electricity north west
Bringing energy to your door

NIA ENWL010
Value of Lost Load to Customers

Customer Survey (Phase 3)
Key Findings Report

5 October 2018

VERSION HISTORY

Version	Date	Author	Status	Comments
0.1	12 January 2018	Impact Research	Draft	
0.2	17 January 2018	Tracey Kennelly	Draft	Amendments following revision of draft
0.3	6 February 2018	Impact Research	Draft	Amendments following Electricity North West outstanding queries
0.4	3 July 2018	Impact Research	Draft	Amendments following peer review
0.5	13 July 2018	Tracey Kennelly	Draft	Amendments following peer review
1.0	26 September 2018	Impact Research	Final	Final review

APPROVAL

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

CONTENTS

GLOSSARY

Abbreviation	Term
BEIS	Department for Business, Energy and Industrial Strategy
C_2C	Capacity to Customers
CE	Choice experiment
CoF	Consequence of failure
DECC	Department of Energy and Climate Change
DNO	Distribution network operator
DSR	Demand side response
DUoS	Distribution use of system
ECP	Engaged customer panel
EV	Electric vehicle
GB	Great Britain
HP	Heat pump
I&C	Industrial and commercial
LCN Fund	Low Carbon Networks Fund
IDNO	Independent distribution network operator
LCT	Low carbon technology
MDE	Medically dependent
MPAN	Meter Point Administration Number
NIA	Network Innovation Allowance
NPV	Net present value
Ofgem	Office of Gas and Electricity Markets
RIIO-ED1	Electricity distribution price control 2015 to 2023
SME	Small to medium enterprise
VoLL	Value of Lost Load
WTA	Willingness to accept
WTP	Willingness to pay

FOREWORD

This report seeks to re-examine the existing model used by distribution network operators (DNOs) to place a value on the loss of electricity supply to customers. Electricity North West and its project partner, Impact Research, have conducted 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 aims 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 will also examine if VoLL could be influenced by adopting different approaches to managing outages.

At present in Great Britain (GB), a single VoLL provides an assessment of the value that electricity consumers attribute to the security of supply. This represents the amount that customers would be willing to accept to avoid a supply interruption of average duration. The value of loss can be expressed as a customer damage function relative to the duration, season, time of day and notice of an outage. Previous research has identified that VoLL varies significantly among three distinct customers groups: residential, small/medium commercial and industrial enterprises (SMEs) and large commercial/industrial users. The value also varies considerably within each of these groups, for example, between rural and urban customers, different income groups and those in vulnerable circumstances. At present the single VoLL is aggregated to provide an overall estimate of the value given to loss across all domestic and SME customer segments. This acts as a price signal for the adequate level of supply security in GB and is a useful guide for determining how much money should be spent to deliver security of supply[1]. Ofgem established a value of £16,000/MWh for RIIO ED1 but recognised that this might change in the light of further research[2]

Modern network management systems allow DNOs to view the number and segmentation of customers fed from specific assets. This visibility coupled with a detailed understanding of VoLL by customer segment could be harnessed to calculate the VoLL that should be applied in a given investment decision on a specific asset. Understanding the relative VoLL for every individual asset on the network will allow much greater efficiency in future investment decisions and ensure investments are more fully informed by customer need.

This project investigated if the current single VoLL remains appropriate, to guide investment decisions as GB moves towards a decarbonised economy.

To explore this question, this study sought to gain a much more comprehensive understanding of the value that specific types of customers place on their electricity supply. A key objective of the project was to deliver new understanding and practical models that will allow DNOs to better plan their network investment and customer strategies to more efficiently serve the various segments of their customer base.

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

This document outlines the key findings from the third and final phase of the project, and quantifies customers' willingness to make or accept a payment for changes in reliability of

[1] [1]Security of supply refers to the electricity industry providing appropriate electricity system capabilities, such as generation and transmission capacity to maintain normal supply to consumers (https://www.ofgem.gov.uk/electricity/wholesale-market/electricity-security-supply)

[2] Ofgem, March 2011, Strategy for the next transmission price control – RIIO-T1: Outputs and incentives, Supplementary Annex, p 42.

service. The overall research approach was designed by Electricity North West and Impact Research. The approach also incorporated feedback from 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). The methodology statement and all associated documents are published on the VoLL webpage.

1 EXECUTIVE SUMMARY

1.1 Introduction

This report details the results and analysis associated with a large scale quantitative customer survey.

The survey was informed by previous research in this area and extensive customer engagement, undertaken as part of the VoLL project. It was subject to robust piloting and peer review before implementation. The research comprised of a winter season survey conducted during December 2016 and January 2017 and a summer season survey, carried out in August 2017. This allowed for the control of seasonal and time effects on VoLL.

A total of 6,000 surveys were completed covering domestic and SME customers from across the whole of GB; 2,000 respondents were from within Electricity North West's operating region. Approximately 5,000 of these surveys were conducted with domestic customers and 1,000 were completed by a broad sample of SME customers.

Details of the research approach are set out in the VoLL methodology statement (version 2), which also comprehensively explains the background of the VoLL project and the analysis protocols utilised.

1.2 Summary of key findings

The objective of this phase of the research was to find answers to four key hypotheses:

- Does VoLL vary by customer segment and what are the relative value assignments of these segments?
- How will VoLL vary with low carbon technology (LCT) adoption?
- How would the level of incentives tested for demand side response (DSR) in other Low Carbon Networks (LCN) Fund trials compare to future VoLL?
- Which segments, if any, would support a strong VoLL and hence potentially higher investment?

Evolution of this study has also raised the following significant questions:

- What is the impact of the scale and duration of supply interruptions on VoLL?
- Is the value that an individual places on an outage at their property the same for localised events and those where the entire community is affected?
  - Given that the survey results represent an average value for a single customer, how is this best extrapolated to a population?
- How might DNOs mitigate the cost of lost load to customers?

The findings from the customer survey are summarised below.

Does VoLL vary by customer segment and what are the relative value assignments of these segments?

This research provides robust evidence that the existing single 'vanilla' VoLL, applied to all customer segments, fails to adequately reflect the significant variation that exists in the financial and social impact of supply interruptions across the full spectrum of customer types.

The research shows that domestic customers' willingness-to-pay (WTP) to avoid loss of supply is approximately £2,000 per MWh and the equivalent measurement for SMEs is £17,500[3].

Customers' willingness-to-accept (WTA) compensation for lost load is much higher than the comparable WTP figures for both segments. For domestic customers it is £17,500 and for the SME segment it is £47,500.

The higher WTA value was anticipated and is consistent with previous studies in this area. When consumers are accustomed to receiving a service for which they pay, they typically expect greater compensation for the loss of that service than the extra amount they are willing to pay to retain it. This is an important point and illustrates that customers are generally far less willing to accept a decrease in supply reliability than pay for an improvement. This noted 'ownership' effect, using the WTA estimates, is considered to be the most appropriate in the context of valuing security of supply for electricity; the WTA figure indicates consumers' inconvenience value if the reliable service they already enjoy is interrupted. The use of WTA is consistent with earlier work in this area.

WTA values are predominantly used in this analysis to make comparisons across the customer groups, as this is the metric used in previous studies, and because it gives an average value across domestic and SME customers that is closest to the value currently used by Ofgem. Further information about the use of WTA can be found in Section 2.1.

How will VoLL vary with low carbon technology adoption?

The electricity industry accepts that there will be fundamental changes in customer behaviour associated with the widespread adoption of LCTs. As a consequence, it is considered likely that current estimates of VoLL will significantly change. A key objective of this study was to investigate the potential changes and the impact on VoLL assignment, to ensure that future policy is driven by evolving customer needs.

A reliable indication of a future VoLL can be achieved by measuring the VoLL of customers who are current users of LCTs, as these early adopters are reflective of the future scenario. This measure can be compared with non-users of LCTs.

The VoLL of domestic customers using LCTs, who as a consequence have an increased dependency on electricity, is +9% higher than the average for all domestic customers. VoLL for users of heat pumps is higher at +14% and increases further for users of electric vehicles (EVs) at +23%. This is a significant finding for determining future network investment needs and standards driven by VoLL as LCT adoption is projected to increase.

How would the level of incentives tested for DSR in other LCN Fund trials compare to future VoLL?

The Capacity to Customers (C_2C) study, carried out in 2015 by Electricity North West[4], sought to obtain a price per MW of demand response from industrial and commercial (I&C)

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3 Based on one hour of unplanned lost supply every three years. All figures rounded to nearest £100.
4 Electricity North West, Capacity to Customers: Second Tier LCN Fund Project Closedown Report, 7 August 2015.

customers[5]. One of the key objectives of C_2C was to establish an optimal price point at which commercial customers are willing to 'trade' ie to accept a short-term detriment in service in return for an incentive. While at first inspection the VoLL and the price to purchase demand side response appears to represent a similar customer valuation of a supply interruption, research has shown these values to be very different. Although, conceptually the trade-off associated with C_2C is comparable to the VoLL WTA, there are important differences between the two studies, which mean that comparison of the results is not possible.

Which segments, if any, would support a strong VoLL and hence potentially higher investment?

VoLL varies significantly across the broad customer spectrum sampled, influenced by socio-economic, demographic, geographic, attitudinal, behavioural and event-based factors. For example, a relatively high VoLL was identified in domestic customers aged 30-44, those in rural locations and those who want to see an improvement in supply. The VoLL of vulnerable customers is also high when adjusted for income[6] and it is substantially higher for less affluent groups, eg those classified as 'fuel poor'.

What is the impact of the scale and duration of supply interruptions on VoLL?

An outage generally incurs a higher VoLL the longer it lasts. However, the marginal hourly value declines steadily; there is a levelling out in the upward trajectory of VoLL for extremely long duration interruptions typically associated with extreme weather events. This is likely to reflect an awareness that such incidents are largely outside the control of the DNO and therefore less worthy of additional compensation.

For domestic customers who experience one unplanned outage in a three-year period, VoLL increases by approximately 80% when the duration rises from one hour to 12 hours. There is also a significant increase in VoLL when the number of outages experienced in a three-year period exceeds six. The VoLL for planned interruptions is substantially less than for unplanned outages, but this reduction diminishes as frequency increases.

For SMEs, a similar pattern is observed for unplanned and planned outages. However, there is a suggestion that while there is tolerance for limited planned work requiring outages, acceptance diminishes after more than three planned interruptions lasting a full day over a three-year period. This demonstrates the importance of a cohesive approach to construction and maintenance strategies and the need to consolidate planned work where possible.

Is the value that an individual places on an outage at their property the same when the entire community is affected?

There has been no work that has looked at how a widespread outage affects the individual VoLL. However, anecdotal evidence suggests that widespread outages often foster increased societal cohesion, when a community recognises that 'we're all in it together' and take measures to support each other, particularly those less able to cope. This is supported by a lower VoLL observed in this study for those who say they have experienced such events. Elsewhere, high levels of customer satisfaction have been reported when there is recognition that a major problem is the result of conditions outside the control of the DNO.

Given that these survey results represent an average value for a single customer, how is this best extrapolated to a population?

The single VoLL is only representative of all customers in a particular area if the distribution of individual values is uniform, which is unlikely. The overall VoLL for a large number of

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5 This was approximately £20,000 per MW over 3 x 8 hour slots. This means it costs the DNO £833 per MWh (£20,000/24 hours). This is much lower than the £40,000 per MWh for SMEs observed in this study, but the two studies are not directly comparable.

6 See Appendix 6.6 for a discussion on the income adjustment of WTA values

customers will therefore not accurately be reflected by a simple multiplication of the total number.

It is not feasible to provide an extrapolated population measure based on the actual VoLL of each individual customer, but a good approximation can be obtained by using the mean VoLL from groups of customers as derived from the survey, based on their characteristics. In this way, the single VoLL calculated from the VoLLs derived for each group will give a more representative overall value.

Further research is required to understand VoLL at local and community level relative to the duration and scale of outages.

How can DNOs mitigate the cost of lost load to customers?

The research identified that proactive network investment, to reduce the duration and frequency of interruptions, will mitigate the costs of loss of supply to customers. However, in addition to testing the core set of supply interruption attributes, the study also explored:

- Levels of additional assistance available for vulnerable customers
- Communication channels via which information about the supply interruption can be proactively provided
- Quality of information provided.

Targeted customer communications, such as telephone calls made directly to domestic customers are more than three times as effective in mitigating the impact of a supply interruption as updates through social media. In the case of proactive telephone calls, the analysis suggests that these can directly mitigate the loss of supply for up to five minutes in an hour.

The implication suggested in these findings, is that offering support to customers could provide an economically efficient means of reducing the impact of lost supply and consequently, positively influence VoLL.

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. This learning has potentially wider implications for DNOs in relation to future customer compensation strategies.

1.3 Lessons learned for future innovation projects

A number of lessons were learned from this phase of research relating to aspects of the survey instrument's design, particularly the stated preference exercise. There were also a number of interesting learning outcomes concerning customers' knowledge, their increased willingness to provide address details and supply specific information, if the purpose of the request is sufficiently explained.

1.4 Conclusions

The results of this phase of the project provide clear evidence to support the project's primary research objective that a single vanilla VoLL, applied to all customer segments, may no longer be appropriate. This research and modelling allows a much more representative VoLL model to be established. This more sophisticated approach will significantly improve efficient targeting of investments and ensure those investments are based on a much richer and more representative understanding of customers' needs.

Application of a revised segmented VoLL is attractive because it does not involve a significant change in 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 strategies, which focus on the impact of decisions.

The overall estimate of VoLL has risen since the last major study in 2013, suggesting increasing customer expectations and dependence. While VoLL does not drive investment levels, it helps to prioritise any given level of investment and adds a customer driven dimension to the decision-making process.

A separate conclusions and recommendations report has been produced to support this document and presents an initial argument for adopting a segmented VoLL model. This outlines the network and customer benefits of using a more sophisticated VoLL calculation to assist DNOs in better planning network investment and customer compensation strategies. However, it is recognised that further vector analysis is required to establish the optimum level of complexity for a revised model and the most appropriate mechanism for implementation, at scale.

1.5 Next steps

The engaged customer panel (ECP), originally convened to assist in informing this study, will be reconvened to review and evaluate the research findings.

An early segmentation and future VoLL model has been developed to allow DNOs to identify VoLL by key customer groups, in order to help guide investment decisions. Further detailed analysis is planned to explore the most economic, pragmatic and practical mechanism for adopting a revised model at scale, which considers the stability and variability of VoLL drivers over time.

The study has highlighted a need for more detailed understanding of VoLL at a community level, relative to the duration and scale of outages. The findings also introduce questions about fairness, legitimacy and the socialised costs of adopting a segmented VoLL model, which require further investigation.

Further research is recommended to provide clarity on factors responsible for the low VoLL of customers served by relatively poorly performing networks. Given the diversity of the SME sample, additional research is proposed to deliver greater insights to add to the findings revealed in this study.

This research has reveal the significant impact of supply interruptions on those in fuel poverty and a new collaborative study is planned with Citizen's Advice to build on these findings.

A closedown report will be published setting out the conclusions of the VoLL project and documenting how its objectives have been met.

In line with NIA governance requirements, there will be ongoing knowledge sharing and dissemination at appropriate industry events and all project information will be published on the project webpage.

2 ANALYSIS AND RESULTS: KEY FINDINGS

This section of the report details the analysis and results of circa 6,000 surveys administered during the main customer survey.

The main component of the survey instrument was a ‘stated preference choice experiment’ (CE)[7] which is widely accepted as the most robust technique for measuring metrics such as VoLL. Respondents were presented with a series of scenarios and asked to trade off different levels of supply reliability and possible support mechanisms available during an interruption, in exchange for a hypothetical financial incentive or penalty. For parity of approach with previous studies, VoLL was measured in terms of customers’ WTA compensation for lost load and WTP for avoidance of lost load.

The analysis utilised a fixed baseline scenario of an ***unplanned supply interruption lasting one hour and occurring at a time that would be most inconvenient for the customer***. This rationale allowed the respondent to specify the time that an outage would be most disruptive to their household or business and base their responses on this worst case scenario. This thereby ensured that the VoLL captured was representative of the true disruption that would occur. This baseline of a one-hour interruption is considered appropriate as it is founded on an assessment of electricity demand profiles, originally produced by DECC, which are suitable for the conversion of WTA estimates into VoLL in £/MWh. The data referenced herein is weighted to ensure it is representative of the demographic (gender, age and affluence) and geographic (urban and rural) profile of customers in GB. Weighting values and the rationale for the application are provided in Appendix 6.1.

2.1 Does VoLL vary by customer segment and what are the relative value assignments of these segments?

Overall VoLL

A multinomial logit econometric estimation method[8] was utilised to convert the CE results into £/MWh VoLL figures and confidence intervals. The WTA measurement of VoLL produced a much larger estimate than the comparable WTP for both the domestic and SME segments (see Figure 2.1).

Figure 2.1: Overall VoLL in £/MWh among domestic and SME segments

VoLL measure[9]	Domestic	SME
Willingness to pay (£/MWh)	£2,000	£17,500
Willingness to accept (£/MWh)	£17,500	£47,500

Psychologically, the loss from giving something up feels greater than the gain from retaining it and avoiding the loss, and thus WTA is generally empirically greater than WTP. These constructs have been studied for roughly 30 years within a wide variety of goods and services[10]. Research has concluded that the less the good is like an ‘ordinary market good’ (ie a physical item), the higher the ratio of WTA relative to WTP. This is the case with energy. A similar effect can be observed in insurance and travel sectors. In the latter case, the amount of money consumers are willing to pay for their travel ticket is substantially lower than the compensation expected when that service is disrupted or temporarily withdrawn.

7 CE is a specialised type of survey question that presents respondents with choices between alternative levels of service at different prices. The way respondents choose infers their willingness to pay higher prices for a better service, or to accept compensation for a loss in service. This is widely considered to give more objective measures of WTP /WTA than any form of direct questioning.
8 The multinomial logit model is a standard limited dependent variable estimation method and is a well known method for choice experiment modelling.
9 The values are notably higher than those observed in the pilot. The main reason for this was the development of a statistical model that more faithfully captures the non-linear impact of the duration of the interruption, which is higher per hour for the first hour and lower for longer interruptions. In the pilot, a single linear estimate was used, in line with previous studies where values of less than one hour were not tested.
10 Department of Agricultural and Resource Economics, University of Maryland, 2002. A Review of WTA/WTP Studies

The higher WTA value was therefore anticipated, as when consumers are accustomed to receiving a service for which they pay, they typically expect a greater payment to bear a loss of that service than they are willing to pay, in addition, to retain it. This is because individuals feel a sense of ownership or entitlement for something they already have (in this case, a reliable electricity supply). This noted 'ownership' effect, using the WTA estimates, is most appropriate in the context of valuing security of supply for electricity than WTP figures, which suffer from a recognised downward bias due to entitlement and strategic responses that risk underestimating the true value customers place on security of supply. The WTA figure indicates consumers' inconvenience value if the reliable service they already enjoy is interrupted.

The WTP value cited in Figure 2.1 for domestic customers is comparable to the figure reported by London Economics in 2013[11] (£2,000 versus £2,000) while the one-off payment expected by customers (WTA value) is higher (£17,500 v £12,000).

The difference in the WTA values may be a reflection of the difference in the frequency of interruptions used to set the context of the CE choices. This research set them as once every three years, compared with once every 12 years in the London Economics study. Both studies introduced the WTA CE questions as a 'one-off' payment that respondents would be prepared to accept in compensation for a supply interruption; however, the two studies explained the baseline in quite different ways. The London Economics 'one in 12' frequency estimate was based on Ofgem's 2012 capacity assessment which estimated that in 2015/16 the expectation of customer disconnections would be around once in 12 years. As such, this perception measure is not directly comparable to the actual customer interruptions and customer minutes lost data referenced in this current study.

Customer interruptions (CIs) are measured as the number of interruptions per 100 connected customers = (number of interruptions in the year/total number of customers) x 100. Figure 2.2 below shows the average customer interruption figures for GB DNOs. Based on this, the average GB figure is ~ one interruption every two years; this is substantiated by the 2015/16 ENA figures.

Figure 2.2: Average customers interruptions

Customers Interrupted **Latest Ofgem figures @ Dec 2017**	**Target**	**Actual**
Electricity North West	48.03	32.9
Northern Powergrid	65.13	50.91
Western Power Distribution	62.95	49.3
UK Power Networks	53.68	37.95
SP Energy Networks	44.98	40.53
Scottish and Southern Electricity Networks	66.38	57.96
Total	341.15	269.55
Average	**56.86**	**44.9**

This divergence from the London Economics approach was made to optimise the research, by more accurately reflecting average industry service performance for supply reliability and availability. A frequency of 'one interruption every three years' was used to reflect Electricity

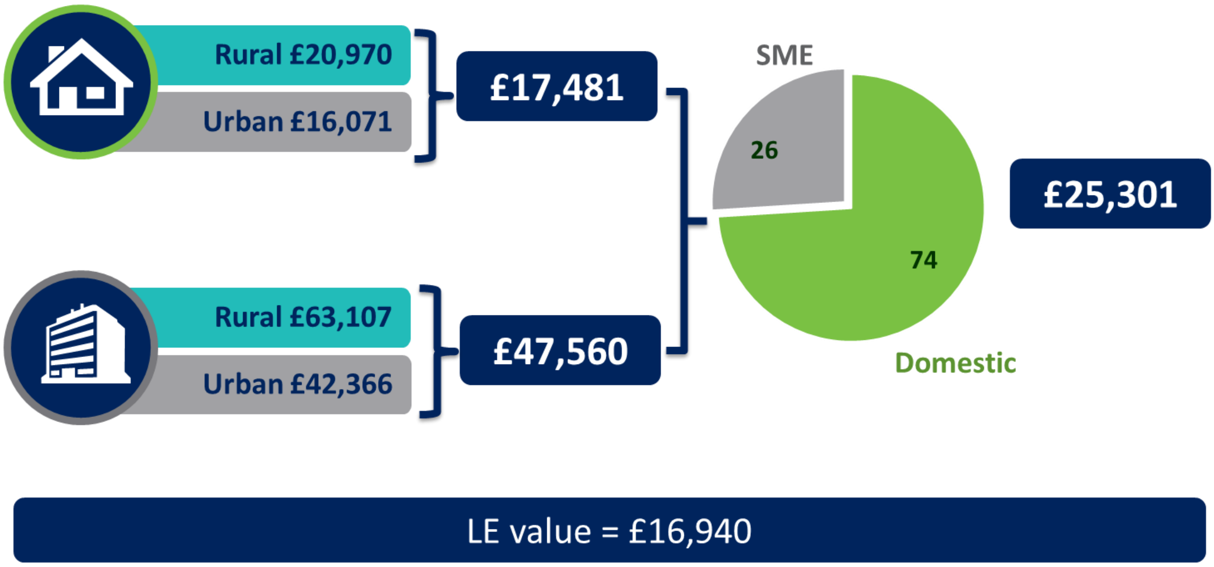
11 London Economics, 2013. The Value of Lost Load (VoLL) for Electricity in Great Britain, Final Report for Ofgem and DECC.

North West's actual average CI performance. This was considered more appropriate than the national average of once every two years as it more accurately emulates the experience of the majority of customers, particularly those served by more robust networks.

WTA values are predominantly used in the remainder of this analysis to make comparisons across the customer groups. This is because it is the metric used in previous studies and it gives an average value across domestic and SME customers that is closest to the value currently used by Ofgem. Results for WTP are summarised in the appendices.

Figure 2.3 shows the overall VoLL when the results for the two main customer types are combined in a weighted average, in the same way as the LE study. This final figure of £25,301 MWh compares to LE's 2013 figure of £16,940. The LE figure of £16,940 would now be closer to £18,500[12], if adjusted for inflation. This suggests that over time, VoLL is on the increase and intuitively, this reflects increasing levels of customer needs and expectations.

Figure 2.3: Group-level VoLL combined to give a single overall VoLL



The WTA values delivered from the research are given as £ per hour. This represents the mean average amount a customer would wish to be compensated for an entire one hour outage, once every three years. To convert this value to £ per MWh, it is divided by a customer's average MW consumption per hour.[13]

Variations in VoLL by customer segment

Prior to undertaking the analysis, there were no presuppositions about how VoLL might be segmented or how this information could be utilised by DNOs.

VoLL was initially analysed by means of a high level and simplistic domestic and SME classification and then segmented further by key demographic, socio-economic, geographic, attitudinal, behavioural and event-based information collected during the survey. The research methodology was designed to analyse VoLL at a much more granular level than in previous studies by taking account of more detailed customer information. The objective of achieving an enhanced and segmented understanding of VoLL is to allow DNOs to consider their investment strategies in a more informed and targeted manner. The ability to calculate

[12] Based on Bank of England inflation figures averaged at 2.2% a year using the composite price index.
[13] The average consumption for domestic customers is 0.00045 MW per hour. An average WTA value of £7.87 per hour (range £7.30 - £8.44) was obtained for all domestic customers, giving a MWh value of £7.87/0.00045 = £17,481 (range £16,209 - £18,753). The average consumption for SME customers is 0.00336 MW per hour. An average WTA value of £160 per hour (range £152 - £167) was obtained for all SME customers, giving a MWh value of £160/0.00336 = £47,560 (range £45,289 - £49,830). The actual calculations were based on numbers to 16 decimal places.

the collective VoLL of customers served by individual assets will allow DNOs to prioritise investment decisions, informed by customer need and may be influential in reforming future customer compensation strategies.

The results of the analysis for domestic customers indicate that VoLL assignment differs significantly across various segments (see Figures 2.4 and 2.5); for example, a high VoLL is exhibited among the fuel poor, early adopters of EV and those living in rural locations, when compared with the average. Relatively high VoLL was also measured among those who had no experience of either a planned or unplanned power cut and for those who perceived a low impact associated with the most recent outage affecting their household. However, respondents who classified themselves as having been severely impacted[14] by a supply interruption have a low VoLL and it is also directionally lower for those classified as 'worst served'[15]. It is not possible to provide a definitive explanation for this directional finding because of the small 'worst served' sample size and the mix of definitions for this group.[16] However, while the low VoLL initially appears to be counter-intuitive, empirical evidence suggests that customers served by consistently poorly performing networks have a lower reference state than those used to a higher level of service and it is possible that, for this group, the assessment of gain or loss is in the context of lower expectations.

Anecdotal evidence also suggests that worst served customers tend to be more resilient and better able to managed outages, based on their previous experiences and established mitigation strategies. It is of note that VoLL assignment from the survey is based on customers' perceptions and as such, it may be that responses from the larger sub-group that 'want to improve supply' (whose VoLL is significantly higher than the average) may provide a better indicator of VoLL, because they perceive the need for a better service.

The VoLL of respondents who believe the DNO's investment priority should be to 'improve supply quality for those worst served' was fractionally under the average, at odds with the much higher VoLL of those wishing to 'improve supply reliability where benefits to customers outweigh the costs of making improvements', who report a VoLL 45% above the average.

These findings raise important questions that warrant further exploration to substantiate the underlying factors responsible for a low VoLL among the worst served. The results expressed by this customer segment also highlight the need to consider wider issues of equity, fairness and socialised costs when applying a segmented VoLL model. For example, given that all customers fund investment in infrastructure, is it legitimate, on the basis of a blended VoLL, to divert investment to networks serving customers with high expectations of supply reliability at the expense of underperforming assets, in sparsely populated areas, serving customers with a lower reference state and consequently, a lower VoLL? Contrarily, the high VoLL expressed by rural customers introduces questions about the appropriateness of investing finite resources that directly benefit only a relatively small number of customers.

A similarly unexpected finding was revealed in the low VoLL assignment of those with experience of large scale, long duration interruptions. It is possible that the 'ownership effect' described above could be lower for customers who have been severely impacted by a recent supply interruption because they expect a proportionally smaller payment to bear the loss of a service that they are not benefitting from as much as others. Arguably, this is because they have less to lose and already feel a deeper sense of inconvenience.

However, this interpretation of the 'ownership' effect fails to explain the lower VoLL for customers with above-average consumption (based on industry standard typical domestic

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14 . Significant impact that resulted in large financial loss directly associated with the power cut, or an inability to use critical medical equipment.

15 A worst served customer 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.

16 Approximately two thirds of respondents in the worst served classification were actively recruited using Electricity North West's network data to identify those served by underperforming networks meeting the criteria. The remainder were respondents served by other DNOs who self-identified in the survey on the basis of having experienced 15 or more outages in the preceding three years.

consumption values). It is reasonable to assume that those with higher consumption patterns are generally able to afford higher expenditure on energy and by extension, may be better placed to make alternative provision during a power cut. They are also likely to be better positioned to absorb consequential losses arising from an outage with less impact than those on average or low incomes, particularly those in fuel poverty. This could be reflected in the lower VoLL assignment for this group, which is comparable to the reduction in VoLL seen in low consumers of electricity.

While VoLL is substantially higher for EV and heat pump (HP) users, this is not similarly reflected among those who own solar panels, where VoLL is only fractionally above the average. This does not appear to reflect the affluence of these customers, which is actually higher than average (£31,500 pa v £30,000 pa for all domestic customers) and similar to HP users (£32,000 pa). This is despite there being many customers living in social housing who benefit from solar panels. In contrast, EV users are notably more affluent (£41,500 pa).

The damage function

The value of loss can be expressed as a customer 'damage function' relative to the duration, frequency and notice of an outage. That is, a monetary value that represents the total personal discomfort and inconvenience perceived by the customer. The values depicted in Figure 2.4 demonstrate the damage function, which is presented as a multiple of average domestic VoLL.

Figure 2.4: Domestic customers with higher than average VoLL (>£17,500/MWh)

Domestic segment	VoLL £/MWh	Damage function[17]
Fuel poor[18]	£32,500	x 1.85
Electric vehicles (EV)	£21,500	x 1.25
Rural[19]	£21,500	x 1.20
Low income groups[20]	£20,500	x 1.15
Aged 30-44	£20,000	x 1.15
Heat pumps (HP)	£20,000	x 1.15
Vulnerable[21]	£19,500	x 1.10
Experienced no planned or unplanned power cuts	£19,000	x 1.10
Off gas network	£18,500	x 1.05
Medically dependent equipment users[22]	£18,000	x 1.05

17 Multiple of average domestic WTA, rounded to 0.05.
18 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.
19 2011 Rural-Urban Classification of Local Authority Districts and other higher level geographies.
20 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.
21 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).
22 WTA figure adjusted for income.

Figure 2.5: Domestic customers with lower than average VoLL (<£17,500/MWh)

Domestic segment	VoLL £/MWh	Damage function
Worst served[23]	*£7,000*	*x 0.40*
Experienced large scale, lengthy supply interruption in last twelve months	£12,000	x 0.70
Urban	£16,000	x 0.90
Experienced a planned power cut[24]	£16,000	x 0.90

Sub-group analysis of SMEs is more limited due to the smaller sample sizes, but in Figures 2.6 and 2.7, it is clear that experience of interruptions is a key differentiator of VoLL. Given the diversity of the SME sample relative to size, economic activity and consumption profile, additional surveys are proposed to deliver more robust and nuanced insights, to support the findings for this segment.

Figure 2.6: SME customers with higher than average VoLL (>£47,500/MWh)

SME segment	VoLL £/MWh	Damage function[25]
Rural[26]	£68,500	x 1.45
Experienced power cuts (either planned or unplanned)	£51,500	x 1.10
Off-gas[27]	£50,000	x 1.05

Figure 2.7: SME customers with lower than average VoLL (<£47,500/MWh)

SME segment	VoLL £/MWh	Damage function
Want to improve supply	£33,000	x 0.70
No experience of power cuts (either planned or unplanned)	£38,000	x 0.80
Want to keep reliability	£38,500	x 0.80
Urban[28]	£44,000	x 0.90

VoLL was also observed to vary significantly among SMEs, based on the season in which the survey was conducted. Figure 2.8 below shows VoLL for the separate summer and winter phases of research.

Intuitively, VoLL might be expected to be higher in winter than summer, given that the impact of an interruption is likely to be greater. The 2013 LE study specifically tested seasonal and time attributes. However, because the DNO is unable to influence the season or time that an

23 Based on a sample of only 108 people, so this result should be treated with caution

24 Derived by estimating the standard trade-off scenario (unplanned, one hour outage, once every three years) for respondents with experience of planned outages. The standard unplanned scenario was used to provide like for like comparisons for parity with the LE approach.

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 participants to base responses on the worst case scenario, ensuring that the VoLL captured was representative of the true disruption that might occur. The choice scenarios were presented in exactly the same way in the summer and winter survey, framed around the 'most inconvenient time', so in principle the seasonal timing of the survey should not have had a large effect, which appears to be largely the case for domestic customers.

The findings of the LE study, which specifically introduced seasonal peak and off peak demand scenarios into their survey, indicated that both domestic and SME customers require a higher level of payment if an outage occurs in winter. In contrast and contrary to expectations, respondents who completed Electricity North West's survey in the summer expressed a higher VoLL than those who responded in winter, with notably higher values in the SME sample.

The data was weighted so that customer profiles were comparable across both seasonal surveys. Comparison of the two groups did not show differences that would suggest a reason for these variations; therefore, the results reveal an unidentified difference between the two samples with regard to SME VoLL, which may simply reflect the context in which the survey questions were framed, ie based on an outage occurring at the worst possible time.

Figure 2.8: VoLL in £/MWh by seasonal survey

VoLL measure[29]	Domestic	SMEs
VoLL summer survey (£/MWh)	£18,500	£78,000
VoLL winter survey (£/MWh)	£16,500	£20,000

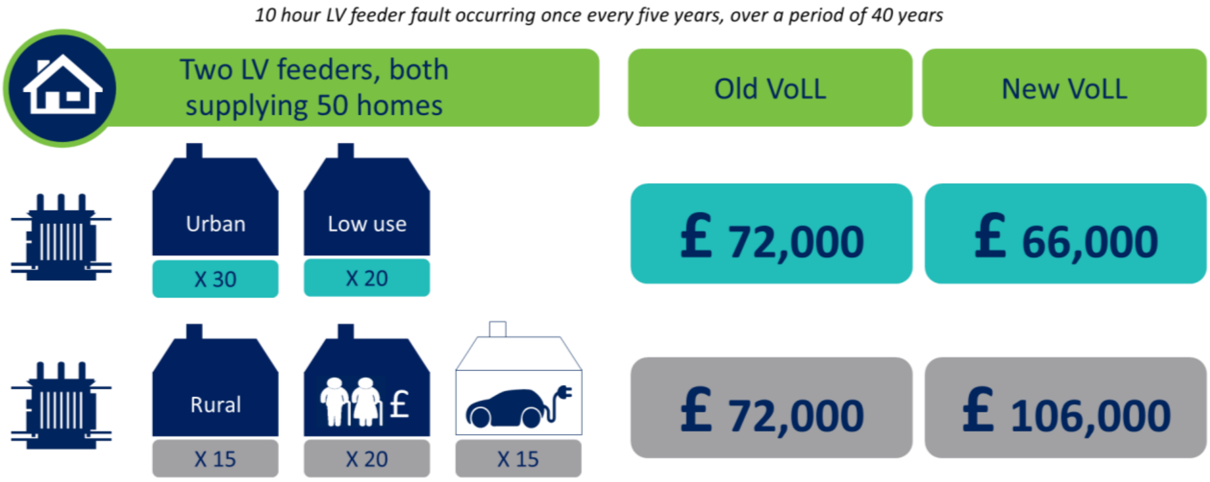
The implications of using a segmented VoLL

A segmented VoLL model will allow DNOs to calculate the combined value of loss, by blending the unique VoLL assignments of the specific customers served by a particular asset. Understanding the collective VoLL associated with an asset will enable DNOs to factor customer need into the equation, when prioritising investment decisions.

The potential impact of applying VoLL that varies by customer type is illustrated in Figure 2.9. This considers two feeders which each serve 50 domestic properties; however, the profile of these two groups of households is quite different.

25 Multiple of average domestic WTA, rounded to 0.05.
26 2011 Rural-Urban Classification of Local Authority Districts and other higher level geographies. Caution small sample (108)
27 Properties that are off the gas grid, ie do not have a mains gas supply.
28 2011 Rural-Urban Classification of Local Authority Districts and other higher level geographies.
29 The values are notably higher than those observed in the pilot. The main reason for this was the development of a statistical model that more faithfully captures the non-linear impact of the duration of the interruption, which is higher per hour for the first hour and lower for longer interruptions. In the pilot, a single linear estimate was used, in line with previous studies where values of less than 1 hour were not tested.

Figure 2.9: Example of a VoLL application: single VoLL versus VoLL varied by customer type



In this representation, the first feeder is mainly composed of urban households, a proportion of which are low electricity users. 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[30] is £72,000.

This simple graphic demonstrates that quite different figures are derived when the consequence of failure (CoF) for different assets is calculated by applying a more sophisticated segmented model, which reflects the mix of customer types, rather than by simply multiplying a single uniform VoLL. 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.

Using 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 dependency and impacts on the customers served, demonstrating how DNOs might better target finite resources to deliver greatest value.

The current uniform 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.

It is recognised that these findings introduce questions about fairness and the socialised costs of prioritising investment on the basis of customer need and expectation, which warrant further investigation.

It is also of note that this simple representation references certain customer characteristics which DNOs are currently unable to access from standard industry data. The source and

30 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.

appropriateness of including particular VoLL characteristics in the proposed VoLL calculation tool is discussed in the final conclusions and recommendations report, published on the project webpage.

2.2 How will VoLL vary with LCT adoption?

A key objective of this project was to define how VoLL might change in a low carbon future, as this understanding will become increasingly important in informing issues such as network reliability standards and design policy for LCT intensive networks.

In the pilot study, half the respondents were asked to imagine a future state in which they were a user of a specified LCT and therefore more reliant on electricity. The pilot results demonstrated that for domestic customers, there were no statistically significant differences between the WTP and WTA estimates for current and imaginary future scenarios. These results suggest that respondents were unable to imagine the future scenario and the greater dependency on electricity that is likely to exist. Therefore, in the main survey, respondents were asked to make choices relative to their current actual experience.

The main survey utilised stratified random sampling to ensure that a cross-section of current LCT users were included in the survey population. VoLL for these existing adopters was compared with the VoLL assignment of all domestic customers. The potential change in VoLL associated with increased LCT adoption, and consequentially higher reliance on electricity, can be inferred from this comparison.

As shown in Figure 2.10, current domestic users of LCTs have a higher VoLL than the average for all domestic customers. Within the general segment of current domestic LCT adopters, VoLL for EV-only users is 23% higher than the average VoLL of all domestic customers. The number of SME LCT users was too few to give a reliable estimate.

This approach had the advantage of using values that were derived from actual experience; however, it assumes that future adopters will have the same values as current LCT users. This is an important consideration given the anticipated increase in LCT adoption and hence, customers' greater dependency on electricity. This will be a critical factor influencing future VoLL and consequently, will have significant implications for DNOs' long-term investment strategies.

Figure 2.10: VoLL in £/MWh based on current LCT usage

Domestic segment	VoLL £/MWh	Damage function *(multiple of average domestic VoLL)*
All domestic customers	£17,500	x 1.00
Current domestic LCT[31] users	£19,000	x 1.10
Current domestic customers with PV	£18,000	X 1.05
Current HP users	£20,000	x 1.15
Current domestic EV users	£21,500	x 1.25

31 LCT users are customers who own and/or operate electric vehicles, photovoltaic systems or electric heat pumps.

2.3 How would the level of incentives tested for demand side response (DSR) in other Low Carbon Networks (LCN) Fund trials compare to future VoLL?

The C_2C study carried out in 2015 by Electricity North West[32] sought to obtain a price per MW of demand response from I&C customers[33]. The specific focus of C_2C was on market sizing and finding an optimal price point at which commercial customers are willing to 'trade,' ie to accept a short-term detriment in service in return for an incentive. While at first inspection, the VoLL and the price to purchase demand side response would appear to represent a similar customer valuation of a supply interruption, research has shown these values to be very different. Conceptually the trade-off associated with C_2C is comparable to the VoLL WTA, but there are important differences between the two studies that should be noted:

- The VoLL research was focused on domestic and SME customers (from a range of sectors and of all sizes); whereas, C_2C surveyed solely larger I&C customers. These large consumers of electricity were omitted from the VoLL research for parity with the LE study. This recognised that while these organisations have widely varying assessments of VoLL, they are deemed to be more technically and commercially empowered to mitigate risk from loss of supply to their operations. This results in a systematic difference in the source data between the two studies.

- C_2C calculated a WTA for larger organisations more likely to participate in the DSR market, most of whom were able to mitigate the risk of a set number of interruptions. In comparing VoLL and the cost/MWh of DSR it is important to note that VoLL for SME customers represents the cost or damage function for an unforeseen interruption to their supply over which they have no control of the timing, duration or indeed frequency. In comparison, the price for DSR allows the customer to have control over all three or at least two of these dimensions. For example DSR contracts typically allow both the duration and frequency to be capped. This naturally creates a greater value of VoLL versus DSR.

- The hypothetical incentives tested in C_2C were quite different from the VoLL study, with guaranteed payments (even if no interruptions were to occur) versus capped payments for multiple interruptions.

For these reasons, a meaningful comparison of the two studies is not possible. However, the C_2C research remains valuable as a demonstration of the existence of a market for DSR to mitigate economic and social costs of electricity shortfalls.

2.4 Which segments, if any, would support a strong VoLL and hence potentially higher investment?

VoLL varies significantly across the broad customer spectrum sampled, influenced by socio-economic, demographic, geographic, attitudinal, behavioural and event-based factors. As discussed above, the following customer segments all have a relatively high VoLL:

- Fuel poor
- Domestic customers aged 30-44
- Those in rural locations
- Those who are off the gas grid and therefore, reliant on electricity as their primary energy source
- LCT adopters, notably EV and heat pump users.

32 Electricity North West, Capacity to Customers: Second Tier LCN Fund Project Closedown Report, 7 August 2015.

33 This was approximately £20,000 per MW over 3 x 8 hour slots. This means it costs the DNO £833 per MWh (£20,000/24 hours). This is much lower than the £40,000 per MWh for SMEs observed in this study, but the two studies are not directly comparable.

It is worth noting that, when adjusted for income, VoLL is substantially higher for less affluent groups and the vulnerable. The VoLL of customers classified as ‘fuel poor’ is 24% higher than the average before any adjustment is made for income, but when the adjustment is applied, the figure rises to 89% above the average domestic value. Justification for applying a weighting to reflect income is widely recognised as appropriate in studies of this nature and is discussed at length in Appendix 6.6. Income-adjusted VoLL values are also referenced in Figure 3.4 of the technical appendices supporting this report. The relative high weighted VoLL of vulnerable and low income groups is significant and demonstrates that Ofgem’s focus on identifying and tackling consumer vulnerability in the energy market is correct. This finding also supports the assumption that these customers are significantly more likely to suffer detriment than typical customers as a result of an outage, and that the detriment is likely to be more substantial.

2.5 What is the impact of the scale and duration of supply interruptions on VoLL?

An outage generally incurs a higher VoLL the longer it lasts, but the marginal hourly value declines steadily. There is a levelling out in the upward trajectory of VoLL for extremely long duration interruptions typically associated with extreme weather events. This is likely to reflect awareness, by those affected, that these major incidents are largely outside the control of the DNO and therefore less worthy of additional compensation.

Figures 2.11 and 2.12 below illustrate the impact of frequency and duration on VoLL as a consequence of unplanned and planned interruptions respectively for domestic customers. Figure 2.11 demonstrates how the impact of a long unplanned outage incurs a lower hourly rate the longer the outage lasts. However, the step up to more than six outages every three years leads to a significant increase in VoLL.

When an interruption is planned, with at least two days warning, VoLL is greatly reduced relative to a comparable unplanned outage. In the case of a one-hour outage once every three years, VoLL falls from £17,500 to £500. Even at the higher levels of frequency and duration, the reduction is still notable; for example in the case of an outage of over six hours, occurring 7-14 times every three years, VoLL falls from £64,500 to £48,000.

Figure 2:11 Domestic unplanned VoLL in MW/h by frequency and duration of outage

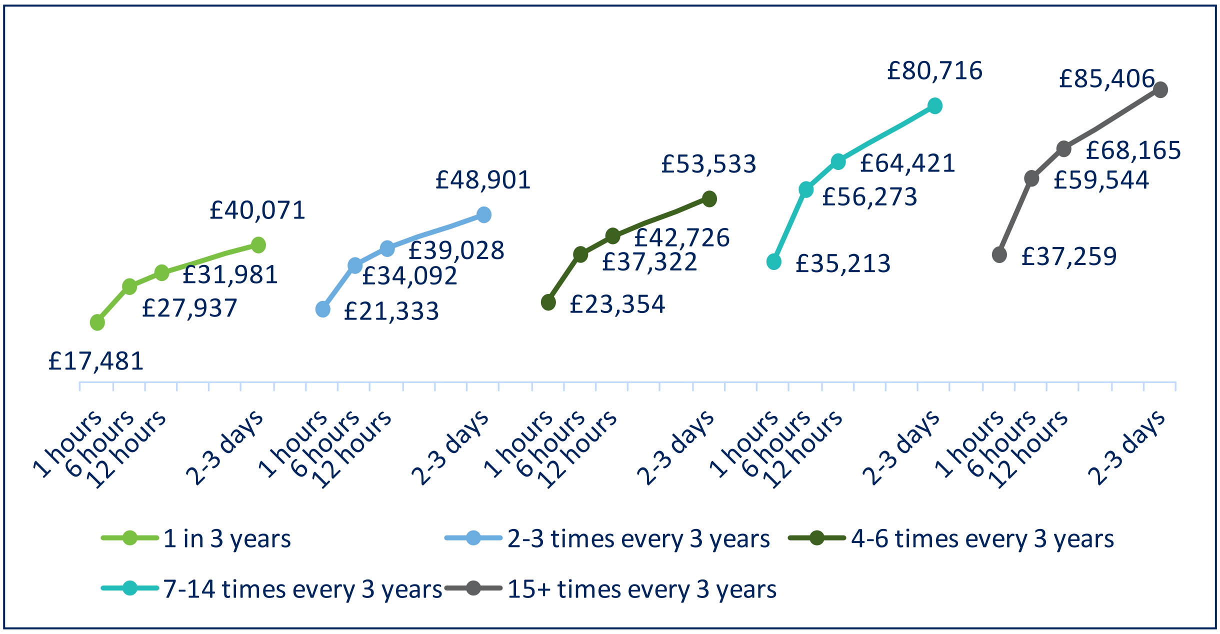
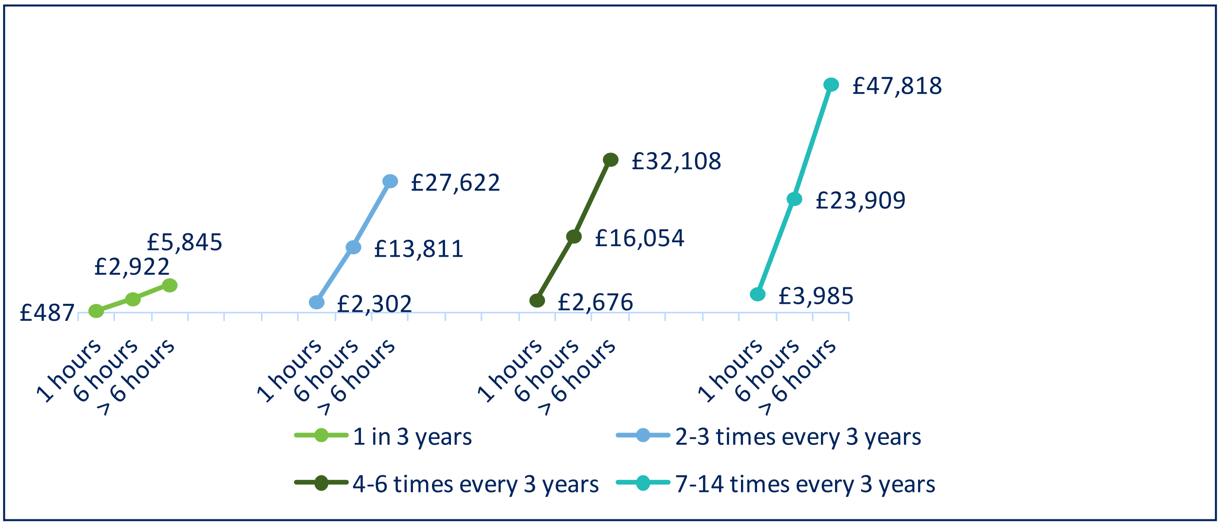


Figure 2:12 Domestic planned VoLL in MW/h by frequency and duration of outage



For SMEs, a similar shape to the curves can be observed in Figures 2.13 and 2.14, the hourly rate for VoLL decreasing as the length of an outage increases. There is a significant step up in VoLL when the frequency of outages reaches more than once a year (4-6 every three years) but then no further increase until five or more outages a year (15+ every three years).

The large reduction in VoLL for planned outages (with a minimum two days warning) is also evident for SMEs when compared to unplanned interruptions of equivalent frequency and duration. However, at the worst level (planned outage of more than six hours occurring 7-14 times every three years) we observe a significant increase in VoLL, which is higher than the comparable figure for unplanned interruptions. This suggests that while there is tolerance for limited planned work requiring outages; acceptance diminishes when customers are exposed to more than three 'full day' interruptions in a three-year period, demonstrating the importance of a cohesive approach to construction/reinforcement and maintenance strategies, which consolidate planned work where possible.

It is of note that DNOs have a statutory obligation to provide their customers with advanced written notification of planned outages. This notice briefly outlines the nature of the work to be conducted. It is possible that this knowledge, combined with actual experience of outages has a causal effect of heightening expectations of increase supply reliability and consequently, VoLL assignment.

Figure 2:13 SME <u>unplanned</u> VoLL in MW/h by frequency and duration of outage

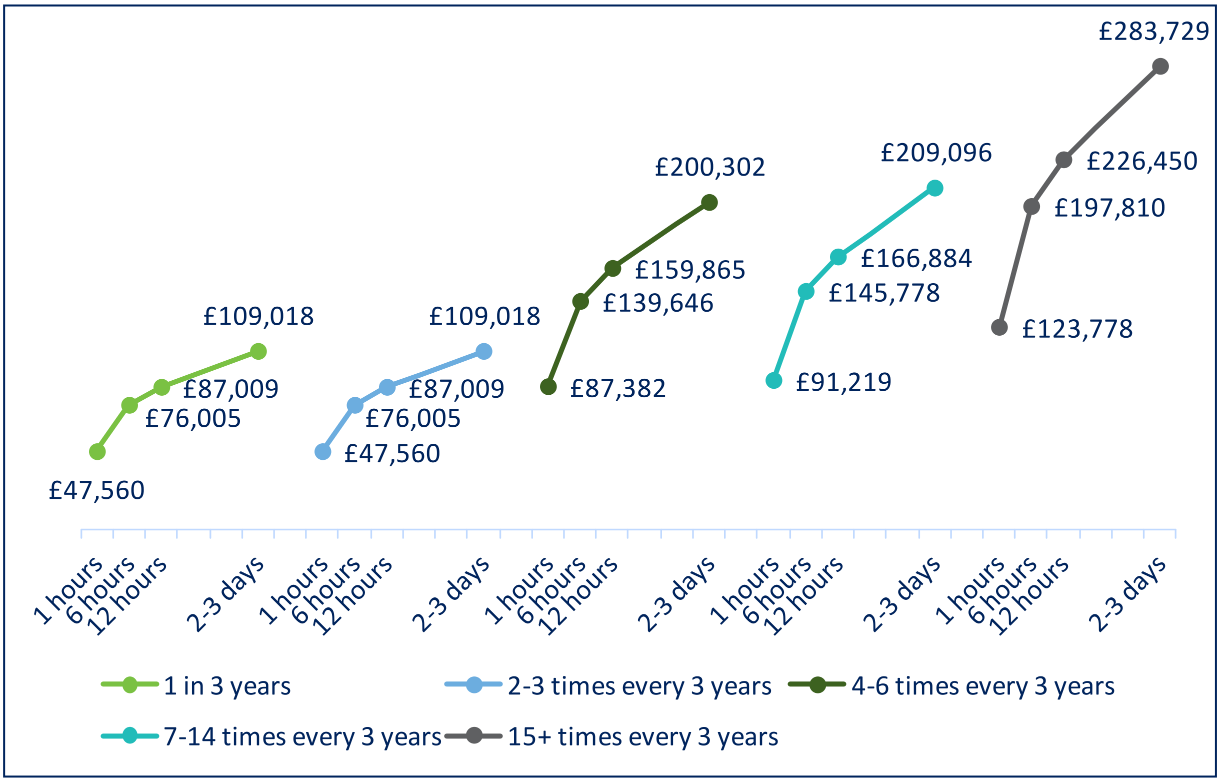
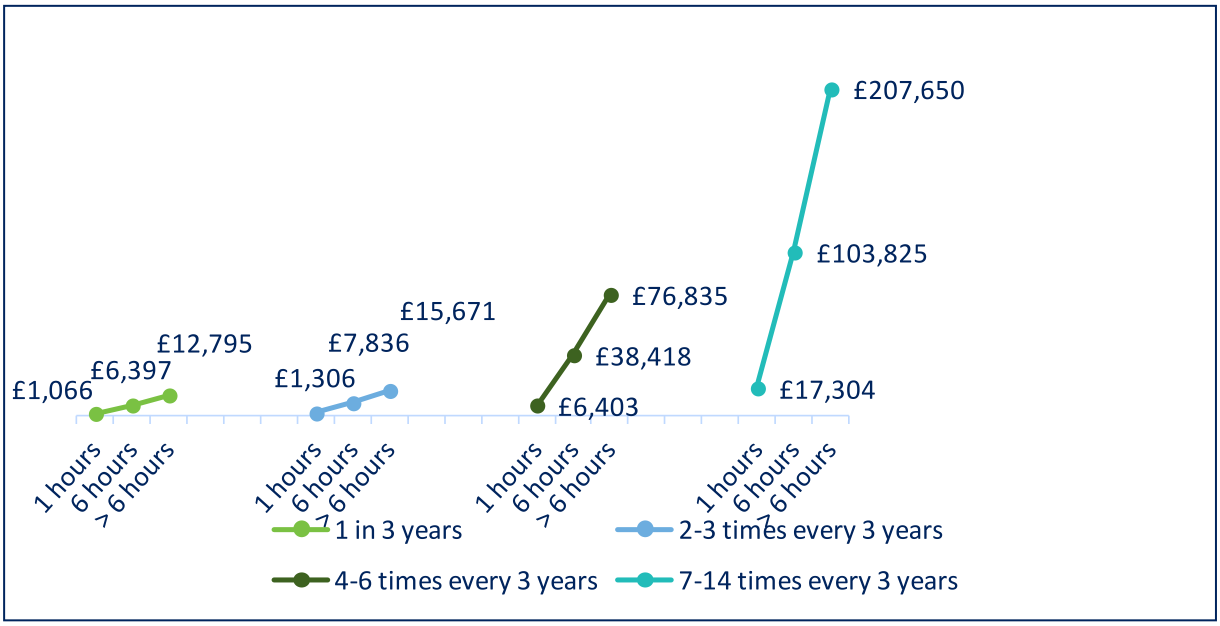


Figure 2:14 SME <u>planned</u> VoLL in MW/h by frequency and duration of outage



2.6 Is the value that an individual places on an outage at their property the same when the entire community is affected?

This question concerns the extent to which the VoLL measured in this survey can reflect the impact of a large area-wide outage. The results summarised in the section above indicate that the hourly WTA value falls as outages become longer, suggesting that customers might envisage adopting strategies to cope with the absence of supply, so that the additional time is more tolerable. However, VoLL is expressed in this study simply as a value for a single customer (household, company), reflecting the respondents' perceptions of how inconvenient an outage would be if it occurred at the most inconvenient time.

In this research respondents were not asked to consider the possible wider impacts, such as supply interruptions to local services (ie shops, petrol stations). As an outage becomes more widespread, it might be that substitute services (shops further away) also become unavailable and the disruption impacts on the individual customer more severely. Widespread interruptions, typically associated with extreme weather events, which affect the extended community, may introduce communication difficulties for those affected, as the infrastructure of mobile networks is compromised. These large scale outages may also disrupt potential support networks that might otherwise be afforded by family and friends when they too are equally impacted.

Counter-intuitively, this research has indicated that domestic customers with experience of large scale supply interruptions have a lower VoLL (at around 30% below the average), which may reflect a number of possible explanations. One possibility is that the impact may not necessarily be as disruptive as might be imagined, or more plausibly, it might reflect the ability of a local community to find ways of addressing the effects of the outages to mitigate the impact.

There are no studies that examine how a widespread outage affects the individual VoLL. However, anecdotal evidence suggests that large scale, high impact and lengthy outages can foster increased societal cohesion, when a community recognises that 'we're all in it together' and takes measures to support each other, particularly those less able to cope. This is supported by high levels of customer satisfaction reported when there is a recognition that a major incident is the result of conditions outside the control of the DNO, ie extreme weather events, and the community is aware that the operator is taking all reasonable steps to remedy the problem and mitigate the impact on those affected.

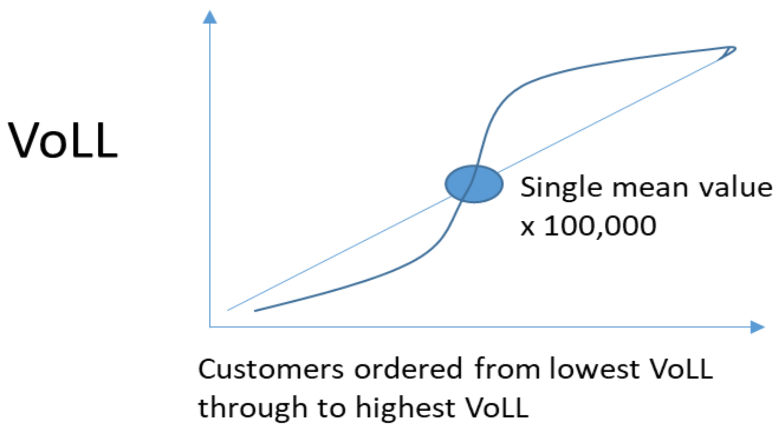
It is possible to draw parallels with flight delays or ferry cancellations, where everybody is facing the same issue. This does not make the situation more tolerable, but at least an individual is not suffering alone. In these cases, actual compensation payments are worked out using a standard formula; the value reflected in the level of compensation does not differ by individual or by the group (community) being impacted. So there are no adjustments for network externalities.

This study highlights the need for further research to better understand the effect on individual VoLL, relative to the duration and scale of outages.

2.7 Given that these survey results represent an average value for a single customer, how is this best extrapolated to a population?

This is a question of how much granularity can be incorporated in the calculation of total VoLL representing all customers. Consider 100,000 customers served by a particular circuit, all experiencing an outage, a single VoLL could look like this:

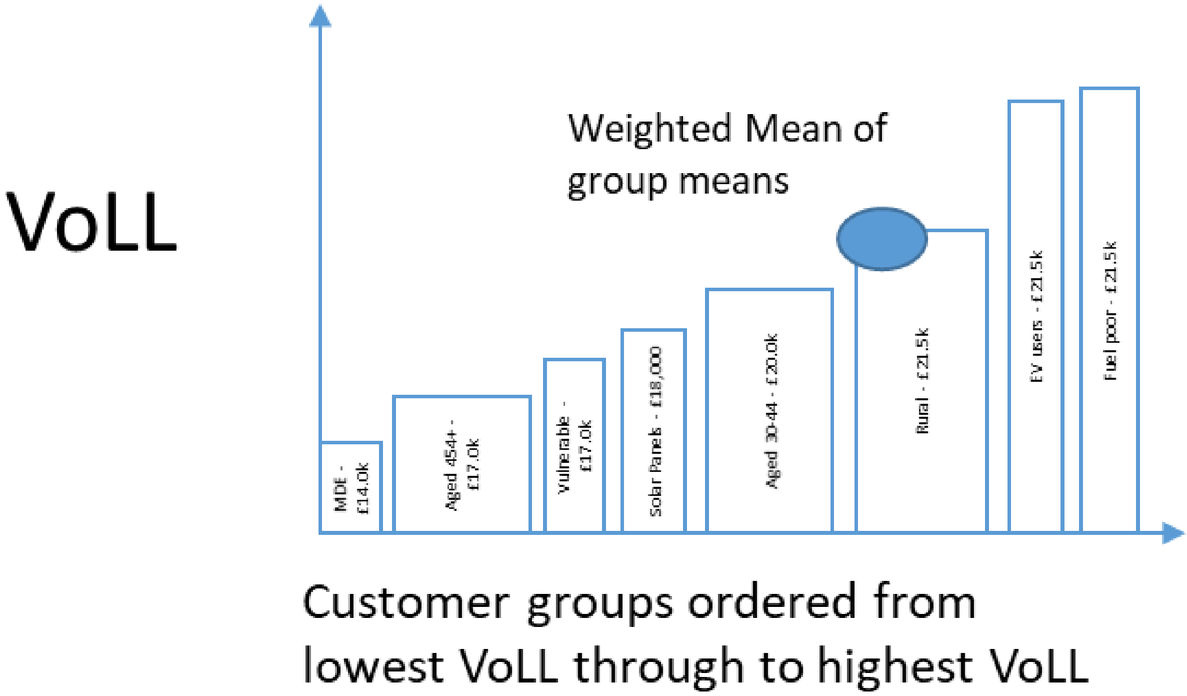
Figure 2:15 Schematic for a single VoLL



The single VoLL is representative of the total 100,000 customers if the distribution of individual values is uniform (the straight line), but it is potentially misleading if the values are not uniform (the curved line). This study has demonstrated that for this reason, the overall VoLL for a large number of customers may not accurately be reflected by a simple multiplication of the total number. It is also likely that locational effects will influence the impact of each individual.

It is not feasible to measure the actual VoLL of each individual customer, but a good approximation can be obtained by using the mean VoLL from groups of customers as derived from the survey, based on their characteristics. In the example below, the 100,000 customers are divided into groups, according to a defining characteristic (eg age, fuel poor, etc).

Figure 2:16 Schematic of VoLL averaged over customer groups



In this way, the single VoLL calculated from the VoLLs derived for each group will give a more representative overall value. This is the principle behind the VoLL calculation tool developed from this study. The user defines a population of customers by their defining characteristics ie (the number of householders aged 35-44, the number of vulnerable households, and so on) and the blended value is calculated from the mean VoLL of reach of these sub-groups.

2.8 How can DNOs mitigate the cost of lost load to customers?

The study has identified that VoLL increases as the duration and frequency of interruptions increases indicating that proactive network reinforcement, designed to reduce unplanned interruptions, will mitigate the costs of loss of supply to customers. The lower VoLL for unplanned outages suggests that both domestic and SME customers are tolerant of a limited number of planned outages to facilitate maintenance and reinforcement works, to improve overall supply reliability.

However, in addition to the core set of supply interruption attributes included in the choice experiment, a secondary exercise was incorporated to evaluate if VoLL could potentially be reduced through a range of communication and customer support strategies, deployed during supply interruptions. These were:

- Levels of additional assistance available for vulnerable customers
- Communication channels via which information about the supply interruption can be proactively provided
- Quality of information provided.

Analysis was conducted to identify the relative importance of specific types of additional support. In Appendix 6.5 to this report, Figure 6.13 demonstrates the degree to which support components mitigate the loss of supply based on the industry's key availability measure of service performance, measured in customer minutes lost.

For both domestic and SME customers, the majority of communication components tested were considered more important than the physical forms of support, which included the provision of generators, welfare packs and a mobile catering unit.

The most effective support components for mitigating the loss of supply to domestic customers were found to be:

- Telephone call(s) made to a customer's mobile or landline
- Accurate information confirming when power will be restored
- Text (SMS) messages
- Automated text-to-speech message
- A justified reason for the power cut.

Figure 6.13 illustrates that *targeted* customer communications, such as telephone calls made directly to domestic customers are more than three times as effective in mitigating the impact of a supply interruption as updates through social media. Analysis also reveals that proactive telephone calls can directly mitigate the loss of supply to domestic customers for up to five minutes in an hour, with a similar value being placed on accurate information about when power will be restored.

Priorities were similar for SME customers, for whom the most important components were: updates sent via SMS, proactive telephone calls and accurate information about supply restoration, which have the potential to mitigate the impact of an outage by between six to eight minutes, as demonstrated in Figure 6.14. It is of note that social media platforms are also important for SME customers and it is reasonable to assume this is because the value that business customers place on instantaneously updated information is now an expectation rather than an aspiration.

This introduces questions about how VoLL mitigation strategies might be implemented by DNOs on a regional or circumstantial basis ie whether the benefits of preferred channels for some customers (telephone calls and text messages) can justify the relatively high cost when compared with social media, which offers DNOs a cheaper, faster and easier alternative, with greater reach than traditional methods of communication, but which appears to have less impact in reducing VoLL.

A further consideration is that social media channels are more positively rated by the younger age group (18-29 year olds). For this customer base, communication via social media (Twitter, Facebook etc) has the greatest effect in mitigating VoLL, followed by information relayed by public address/tannoy systems and confirmation that supply has been restored. The latter suggests that this group is more likely to vacate premises affected by an outage, only returning after supply is restored. Conversely, targeted phone calls to a mobile or landline are rated much lower by this group. The significance of differences in the value given to support and communication mechanisms by this demographic, when compared to those currently valued highest by the average domestic customer, implies that effective communication strategies will need to evolve to reflect future needs and expectations.

Using public address/tannoy systems to provide information was demonstrated to have less impact on VoLL generally but the study suggests that VoLL could be mitigated by implementing this technique, at a local level under certain circumstances.

Anecdotal evidence from customer engagement, conducted early in this study and from other research, supports these findings and emphasises the importance placed on effective communications platforms and accurate, up-to-date information. This may help to explain the unexpectedly low VoLL of those who had recent experience of a large scale event, affecting the entire community. It is of note that a significant increase in customer satisfaction was observed in recent severe weather-related events in Cumbria, when the DNO’s presence was evident in the community. The most vulnerable members of the community received proactive updates and welfare calls. Catering vans were deployed to strategic locations to provide sustenance. Local radio was actively engaged to relay updates to the widest possible audience and to overcome communication problems associated with failures of the mobile network infrastructure.

The implication of these findings, is that offering support to customers could provide an economically efficient means of reducing the impact of lost supply and consequently, positively influence VoLL. This learning has potentially wider implications and could be influential in informing future customer compensation strategies. This is discussed further in the conclusions and recommendations report, supporting this document.

3 LESSONS LEARNED FOR FUTURE INNOVATION PROJECTS

The following lessons were learned regarding the survey instrument:

- Customers find it difficult to identify their DNO with 35% selecting ‘don’t know’ even when provided with a map clearly defining regional boundaries. It is therefore useful to collect postcode information to validate domestic and commercial respondents’ DNOs.
- Despite clear instruction, SME customers found it difficult or were unwilling to provide their meter point administration number (MPAN) information, further validating the need to collect postcode information.
- Domestic and SME customers are more inclined to provide postcode information when its purpose is clearly explained. However, it should be recognised that a proportion of respondents will actively safeguard their anonymity and omit data which links them to their residence/place of work. Appropriate mitigation should be incorporated into the survey to minimise the potential for erroneous entries.
- The option of selecting an independent distribution network operator (IDNO) was added after the pilot and this was chosen by 5% of respondents in the main survey.
- Actual electricity consumption data was obtained from meter readings, with the explicit consent of respondents. This was achieved by using the MPAN, postcode and address details provided, to retrieve records held in the distribution use of system (DUoS) and associated distribution systems database. Consumption data was assessed across 24 months to ensure that full seasonal average values were used as a basis for categorisation. Using accurate consumption data is preferable to segment high, medium and low users in contrast to respondents’ more subjective views of their consumption profiles. However, the data did contain anomalies. Analysis was conducted and a tool developed to identify estimated annual consumption which took into consideration meter changes, incorrect number of digits recorded and multiple

readings for 'multi rate meters', associated with differential tariffs such as Economy 7. The median typical domestic consumption values published by Ofgem in 2017 were used as a basis for consumption profiling. The actual ranges for classification are outlined in Figure 3.1 below.

- Customers have limited understanding of what a 'heat pump' is and required additional background information and supporting images. The additional communication materials introduced in the seasonal surveys led to a significant decrease in the proportion of customers saying they didn't know whether their heating and/or hot water is supplied by an electric heat pump.

- 43% of SME customers found it difficult to allocate their business to a standard industrial classification code, with a substantial proportion selecting 'other.' This introduces a challenge when customer segmentation is important to a survey but can be mitigated by simply asking respondents to specify their industry sector.

Figure 3.1: Electricity profile classifications

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		

Amendments made to simplify the CE following the pilot survey had a positive impact on respondents' ability to comprehend the exercise in the main survey, as there was greater parity in the trade-off scenarios. This meant that it was easier to make a considered choice when stating a preference. Respondents in phase 3 provided more complete information, even though the time taken to complete the survey was shorter.

In particular, the CE was split so that respondents only ever traded off planned or unplanned scenarios. Therefore, planned attributes and levels were evaluated alongside other planned attributes and levels (the same being true for unplanned). This approach was clearer for respondents, allowing them to make more meaningful choices and meant that VoLL could be calculated and compared for planned and unplanned outages.

The design of the CE used in this study sought to cover a wide range of variables and this in turn required an extensive analytical effort to derive the final VoLL results. The challenging process of developing and analysing the designs reflected the underlying complexity of the real world choices confronting domestic and SME customers. Future applications of the CE method should aim for as much simplicity as possible and further research into the efficient development of this approach is recommended.

4 CONCLUSIONS

This report sets out the key findings from the final phase of strategic quantitative market research and its subsequent analysis. The results of the survey provide robust evidence to support the project's primary research objective that a single uniform VoLL, applied to all customer segments, which assumes that all customers are equally impacted, may no longer be appropriate.

Analysis of survey responses demonstrates significantly different impacts of supply interruption across a range of domestic and SME sub-groups, which has the effect of large variations in the segmented assignment of VoLL. The range of values is almost double when considering the lowest to highest estimates reported.

This study demonstrates the potential of blending these different values of VoLL, which are reflective of particular customers' needs, in specific areas, to inform very particular investment decisions.

This research and modelling allows a much more representative VoLL model to be established and this has significant implications for DNOs. This understanding demonstrates the need for a more sophisticated approach which will significantly improve efficient targeting of investments and ensure those investments are based on a much richer and more representative understanding of customers' needs.

A revised, segmented VoLL model would enable DNOs to re-distribute investment without increasing customers' bills to deliver the greatest value now and into the future. This approach will ensure bills remain affordable and investment decisions to deliver improvements in service are informed by those most impacted by outages.

The overall estimate of VoLL has risen since the last major study in 2013, suggesting increasing customer expectations and dependence. While VoLL does not drive investment levels, it helps to prioritise any given level of investment. The more diverse understanding of VoLL derived from this study provides an additional, customer-driven dimension to the decision-making process, using customer need to support the common network asset indices methodology, customer satisfaction and worst served customer metrics.

A separate conclusions and recommendations report has been produced to support this document and presents an initial argument for adopting a revised VoLL model, which reflects customer segmentation. This outlines the network and customer benefits of using a more sophisticated VoLL calculation to assist DNOs in better planning network investment and customer compensation strategies.

These findings are not presented as a definitive answer to the most appropriate practice for setting and applying VoLL; indeed, the study introduces challenging questions about the most practicable and pragmatic approach of implementing a new model, at scale. It also highlights issues concerning fairness, legitimacy and the socialised cost of using a segmented VoLL model to inform smarter investments, more reflective of divergent customer need. However, this research represents a significant contribution to better understanding VoLL, and in particular its variability across customer groups. These findings are significant and have value to policy makers who might need to consider issues of equity as well as efficiency when it comes to future policy design and implementation.

5 NEXT STEPS

5.1 Engaged customer panel

The ECP, originally consulted to assist in informing this study, will be reconvened to review and evaluate the research findings. In line with NIA dissemination requirements, feedback and learning from this activity will be published on the project webpage.

5.2 Further investigation into the relative VoLL assignment of specific groups

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. This analysis will also assess the stability and variability of VoLL drivers over time. 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 and network output measures. This will ensure DNOs continue to target investment in the right areas to manage network risk effectively and will continue 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 equitable DUoS charges at a low level, 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 being conducted to provide clarity on factors responsible for the low VoLL expressed by customers served by relatively poorly performing 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 for this segment.

This follow-up study will also explore 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.

The research unexpectedly revealed that SME VoLL was higher during the summer compared to winter survey results. The reasons for this are not completely clear; however, analysis suggests the higher summer VoLL reflects the context in which the questions were framed, focused on outages occurring at the worst possible time. Further research is suggested to quantify the reason for the seasonal variation in responses.

Given the results of this research, which reveal the significant impact of supply interruptions on those in fuel poverty, collaboration with Citizen’s Advice 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.

5.3 Final reporting

A closedown report will be published containing a high level summary of the final conclusions of the VoLL project to address how the following research objectives were met:

- What is the impact on customers of lost load?
- What is the value of this impact in terms of financial and social costs to customers in £ per MWh?
- How does this vary by customer type?
- How can Electricity North West and key stakeholders mitigate the costs of lost load to customers?
- How will this vary with LCT adoption?

This report will also specify how the project has met the following success criteria, as set out in the initial project registration document:

- An understanding of customer impact, how value is defined and how this might be influenced (eg better communications)
- A credible segmentation and future VoLL model by key customer groups to guide investment decisions
- A demonstration of how these values would help Electricity North West to better plan their network investment strategy
- Guidance on customer compensation strategies.

5.4 Conclusions and recommendations report

This report presents initial recommendations for adopting a segmented VoLL model. This document focuses specifically on 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. The report makes suggestions for how the revised VoLL might be applied, summarises the standard industry data used in the study and provides details of other external data sources that could be exploited to enhance the proposed VoLL calculation tool.

5.5 VoLL calculation tool

An early segmentation and future VoLL model has been developed that will allow DNOs to identify VoLL by key customer groups, in order to help guide investment decisions. The prototype tool was developed on the basis of detailed analysis conducted by Impact Research to predict VoLL for complex households, as outlined in Appendix 6.4 of this document. The tool and its proposed application are discussed further in the conclusions and recommendations report. However, it is recognised that further detailed analysis is required to explore the most economic, pragmatic and practical mechanism for adopting a revised model at scale, which considers the stability and variability of VoLL drivers over time.

5.6 Dissemination of findings

In line with the vision of the NIA funding mechanism and the project commitments documented in the VoLL methodology statement (version 2), all outputs and learning attained from VoLL customer engagement activities will be made available to other DNOs. Specifically, all communication and survey materials developed as part of this project are publicised on the VoLL webpage. Ongoing learning will be disseminated through an annual NIA project progress report, quarterly stakeholder updates and other appropriate forums including learning events.

6 APPENDICES

6.1 Survey design

They key elements of the main survey are detailed below.

Questionnaire

The full customer questionnaire can be found on the project website.

Choice experiment

A detailed description of the choice experiment designed to measure VoLL is available in a separate technical appendix, which is published on the VoLL webpage.

Sample profile

Figure 6.1 depicts the profile of the sample surveyed in this study. Specific quotas were set to ensure a broadly representative profile of customers, while ensuring sufficient numbers of key groups such as the fuel poor and EV owners were consulted. The sample was also deliberately skewed to include a higher percentage of customers from within Electricity North West's operating region, to allow the robust analysis of VoLL across this region in isolation.

Figure 6.1: Sample profile

	Winter wave	Summer wave
Total	**3010**	**2998**
Customer type		
Domestic	2450	2518
SME	560	480
Gender		
Male	1412	1341
Female	1591	1649
Other + not stated	4 + 3	7 + 1
Age		
18-29	721	569
30-44	824	841
45-59	729	785
60+	736	803
SEG		
AB	587	669
C1	783	757
C2	459	435
DE	623	549
Population density		
Urban	2029	2245
Rural	945	738

	Winter wave	Summer wave
DNO		
Electricity North West	950	810
Scottish and Southern Energy	232	280
SP Energy Networks	242	243
Northern Ireland Electricity	32	20
Northern Powergrid	219	372
Western Power Distribution	417	648
UK Power Networks	488	620
Other – IDNO	4	5
Unidentified	5	0
Faults		
Electricity North West worst served	19	2
Non-Electricity North West worst served	49	29
Worst served list	76	100
Large scale interruptions	385	339
Other key groups		
Fuel poor	208	149
Vulnerable	1528	1525
High vulnerable	173	79
Off-gas	892	712
LCT	1064	691
Electric vehicle	350	239
PV	606	376
Heat pump	558	286

Weighting

To ensure the results of the research are representative of the GB population, the data was weighted to match the national profile. An iterative Excel-based algorithm was applied to assign a weighting factor to each respondent. This ensured the incidence of any characteristic in the weighted sample profile fell within ±5% absolute difference and the individual respondent factor was less than or equal to 2.0. Where information was not available in relation to a particular characteristic, the factor was set at 1.0.

A comparison of the target nationally representative profile is shown against the unweighted sample profile in Figures 6.2 and 6.3 for domestic and SME customers respectively.

Figure 6.2: Domestic target profile v sample profile by season

	Nationally representative	Winter	Summer
Male	49%	45%	45%
Female	51%	54%	55%
18-29	21%	26%	19%
30-44	25%	23%	25%
45-59	25%	23%	25%
60+	29%	28%	30%
AB	23%	24%	27%
C1	31%	32%	30%
C2	21%	19%	17%
DE	25%	24%	26%
Electricity North West	8%	40%	24%
Scottish and Southern Energy	13%	7%	10%
SP Energy Networks	12%	9%	9%
Northern Powergrid	13%	8%	13%
Western Power Distribution	26%	16%	22%
UK Power Networks	28%	16%	21%
Fuel poor	17%	8%	6%
Vulnerable	50%	61%	61%
Off-gas	15%	26%	18%
Electric vehicle	1%	11%	7%
PV	2%	20%	12%
Heat pumps	1%	17%	8%

Figure 6.3: SME target profile v sample profile by season

	Nationally representative	Winter	Summer
Agriculture, forestry & fishing	5%	1%	4%
Mining and quarrying	1%	1%	1%
Manufacturing	5%	23%	27%
Construction	11%	10%	11%
Wholesale and retail trade	18%	8%	8%
Transport and storage	3%	8%	6%
Accommodation and food service	6%	6%	6%
Information and communication	7%	6%	6%
Finance and insurance	2%	4%	6%
Real estate	4%	5%	2%
Arts, entertainment and recreation	3%	7%	6%
Professional, scientific and technical	17%	7%	11%
Education	2%	7%	7%
Human health and social work	6%	8%	10%
Administrative and support service	8%	6%	3%
Public sector	17%	24%	23%
Private sector	83%	74%	75%
Charity	3%	1%	0%
<10 employees	54%	56%	62%
10 to 49 employees	25%	22%	16%
50 to 249 employees	21%	22%	22%

6.2 CE analysis

A detailed description of the modelling process is given in the technical appendix.

6.3 VoLL estimations

Summary of results

Figures 6.4 to 6.7 summarise the mean WTA values calculated from the model results and then grossed up to a MW/h value. A value range for the 95% confidence interval is also shown.

In figures 6.5 and 6.7 we see how SME customers value planned outages relative to unplanned, which demonstrates the reduction in WTA when notice is provided. The difference is more dramatic than for domestic customers (as seen in figures 6.4 and 6.6).

The broader confidence intervals around the estimates for SME customers, when compared to domestic customers, is partly a function of sample size, but also indicates more diversity of VoLL among SME customers. VoLL is then broken down by sub-group for domestic and SME customers in Figures 6.8 and 6.9.

Figure 6.4: Domestic VoLL by frequency and duration of outages (unplanned)

						Confidence Interval (95%)	
Domestic WTA unplanned		**WTA**	**Lower**	**Upper**	**VoLL**	**Lower**	**Upper**
Once every 3 years	1 hour	**£7.87**	***£7.30***	***£8.44***	**£17,481**	***£16,209***	***£18,753***
2-3 times every 3 years	1 hour	£9.61	*£8.96*	*£10.26*	£21,333	*£19,887*	*£22,779*
4-6 times every 3 years	1 hour	£10.52	*£9.82*	*£11.21*	£23,354	*£21,813*	*£24,895*
7-14 times every 3 years	1 hour	£15.86	*£14.88*	*£16.84*	£35,213	*£33,037*	*£37,388*
15+ times every 3 years	1 hour	£16.78	*£15.75*	*£17.81*	£37,259	*£34,966*	*£39,552*
Once every 3 years	6 hours	**£12.58**	***£11.66***	***£13.50***	**£27,937**	***£25,903***	***£29,970***
2-3 times every 3 years	6 hours	£15.35	*£14.31*	*£16.39*	£34,092	*£31,781*	*£36,404*
4-6 times every 3 years	6 hours	£16.81	*£15.70*	*£17.92*	£37,322	*£34,859*	*£39,785*
7-14 times every 3 years	6 hours	£25.34	*£23.78*	*£26.91*	£56,273	*£52,797*	*£59,750*
15+ times every 3 years	6 hours	£26.81	*£25.16*	*£28.46*	£59,544	*£55,879*	*£63,208*
Once every 3 years	12 hours	**£14.40**	***£13.35***	***£15.45***	**£31,981**	***£29,654***	***£34,309***
2-3 times every 3 years	12 hours	£17.58	*£16.38*	*£18.77*	£39,028	*£36,383*	*£41,674*
4-6 times every 3 years	12 hours	£19.24	*£17.97*	*£20.51*	£42,726	*£39,906*	*£45,545*
7-14 times every 3 years	12 hours	£29.01	*£27.22*	*£30.80*	£64,421	*£60,441*	*£68,400*
15+ times every 3 years	12 hours	£30.70	*£28.81*	*£32.59*	£68,165	*£63,969*	*£72,360*
Once every 3 years	2-3 days	**£18.04**	***£16.73***	***£19.36***	**£40,071**	***£37,154***	***£42,987***
2-3 times every 3 years	2-3 days	£22.02	*£20.53*	*£23.51*	£48,901	*£45,586*	*£52,215*
4-6 times every 3 years	2-3 days	£24.11	*£22.52*	*£25.70*	£53,533	*£50,000*	*£57,065*
7-14 times every 3 years	2-3 days	£36.35	*£34.10*	*£38.59*	£80,716	*£75,730*	*£85,702*
15+ times every 3 years	2-3 days	£38.46	*£36.09*	*£40.83*	£85,406	*£80,150*	*£90,663*

Figure 6.5: SME VoLL by frequency and duration of outages (unplanned)

						Confidence Interval (95%)	
SME WTA unplanned		**WTA**	**Lower**	**Upper**	**VoLL**	**Lower**	**Upper**
Once every 3 years	1 hour	**£158**	**£151**	**£165**	**£46,972**	***£44,833***	***£49,110***
2-3 times every 3 years	1 hour	£158	£151	£165	£46,972	*£44,833*	*£49,110*
4-6 times every 3 years	1 hour	£288	£277	£298	£85,621	*£82,428*	*£88,814*
7-14 times every 3 years	1 hour	£302	£291	£313	£89,854	*£86,536*	*£93,173*
15+ times every 3 years	1 hour	£403	£389	£417	£119,919	*£115,773*	*£124,065*
Once every 3 years	6 hours	**£252**	**£241**	**£264**	**£75,065**	***£71,649***	***£78,482***
2-3 times every 3 years	6 hours	£252	£241	£264	£75,065	*£71,649*	*£78,482*
4-6 times every 3 years	6 hours	£460	£443	£477	£136,831	*£131,728*	*£141,934*
7-14 times every 3 years	6 hours	£482	£465	£500	£143,597	*£138,294*	*£148,899*
15+ times every 3 years	6 hours	£644	£622	£666	£191,643	*£185,017*	*£198,268*
Once every 3 years	12 hours	**£289**	**£276**	**£302**	**£85,934**	***£82,022***	***£89,845***
2-3 times every 3 years	12 hours	£289	£276	£302	£85,934	*£82,022*	*£89,845*
4-6 times every 3 years	12 hours	£526	£507	£546	£156,642	*£150,800*	*£162,484*
7-14 times every 3 years	12 hours	£552	£532	£573	£164,387	*£158,317*	*£170,458*
15+ times every 3 years	12 hours	£737	£712	£763	£219,389	*£211,805*	*£226,974*
Once every 3 years	2-3 days	**£362**	**£345**	**£378**	**£107,670**	***£102,769***	***£112,571***
2-3 times every 3 years	2-3 days	£362	£345	£378	£107,670	*£102,769*	*£112,571*
4-6 times every 3 years	2-3 days	£659	£635	£684	£196,264	*£188,944*	*£203,583*
7-14 times every 3 years	2-3 days	£692	£666	£718	£205,968	*£198,362*	*£213,574*
15+ times every 3 years	2-3 days	£924	£892	£955	£274,883	*£265,379*	*£284,386*

Figure 6.6: Domestic VoLL by frequency and duration of outages (planned)

						Confidence Interval (95%)	
Domestic WTA planned		**WTA**	**Lower**	**Upper**	**VoLL**	**Lower**	**Upper**
Once every 3 years	1 hour	**£0.48**	**£0.00**	**£1.10**	**£1,066**	***£0***	***£2,438***
2-3 times every 3 years	1 hour	£0.59	£0.00	£1.25	£1,306	*£0*	*£2,781*
4-6 times every 3 years	1 hour	£2.88	£1.72	£4.04	£6,403	*£3,830*	*£8,975*
7-14 times every 3 years	1 hour	£7.79	£5.04	£10.54	£17,304	*£11,194*	*£23,414*
Once every 3 years	6 hours	**£2.88**	**£0.00**	**£6.59**	**£6,397**	***£0***	***£14,626***
2-3 times every 3 years	6 hours	£3.53	£0.00	£7.52	£7,836	*£0*	*£16,688*
4-6 times every 3 years	6 hours	£17.30	£10.35	£24.25	£38,418	*£22,982*	*£53,853*
7-14 times every 3 years	6 hours	£46.75	£30.25	£63.26	£103,825	*£67,164*	*£140,486*
Once every 3 years	>6 hours	**£5.76**	**£0.00**	**£13.17**	**£12,795**	***£0***	***£29,251***
2-3 times every 3 years	>6 hours	£7.06	£0.00	£15.03	£15,671	*£0*	*£33,376*
4-6 times every 3 years	>6 hours	£34.60	£20.70	£48.50	£76,835	*£45,964*	*£107,706*
7-14 times every 3 years	>6 hours	£93.51	£60.49	£126.53	£207,650	*£134,328*	*£280,973*

Figure 6.7: SME VoLL by frequency and duration of outages (planned)

						Confidence Interval (95%)	
SME WTA planned		**WTA**	**Lower**	**Upper**	**VoLL**	**Lower**	**Upper**
Once every 3 years	1 hour	**£0.22**	**£0.17**	**£0.27**	**£487**	***£371***	***£603***
2-3 times every 3 years	1 hour	£1.04	£0.96	£1.11	£2,302	*£2,134*	*£2,470*
4-6 times every 3 years	1 hour	£1.20	£1.12	£1.29	£2,676	*£2,490*	*£2,861*
7-14 times every 3 years	1 hour	£1.79	£1.69	£1.90	£3,985	*£3,753*	*£4,217*
Once every 3 years	6 hours	**£1.32**	**£1.00**	**£1.63**	**£2,922**	***£2,227***	***£3,618***
2-3 times every 3 years	6 hours	£6.22	£5.77	£6.67	£13,811	*£12,803*	*£14,819*
4-6 times every 3 years	6 hours	£7.23	£6.73	£7.73	£16,054	*£14,939*	*£17,168*
7-14 times every 3 years	6 hours	£10.77	£10.14	£11.39	£23,909	*£22,517*	*£25,301*
Once every 3 years	> 6 hours	**£2.63**	**£2.01**	**£3.26**	**£5,845**	***£4,454***	***£7,236***
2-3 times every 3 years	> 6 hours	£12.44	£11.53	£13.35	£27,622	*£25,606*	*£29,638*
4-6 times every 3 years	> 6 hours	£14.46	£13.45	£15.46	£32,108	*£29,879*	*£34,337*
7-14 times every 3 years	> 6 hours	£21.53	£20.28	£22.79	£47,818	*£45,034*	*£50,602*

Figure 6.8: Domestic VoLL (WTA) by sub-groups[34]

Domestic WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%) Lower	Upper	Index v Total
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+[35]	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[36]	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
SP Energy Networks	308	**£6.69**	£5.02	£8.36	**£14,707**	***£11,033***	***£18,380***	84

[34] The average consumption for domestic customers is 0.00045 MW per hour. An average WTA value of £7.87 per hour (range £7.30 - £8.44) was obtained for all domestic customers, giving a MWh value of £7.87/0.00045 = £17,481 (range £16,209 - £18,753). The average consumption for SME customers is 0.00336 MW per hour. An average WTA value of £160 per hour (range £152 - £167) was obtained for all SME customers, giving a MWh value of £160/0.00336 = £47,560 (range £45,289 - £49,830). The actual calculations were based on numbers to 16 decimal places.
[35] Unadjusted for income (adjusted WTA = £19,372 (Index 111)
[36] 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
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[37]	1951	**£8.54**	£7.56	£9.51	**£19,632**	***£17,388***	***£21,875***	112
Fuel poverty[38]	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)[39]	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

37 Adjusted for income (unadjusted WTA = £16,941 (Index 97)
38 Adjusted for income (unadjusted WTA = £21,646 (Index 124)
39 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[40]	872	**£8.63**	£7.25	£10.01	**£19,175**	***£16,115***	***£22,235***	110
Medium vulnerable[41]	397	**£8.99**	£6.78	£11.19	**£21,106**	***£15,929***	***£26,284***	121
High vulnerable[42]	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

40 Adjusted for income (unadjusted WTA = £17,447 (Index 100)
41 Adjusted for income (unadjusted WTA = £16,608 (Index 95)
42 Adjusted for income (unadjusted WTA = £15,211 (Index 87)

Figure 6.9: SME VoLL (WTA) by sub-groups

SME WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%) Lower	Upper	Index v Total
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**
Off-gas	316	**£152**	£144	£161	**£49,056**	*£46,406*	*£51,706*	**103**
Want to keep bills constant	188	**£144**	£132	£155	**£45,823**	*£42,297*	*£49,349*	**96**
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**

SME WTA unplanned	n	WTA	Lower	Upper	VoLL	Confidence Interval (95%) Lower	Upper	Index v Total
No power cuts (either planned or unplanned)	239	**£147**	£137	£157	**£38,167**	*£35,648*	*£40,686*	**80**
Power cuts (either planned or unplanned)	376	**£153**	£143	£163	**£51,341**	*£47,981*	*£54,701*	**108**
Experienced planned power cut	185	**£232**	£215	£248	**£58,227**	*£54,077*	*£62,377*	**122**
Experienced large scale interruption L12M	87							
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**

Grey font indicates small sample size, interpret with caution

6.4 Estimating VoLL for customers with multiple characteristics

Background

This research corroborates previous studies by demonstrating that VoLL varies substantially across different domestic and business sub-groups. This is clear when drawing comparisons across single characteristics; however, complications are introduced when considering how VoLL should be represented for customers defined by multiple characteristics ie, more than one household attribute.

The most accurate way of achieving a credible value is to extend the model used to calculate VoLL to include any number of combinations of customer characteristics, with minimum limits placed on sample size to ensure robustness. This is possible, but the number of combinational possibilities moves rapidly into the thousands if more than two groups are used, and sample sizes quickly become too small to give reliable estimates.

A more flexible method is to look at the variation in VoLL seen for single characteristics and combinations of only two or three characteristics. This provides a means of calculating a set of reliable criteria to predict VoLL for more complex groups. An investigation of the feasibility of such an approach is given below.

Predicting VoLL for complex households using simple households

This analysis focused on whether it was possible to use the VoLL calculated for single household characteristics (ie females or ages 18-29 years) to predict the VoLL when the two are combined (ie females and 18-29 years). If so, it could potentially be extended to very complex households comprised of three plus attributes.

Stage 1: Deriving the VoLL for individual sub-groups

The first stage was to compare the VoLL for individual sub-groups (ie females only) with that of the total sample. This can be achieved by creating a ratio of the total VoLL with the VoLL for females. A ratio of 1.0 indicates that the sub-group is very close to the total, greater than 1.0 indicates the sub-group VoLL is greater than the total and less than 1.0 indicates the sub-group VoLL is less than the total.

These ratios show the effect that the sub-group has on increasing or decreasing the total VoLL (the VoLL calculated for the total). Figure 6.10 below shows that VoLL varies little by gender but substantially by age[43].

Figure 6.10: Examples of the effect each sub-group has on the total VoLL

Single sub-group	VoLL ratio
Female	1.054
Male	0.966
18 – 29 years	0.945
30 – 44 years	1.146
45 – 59 years	0.968
60+ years	0.986

43 It should be noted that, as the VoLL calculation is made separately for each group at the aggregate level (ie not a simple mean average of individual respondent values), the VoLL ratios will not always average to 1.0. For example, Females have a ratio of 1.0 and males a ratio of 0.992 due to the variations in the estimates for each group (an exact average would show both to be 1.0)

Stage 2: Extending to more than one sub-group

The purpose of this analysis was to attempt to use the *effect* that individual sub-groups had on VoLL and accurately apply this information to predict VoLL for complex households (ie. more than three attributes).

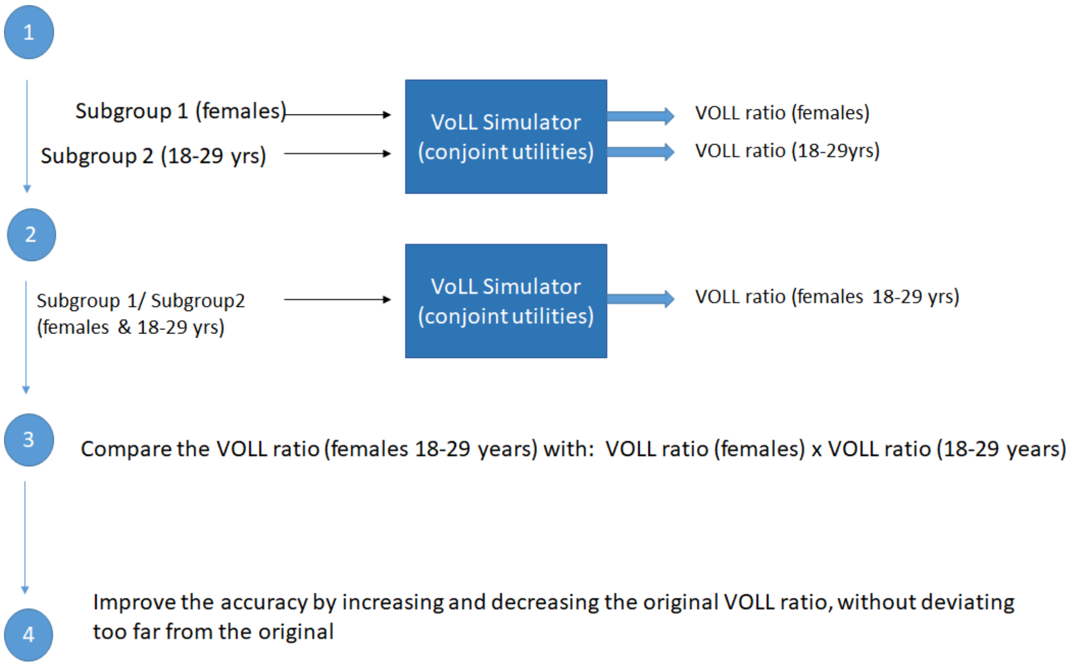
To develop the model, the mean average of two individual sub-groups was used and the result compared to the *actual* VoLL for households containing two attributes. If this proved accurate, it could then extend to households containing three attributes or more.

Modelling complex households using the main sub-group effects

In the prediction of VoLL for several sub-groups, the main effects (one sub-group only) was used to mathematically derive the VoLL for two sub-groups, which was then compared against the actual VoLL for two sub-groups.

To minimize this error, the multiplication of the sub-group effects is then weighted using the Excel Solver algorithm. Figure 6.11 below summarises this process.

Figure 6.11: Process for testing accuracy using the multiplicative model



Accuracy of the model

Using this approach, it was found that 60% of the combinations had more than 10% difference between the predicted and actual. In addition, 32% had more than 20% difference. This shows a level of volatility that cannot be directly explained using the single sub-groups alone. Other factors influencing this include:

Sample size

- The prediction is more stable with larger sample sizes

Specific sub-groups

- Combinations with MDE, worst served and social group DE tended to produce the largest differences from actual VoLL.

The original VoLL calculation is an estimation in itself

- Given the mathematical design (the conjoint design) of the original VoLL, this can be expected to be the best estimation possible in a simulated environment; however, it is still an estimate.
- The process of trying to derive a formula to predict VoLL in complex households is, by its nature, an estimation. This exercise is therefore 'an estimation of an estimation', which presents significant challenges in obtaining a level of accuracy that is sufficiently stable.

Application to complex households

The purpose of this model was to credibly predict VoLL in complex households ie more than two sub-groups at the same time. Analysis demonstrated that a VoLL prediction, using this methodology, is only possible when confined to just two sub-groups. Given the unacceptable accuracy level when predicting VoLL for two sub-groups, it was recognised that it would be less acceptable, when trying to predict VoLL with more than three sub-groups.

Final VoLL estimation tool

Given these findings, it was concluded that the most accurate method for deriving VoLL for complex households is to obtain these for only two sub-groups at a time.

Use of the tool

Figure 6.12 illustrates the VoLL calculation tool for households and SMEs. Each row represents a meter point administration number (MPAN). The user codes each MPAN in terms of its salient features (customer type, region, supply quality, LCT, power cuts, vulnerability and consumption). The subsequent average and maximum VoLL are automatically populated when the user clicks on the 'calculate VoLL' button. The tool then takes the two highest VoLL values relevant to each MPAN and multiplies these together for the final estimate. The maximum VoLL is the single highest user group value for that MPAN.

This tool runs under Microsoft Excel and should therefore be regarded as a test tool. When large numbers of MPANs need to be processed, a more efficient database platform should be developed as the basis for the tool.

Figure 6.12: VoLL calculation tool for households

	A	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP
2	Calculate VoLL	VoLL		Customer Type		Region		Supply quality				LCT			Power Cuts		Vulnerability			Consumption		
3	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
4	1	£18,543	£18,543	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0
5	2	£21,314	£21,314	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0
6	3	£17,884	£17,884	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0
7	4	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
8	5	£21,493	£21,493	1	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0
9	6	£19,221	£19,221	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0
10	7	£21,493	£21,493	1	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0
11	8	£21,962	£22,610	1	0	1	0	1	0	0	1	0	0	0	0	1	0	1	0	0	1	0
12	9	£18,543	£18,543	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0
13	10	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
14	11	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
15	12	£32,470	£32,470	1	0	1	0	0	1	1	0	1	0	0	0	1	0	1	0	0	1	0
16	13	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
17	14	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
18	15	£17,142	£17,481	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0
19	16	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
20	17	£51,341	£51,341	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
21	18	£22,987	£24,480	1	0	0	1	0	0	0	0	1	0	1	1	0	0	1	0	0	1	0
22	19	£19,443	£19,664	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0
23	20	£17,464	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0
24	21	£19,443	£19,664	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0
25	22	£47,560	£47,560	0	1	0	1	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0
26	23	£51,341	£51,341	0	1	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0
27	24	£32,470	£32,470	1	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0
28	25	£17,142	£17,481	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
29	26	£17,884	£17,884	1	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0
30	27	£71,173	£73,894	0	1	1	0	0	0	0	1	0	0	1	0	1	0	1	0	0	1	0
31	28	£45,722	£47,560	0	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0
32	29	£21,314	£21,314	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
33	30	£47,560	£47,560	0	1	0	1	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0

Conclusions

This section summarises the analysis conducted when attempting the prediction of VoLL for complex households (up to two sub-groups combined). This analysis was lengthy and complex, as a model is only useful if it is accurate across many scenarios. VoLL in itself is an estimation derived from simulating an unfamiliar environment and asking respondents to make choices, therefore this task presented real challenges.

It was concluded that the most accurate method of deriving VoLL for different household structures was to limit the calculation to estimates based on a maximum of two sub-groups. This approach ensured that the highest level of accuracy possible was taken into consideration in the interpretation of the results. The tool produced for this purpose ensures quick access to VoLL estimations for different sub-group combinations of households and businesses.

6.5 Mitigation summary tables

Figure 6.13: Importance of support components relative to the least important (mobile charging unit) in mitigating the impact of a supply interruption lasting one hour

Support component appraised by domestic customers	Relative importance of each component	Mitigated time (minutes)
Phone call(s) made to your mobile or landline	x 3.0	4.9
Accurate information confirming when power will be restored	x 2.6	4.3
SMS (short message service)	x 2.6	4.3
Automated text-to-speech message	x 2.3	3.8
A justified reason for the power cut	x 1.9	3.2
Updates sent to a nominated friend or family member	x 1.6	2.6
Information about the area affected by the power cut	x 1.4	2.3
Generator	x 1.4	2.3
Confirmation that your electricity is back on	x 1.4	2.3
Advice about what to do during a power cut	x 1.4	2.3
Sending a mobile catering van	x 1.3	2.2
An indication of the number of properties affected	x 1.3	2.1
Social media	x 1.2	2.0
A welfare pack	x 1.2	2.0
Public address/tannoy system	x 1.1	1.9
Home visits	x 1.1	1.8
Sending a mobile charging unit	x 1.0	1.7

Similar priorities can be observed for SME customers in Figure 6.14 below.

Figure 6.14: Importance of support components relative to the least important (mobile charging unit) in mitigating the impact of a supply interruption lasting one hour.

Support component appraised by SME customers	Relative importance of each component	Mitigated time (minutes)
SMS (short message service)	x 3.1	7.7
Phone call(s) made to your mobile or landline	x 2.7	6.7
Accurate information confirming when power will be restored	x 2.5	6.3
Updates sent to a nominated friend or family member	x 2.3	5.9
Automated text-to-speech message	x 2.3	5.9
Confirmation that your electricity is back on	x 2.2	5.6
A justified reason for the power cut	x 2.0	5.0
Social media	x 2.0	5.0
Information about the area affected by the power cut	x 1.9	4.7
Indication of the no of properties affected by the power cut	x 1.8	4.6
Advice about what to do during a power cut	x 1.7	4.3
Home visits	x 1.7	4.2
Generator	x 1.6	4.1
Sending a mobile charging unit	x 1.6	3.9
Sending a mobile catering van	x 1.4	3.6
A welfare pack	x 1.3	3.3
Public address/tannoy system	x 1.0	2.5

6.6 Adjustments to 'willingness to accept' and pay estimates given the existing distribution of income

Professor Iain Fraser, School of Economics, University of Kent

Adjusting WTA by household income

There is a long standing tradition within economics that sees economic data being adjusted for reasons associated with equity eg, taking account of income distribution in terms of policy choices. The reason why such adjustments have been advocated stems from the distributional incidence of costs and benefits associated with an actual or proposed change. Clearly, all policy implementations and proposals have distributional impacts and as a result there is always the basic issue of equity versus efficiency that confronts economists. In general economists are asked to provide about the incidence of costs and benefits within society but making actual changes is less common in policy.

We also note that it is well understood within the valuation literature that the existing distribution of income in society impacts estimates of WTA and WTP. Essentially, it has been established that social WTP for environmental improvements increases as average income rises.

Applied cost-benefit analysis

One area in which adjustments to model estimates is frequently encountered is applied cost-benefit analysis (CBA). A useful summary of how to practically implement CBA is provided by Pearce et al. (2006) and subsequently updated by Atkinson and Mourato (2015). Both include discussion of how to consider and deal with the distributional impacts of policy.

When implemented in its standard form CBA ignores distributional implications simply indicating if a policy provides benefits greater than costs (the Kaldor-Hicks principle of welfare economics). This can occur even when those who benefit are the better-off in society and those who lose are the worse-off. In contrast, the justification for using weights within CBA or any form of welfare analysis can be based on a social welfare function (SWF) (Adler, 2013, 2016).

To understand how distributional weights work in principle assume we have two groups in society – 1 and 2. Then the net benefit (NB) to society from a policy is simply the sum of NBs. Now if we assume that there is no distinction made between the groups then the weights we attach to the groups (a1 and a2) are equal to one. However, if we wish to place greater weight on the NBs of group 1 compared to group 2 we can either increase a1 or decrease a2. The main issue with making these changes essentially relates to how to decide upon the weights that are used.

To include distributional changes in any analysis requires that some characteristic is identified within the population that can be used to assess equity. Typically, this is income or wealth. Then in order to make adjustments it is necessary to employ 'weights' that in some way reflect existing views about the distributional changes or impacts being examined. The potential impact of distributional weights on policy evaluation can have significant effects as noted by Pearce et al. (2006):

"On the other hand, even apparently small changes in assumptions about the size of distributional weights – indicated by the range of values in available empirical studies – can have significant implications for recommendations about a project's social worth."

However, in Pearce et al. (2006) they discuss how to derive these weights (see section 15.3.3. Explicit Distributional Weights). As they explain, economic theory can provide some guidance as to how to derive these weights. Specifically, it is assumed that if we have diminishing marginal utility of income then it follows that the utility value associated with a one unit change in a poor person's income will be greater than that of a rich person. This then means that there is a difference in net benefits from a policy once we explicitly take account of the relative contribution from the distribution of income within society and its resulting impact on social welfare.

Pearce et al. (2006) explain how distributional weights can be implemented as follows:

$$a_i = \left(\frac{\bar{Y}}{Y_i}\right)e$$

where $\bar{Y}$ bar is average income, Y_i is group of individual income and e is the elasticity of the marginal utility of income. If it is assumed that e=1 then we have standard weights as a_i=1. However, as the weights diverge from one there are changing impacts on how specific groups are weighted.

Within the literature there is some debate as to how e can be identified. Typically, it has been proposed that it can be assessed given the tax regime that prevails within a specific country. There are, however, some issues with this approach and alternatives have been proposed.

There is extensive discussion within the literature on how to generate the distributional weights that can be used. For a recent discussion and overview of the literature see Fleurbaey and Abi-Rafeh (2016).

Adjustments to WTA/WTP

The same justifications that underpin adjustments to CBA can also be employed to defend adjustments to WTA/WTP estimates that in turn feed into applied policy analysis. A simple example of this type of adjustment is provided by Pearce and Barbier (2000). In Pearce and Barbier (2000) the method of adjustment made to WTP is simple and of the following form:

$$\text{Adjusted WTP}_i = (Y^*/Y_i)*\text{WTP}_i$$

where Y^* is the average level of income; Y_i is the group or individual specific measure of income; and WTP_i is the WTP estimate for group or individual i. So what is assumed in this type of adjustment is that the weight attached to any specific estimate of WTP (or WTA) depends on where in the income distribution an individual person is located.

An area in which adjustments to WTA/WTP are frequently made with a policy application in mind is with regard to benefit transfer (BT) (Meya et al, 2018). This is the situation in which an estimate of WTA/WTP is taken from an existing study context (eg, country A) and then used in a policy evaluation is another context (eg, country B) as this reduces the need to duplicate a study and generate country-specific WTA/WTP estimates.

Government justification for adjustments

The extent to which adjustments are made to take account of distributional outcomes of a policy means that the UK government and others provide guidance on when and how this can and should be done. Specifically, the HM Treasury (2018) Green Book provides very useful guidance on this topic.

In particular, it is noted that:

"5.69. Distributional weights are factors that increase the monetary value of benefits or costs that accrue to lower income individuals or households. They are based on the principle that the value of an additional pound of income may be higher for a low-income recipient than a high-income recipient.

5.70. Distributional weights can be used as part of the distributional analysis where there is understood to be a social value that differs from simple additionality due to who gains or loses. To account for the uncertainties, sensitivity analysis is recommended and it may be useful to estimate switching values ie the distributional weights required to change the preferred option. This provides an estimate of the certainty of the results based on the weights used.

5.71. In practice the use of distributional weighting is challenging. This is due to uncertainty in the assumptions relating to the groups between whom redistribution is measured and uncertainty in estimation of distributional weights.

5.72. Distributional results should be presented transparently. For example, if distributional weightings are used to adjust estimated costs or benefits depending on which groups in society they fall on, the analysis with weightings should be presented alongside the analysis without weightings." (p. 34 and 35).

Furthermore, within the Green Book (HM Treasury, 2018) it is stated that the Department of Work and Pensions (DWP) currently employs an estimate of 1.3 for the elasticity of marginal utility of income that is based on the research of Layard et al. (2008). How to understand this estimate is neatly summarised as follows in the Green Book:

"Broadly a value of 1 for the marginal utility of income would indicate that the utility of an additional pound is inversely proportional to the income of the recipient. An additional £1 of consumption received by someone earning £20,000 per year would be worth twice as much than to a person earning £40,000. Higher estimates of the marginal utility of income will mean the value of an additional pound declines more quickly relative to increases in income." (p. 80)

Finally, there is also guidance as to when to undertake distributional adjustments:

"A3.24 When considering how to apply the guidance above consider the following steps:

"... does the policy have different financial impacts across income groups, or is redistribution a consequence? If yes, then consider applying welfare weights." (p. 80).

Summary and observations

There is an existing precedent for making adjustments within an economic analysis of policy to take account of distributional consequences. There is also explicit government support and guidance on this practice. However, what is currently lacking in the literature is explicit guidance on how adjustments to WTA/WTP should be made other than with reference to average levels of income as well as possibly the elasticity of the marginal utility of income.

In the case of the current research project it is easier to defend an adjustment to WTP estimates given that we know that these are influenced by the existing level of income. However, it is less clear that adjustments are required for WTA estimates. If it can be argued that estimates of WTA by income group are lower for low income households, then the same rationale for changes that can be made to WTP can be defended.

In many ways the results reported by London Economics provides support for how WTA is impacted by income levels:

"Interestingly, we observe that the level of compensation required by respondents in the face-to-face interviews, by vulnerable consumers (including vulnerable consumers from both the face-to-face survey and from the online survey) and by consumers who cannot keep their home heated to a comfortable level is lower than the level of compensation required by the average respondent (ie, the baseline estimate).

In this study we see the same lower WTA values for low income customers and argue that income adjustment is necessary for an equitable comparison. This will affect all predominantly low income groups: DE social groups, vulnerable customers, those in fuel poverty and those who are medically dependent on electricity (MDE), this particular group being more likely not be working and hence on a restricted income.