficiently, to benefit those most impacted by outages, and, in so doing, help to drive down prices from RIIO-ED1 levels. The WTA figures for the fuel poor[15] and customers on low incomes[16] have been adjusted for income. While customers in these two groups are likely to require lower payments, VoLL in relative terms is significantly higher when factored as a proportion of income, with the fuel poor having a VoLL approaching double that of the average domestic customer.

In view of the significance of this characteristic on VoLL, it is important that it is reflected in the revised VoLL model. However, fuel poverty classification data is unavailable from standard industry sources and will require reliable external validation from customer champions in this field and sources such as the fuel poverty tables produced by BEIS under the Low Income High Costs indicator.

Geography/population density

Analysis demonstrates that rural domestic customers have a higher VoLL, which is x 1.22 the average. This correlates with those dependent on electricity as the primary energy source (ie off a mains gas network), low income groups, vulnerable customers and the elderly (when VoLL is adjusted to reflect income). This illustrates the high value customers in remote locations place on the reliability of supply and indicates the impact of more frequent exposure to interruptions than customers served by urban networks, that have a VoLL lower than the average (x.0.90 for both domestic and SME customers).

Customers were asked to provide their own classification which, for validation purposes, was cross-matched against Office of National Statistics (ONS) geographic classifications. The multiple classifications were simplified into two broad categories of urban and rural[17] to crudely illustrate population density.

Non-standard industry data such as that utilised from ONS could theoretically be used to populate the VCT; however, DNOs can also make a number of assumptions to validate geographic classifications from its own data sources. DNOs can map the type of network ie overhead versus underground; the type and rating of secondary transformers; the number of customers served by the asset and the load index. As the VCT is refined, there may be a need for DNOs to enhance system architecture to improve the accuracy of data migrated into the tool. This should be periodically updated to ensure geographic data is captured when new assets are commissioned and checked during routine inspections. While the regional characteristic is likely to remain largely static, this approach ensures that any significant changes, such as those that might arise from large scale development of rural land, are captured in the VCT when networks are extended to accommodate increased demand.

Off-gas customers

Domestic customers who are not connected to a mains gas grid, and are therefore reliant on electricity as their primary energy source, value VoLL £/MWh x 1.05 higher than the average residential customer. Intuitively, an electricity outage will have a higher impact on these

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14 National Energy Action (national charity working to end fuel poverty in England, Wales and Northern Ireland)

15 This research uses Energy UK's definition of a fuel-poor household as one which needs to spend more than 10% of its income on all fuel use to heat its home to an adequate standard of warmth. In England, this is defined as 21°C in the living room and 18°C in other occupied rooms. The WTA figure has been adjusted for income.

16 Social grade category DE: a socio-economic classification produced by the Office for National Statistics where DE largely represents unskilled occupations, pensioners and students. The WTA figure has been adjusted for income.

17 2011 Rural-Urban Classification of Local Authority Districts and other higher level geographies.

customers, particularly in sub-groups such as those in remote rural areas. A comparable VoLL assignment was reflected in off-gas SME customers (x 1.05).

The MPAN profile classification enables a DNO to simply map domestic and commercial properties served by multi-rate meters to identify clusters, indicating the absence of a mains gas supply. This information, when supported with publically available data from Xoserve, the Central Data Service Provider for Britain's gas market, which lists GB postcodes which lie off the mains gas grid, can be used to populate the VCT with relative accuracy. However, mechanisms for populating and updating this data should be finessed as the prototype is developed into a fully functional tool.

Electricity consumption data

The segmented VoLL of sub-groups based on levels of electricity consumption was derived using actual consumption data. The survey asked customers to state their perceived 'self assessed' classification of usage based on expenditure, in addition to providing explicit consent for Electricity North West to source their consumption data records to reveal actual usage. Comparisons of actual consumption data against 'customer provided' estimates, demonstrated that reliance on perceived usage from electricity bills, introduced significant levels of ambiguity and inaccuracy.

As part of the VoLL study a mechanism was developed to extract actual meter readings from DADS over a two-year period; this information is linked to DURABILL, a St Clements' DUoS billing platform, which calculates half-hourly and non half-hourly invoices and is compliant with the common distribution charging methodology.

These readings were processed via an Excel tool, which was specifically built to eliminate erroneous readings, manage multiple readings from multi-rate meters and calculate the actual annual consumption of each matched MPAN in the sample.

Analysis of domestic VoLL and classification of usage was based on industry standard values for the annual electricity consumption of a typical domestic consumer. The typical domestic consumption values (TDCVs), illustrated in Figure 5.3 below, show the values which took effect on 1 October 2017. The table also identifies the classification ranges which were used in this research to categorise low, medium and high consumption in the domestic sample.

Figure 5.3: Ofgem typical domestic consumption values published 2017

Domestic Classifications		Median Domestic Consumption Values (2017)	Classification (KWh)	SME Classifications	Classification (KWh per year)
Electricity : Profile Class 1	Low	1,900	Up to 2,500	Low	Less than 15,000
	Medium	3,100	2,500 to 3,849		
	High	4,600	3,850 or more	Medium	15, - 24,999 kWh
Electricity : Profile Class 2	Low	2,500	Up to 3,350		
	Medium	4,200	3,350 -5,649	High	over 25,000 kWh
	High	7,100	5,650 or more		

There is no equivalent classification to determine low, medium and high users in the SME group as consumption patterns are so diverse as to make this impractical. These assumptions will become increasingly more diverse following introduction of the P272 rule which mandates commercial customers with profile classifications of 5-8 to switch to either a half-hourly metered tariffs (if current-transformer metered) or non-half-hourly, non-daily metered (NDM) tariff (if whole current metered). However, for the purpose of this study, a figure of £2,500 was used as the estimate of the average annual SME electricity bill, based on research conducted by LE in the 2013 study. Existing legacy data for MPANs with profile classification 5-8 provides an indication of usage, based on the load factor and maximum input capacity, which is maintained in DADS for NDM sites, subject to anomalies for accuracy.

The sub-group analysis of SMEs was limited due to the smaller sample sizes. This study demonstrates that experience of interruptions is a key differentiator of VoLL as is regional difference. Given the diversity of the SME sample, relative to the size of the operation, number of employees, economic activity and consumption profiles, additional surveys are proposed. This will deliver more robust and nuanced insights, to support the findings for this segment, which will be critical for future refinements to the VCT.

However, it must be assumed that completion of the smart meter rollout will provide greater visibility of half-hourly electricity consumption data for both domestic and commercial customers, which could theoretically be uploaded into the VCT to inform strategic planning.

Access to consumption information to provide visibility of demand and constraints is derived when the data is aggregated at feeder and asset level. Migration of consumption data to the VCT, at individual MPAN level, to facilitate a blended calculation of VoLL by asset will be subject to regulatory approval and the conditions of the Smart Energy Code, which governs the end-to-end management of data via the data collection company. Appropriate mechanisms to identify and include accurate customer consumption profiles must be considered in the development of the VCT.

The General Data Protection Regulations (GDPR) also introduces considerations around the context of customer profiling which may restrict DNOs linking consumption data to other data sources that may be deemed more sensitive

5.6 Other considerations

While it is not possible to understand the composition of a household from standard industry data, it is possible for DNOs to supplement the VCT with census data. This is not static information and will have become progressively out-of-date since the last census was taken in 2011. However, by providing a snapshot of household composition, the number of bedrooms etc which, when considered against annual consumption data, allows algorithms to be built to make general assumptions for a particular area. For example census data for a small estate of one and two bedroom bungalows with one or two occupants over the age of 64 allows certain assumptions to be made about the broad demographic and consequently VoLL characteristics in that region.

It is, however, important to note that the GDPR introduces greater restriction on customer profiling and using data in this manner would be subject to the appropriate safeguards.

DNOs are likely to have shadow databases holding details of customer or business names and personal contact details; however, these are subject to varying degrees of accuracy and this data is not required for the VCT. Including this information may introduce certain conflicts with GDPR regulations which restrict the linkage of personal and sensitive information and associated opportunities for profiling. However, there will be circumstances which require validation of certain characteristics of the MPAN such as the PSR code, where it would be useful to see personal information, for legitimate purposes. This reference to personal data is included only in consideration of such future requirements.

It is recommended that to negate any potential breach of the GDPR, specific PSR codes are anonymised in the VCT and replaced with a marker which simply identifies the customer associated with the MPAN as high, medium or low dependency, based on Ofgem's classification codes (Appendix 9.5).

Visibility of the address, post code and unique property location coordinates is recommended to ensure accuracy of the VCT as, inevitably, there is always the potential for a small number of erroneous or unmatched MPANS, which might not easily be identified without sight of address-specific information and could therefore distort the final calculation.

The fully developed VCT must also take account of the energisation status of MPANs and apply protocols to account for de-energised or unmetered supplies, so as not to negatively impact the blended VoLL calculation of an asset.

5.7 Socialised cost of adopting a revised VoLL model

The new segmentation model provides a mechanism for DNOs to make smarter investment decisions that are more reflective of divergent customer needs. However, it is recognised that these findings introduce challenging questions about fairness, legitimacy and socialised costs of informing investment on the basis of customer need, dependency and expectation, which require further investigation.

6 CONCLUSIONS

The research has delivered a set of VoLL estimates that reflect the varying needs of different customer groups far more accurately than the single-value approach currently used. Analysis and modelling allows a much more representative VoLL model to be established. This more sophisticated approach could significantly improve efficient targeting of investments and ensure those investments are based on a much richer and more representative understanding of customers' needs.

Disaggregated VoLL drivers have been incorporated into a prototype calculation tool, which demonstrates how DNOs can assess the collective VoLL of all customers served by specific assets.

This revised model does not replace the cost benefit framework, principles and calculation methodologies adopted by DNOs to evaluate investment decisions based on condition-based CoF (common network asset indices methodology); rather it provides an additional customer-driven dimension to improve the sophistication of the decision-making process.

The new model is attractive because it does not involve a significant change in the way that DNOs assess the benefits of lost load mitigation but refines existing models to produce a more precise method for prioritising investments, which focus on the impact of decisions.

A segmented VoLL model would enable DNOs to re-distribute investment without increasing customers' bills to deliver the greatest value from finite resources now and into the future. This approach ensures DNOs target investment in the right areas to manage network risk effectively and continue to deliver their primary outputs in the future.

These results are significant and have wider implications for Ofgem and GB DNOs in planning their future investment and customer strategies, which might need to consider issues of equity as well as efficiency when it comes to policy design and implementation. As such, it is anticipated that the values for segmented VoLL, calculated as part of this study, will be important in informing DNO policies and investment plans for RIIO-ED2 and beyond.

These findings significantly add to the debate about the most appropriate practices for setting VoLL and introduce challenging questions about fairness, legitimacy and socialised costs, which require further empirical investigation.

7 RECOMMENDATIONS

This study suggests that adopting a more sophisticated VoLL model will provide DNOs with an important tool enabling more efficiently targeting of investments. The model also has important implications for better informing customer compensation strategies and the measures adopted to mitigate the impact of interruptions, as GB transitions to a low carbon economy.

The suggested application of a blended VoLL derived from a simple estimation tool will provide a far more nuanced understanding of the relative needs of customers and assist in meeting some of the long-term challenges faced by DNOs in delivering an affordable, secure and sustainable electricity supply. However, it is recognised that further detailed vector analysis is required to determine the requisite degree of aggregation and the level of complexity required of the final tool.

This insight will facilitate more informed decisions to improve network resilience and will provide a justifiable mechanism to demonstrate the societal benefits of investment in assets, such as automation equipment, to reduce the risk of prolonged supply interruptions on the most vulnerable communities. This understanding is also expected to be influential in decisions concerning the deployment of new innovative techniques, as trial concepts transition to business as usual strategies. Understanding the relative VoLL of specific assets will determine where the greatest network and customer benefit of deploying new technologies might be achieved. These wider customer benefits are not apparent or quantifiable using the traditional single VoLL model.

Adopting a revised model does not involve a significant change to the way that DNOs assess the benefits of lost load mitigation. Rather, it allows them to refine their models to produce a more precise method for prioritising investment decisions.

7.1 Next steps

To aid the practical implementation of a differentiated VoLL, it is recognised that further detailed vector analysis is required to explore the optimum level of complexity for a revised model and most practicable mechanism for its adoption at scale. This study will consider the impact of a more sophisticated approach on the CBA/lifetime costing of investment decisions. It will also develop the prototype VCT, to determine the level of detail at which VoLL variables might be combined/aggregated relative to network parameters. To assess the stability or variability of VoLL characteristics at network level, over time, the study will consider forecasts and VoLL drivers from official, external (non-industry) sources that might practicably be utilised to enhance the new model.

There will be consultation with key industry stakeholders to consider the regulatory implications and practicalities of national implementation of a new tool, which maintains the principals of the common network asset indices methodology, ensuring DNOs continue to target investment in the right areas to manage network risk effectively in order to deliver their primary outputs in the future.

Additional empirical customer research will investigate issues around the fairness and legitimacy of an alternative model, which maintains low and equitable DUoS charges, but allows for more sophisticated investment decisions, influenced by divergent customer need and dependency. This is of particular relevance when considering the VoLL drivers of the worst served, those in vulnerable circumstances and those on low incomes.

Further research is recommended to provide clarity on factors responsible for the low VoLL expressed by customers served by underperforming networks. In addition, given the diversity of the SME sample in relation to size, economic activity and consumption profile, additional surveys are proposed to deliver more robust and nuanced insights, to support the findings and identify outliers in this segment.

A follow-up study is also proposed to better understand the impact on individual VoLL, relative to the duration and scale of outages and how this is extrapolated to community level in response to widespread events.

Given the results of this research, which reveal the significant impact of supply interruptions on those in fuel poverty, a collaborative study is planned with Citizen's Advice. This will build on the findings and demonstrate how effective investment, mitigation and compensation strategies might influence the VoLL of the most vulnerable members of society.

8 APPENDICES

Appendix 9.1a: VoLL attributes tested in the study

*Domestic – VoLL (WTA) by sub-groups (*** denotes attributes included in the proposed VCT)*

Domestic WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%)		Index v Total
						Lower	Upper	
Total	3381	**£7.87**	£7.30	£8.44	**£17,481**	***£16,209***	***£18,753***	100
Female	1791	**£8.26**	£7.33	£9.18	**£18,432**	***£16,373***	***£20,490***	105
Male	1510	**£7.62**	£6.89	£8.36	**£16,891**	***£15,272***	***£18,510***	97
Age: 18 – 29	702	**£7.50**	£6.02	£8.98	**£16,516**	***£13,252***	***£19,779***	94
Age: 30 – 44	770	**£8.95**	£7.60	£10.31	**£20,042**	***£17,017***	***£23,066***	115
Age: 45 – 59	844	**£7.59**	£6.72	£8.46	**£16,921**	***£14,973***	***£18,869***	97
Age: 60+[18]	994	**£7.80**	£6.66	£8.94	**£17,237**	***£14,719***	***£19,755***	99
AB	835	**£8.13**	£6.93	£9.32	**£17,867**	***£15,241***	***£20,493***	102
C1	1040	**£9.05**	£7.97	£10.12	**£20,053**	***£17,667***	***£22,439***	115
C2	569	**£8.54**	£6.95	£10.14	**£19,217**	***£15,634***	***£22,801***	110
DE[19]	843	**£6.15**	£5.16	£7.13	**£13,667**	***£11,479***	***£15,855***	78
*** Rural ***	1023	**£9.63**	£8.29	£10.96	**£21,314**	***£18,361***	***£24,268***	122
*** Urban ***	2353	**£7.16**	£6.55	£7.77	**£15,934**	***£14,572***	***£17,295***	91
Electricity North West	969	**£6.46**	£5.39	£7.52	**£14,080**	***£11,752***	***£16,409***	81
Scottish and Southern Energy	294	**£10.60**	£7.88	£13.32	**£22,702**	***£16,880***	***£28,523***	130

[18] Unadjusted for income (adjusted WTA = £19,372 (Index 111)
[19] Unadjusted for income (adjusted WTA = £20,501 (Index 117)

Domestic WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%) Lower	Upper	Index v Total
SP Energy Networks	308	**£6.69**	£5.02	£8.36	**£14,707**	***£11,033***	***£18,380***	84
Northern Powergrid	378	**£8.01**	£6.35	£9.66	**£18,012**	***£14,283***	***£21,742***	103
Western Power Distribution	646	**£8.36**	£7.12	£9.60	**£18,285**	***£15,578***	***£20,991***	105
UK Power Networks	690	**£8.38**	£7.21	£9.54	**£19,289**	***£16,607***	***£21,971***	110
*** Worst served ***	163	**£3.16**	£1.07	£5.24	**£6,894**	***£2,345***	***£11,442***	39
Vulnerable[20]	1951	**£8.54**	£7.56	£9.51	**£19,632**	***£17,388***	***£21,875***	112
*** Fuel poverty[21] ***	239	**£17.52**	£15.25	£19.80	**£32,470**	***£28,256***	***£36,683***	186
*** Off-gas ***	721	**£7.13**	£5.61	£8.65	**£18,543**	***£14,598***	***£22,489***	106
LCT users	960	**£8.69**	£5.38	£12.00	**£18,973**	***£11,743***	***£26,203***	109
*** Domestic - Electric vehicle (EV) ***	275	**£9.20**	£0.54	£17.85	**£21,493**	***£1,264***	***£41,722***	123
*** Domestic - Solar panels (PV) ***	538	**£8.42**	£3.57	£13.28	**£17,884**	***£7,580***	***£28,189***	102
*** Domestic - Heat pump (HP) ***	428	**£8.98**	£2.52	£15.44	**£19,911**	***£5,578***	***£34,243***	114
*** Low usage ***	1216	**£7.26**	£6.44	£8.09	**£16,371**	***£14,510***	***£18,231***	94
*** Medium usage ***	1752	**£8.53**	£7.62	£9.44	**£18,768**	***£16,762***	***£20,774***	107
*** High usage ***	328	**£7.60**	£5.97	£9.24	**£16,504**	***£12,952***	***£20,056***	94
MDE (medically dependent)[22]	310	**£6.15**	£4.34	£7.96	**£18,013**	***£12,711***	***£23,315***	103
Want to keep bills constant	1265	**£7.19**	£6.36	£8.02	**£15,863**	***£14,024***	***£17,702***	91
Want to keep reliability	963	**£7.85**	£6.80	£8.90	**£17,745**	***£15,368***	***£20,121***	102
Want to improve worse served	651	**£7.74**	£6.48	£9.00	**£17,261**	***£14,447***	***£20,075***	99

20 Adjusted for income (unadjusted WTA = £16,941 (Index 97)
21 Adjusted for income (unadjusted WTA = £21,646 (Index 124)
22 Adjusted for income (unadjusted WTA = £13,487 (Index 77)

Domestic WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%) Lower	Upper	Index v Total
Want to improve supply	431	**£11.28**	£8.56	£13.99	**£25,334**	***£19,240***	***£31,429***	145
*** Low vulnerable[23] ***	872	**£8.63**	£7.25	£10.01	**£19,175**	***£16,115***	***£22,235***	110
*** Medium vulnerable[24] ***	397	**£8.99**	£6.78	£11.19	**£21,106**	***£15,929***	***£26,284***	121
*** High vulnerable[25] ***	417	**£7.09**	£5.20	£8.98	**£18,313**	***£13,427***	***£23,198***	105
*** No experience of power cuts (planned or unplanned) ***	1178	**£8.63**	£7.42	£9.83	**£19,221**	***£16,534***	***£21,908***	110
*** Experience of power cuts (either planned or unplanned) ***	2203	**£7.57**	£6.93	£8.22	**£16,802**	***£15,376***	***£18,228***	96
Experienced four or more unplanned power cuts	464	**£6.42**	£5.30	£7.54	**£14,233**	***£11,751***	***£16,714***	81
Experienced two or three unplanned power cuts	847	**£8.65**	£7.35	£9.96	**£18,780**	***£15,957***	***£21,603***	107
Experienced one unplanned power cut	723	**£8.85**	£7.46	£10.24	**£19,755**	***£16,646***	***£22,865***	113
Experienced no unplanned power cuts	1200	**£7.23**	£6.36	£8.10	**£16,093**	***£14,159***	***£18,028***	92
Experienced planned power cuts	859	**£7.30**	£6.05	£8.55	**£16,161**	***£13,395***	***£18,928***	92
Experienced large scale interruption in last 12 months	377	**£5.82**	£3.67	£7.96	**£12,140**	***£7,660***	***£16,619***	69
Impact of power cut – low	1442	**£8.83**	£7.88	£9.79	**£19,737**	***£17,605***	***£21,869***	113
Impact of power cut – medium	507	**£7.87**	£6.45	£9.28	**£17,316**	***£14,208***	***£20,423***	99
Impact of power cut – high	166	**£6.40**	£2.89	£9.91	**£13,613**	***£6,147***	***£21,078***	78

Grey font indicates small sample size, interpret with caution

23 Adjusted for income (unadjusted WTA = £17,447 (Index 100)
24 Adjusted for income (unadjusted WTA = £16,608 (Index 95)
25 Adjusted for income (unadjusted WTA = £15,211 (Index 87)

Appendix 9.1b: SME VoLL (WTA) by sub-groups

SME WTA Unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%)		Index v Total
						Lower	Upper	
Total	615	**£160**	£152	£167	**£47,560**	*£45,289*	*£49,830*	100
*** Rural ***	118	**£217**	£184	£249	**£68,452**	*£58,201*	*£78,703*	144
*** Urban ***	489	**£152**	£144	£160	**£43,885**	*£41,680*	*£46,090*	92
Electricity North West	325	**£186**	£175	£198	**£47,466**	*£44,561*	*£50,371*	100
Scottish and Southern Energy	34							
SP Energy Networks	22							
Northern Powergrid	44							
Western Power Distribution	77							
UK Power Networks	106	**£144**	£125	£164	**£59,762**	*£51,572*	*£67,951*	126
Experienced large scale interruption L12M	87							
*** Off-gas ***	316	**£152**	£144	£161	**£49,056**	*£46,406*	*£51,706*	103
*** No power cuts ***	239	**£147**	£137	£157	**£38,167**	*£35,648*	*£40,686*	80
*** Power cuts ***	376	**£153**	£143	£163	**£51,341**	*£47,981*	*£54,701*	108
Impact of power cut – Low	161	**£114**	£101	£127	**£42,375**	*£37,455*	*£47,296*	89
Impact of power cut – Medium	149	**£131**	£113	£150	**£36,629**	*£31,458*	*£41,801*	77
Impact of power cut – High	68	**£146**	£126	£166	**£48,005**	*£41,454*	*£54,555*	101
Want to keep bills constant	188	**£144**	£132	£155	**£45,823**	*£42,297*	*£49,349*	96

SME WTA Unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%)		Index v Total
						Lower	Upper	
Want to keep reliability	141	**£124**	£109	£139	**£38,564**	*£33,832*	*£43,296*	81
Want to improve worse served	116	**£233**	£196	£269	**£63,896**	*£53,833*	*£73,958*	134
Want to improve supply	161	**£131**	£119	£142	**£32,919**	*£30,044*	*£35,793*	69
Winter	319	**£73**	£66	£81	**£19,099**	*£17,079*	*£21,119*	40
Summer	287	**£229**	£216	£241	**£77,843**	*£73,572*	*£82,115*	164
Experienced planned power cut	185	**£232**	**£215**	**£248**	**£58,227**	*£54,077*	*£62,377*	122

Grey font indicates small sample size, interpret with caution

Appendix 9.2: Summary Common Network Asset Indices Methodology (Network Asset Secondary Deliverables)

In RIIO-ED1, Ofgem introduced regulatory reporting requirements for GB DNOs to report information relating to asset health and criticality. This metric is known as the Network Asset Indices and provides an indication of the risk of condition based failure of network assets. The requirement for reporting of Network Asset Indices is outlined in Standard Licence Condition 51. The network asset secondary deliverables relate to the improvement in risk that is delivered by asset replacement, as well as some refurbishment activities

When an asset fails, there is an associated impact, directly resulting from that failure; however, there are other consequences such as injury. Such impacts are referred to as consequences of failure (CoF).

DNOs use a common methodology for the evaluation of the likely CoF associated with the condition-based failure of individual assets which provides a monetised value. For each asset, the methodology determines:

- The probability of failure (PoF)/per annum
- The CoF (£).

This information is used for regulatory reporting of the network asset indices for each asset, which is comprised of three components:

- Health index (HI) – which relates to asset health and PoF
- Criticality index (CI) – a relative measure of the CoF compared with the average for the asset type
- Risk index – a monetised risk measure, determined from the combination of the HI and CI.

The reference network performance cost of failure is based on an assessment of the amount of 'load at risk' (LAR) during three stages of failure and the typical duration of each stage:

- During fault (T1) – the time period between the initial circuit protection trip operation and automatic switching to reconfigure the network
- During initial switching (T2) – the time period during which further manual network switching is undertaken to reconfigure the network to minimise the risk associated with a further circuit outage
- During repair time (T3).

The LAR is evaluated based on a typical value of maximum demand under normal running conditions. This is then multiplied by the relevant VoLL figure to derive a typical reference network performance CoF for the asset, taking account of the probability of a further circuit outage.

The VoLL measure used is consistent with the values for cost of customer interruptions and customer minutes lost in the evaluation of the reference network performance CoF for low voltage (LV) and high voltage (HV) assets. Therefore, calculation of the reference network performance CoF for extra high voltage (EHV) and 132kV assets is consistent with evaluation of the impact in distribution assets.

Appendix 9.3: Electrical network system data sources

System	Description
CRMS	The control room management system (CRMS) is the real-time control system that holds Electricity North West's network topology and some asset data relevant to control.
ECOES	The Electricity Central Online Enquiry Service ("**ECOES**") is operated by the Master Registration Agreement Service Company Limited. ECOES enables the use of meter point Information in accordance with the permitted uses set out in the MRA and any ECOES access agreement between MRASCo and a named person.
Ellipse	Electricity North West's Ellipse database holds details of physical electrical point assets (ie switches and transformers), substations, link boxes and support structures such as woodpoles and towers. It provides a repository for static data from the nameplate and condition data captured during asset inspections.
DADS	DUoS and Associated Distribution Systems (DADS) is a web-based solution for all Distribution functions. It helps Electricity North West meet the regulatory requirement to separate Distribution and supply businesses so that it can operate in the competitive electricity market as a discrete business unit.
PowerGIS Browser	PowerGIS Browser displays the location of our assets and details of our cables from our central GIS database as an online map.

Appendix 9.4: Mandated reporting requirements

The RIIO price control framework mandates each DNO to provide specific information under its license agreement, as part of the regulatory instructions and guidance (RIGs). This allows Ofgem to monitor each DNO's performance against the IIS and to provide underlying data to assist with target setting for future price controls.

Specific reporting requirements are set around quality of service and include the following:

- Customer interruptions
- Customer minutes lost (duration of interruptions to supply)
- Short interruptions
- Customers re-interrupted
- Occurrences not incentivised.

Most DNOs use NaFIRS which is administered by the ENA. Others use an equivalent system to collect information on the number of customers interrupted and duration of interruptions to supply.

When completing the reporting worksheets, DNOs must report separately both the pre-arranged and unplanned number of customers interrupted by the following duration bands:

- Three minutes up to but excluding one hour
- One hour up to but excluding two hours
- Two hours up to but excluding three hours
- Three hours up to but excluding six hours
- Six hours up to but excluding 12 hours and from 12 hours onwards (in six-hour bands up to and including the longest time any customers have been recorded as being off supply)

Ofgem also specifies minimum levels of accuracy for the reporting of:

- The number of customers interrupted – at the 132kV and EHV, the HV and LV levels
- The duration of interruptions to supply – at the 132kV and EHV, the HV and LV levels.

New IT architecture, capable of populating information from the RIGs workbook or direct from NaFIRS might be required to either continuously or periodically update the VCT with performance data for each asset to identify the number customer interruptions. In a future model, the number of minutes lost for each MPAN may be incorporated into the aggregated calculation, given the impact of frequency and duration on VoLL.

Appendix 9.5: Priority service register – categorisation of vulnerability

Vulnerability Category	Level of Vulnerability
1. Nebuliser/Apnoea	High
2. Heart, lung and ventilator	High
3. Dialysis, feeding pump and automated medication	High
4. Oxygen concentrator	High
8. Blind	Medium
9. Partial sighted	Medium
10. Hearing/speech difficulties	Medium
12. Stair lift, hoist, electric bed	High
14. Pensionable age	Low
15. Physical Impairment	All three – high, medium or low assignment based on information provided
17. Unable to communicate in English	Low
18. Developmental condition	Low
19. Unable to answer door/ restricted movement	All 3 – high, medium or low assignment based on information provided
20. Dementia	All 3 – high, medium or low assignment based on information provided
22. Chronic/ serious illness	High
23. MDE Electric showering	High
24. Care line/ telecare system	Medium
25. Medicine refrigeration	High
26. Oxygen use	Medium
27. Poor sense of smell	Low
28. Restricted hand movement	Low
29. Families with young children five or under	Medium
30. Mental health	Medium
31. Additional presence preferred	Low
32. Temporary – Life changes	Low
33 Temporary – Post hospital recovery	Medium
34. Temporary – Young adult householder	Low