Reckon LLP
Data analysis | Economic regulation | Competition law

Desktop review and analysis of information on Value of Lost Load for RIIO-ED1 and associated work

25 May 2012

Summary and findings

Scope of the study

1. This study is concerned primarily with valuing interruptions in the electricity supply. It covers:

   (a) published estimates of willingness to pay (WTP), measuring how much a customer would be willing to pay to avoid an interruption, or to avoid lengthier interruptions;

   (b) published estimates of willingness to accept (WTA), measuring how much a customer would be willing to accept in exchange for enduring an additional interruption or longer interruptions; and

   (c) published estimates of costs of an interruption, measuring the costs a customer incurs due to an interruption.

2. The study is also concerned with discussing ways in which estimates may be used by Ofgem as part of its work for the forthcoming distribution price control review, RIIO-ED1.

Abuse of the term VOLL

3. The term value of lost load, abbreviated to VOLL, is used in a number of settings, including sometime in studies on reliability of supply. In this report we abuse the term VOLL. We use it as shorthand to refer to estimates of WTP, of WTA or of costs due to interruptions in the electricity supply. We also use it to refer to estimates irrespective of the units in which the estimates are expressed, including pounds sterling, pounds sterling per unit of consumption, pounds sterling per interruption, pounds sterling per customer minute loss. This shorthand is for convenience alone.

We selected those studies that appeared most relevant

4. Valuing interruptions in the electricity supply is a topic that has been of interest to energy regulators, companies and academics. We have found numerous published studies on the subject and have reviewed a subset of these. We made our choice on the basis of how far back the studies relate to, and of how similar the context of the study is to the UK.

5. We sought to strike a balance between reporting a sufficient number of estimates to provide Ofgem with a sense of the range of estimates reported in published papers, and reporting too many estimates (of perhaps tenuous relevance) that would risk cluttering the picture.

6. The approaches followed by the studies we review are of one of two broad types:

   (a) an approach based on survey of costumers about their WTP, their WTA or about the costs they would incur due to changes in the reliability of their electricity supply; and

   (b) an approach based on macroeconomic data, namely the gross value added of sectors, and on sector-wide annual electricity consumption.

Drawing together estimates from across studies

7. The studies we reviewed report estimates of VOLL in a variety of ways, expressed in different units, e.g. as a monetary value, as a monetary value per unit of consumption, as a percentage of electricity bill.

8. For the purpose of comparing sets of estimates, we have converted estimates from the different studies into a common unit.

   (a) For domestic customers, we have derived estimates of VOLL for a 1-hour and for an 8-hour interruption in pounds sterling.

   (b) For non-domestic customers, we have derived estimates for a 1-hour interruption expressed as pounds sterling per kW per hour.

9. We have normalized the estimates for non-domestic customers on the basis of the annual electricity consumption, scaled down to reflect the duration of the interruption. Because we were concerned with 1-hour interruption, the scaling factor was the

number of hours in the year. We normalized the estimates for non-domestic customers because this allows for better comparability across businesses of different sizes and with different energy intensity.

10. When bringing together estimates of VOLL from across different studies we will expect to obtain a wide range of estimates.

11. The estimates reflect the preferences of customers in the countries or regions, and at different points in time, with which a particular study was concerned with and it is reasonable to expect for these preferences to vary. We expect that there are many factors that contribute to the difference in the preference of respondents sampled in different studies. These may include, for example, differences in customers' attitudes to an "entitlement" to continuous electricity supply, differences in the reliability of supply that customers are accustomed to or differences in customers' income levels.

12. With respect to business customers, we would expect their preferences regarding electricity reliability to be influenced by factors such as the degree to which their economic activity is dependent on electricity as well as by the size of their operation,

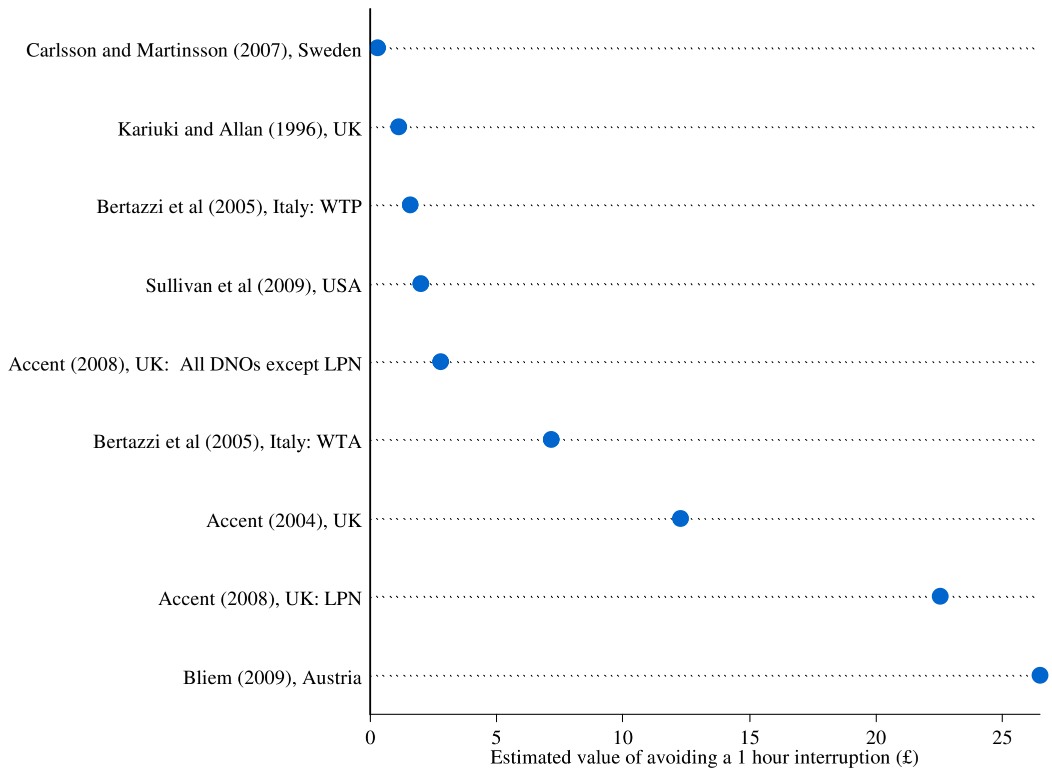
13. The estimates derived by the different studies are based on different methodologies regarding the collection and the analysis of the data. Such differences of approach will also impact on the estimates obtained. That is to say, even if it were the case that the exact same group of respondents were sampled by different studies, we would expect the different studies to produce different estimates of VOLL as the estimates would be sensitive to the details of how the data were collected and analysed. Restricting ourselves to methods relying on a survey of customers as an example, the estimates obtained would be sensitive to exactly how the set of questions were asked (e.g. what attributes of reliability were respondents asked about, what levels were chosen, how were the questions framed, were respondents asked about WTP, WTA or direct costs) as well as to how the data were subsequently analysed (e.g. what econometric modelling was done, how was the model specification chosen).

14. It is not possible to disentangle the factors that contribute to the differences that are observed in the estimates from the different studies.

Estimates for domestic customers

15. Figure 1 compares the estimates for domestic customers for a 1-hour interruption, identifying the study from which the estimate was derived. As is the case of the other two figures in this section, figure 1 presents the estimates only from those studies we considered to be of relatively high relevance.

Figure 1 Domestic customers: estimated value of a 1 hour interruption (£)



16. The figure shows the estimates range from £0.30 to £26.46, for a 1-hour interruption. This range contains several estimates relating to the UK, namely the work by Accent for Ofgem in 2004 and 2008 and the 1996 article by Kariuki and Allan.

17. The highest estimate, £26.46, is derived from a study for Austria by Bliem (2009). One hypothesis is that this particularly high estimate is driven by the structure of the survey questions, and subsequent econometric modelling, used by the author. The specification of the model in the econometric analysis is such that it identifies, for example how the total time in a year during which there would be outages affects customers' choice between one reliability scenario or another, keeping other things constant including the frequency of interruptions. We do not think such an estimate is intuitive to interpret and we suggest that this contrived specification may explain the particularly high estimate derived by the study.

18. Another of the higher estimates, £22.55, is derived from Accent's 2008 estimate on the WTP for one less interruption by domestic customers in the LPN area in the UK; this is labelled in figure 1 as "Accent (2008), UK: LPN, interruption". This estimate is significantly higher than the estimate that was derived in that same study for customers in the remaining electricity distribution network operator (DNO) regions, £2.81. A hypothesis that may contribute to explaining the difference between these two estimates is that the reliability of supply in the LPN region is better than in other

regions — the frequency of interruptions is lower and the average duration of an interruption is significantly lower — and that customers with less experience of dealing with, and accommodating, interrupted supply have a higher valuation of avoiding an interruption.

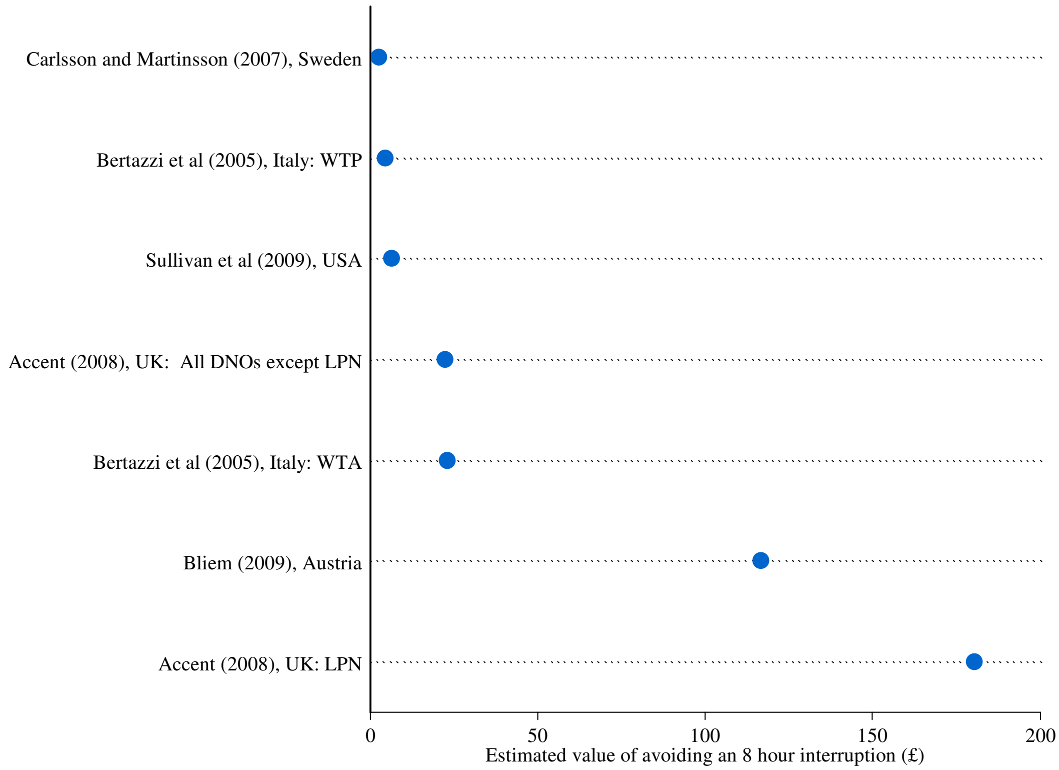
19. Other than the two estimates derived from Accent (2008), figure 1 includes two other estimates for the UK: the estimate derived from Accent (2004) is £12.28 and the estimate derived from Kariuki and Allan (1996) is £1.12. The Accent (2004) estimate is significantly higher than the Accent (2008) estimate for customers in areas other than LPN. The two studies were based on surveys with similar sampling procedure but the framing of the questions to respondents and the econometric analysis done on the data collected differs. We are not able to pin-point a possible reason for the difference between the two estimates. Accent (2008) itself is no more precise than suggesting methodological differences as one reasons for the difference in relation to its 2004 estimate. At the other end of the range of estimates for the UK is the one based on the results of Kariuki and Allan (1996), £1.12 for a 1-hour interruption. We have not identified a hypothesis that could explain this particularly low estimate.

20. The estimates derived from Carlsson and Martinsson (2007), a study relating to Sweden, is at the low end of the range. We find no feature in the design of the survey or in the analysis of those studies why this should be the case.

21. Lastly, we note that the estimate that is based on customer responses about their WTA — labelled in figure 1 as "Bertazzi et al (2005), Italy: WTA" — is also towards the higher end of the range, and is greater than the estimate "Bertazzi et al (2005), Italy: WTP" from the same study but based on WTP. A possible explanation for this is that domestic customers have a sense of entitlement to a reliable energy supply, leading them to be willing to depart with relatively little money to obtain an improvement in performance compared to the money they would be willing to accept in exchange for a worsening in performance.

22. Figure 2 compares the estimates of VOLL to domestic customers of an 8-hour interruption.

Figure 2 Domestic customers: estimated VOLL of a 8 hour interruption (£)



23. We have found fewer studies reporting estimates from which we can derive, or extrapolate, values for an 8-hour interruption. The estimates from the studies we consider to be of relatively high relevance range from £2.66 to £180.44.

24. Similar considerations to those set out earlier when discussing the variations in the estimates for a 1-hour interruption apply to a discussion of the variation in the estimates for an 8-hour interruption.

Estimates for non-domestic customers

25. We have reviewed a number of studies that estimate VOLL for non-domestic customers. Typically, those estimates distinguish between different categories of non-residential customers. The categorization used is not common across all studies. The categorisation may be done on the basis of:

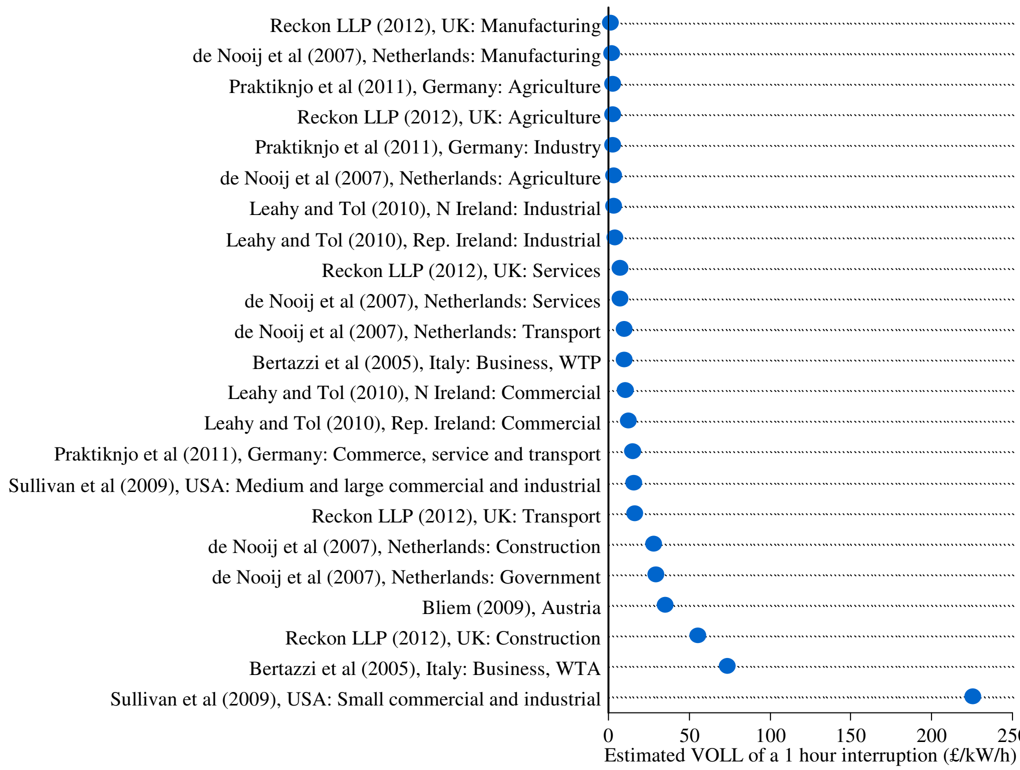
(a) the sector of economic activity, at varying degrees of granularity, e.g. agriculture, manufacturing, construction, services; or

(b) the size of the customer, e.g. small commercial and industrial, medium and large commercial and industrial.

26. Where businesses are categorized, there is no consistency across studies in the definition used. A business categorized as "large" in the eyes of one study, need not qualify as "large" in the eyes of another.

27. Figure 3 brings together the estimates of VOLL for a 1-hour interruption, reported in terms of £/kW/h from across the set of relevant studies.

Figure 3 Non-domestic customers: estimated VOLL of a 1-hour interruption (£)



28. The estimates for non-domestic customers range from just over £1/kW/h to £225/kW/h.

29. It is noticeable that the estimate for "Sullivan et al (2009), USA: Small commercial and industrial" is, at £225/kW/h very much higher than all other estimates. One possible explanation for this is that this estimate, unlike the other estimates presented in the figure, relates to small business users. Small business users have a low electricity consumption compared to businesses on average and, medium and large businesses in particular. For example, within the sample of businesses covered by Sullivan et al (2009), annual energy consumption by medium and large businesses was more than 350 times that of businesses included in the "small commercial and industrial" sample. Given that the estimates of VOLL shown in figure 3 have been normalised with respect to consumption, the low level of consumption by small business leads to the estimate being particularly high.

30. Two of the studies from which the studies in figure 3 are derived are based on surveys of businesses costs, namely the work by Bertazzi et al (2005) and Sullivan et al (2009). The figure includes two estimates derived from Bertazzi et al (2005): one based on WTP and another based on WTA. As may be expected, the latter is considerably higher than the former.

31. The remaining estimates are derived from studies based on macroeconomic data, namely on a sector's ratio of value added to energy consumption. Amongst these are a set of estimates that we have derived ourselves, applying the method laid out in de Nooij et al (2007) to UK national accounts data; these are labelled in the figure with the prefix "Reckon LLP (2012), UK". Of the sector-specific estimates, those for the construction sector appear at the upper end. One hypothesis that could explain this is that a significant proportion of the gross value added of that sector is generated by activity that is not dependent on electricity, leading to an overestimation of VOLL by businesses in that sector.

Factors affecting estimates of VOLL

32. A small number of the studies we reviewed report on how estimates of VOLL vary according to the characteristic of the interruption, such as the expected day of the week in which interruptions occur or whether the interruption is planned or not.

33. For domestic customers, the estimated VOLL tends to be higher for unplanned rather than planned interruptions, for interruptions in winter rather than summer, and for interruptions on weekends rather than on weekdays.

34. For non-domestic customers, our review suggests that businesses, contrary to domestic customers, have a higher VOLL for weekday rather than weekend interruptions.

35. These readings are based on a small number of studies and we do not consider them to be sufficiently robust.

How may estimates of VOLL change in a low carbon economy?

36. We were asked to search for evidence on how estimates of VOLL may change in the transition to a low carbon economy.

37. We identified a number of features that could exist in a future low carbon economy. These include an increase in the number of electric vehicles, a greater proportion of generation being distributed generation, an increase in the penetration of electric heating in homes and development of smart grids. We have suggested the direction that the development of these features might have on VOLL. In some cases the direction is ambiguous.

38. It is also uncertain the pace at which the features we have identified may materialize, whether we would expect to see them take place over the next decade or later, or perhaps even at all.

39. Within this context, it would take a giant leap to speculate on how VOLL might develop over the next decade as a result of the emergence of features related to a change to a low carbon economy.

How can Ofgem make use estimates of VOLL?

40. We identify three areas in which Ofgem may be able to draw on estimates of VOLL.

(a) **Output incentive schemes**. Estimates could contribute to decisions about the incentive rate and also the level of baseline performance specified in output incentive schemes such as the current interruption incentive scheme.

(b) **Secondary deliverables**. Estimates could contribute to decisions about the secondary deliverables a DNO is expected to deliver during a price control period, taking account of the potential impact of secondary deliverables on interruptions over the longer term.

(c) **Compensation schemes**. Estimates could contribute to decisions about the value of any compensation payments that DNOs are required to make to consumers who have suffered from interruptions.

41. Apart from regulatory decisions by Ofgem, DNOs might draw on estimates of the harm to consumers from interruptions as part of their business plan, particularly in support of proposals for baseline performance levels and secondary deliverables. They might also use them more generally as part of their asset management and network planning policies

Findings on estimates of value of lost load

42. This section brings together the findings from a number of published studies that report estimates of the harm to customers from interruptions to their electricity supply.

43. The section is structured as follows:

(a) first, we give an overview of the studies from which we have drawn estimates on the harm to customers from interruptions;

(b) second, we outline the methods used to express the findings from different studies into comparable units; and

(c) third, we compare and discuss the estimates themselves.

Overview of studies reviewed

44. We searched for relevant studies using the EconLit and Business Source Complete databases, as well as online search engines. In addition, we carried out a search from within the website hosting publications from the Institute of Electrical and Electronics Engineers. The search terms we used included: value of lost load; value of supply reliability; cost of unreliability; cost of power interruptions; cost of power outages;

cost of electricity outages. Where appropriate, we followed up references listed in the articles found.

45. We did an initial cursory reading of the studies found and chose those that we would review as part of this study. We chose to review studies that:

(a) include in the results an estimate of VOLL that is original rather the replication of estimates from other work;

(b) include sufficient information about the approach followed to allow us to come to some view on the merit of the estimates presented;

(c) are relatively recent (with the exception of UK studies all are 2004 or later);

(d) are written in English.

46. There are different methodologies that have been used to derive estimates of VOLL. One categorisation of the methods covered in the studies we have reviewed is as follows.[1]

(a) **Stated preference methods.** These methods are typically based on surveys where respondents are asked about their valuation of interruptions. This may be done directly or indirectly. Within this class of methods, it is possible to distinguish between:

(i) Contingent valuation methods — respondents are asked directly about their WTP or WTA energy supply with a specific hypothetical reliability.

(ii) Conjoint analysis — respondents are asked to choose between alternative scenarios of energy reliability, with each different scenario having a particular price tag.

(iii) Direct worth — respondents are asked about the costs they estimate they would incur in particular scenario.

(iv) Preparatory action method — respondents are asked to select from within a list of actions, those that they would take for the purpose of mitigating the effect of a particular interruption.

(b) **Revealed preference methods.** These methods make use of information on how respondents have behaved in the past which may reveal their preferences with respect to energy supply reliability. This may involve analysing data, for example, on the expenses that customers have incurred in purchasing equipment such as back-up generators as a means of avoiding disruptions due to power outages.

[1] See SINTEF (2010) "Study on estimation of costs due to electricity interruptions and voltage disturbances", pp 61–72.

(c) **Production function methods.** These methods rely on macroeconomic data, namely the gross value added of sectors, and on sector-wide annual electricity consumption to estimate VOLL.

47. The set of studies we review do not include ones based on analysis of black-out events, such as Anderson et al. (2007).[2] We find that the findings and lessons from such studies may be helpful in the context of being concerned with very long interruptions affecting large areas but less so in the context of estimating VOLL of shorter ones in a more limited area.

48. For the purpose of presenting the results, we have categorised the studies according to our view on the relative relevance of their estimates of VOLL. We explain the factors we considered as part of the overview of the studies we reviewed which we report below.

An overview of the studies reviewed

49. Table 1 gives an overview of the studies from which we report results. We have included in the table our view about the relative relevance of the study — whether of relatively high or low relevance — and the main reasons behind that view. Each of the studies is reviewed in more detail in appendix 1.

[2] Anderson, C et al (2007) "A Risk-based Input–Output Methodology for Measuring the Effects of the August 2003 Northeast Blackout", Economic Systems Research, 19:2, pp. 183-204.

Table 1 Overview of studies reviewed

Reference	Coverage	Customers	Method	Output	Comments	Relative relevance
Accent (2004)	UK, split for each DNO area Year: 2004	Domestic and business customers Business customers split between large, medium and small users	Survey, conjoint analysis	WTP and WTA for change in frequency of interruptions WTP and WTA for a 1-minute change in average duration of interruptions Estimates for domestic customers expressed as pounds sterling Estimates for business customers expressed as percentage of annual bill Separate estimates for each DNO	Survey asks about interruptions in rural and in urban areas, rather than directly about interruptions where respondent lives.	High
Accent (2008)	UK, split for each DNO area Year: 2008	Domestic and business customers Business customers split between large, medium and small users	Survey, conjoint analysis	WTP and WTA for change in frequency of interruptions WTP and WTA for a 1-minute change in average duration of interruptions Estimates for domestic customers expressed as pounds sterling Estimates for business customers expressed as percentage of annual bill Separate estimates for each DNO	The process for selecting models in the econometric analysis involves aggregating data from different DNOs when DNO-specific variables are found to be statistically not significantly different from each other Estimates are adjusted to correct for packaging effects	High
Kariuki and	Regions covered	Domestic and	Survey,	Estimates associated with	Non-residential respondents were	High

Reference	Coverage	Customers	Method	Output	Comments	Relative relevance
Allan (1996)	by three former DNOs: Manweb, MEB and Norweb Year: 1993	business customers Business customers split between commercial, retail, industrial and large users	contingent valuation and preparatory action methods for residential customers Survey, direct worth for business customers	interruptions of different duration reported in pounds sterling, in £/kWh and in £/kW	asked to estimate costs on basis of interruption on a Wednesday at 10am in January. Residential were asked to use a winter weekday at 4pm as reference point. Neither need be representative	
Willis and Garrod (1997)	An area in the south-east of Northumberland, UK Year: 1996	Non-domestic customers	Survey, conjoint analysis	Estimates of WTP to avoid interruptions with different maximum duration expressed in pounds sterling	Sample of businesses is small and not representative Specification of econometric does not allow for interaction between duration and frequency of outage	High
Bertazzi et al (2005)	Italy Year: 2003	Domestic and business customers	Survey, contingent valuation and direct worth	WTA, WTP and direct costs for interruptions of different durations expressed in value terms for households, and normalised by annual consumption for businesses	Direct costs are gross; not relevant Over a sixth of observations are dropped from analysis on grounds that they are considered to be outliers	High
Blass, A et al (2008)	Israel Year: 2005	Domestic customers	Survey, conjoint analysis type approach; respondents asked about	Through econometric modelling, estimates of WTP for a one-minute reduction in outage time per season by reducing average duration of each interruption, and by reducing	Israeli context is far removed from the UK	Low

Reference	Coverage	Customers	Method	Output	Comments	Relative relevance
			probabilities of choosing between alternative scenarios	number of interruptions Estimates reported in value terms Split between weekday/weekend and peak/off-peak		
Bliem (2009)	Austria Year: 2007	Domestic customers and businesses	Survey, conjoint analysis	Estimates of WTP for changing duration of outages over a year, and for changing frequency of interruptions in a year Estimates reported in terms of percentage change from annual bill Estimates relevance of day/night, weekend/weekday and planned/unplanned on WTP	Specification of econometric model is not intuitive; e.g. it identifies the effect of changing the total period of outages in a year, whilst keeping the number of outages constant	High
Carlsson and Martinsson (2004)	Sweden Year: 2004	Domestic customers	Survey, contingent valuation	Mean and other descriptive statistics of WTP to avoid interruptions of different lengths, expressed in value terms Distinguishes between planned and unplanned interruptions	Estimates refer to a “worst case scenario” — an interruption starting at 6pm on January evening; unlikely to be a reasonable estimate of WTP to avoid interruptions in general	Low
Carlsson and Martinsson (2007)	Sweden Year: 2004	Domestic customers	Survey, conjoint analysis	WTP for reducing outages of different length Distinguishes between winter and summer months		High
Charles River	Australia	Residential and non-residential	Survey, direct worth	Costs, by sector, for interruptions of different durations	Estimates relate to worst case scenario and so not representative	Low

Reference	Coverage	Customers	Method	Output	Comments	Relative relevance
Associates (2008)	Year: 2007	customers, the latter split between agriculture, commercial and industrial		Estimates reported in value terms and normalised by annual consumption	of costs of interruptions in general.	
de Nooij et al (2007)	Netherlands Year: 2000	Domestic customers and various non-domestic sectors of economy	Production function	VOLL measured in £/kWh.	Estimate for households is based on assumption that households value leisure at marginal value or labour, and that value of leisure is a reasonable proxy for value of electricity supply	Low for household estimates High for other estimates
Kjolle et al (2008)	Norway Year: 2000/2001	Domestic and several non-domestic sectors of the economy	Survey, contingent valuation and direct worth	Estimates of direct worth and WTP associated with interruptions of different lengths; for households and for each different sector. Estimates are normalised by annual consumption	Estimates are for worst case scenario	Low
Leahy and Tol (2010)	Rep. of Ireland and N. Ireland Year: 2000 to 2007	Domestic customers and various non-domestic sectors of economy	Production function	VOLL measures in £/kWh	Estimate for households is based on assumption that households value leisure at marginal value or labour, and that value of leisure is a reasonable proxy for value of electricity supply	Low for household estimates High for other estimates
Praktiknjo et al (2011)	Germany Year 2008	Domestic customers and various non-	Production function	VOLL measures in £/kWh	Estimate for households is based on assumption that households value leisure at marginal value or	Low for household

Reference	Coverage	Customers	Method	Output	Comments	Relative relevance
		domestic sectors of economy			labour, and that value of leisure is a reasonable proxy for value of electricity supply	estimates High for other estimates
Sullivan et al (2009)	Various American states Year: 1989 to 2005	Domestic and non-domestic customers, the latter split into: small commercial and industrial; large commercial; and industrial	Meta-data compiled from 28 different studies, each based on surveys on WTP or costs of interruptions	Cost, in value terms, associated with different length interruptions. Shows variations for different times of day, and days of the week		High

50. Table 1 identifies the set of estimates we considered to be of relatively high relevance and those that we considered to be of relatively low relevance. We considered the following to be of relatively low relevance:

(a) Estimates of VOLL that are obtained from asking respondents about their behaviour in the event of an interruption at the worst possible time as they are unlikely to be reasonable estimates of VOLL associated with an interruption in general. This was relevant for the estimates put forward by Carlsson and Martinsson (2004), Charles River Associates (2008) and Kjølle et al (2008).

(b) Estimates of VOLL derived on the basis of estimates about households' valuation of leisure, which, in turn is drawn from data on average wages. We do not find this approach persuasive. For this reason, we considered the estimates of VOLL for households put forward in de Nooij et al (2007), Leahy and Tol (2010 and Praktiknjo et al (2011) to be of low relevance.

(c) Estimates based on a survey of a manifestly unrepresentative sample of respondents. For this reason, we consider the study by Willis and Garrod (1997) to be of low relevance.

(d) Estimates relating to VOLL of VOLL of Israeli households, given differences in the context of the two countries. For this reason we consider the study by Blass et al (2010) to be of relatively low relevance.

51. Each of these reasons is discussed in more detail in the review of the studies that is set out in appendix 1 of this report.

52. We categorised the remaining studies to be of relatively high relevance. This should not be understood to imply that we consider those studies to be free of criticism, and that the estimates of VOLL they report can be interpreted blindly as estimates of VOLL for UK customers. That is not the case. For example we have identified some short-comings in the methodologies followed in some studies, including in some studies that we have classified as being of relatively high relevance, for example Bliem (2009).

53. Our review of the studies in appendix 1 covers these points in greater detail.

Expressing estimates in a common unit

Choice of unit for comparison

54. Estimates on VOLL are expressed in a variety of ways. Amongst the set of papers we reviewed, these include:

(a) a value per interruption;

(b) a value per interruption of a particular duration; and

(c) a value per additional duration of interruptions over the course of a year.

55. Some studies report the value as a percentage of the electricity bill, rather than as a value.

56. In addition, some studies report the findings after normalising them with respect to some variable. Typically, the normalisation is done with respect to the annual consumption, or — when reporting interruptions of different durations — with respect to an allocation of the annual consumption to a period of time of the length of the interruption. The latter is often referred to as the "energy not supplied".

57. In bringing together estimates from across the various studies we have had to address these differences.

58. A first task is to choose what common unit to express the findings in. We have made a different choice for domestic customers than for non-domestic customers.

(a) For domestic customers, we present two estimates: one on VOLL of a 1-hour interruption, and one on VOLL for an 8-hour interruption.

(b) For non-domestic customers, we present estimates on VOLL of a 1-hour interruption, expressed in terms of £/kW/h.

59. For domestic customers we present the numbers expressed as a value, in pounds sterling, whilst for non domestic customers it is reported in terms of pounds sterling per kW/h. There are two key reasons for this.

(a) Expressing the normalised results for non-domestic customers allows for some sort of comparison between estimates from different studies where different categories of non-domestic customers are considered. For example, a number of the studies report estimates for businesses customers according to size categories, distinguishing between small, medium and large businesses. Other studies may not have those same categories or, if they do, they may have been defined in a different way. Normalising the estimates makes a comparison across findings easier to interpret.

(b) Where estimates for non-domestic customers are presented, it is generally the case that they are reported in the study in terms of value per unit of consumption. To reverse engineer those estimates into pounds sterling we would need information on the average annual consumption of the relevant set of businesses. That information is generally not reported in the published paper.

60. For some studies, the findings reported in the paper can be applied directly to the comparison we wish to make. For example, Sullivan et al (2009) report estimates, in value terms, for the WTP by domestic customers to avoid a one-hour interruption.

61. In other cases, it is necessary for us to convert the estimates that are reported so that we can compare them with the estimates from other studies. The review of the studies in appendix 1 to this report describes, for each study, the assumptions made, and corresponding calculations carried out, to make the relevant conversion.

Converting values to pounds sterling

62. To compare the estimates from the different studies, we express, all numbers in 2012 pounds sterling:

(a) For estimates originally reported in pounds sterling, we update them using the retail price index (RPI) published by the Office of National Statistics. All values are updated up to the index value for January 2012.

(b) For estimates originally reported in foreign currency, we first convert them to pounds sterling using the average exchange rate in the period over which the data in the study refer to. For example, if the study reports a survey carried out in the summer 2005, we use the average exchange rate over the period June to September 2005. We have used the interbank exchange rate reported by the online site www.oanda.com. Once expressed in pounds sterling, we then update the values using the RPI so that they are expressed at January 2012 levels.

63. We think this is a reasonable approach but it is worth to reflect briefly on, and recognise, the assumptions that we are implicitly making.

64. First, we use RPI to update estimates over time. This is the case irrespective of whether those estimates relate to WTP or WTA, whether they relate to estimates of costs of damage caused by interruptions or of costs in taking preparatory actions. The question then is whether RPI is a reasonable index by which to update estimates of (any of) these different measures. It could be argued that other indices might be better suited, depending in part on what it is that is being updated. For example, if an estimate is based on the responses given by businesses on what equipment they have purchased to get around potential outages, then it would be more appropriate to update that estimate using a price index that captures the trend in the cost of machinery such as back-up generators. If, on the other hand, an estimate is based on a survey of consumers regarding their WTP for improvements in service, then the use of RPI to update estimates over time might seem a natural candidate although other indices could arguably also be used, e.g. an index of average earnings. This is not a question we can resolve here.

65. We have settled on using RPI because we think it is reasonable to do so in the context of estimates regarding consumers' WTP — which a large number of the estimates we have reviewed relate do — and because we considered that using alternative specific indices for other estimates risks giving a veneer of rigour that is not due. It is also the case that the studies we have selected are relatively recent — the oldest one reports data from 1997 — so that there is relatively different impact from using RPI rather than an index of average earnings or the GDP deflator (which captures price movements in a basked of goods and services wider than the RPI).

Findings: domestic customers

66. For domestic customers, we have chosen to present estimates of VOLL associated with a 1-hour and an 8-hour-interruption.

67. Table 2 reports the set of estimates that are presented and discussed in this section. For ease of reference in the set of figures presented subsequently, we have labelled each estimate by stringing together the following elements:

(a) author(s) of the paper and year of publication;

(b) geographic region to which the estimate relates; and

(c) where more than on estimate is sourced from the same study, information on the feature that distinguish it from other estimates derived from the same study.

68. The labels of the estimates are shown in the first column of table 2. The table also includes a brief clarification of the last element of the label for those cases where more than one estimate is presented from the same study. A more detailed explanation is given in the review of the studies in appendix 1. The last column of the table sets out whether we have judged the estimate to be of high or of low relevance, in line with the discussion earlier in this section.

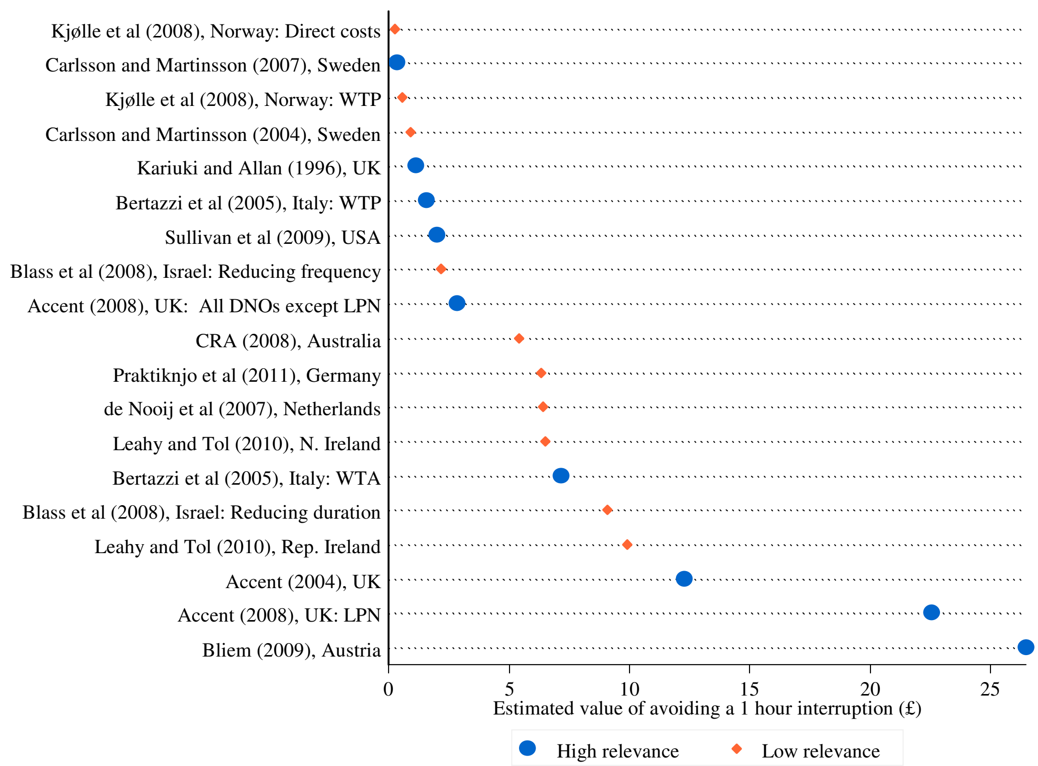
Table 2 Labels of the estimates of VOLL for domestic customers

Label	**Clarification**	**Relative relevance**
Accent (2004), UK	Average across all DNOs based on WTP for an additional interruption	High
Accent (2008), UK: All DNOs except LPN	Average across all DNOs except LPN based on WTP for an additional interruption	High
Accent (2008), UK: LPN	Based on WTP for LPN customers for an additional interruption	High
Bertazzi et al (2005), Italy: WTA	Based on survey of WTA	High
Bertazzi et al (2005), Italy: WTP	Based on survey of WTP	High
Blass et al (2008), Israel: Reducing duration	Based on WTP of reducing average duration of each interruptions	Low
Blass et al (2008), Israel: Reducing frequency	Based on WTP of reducing frequency of interruptions	Low
Bliem (2009), Austria		High
Carlsson and Martinsson (2004), Sweden		Low
Carlsson and Martinsson (2007), Sweden		High
CRA (2008), Australia		Low
de Nooij et al (2007), Netherlands		Low

Label	Clarification	Relative relevance
Kariuki and Allan (1996), UK		High
Kjølle et al (2008), Sweden: Direct costs	Based on survey of direct costs	Low
Kjølle et al (2008), Sweden: WTP	Based on survey of WTP	Low
Leahy and Tol (2010), N. Ireland		Low
Leahy and Tol (2010), Rep. Ireland		Low
Praktiknjo et al (2011), Germany		Low
Sullivan et al (2009), USA		High

69. Figure 4 compares the estimates of VOLL for domestic customers associated with a 1-hour interruption.

Figure 4 Domestic customers: estimated VOLL of a 1-hour interruption (£)



70. We have marked with smaller orange diamonds the estimates from those studies that we consider to have relatively low relevance and marked with a larger blue dot those from studies that are of relatively high relevance. We adopt this same convention in the remaining figures presented in this section.

71. The estimates from the studies we consider to be of relatively high relevance range from £0.30 to £26.46.

72. It is not surprising that the estimates produce a range of estimates.

73. The estimates reflect the preferences of domestic customers in different countries or regions, and at different points in time, and it is reasonable to expect for these preferences to vary. We expect that there are many factors that contribute to the difference in the preference of respondents sampled in different studies. These may include, for example, differences in customers' attitudes to an "entitlement" to continuous electricity supply, differences in the reliability of supply that customers are accustomed to or differences in customers' income levels.

74. The estimates derived by the different studies are based on different methodologies regarding the collection and the analysis of the data. Such differences of approach will also impact on the estimates obtained. That is to say, even if it were the case that the exact same group of respondents were sampled by different studies, we would expect the different studies to produce different estimates of VOLL as the estimates would be sensitive to the details of how the data were collected and analysed. Restricting ourselves to methods relying on survey of customers as an example, the estimates obtained would be sensitive to exactly how the set of questions were asked (e.g. what attributes of reliability were respondents asked about, what levels were chosen, how were the questions framed, were respondents asked about WTP, WTA or direct costs) as well as to how the data was subsequently analysed (e.g. what econometric modelling was done, how was the model specification chosen).

75. It is not possible to disentangle the factors that contribute to the differences that are observed in the estimates from the different studies. This said, it is worth exploring hypotheses that may help explain some of the differences in the estimates charted in figure 4.

76. The highest estimate, £26.46, is derived from a study for Austria by Bliem (2009). One hypothesis is that this particularly high estimate is driven by the structure of the survey questions, and subsequent econometric modelling, used by the author. The survey asked respondents to express a preference about the reliability of supply with respect to a number of attributes including the frequency of interruptions and the total length of outages in a year. Following on from this, the specification of the model estimated in the econometric analysis is such that it identifies, for example how the total time in a year during which there would be outages affects customers' choice between one reliability scenario or another, keeping other things constant including the frequency of interruptions. We do not think such an estimate is intuitive to interpret, or indeed the survey question underlying it. Are respondents trading-off fewer interruptions for interruptions each lasting a bit longer, so that the total duration of interrupted supply in the year remains constant? Would the respondents to the survey be able to make that trade-off? It is possible that the high estimates obtained

by the study may in part be driven by the study's particular choice of survey questions and model specification.

77. Another of the higher estimates, £22.55, is derived from Accent's 2008 estimate on the WTP for one less interruption by domestic customers in the LPN area in the UK; this is labelled as "Accent (2008), UK: LPN, interruption". This estimate is significantly higher than the estimate that was derived in that same study for customers in the remaining DNO regions, £2.81. A hypothesis that may contribute to explaining the difference between these two estimates is that the reliability of supply in the LPN region is better than in other regions — the frequency of interruptions is lower and the average duration of an interruption is significantly lower — and that customers with less experience of dealing with, and accommodating, interrupted supply have a higher valuation of avoiding an interruption.

78. Other than the two estimates derived from Accent (2008), figure 4 includes two other estimates for the UK: the estimate derived from Accent (2004) is £12.28 and the estimate derived from Kariuki and Allan (1996) is £1.12. The Accent (2004) estimate is significantly higher than the Accent (2008) estimate for customers in areas other than LPN. The two studies were based on surveys with similar sampling procedure but the framing of the questions to respondents and the econometric analysis done on the data collected differs. We are not able to pin-point a possible reason for the difference between the two estimates. Accent (2008) itself is no more precise than suggesting methodological differences as one reasons for the difference in relation to its 2004 estimate. At the other end of the range of estimates for the UK is the one based on the results of Kariuki and Allan (1996), £1.12 for a 1-hour interruption. We have not identified a hypothesis that could explain this particularly low estimate.

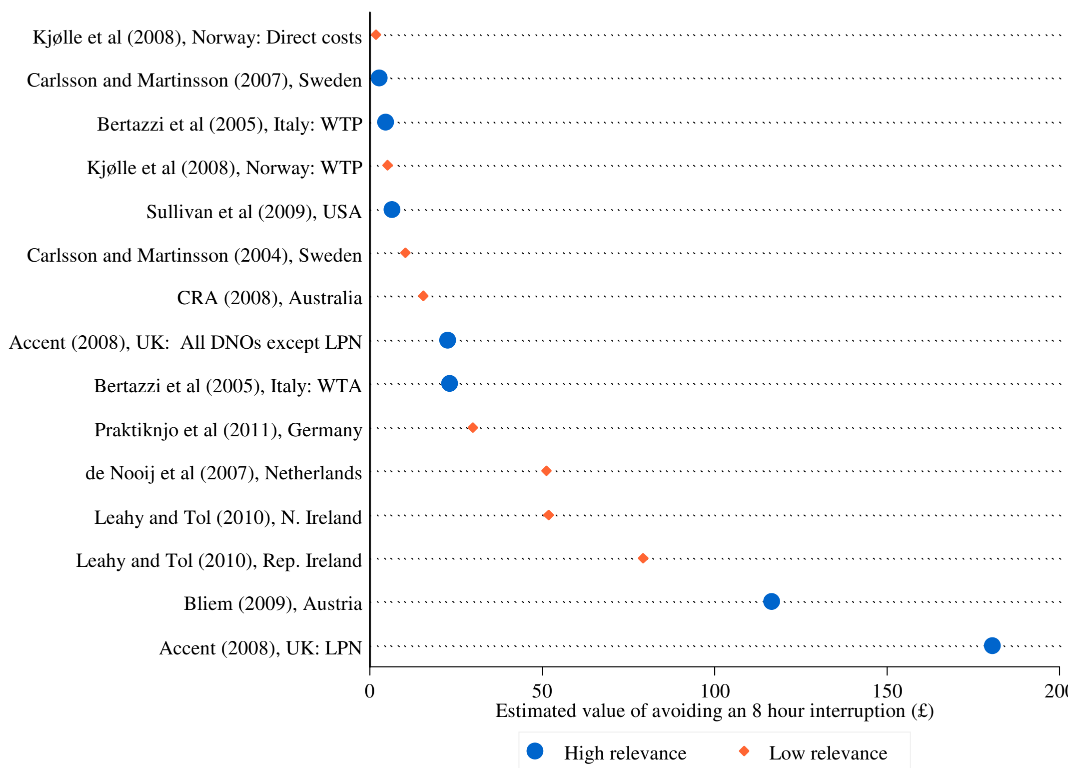
79. The estimates derived from the studies in Norway and Sweden are at the low end of the range. We find no feature in the design of the survey or in the analysis of those studies why this should be the case. This said, in the case of the estimates derived from Kjølle et al (2008) this may be partly explained by the fact that that paper reports their findings of VOLL in normalised terms, as a monetary value per kWh. For the purpose of drawing figure 4, we have reverse engineered those values, assuming an average household consumption of 4,000 units per year, around the UK average. In this way, the estimates based on that study that are shown in the figure can be interpreted as an estimate of the VOLL associated with a 1-interruption for consumers with preferences for energy reliability like those of Norwegian domestic customers but with an energy consumption level like that of a UK household. Had we calculated the estimate on the basis of the average consumption level of a Norwegian household, the estimate of VOLL would have increased by a factor of between 2 and 3, although it would have remained at the lower end of our range of estimates.

80. An interesting feature of the range of estimates in figure 4 is that the estimates from studies dealing with examining customers' preferences in "worst case scenarios" are in fact towards the lower half of the range. This is the case of the estimates labelled "Kjølle et al (2008), Sweden: Direct costs", "Kjølle et al (2008), Sweden: WTP", "Carlsson and Martinsson (2004), Sweden" and "CRA (2007), Australia". Other things equal, we would have expected estimates based on "worst case scenarios" to be higher than based on "anytime" interruptions.

81. Lastly, we note that the estimate that is based on customer responses about their WTA — labelled in figure 4 as "Bertazzi et al (2005), Italy: WTA" — is also towards the higher end of the range, and is greater than the estimate "Bertazzi et al (2005), Italy: WTP" from the same study but based on WTP. A possible explanation for this is that domestic customers have a sense of entitlement to a reliable energy supply, leading them to be willing to depart with relatively little money to obtain an improvement in performance compared to the money they would be willing to accept in exchange for a worsening in performance.

82. Figure 5 compares the estimates of VOLL for domestic customers associated with an 8-hour interruption.

Figure 5 Domestic customers: estimated VOLL of an 8-hour interruption (£)



83. We have found fewer studies reporting estimates from which we can derive, or extrapolate, values for an 8-hour interruption. The estimates from the studies we consider to be of relatively high relevance range from £2.66 to £180.44.

84. Similar considerations to those set out earlier when discussing the variations in the estimates for a 1-hour interruption apply to a discussion of the variation in the estimates for an 8-hour interruption.

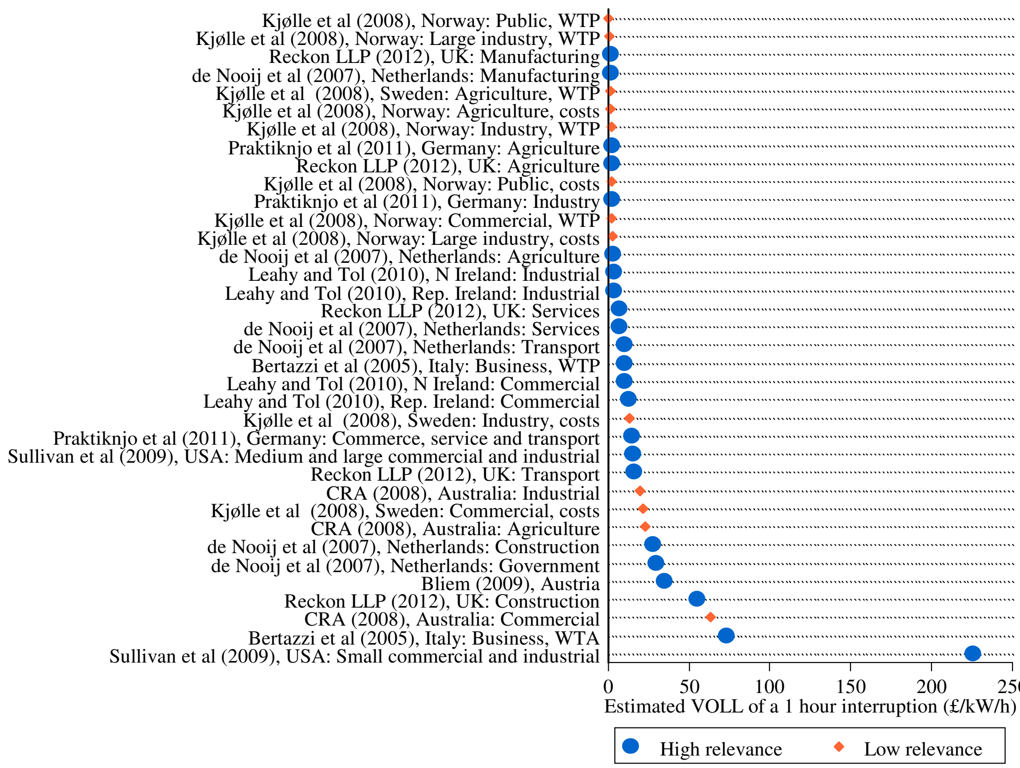
85. As is the case of the estimates for a 1-hour interruption, the two studies reporting estimates at the top end of the range are Bliem (2009), relating to Austria, and Accent (2008) relating to domestic customers in the LPN area. The estimate for "Accent

(2008), UK: LPN" is based on extrapolations from the same results used to compute the estimate for a 1-hour interruption. In the case of Bliem (2009), the estimate of VOLL for an 8-hour interruption was based on extrapolating from a result in the study relating to a 10-hour interruption, whereas the 1-hour estimate shown in the earlier figure 4 was based on extrapolating from a result relating to a 4-hour interruption. This difference is the reason for the switch in the relative positions of the Bliem (2009) and "Accent (2008), UK: LPN" estimates between the two previous figures.

Findings: non-domestic customers

86. Figure 6 compares the estimates of VOLL for non-domestic customers for a 1-hour interruption.

Figure 6 Non-domestic customers: estimated VOLL of an 1-hour interruption (£/kW/h)



87. On the basis of the studies we have considered to be relevant, the estimates of VOLL for non-domestic customers of a 1-hour interruption ranges from just £1/kW/h to around £225/kW/h.

88. As with the estimates for domestic customers we expect to observe a variation in the estimates of VOLL for business customers.

89. The variation in the estimates reflect the preferences of business customers in different countries or regions, and at different points in time, and these preferences would be expected to vary across the sample of businesses covered in the various studies.

90. For business customers we would expect that the economic activity to be an important factor in shaping their preference over reliability of supply. One hypothesis is that business customers whose activity is heavily dependent on energy supply place a higher valuation on good reliability of energy supply.

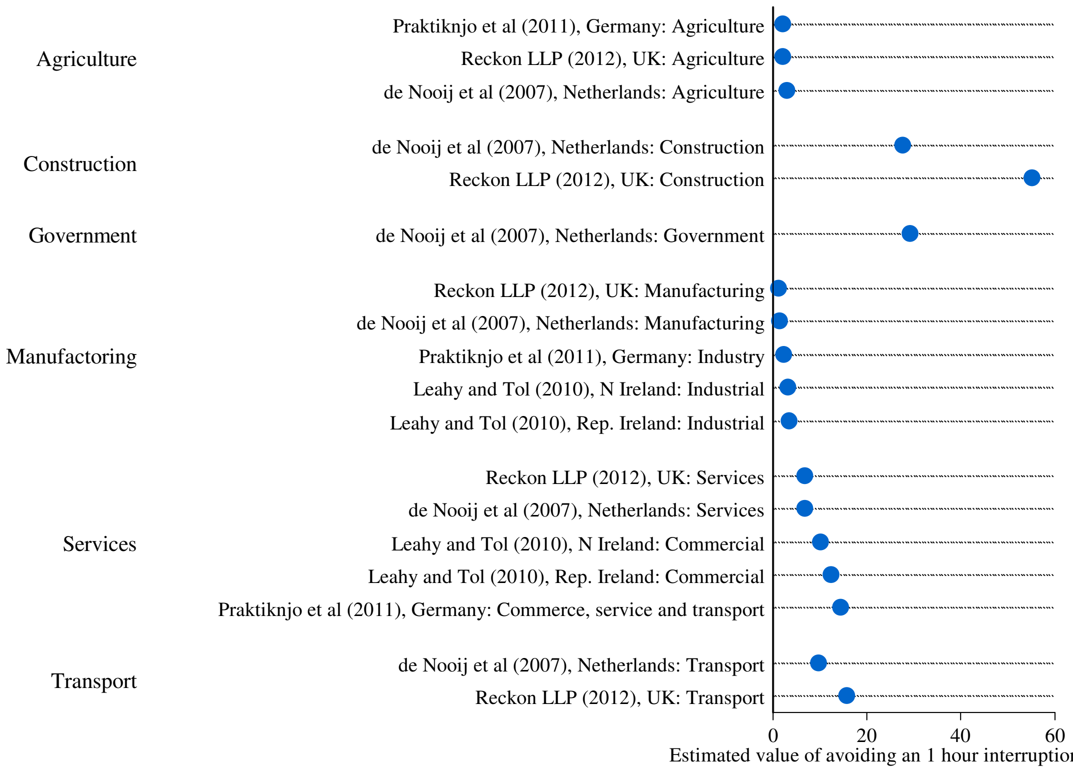
91. On the other hand, it could also be hypothesised that businesses that are heavily dependent on energy supply will have taken action to prevent disruption to their activity in the event of an interruption, e.g. by having invested in back-up generators of their own. Under this hypothesis, the WTP for a more reliable energy supply would be lower for businesses that are more electricity dependent.

92. In a similar vein to this latter hypothesis, it may be suggested that larger businesses may be better equipped to deal with an interruption — because they are more likely to have invested in pre-emptive measures — than smaller businesses.

93. With regard to the estimates shown in figure 6, it is noticeable that the estimate for "Sullivan: Small commercial and industrial" is, at £225/kW/h very much higher than all other estimates. One possible explanation for this is that this estimate, unlike the other estimates presented in the figure, relates to small business users. Small business users have a low electricity consumption compared to businesses on average and, medium and large businesses in particular. For example, within the sample of businesses covered by Sullivan et al (2009), annual energy consumption by medium and large businesses was 7,140 MWh whereas that of small commercial and industrial was 19 MWh. Given that the estimates of VOLL shown in figure 6 have been normalised with respect to consumption, the low level of consumption by small business leads to the estimate being particularly high.

94. To try to identify more clearly whether there is any pattern in the estimates of VOLL across businesses in different sectors of the economy, we recast in figure 7 those estimates from relevant studies organised by sector.

Figure 7 Non-domestic customers, by sector: estimated VOLL of an 1-hour interruption (£/kW/h)



95. All of the estimates presented in figure 7 are based on studies that derive an estimate of VOLL by dividing the annual gross value added of the sector by the annual electricity consumption of that sector. In the light of this, the relatively narrow ranges for some of the sectors are a reflection of the relative similarity of the energy intensity of the sectors across the UK, Ireland and the Netherlands. One hypothesis that could explain the relatively high estimate for the construction sector is that a significant proportion of the gross value added of that sector is generated by activity that is not dependent on electricity, leading to an overestimation of VOLL by businesses in that sector.

Factors affecting VOLL

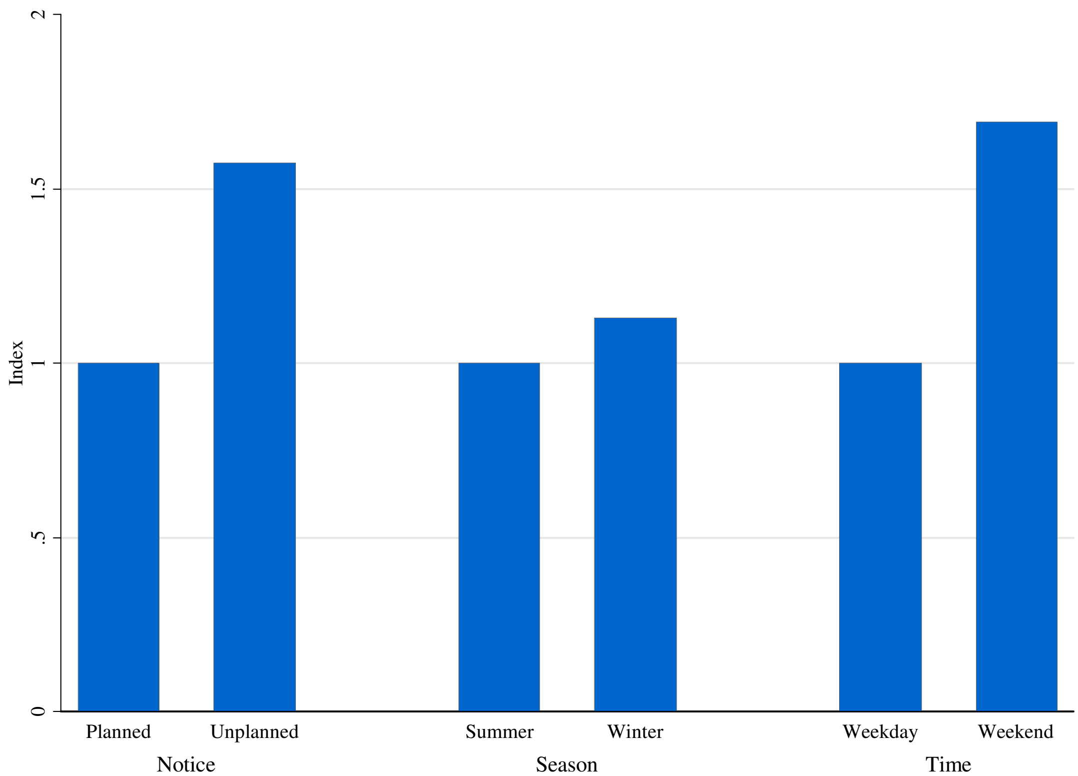
96. The value that a household or business places on maintaining electricity supply is not always the same. It varies due to a number of different factors.

97. Some of the studies that we have reviewed have included information on how VOLL varies according to different factors such as the time of day, the season, whether the interruption is planned and the area of the interruption.

98. These studies often present results in subtly different ways, for example covering different periods of time or defining winter differently so that it is difficult to make a reading across different studies.

99. Despite this, some themes of how estimates of VOLL vary with respect to some attributes of interruptions do emerge from the literature. Figure 8 pulls together and averages the divergence between different attributes across the studies we have reviewed for domestic customers.

Figure 8 Variance of VOLL by attributes for residential customers



100. Figure 8 compares three different sets of attributes of an interruption:

(a) whether it is a planned or unplanned;

(b) whether it occurs in winter or in summer months; and

(c) whether it occurs in the weekday or the weekend.

101. The indices charted in the figure were computed as follows. As an example, take the attribute relating to whether the interruption is planned or unplanned. For each study which reports estimates of VOLL for planned and unplanned interruptions, we normalised the estimate using the estimate of VOLL for planned interruption as a benchmark. We then calculated the average of those normalised values across the set of studies that reported estimates of VOLL for planned and unplanned interruptions.

102. As illustrated in figure 8, domestic customers' VOLL is higher for unplanned than for planned interruptions. This is as expected; forewarned customers may take remedial

actions to mitigate the effect of an interruption, including revising their plans of when to do particular activities that are dependent on electricity supply.

103. Figure 8 also shows that domestic customers' VOLL is higher at weekends than at weekdays. As suggested in the studies that report on this, this feature may be explained by the fact that domestic customers spend a greater number of hours at home during weekends rather than during weekdays, when they might be at work.

104. Note that the relative VOLL associated with interruptions in winter or summer months shown in figure 8 is based on one single paper, Carlsson and Martinsson (2007), relating to Sweden.

105. Across the set of studies we reviewed, we found fewer estimates on the effect of the above set of factors on business customers' VOLL. Our review does suggest that businesses' WTP to avoid interruptions is higher in relation weekday interruptions than in relation to ones occurring in the weekend, the opposite of what is found for residential customers. This is not surprising since it is in weekdays that most businesses operate and when disruption from an interruption would be greater.

Replicating the production function technique using UK data

106. We have reviewed papers that used a production function approach to estimating VOLL, including the paper by de Nooij et al (2007). This approach looks at the output and the electricity consumption of a sector in order to produce an estimate of the value added that would be lost due to a reduction in the supply of electricity. A sector's VOLL is estimated as the ratio of its value added and its electricity consumption. The equation used to calculate VOLL for any sector i can be expressed as:

$$VOLL_i = \text{value added}_i \; / \, \text{electricity consumption}_i$$

107. In this section we aim to produce a similar set of estimates as seen in de Nooij et al. (2007) for the UK. It is not within our scope to hone this approach in order to produce more robust estimates. Instead, we concentrate on applying a similar approach to data from the UK. The results should be interpreted as a replication of the method using UK data rather than seen as the production of original estimates of VOLL.

108. We use data from the UK's national accounts to provide data on value added of different sectors over time.[3] We have taken electricity consumption data from DECC publications on electricity usage.[4] The most recent year for which we have data on both necessary data items is 2009. We have also been able to estimate VOLL for previous years, allowing us to compare the numbers over time.

109. VOLL is estimated for a number of sectors of the UK economy, based largely on the selected sectors in de Nooij et al. (2007), although we chose not to estimate VOLL for the energy, government and residential sectors. We felt that the estimates of VOLL

[3] Office for National Statistics (2011) United Kingdom National Accounts – The Blue Book, 2011 edition, table 2.3
[4] DECC (2011) Digest of UK Energy Statistics (DUKES), Chapter 5: Electricity, 5.2 electricity supply and consumption

for these sectors were particularly vulnerable to criticism. Using this method is inappropriate for the energy and government sectors since lost value is a particularly difficult concept to define for these sectors, and "value added" does not capture the potential losses due to an outage. The approach to estimate VOLL for the residential sector differs from the method used for the other sectors. Our critique of this approach, and hence the reasons we have chosen not to replicate it for households here, are set out in the review of de Nooij et al (2007) in appendix 1.

110. We have tried to map the data collected to the sectors covered in de Nooij et al (2007). However, sector classification is a complex area and, as such, it is possible that we have not defined our sectors in the exact same way.

111. The results of our analysis for 2009 are produced in table 3. The results are based on value added at current basic prices from July 2011.

Table 3 Estimates of VOLL for the UK in 2009 using the production function approach of de Nooij et al (2007)

Sector	Value added (£ million)	Electricity consumption (GWh)	VOLL (£/kWh)
Agriculture	8,030	3,801	2.11
Manufacturing	126,739	99,255	1.28
Construction	87,373	1,586	55.08
Transport	61,870	3,906	15.84
Services	520,000	76,187	6.83

112. For the purposes of comparison, we also estimated VOLL using this method for previous years dating back to 2004. We were interested to see how volatile the estimates appeared over time.

113. The estimates over time for the different sectors are shown in figure 9. For the manufacturing, agriculture, transport and services sectors the estimates of VOLL have been stable over the period. The estimate of VOLL for the construction sector has increased substantially since the beginning of the period. This increase appears to be largely focussed on an increase between 2005 and 2007. This was caused by a decrease in reported consumption in the sector but steady value added growth.

Figure 9 Estimates of VOLL other time using the de Nooij et al (2007) method with UK data

Discussion on potential expansions and refinements in the approach

114. Using this method to value any one specific interruption is problematic. But as an estimate for an average interruption the method provides relevant and useful estimates of VOLL for different sectors. We discuss the various pitfalls of this method in the detailed review of de Nooij et al (2007) in appendix 1.

115. It would be interesting to examine whether improvements could be made to the method to decrease the vulnerability of the estimates to accusations that the assumptions underpinning it are unrealistic.

116. It is not within the scope of this study to conduct further analysis and so we have not sought to apply our suggested refinements to the method used in de Nooij et al. (2007). However, we have identified a number of potential adjustments to the method which might improve the reliability of the VOLL estimates and which could be considered in future applications of this production function approach. We outline these below. We stress that these suggestions are speculative in nature and we have not tested the feasibility of applying them in practice.

117. Firstly, it could be useful to refine the method to reflect how the use of electricity varies by sector. The model currently assumes that all output in a particular sector is dependent upon electricity. There will be cases when this is untrue to varying degrees. Certain activities might not be reliant at all on electricity, taxi driving for example. Others might be able to produce some output without electricity but only for selected activities. We suspect that not reflecting this reality in the method leads to the estimates for some sectors, like construction, being very high compared to other sectors. Without examining the sector in detail it is not possible to form a definitive view on the likely effect of this, but given the very high estimates of VOLL for construction, around five to ten times above the other sectors, it seems likely an overestimation has occurred due to the value added of non-electricity dependent activity being included in the model. Therefore, a potential refinement of the method could be to consider at a more disaggregated level how much production does depend upon electricity in different sectors.

118. The current method also assumes that there are no damages caused by an interruption itself, something potentially untrue in the face of, for examples, machines that take time to be restarted before production is resumed. As a result, the value of avoiding short interruptions could be underestimated using this approach. Estimates on the average cost of an interruption due to factors such as these could help mitigate this.

119. Another area for potential refinement could be to incorporate the availability of back-up generators at individual plants. The current method calculates VOLL as the value added produced per unit consumed over a year. However, given that we are interested in the cost of interruptions due to the electricity distribution networks, it would be more useful to reflect the availability of back-up generation in the calculations. Attaining estimates of the proportion of electricity consumption that could be maintained by back-up generation could refine the approach by removing such consumption, and associated value added, from the calculation.

Voltage dips

120. A voltage dip refers to an electricity customer experiencing a drop in voltage. Customers may incur a cost from voltage dips if the dip is such that it leads to a disruption in the running of the electrical appliances and machinery used. For example, if the dip is such that voltage falls below the level that machines were designed to operate at, then the machine may halt altogether. A severe dip may have the same effect of an interruption.

121. Our study is focused on interruptions and not on voltage dips. However, two of the studies that we reviewed in relation to exploring estimates on VOLL associated with interruptions, also examine voltage dips. In this section we present the estimates of these two papers. Further details of those papers' approach are presented in appendix 1.

122. The first relevant paper is Kjølle et al. (2008). This study surveys customers about the costs they would incur due to a voltage dip. Respondents are asked to consider the dip occurring at the worst possible time. Estimates are presented of the direct worth for avoiding voltage dips for five business sectors. No estimates are given for domestic customers. Table 4 presents the results from the paper concerning direct

worth estimates of avoiding a one second voltage dip of 50 per cent. The estimates are normalised by power, in kW, at the time of interruption. The estimates have been converted to 2012 pounds sterling.

Table 4 Direct worth to avoid a voltage dip (one second, 50%) from Kjølle et al. (2008)

Customer Group	Sample size	Direct worth (£/kW)
Industry (not large)	123	3.25
Commercial	128	2.36
Large industry	13	0.60
Public sector	86	0.17
Agriculture	83	1.45

123. As shown in the table, the estimates of the normalised direct is greatest for industrial customers that are not large and lowest for large industrial customers.

124. The second paper which contains estimates relating to voltage dips is Delfanti et al (2010). This paper monitored voltage quality for a small sample of businesses in Italy and surveyed them to estimate the costs associated with dips. The mean and median cost due to a voltage event for the businesses surveyed are shown in table 5. A voltage event refers to very short interruptions (one to five seconds) and voltage dips of varying size.

Table 5 Costs to businesses per voltage quality event from Delfanti et al. (2010) in £/kW

Sector	Sample size	Median	Mean
Food products	7	0.5	5.4
Textiles	1	2.9	2.9
Paper	11	0.7	0.8
Refined petroleum products	1	12.1	12.1
Chemicals and man-made fibres	3	0.5	0.4
Plastic products	10	1.7	2.0
Glass and ceramic products	4	0.7	0.8
Metals products	3	1.0	3.0
Electrical equipment	3	8.5	9.6
Auto and auto components	2	2.6	2.6
All sectors		**0.7**	**2.6**

125. The number of respondents in each of industrial sectors is very small. As such, we do not think that the estimates reported in table 5 should be considered representative of the sectors surveyed, let alone of the business users in the economy as a whole.

126. The estimates produced by Delfanti et al (2010) cannot be compared directly to those of Kjølle et al. (2008) set out earlier in table 4 as the two studies examined voltage dips with different characteristics: Kjølle et al. (2008) asked respondents about 50 per cent voltage dips lasting 1 second, whereas Delfanti et al (2010) was interested in voltage dips of varying size and very interruptions of between 1 and 5 seconds.

Impact of the low carbon economy on VOLL

127. Ofgem asked us to review the literature on how VOLL might change as the UK moves to a "low carbon economy".

128. Ofgem uses VOLL to inform decisions regarding the interruptions incentive scheme which forms part of price controls determinations for electricity distribution network operators (DNOs). This scheme provides a financial incentive by rewarding or penalising DNOs for performing better or worse than a benchmark of the number of customer interruptions and the number of customer minutes lost.

129. The next price control period for electricity distribution, RIIO-ED1, will commence in 2015. It will be the first price control period for electricity distribution based on the

new revenues, incentives, innovation and outputs (RIIO) model which was emerged from Ofgem's RPI-X@20 review.

130. The new RIIO model envisages most price control periods lasting eight years, which would take RIIO–ED1 through to 2023. Over this eight year period it is possible that the UK electricity sector will undergo changes that result in a quite different market electricity than that which we see now. One such change could relate to the transition to a low carbon economy.

131. If this potential transition looked likely to impact on how electricity customers value reliability, or VOLL, then this is something Ofgem would have to bear in mind when developing proposals for RIIO-ED1. For example, it might wish to allow the values in the incentive interruption scheme to change in the course of the price control period.

132. In our review of the literature on VOLL, we did not find any studies that considered directly the likely impact of the transition to a low carbon economy on VOLL. We did find a couple papers that speculated on what VOLL might be in the future, but these were essentially just speculative guesses; furthermore, they did not refer to the UK context or to a low carbon economy context. We do not review those speculations further.

133. In this section we explore some of the issues that Ofgem could consider.

What features of a low carbon economy have the potential to change the value of lost load?

134. The term "low carbon economy" refers to an economy that emits lower levels of carbon dioxide and, potentially, other greenhouse gasses. This could be achieved in a myriad of ways, making it difficult to define an exact image of what a future low carbon economy would look like.

135. One way to address this is to look at potential changes on a more granular level, identifying features that a low carbon economy might possess and considering how these features would impact upon VOLL, rather than addressing the question in a top-down fashion.

136. There are many sources of information that consider what a future low carbon economy might look like. We have drawn upon some of these to identify a set of low carbon features that might form part of a low carbon economy. The features that we have identified are:

(a) an increase in the number of electric vehicles;

(b) a large proportion of generation is distributed generation;

(c) the number of households heated via electric heating increases;

(d) energy efficiency increases;

(e) storage becomes more viable;

(f) developments in combined heat and power; and

(g) development of smart grids.

137. We have not set out to be exhaustive in this work; we have not aimed at identifying every possible feature that could be thought to characterise the transition to a low carbon category and neither have we tried to provide definitive views ideas on how the different features might affect VOLL. The discussion below outlines some thoughts that Ofgem may wish to build upon when considering whether VOLL is likely to change in the event of a transition to a low carbon economy.

Electric vehicles

138. An increase in the number of electric vehicles is one possible feature of a transition to a low carbon economy. We refer here mainly to the adoption of battery electric vehicles, although the points may apply equally well to plug-in hybrid electric vehicles.

139. For a household with an electric car, electricity is now required to recharge the vehicle. If there are interruptions, it might mean the car cannot be used for as long distances or even at all.

140. Owners of electric cars would probably place some value on not losing some charging time through the interruption. The value placed on avoiding an interruption would be even greater for longer interruptions as the ability to be flexible with charging diminishes and would be dependent upon the feasibility of charging cars at flexible locations (which in itself would depend upon access to charging points and the speed of recharging).

141. The impact on businesses would vary significantly depending upon the type of business and potential use of electric vehicles. Some businesses use a significant amount of transport to conduct their business, travelling to clients or attending to jobs for example. If such businesses switched to electric vehicles, then an interruption could prevent them from carrying out some of their business functions. As with households, this will be especially true for longer interruptions. The impact of an increase in electric vehicle take-up on the value placed on avoiding an interruption will depend on the amount of business a sector conducts that is dependent on, now electrified, transport. The more essential transport is to a business, the more valuable the continuous ability to charge and run vehicles will be.

142. The transport sector is a special case. Whilst the electrification of transport services is nothing new (e.g. London underground, Thameslink and trolley buses) the development of storage technology could spur on increased electrification of the transport sector. This could then lead to an increased dependence on electricity from the sector and an increase in its desire for supply reliability. For example, if buses were to install electric motors power by battery, then bus companies would probably place a high value on ensuring continuous supply so that they could keep their buses charged and the service running.

143. Similar effects would be expected for delivery firms and potentially taxis.

144. For businesses that make very little use of transport, we have not identified strong reasons for VOLL to differ for businesses due to higher electric vehicle take up.

145. There is potential for future electric vehicles to be fitted with inverters and hence be effective storage units. We discuss the potential effect of increased storage capabilities on VOLL further below.

Distributed generation

146. The second feature in our list is that a larger proportion of generation is distributed generation. This refers to generators that are directly connected to the distribution network. In particular, we have in mind here generation technology perhaps most likely to become more prevalent in the move to a low carbon economy, partly encouraged by schemes like the feed-in-tariff, such as solar and wind technology. The impacts on businesses would probably apply more or less to other types of distributed generation.

147. The impact of an increased amount of distributed generation on VOLL is likely to be small for the majority of customers.

148. The effect of an increase in the amount of distributed generation on the value placed on preventing interruptions and maintaining supply security will vary according to the exact nature of that generation. If it is the case that generators attached to the distribution networks can continue to produce power in the event of an interruption, then this could restrict the spread of interruptions, or the amount of power lost, due to distribution faults.

149. Conversely, if an interruption prevents electricity production for distributed generation, this may reduce financial rewards for generators, depending upon the structure of their tariffs. Distributed generators might then place additional value on preventing an interruption on a distribution network.

Households use of electric heating

150. The next feature we consider is an increased use of electric heating by households. This would increase electricity consumption, although exactly how much would be dependent on other factors such as energy efficiency.

151. Increasing the number of activities dependent upon electricity will increase the detriment to electricity customers in the event of an interruption. This effect will be more pronounced for activities that are valued highest and dependent on electricity, such as heating.

152. A widespread uptake in electric heating will almost certainly increase the value that a customer places on avoiding an electricity interruption. The effect on VOLL in terms of £/kWh is more uncertain. Whilst interruption costs will increase, so will the amount of energy lost. It is not straight-forward to predict the net effect. A potential clue could come from looking at countries that already have a high uptake of electric heating.

153. Norway is a country with predominantly electric heating. According to a study by Kjølle et al. (2008), VOLL for the residential sector is £0.98/kWh (2012 GBP) for a one hour interruption. This is smaller than most of the numbers presented in this report. An equivalent pounds per kWh estimate from the Accent (2008) study would be around £15/kWh based on the assumption of 4000 kWh annual consumption. There are problems with this comparisons, and these are discussed in the review of the relevant studies in appendix 1, but the relatively low estimate of VOLL for Norway, and interestingly Sweden as well, might suggest an increase in electric heating would actually lower estimates of VOLL expressed in £/kWh in the UK, despite an increase in the value attributed to avoiding an interruption of a given duration.

Combined heat and power

154. Combined heat and power (CHP) concerns generating plants connected to the electricity distribution network distributing the heat produced when generating electricity to buildings. This type of arrangement could be a feature of a low carbon economy.

155. It is possible that a fault on an electricity distribution network could prevent such a plant from exporting electricity. The plant would then cease generation and stop producing heat. A distribution fault would therefore result in a disruption to heating services.

156. If this were to be the case, then there would be an increase in the value of maintaining a secure supply due to increased CHP.

Increased energy efficiency

157. We have also identified an improvement in energy efficiency as a possible feature of a low carbon economy. This relates mainly to improved insulation and the consequent impact of energy consumed on air temperature in a building.

158. This will only have an effect on VOLL if electric heating use increases. If houses are better insulated, the cost of a short interruption might be lower since the overall heat lost due to losing heating will be less.

159. This is unlikely to make too much difference to estimates of VOLL associated with longer interruptions as even the best insulated properties require reheating eventually.

160. The impact of increased energy efficiency on the value placed on supply reliability by businesses will depend upon how dependent businesses are on electric heating. For some businesses, such as hotels and other similar service industries, we would expect similar effects as for domestic customers.

Storage

161. Improvements in the technology to store electricity may also be a feature of a low carbon economy. This could be closely linked to an increase in electric vehicles

ownership if the vehicles are fitted with inverters allowing stored electricity to be used as power in a household.

162. Effective storage by end users of electricity could mean continued electricity use even in the event of a distribution related power cut. This might allow the same level of use or, at any rate, mitigate the impact of an interruption in the network's supply of electricity. Either way, the amount of load lost due to an interruption would decrease if storage technology improved or became widespread.

Smart grids

163. Another factor which might be relevant could be the adoption of smart grids. Smart grid technology might allow increased flexibility of certain loads, reducing the cost of an interruption.

164. Increased communication might allow networks to provide customers with better information on interruptions, reducing the cost of an interruption as this reduces anxiety and allows better planning.

Other factors

165. Besides the low carbon economy, it is possible to imagine other advances that impact on VOLL. These could include:

(a) an increase in the use of mobile electronic goods which, because of their (albeit limited) autonomy, allow households to enjoy leisure activities and businesses not to interrupt all their activities in the event of a black-out; and

(b) reductions in generation costs which make back-up generation more feasible.

166. The analysis above is at a high level and does not attempt to seek out all possible outcomes relating to the low carbon economy and its effect on VOLL. There are several points of caution to note in undertaking a common sense analysis of the low carbon economy's effect on VOLL.

(a) The effects of features need to be considered as a package as many of them interact. For example, heating and energy efficiency need to be considered together and the possibility for storage could mitigate other factors that seemingly increase the value of avoiding interruptions.

(b) It is not possible to predict with any certainty how new technology will develop, and it is difficult to quantify what their effect might be on customers' valuation of electricity reliability.

Using estimates of VOLL as part of RIIO-ED1

167. The earlier sections of this report concern estimates of VOLL. In this section we identify how Ofgem, and electricity distribution companies (DNOs), could make use of such estimates as part of the next electricity distribution price control review, RIIO-ED1.

168. We discuss below three potential areas where the information could be drawn on:

(a) **Output incentive schemes**. Estimates could contribute to decisions about the incentive rate and also the level of baseline performance specified in output incentive schemes such as the current interruption incentive scheme.

(b) **Secondary deliverables**. Estimates could contribute to decisions about the secondary deliverables a DNO is expected to deliver during a price control period, taking account of the potential impact of secondary deliverables on interruptions over the longer term.

(c) **Compensation schemes**. Estimates could contribute to decisions about the value of any compensation payments that DNOs are required to make to consumers who have suffered from interruptions.

169. Apart from regulatory decisions by Ofgem, DNOs might draw on estimates of VOLL as part of their business plans, particularly in support of proposals for baseline performance levels and secondary deliverables. They might also use them more generally as part of their asset management and network planning policies

170. At DPRC5, Ofgem defined the incentive rates for the interruption incentive scheme on the basis of its estimates of WTP associated with the number of interruptions and the length of interruptions. These estimates were those put forward in the study by Accent (2008).[5] The estimates from the customer research were scaled back by 10 per cent to take account of the worsening in the economic situation of the economy between 2008, when the research was done, and 2009.

A general output incentive scheme

171. In the next few sub-sections, we highlight the potential role of estimates of VOLL as part of an output incentive scheme along the lines the DPCR5 interruptions incentive scheme.

172. There are different ways in which an output incentive scheme can be designed and described. To ensure our discussion is relevant beyond the specific features of the scheme applied at DPCR5, we set out below the main features of a more general output incentive scheme:

(a) **Output measure**. This could, for example, be the number of interruptions, the average length of interruptions or a measure of the total length of interrupted supply.

(b) **Baseline level of performance**. Under the RIIO framework, Ofgem will determine a (maximum) revenue allowance over the price control period. This will be set on using estimates of the (efficient) costs the DNO would incur in delivering a baseline level of performance across its various output measures. Leaving aside the impacts of other incentive schemes, the idea is that a DNO that

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5 Ofgem (2009) "Electricity distribution price control review: Final proposals — incentives and obligations", p. 87.

delivers the baseline level of performance will be able to earn a level of profit compatible with its cost of capital.

(c) **Output incentive rate**. This specifies how variations in performance against the output measure affect the maximum revenue that a DNO is allowed to collect from consumers. There could be a single incentive rate that applies across all performance levels. Another possibility would be to have a different rate for performance above and below the baseline. It would also be possible to set a scheme that is downside-only or penalty-only in the sense that revenue is reduced for performance below the baseline but there is no opportunity for the DNO to get additional revenue from performance above the baseline.

(d) **Caps and collars (optional).** Caps and collars limit the financial exposure of the DNO under the output incentive scheme. A cap places a limit on maximum financial benefits from improved performance, and a collar a limit on the maximum financial downside from worse performance.

173. We highlight below the potential contribution of estimates of VOLL to set the output incentive rate and the baseline level of performance. We then discuss some further issues related to the choice of output measure.

Contribution of estimates to the output incentive rate

174. An output incentive scheme allows each DNO to collect more money from consumers (and so charge higher prices) the greater its performance against the output measure. By the same token, worse performance under the scheme reduces the revenue the DNO can collect from consumers.

175. Such a scheme may encourage a DNO to do things that improve its performance if the additional revenue that it expects to receive under the scheme is greater than the costs it faces from doing these things. The scheme may also encourage a DNO to do things that would reduce its costs if the revenue it expects to lose from a reduction in performance is outweighed by the money it saves. These financial incentives will depend on the output incentive rate (subject to any caps and collars).

176. One potential motivation for using an output incentive scheme would be to try to meet the following objectives:

(a) Provide financial incentives that encourage a DNO to deliver better performance (e.g. fewer interruptions or interruptions of a shorter duration) if the benefits to consumers of this improvement in performance outweigh the cost of achieving it.

(b) Provide financial incentives that encourage a DNO to take actions that reduce its costs, albeit with some deterioration of performance (e.g. more interruptions or longer interruptions) if the costs saved outweigh the harm that consumers experience from the reduced performance.

177. Estimates of VOLL may be relevant to the calibration of the output incentive rate because they provide estimates of the benefits to consumers from better performance and the harm to consumers from worse performance.

178. In a very simple model, in which consumers are homogenous, the DNO bears its costs in full and there is an infinite price control period, the two objectives for financial incentives above are met if the output incentive rate is set equal to consumers' marginal valuations of better performance.

179. It may not be appropriate to extrapolate from this simple model to calibrate an incentive scheme for a DNO. We discuss in the next sub-section why it is important that any decisions to set output incentive rates by reference to estimates of VOLL also take account of the efficiency incentive rate.

180. There are other factors that may make it difficult to design an output incentive scheme that fully meets the two objectives above. In particular, where companies are taking investment decisions that will affect their performance across a number of different price control periods, the financial incentives they face to make investment decisions today will depend on their expectations about the extent to which they will benefit from the improvement in future price control periods (e.g. whether the company will retain the benefits or whether improved performance may lead to a more-demanding baseline performance next time round).

Interactions with the efficiency incentive rate

181. Under the RIIO framework, there is a form of risk-sharing arrangement such that variations between forecast costs and outturn costs are shared between investors and consumers. This is achieved by adjusting the DNO's maximum revenue allowances in the light of actual expenditure in previous years which, in turn, affects the level of charges the DNO can impose on consumers. If a company spends more than expected, these arrangements allow the company to collect some additional revenue from consumers to partly (but only partly) compensate for the additional costs. If a company spends less then expected, these arrangements would reduce the revenue that the company is allowed to collect so that part of the cost saving is passed on to consumers.

182. The efficiency incentive rate governs the extent to which variations in a company's actual expenditure, compared to that forecast at the price control review, are passed through to consumers (e.g. through higher charges in subsequent years). If the efficiency incentive rate is 40 per cent, the aim is that future charges are adjusted so that 60 per cent of the difference between forecast and actual costs is passed through to consumers.

183. If a DNO is only exposed to a proportion of its marginal expenditure during the price control period, with the remainder passed through to consumers, this proportion may need to be recognised in the specification of the incentive scheme.

184. Suppose that consumers value reductions in the number of interruptions at a rate of £10 per interruption. A proponent of an output incentive scheme might suggest that the output incentive rate should then be set at £10 per interruption on the basis that this would provide financial incentives for companies to incur additional expenditure to improve performance if (and only if) the benefits to consumers are worth more than the additional costs. This argument would not be valid if the company is only exposed to a proportion of any variation in its costs, with the remainder passed on to

consumers. Suppose that the company identifies some changes to its working practices that would reduce the number of interruptions by one hour and cost around £15 per interruption. The benefit to consumers of this change would be £10 per interruption and the total costs £15 per interruption avoided, which suggests that it would not be a good idea. However, if the company faces an efficiency incentive rate of, say, 40 per cent, the output incentive scheme would provide the company with a financial incentive to make this change. The company would stand to gain an additional £10 per avoided interruption, but would only bear a cost of £6 per interruption (40 per cent of £15) as the remaining £9 would be passed through to consumers.

185. In short, taking an estimate of VOLL and using this directly as the output incentive rate, risks providing DNOs with financial incentives to improve performance in cases where the benefits do not outweigh the costs.

186. In a simple case, this risk can be addressed by setting the output incentive rate as no more than the efficiency incentive rate multiplied by an estimate of VOLL. However, price controls can include a complex set of financial interactions and this is not a hard and fast rule; some case-specific analysis would be prudent.

187. Ofgem has recognised these interactions in its recent price control work. The initial proposals for the electricity transmission companies in Scotland include incentive schemes for reliability outputs. The output incentive rate is aligned with the estimated VOLL in £/MWh and then halved on account of the 50 per cent efficiency incentive rate.[6]

Potential drawbacks from value-based approach to output incentive rates

188. The level at which the baseline performance is set in output incentive schemes matters to consumers. The baseline line of output performance is funded by consumers based on estimates of the cost a DNO will incur in delivering those outputs.

189. If the output incentive rate is calibrated using estimates relating to VOLL, then for performance improvements over and above the baseline, consumers would (in aggregate) pay an amount that is based on estimates of their valuation of those improvements rather than an estimate of the costs of achieving them.

190. This type of arrangement moves the price control regime away from one under which the prices that consumers pay to a monopoly network company are based on the company's costs or forecast costs. It allows the company to extract consumers' valuation of an improved service.

191. It might be possible to achieve the same level of performance at lower cost to consumers. This may be the case if, instead, a higher baseline level of performance had been set from the start. This may allow consumers to experience improved performance whilst paying an amount that represents the forecast costs to the

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[6] Ofgem (2012) "RIIO-T1: Initial Proposals for SP Transmission Ltd and Scottish Hydro Electric Transmission Ltd", page 16.

company of achieving that improvement rather than paying an amount that matches their valuation of the improvement (which could be much higher).

192. A possible argument in favour of the output incentive scheme is that it helps reveal ways in which companies can bring service improvements and the costs of doing so, by providing profit opportunities from the discovery and implementation of measures that bring greater benefits to consumers than they cost. But this does not detract from the benefits to consumers from endeavours by Ofgem to set an appropriate baseline performance level at the price control review. This could allow consumers to get some improvements at lower cost than if left to a value-based incentive scheme.

Contribution of estimates to setting baseline level of performance

193. Estimates of VOLL may be relevant to decisions about what level is appropriate for the baseline performance in an output incentive scheme.

194. As part of the RIIO framework, Ofgem is looking for companies to justify their business plans as in the interests of consumers, considering different options. This could be taken to include information on costs of possible reliability improvement schemes. The DNO could combine this with estimates, or the range of estimates, of VOLL to help decide which option is in the best interests of consumers.

195. If a DNO is seeking to convince Ofgem that its business plan is well-justified, and provides a good basis on which to set its price control, this sort of assessment would seem an integral part of the plan. A DNO might wish to demonstrate to Ofgem it has high–quality asset management policies that are in the interests of consumers. For instance, a DNO may use estimates of VOLL to decide on whether to implement a specific reliability project or not.

Potential alternatives: penalty-only scheme or cost-based incentive rate

196. DNOs may want to retain opportunities to make additional profit by achieving a higher level of performance under the output incentive scheme. This could hamper efforts, at the price control review, to identify an appropriate level of baseline performance.

197. One way to mitigate this concern would be to make the output incentive scheme penalty-only, so that the company would not earn additional revenue from improvements beyond the baseline: if the company wants to improve performance it would need to justify this as part of its business plan.

198. We have also identified an alternative approach which would provide the DNO with greater flexibility. This would involve an asymmetric output incentive rate:

(a) For performance below the baseline, the output incentive rate would be based on estimates of VOLL, as in the basic approach above. This is to provide a financial incentive for the DNO to avoid performance below the baseline (unless the money saved is greater than the estimated harm to consumers from the degradation in performance).

(b) For performance above the baseline, the output incentive rate would be the lower of (i) estimates of VOLL and (ii) estimates of the average incremental cost of the DNO achieving improvements in interruptions.

199. The rationale for (b) would be that it could remunerate a company for performance above the baseline on the basis of estimated costs, without extracting the full value to consumers of the improvement to performance. Any cost to consumers of performance improvements above the baseline would be limited to the estimated costs of making these improvements, or their estimated value to consumers, whichever is lower.

The choice of output measure

200. One parameter in the output incentive scheme is the choice of output measure on which performance is assessed. Two factors to consider are:

(a) **Data availability**. This includes data relating to the output measure itself (e.g. data on the total minutes of interruptions) and, if used to set the output incentive rate, data relating to consumers' valuation of interruptions against that measure.

(b) **Incentive effects**. The choice of the output measures against which any financial incentive apply is likely to affect the behaviour of DNOs. For example, it could affect a DNO's network planning decisions and the way that it responds to restore the electricity supply following an interruption.

201. Ofgem's current interruption incentive scheme for DNOs assesses performance in terms of (i) the number of customer interruptions and (ii) the number of customer minutes lost. The reliability incentive schemes proposed for the next electricity transmission price controls in Scotland uses energy not supplied (ENS) as the output measure.[7]

202. Under the current electricity distribution scheme, a DNO has a greater financial incentive to restore electricity, or increase resilience, where this affects a large number of consumers. The financial incentive does not depend on any characteristics of the customer. If the purpose of the scheme is to encourage the DNO to improve performance where the benefits to consumers outweigh the costs, this feature of the scheme may be unwelcome. The benefits from improved performance may vary substantially across consumers.

203. As an example, the current scheme may provide the same financial incentive for a company to reduce the duration of an interruption affecting five households as one affecting five retail premises. But the valuation of the benefits from a shorter interruption could be very different across the two groups (e.g. much higher for the retail premises, at least during business hours).

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[7] Ofgem (2012) "RIIO-T1: Initial Proposals for SP Transmission Ltd and Scottish Hydro Electric Transmission Ltd", page 16.

Secondary deliverables

204. We now move on to other uses of the estimates of VOLL as part of RIIO-ED1, beyond the setting of baselines and incentives rates for an output incentive scheme.

205. In addition to output measures, the RIIO framework includes a role for secondary deliverables. Secondary deliverables (e.g. based on asset health measures) are intended to encourage a DNO to behave in a way that supports the cost–effective delivery of a reliable network over the longer–term. Secondary deliverables are important in a context when some decisions about long–lived network assets may have limited effect on outputs such as interruptions until future price control periods. Information on the valuation of interruptions might be relevant to what level of output performance a DNO should seek to provide in the longer–term; this may then feed back to associated levels of secondary deliverables for the RIIO–ED1 price control period.

Compensation schemes for consumers affected by interruptions

206. Estimates of VOLL may be taken into account as part of the introduction or review of regulatory arrangements under which each DNO has an agreed standard of performance and is required to compensate affected consumers in the event that its performance drops below this standard.

207. The Guaranteed Standards applying to DNOs is an example of a compensation scheme. This provides compensation in a range of areas, including certain interruption events.

208. The requirement to offer compensation would provide a financial incentive for the company to take action that avoids shortfalls in performance (at least where it is cheaper to do this than incur the compensation payments). A compensation scheme would differ from the output incentive scheme discussed above in several ways. In particular:

(a) The DNO would make a payment to the specific consumers affected by the interruption. In contrast, under the output incentive scheme, worse performance leads to a reduction in the money that the DNO can collect from consumers, but the corresponding reduction in charges would be spread across all consumers without any specific benefit to those consumers suffering interruptions.

(b) There would be no automatic increase in revenues for the DNO if performance is better than the agreed standard of performance. In the terminology of the output incentive scheme, it would be penalty-only.

209. Estimates of VOLL could be relevant to decisions about the level of compensation payments.

210. It would be possible to tailor the value of compensation payments to the characteristics of the consumer (e.g. domestic versus non-domestic) and features of the interruption (e.g. duration, time of day). This could be done in light of information on VOLL for different consumers and different events.

211. Such a compensation scheme might be seen as either an alternative or complement to an output incentive scheme. If it is applied in addition to an output incentive scheme, there is a risk of creating an overall incentive structure for DNOs that suffers from a double-counting problem. This might be the case if estimates of VOLL are used to set the output incentive rate and the value of compensation payment for interruptions: interruptions would be penalised twice: once through the compensation payment and again through the revenue reduction under the incentive scheme. Similarly, improvements in performance would be rewarded twice.

212. We identified above that, in the case of an output incentive scheme, decisions to use estimates of VOLL in setting the output incentive rate should be taken in light of the efficiency incentive rate. If those estimates are used to determine compensation arrangements for consumers affected by interruptions, it would not be appropriate to scale down the value of compensation according to the efficiency incentive rate. But there may be a case for including the costs of making compensation payments as part of the costs covered by the efficiency incentive rate. If this is not done, the different regulatory treatment of compensation payments and other costs could lead to distortions which cause perverse expenditure decisions by DNOs to avoid compensation.

Appendix 1: Review of studies

213. This appendix contains reviews of the set of studies we have examined.

214. We structure the review of each study into four sub-sections:

(a) Coverage and method — describes what the study is about and outlines the method used.

(b) Findings — sets out the findings from the study that are most relevant to our own work.

(c) Extracting results for comparison — describes how we used the findings in the study to calculate estimates that we compare with estimates from other studies, including setting out any assumptions made in doing so.

(d) Comment — our comment on the study, highlighting in particular any methodological shortcomings we may find.

215. Table 6 lists the order in which the studies are reviewed in this appendix. The first four studies reviewed are those that refer to the UK; these are presented in reverse chronological order. The remaining studies are then ordered alphabetically.

Table 6 List of studies reviewed

Accent (2004) "Consumer expectations of DNOs and WTP for improvement in service"
Accent (2008) "Expectations of DNOs and willingness to pay for improvements"
Kariuki, K. and R. Allan (1996) "Evaluation of reliability worth and value of lost load"
Willis, K and G Garrod (1997) "Electricity supply reliability: Estimating the value of lost load"
Bertazzi, A. et al (2005): The use of customer outage cost surveys in policy decision–making: the Italian experience in regulating quality of electricity supply
Blass, A et al (2008) "Using elicited choice probabilities to estimate random utility models: preferences for electricity reliability"
Bliem, M (2009) "Economic valuation of electrical service reliability in Austria – a choice experiment approach"
Carlsson, F. and P. Martinsson (2004) "Willingness to pay among Swedish households to avoid Power outages — a random parameter Tobit model approach"
Carlsson, F. and P. Martinsson (2007) "Does it matter when a power outage occurs? A choice experiment study on the willingness to pay to avoid power outages"
Charles River Associates (2008) "Assessment of the value of customer reliability (VCR)"
de Nooij, M. et al (2007) "The value of supply security. The costs of power interruptions: Economic input for damage reduction and investment in networks"
Kjølle, G.H. et al (2008) "Customer costs related to interruptions and voltage – problems: methodology and results"
Leahy, E. and R. Tol (2010) "An estimate of the value of lost load for Ireland"
Praktiknjo, A.J. et al (2011) "Assessing energy supply security: Outage costs in private households"
Sullivan, M. et al (2009) "Estimated Value of Service Reliability for Electric Utility Customers in the United States"

216. All results of the studies that are presented in this section in monetary terms are expressed in terms of 2012 pounds sterling. As discussed in the main body of the report, we have done this by using the relevant exchange rate and by updating values using the RPI index for January 2012.

Accent (2008) "Expectations of DNOs and willingness to pay for improvements"

Coverage and method

217. Accent's work in 2008 covered much of the same ground as it earlier 2004 research. Here too, the work sought to estimate customers' WTP and WTA changes in the reliability of electricity supply.

218. The sampling method used was similar to that in Accent (2004). There were 2,154 face-to-face interviews were carried out with domestic customers, and 1,052 telephone interviews with businesses.

219. As with its 2004 work, the analysis was based on data collected from a survey covering a set of questions where respondents were asked to choose between a set of three alternative performance-price combinations, one of which reflected the status quo.

220. Performance levels were characterized with a number of attributes including the number of short interruptions, number of interruptions over 3 minutes, average duration of interruptions over 3 minutes. Prices were expressed in terms of an increase or decrease to customers' annual electricity bill; for domestic customers this was expressed in absolute terms (e.g. an increase in £10) whereas for business customers it was expressed in relative terms (e.g. a 10 per cent increase in annual bill).

221. The data collected from the stated preference exercises were analysed by estimating a series of multinomial logit models. From these, it is possible to calculate estimates of the WTP and WTA for marginal changes in each of the performance attributes.

222. Because of the way the survey questions are structured, the study finds that there is a concern related to potential "packaging effects". This is described as a

> concern that the estimation of the willingness to pay from multiple experiments using a subset of the attributes can lead to an overstatement of the total willingness to pay for all of the improvements, i.e. respondents may indicate that they are willing to pay a certain amount for the service improvements in experiment 1, and another amount for the service improvements in experiment 2 and a further amount for the service improvements in experiment 3. However, in total these may add up to more than the respondent would be willing to pay in total.

223. The study motivates the possibility that packaging effects are material by pointing to theories relating to budgeting effects, to non-linearities in prices and halo effects (respondents assume that improvement in one attribute imply improvements in other attributes). To address this, the survey included a question to allow Accent to investigate and quantify the extent of the packaging effect. Following on from that work, the study reports results relating to the WTP or WTA changes in performance levels after making an adjustment for the estimated packaging effect. It is these adjusted results that we present below.

Findings

224. The report presents an array of results, covering WTP for improvements, and WTA to accept deterioration, in a number of different attributes of reliability. It examines:

(a) the WTP/WTA for a reduction/increase in the frequency of interruptions; and

(b) the WTP/WTA for a reduction/increase in the average duration of an interruption.

225. We set out the estimates for the above, presenting first the findings for domestic customers and then those for businesses. Table 7 sets out the estimates on the WTP and WTA for a change in the number of annual interruptions, for each of the 14 DNO areas for domestic customers. The values are expressed as pounds sterling per interruption per year.

Table 7 Accent (2008) — Domestic customer: willingness to pay and to accept for a change in number of annual interruptions (£ per interruption per year)

DNO	Deterioration in service	Improvement in service
CN– East	–£4.94	£4.49
CN–West	–£6.70	£4.49
EDF–EPN	–£7.36	£4.49
EDF–LPN	–£15.04	£15.04
EDF–SPN	–£7.61	£4.49
SSE– Hydro	–£4.52	£4.49
SSE– Southern	–£5.75	£4.49
CE–YEDL	–£2.87	£4.49
CE_NEDL	–£10.19	£4.49
UU	–£19.52	£4.49
WPD S Wales	–£7.78	£4.49
WPD S West	–£8.46	£4.49
SP Manweb	–£8.00	£4.49
SP Distribution	–£8.00	£4.49

226. The interpretation of table 7 is as follows. On average, domestic customers in CN–East are willing to pay, each year, £4.49 for enduring one fewer power cut per year.

At the time of Accent 2008's report, CN–East's level of performance was of 4 cuts per 5 years. Therefore, an improvement to 3 cuts per 5 years would be valued at £4.49*(4/5–3/5) which is equal to £0.90.

227. Other than for EDF–LPN, the study does not find statistical significant differences in the valuations of improvements in service levels across the remaining 13 DNO areas. As such, a single value for WTP for improvement was calculated for those thirteen areas, as shown in table 7. With respect to estimates of WTA a deterioration in performance, the study did find differences across the DNOs, so that different numbers are reported for each. Typically, the WTA is greater, in absolute terms, than the WTP. However, for EDF–LPN this was not the case; the study was only able to identify a single coefficient to reflect the value of a marginal improvement and of a marginal deterioration.

228. We turn now to the results relating to domestic customers' WTP and WTA for changes in the average duration of power cuts. Table 8 sets out these results. It reports the value associated with an increase and with a decrease by one minute in the average duration of an interruption.

Table 8 Accent (2008) — Domestic customers' willingness to pay and to accept change in average duration of a power cut by a minute (£ per minute change)

DNO	Deterioration by 1 min	Improvement by 1 min
CN– East	–£0.15	£0.08
CN–West	–£0.15	£0.08
EDF–EPN	–£0.15	£0.08
EDF–LPN	–£0.07	£0.07
EDF–SPN	–£0.15	£0.08
SSE– Hydro	–£0.13	£0.13
SSE– Southern	–£0.11	£0.08
CE–YEDL	–£0.15	£0.08
CE_NEDL	–£0.22	£0.08
UU	–£0.18	£0.18
WPD S Wales	–£0.15	£0.08
WPD S West	–£0.15	£0.08
SP Manweb	–£0.04	£0.04
SP Distribution	–£0.15	£0.08

229. The study identified differences across DNOs in the WTP to avoid an increase by one minute in the duration of the average interruption, with values ranging from 4 to 15 pence. With respect to improvements in the service, the values for WTP ranged from 4 to 19 pence.

230. We turn to the findings relating to business customers.

231. Table 9 sets out the findings on businesses WTP and WTA for changes in the frequency of interruptions. The results are expressed as percentages of the annual bill. For DNOs other than EDF-LPN and SP Manweb, the study found significant differences between manufacturing and non-manufacturing business in their WTP for improved service, i.e. for a reduction in the frequency of interruptions. Those more granular findings are shown separately in table 10.

Table 9 Accent (2008) — Business customers' willingness to pay, or to accept, change in frequency of interruptions (% of annual bill)

DNO	Deterioration in service			Improvement in service		
	Small	Med.	Large	Small	Med.	Large
EDF– LPN	–12.5%	–12.5%	–4.8%	–12.5%	–12.5%	–4.8%
SP Manweb	–5.3%	–5.3%	–4.2%	8.4%	8.4%	6.6%
SP Distribution	–15.2%	–15.2%	–12.1%	See table 10.		
11 remaining DNOs	–5.3%	–5.3%	–4.2%			

Table 10 Accent (2008) — Business customers' willingness to pay to reduce frequency of interruptions for all DNOs other than EDF–LPN and SP Manweb (% of annual bill)

Type of business	Small	Med.	Large
Manufacturing	3.7%	3.7%	2.9%
Non–manufacturing	2.6%	2.6%	2.0%

232. Tables 9 and 10 point to the finding that, as a share of their annual bill, smaller and medium business customers are willing to pay more than large businesses for a decrease in the frequency of interruptions than larger customers. It is interesting that no difference between small (defined as having annual bills below £30,000) and medium (annual bills between £30,000 and £275,000) was found.

233. We turn to the findings relating to business customers' WTP and WTA for a change in the average duration of an interruption.

234. For business customers in the EDF-LPN area, the study did not find any significant WTP or WTA for changes in the average duration of interruptions. The estimates for business customers in all other areas are set out in table 11, expressed as a percentage of their annual electricity bill.

Table 11 Accent (2008) — Non–LPN business customers: willingness to pay and to accept change in average duration of a power cut (% electricity bill per minute)

	Size of business customer		
Change in service	**Small**	**Medium**	**Large**
Deterioration	0.07%	0.07%	0.06%
Improvement	0.05%	0.05%	0.04%

Extracting results for comparison

235. For domestic customers, we derive estimates of VOLL to avoid a 1-hour and for an 8-hour interruption. We derive these estimates by drawing on the study's findings relating to the WTP to avoid an increase in the frequency of interruption, shown in an earlier table. Because the analysis produces an estimate of WTP for customers in LPN area and one for customers in all other areas, two numbers are computed. To illustrate the mechanics of the calculation take as an example the estimate for all DNOs other than LPN.

236. As shown earlier, the WTP of domestic customers to avoid an additional interruption in areas other than LPN is £4.49. On the basis of the information included in Accent (2008), the average duration of an interruption in areas other than LPN is 96 minutes. Given this, we calculate an estimate of VOLL for avoiding a 1-hour interruption as £2.8, obtained from £4.49 * (60/96). We follow an analogous procedure to calculate estimate for customers in the LPN region, and for estimates relating to 8-hour interruptions.

237. With regard to business customers, we are not able to translate Accent's findings for business customers into a set of estimates expressed as pounds sterling per unit of consumption to make them comparable with estimates from other sectors. This is because results of VOLL for business customers are expressed as a percentage of annual energy bill and we do not have information on the average bill or average consumption of the different categories of business customers it considers.

Comment

238. The sampling of customers interviewed seems to have been carefully constructed and to be sufficiently large.

239. The authors make an explicit adjustment to the estimates to reflect the packaging effect described earlier. The adjustment is significant; adjusted numbers are around a

fifth of the unadjusted ones. We find the reasoning set out by the authors to make this adjustment to be a convincing one.

240. There is one aspect of the econometric analysis which we do take issue with.

241. The study states at page 55 the principle of aggregating data across DNOs unless their "analysis suggests that customers from a specific DNO have statistically significant different valuation", with an exception made for LPN data. It is because this principle is followed that, in some of the tables reported above the same number is reported for multiple DNOs. Whilst following the principle is attractive for the purpose of ending up with simpler models it is not clear that it can be justified in all cases. As an example, take the case of the coefficients relating to "Reductions of Power Cuts over 3 mins" that will have been estimated for each DNO separately. In line with its principle, Accent will have tested the hypothesis that all of those coefficients, other than that of LPN, are the same, against the hypothesis that they are not. This would be appropriate if it were the case that there were reasonable grounds for thinking that the hypothesis were true. In this case that would not seem to hold. Given the differences in the average duration of interruptions across DNOs we would not think it a reasonable hypothesis to suggest that across all DNOs, other than LPN, the WTP for one less interruption would be the same.

242. We think it would have been preferable had Accent not sought to aggregate data across DNOs and had instead reported estimates for each DNO separately.

243. The report includes a brief comparison of its 2008 findings with those from its earlier 2004 work. With regard to the WTP for a 20 minute reduction to average cut:

(a) Accent (2004) reports an estimate of £21.90 for domestic customers; Accent (2008) reports a value of £1.80 for LPN domestic customers and of £1.20 for non-LPN domestic customers.

(b) Accent (2004) reports an estimate of 2.9 per cent of annual bill for businesses; Accent (2008) reports estimates from 0.8 to 1.6 per cent, depending on the size of the business and whether it is a LPN customer or not.

244. In short, the estimates reported in Accent (2008) are significantly lower than those in Accent (2004). Differences in the methodology used are one reason given for this.

Accent (2004) "Consumer expectations of DNOs and WTP for improvement in service"

Coverage and method

245. This study was commissioned by Ofgem as part of the work leading up to the 2005 distribution price control review. The study is concerned with domestic and business customers' experience with the service of electricity distribution companies, their priorities for improvements in the quality of service and with their WTP for such improvements. Here, we focus on the research on customers' WTP and WTA.

246. Information was collected through 2,118 face-to-face interviews with domestic customers, and 1,965 business customers. Interviews were carried out in 2004.

247. The target sample for domestic customers was 2,100 interviews; 150 in each of the 14 DNO areas. Within each of these areas, minimum targets were set according to age groups, socio-economic groups, previous experience of interruptions and, with the except of the area covered by EDF Energy Networks (LPN), type of location (rural or urban). The LPN area does not include rural locations. The data were weighted by these different attributes so that the total weighted sample reflected the relative number and profile of domestic customers in each DNO area.

248. For business customers too, the target sample was 150 for each of the 14 DNO areas. The sample was selected to ensure a minimum number in each of three size categories, measured by maximum demand or annual electricity bill: large (over 1MW or £159,000), medium (over 100kW or over £15,000) and small. The data from business customers were weighted in line with the experience of cuts within each DNO area. Overall numbers were weighted by the number of customers in each DNO area.

249. The interview included a series of four stated preference exercise. In the first three, respondents were asked to select between pairs of packages of improvements in the quality of service. In the fourth, the respondents were asked to trade off bundles of improvements with changes in their electricity bill.

250. The attributes of the service that respondents were asked about covered:

(a) an increase or decrease in the number of interruptions over 5 years in rural and, separately, in urban areas; up to 3 more or 3 fewer interruptions than the DNO's current level;

(b) longer or shorter average interruptions; up to 20 minutes longer or shorter than the DNO's average;

(c) improvement in the resilience of the network: a 1 per cent chance of customers suffering an interruption greater than 24 hours following a major storm, currently once a year, improvement to once every 2 or once every 5 years;

(d) maximum time to restore consumers after a major storm decreasing to 24 or 36 hours or increasing to 60 hours, compared to current 48 hours;

(e) consumers entitled to compensation after 3 or 5 unplanned cuts of over three hours; current standard is set at four unplanned cuts.

251. Because the LPN area does not include rural locations, a separate questionnaire was used for customers of that DNO's.

252. As with domestic users, businesses' questionnaire included a series of stated preference exercises, similar to that of domestic users.

Findings

253. The report presents a large number of findings on the WTP or WTA by domestic and business customers for improvement or deterioration in reliability. We present here those that are most relevant to our study.

254. Table 12 sets out a summary of the findings from the survey with domestic customers, distinguishing between customers in rural and in urban locations.

Table 12 Accent (2004) — Domestic customers

	Rural	Urban	Total
Value in reducing duration of average cut			
Value per minute reduction to average cut	£1.69	£1.02	£1.41
Value of 20 minute reduction to average cut	£31.27	£20.41	£28.17
Value of 40 minute reduction to average cut	£62.54	£40.83	£56.33
Value in reducing frequency of cuts over 5 years from current level			
Value per unplanned rural cut	£25.89	£0.00	£5.62
Value per unplanned urban cut	£0.00	£23.84	£18.85
Value per planned rural cut	£14.24	£0.00	£2.92
Value per planned urban cut	£0.00	£11.99	£9.81

255. Taking the value per unplanned rural cut as an example, the numbers in the lower half of the table should be interpreted as follows: £25.89 is the annual amount a rural customer is willing to pay to reduce the number of interruptions in a year from the current level by one.

256. Table 12 shows that rural customers' WTP to decrease the average duration of an interruption is around 50 per cent higher than that of urban customers. Their WTP to reduce the number of interruptions from the current level by 1 is also higher than that of urban customers but only marginally so.

257. It is interesting to see from the lower half of the table that rural customers WTP to reduce number of interruptions suffered by urban customers is £0; and the reverse is also true. The left most column in the table, labeled "Total", reports a weighted average of the urban and rural customers.

258. For businesses, the stated preference exercise was carried out on the basis of percentages of their electricity bill. Table 13 reports a summary of the findings.

Table 13 Accent (2004) — Business customers

	Large	Medium	Small	Overall
Value in reducing duration of average cut				
Value per minute reduction to average cut	0.12%	0.12%	0.17%	0.14%
Value of 20 minute reduction to average cut	2.47%	2.43%	3.36%	2.88%
Value of 40 minute reduction to average cut	4.93%	4.86%	6.72%	5.77%
Value in reducing frequency of cuts over 5 years from current level				
Value per unplanned rural cut	0.00%	0.46%	0.84%	0.54%
Value per unplanned urban cut	3.58%	3.93%	3.06%	3.52%
Value per planned rural cut	0.00%	0.25%	0.42%	0.29%
Value per planned urban cut	2.22%	2.11%	1.54%	1.86%

259. The findings reported in table 13 do not point to a clear relation between size of the business and the WTP — expressed as a percentage of annual bill — by business customers to reduce the average duration of an interruption or to reduce the frequency of interruptions. The finding that large business are not willing to pay anything for changing the frequency of interruptions in rural areas is a reflection of the fact that none of the large businesses sampled operate in rural areas.

Extracting findings

260. For domestic customers, we derive estimates of VOLL to avoid a 1-hour and for an 8-hour interruption. As was our approach in relation to Accent (2008), we derive these estimates by drawing on the study's findings relating to the WTP to avoid an increase in the frequency of interruption, shown in an earlier table. In Accent (2004), the same estimate is produced for customers in all DNO regions so that no separate estimate for those in the LPN region is calculated. To derive estimates of VOLL for a 1-hour and an 8-hour interruption, we follow an analogous approach to the one we took with respect to Accent (2008) and which is described above.

261. As is the case with Accent (2008), we are not able to translate Accent's findings for business customers into a set of estimates expressed as pounds sterling per unit of consumption to make them comparable with estimates from other sectors

Comment

262. The sample of customers interviewed seems to have been carefully constructed and is sufficiently large.

263. With respect to the questionnaire itself, we are surprised that, for domestic customers, the questions regarding the frequency of interruptions was couched in terms of the number of interruptions to rural areas and number of interruptions to urban areas, rather than in terms of the number of interruptions to you, the respondent. As asked, the question opens the possibility for respondents to express altruistic attitudes which may vitiate the findings.

264. The work Accent carried out in 2008 makes a correction for what are termed "package effects"; see discussion below within our review of Accent (2008). That correction done in its 2008 work was a significant one; leading to a reduction in the WTP to about a fifth. It is not clear from the description in Accent (2004) whether such an adjustment was made, or to be fair, whether given the differences in the way the questionnaires were structured such an adjustment is necessary.

Kariuki, K. and R. Allan (1996) "Evaluation of reliability worth and value of lost load"

Coverage and method

265. This paper draws upon surveys conducted by the University of Manchester Institute of Science and Technology (UMIST) and supported by three regional electricity companies in the early 1990s. These surveys provide customer interruption costs which the study uses to calculate sector consumer damage functions and, ultimately, an estimate for VOLL. The sectors considered are: residential, commercial, industrial and large users.

266. The paper takes the following steps to calculate VOLL:

(a) Start with the cost of interruptions for various interruption durations and broken down by SIC class

(b) Normalise these costs by dividing by annual energy consumption or peak demand.

(c) Sector customer damage functions are then estimated by weighting the normalised costs by energy demand where possible, and averaging across SIC where not.

(d) All sectors are then weighted by their energy demand to give a composite consumer damage function.

(e) The VOLL for different duration lengths is then calculated by taking the composite consumer damage function and dividing it by the product of the duration length and a load factor — assumed to be between 50 and 66 per cent. The load factor is the same for all sectors and therefore the VOLL values are only given averaged across all sectors rather than separately for each sector.

(f) Using data on restoration stages from the three regional electricity companies, the expected VOLL is then calculated by multiplying the probability of each duration occurring by the estimated VOLL for an interruption of that duration.

Findings

267. The expected VOLL given in the paper is £15.93/KWh.

268. The report also presents the cost of an interruption of differing durations broken down by sector. Table 14 shows the costs associated with a one hour interruption in current prices.

Table 14 Kariuki and Allan (1996): Estimates of cost per 1-hour interruption

Sector	Cost per 1-hour interruption (£)
Residential	£1
Commercial	£169
Industry	£6,863
Large user	£371,925

Comment

269. This figure was for the customer of the three distribution networks amongst whom the survey was carried out. And it relates to a survey carried out in 1996, sixteen years ago.

270. One other potential concern in drawing on that figure relates to the low response rates to the initial survey data which provided the interruption costs data. One other concern relates to the uncertainty from consumer responses relating to how they might behave in hypothetical circumstances that have a very low probability of happening.

271. In a separate paper, the authors describe the survey method in greater detail. Interestingly, residential respondents to the survey were disproportionally over the age of 50, with around half of all respondents being aged over 51. Residential respondents were also disproportionally situated in rural communities, with 24 – 31 per cent living in a village or isolated property. These figures are not concerning enough to invalidate the results of the survey, but should be remember when inferring from the results since it seems quite likely older rural residential customers might value electricity reliability different from other customers.

272. The response rate for non-residential customers was lower than for residential. There were 1,700 commercial, 700 industrial and only 65 large user respondents. Respondents were asked to estimate their costs on that they would incur due to an interruption on a Wednesday at 10am in January. The results cannot be considered an estimate of average interruption costs.

273. Residential customers were asked to estimate the costs due to an interruption occurring at 4pm on winter weekdays. Similarly, this cannot be considered an estimate of average interruption costs.

Willis, K and G Garrod (1997) "Electricity supply reliability: Estimating the value of lost load"

Coverage and method

274. The paper reports the findings of a survey of industrial businesses in the area of south-east Northumberland on VOLL. The survey was carried out over the phone and 64 businesses completed the questionnaire. We infer from the paper that it was carried out in 1996.

275. There is no description of how the set of businesses sampled were chosen and the paper makes no claim that it is representative, either of the region covered by the survey or wider. Indeed, the paper implicitly suggests that it is not, as it notes the high-proportion of engineering firms in the sample (38 per cent). There is a wide range in the values of the electricity bills of the respondents: from £120 to £600,000 per year.

276. The questionnaire included an exercise based on a "contingent ranking methodology". Respondents were presented with sets of four scenarios and asked to rank them according to their preference. The scenarios were defined in terms of reduction to the level of reliability to their electricity supply and in terms of changes to their annual electricity bill. Reliability was characterised in terms of:

(a) number of additional supply interruptions in a 12 month period;

(b) maximum duration of these interruptions;

(c) timing of outages (morning or afternoon); and

(d) amount of advance notice

277. The paper does not describe the levels that each of these attributes was allowed to take in the definition of the different scenarios; it states that they were chosen randomly.

278. The paper uses regression analysis to estimate, by maximum likelihood, the marginal trade-off to customers between the different attributes of reliability and their electricity bill. Because the survey is couched in terms of the reduction in electricity bill required to offset a fall in reliability, the results are presented as estimates of WTA.

Results

279. One of the models estimated by the authors allows for interactions between characteristics of customers (e.g. number of employees, experience of outages) and

attributes of reliability and/or reductions in the electricity bill required. Estimation of this model leads to the findings that business would need to be compensated by:

(a) A reduction of 0.04 per cent in their annual bill for one extra minute of maximum duration of interruptions.

(b) A reduction of 6.64 per cent in their annual bill for one extra interruption per year is 6.64 per cent.

(c) A reduction of 6.44 per cent in their annual bill for reduction in notice period from current notice period to next shortest one.

280. On the basis of the results, the authors present a table setting out the average customer valuation, in pounds sterling, for interruptions of different duration. These results are shown in table 15.

Table 15 Willis and Garrod (1997): Average customer valuation for maximum outage duration

1 min	**20mins**	**1 hour**	**4 hours**	**8 hours**	**24 hours**
£39	£776	£2,330	£9,324	£18,646	£55,937

Extracting results for comparison

281. The study does not report information on the average annual consumption of the respondents to the survey and so we are not able to express the figures in table 15 in terms of pounds sterling per unit of consumption, to make them comparable with those for businesses which we extract from other studies.

Comment

282. We have concerns about making a wider reading of the estimates put forward in this study.

283. A first concern is due to the fact that the sample surveyed is not representative of the set of industrial customers in the UK, or indeed of any one DNO region. The authors did not adopt any stratification procedure to ensure that business were representative in terms of the sector they operated in, or in terms of their size.

284. A second concern relates to the specification of the model that the authors estimate by maximum likelihood. The models estimated do not allow for an interaction between the attribute relating to the number of interruption in a year and the maximum duration of outages. An implication of such a specification is that customers' WTA an increase in the maximum duration of an outage is not dependent on the number of interruptions they may expect to have over a year. This is unlikely to be a fair description of customers' attitudes.

Bertazzi, A. et al (2005): The use of customer outage cost surveys in policy decision–making: the Italian experience in regulating quality of electricity supply

Coverage and method

285. This is a brief paper setting out the findings of research carried out in 2003 on behalf of the Italian energy regulator, the Autorità per l'energia elettrica e il gas. The study sought to estimate costs of interruptions of varying lengths for different customer categories.

286. Information was collected on the basis of face to face interviews with 1,100 domestic and 1,500 business customers (600 in the industrial sector and 900 in the commerce and service sector). The businesses interviewed covered customers of a range of sizes.

287. The interviews were centered on a questionnaire designed to elicit information on the direct costs associated with the damage following a hypothetical interruption scenario, and information on:[8]

> – willingness to pay (WTP), expressed as the price at which the consumer would be willing to pay another company ready to take over with a reserve service in the event of supply interruptions on the part of the main supplier;
>
> – willingness to accept (WTA), expressed as the amount that would be considered satisfactory if the company supplying electricity should decide to discount payment of the supply each time an interruption occurs

288. The authors note that, from an economic point of view, the two numbers should match. In practice, respondents reply differently to the two questions and it is because of this that the questionnaire seeks to gather information on the two numbers. The study does not give information on the questions dealing with obtaining information on direct costs.

289. Each respondent was presented with a scenario where a 2 hour interruption occurs at a given time of day and day of the week and asked to estimate the damage to them of this. They were then asked how the damage would differ from this, in percentage terms, if the interruption had lasted 3 minutes, one hour, 4 or 8 hours.

Findings

290. The published paper reports on a handful of high–level results.

291. Table 16 sets out the findings on the direct costs, WTP and WTA of domestic customers and of business customers that are associated with interruptions of different lengths. The numbers reported in table 15 for interruption greater than 3 minute have been normalised with respect to the share of annual consumption corresponding to that duration, i.e. values for 1 hour were normalised by dividing the direct costs, WTA

[8] Bertazzi, A. et al (2005), second page (pages are not numbered).

and WTP value by (annual consumption/(24*365)). For interruptions of 3 minute normalisation was done on the basis of the power at the time of the interruption.

Table 16 Bertazzi, A. et al (2005): Direct costs, WTP and WTA for domestic and business customers (£/kW for 3 minute interruption, £/kWh for other)

Duration of interruption	Domestic customers			Business customers		
	Direct costs	WTA	WTP	Direct costs	WTA	WTP
3 mins	7.3	4.9	1.3	50.1	31.0	4.5
1 hour	23.0	15.5	3.4	107.2	72.5	9.7
2 hours	18.5	12.6	2.4	76.1	51.9	7.0
4 hours	14.3	10.2	2.0	61.0	44.0	6.0
8 hours	8.8	6.3	1.2	36.3	26.3	3.6

292. The estimates in table 16 show that the estimates of the costs — normalised with respect to kWh or, for the 3 minute interruption, with respect to kW — vary between households and business.

293. The table also shows that the estimates of the damage vary significantly with respect to whether the costs are defined in terms of direct costs, of WTP or WTA. Estimates based on WTA are four to seven times as high than those based on WTP. This is as might be expected.

294. The estimates of direct costs are even higher than those based on WTA. This may be explained by the fact that these are "gross direct costs", in the sense that the figures include the estimates of the costs of actions that the respondent may take due to the interruption but does not subtract the benefit to the respondent of that same action. For example, estimates of the costs of having to go eat out to overcome the power cut are included, without netting away the benefit to the household associated with eating out.

Extracting results for comparison

295. For the sake of establishing a comparison with the results of other studies, we have calculated the costs of a 1 hour and an 8 hours interruption for domestic customers for:

(a) a household with annual consumption of 2,800 kWh; and

(b) a household with annual consumption of 4,000 kWh.

296. The first of these corresponds to the average annual consumption of the households surveyed in the study. This level of consumption is lower than the average annual

household consumption in the UK. The second case corresponds to the standard 4,000 kWh household that we have chosen as a point of reference in this report. Our estimate for the 4,000 kWh/year household is based on extrapolating the values reported in the study for the average surveyed household. Table 17 sets out the results from these calculations. Because the estimates based on direct costs refer to "gross direct costs" we do not think they are comparable and so do not propose to draw on them.

Table 17 Bertazzi, A. et al (2005): Estimates of costs to households of a 1 hour and an 8 hours interruption (£)

Duration of interruption	Annual average consumption	Willingness to accept	Willingness to pay
1 hour	2,800 kWh	£4.95	£1.09
1 hour	4,000 kWh	£7.06	£1.56
8 hours	2,800 kWh	£2.00	£0.39
8 hours	4,000 kWh	£2.86	£0.56

297. The analysis of how estimates of damage vary depending on the time of day and day of the week is not reported in the published paper.

298. For business customers, we propose to compare the estimates of the WTP and WTA for a one hour interruption, as reported earlier in table 16; those estimates are already expressed in terms of pounds sterling per unit of consumption.

Comment

299. According to the report, the sample was defined by stratifying contacts across a number of important variables namely geographic region, size of business, size of locality (metropolitan areas, large, small and medium localities). The authors state that given their stratification and the number of interviews made, they expect small margins of statistical error in their estimates.

300. One area of possible concern relates to the study's treatment of outliers, responses that stood out as very different from average ones. Across household responses, the paper reports that 191 responses were excluded following the outlier analysis; this account for just over a sixth of the initial 1,100 responses sought amongst households. For businesses, the share of responses excluded was slightly higher. Our concern with dropping observations because they are outliers is that this may bias the results of the subsequent analysis.

Blass, A et al (2008) "Using elicited choice probabilities to estimate random utility models: preferences for electricity reliability"

Coverage and method

301. The paper reports on the findings of a questionnaire on the WTP for improvements in the reliability of electricity supply amongst domestic customers in Israel. The survey was carried out in the summer of 2005 and covered a stratified random sample of 557 households. Interviews were carried out face–to–face.

302. The questionnaire was structured around a stated–preference type approach. Respondents were presented with two alternative scenarios, each characterised by different bi–monthly electricity bills and by different reliability of the electricity supply. Respondents were asked to state their probabilities of choosing each of the two alternatives. The sum of these probabilities should add to 100 per cent.

303. The authors motivate the advantages of such an "elicited choice probabilities" approach over the more common stated preference approach — where respondents are asked to choose between one of the alternative scenarios — observing that it allows respondents to "express uncertainty about their behaviour in incomplete scenarios". The point here is that the scenarios described in the questionnaire are never complete in that they do not capture all information that respondents would have when making a choice in real circumstances. Given this, the authors suggest that stated choices "cannot be more than point predictions of actual choices." By eliciting choice probabilities, this inadequacy is overcome; respondents are permitted to reflect the uncertainty on how they would react.

304. The alternative scenarios respondents were asked to choose between were characterised with respect to the following attributes:

(a) average duration of interruptions — 0 to 10 minutes, 10 to 60 minutes, 1 to 2 hours and 2 to 4 hours;

(b) frequency of interruptions — 0, 1, 2, 4, 5 or 8 per season;

(c) electricity bill — the household's current bill, 15 or 40 per cent above current bill, 10 or 20 per cent below the current bill;

(d) season — Winter, Summer or Spring (Autumn, reported to be a very short season in Israel was not considered);

(e) time of day — peak hours, off–peak hours, intermediate hors;

(f) days of the week — weekend or weekdays; and

(g) warning — advance warning of interruption given, or not.

305. The study uses regression analysis to estimate the parameters of three different specifications of a model. On the basis of those estimated parameters, the study

calculates the average WTP for changes in different attributes of reliability in electricity supply.

306. The specifications estimated differ in their sophistication. In this respect, it is interesting that, commenting on the least sophisticated of the models estimated, the paper observes that that model makes unrealistic assumptions as:

(a) it assumes that households' disutility of an additional interruption is the same regardless of the average duration of the interruptions; and

(b) it assumes that households' disutility of an additional minute of interruption per interruption is the same regardless of the number of interruptions.

307. The other specifications estimated do not make this assumption and it is the results from one of those specifications that we report below. We raised the above point here because the assumptions which this paper regards as "unrealistic" are ones that are found in some of the papers reviewed, for example Willis and Garrod (1997) and Bliem (2009).

Findings

308. Table 18 reports the WTP for a one minute reduction in the total length of outage per season. The estimates relate to unplanned interruptions. The table reports estimates for different consumption times and, more interestingly, depending on whether the one minute reduction is achieved by reducing the frequency of interruptions or the average duration of each interruption. The numbers are based on Table 4 of the study.

Table 18 Blass, A et al (2008): Willingness to pay for a one minute reduction in outage time per season

	Weekday peak	Weekday off–peak	Weekend off–peak
Reduction in average duration			
Number of interruptions per season			
1	£0.60	–£0.08	£0.67
2	£0.40	£0.03	£0.41
3	£0.33	£0.07	£0.32
4	£0.31	£0.10	£0.27
5	£0.29	£0.11	£0.24
Reduction in number of interruptions			
Average duration (mins)			
10	– £0.16	£0.26	£1.03
30	£0.08	£0.19	£0.43
60	£0.14	£0.18	£0.29
90	£0.16	£0.17	£0.24
120	£0.17	£0.17	£0.21
150	£0.18	£0.16	£0.20
180	£0.18	£0.16	£0.19
300	£0.19	£0.16	£0.17

309. The numbers in table 18 are interpreted as follows. Consider first the top–half of the table and take as an example the value £0.60 reported in the first row under weekday peak. This finding shows that respondents are willing to pay £0.60 for a one minute reduction in total length of interruption that achieved by reducing average duration of each interruption when there is one interruption per season, and interruptions are on weekday peak hours. The value decreases with the number of interruptions. When there are five interruptions per season, the WTP for a one–minute reduction in total length of interruption by reducing the average duration of each is £0.29.

310. The lower half of the table reports the WTP for a one minute reduction in total length of interruptions achieved by having fewer interruptions. When the average duration of each interruption is 60 minutes, say, the WTP is £0.14 for a weekday peak hour.

311. An interesting reading from comparing the upper and the lower half of table 18 is that its suggests that customers place a greater value in reducing the length of outage time by reducing the number of interruptions compared to achieving it by lowering the average length of each interruption.

312. Table 18 also shows that:

(a) WTP is similar for weekdays and weekends, both for peak and off–peak;

(b) for weekends and weekdays off–peak, the WTP for a one minute reduction in total length of interruptions falls with the average duration of each interruption, whilst for weekday peaks this relation is not observed;

313. The study also reports results on how the WTP is different for households with different income levels. For those with above average income, the WTP is 3.75 times the numbers reported in table 18, and for household with below average income the WTP is around half those values.

Extracting results for comparison

314. We use the findings reported in the study to calculate two sets of estimates of the WTP for a one hour reduction in the duration of outages over a year.

315. A first set of estimates is based on the findings reported in upper half of table 18. We take the estimates relating to the case where there is 1 interruption per season — because this is the case closest to the performance in the UK — and extrapolate it estimate the WTP for a one hour reduction over the course of the year by multiplying it by 15 (given that there are four seasons in the year).

316. A second set of estimates is based on the estimates in the lower half of the table. Here, we take the estimates relating to the case where the average interruption is 1 hour, and again extrapolate them by multiplying by 15 it to obtain an estimate of the WTP for a one hour reduction in interruption time over a year.

317. Table 19 sets out the results of these calculations. Different estimates are calculated for different times of the week.

Table 19 Blass et al (2008): Estimates of willingness to pay for a one hour reduction in annual length of interruptions (£)

	Weekday peak	Weekday off-peak	Weekend off-peak
By reducing frequency of interruptions	£9.07	-£1.24	£10.10
By reducing duration of average interruption	£2.16	£2.68	£4.33

318. Leaving aside the fact that the estimate for weekday off peak is negative — the authors report those estimates to not be statistically significant — we are not altogether comfortable with the extrapolation necessary to derive the above set of numbers. In short, the method assumed that WTP to reduce the length of interruption time is linear with respect to the length of that reduction: we extrapolated an estimate for a 1 minute reduction per season, to an estimate of 60 minutes per year.

319. A further concern is that the Israeli context, to which this study relates, may be too removed from the UK one in terms of the reliability of electricity supply and customers' preferences.

Comment

320. We find the approach used by the paper, asking respondents to reveal the likelihood of choosing one of two possible scenarios to be interesting and reasonable, and different from contingent valuation studies where respondents are asked to select between possible scenarios.

321. The model specification estimated is careful about the interplay between frequency and duration of interruption, unlike other studies we have reviewed.

322. As discussed above, the relevance of this study's findings for the purpose of our study is limited by the assumptions we made to compute, by extrapolation, an estimate of the WTP for an hour reduction in outages in a year, and by the contextual differences between Israel and the UK.

Bliem, M (2009) "Economic valuation of electrical service reliability in Austria – a choice experiment approach"

Coverage and method

323. The study reports on a "choice experiment" survey carried out in Austria in 2007 on customers' preferences for electricity supply reliability. The survey covered two customer groups: households and businesses.

324. Respondents were asked to choose between two options: one based on the current level of reliability of electricity supply, and the second around alternative levels of reliability. Reliability was characterised in terms of the following attributes:

(a) Duration of outage, in minutes or hours: 3 minutes, 30 minutes (current situation), 4 hrs, 10 hrs;

(b) Frequency: number of outages per year; 0.5, 1 (current), 4, 10;

(c) Time of day: day or night;

(d) Day of the week: Tuesday or Sunday

(e) Advance notification of outage: yes or no;

(f) Price (percentage change in current bill): no change, –20, –10, +10 per cent.

325. With respect to the first two attributes, duration and frequency of interruptions, the alternative was characterised as deviations from the current level of performance.

326. The study's analysis was based on a discrete choice model, which allows to compute marginal rate of substitution relating to any of the attributes; because price is one such attribute (expressed as the percentage change from current bill)

327. The study sought to get a representative sample of households; it is not clear that that was the case for businesses. Despite this, it finds some over/under representation of some groups of respondents: for households, the set of respondents are a disproportionately low share of over 65 year–olds and too great a share of men. Amongst businesses, the service sector, especially the financial sector, is slightly underrepresented. We are not told about the representativeness of the businesses interviewed with respect to other characteristics, notably size.

Findings

328. The study's findings are summarised in table 20.

Table 20 Bliem (2009): Summary of estimates on willingness to pay (% of annual bill)

Attribute	Households	Businesses
Duration 3 mins	–1%	5%
Duration 4h	–16%	–10%
Duration 10 h	–22%	–20%
Frequency	–1%	–6%
Time of day (night)	–1%	14%
Day of the week (Sunday)	–7%	16%
Notification (yes)	3%	–2%

329. The table is interpreted as follows. Taking households as an example, the study finds that they would need a 16 per cent reduction in their current bill to accept a service that would result in the total length of outages in a year being 4 hours; the status quo was 30 minutes. The results also show that households would wish to have a 1 per cent reduction in their bill if the number of interruptions per year were to increase by one.

330. Some further comments on the results reported in table 20.

(a) The study estimates households' WTP for the average duration of an interruption to be 3 minutes — shorter than the status quo average of 30 minutes — to be minus one per cent of the bill. The study finds that the coefficient for this attribute is not statistically significant and concludes that it shows that households have no WTP for reducing duration of interruptions to 3 minutes on average. The estimates for the compensation required to endure longer average interruptions are found to be significant.

(b) The study finds that households prefer interruptions on weekdays.

(c) The study finds that estimates on the WTP for being interrupted at different times of the day, and for receiving notification of the interruption are not statistically significant.

(d) The study finds that the preferences by business are similar to those of households. As with households, the estimate on the WTP to reduce the average duration of an interruption to 3 minutes is found to not be statistically significant. It does find that businesses prefer interruption at night rather than day time, and on Sunday rather than on Tuesday (these are proxies for weekend and weekday).

Extracting results to compare

331. The paper includes information on the average annual bill and annual electricity consumption for the households and for the businesses in the sample. On the basis of this, and of the findings in the table above, we calculate the following.

(a) For households, we calculate the WTP to avoid an interruption of one hour and to avoid an interruption an interruption of eight hours by summing the study's estimates of WTP associated with the frequency and with duration of interruptions.

(b) For businesses, we calculate the WTP per kWh to avoid a 1-hour interruption by summing the study's estimates on businesses WTP to avoid an increase in the frequency of interruptions and its estimates on the WTP to avoid an increase in the total length of interrupted supply. We normalise the estimated WTP using the information on the average energy consumption by businesses that is reported in the study.

Comment

332. The survey asked respondents to express a preference about the reliability of supply with respect to a number of attributes including the frequency of interruptions and the total length of outages in a year. Following on from this, the specification of the model estimated in the econometric analysis is such that it identifies:

(a) how the total time in a year during which there would be outages affects customers' choice between one reliability scenario or another, keeping other things constant including the frequency of interruptions; and

(b) how the frequency of outages in a year affects customers' choice between one reliability scenario or another, keeping other things constant including the total length of outages in a year.

333. We do not think such estimates are intuitive to interpret. In particular, we find it difficult to interpret an estimate of customers' WTP to reduce the frequency of interruptions in a year whilst keeping the total length of outages in the year constant. Is the customer trading off fewer interruptions for interruptions each lasting a bit longer, so that the total duration of interrupted supply in the year remains constant? Would the respondents to the survey be able to make that trade-off?

334. The estimates of VOLL based on Bliem (2009)'s results are high, relative to those of from the other studies we have reviewed. One hypothesis is that this may in part be driven by the model that the author specified and estimated.

Carlsson, F. and P. Martinsson (2004) "Willingness to pay among Swedish households to avoid Power outages — a random parameter Tobit model approach"

Coverage and method

335. The paper reports on a survey carried out amongst Swedish households in 2004 relating to their WTP to avoid an interruption to their electricity supply of a certain duration. Questions were asked about interruptions of 1, 4, 8 and 24 hours. A distinction was also made between planned and unplanned outage, the difference between the two being that electricity supplier are required to provide a few days warning when planning an outage.

336. The questionnaire was open-ended in that households were free to choose their level of maximum WTP, rather than being presented with a menu of possible numbers.

337. A word of warning. Respondents were told that the interruption hypothesised in the survey question was due to start at 6pm on a January evening. This was deliberately chosen to represent a "worst case" scenario. In the light of this, the findings of the survey may be thought of as defining an upper limit of the WTP rather than the average WTP that respondents would say if asked about an "anytime" interruption.

338. Using the data collected, the authors use regression analysis to identify how certain socio-economic factors (e.g. place of residence, gender, age, income) may help explain the variations in WTP.

339. The analysis was carried out on the basis of just under 1,500 responses. The authors note that there is an over-representation of older people in their sample.

Findings

340. Table 21 presents some descriptive statistics of the WTP put forward by respondents (they reflect the answers to the survey, rather than the output of econometric analysis).

Table 21 Carlsson and Martinsson (2004) Willingness to pay to avoid an interruption: worst case scenario (£)

	Mean	Median	Max	Share of zero WTP
Planned interruption				
1 hour	0.59	0	46.80	0.9
4 hours	2.66	0	93.60	0.74
8 hours	7.90	0	187.20	0.51
24 hours	17.71	4.68	280.80	0.39
Unplanned interruption				
1 hour	0.88	0	46.80	0.86
4 hours	3.49	0	70.20	0.68
8 hours	10.12	1.40	187.20	0.46
24 hours	20.87	8.42	280.80	0.36
Of uncertain duration: between 2 and 6 hours	6.44	0.00	112.32	0.59

341. The table shows that the mean WTP increases with the duration of the outage, and the WTP to avoid an unplanned outage is greater than it is to avoid a planned one.

342. The table also reports the share of responses in which respondents stated that their WTP was zero. This share is very high for questions about a one hour outage — 90 per cent if planned, 86 per cent if unplanned. The share of respondents with a zero WTP falls as the length of the interruption increases. But even for outages of 24 hours, a bit over a third of respondents still claim that their WTP to avoid such an interruption is zero.

Extracting results to compare

343. We extract from table 21 the results relating to the mean WTP to avoid a 1-hour and an 8-hour interruption; for planned and for unplanned interruptions.

Comment

344. The survey question on which the study is based asked respondents about their behaviour in a worst case scenario. The findings are therefore unlikely to be representative of the WTP to avoid interruptions in general.

Carlsson, F. and P. Martinsson (2007) "Does it matter when a power outage occurs? A choice experiment study on the willingness to pay to avoid power outages"

Coverage and method

345. The paper presents a study based on a survey of Swedish individuals about their WTP to avoid interruptions to their supply of electricity. The survey covered 473 individuals and was carried out in 2004.

346. In each question, respondents were asked to choose between two alternative scenarios. The scenarios were defined in terms of a set of attributes relating to the hypothetical interruption and in terms of a cost, expressed in Swedish Krone, associated with the connection fee to be paid to guarantee the number of interruptions to the stated level,. The attributes of the interruptions covered:

(a) duration: 4, 8 or 24 hours

(b) day of the week: weekend or weekday;

(c) number of interruptions over five years: 0, 1 or 2; and

(d) cost in Swedish Krone: 125, 200, 225, 275 or 375

347. Respondents were told that the survey related to unplanned interruptions; the number of planned interruptions — which have to be announced with at least 3 working days warning — would be unchanged.

348. The authors carry out econometric analysis — they construct a logit model, allowing the coefficients to be random, individual specific, parameters — to estimate the WTP associated with avoiding interruptions of different durations at different times of the year and of the day.

Findings

349. The focus of the paper is to identify how WTP varies according to when the interruption occurs. Table 22 sets out the findings on this

Table 22 Carlsson and Martinsson (2007) Relative WTP for reducing power outages (£)

Duration and day of interruption	November — March	April — October
4 hour weekday	£0.69	£1.00
8 hours weekday	£1.98	£2.47
24 hours weekday	£8.95	£7.24
4 hours weekend	£2.76	£1.88
8 hours weekend	£3.53	£3.76
24 hours weekend	£11.71	£9.85

350. The WTP is highest for interruptions of longer duration. Interestingly, for interruptions of a given duration and on a given day of the week, the WPD is not always higher in winter months than in summer months. For example, interruptions of 4 and 8 hours on a weekday have a higher WTP in the April to summer months, than in the period from November to March. The opposite is the case for the longer 24 hour interruptions.

351. The results do show that individuals do have a lower WTP to avoid interruptions on weekdays than on weekends.

Extracting results for comparison

352. On the basis of the set of the above set of results, we have calculated a weighted average WTP for interruptions of different durations, across the calendar year. These are shown in table 23. The paper does not consider durations of 1 hour. We have estimated this value by dividing the WTP for the four-hour interruption by four. This is clearly an approximation; we have done so for the purpose of being able to compare the findings across studies in the summary section at the start of this report.

Table 23 Carlsson and Martinsson (2007) Willingness to pay to avoid an interruption to electricity supply (£)

Duration of interruption	Average willingness to pay (£)
1 hour	£0.32
4 hours	£1.27
8 hours	£2.63
24 hours	£8.86

Comment

353. The survey method used, described as a choice experiment survey, is often used as a means of extracting information on consumer's WTP. On the basis of the information provided in the paper, we have no concerns on the use of this method as such.

Charles River Associates (2008) "Assessment of the value of customer reliability (VCR)"

Coverage and method

354. The study estimates the "value of customer reliability" of electricity supply in the state of Victoria, Australia. It was commissioned by VENCorp and it provides an update to an earlier 2002 study, also carried out by Charles River, and to a 1997 study by Monash University. The findings were to be used for the purpose of informing VENCorp assess the benefits of investments in its transmission system.

355. The notion described as "value of customer reliability" seems identical to that of VOLL.

356. The estimates are based on surveys of customers concerning the impact of unplanned interruptions to their electricity supply. The survey question asks about the costs that respondents would bear in the event that a power cut of a specific duration occurs at the worst time possible.

357. The study distinguishes between the following four sectors: residential, agricultural, commercial and industrial. Different survey techniques are used:

(a) For the residential sector, respondents are asked to select from a list of actions they would take (and associated costs they would incur) to mitigate costs of interruptions of varying durations. The authors describe this as being based on the "economic principle of substitution".

(b) For the remaining sectors, respondents are asked for their estimates, in money terms, of a set of generic cost categories that might be relevant to them in the event of an interruption to their energy supply (e.g. costs of operating backup emergency supply, cost of perishable products). This is described as the "direct cost approach".

358. The study calculates sector–level and state–level estimates of the value of customer reliability by aggregating the values reported by respondents using annual electricity consumed as a normalising variable, and then computing a weighted average accordingly.

Findings

359. Table 24 reports the average annual VOLL based on the results of the surveys; it reproduces Table 4 in the Charles River study after converting the values from Australian dollars to pounds sterling using the average exchange rate in 2007.

Table 24 CRA (2007) Un–weighted annual value of lost load (£/kWh of unserved energy)

	Sector			
Interruption duration	**Residential**	**Agricultural**	**Commercial**	**Industrial**
20 minutes	Not assessed	£41.99	£103.09	£41.70
1 hour	£11.81	£22.71	£63.14	£19.49
2 hours	Not assessed	£98.37	£22.66	£13.96
4 hours	£5.97	£62.01	£21.47	£12.06
8 hours	£4.19	£58.25	£20.67	£13.72
24 hours	£2.33	£38.07	£10.83	£14.13

360. As mentioned, the study aggregates the above set of figure to produce sector– and state–level estimates of VOLL by using annual energy consumption to weight the contribution from each sector, and by using the probability of interruptions of different durations occurring, based on historical performance. We expect both of these sets of figures to be different from those applicable in the UK and so there is no sense in reporting the full details of those here. For the record, we note that the overall, Victoria–wide, estimate of VOLL was £20/kWh.

361. Respondents were also asked about when the worst time for having a power interruption would be, in terms of month of the year, day of week and time of day. Given this relates to Victoria, Australia, the worst month is not necessarily the same as in the UK. With respect to the remaining points:

(a) Around 70 per cent of residential respondents said the day of the week was of little relevance. Of the 30 per cent that did, most nominated Saturday or Sunday.

(b) The worst time for an interruption was reported to be the evening peak period, between 6 and 9pm.

362. The study also reports on estimates of what it calls "social disruption costs" that might result from a wide spread power outage in Victoria. This relates to the costs to police, ambulance, hospital and other emergency services in coping with the consequences of a large disruption to the electricity supply. Estimates are based on interviews with a set of institutions that handle such emergencies. We see nothing wrong in principle with this; it is a recognition that not all electricity consumers are either residential or commercial/industrial and that there may be some costs associated with a wide outage than the sum of the costs of interruptions to individuals. But the very low probability of such an event dwarfs the contribution compared to the estimate of VOLL fom other sectors.

Extracting results for comparison

363. To compare estimates from this study with those of others, we carry out the following calculations:

(a) For households: we extract the result in table 24 on the damage from a one-hour interruption, £11.81 per kWh of unserved energy, and apply this on an assumption that annual household consumption is 4,000 kWh.

(b) For businesses: we extract the estimates in table 24 relating to the damage from a one-hour interruption.

Comments

364. The study asks respondents for their value of reliability based on the worst case scenario. This is inconsistent with other steps in the approach. In particular, it is wrong to combine these figures with the value on the probability of interruptions of different duration — done for the purpose of producing a single VOLL — as not all of those interruptions will have occurred at the "worst time" possible.

365. The figures we presented in table 24 do not suffer from this criticism as they have not been combined with such information. This said, figures in table 24 should be interpreted as the VOLL for energy not served at the worst possible time, rather than for energy not supplied in general.

Delfanti, M. et al (2010) "Toward Voltage-Quality Regulation in Italy"

Coverage and method

366. This paper considers the direct costs associated with very short interruptions and voltage dips to certain sensitive industrial sectors in Italy. The paper then extrapolates its estimates of direct costs and indirect costs of very short interruptions (one to five seconds) and voltage dips for the whole of Italy.

367. The study uses a monitoring and survey approach to estimate direct costs due to these incidents. The sample of businesses is focused on those connected to the medium voltage network and who are equipped with voltage-quality recorders. This allows the collection of accurate voltage quality data for the participants. Another factor in selecting their sample was that the sector should have sufficient weight within the Italian economy, since the ultimate aim was to estimate national costs due to voltage quality incidents.

368. For some sectors, all the sampled businesses within it were found to have negligible costs and therefore not processed further.

369. Information was collected from respondents regarding the costs of incidents. For each sampled business, the survey collected information from frontline, technical and accounting personnel on each halt in production. The study then used this to calculate the direct end-user costs.

370. The authors assumed that direct costs were the sum of three elements:

(a) the cost of recovering production;

(b) the cost of wasting production; and

(c) the cost of replacing or repairing damaged equipment.

371. The study acknowledges that these costs may vary according to whether the production process is continuous or not, and take this into account in their estimation method.

Findings

372. Table 25 shows the estimated direct costs per event per kilowatt for the sectors analysed. It presents the median and mean values for sectors where respondents were found to have non-negligible costs inflicted due to a voltage dip or very short interruption. Estimates are in current pounds sterling.

Table 25 Direct costs per very short interruption or voltage dip event (£/kW)

Sector	Sample	Median (£/kW)	Mean (£/kW)	Interval (£/kW)
Food products	7	0.5	5.4	0.2 – 27.3
Textiles	1	2.9	2.9	2.9
Paper	11	0.7	0.8	0.1 – 2
Refined petroleum products	1	12.1	12.1	12.1
Chemicals and man-made fibres	3	0.5	0.4	0 – 0.7
Plastic products	10	1.7	2.0	0.1 – 3.8
Glass and ceramic products	4	0.7	0.8	0.1 – 2.1
Metals products	3	1.0	3.0	0 – 7.9
Electrical equipment	3	8.5	9.6	0.1 – 20.4
Auto and auto components	2	2.6	2.6	0.6 – 4.6
All sectors		**0.7**	**2.6**	**0 – 27.3**

Comment

373. The paper estimates the costs of voltage events for a small number of businesses in Italy. The sample sizes are small and the range of direct costs quite large even within sectors.

374. The direct costs per event refer to a very short interruption (one to five seconds) or a voltage dip. The study also reports that almost two thirds of the voltage incidents picked up by the voltage quality recorders were identified by businesses in the sample. This highlights that not all voltage quality events incur direct costs to businesses.

375. In order to be selected, businesses needed to have a voltage quality recorder fitted, something which the study reports has to be paid for by the business themselves. It is quite likely that this leads to firms with the highest sensitivity being sampled, even within sectors. As such, the results cannot be inferred as average costs for voltage dips, even within the sectors they represent.

376. The study highlights how certain businesses can be sensitive to voltage quality events. Further extrapolation from this result would be optimistic given the small sample size and sample method.

de Nooij, M. et al (2007) "The value of supply security. The costs of power interruptions: Economic input for damage reduction and investment in networks"

Coverage and method

377. This paper uses a production function approach to estimate VOLL for different sectors of the economy and households in the Netherlands.

378. The paper also provides some breakdowns for different parts of the day, although these are averaged across all consumers.

379. The production function approach for industrial customers estimates VOLL as the average value added per kWh of electricity demand by dividing value added by annual electricity demand.

380. The intuition behind this method is that output is a linear function of electricity demand and therefore a reduction in electricity demand (due to an outage) will cause a reduction in output. This is obviously a simplification: some output can be made without electricity and it is not obvious why the relationship should be linear. This method also fails to reflect the fact that some output that is not produced when there is an outage can be produced at a later date and so is not always lost. On the other hand, there may be additional costs from a power cut that this method does not capture. This might be the case if for example a short interruption causes the loss of files or the case where machines require a lengthy restart time after an interruption. In sectors where electricity use plays a small and non–essential part in production, this method will provide an unreliably high estimate of VOLL due to the method wrongly interpreting a high ratio of output to electricity demand as a statement that electricity is valuable.

381. For households, the paper takes the view that household output can be measured by their value of leisure. The paper makes an assumption that leisure loses all value if there is an interruption. Given this, the estimate of VOLL for households is equal to the value of leisure. The paper provides some evidence on the activities people spend

their time on and suggests that the assumption is reasonable given that the most common leisure activities are electricity dependent.

Findings

382. Table 26 reports the estimates of VOLL for different sectors of the Dutch economy as reported in the paper.

Table 26 Results from De Nooij et al. (2007) (£/kWh)

Sector	**VOLL (GBP/kWh)**
Agriculture	3.05
Manufacturing	1.46
Construction	27.37
Transport	9.68
Services	6.75
Government	28.89
Total (excluding households)	5.18
Households	13.83
Total (including households)	**3.05**

383. The values reported in table 26 are those in the study. They relate to the Dutch context and reflect the structure of the Dutch economy and not that of the UK.

384. The authors also provide a breakdown in VOLL by the time in which the interruption might occur. Each day is split three sections: daytime (8am – 6pm), evening (6pm – 12midnight) and night (12midnight – 8am). There are also three different categories for the time of week: weekdays, Saturdays and Sundays. The authors calculate average VOLL numbers for all sectors that are active in that period of the day, using data on firm production times and household electricity use profiles. Table 27 sets out the results. Rather than presenting the actual number, in EUR/kWh, we have normalised them: the number associated with a particular time of the day or week measures the degree to which VOLL in that period departs from the overall average. Presenting this index, rather than VOLL in EUR/kWh, side–steps the issue raised earlier that the values are Dutch–specific. On the other hand, reporting the indices might be reasonable if one is willing to consider that the Dutch and the UK economy and households organise their activity in broadly similar ways (e.g. working days between 9am and 6pm, Monday to Friday).

Table 27 Variation of VOLL across days and time of day (average = 1)

Day	Time	Index of VOLL
Weekdays	Day (8am – 6pm)	1.08
	Evening (6pm – 12 midnight)	1.21
	Night (12midnight – 8am)	0.36
Saturdays	Day (8am – 6pm)	1.18
	Evening (6pm – 12 midnight)	1.69
	Night (12midnight – 8am)	0.52
Sundays	Day (8am – 6pm)	1.39
	Evening (6pm – 12 midnight)	1.69
	Night (12 midnight – 8am)	0.52
Average		**1.00**

Extracting results for comparison

385. For the purpose of comparison with other studies, we extract the numbers reported in table 26. For households, we calculate VOLL per hour of interruption assuming annual household consumption of 4,000 units.

Comment

386. In the description of the method we outlined some criticisms to the method of estimating VOLL for businesses on the basis of the value added of each sector. Of perhaps greater concern, however, is the approach used to estimate VOLL for households.

387. At the heart of that approach is the assumption that households value leisure at the marginal value of labour. It equates this to the average hourly wage, halving it for the unemployed. The basis for this is taken from the theory of Gary Becker (1963) on time use. In a free labour market, people will select their working hours until they value an extra hour of work equal to an extra hour of leisure. There are several potential criticisms for such an approach, some of which are acknowledged in the paper. For example, the lost hour of leisure is not going to be at the margin, instead being a random hour. As the authors concede an hour of electricity lost during the world cup football final is likely to be more costly than the marginal rate, especially in the context of this theory which predicts people will "consume" leisure until they reach the marginal benefit is equal to the marginal cost, in this case being the opportunity cost of work and therefore the marginal benefit of labour.

388. The paper uses data from 2000. Since then the way in which people spend their leisure time may have changed in important ways with respect to their dependency on electricity. It is conceivable, for example, that the widespread adoption of more powerful mobile devices has decreased dependency on electricity for leisure time, at least for short durations.

Kjølle, G.H. et al (2008) "Customer costs related to interruptions and voltage – problems: methodology and results"

Coverage and method

389. The paper describes the findings from a survey carried out in Norway in 2001–2002 aimed at gathering information on customers' costs of interruption to their electricity supply. The survey was done on behalf of the Norwegian Water Resources and Energy Directorate and it was intended to help define the compensation schemes as well as to assist in companies' planning.

390. The exercise was organised as a postal survey, distinguishing between six group of customers:

(a) Industry;

(b) Commercial;

(c) Large industry;

(d) Public sector;

(e) Agriculture; and

(f) Residential.

391. Specific questionnaires were prepared for each customer group. Respondents were asked to respond to certain interruption scenarios. The scenarios were defined with respect to the duration of the interruption, the season, time of the week and time of day in which the hypothesized interruption was to occur. The questions included requests for information on:

(a) Direct worth: an estimate of the costs respondents would experience if the interruption envisaged in the scenario were to take place;

(b) WTP: an estimate of how much respondents would be willing to pay to avoid the interruption envisaged in the scenario.

392. The survey defined as the "reference time" a specific hour on a Thursday (weekday) in January. The hour specified varied across customer categories: it was 6am for those in agriculture, 4pm for residential customers and 10am for all other groups. The reference time selected was that deemed to represent the "worst case" scenario. Respondents' estimates on their costs and on their WTP to avoid interruptions in other settings were to be expressed as a percentage change of their costs and WTP to avoid interruptions in that reference time.

Findings

393. The study presents estimates of the costs of interruption of different duration for each of the customer groups. These are expressed in terms of Norwegian Krone per kWh or, for interruptions of 1 minute, per kW. The results, expressed in terms of pounds sterling per kWh or per kW, are set out in table 28. The table reports both the figures relating to direct worth and those related to WTP.

Table 28 Kjølle et al (2008) Average cost of interruptions, worst case scenario (£/kWh or £/kW)

Customer category	Measure	1 minute (£/kW)	1 hr (£/kWh)	4 hours (£/kWh)	24 hours (8 hours for residential) (£/kWh)
Industry	Direct worth	3.32	10.64	9.26	5.65
	WTP	0.50	1.51	1.20	0.69
Commercial	Direct worth	2.99	17.43	14.40	8.55
	WTP	0.61	1.98	1.34	0.69
Large industry	Direct worth	0.71	2.06	1.79	0.64
	WTP	0.38	0.85	0.88	0.35
Public	Direct worth	0.12	1.72	2.21	1.32
	WTP	0.07	0.14	0.20	0.10
Agriculture	Direct worth	0.39	1.44	1.19	1.06
	WTP	0.14	1.36	0.80	0.36
Residential	Direct worth		0.99	1.10	0.96
	WTP		0.43	0.39	0.35

394. The authors observe that the questions on respondents' "direct worth" yielded values that were significantly higher than the responses based on WTP. They suggest that this is in line with other studies finding that estimates of the costs incurred by an interruption tend to be overstated whilst the WTP tend to understated. The authors resolve this by computing the arithmetic average of the two values, something they denote as the "estimated WTP".

395. The study also reports on how the reported costs of interruption vary according to when the interruption occurs. It finds that:

(a) For the large industry sector, the cost per interruption tends to be the same over the week, and over the hours of the day.

(b) For commercial, public and other industrial groups, the cost per interruption will be around 30 to 60 per cent lower from the cost at reference time (defined as 10am on a weekday in January) if the interruption is on a Sunday or holiday, or during the night.

(c) The season in which the interruption occurs was found to be of little significance, other than for the customer group defined as public sector, for whom the cost of interruptions is up to 40 per cent less than the cost in winter.

Extracting results for comparison

396. From table 28 we extract the findings on the direct costs and WTP for the non-residential sectors relating to the value per kWh for a one hour interruption.

397. We do similarly for households. In this case, however, we convert the findings into a pounds sterling figure on the assumption of household annual consumption of 4,000 kWh.

Comment

398. The study put forward estimates based on direct costs and on the WTP to avoid interruptions, and it is interesting to observe the difference between the two estimates.

399. Our concerns about the relevance of these estimates to the UK context include:

(a) The study estimates customer's costs and valuation of interruption in a "worst case" scenario. The estimates on the costs of interruption extracted from this study must be interpreted accordingly, and not interpreted as being an average.

(b) Electricity consumption in Norway is more than double that of the UK. Given this, the estimate we calculate for residential customers — based on multiplying the estimates of the study that are reported in £/kWh by an assumed annual consumption of 4,000 kWh, a level reasonable in the UK — will be an underestimate.

Leahy, E. and R. Tol (2010) "An estimate of the value of lost load for Ireland"

Coverage and method

400. This study produces estimates on VOLL for the Republic of Ireland and for Northern Ireland on the basis of the methodology developed by de Nooj et al (2007). Estimates are produced for each year in the period 2000 to 2007.

401. For the household sector, it estimates VOLL on the basis of data on average hourly post–tax wages. For individuals at home but not at work, the authors assume that the cost associated with an interruption is half of the average wage, the same assumption that had been made by de Nooij et al (2007).

402. For the remaining sectors in the economy, the estimates of VOLL are based on the ratio of the value added of that sector and its annual electricity consumption.

403. Estimates of VOLL are expressed in terms of Euros per kWh.

404. We discussed the limitations of this approach in our review of de Nooj et al (2007); the same issues apply here.

Findings

405. Table 29 sets out the findings of the study, expressed in pounds sterling.

Table 29 Estimates of VOLL for the Republic of Ireland and for Northern Ireland (£/kWh)

Customer group	Republic of Ireland (2008)	Northern Ireland (2007)
Residential	21.4	14.0
Commercial	12.2	10.1
Industrial	3.5	3.1

406. On the basis of the above estimates, we have calculated an estimate of VOLL for residential customers associated with a one hour interruption, assuming a 4,000 units a year consumption. These estimates are:

(a) £9.8 for the Republic of Ireland; and

(b) £6.4 for Northern Ireland.

407. The paper also presents estimates of how VOLL for residential customers varies across seasons, across days of the week and hours of the day. Given the method used, the variation in these estimates is merely a reflection of the profile of electricity consumption over the year, week or day, rather than a reflection of how households' valuation of electricity varies over time.

Extracting results for comparison

408. The numbers compared with other studies are those reported in table 29. For residential customers, we convert the figure into a pounds sterling number on the assumption that annual household consumption is 4,000 kWh.

Comment

409. The study applies the approach followed by de Nooij et al (2007) and our comments laid out in our review of that paper are also relevant here. We also review the strengths and weaknesses of this approach in the main body of the report, when we lay out our estimates for the UK calculated on the basis of the de Nooij et al (2007) method.

Praktiknjo, A.J. et al (2011) "Assessing energy supply security: Outage costs in private households"

Coverage and method

410. This study presents estimates of costs of interruptions in Germany for residential users, for commercial and industrial users, and for public administration. The estimates are expressed in terms of a monetary value per kWh. A different approach is used for each of these three groups.

(a) For residential users, the estimate is based on a value of leisure (proxied by the average hourly wage) and on a measure of the dependence of households on electricity, which is done by constructing an index obtained from data on how households make use of their time.

(b) For commercial and industrial users, the estimate of VOLL is calculated as the ratio of the value added of each sector and the annual consumption of electricity. The paper breaks down this category of users into three broad areas of activity — industry; commerce, service and transportation; and agriculture — and calculates VOLL for each one separately. The estimates are then combined into a single number by weighting according to electricity consumption.

(c) For public administration, the estimate of VOLL is computed as the ratio of taxation raised and annual electricity consumption.

411. From our reading of the paper, most of the data used seem to relate to 2008.

Findings

412. Table 30 reports the estimates of VOLL for households for interruptions of 1 hours and of 8 hours produced by the study, after converting the values from Euros to 2012 pounds sterling.

Table 30 Praktiknjo, A.J. et al (2011): Estimates of costs of interruption for household customers

Duration of interruption	VOLL (£/kWh)
1 hour	13.7
8 hours	8.1

413. The estimates for businesses customers are shown in table 31.

Table 31 Praktiknjo, A.J. et al (2011): Estimates of costs of interruption for business customers

Sector	**VOLL (£/kWh)**
Agriculture	2.0
Industry	2.2
Commerce, service and transportation	14.2
Weighted average	5.3

Extracting results for comparison

414. For the purpose of comparing estimates with other models, we extract the findings reported in two tables above. For households, we compute an estimate in pounds sterling by first assuming average annual consumption for households of 4,000 kWh.

Comment

415. We have not reported the estimates of VOLL that the study calculated for public administration by dividing tax revenue by the relevant electricity consumption because we found no basis for this approach. The amounts collected by tax is better seen as a measure of how much is redistributed by government, rather than a measure of the activity of government itself.

416. Whilst we have reported the estimates for residential customers, we have significant concerns with the approach that was used. These include:

(a) The assumption that leisure time is valued at the average hourly wage.

(b) Our understanding from the paper is that the authors excluded from the sample that was used to calculate the value of time those individuals that did not earn a wage, i.e. were under the age of 16 or were unemployed. If our interpretation of this is correct, then the results will be biased if the value on electricity from that set of customers is different from that of customers that are employed.

Sullivan, M. et al (2009) "Estimated Value of Service Reliability for Electric Utility Customers in the United States"

Coverage and method

417. This study analyses a meta–database that combines the data from 28 different studies on the costs of electricity interruption to consumers in the United States. Analysis is carried out on the combined database.

418. The 28 different studies were carried by US electricity utilities at different points in time over the period from 1989 to 2005. The authors state that these studies used

"nearly identical interruption cost estimation or willingness to pay, or to accept, methods", allowing the data to be brought together.

419. The study identifies three groups of customers:

(a) residential;

(b) small commercial and industrial (less than 50 MWh per year); and

(c) medium and large commercial and industrial; (above 50 MWh per year).

420. Separate meta–databases were compiled for each of these categories.

421. The underlying data were collected through surveys of customers. Customers were asked to estimate interruption costs they would incur from hypothetical interruptions of varying durations. Residential customers were asked about their WTP to avoid hypothetical interruptions. Business customers were asked about the costs they would incur if they were to suffer an interruption. Customers were typically asked to estimate costs for between four and eight hypothetical interruptions, varying in duration, seasons, time.

422. Regression analysis was used to estimate the interruption costs for each category of customer for interruptions of different durations and with different other attributes (e.g. season, day of interruption, time of interruption).

Findings

423. The study reports a wealth of results. For each of the three customer groups, it reports the costs of interruptions of different lengths, for each of the 16 possible combinations of:

(a) Season: winter or summer;

(b) Day of the week: weekend or weekday;

(c) Time of day: morning, afternoon, evening or night.

424. The study also breaks down each of the two sets of non–residential customers into finer, industry, categorizations e.g. agriculture, mining, construction, services, public administrations.

425. We report here on the more high level findings. The values set out in the study are expressed in 2008 US Dollars. We have converted the values to 2012 GBP using the market exchange rates and the UK RPI.

426. Table 32 reports the cost of interruption, by duration of interruption, for each of the three customer categories.

Table 32 Sullivan, M. et al (2009) Cost of interruption, by customer type and duration (£)

Customer type	Length of interruption				
	Momentary	30 mins	1 hour	4 hours	8 hours
Residential	1.3	1.6	2.0	4.4	6.3
Small commercial and industrial	1,74.7	259.4	369.1	1,564.2	3,097.9
Medium and large commercial and industrial	3,910.7	5,496.3	7,446.3	2,5347.3	4,1315.6

Source: Sullivan, M. et al (2009) Tables 3.10, 4.10 and 5.11.

427. The figures in table 32 are the costs of the interruptions at "any time", that is to say, they are the average of the costs across each the different seasons, days of the week and times of day considered by the study, duly weighted.

428. Table 33 reports for each customer category the variation in the cost of interruption depending on when the interruption occurs. We have expressed these values as deviations from the average cost of each of the customer category.

Table 33 Variation of cost of 1 hour interruption across time of interruption (average =1 for each customer category)

	Customer category		
Time of interruption	Residential	Small commercial and industrial	Medium and large commercial and industrial
Summer weekday	1.18	1.32	1.63
Summer weekend	1.39	0.84	1.19
Winter weekday	0.79	1.88	1.39
Winter weekend	0.94	1.15	0.98
Morning	1.58	1.09	1.16
Afternoon	1.18	1.32	1.63
Evening	1.12	0.70	1.37

Source: Sullivan, M et al (2009) Tables ES3 and ES4

429. Table 33 shows that the pattern is not the same across customer types. For residential customers, the cost is higher in summer than in winter, and higher in the weekend. For small business customers, the opposite is the case: costs are higher in summer and on weekdays. The finding that for residents costs are higher in the summer — a finding at odds with what is the case in northern European countries — may perhaps be explained by the greater use of air conditioning in some of the States that were covered by the study.

430. Table 33 also reports how costs of interruption vary across the time of day. Here too the pattern is not common across the three customer categories. For residential customers, costs are highest in the morning whereas for business users costs are highest in the afternoon.

Extracting results for comparison

431. For the purpose of comparison with estimates from other studies, we use the findings reported in table 32. For households, that table reports the WTP for a 1-hour and for an 8-hour interruption directly. For businesses, we calculate the value per unit of consumption using the figure reported for 1-hour interruption and the data on annual consumption that are disclosed in the study.

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